RAMP
Regional Aquatics Monitoring Program

2009 Technical Report

Final

REGIONAL AQUATICS MONITORING PROGRAM

2009 Technical Report

FINAL

Prepared for:

RAMP STEERING COMMITTEE

Prepared by:

The RAMP 2009 Implementation Team

Consisting of:

HATFIELD CONSULTANTS
KILGOUR AND ASSOCIATES LTD.
***and* WESTERN RESOURCE SOLUTIONS**

APRIL 2010

RAMP1467

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

Funding for RAMP in 2009 was provided by Suncor Energy Inc. (Suncor), Syncrude Canada Ltd. (Syncrude), Shell Albian Sands, Canadian Natural Resources Limited (Canadian Natural), Imperial Oil Resources (Imperial Oil), Nexen Inc. (Nexen), Husky Energy (Husky), Total E&P Canada Ltd. (Total E&P), and Hammerstone Corporation (Hammerstone).

The RAMP chairperson during the 2009 program year was Patrick O'Brien (Suncor). Andrews Takyi (Total E&P) was chair of the Technical Program Committee, Neil Rutley (Nexen) was chair of the Finance Sub-committee and Melissa Pennell was the Communications Coordinator for RAMP.

RAMP is a multi-stakeholder environmental monitoring program that is composed of representatives from industry; municipal, 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 Program Committee, Finance Sub-committee and the Communications Committee;
- Syncrude, Canadian Natural, Suncor, Nexen, Shell Albian Sands, Husky, and ASRD for in-kind contribution towards the fish inventory program;
- ASRD for providing fish for tissue analyses from Unnamed "Jackson" Lake;
- Alberta Environment (AENV), Syncrude, Canadian Natural, and Shell Albian Sands 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/anglers who provided information for the Fish Tag Return Program.

In addition, the 2009 RAMP Implementation Team would like to acknowledge the following contractors who assisted with the program:

- ALS Laboratory Group (chemical analyses);
- AXYS Analytical Services Ltd. (chemical analyses);
- University of Alberta Limnological Laboratory (chemical analyses);
- Alberta Research Council (chemical analyses);
- HydroQual Laboratories Ltd. (toxicity testing);
- Dr. Jack Zloty (benthic invertebrate taxonomy);
- North/South Consultants Inc. (fish ageing); and
- Flett Research Ltd. (non-lethal fish tissue analyses).

2009 IMPLEMENTATION TEAM

The RAMP Implementation Team for 2009 included the following personnel from Hatfield Consultants Partnership (HCP), Kilgour and Associates Ltd. (KAL) and Western Resource Solutions (WRS):

Program Manager:	Wade Gibbons (HCP)
Assistant Manager:	Heather Keith (HCP)
Senior Review:	Peter McNamee (HCP)
Water and Sediment Quality Manager:	Martin Davies (HCP)
Water and Sediment Quality Assistant Manager:	Jasmin Gee (HCP)
Fish Populations Manager:	Heather Keith (HCP)
Fish Populations Assistant Manager	Rick McCulloch (HCP)
Climate and Hydrology Manager:	Heidi Biberhofer (HCP)
Climate and Hydrology Manager Assistant Manager:	Steven Guenther (HCP)
Benthic Invertebrate Communities Manager:	Bruce Kilgour (KAL)
Acid-Sensitive Lakes Manager:	Daniel Andrews (WRS)
Additional Component Assistance:	Dan Bewley (HCP)
	Jane Elser (HCP)
	Cayla Eastman (HCP)
	Sarah Eaton (HCP)
	Noah Baker (HCP)
	Glen Bruce (HCP)
	Lise Galand (HCP)
	Dan Moats (HCP)
	Jackie Porteous (HCP)
	Valerie Smith (HCP)
	Chris Wellwood (HCP)
Geomatics and Database	Susan Stanley (HCP)
	Jason Suwala (HCP)
	Aneeqa Syed (HCP)
Document Production	Tatyana Kovyneva (HCP)
	Tania Pye (HCP)

EXECUTIVE SUMMARY

OVERVIEW

The Regional Aquatics Monitoring Program (RAMP) was initiated in 1997 in association with mining development in the Athabasca oil sands region near Fort McMurray, Alberta. RAMP is an industry-funded, multi-stakeholder initiative that monitors 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 assessed. In 2009, RAMP was funded by Suncor Energy Inc., Syncrude Canada Ltd., Shell Albian Sands, Canadian Natural Resources Ltd., Imperial Oil Resources, Nexen Inc., Husky Energy, Total E&P Canada Ltd., and Hammerstone Corporation. Non-funding participants included municipal, provincial and federal government agencies an Aboriginal group.

The Regional Municipality of Wood Buffalo in northeastern Alberta is the RAMP Regional Study Area (RSA). Within this area, a Focus Study Area (FSA) has been defined and includes watersheds where oil sands and other developments are occurring or planned, including:

- Lower Athabasca River;
- Major tributary watersheds/basins of the lower Athabasca River including the Clearwater-Christina rivers, Hangingstone River, Steepbank River, Muskeg River, MacKay River, Ells River, Tar River, Calumet River, and Firebag River;
- Select minor tributaries of the lower Athabasca River (McLean Creek, Mills Creek, Beaver River, Poplar Creek, and Fort Creek);
- Specific wetlands and shallow lakes in the vicinity of current or planned oil sands and related developments; and
- A selected group of 50 regional acid-sensitive lakes.

The RAMP FSA also includes the Athabasca River Delta as the receiving environment of any oil sands developments.

RAMP incorporates 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 in RAMP on monitoring sensitive biological indicators that reflect the overall condition of the aquatic environment. By combining both monitoring approaches, RAMP strives to achieve a more holistic understanding of potential effects on the aquatic environment related to oil sands development.

The scope of RAMP focuses on the following key components of boreal aquatic ecosystems:

- Climate and hydrology are monitored to provide a description of changing climatic conditions in the RAMP FSA, as well as changes in the water level of selected lakes and in the quantity of water flowing through rivers and creeks.
- Water quality in rivers, lakes and the Athabasca River Delta is monitored to assess the potential exposure of fish and invertebrates to organic and inorganic chemicals.
- Benthic invertebrate communities and sediment quality in rivers, lakes and the Athabasca River Delta are monitored because they reflect habitat quality, serve as biological indicators, and are important components of fish habitat.

- Fish populations in rivers and lakes are monitored as they are biological indicators of ecosystem integrity and are a highly valued resource in the region.

- Water quality in regional lakes sensitive to acidification is monitored as an early warning indicator of potential effects related to acid deposition.

RAMP is funded by member companies that are constructing and operating oil sands projects in the RAMP FSA. However, there are other companies that are constructing or operating oil sands projects, but who are not members of RAMP. Therefore, the term "focal projects" is used in the RAMP 2009 Technical Report to define those projects owned and operated by the 2009 industry members of RAMP listed above which were under construction or operational in 2009 in the RAMP FSA. For 2009, these projects included a number of oil sands projects and a limestone quarry project.

2009 RAMP industry members do have other projects in the RAMP FSA that were in the application stage as of 2009, or which received approval in 2009 or earlier, but on which construction had not yet started as of 2009. These projects are noted throughout this technical report, but are not designated as focal projects, as these projects in 2009 would not have contributed to any possible influences on aquatic resources covered by RAMP components.

The term "other oil sands developments" is used in the RAMP 2009 Technical Report to define those projects operated by non-RAMP members located within the RAMP FSA.

The overall analytical approach for the 2009 RAMP Technical Report builds on the methodology used in previous years and the RAMP Technical Design and Rationale document. The analysis:

- is conducted at the watershed/river basin level, with an emphasis on watersheds in which development has already occurred, as well as the lower Athabasca River at the regional level;

- uses a set of measurement endpoints representing the health and integrity of valued environmental resources within the component; and

- uses specific criteria (e.g., criteria used in focal project EIAs, AENV, CCME guidelines, generally-accepted EEM effects criteria) for determining whether or not a change in the measurement endpoints has occurred and is significant with respect to the health and integrity of valued environmental resources.

The RAMP 2009 Technical Report uses the following definitions for monitoring status:

- ***Test*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches) downstream of a focal project; data collected from these locations are designated as ***test*** for the purposes of analysis, assessment, and reporting. The use of this term does not imply or presume that effects are occurring or have occurred, but simply that data collected from these locations are being tested against *baseline* conditions to assess potential changes; and

- ***Baseline*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 2009) or were (prior to 2009) upstream of all focal projects; data collected from these locations are to be designated as ***baseline*** for the purposes of data analysis, assessment, and reporting. The terms ***test*** and ***baseline*** depend solely on location of the aquatic resource in relation to the location of the focal projects to allow for long-term comparison of trends between *baseline* and *test* stations.

Satellite imagery was used in 2009 in conjunction with more detailed maps of Athabasca oil sands operations provided by a number of RAMP industry members to estimate the type, location, and amount of land changed by focal projects and other development activities. As of 2009, it is estimated that there were approximately 82,800 ha of the RAMP FSA that have undergone land change from focal projects and other oil sands developments. The percentage of the area of watersheds with land change as of 2009 varies from less than 1% for many watersheds (MacKay, Ells, Christina, Hangingstone, Horse, and Firebag rivers), to 5% to 10% for the Upper Beaver watershed, to more than 10% for the Muskeg River, Fort Creek, Mills Creek, Tar River, Shipyard Lake, and McLean Creek watersheds, as well as the smaller Athabasca River tributaries from Fort McMurray to the confluence of the Firebag River.

ASSESSMENT OF 2009 MONITORING RESULTS

A tabular summary of the 2009 results by watershed and component is presented at the end of this executive summary.

Lower Athabasca River and Athabasca River Delta

Hydrology The observed 2009 discharge for the Athabasca River is estimated to be 0.85% less than the *baseline* discharge would have been in the absence of focal projects. The mean open-water period (May to October) discharge, open-water minimum daily discharge, annual maximum daily discharge, and mean winter discharge calculated from the observed *test* hydrograph are 0.7%, 1.2%, 0.4% and 1.7% lower, respectively, than from the estimated *baseline* hydrograph. These differences are all classified as **Negligible-Low**. The results of the hydrologic assessment are essentially identical to these results in the case in which focal projects plus other oil sands developments are considered.

Water Quality In fall 2009, water quality at *test* and *baseline* stations in the Athabasca River were assessed as having **Negligible-Low** differences from regional *baseline* water quality conditions. Concentrations of water quality measurement endpoints at *test* stations were similar to those at *baseline* stations and were consistent with regional *baseline* concentrations. There were no consistent patterns between *baseline* and *test* stations in the selected water quality measurement endpoints. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem in September 2009 was consistent with previous sampling years, showing little year-to-year variation.

Benthic Invertebrate Communities and Sediment Quality The variations in benthic invertebrate community measurement endpoints in the Athabasca River Delta (ARD) reaches are classified as **Negligible-Low** because the measurement endpoints in fall 2009 were within the range of historical values for these reaches, and there are no trends over time in the measurement endpoints indicating a degradation of community composition. Sediment quality at stations in the ARD exhibited **Negligible-Low** differences from regional *baseline* sediment quality conditions because concentrations of sediment quality endpoints in fall 2009 were generally within previously-measured ranges.

Fish Populations Seasonal patterns were observed in species dominance among years with white sucker dominating the spring catch over the last three years, and the increasing dominance of goldeye in summer since 1997. Goldeye and walleye have dominated the catch in fall among years. As of 2009, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, length-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition and length-frequency distribution for all KIR species. However, the variability of these measurement endpoints among years does not indicate consistent negative or positive changes in the fish populations and likely reflect natural variability of these migratory fish species across time.

Muskeg River Watershed

Hydrology The mean open-water discharge and the annual maximum daily flow calculated from the observed *test* hydrograph are 2.5% and 6.4% lower, respectively, than from the estimated *baseline* hydrograph for the Muskeg River watershed; these differences are classified as **Negligible-Low** and **Moderate,** respectively. The mean winter discharge and the open-water period minimum daily discharge calculated from the observed *test* hydrograph are 31.6% and 17.3% higher, respectively, from the estimated *baseline* hydrograph; these differences are classified as **High**.

Water Quality In fall 2009, water quality at most stations in the Muskeg River watershed was generally consistent with regional *baseline* conditions with the exception of Shelley Creek as measured at *test* station SHC-1. Differences in water quality in fall 2009 at seven of the eight stations monitored in the Muskeg River watershed as compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**. Differences in water quality in Shelley Creek as measured at *test* station SHC-1 as compared to regional *baseline* conditions was assessed as **High** because concentrations of several measurement endpoints in fall 2009 were outside regional *baseline* concentrations; however, similarly high concentrations of these endpoints also fell outside the range of regional *baseline* concentrations in previous sampling years at this station in the late 1990s, prior to any oil sands development in the Shelley Creek watershed, suggesting that the difference in water quality may be naturally occurring.

Benthic Invertebrate Communities and Sediment Quality The difference in the condition of benthic invertebrate communities in the lower Muskeg River as compared to regional *baseline* conditions is classified as **Negligible-Low** on the basis that none of the benthic invertebrate community measurement endpoints have had a significant time trend relative to background variation as of 2009, and the values of all benthic invertebrate community measurement endpoints in fall 2009 were within the range of values for *baseline* erosional reaches. The difference in the condition of benthic invertebrate communities in the middle Muskeg River as compared to regional *baseline* conditions is classified as **Negligible-Low** for the same reasons as for the lower Muskeg River. The difference in the condition of benthic invertebrate communities in the upper Muskeg River as compared to regional *baseline* conditions is classified as **Negligible-Low** because none of the benthic invertebrate community measurement endpoints were significantly different between the years in which the reach has been designated as *test* from years it was designated as *baseline*.

The data from Jackpine Creek support a conclusion that the benthic invertebrate communities in *test* reach JAC-D-1 have changed over time with increases in number of taxa, diversity, and evenness that were not observed in *baseline* reach JAC-D-2. The variation in benthic invertebrate community measurement endpoints in *test* reach JAC-D-1 are classified as **Negligible-Low** on the basis that although there was a significant decrease in %EPT in 2009 compared to 2008, %EPT in 2009 was greater or similar to previously-measured values at this reach, and within regional *baseline* conditions and. Significant increases in diversity and evenness were also observed at *test* reach JAC-D-1 that does not imply a negative change in benthic invertebrate communities. All other measurement endpoints were within the range of regional *baseline* conditions.

The differences in benthic invertebrate community measurement endpoints between Kearl Lake and McClelland Lake in the RAMP FSA are classified as **Negligible-Low**. None of the seven measurement endpoints of benthic invertebrate community composition provided statistical evidence of a change related to *test* conditions. All of the measurement endpoints were within the range of expected *baseline* lake conditions in the RAMP FSA.

Sediment quality at all Muskeg River watershed stations sampled in 2009 was generally consistent with that of previous years, and largely within historical concentrations and regional *baseline* conditions. Differences in sediment quality in fall 2009 at all five stations monitored in the Muskeg River watershed as compared to regional *baseline* conditions are assessed as **Negligible-Low**.

Fish Populations The 2009 Muskeg River fish fence results were compared to results of the 2003 and 2006 Muskeg River fish fences. Although the Muskeg River continues to be utilized by populations of a number of species, dominated by white sucker, longnose sucker, and northern pike, significantly higher numbers of white sucker and much lower numbers of all other species were observed in 2009 compared to the previous two sampling years. The timing of migration for sucker species in 2009 was different from 2003 and 2006 given the runs were not dictated by an initial temperature threshold of about 10°C. Mean age of the dominant species between years was significantly different with younger fish being captured in 2009 compared to 2003 and 2006, with narrower age ranges of fish captured in 2009. The weight-length relationship in dominant species was generally consistent between sampling years but sex-specific differences were observed between male and female white sucker in all three years (i.e., female were heavier than males).

Based on the intermittent operation of fish fence programs on the Muskeg River, any changes related to oil sands development remains undetectable from the natural variability in spawning runs of large-bodied fish species.

Results from the sentinel species monitoring program, which included a site on the lower Muskeg River (MR-E), showed that differences in condition of slimy sculpin at *test* site MR-E relative to *baseline* sites were assessed as **Moderate**, due to an exceedance greater than 10% in the average condition of slimy sculpin from the average condition of slimy sculpin at *baseline* sites but exceedances were not observed across sampling years. In addition, the abundance of young of year slimy sculpin was highest at *test* site MR-E indicating the presence of suitable habitat for young slimy sculpin and good recruitment of young individuals to the population.

Steepbank River Watershed

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.14% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph for the Steepbank River; these differences are classified as **Negligible-Low**.

Water Quality Concentrations of a number of water quality measurement endpoints in the Steepbank River watershed in fall 2009 were above and below the range of previously-measured values, and a smaller number had concentrations outside the range of regional *baseline* concentrations. The ionic composition at all water quality monitoring stations in the watershed in fall 2009 was consistent with previous years and continued to exhibit little temporal variation. Differences in water quality in fall 2009 at all four stations monitored in the Steepbank River watershed compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**.

Benthic Invertebrate Communities The benthic invertebrate community of the lower Steepbank River differs in composition from the upper Steepbank River. However, all statistical reach-year differences in measurement endpoints between the upper and lower reaches of the Steepbank River were either insignificant or weaker than the background "noise". In addition, all benthic measurement endpoints in 2009 were within regional *baseline* values for erosional reaches. These results indicate **Negligible-Low** differences in benthic invertebrate community conditions in the Steepbank River watershed from regional *baseline* conditions.

Fish Populations Previous monitoring studies and results from the 2009 sentinel species monitoring study suggested that the abundance and recruitment of young individuals in the slimy sculpin population at *test* site STR-E is lower compared to *baseline* sites. Although other fish species were captured at this site, the 2009 results and historical sentinel species studies suggests that this site does not provide optimal conditions for slimy sculpin. The absence of slimy sculpin in summer and low sample size in fall at *test* site STR-E prevented an accurate classification of results based on the impact criterion established by Environment Canada (2005). Differences in condition of adult slimy sculpin at *test* site STR-R relative to *baseline* sites was assessed as **Negligible-Low** given the difference in average condition of fish between this site and the *baseline* sites was less than ±10%.

Comparisons across years for this site was not included in the classification of results because this site was only designated as *test* in 2008, and previous sentinel species monitoring was conducted prior to 2008.

Tar River Watershed

Hydrology The mean open-water discharge and the annual maximum daily discharge calculated from the observed *test* hydrograph are 18.5% and 18.8% lower, respectively, than from the estimated *baseline* hydrograph for the Tar River watershed; these differences are classified as **High**. The open-water minimum daily discharge calculated from the observed *test* hydrograph is 12.8% lower than from the estimated *baseline* hydrograph; this difference is classified as **Moderate**.

Water Quality Differences in water quality in fall 2009 in the lower Tar River as compared to regional *baseline* conditions are assessed as **Negligible-Low**. This is in contrast to water quality conditions in the lower Tar River in 2007 and 2008, when water quality was assessed as being measurably different from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality The data from the *test* reach of the Tar River support a conclusion that the benthic invertebrate community had been influenced by focal projects in 2005 and 2006, but have recovered to conditions within the historical *baseline* range in 2009. The variation in benthic invertebrate community composition in the *test* reach of the Tar River are classified as **Negligible-Low** on the basis that changes were modest relative to the remainder (noise) component, and because all measurement endpoints were within regional *baseline* conditions. The reach had previously exhibited changes classified as **High**, but recovered to an approximate *baseline* condition in 2009. Differences in sediment quality observed in fall 2009 between the lower Tar River and regional *baseline* conditions were **Negligible-Low**.

MacKay River Watershed

Hydrology The observed 2009 total discharge for the MacKay River watershed is estimated to be 0.01% less than the total discharge would have been in the absence of oil sands developments in the watershed. Watershed-level differences in the hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality Differences in water quality in fall 2009 in the MacKay River as compared to regional *baseline* conditions are assessed as **Negligible-Low**:

1. Any exceedances of water quality guidelines in 2009 occurred at multiple stations (both *test* and *baseline*) throughout the watershed.
2. Concentrations of almost all water quality measurement endpoints in fall 2009, were within the range of natural variability as they have consistently been since the beginning of the RAMP water quality data record for the MacKay River watershed.

Ionic composition at all water quality monitoring stations in the watershed in 2009 was consistent with previous years and continues to show little year-to-year variation.

Benthic Invertebrate Communities The differences in the benthic invertebrate community in the lower MacKay River as compared to the upper MacKay River are assessed as **Negligible-Low**. Differences in benthic invertebrate community measurement endpoints between the *test* and *baseline* reaches of the Mackay River were statistically weak and values of all benthic invertebrate community measurement endpoints in the lower MacKay River in fall 2009 were within the range of variation for *baseline* erosional reaches in the RAMP FSA. The benthic invertebrate community of the *baseline* reach of the Dunkirk River provides additional data describing the *baseline* condition of erosional reaches in the RAMP FSA.

Calumet River Watershed

Hydrology The short measurement record for the Calumet River in 2009 prevented the calculation of changes to most open-water season measurement endpoints from being reliably determined. The calculated mean open-water period discharge (from 97-days of available data) is 1.0% lower in the *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low**.

Water Quality In fall 2009, water quality at the lower Calumet River showed **Negligible-Low** differences from regional *baseline* conditions. However, water quality at the upper *baseline* station of the Calumet River showed deviations from regional *baseline* conditions, in concentrations of suspended solids, total arsenic and total dissolved phosphorus in fall 2009, indicating a **Moderate** difference from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Summary Reach-year differences in abundance, richness, and %EPT of the benthic invertebrate community between *test* reach CAR-D-1 and *baseline* reach CAR-D-2 were significant but not reflective of an impaired benthic invertebrate community in *test* reach CAR-D-1 because richness and %EPT was higher in *test* reach CAR-D-1 than *baseline* reach CAR-D-2. All other reach-year differences in values of benthic invertebrate community measurement endpoints were not significant between *test* reach CAR-D-1 and *baseline* reach CAR-D-2. In addition, all benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Calumet River watershed from regional *baseline* conditions. Sediment quality at *test* station CAR-D-1 and *baseline* station CAR-D-2 indicated a **Negligible-Low** difference from regional *baseline* sediment quality conditions.

Firebag River Watershed

Hydrology The mean open-water period discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to be 0.07% greater than the estimated *baseline* hydrograph for the Firebag River watershed. Watershed-level differences in hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality With few exceptions, concentrations of water quality measurement endpoints in fall 2009 were within the range of regional *baseline* concentrations, and consistent with historical observations at these stations over the period of record. There was no change in ionic composition in fall 2009 from previous years, and the water quality index for fall 2009 indicated **Negligible-Low** differences in water quality conditions from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Measurement endpoints for the benthic invertebrate community in McClelland Lake were within or above the range of variation for *baseline* lakes in the RAMP FSA. Differences in sediment quality in McClelland Lake compared to regional *baseline* conditions are assessed as **Negligible-Low**.

Ells River Watershed

Hydrology The mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to change by up to 0.003% from the estimated *baseline* hydrograph for the Ells River watershed. Watershed-level differences in hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality Water quality in fall 2009 in the Ells River was consistent with previous years and between the *test* and *baseline* stations and had **Negligible-Low** differences from regional water quality *baseline* conditions.

Clearwater-Christina River System

Hydrology Based on the estimated flow for the Christina River at the mouth, the effects of both focal projects and other oil sands developments were estimated to increase the discharge by 0.01% from *baseline* values that would have occurred in the absence of these activities. The differences in the Christina River watershed between the observed *test* hydrograph and the estimated *baseline* hydrograph are assessed as **Negligible-Low** for all calculated hydrologic measurement endpoints.

Water Quality As of 2009, water quality at stations in the Clearwater River showed **Negligible-Low** differences from regional *baseline* conditions. Water quality at the *test* station in the Christina River showed a **Moderate** difference from regional *baseline* conditions, resulting from higher concentrations of total nitrogen, total boron, and several ions exceeding historical values and regional *baseline* ranges and **Negligible-Low** differences at the *baseline* station from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Differences in time trends of measurement endpoints for benthic invertebrate communities between the *baseline* and *test* reaches were either insignificant, significant but weaker than the background "noise" component of these differences, or significant but not consistent with a negative impact at the *test* reach. In addition, values of most benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicate a **Negligible-Low** difference in benthic invertebrate community conditions in the Christina River watershed from regional *baseline* conditions of benthic invertebrate communities in depositional habitats. Sediment quality conditions in fall 2009 at both Christina River stations indicated **Negligible-Low** differences from regional *baseline* conditions. Sediment quality at the *test* and *baseline* stations was generally consistent with that of previous years, with concentrations of sediment quality measurement endpoints largely within previously measured and regional *baseline* ranges.

Fish Populations The 2009 Clearwater River inventory results suggests that the relative abundance of fish species is within the natural variability established during historical fish sampling years (2003 to 2008). Species richness in the spring of 2009 was lower than in 2008, but within the range of natural variability. Statistically significant differences were observed between years for length-frequency distributions and condition of KIR species with no significant increasing or decreasing trends over time.

Mean mercury concentrations across all size classes in northern pike (200 to 700 mm) were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. A **Negligible-Low** risk to the health of northern pike was identified given all metals in composite samples were below sublethal effects and no-effects criteria. All tainting compounds in northern pike muscle tissue from the Clearwater River were below guideline concentrations indicating a **Negligible-Low** influence on fish palatability.

Hangingstone River Watershed

Hydrology The observed total discharge for the Hangingstone River watershed from March 1 to October 31, 2009 is estimated to be 0.05% less than the total discharge in this period would have been in the absence of oil sands developments in the watershed. The watershed-level hydrologic effects of these oil sands developments are assessed as **Negligible-Low** for mean open-water season discharge, annual maximum daily discharge, and minimum open-water season discharge.

Horse River Watershed

Water Quality Concentrations of seven out of 15 selected water quality measurement endpoints at the Horse River *baseline* station in fall 2009 were outside the range of regional *baseline* concentrations. The WQI value for the Horse River watershed indicated a **Moderate** difference from regional *baseline* conditions, primarily due to relatively high concentrations of nutrients (nitrogen and phosphorus) and total mercury.

Benthic Invertebrate Communities Benthic invertebrate communities in fall 2009 in the *baseline* reach of the Horse River were similar to regional *baseline* conditions of benthic invertebrate communities in erosional reaches in the RAMP FSA.

Miscellaneous Aquatic Systems

Mills Creek The differences in the Mills Creek watershed between the observed *test* hydrograph and the estimated *baseline* hydrograph are assessed as **High** for all calculated hydrology measurement endpoints.

Isadore's Lake The water level of Isadore's Lake was consistently near the historical maximum values until monitoring temporarily ceased in late June due to equipment malfunction. When monitoring resumed in early October, the water level was above the historical upper quartile value, and reduced to the median level by the end of 2009.

Water quality in Isadore's Lake in fall 2009 showed a **Moderate** difference from regional *baseline* lake water quality concentrations. Ionic composition continued recent trends towards a higher proportion of bicarbonate ions, and a number of dissolved ions exceeded the 95th percentile of regional *baseline* concentrations.

The differences in benthic invertebrate communities between Isadore's Lake and benthic invertebrate communities of *baseline* lakes in the RAMP FSA are classified as **High.** Number of taxa, Simpson's diversity and evenness were significantly lower than what is observed in *baseline* lakes, and there have essentially been no mayflies, stoneflies, caddisflies in Isadore's Lake during the entire sampling period for this lake. Values of six of seven measurement endpoints for benthic invertebrate communities in 2009 were outside the range of variation observed for *baseline* lakes. Differences in sediment quality observed in fall 2009 in Isadore's Lake compared to conditions in regional *baseline* lakes were **Negligible-Low**.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2009 at Shipyard Lake were within historical ranges with the exception of concentrations of sodium and chloride which have shown consistent increases over the period of record. Concentrations of these ions in fall 2009 are now well above regional *baseline* concentrations. Differences in water quality in fall 2009 at Shipyard Lake compared to regional *baseline* conditions are assessed as **Moderate**.

The differences in benthic invertebrate communities between Shipyard Lake as measured at *test* station SHL-1 and regional *baseline* lakes in the RAMP FSA are classified as **Negligible-Low**. Differences in values of benthic invertebrate community measurement endpoints between Shipyard Lake and *baseline* lakes in the RAMP FSA were statistically-weak, with only one measurement endpoint (CA axis score 1) exceeding its regional *baseline* range. Differences in sediment quality conditions at Shipyard Lake were **Negligible-Low** compared to regional *baseline* conditions.

Poplar Creek and Beaver River The mean open-water discharge (May to October) calculated from the observed *test* hydrograph is 49% higher than from the estimated *baseline* hydrograph; this difference is classified as **High**. The annual maximum daily discharge from the observed *test* hydrograph is 1.3% less than from the estimated *baseline* hydrograph; this difference is classified as

Negligible-Low. The open-water minimum daily discharge from the observed *test* hydrograph is 2.1% less than from the estimated *baseline* hydrograph; this difference is classified as **Negligible-Low**.

In fall 2009, differences in water quality from regional *baseline* conditions were **Moderate** for *test* stations of lower Beaver River and Poplar Creek, largely as a result of relatively high concentrations of a number of ions and total dissolved solids. Differences in water quality in fall 2009 at the upper Beaver River, designated as *baseline*, as compared to regional *baseline* conditions are assessed as **Negligible-Low**.

The data from lower Poplar Creek support a conclusion that the benthic invertebrate community has exhibited changes over time, potentially related to oil sands developments. The variations in benthic invertebrate community measurement endpoints at lower Poplar Creek are classified as **Moderate** on the basis that there are significant differences in diversity, evenness, and %EPT, while measurement endpoint values are within the range of regional *baseline* conditions. Differences in sediment quality at lower Poplar Creek and the upper Beaver River indicated a **Negligible-Low** difference from regional *baseline* conditions.

McLean Creek Water quality in fall 2009 in lower McLean Creek showed a **Negligible-Low** difference from regional *baseline* conditions and was generally consistent with previous sampling years.

Fort Creek The mean open-water period (May to October) discharge, minimum daily discharge, and annual maximum daily discharge calculated from the observed *test* hydrograph are approximately 11% higher than from the estimate *baseline* hydrograph; these differences are classified as **Moderate**.

Differences in water quality in fall 2009 in lower Fort Creek compared to regional *baseline* water quality conditions are assessed as **Moderate** on the basis of exceedances of total dissolved solids, sulphate, and calcium above and total aluminum, total dissolved phosphorus, and total suspended solids below the range of regional *baseline* conditions.

Unnamed Jackson Lake A fish tissue sampling program was conducted in an unnamed lake, known locally as Jackson Lake. The measurement endpoint used in the assessment of results is mercury concentration in fish tissue related to potential effects on human health and fish health. The average mercury concentration in lake whitefish from Jackson Lake across all size classes (200 to 600 mm) was below the subsistence fisher guideline indicating a **Negligible-Low** risk to human health. The average mercury concentration in captured walleye greater than 400 mm (0.9 kg) from Jackson Lake in 2009 was above the Health Canada subsistence fisher guideline indicating a **High** risk to health of subsistence fishers and a **Moderate** risk to health of general consumers for consumption of fish of this size. For fish less than 400 mm in length, the risk to human health is classified as **Negligible-Low** for subsistence fishers and general consumers. The mercury concentration in the single captured northern pike (323 mm) from Jackson Lake in 2009 was below the Health Canada subsistence fisher guideline indicating a **Negligible-Low** risk to human health for subsistence fishers and general consumers. Fish tissue results for Jackson Lake in 2009 indicate a **Negligible-Low** risk to fish health given mercury concentrations did not exceed the lethal (survival) and non-lethal (growth, reproduction) effects thresholds.

REGIONAL SYNTHESIS

Hydrology

The hydrologic effects of focal projects and other oil sands developments on the Athabasca River are assessed as being Negligible-Low. Mean open-water season discharge, mean winter discharge, annual maximum daily discharge, and open-water season minimum daily discharge are all calculated to be lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph; values of these measurement endpoints are less than what they would have been in the absence of focal projects plus other oil sand development activities. The percent change varies with the specific measurement endpoint being considered. The impact on low flows is greater in percentage terms than on high flows, because the withdrawals from the Athabasca River are proportionately larger during low-flow than during high-flow periods.

Hydrologic effects on particular measurement endpoints were observed in the Muskeg River, Tar River, Poplar Creek, Mills Creek and Fort Creek watersheds while hydrologic assessments of all other watersheds were rated as Negligible-Low. The focal project and other oil sands development activities influencing these assessments, in order of decreasing importance, are:

- water withdrawals, releases, and diversions;
- closed-circuited land area creating a loss of flow to natural watercourses that would have otherwise occurred; and
- land area that is not closed-circuited creating increased flows to natural watercourses that would have otherwise not occurred.

The cumulative hydrologic effects of focal project activities plus other oil sands developments in the RAMP FSA are estimated to be at most 0.004% different than the hydrologic effects of the focal projects alone.

A review of the average estimated percent change from 2004 to 2009 for each of the four hydrologic measurement endpoints indicates that, in all cases, most of the assessed area has experienced Negligible-Low hydrologic impacts. Therefore, while there have been changes in some hydrologic measurement endpoints in particular watersheds that have been Moderate to High, hydrologic effects of focal projects and other oil sands developments at a regional level, based on watercourses monitored by RAMP, have been largely **Negligible-Low** to 2009.

Water Quality

Aside from the exceptions noted below, regional water quality data collected by RAMP in fall 2009 was generally similar for all key water quality measurement endpoints between stations designated as *test* and those designated as *baseline*, as well as generally falling within the range of historical observations from previous years.

Exceptions to the consistent regional water quality results included metals, nutrients and major ions. The main regional exception for metals was ultra-trace mercury, which was detected (at concentrations below relevant water quality guidelines) more frequently in fall 2009 than in previous years, across the entire study area and at an equal frequency at both *baseline* and *test* stations. This regional analysis also highlighted the following watershed-specific exceptions:

- concentrations of several dissolved ions that exceeded regional *baseline* concentrations in small tributaries and flood-plain lakes of the Athabasca River, including Beaver River, Poplar Creek, Isadore's Lake and Shipyard Lake; and
- generally higher dissolved organic matter and total nitrogen (comprised predominantly of organic nitrogen) at both *baseline* and *test* stations sampled by RAMP in 2009 relative to previous years.

Few trends in water quality were observed in the Athabasca River mainstem in this report and in other studies in the lower Athabasca River near the Athabasca River Delta (ARD), that were not also measured upstream of Fort McMurray.

Benthic Invertebrate Communities and Sediment Quality

At the regional level, variations within and among reaches (and lakes) designated as *test* have been within the *baseline* range of variability as observed in *baseline* reaches (and lakes). In addition, with a few exceptions, most differences in benthic invertebrate community measurement endpoints between *test* reaches and *baseline* reaches in watersheds were not significantly different in 2009. The exceptions to this in 2009 were the lower Poplar Creek, lower Jackpine Creek, and Isadore's Lake, all of which had a number of significant differences between *test* and *baseline* concentrations, and values of benthic invertebrate community measurement endpoints that were below and above the 5th and 95th percentiles of *baseline* ranges for the particular habitat type in the RAMP FSA.

Sediments in the RAMP FSA naturally contain hydrocarbons and PAHs at concentrations that may exceed environmental quality guidelines. Spatial and temporal comparisons of sediment quality since monitoring by RAMP began in 1997 do not indicate any consistent trends over time in concentrations of hydrocarbons or metals, any consistent, regional differences in sediment quality between *baseline* and *test* stations, or any relationships between sediment chemistry and composition of benthic invertebrate communities.

Fish Populations

Fish Inventory The results from the fish inventories suggest that, although there is variation in fish inventory measurement endpoints across years, relative abundance, species richness and condition of Key Indicator Resource fish species since 1997 has generally remained within historical *baseline* ranges of values for these measurement endpoints:

1. The CPUE of all KIR fish species combined was generally greater than historical *baseline* ranges for CPUE in 1997 and 1998, and within the historical *baseline* range from 2000 to 2004. The CPUE began increasing in 2005 with values in 2008 and 2009 often greater than the 95th percentile of the regional *baseline* range of CPUE. CPUE values for 2009 in spring, summer, and fall were all greater than the regional *baseline* range for CPUE.

2. The number of species in the Athabasca River has been relatively consistent over time and, including 2009, either within or greater than the historical *baseline* range of species richness for the Athabasca River.

3. The condition (i.e., weight-length relationship) of KIR fish species in the Athabasca River has remained within historical *baseline* ranges of condition since 1997, with the exception of condition of goldeye, northern pike and walleye in summer 2009, which were below the 5th percentile of regional *baseline* condition values.

Fish Tissue To provide a regional context for the 2009 fish tissue results for the Clearwater River and Jackson Lake, the 2009 fish tissue results were compared to mercury concentrations in fish tissue from waterbodies not downstream of focal projects and from previous RAMP sampling programs.

Lake whitefish:

- 0% of lake whitefish collected from Jackson Lake exceeded the Health Canada subsistence fisher and general consumer guidelines.
- The mean concentration of mercury in lake whitefish in all waterbodies in the regional dataset was below the Health Canada subsistence consumption guideline.

Northern pike:

- 10% of northern pike collected from the Clearwater River exceeded the Health Canada subsistence fisher guideline (0.2 mg/kg), while 0% exceeded the general consumer guideline (0.5 mg/kg). The single northern pike captured from Jackson Lake did not exceed the Health Canada subsistence guideline; and

- In waterbodies sampled for northern pike, mean mercury concentrations in 55% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, mean mercury concentrations in 38% of the waterbody-year combinations exceeded the Health Canada subsistence fisher guideline, and mean mercury concentrations in 6% of the waterbody-year combinations exceeded the Health Canada general consumer guideline.

Walleye:

- 59% of walleye collected from Jackson Lake of fish exceeded the Health Canada subsistence fish guideline and one of these fish exceeded the general consumer guideline; and

- In waterbodies sampled for walleye, mean mercury concentrations in 50% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, 36% of waterbody-year combinations exceeded the Health Canada subsistence fisher guideline, and 14% of waterbody-year combinations exceeded the Health Canada general consumer guideline.

Acid-Sensitive Lakes

Results of the analysis of 2009 RAMP ASL lake data in conjunction with the historical RAMP ASL lake dataset suggest that there has been no significant change in the overall chemistry of the 50 RAMP ASL lakes in 2009 compared to previous years. A long-term decline is noted for DOC but this appears to be a natural regional trend. Based on the analysis of among-year differences in concentrations of ASL measurement endpoints, as well as trend analysis and control plotting of concentrations of ASL measurement endpoints on individual RAMP ASL lakes, there is no overwhelming evidence to conclude that there have been any significant changes in lake chemistry in the RAMP ASL lakes attributable to acidification.

Summary and Recommendations

The following table provides a summary of the 2009 RAMP monitoring program results, by watershed and component.

The report concludes with a number of recommendations directed towards refining the monitoring program and increasing the value of RAMP monitoring activities. These recommendations are outlined in detail in Section 8 for each RAMP component for consideration during the design of monitoring in future years of RAMP.

Summary assessment of RAMP 2009 monitoring results.

Watershed/Region	Differences Between *Test* and *Baseline* Conditions					Fish Populations: Health Risk from Metals and Organics in Fish Tissue						Acid-Sensitive Lakes: Variation from Long-Term Average Potential for Acidification
	Hydrology	Water Quality	Benthic Invertebrate Communities	Sediment Quality	Fish Populations: Sentinel Species	Human Health				Fish Health	Fish Palatability	
						Sp.	Size	Sub.	Gen.			
Athabasca River	🟡	🟡	-	-	-	-	-	-	-	-	-	-
Athabasca Delta	-	-	🟡	🟡	-	-	-	-	-	-	-	-
Muskeg River	🟤	🟡	🟡	-	🟠	-	-	-	-	-	-	-
Steepbank River	🟡	🟡	🟡	-	🟡	-	-	-	-	-	-	-
Tar River	🟤	🟡	🟡	🟡	-	-	-	-	-	-	-	-
MacKay River	🟡	🟡	🟡	-	-	-	-	-	-	-	-	-
Calumet River	🟡	🟡	🟡	🟡	-	-	-	-	-	-	-	-
Firebag River	🟡	🟡	🟡	🟡	-	-	-	-	-	-	-	-
Ells River	🟡	🟡	-	-	-	-	-	-	-	-	-	-
Christina River	🟡	🟠	🟡	🟡	-	-	-	-	-	-	-	-
Clearwater River	nm	🟡	-	-	-	NRPK	all sizes	🟡	🟡	🟡	🟡	-
Fort Creek	🟠	🟡	-	-	-	-	-	-	-	-	-	-
Beaver River	-	🟠	-	-	-	-	-	-	-	-	-	-
McLean Creek	-	🟡	-	-	-	-	-	-	-	-	-	-
Mills Creek	🟤	-	-	-	-	-	-	-	-	-	-	-
Poplar Creek	🟤	🟠	🟠	🟡	-	-	-	-	-	-	-	-
Shipyard Lake	-	🟠	🟡	🟡	-	-	-	-	-	-	-	-
Isadore's Lake	nm	🟠	🟤	🟡	-	-	-	-	-	-	-	-
Unnamed "Jackson" Lake	-	-	-	-	-	LKWH	all sizes	🟡	🟡	All species 🟡	-	-
						WALL	>400 mm	🟤	🟠			-
						NRPK	all sizes	🟡	🟡			-
Stony Mountains	-	-	-	-	-	-				-	-	🟡
West of Fort McMurray	-	-	-	-	-	-				-	-	🟡
Northeast of Fort McMurray	-	-	-	-	-	-				-	-	🟡
Birch Mountains	-	-	-	-	-	-				-	-	🟠
Canadian Shield	-	-	-	-	-	-				-	-	🟡
Caribou Mountains	-	-	-	-	-	-				-	-	🟡

Legend and Notes

🟡 Negligible-Low
🟠 Moderate
🟤 High

"-" program was not completed in 2009.

nm — not measured in 2009.

Hydrology: Calculated on differences between observed *test* and estimated *baseline* hydrographs: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.
Note: As not all hydrology measurement endpoints are calculated for each watershed because of differing lengths of the hydrographic record for 2009, hydrology results above are for those endpoints that were calculated.
Note: mean winter discharge and minimum open-water season discharge in the Muskeg River watershed were assessed as High, annual maximum daily discharge which was assessed as Moderate, and mean open-water season discharge was classified as Negligible-Low.

Water Quality: Classification based on adaptation of CCME water quality index.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparisons to regional *baseline* conditions.

Sediment Quality: Classification based on adaptation of CCME sediment quality index.

Fish Populations (fish tissue): Uses various USEPA and Health Canada criteria for risks to human health, fish health, and tainting from fish tissue concentrations of various substances. LKWH-lake whitefish; WALL-walleye; NRPK-northern pike
Note: The classification of risk to human health for fish populations was Negligible-Low below the size class specified.
Note: For Fish Population Human Health Classification - Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada.

Fish Populations (sentinel species): Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2005) see Section 3.4.7.3 for a detailed description of the classification methodology.

Acid-Sensitive Lakes: Classification based the frequency in each region with which values of seven measurement endpoints in 2009 were more than twice the standard deviation from their long-term mean in each lake.

1.0 INTRODUCTION

This document is the 2009 Technical Report of the Regional Aquatics Monitoring Program (RAMP). RAMP is a joint environmental monitoring program that assesses the health of rivers and lakes in the Athabasca oil sands region of northeastern Alberta, with participation from the oil sands industry, other industries active in the Athabasca oil sands region, regional stakeholders, Aboriginal communities, and local, provincial, and federal governments.

1.1 ATHABASCA OIL SANDS REGION BACKGROUND

With an estimated 275 billion m^3 (1.7 trillion barrels) of total reserves of bitumen (initial volume in place), the Alberta oil sands are the largest component of Canada's known petroleum resources. The Alberta oil sands are a significant component of the world's petroleum resources, with its 27.1 billion m^3 (170.5 billion barrels) of remaining established bitumen reserves[1] (ERCB 2009) being equivalent to approximately 13% of the world's known reserves of conventional crude oil. Total bitumen deposits in the Athabasca oil sands region are the largest of Alberta's three oil sands regions, containing almost 81% of the total provincial reserves, with the total deposits in the Cold Lake and Peace River areas being significantly smaller.

In 1967, Great Canadian Oil Sands Ltd. (now Suncor Energy Inc.) initiated the first commercially successful bitumen extraction and upgrading facility in the Athabasca oil sands region. Since that time, investment and development in the Athabasca oil sands region near Fort McMurray in the Regional Municipality of Wood Buffalo (RMWB) has increased substantially. Approximately 17% of the estimated established bitumen reserves in the Athabasca oil sands region were under active development as of the end of 2008, and 3% of the estimated established bitumen reserves of the Athabasca oil sands region has been extracted by the end of 2008 (Table 1.1-1).

Table 1.1-1 Status of bitumen reserves in the Athabasca oil sands region.

Bitumen Reserve and Production Indicators		Amount (million barrels)
Initial Volume in Place (total reserves)		1,397,645
Estimated Established Reserves		142,711*
Established Reserves under Active Development as of 31 December 2008		24,971
Mineable	23,479	
in situ	1,491	
Cumulative Production as of 31 December 2008		4,639
Mineable	4,214	
in situ	425	
Remaining Established Reserves		138,072

Data from ERCB (2009); all figures are as of December 31, 2008.

* Estimated, established reserves are estimated by applying the ratio of estimated established to the total bitumen reserves for the entire province to total reserves in the Athabasca oil sands region.

With increasing development of the oil sands, there has been an increase in environmental monitoring and research conducted in the region. In addition to RAMP,

[1] Established bitumen reserves are defined as the amount of bitumen that is recoverable under current technology and present and anticipated economic conditions specifically proved by drilling, testing, or production, plus the portion of reserves that are interpreted to exist from geological, geophysical, or similar information with reasonable certainty (ERCB 2009). Remaining established bitumen reserves are established bitumen reserves less cumulative bitumen production.

two other multi-stakeholder organizations address issues related to the environmental integrity of the Athabasca oil sands region:

- Cumulative Environmental Management Association (CEMA) – established to develop guidelines and management frameworks on how best to reduce cumulative environmental effects due to industrial development. CEMA's focus includes: acid deposition; terrestrial biodiversity and landscape diversity; ground-level ozone; land capability; trace metals and air contaminants; ecosystem management; reclaimed landscape; surface water management; and traditional ecological knowledge (TEK); and
- Wood Buffalo Environmental Association (WBEA) – established to monitor and provide information on air quality and air-related environmental impacts in the RMWB. The WBEA implements three programs:
  - Air quality monitoring and reporting, conducted via a network of fourteen air quality monitoring stations in the RMWB;
  - Terrestrial Environmental Effects Monitoring (TEEM) – a program 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
  - A human exposure monitoring program, initiated in 2005, designed to monitor select air contaminants to which individuals in the RMWB are exposed.

In addition to RAMP, there are numerous other ongoing monitoring programs and studies of aquatic resources being conducted by government agencies, academia and industry. For example, Alberta Environment has been monitoring water quality of the Athabasca River since the 1970s and the Muskeg River since the 1990s and has recently initiated intensive, integrated monitoring throughout the Muskeg River watershed, as well as a contaminant loading study involving passive water quality samplers throughout the oil sands region and historical sediment quality assessments (coring studies). Alberta Sustainable Resource Development continues to monitor and manage the fisheries resource in the region and Water Survey of Canada continues to operate several hydrology stations in the area. Individual oil sands companies, including both members and non-members of RAMP, undertake regular water quality monitoring in streams and rivers near their operations, to satisfy permit requirements. Finally, several universities and government research continue to undertake studies in the oil sands region to better understand local aquatic resources and their response to regional development.

1.2 OVERVIEW OF RAMP

The Regional Aquatics Monitoring Program (RAMP) is an industry-funded, multi-stakeholder environmental monitoring program initiated in 1997. The overall mandate of RAMP is to:

> *determine, evaluate, and communicate the state of the aquatic environment and any changes that may result from cumulative resource development within the Regional Municipality of Wood Buffalo.*

In order to fulfill this mandate, the Program integrates aquatic monitoring activities across different components of the aquatic environment, geographical locations, and Athabasca oil sands and other developments. This enables trends in the state of the aquatic environment to be determined, and any changes in the aquatic environment to be assessed and communicated. The coordination of monitoring efforts among RAMP members results in a comprehensive and cost-effective regional database that may be used by operators for their environmental management programs, compliance with environmental requirements of regulatory approvals, assessments of proposed developments, as well as by other stakeholders interested in the health of the aquatic environment in the Athabasca oil sands region.

1.2.1 RAMP Objectives

The objectives of RAMP are to:

- monitor aquatic environments in the Athabasca oil sands region to detect and assess cumulative effects and regional trends;
- collect *baseline* data to characterize variability in the Athabasca oil sands region;
- collect and compare data against which predictions contained in Environmental Impact Assessments (EIAs) can be assessed;
- collect data that assists with the monitoring required by regulatory approvals of oil sands and other developments;
- collect data that assists with the monitoring requirements of company-specific community agreements with associated funding;
- recognize and incorporate traditional knowledge into monitoring and assessment activities;
- communicate monitoring and assessment activities, results and recommendations to communities in the Regional Municipality of Wood Buffalo, regulatory agencies and other interested parties;
- continuously review and adjust the program to incorporate monitoring results, technological advances and community concerns and new or changed approval conditions; and
- conduct a periodic peer review of the program's objectives against its results, and to recommend adjustments necessary for the program's success.

These objectives guide the scope, management and implementation of the program over time.

1.2.2 Organization of RAMP

RAMP is governed by a multi-stakeholder Steering Committee. Membership in this decision-making body is comprised of oil sands and other industries, Aboriginal representatives, and government agencies (municipal, provincial and federal) (Figure 1.2-1). RAMP also has a Technical Program Committee responsible for the development and review of the RAMP technical monitoring program from year to year. The Technical Program Committee is divided into discipline-specific sub-groups that develop and review their component for integration into the overall monitoring program. Investigators (i.e., the Hatfield RAMP Team, consisting of Hatfield Consultants Partnership, Kilgour and Associates Ltd., and Western Resource Solutions), primarily carry out the fieldwork, data analysis and reporting as defined by the program. A Finance Sub-committee focuses on issues related to the budget and funding for the annual monitoring. Finally, RAMP has a Communications Sub-Committee for the purpose of transferring information and monitoring results to local stakeholders and the scientific community. When appropriate, the Communications Sub-Committee participates in communications activities in collaboration with WBEA and CEMA.

In 2009, RAMP was funded by Suncor Energy Inc. (Suncor; includes projects formerly under Petro-Canada), Syncrude Canada Ltd. (Syncrude), Shell Albian Sands (Shell Albian), Canadian Natural Resources Ltd. (Canadian Natural), Imperial Oil Resources (Imperial Oil), Nexen Inc. (Nexen), Husky Energy (Husky), Total E&P Canada Ltd. (Total E&P), and Hammerstone Corp. (Hammerstone; formerly Birch Mountain Resources Ltd.).

Figure 1.2-1 RAMP organizational structure[1].

STEERING COMMITTEE		
Industry	**Stakeholders**	**Government**
Alberta Pacific Forest Industries Inc. Canadian Natural Hammerstone Corp.[2] Husky Energy Imperial Oil Resources Nexen Inc.[3] Shell Albian Sands[4] Suncor Energy Inc.[5] Syncrude Canada Ltd. Total E&P Canada Ltd. (Secretary: Hatfield Consultants)	Fort Chipewyan Metis Local No. 125 Fort McKay First Nations Fort McKay Metis Local No. 122 Fort McMurray First Nations	Alberta Energy Resources Conservation Board Alberta Environment Fisheries and Oceans Canada Environment Canada Health Canada Regional Municipality of Wood Buffalo Northern Lights Health Region Alberta Health and Wellness

Finance Sub-Committee	Technical Program Committee	Communications Sub-Committee	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, industry representatives, and Alberta Environment

Technical Program Implementation	Communication Plan Implementation
Preparation of technical program for review by Steering Committee; Technical workshops.	Annual community report; Open house events, etc.

1 composition of Steering Committee as of December 2009.

2 formerly known as Birch Mountain Resources Ltd.

3 Nexen Inc. is now the operator of the Long Lake oil sands facilities with a 65% working interest. OPTI Canada Inc. holds the remaining 35% interest.

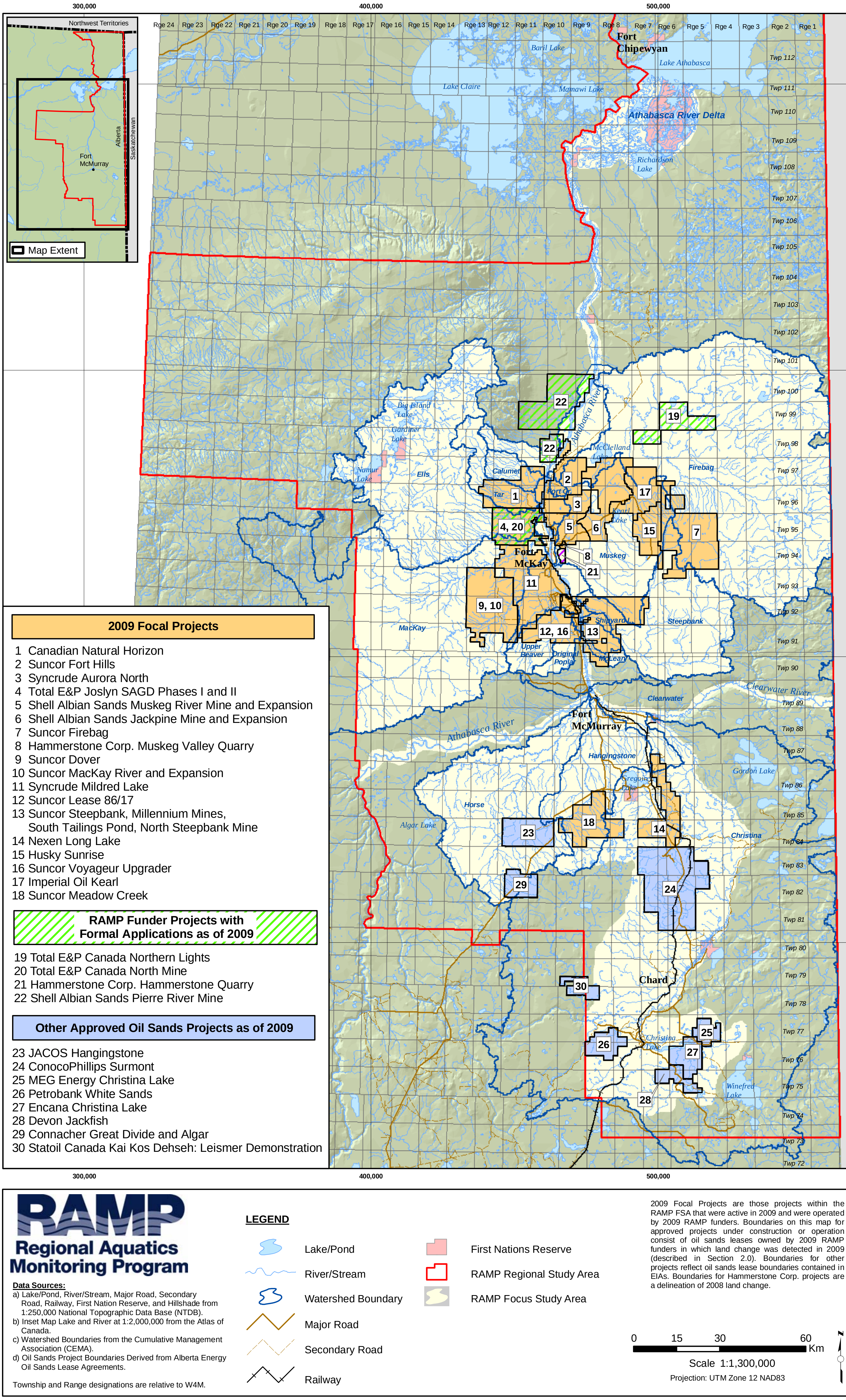
4 formerly known as Albian Sands Inc., and now a subsidiary of Shell Energy Canada.

5 Suncor-Petro-Canada merger occurred in 2009.

1.3 RAMP STUDY AREAS

The RMWB in northeastern Alberta defines the RAMP Regional Study Area (RSA, Figure 1.3-1). The RMWB covers an area of 68,454 km^2 and, according to the 2008 Municipal Census, had a population of over 100,000 persons of which approximately 72,400 persons were residents of Fort McMurray and approximately 26,300 persons were in work-camps; the remaining population resides in surrounding towns (RMWB 2009). The RAMP RSA is bounded by the Alberta-Saskatchewan border on the east, the Alberta-Northwest Territories border on the northeast, Wood Buffalo National Park on the northwest, various demarcations on the west including the Athabasca River, and the Cold Lake Air Weapons Range on the south.

Figure 1.3-1   RAMP study areas.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_A_StudyArea_20091230.mxd

Within the RSA, a Focus Study Area (FSA) is defined by the watersheds in which oil sands development is occurring or is planned, as well as those parts of the Athabasca and Clearwater River channels within the RSA (Figure 1.3-1). Accordingly, much of the intensive monitoring activity is conducted within the RAMP FSA.

The Athabasca River is the dominant waterbody within the RAMP FSA and hydrologically links the upper (southern) portion of the RAMP FSA to the lower (northern) portion. The Athabasca River flows a distance of more than 1,200 km from its headwaters in the Columbia Ice Fields near Banff, Alberta to the Athabasca River Delta (ARD) on the western end of Lake Athabasca. The Athabasca River forms part of the western border of the RAMP RSA before flowing east to Fort McMurray, where it once again flows north, draining the lower portion of the RAMP FSA. The Athabasca River is one of the focal rivers in the Alberta Water for Life Initiative and an initial assessment of the ecological health of the water quality, sediment quality, and non-fish biota was recently conducted as part of the Healthy Aquatic Ecosystems component of the initiative (Alberta Environment 2007). More recently, Alberta Environment has conducted a preliminary assessment of the current state of the surface water quality for the management of transboundary waters between Alberta and the Northwest Territories (Hatfield 2009) as well as an analysis of the water quality conditions and long-term trends on the Athabasca River (Hebben 2009).

The upper portion of the RAMP FSA is within the Mid-Boreal Uplands and Wabasca Lowland Ecoregions, both of which are part of the Boreal Plains Ecozone. This area is dominated by the Clearwater River and Christina rivers, as well as a series of smaller rivers, primarily the Hangingstone and the Horse rivers. The area is characterized by a predominantly sub-humid mid-boreal ecoclimate, closed stands of trembling aspen, balsam poplar with white spruce, black spruce, and balsam fir occurring in late successional stages, as well as cold and poorly-drained fens and bogs covered primarily with tamarack and black spruce. The western part of the southern portion of the RAMP FSA has little relief and is poorly-drained.

The northern portion of the RAMP FSA, dominated by the Athabasca River from Fort McMurray to the ARD, is part of the Slave River Lowlands Ecoregion of the Boreal Plains Ecozone. The mineable portion of the estimated, established bitumen reserves of the Athabasca area is characterized by an undulating sandy plain containing mixed boreal forest. Approximately 50% of the area is covered by peatlands and sporadic discontinuous permafrost. The area is 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. At the ARD, the Athabasca River becomes an interconnected series of braided channels and wetlands flowing into Lake Mamawi and Lake Athabasca. This area experiences a low subarctic ecoclimate, with black spruce as the climax tree species, and with characteristically open stands of low, stunted black spruce with dwarf birch and Labrador tea, and a ground cover of lichen and moss prevailing. The northern portion of the RMWB is within the Selwyn Lake Upland Ecoregion, part of the Taiga Shield Ecozone.

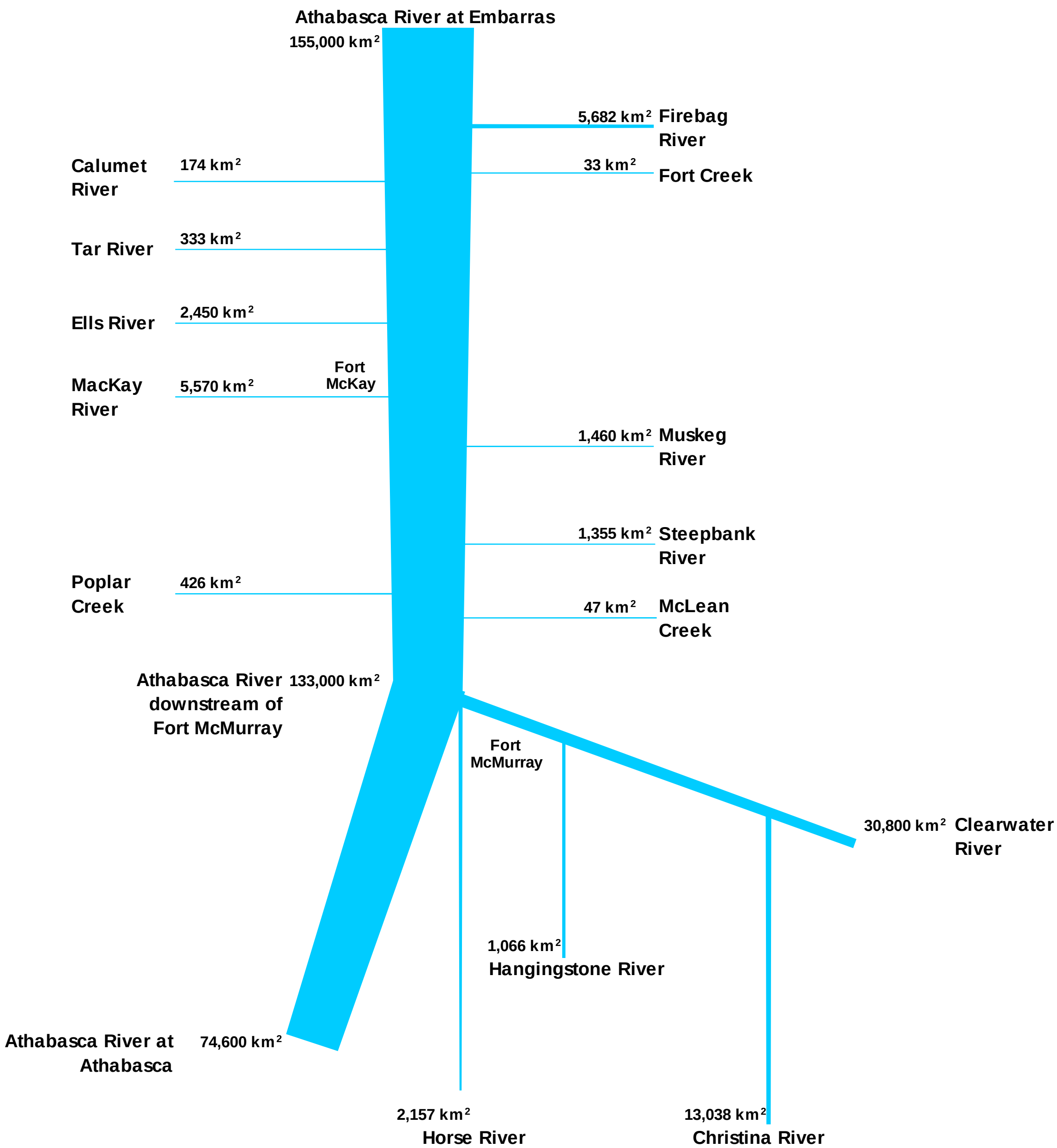
As the Athabasca River flows northward through the RAMP FSA, several smaller tributary streams and rivers join and contribute to the overall flow. Figure 1.3-2 is a hydrologic schematic of the RAMP FSA showing the size (i.e., watershed area) of the larger tributaries relative to the lower Athabasca River. Although approximate, the diagram shows that: (a) there is a range of tributary size in the RAMP FSA; and (b) the size of the lower Athabasca River is much larger than any tributary, even the Clearwater River. Some of the larger of these tributaries include, in upstream to downstream order:

- Clearwater-Christina rivers – the Clearwater originates in Saskatchewan, joins the Athabasca River at Fort McMurray, and includes the contribution of the Christina River, a large tributary of the Clearwater River whose watershed includes several existing and planned *in situ* oil sands developments in the southern portion of the RAMP FSA;
- Hangingstone River – a small river originating in the southwestern portion of the RAMP FSA, joining the Clearwater River immediately upstream of Fort McMurray, and whose watershed includes the Suncor *in situ* Meadow Creek Project and the JACOS (Japan Canada Oil Sands Limited) *in situ* Hangingstone Project;
- Horse River – a small river originating in the southwestern portion of the RAMP FSA, joining the Athabasca River upstream of Fort McMurray, and whose watershed includes the JACOS (Japan Canada Oil Sands Limited) *in situ* Hangingstone Project and the Connacher Great Divide and Algar projects;
- Steepbank River – joins the Athabasca River from the east and whose watershed includes Suncor's existing Steepbank/Project Millennium mines and extensions, the Suncor North Steepbank Mine, and part of the Suncor *in situ* Firebag Project;
- Muskeg River – flows from the east and drains several oil sands development areas, including the Shell Albian Muskeg River Mine and Expansion, Shell Albian Jackpine Mine, Syncrude Aurora North Mine and planned Aurora South Mine, part of the Suncor *in situ* Firebag Project, Imperial Oil Kearl Project, Husky *in situ* Sunrise Thermal Project, and Hammerstone Muskeg Valley Quarry and recently-approved Hammerstone quarry;
- MacKay River – flows from the west and whose watershed includes the Suncor MacKay River and Dover developments, as well as the approved MacKay River expansion, and portions of Syncrude Mildred Lake project area;
- Ells River – flows from the west and whose watershed includes a small portion of the Canadian Natural Horizon Project, the *in situ* projects of Total E&P, and the proposed Total E&P Canada North Mine Project; this river is also the drinking water source for Fort McKay;
- Tar River – also flowing from the west, whose watershed contains most of the Canadian Natural Horizon Project;
- Calumet River – similar to the Tar River, flowing from the west and whose watershed is partly within the Canadian Natural Horizon Project; and
- Firebag River – a river flowing from Saskatchewan whose watershed includes most of the Suncor *in situ* Firebag Project, parts of the Suncor Fort Hills Project, Husky *in situ* Sunrise project, and Imperial Kearl Project.

Other waterbodies monitored under RAMP and within existing or proposed oil sands developments include:

- tributaries within watersheds described above (e.g., Muskeg Creek, Wapasu Creek);
- smaller river tributaries of the Athabasca River (Fort Creek, Mills Creek, Poplar Creek, McLean Creek, and Beaver River) which contain parts of a number of oil sands projects, including the Shell Albian Mills Creek, Syncrude's Mildred Lake development (Beaver River), Suncor's Fort Hills Project (Fort Creek), and Suncor's and Syncrude's oil sands developments on the west side of the Athabasca River (Poplar Creek);

Figure 1.3-2 Hydrologic schematic of RAMP Focus Study Area.



Note: Drainage areas of Athabasca River tributaries derived from watershed boundaries provided by CEMA.

- specific lakes and wetlands such as Isadore's Lake, Shipyard Lake, McClelland Lake, and Kearl Lake;
- a set of regional lakes important from a fisheries perspective; and
- a set of lakes throughout the RAMP RSA for the purpose of assessing lake sensitivity to acidifying emissions.

Finally, there are a number of waterbodies and watercourses monitored under RAMP that are used as *baseline* areas for certain RAMP components.

1.4 GENERAL RAMP MONITORING AND ANALYTICAL APPROACH

1.4.1 Focal Projects

While most of the 2009 industry members of RAMP are companies that are constructing and operating oil sands projects in the RAMP FSA, other industry members of RAMP, such as Hammerstone, are companies constructing and operating other types of projects in the RAMP FSA. Therefore, the term "focal projects" is used in the 2009 Technical Report and is defined as those projects owned by 2009 industry members of RAMP (Section 1.2.2) that were under construction or operational in 2009 in the RAMP FSA. For 2009, these projects include a number of oil sands projects and a limestone quarry project (in the case of Hammerstone); the focal projects are listed and described in Section 2.0.

2009 industry members of RAMP do have other projects in the RAMP FSA that were in the application stage as of 2009, or which received approval in 2009 or earlier, but on which construction had not yet started as of 2009. These projects are noted throughout this technical report but are not designated as focal projects, as these projects in 2009 would not have contributed to any possible influences on aquatic resources covered by RAMP components.

1.4.2 Overall RAMP Monitoring Approach

RAMP incorporates a combination of both stressor- and effects-based monitoring approaches. The stressor-based approach is derived primarily from EIAs prepared for each of the focal projects. EIAs are undertaken in part to evaluate the potential impacts that the proposed project, alone or in combination with other developments, could have on the local and regional environment. To date, EIAs conducted for projects in the Athabasca oil sands region have used primarily a stressor-based approach. A potential stressor is any factor (e.g., chemicals, temperature, water flow, nutrients, food availability, and biological competition) that either currently exists in the environment and will be influenced by the proposed project or will be potentially introduced into the environment as a result of the proposed project. 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 (Munkittrick *et al.* 2000). Using impact predictions from various EIAs, specific potential stressors have been identified that are monitored to document *baseline* conditions, establish natural variation in those conditions, as well as to identify potential changes related to development. Examples from RAMP include specific water quality variables and changes in water quantity.

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. For example, the current federal Environmental Effects Monitoring (EEM) program for the pulp and paper and metal mining industries incorporates an effects-based monitoring approach (Environment Canada 1992, 2002, 2003, 2005). There is a strong emphasis in RAMP on monitoring sensitive biological indicators such as benthic invertebrates and fish populations that reflect and integrate the overall condition of the aquatic environment. By combining both monitoring approaches, RAMP strives to achieve a more holistic understanding of potential effects on the aquatic environment related to the development of focal projects.

1.4.3 RAMP Components

RAMP in 2009 focused on six components of boreal aquatic ecosystems:

- **Climate and Hydrology** – monitors changes in the quantity of water flowing through rivers and creeks in the RAMP FSA, lake levels in selected waterbodies, and local climatic conditions;
- **Water Quality** in rivers, lakes and some wetlands – reflects habitat quality and potential exposure of fish and invertebrates to organic and inorganic chemicals;
- **Benthic Invertebrate Communities** and **Sediment Quality** – benthic invertebrate communities serve as biological indicators and are important components of fish habitat, while sediment quality is a link between physical and chemical habitat conditions to benthic invertebrate communities;
- **Fish Populations** in rivers and lakes – biological indicators of ecosystem integrity and a highly-valued resource in the Athabasca oil sands region; and
- **Acid-Sensitive Lakes** – monitoring of water quality in regional lakes in order to assess potential changes in water quality as a result of acidification.

1.4.4 Definition of Terms

The analysis for each RAMP component is based on a selection of sampling stations and monitoring years to be used in the analysis for each watershed/river basin. For the analysis, the sampling stations and monitoring years are categorized into combinations of spatial and temporal treatments and controls, as described below:

- ***Test*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches) downstream of a focal project; data collected from these locations are designated as *test* for the purposes of data analysis, assessment, and reporting. The use of this term does not imply or presume that effects are occurring or have occurred, but simply that data collected from these locations are being tested against *baseline* conditions to assess potential changes; and
- ***Baseline*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 2009) or were (prior to 2009) upstream of all focal projects; data collected from these locations are designated as *baseline* for the purposes of data analysis, assessment, and reporting.

The terms ***test*** and ***baseline*** depend solely on location of the aquatic resource in relation to the location of the focal projects to allow for long-term comparison of trends between *baseline* and *test* stations.

1.4.5 Monitoring Approaches for RAMP Components

Details on the RAMP monitoring design and rationale are described in the RAMP Technical Design and Rationale document developed by the RAMP Technical Program Committee (RAMP 2009b). A summary of the monitoring design and rationale for each component is provided below.

1.4.5.1 Climate and Hydrology

The quantity of water in a system affects its capacity to support aquatic and terrestrial biota. Changes in the amount or timing of water flow may occur due to natural fluctuations 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:

- provide a basis for verifying EIA predictions of hydrologic changes;
- facilitate the interpretation of data collected by the other RAMP components by placing them in the context of current hydrologic conditions relative to historical mean and extreme conditions;
- document stream-specific *baseline* climatic and hydrologic conditions to characterize natural variability and to allow detection of regional trends;
- support regulatory applications and requirements of regulatory approvals; and
- support calibration and verification of 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 and lake water levels. 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 changes related to development.

Watercourses in the same region may have different hydrologic characteristics related to differences in topography, vegetation, surficial geology, lake storage, groundwater-surface water interaction and geographic influences on precipitation. Accordingly, the scope of the RAMP Climate and Hydrology component has gradually expanded geographically to include catchments affected, or expected to be affected, by focal projects in the area around Fort McMurray. Some watersheds outside the catchments containing focal projects are also monitored to provide *baseline* data. The monitoring program includes the Athabasca River, numerous smaller rivers and streams, and some mine water releases. Data from long-term Environment Canada (i.e., the Water Survey of Canada) and Alberta Environment climatic and hydrologic monitoring stations in the Athabasca oil sands 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 April) flows on some streams that Environment Canada and Alberta Environment monitor during the open-water season.

1.4.5.2 Water Quality

RAMP monitors water quality in order to identify human and natural factors affecting the quality of streams and lakes in the Athabasca oil sands region. Monitoring the chemical signatures of water provides point-in-time measurements; these data help identify potential chemical exposure pathways between the physical environment and biotic communities in the aquatic environment.

The specific objectives of the Water Quality component are to:

- develop water quality database to verify EIA predictions, support regulatory applications and to meet requirements of regulatory approvals;
- monitor potential changes in water 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 quality, *test* stations downstream of development are compared to upstream *baseline* stations (where possible), located beyond the influence of the development, and against an appropriate range of regional *baseline* variability. Water quality is monitored over time to characterize natural temporal variability in *baseline* conditions, and to identify potential trends in water quality related to development, including the focal projects.

A range of characteristics are measured in the Water Quality component, including: conventional variables; major ions; nutrients; biological oxygen demand; other organics; and total and dissolved metals. Sublethal toxicity bioassays are conducted using ambient river water from selected stations to assess potential chronic effects on different aquatic organisms.

RAMP water quality stations are located throughout the RAMP FSA, from the upper Christina River to the Athabasca River downstream of development. Water quality is 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 seasonally (i.e., in winter, spring, summer and fall) in the first year to determine seasonal variation in water quality. Three years of seasonal *baseline* data are collected at stations established in new waterbodies and watercourses.

1.4.5.3 Benthic Invertebrate Communities and Sediment Quality

Benthic invertebrate communities are a commonly-used indicator of aquatic environmental conditions, and are included as a component of the RAMP for several reasons:

- They integrate biologically relevant variations in water, sediment and habitat quality.
- Given they are limited in their mobility and reflect local conditions, they can thus be used to identify point sources of inputs or disturbance.
- The short benthic invertebrate life span (typically about one year) allows them to integrate the physical and chemical aspects of water quality and sediment quality over annual time periods and provide early warning of possible changes to fish communities (e.g. Kilgour and Barton 1999).
- Based on known tolerances of benthic taxa, it is possible to re-create the environmental conditions by determining what animals are present (Rooke and Mackie 1982).

The objectives of RAMP Benthic Invertebrate Community component are to:

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

RAMP focuses on characterizing benthic invertebrate communities on the basis of total abundance, taxonomic richness, and relative dominance in areas downstream of development relative to benthic invertebrate communities upstream of development.

The Benthic Invertebrate Community component focuses on tributaries of the Athabasca River and regional wetlands (shallow lakes). 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. Samples are collected from three areas within the Athabasca River Delta (ARD) because that is an area of significant sediment deposition, and an area in the RAMP FSA that is considered to have the potential to be affected by long-term development.

With an increasing number of focal projects, the component has expanded to include new Athabasca River tributaries and additional stations on previously-monitored Athabasca River tributaries near active development sites. 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 dominant habitat type within a tributary. Within lakes, sampling effort is distributed over the entire open-water area, but restricted to a narrow range in water depth to minimize natural variations in communities.

Benthic sampling is conducted in the fall of each year to limit potential seasonal variability in composition of benthic communities. Where available, historical data collected in previous years of the program are used to place current results in the context of historical trends in benthic invertebrate communities that may be occurring.

Until 2006, sediment quality was a separate component of RAMP. Beginning in 2006, sediment quality sampling was integrated into the Benthic Invertebrate Community component to provide a better link of physical and chemical habitat conditions to a specific biological endpoint. Beginning in 2006, sediment quality was assessed only in depositional benthic invertebrate community sampling locations. Despite the change in focus of sediment quality sampling, sediment quality monitoring objectives remain, as in past years, to:

- develop a sediment quality database to verify EIA predictions, support regulatory applications and to meet requirements of regulatory approvals;
- monitor potential changes in 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.

Taken together, sediment quality and water quality data help identify potential chemical exposure pathways between the physical environment and biotic communities in the aquatic environment.

A range of compounds are measured to characterize sediment quality: particle size; carbon content; target and alkylated PAHs (polycyclic aromatic hydrocarbons); total hydrocarbons; and metals. Sub-lethal bioassay tests also are conducted to assess potential toxicity related to chronic exposure of different aquatic organisms to sediments from selected stations.

1.4.5.4 Fish Populations

The goal of the RAMP Fish Population component is to monitor the health and sustainability of fish populations within the Athabasca oil sands region. Monitoring activities focus on the Athabasca River and its main tributaries potentially influenced by focal projects. Fish populations are monitored because they are key components of the aquatic ecosystem and important ecological indicators that integrate natural and anthropogenic influences. Fish are also an important subsistence and recreational resource. In this regard, there are expectations from regulators, Aboriginal peoples, and the general public with respect to comprehensive monitoring of fish populations in the Athabasca oil sands region.

The specific objectives of the Fish Population component are to:

- collect fish population data to characterize natural or *baseline* variability, assess EIA predictions, and meet requirements of regulatory approvals;
- monitor fish populations for changes that may be due to stressors or impact pathways (chemical, physical, biological) resulting from development by assessing attributes such as growth, reproduction and survival; and
- assess the suitability of fisheries resources in the Athabasca oil sands region for human consumption.

The first two objectives derive from the overall objectives of RAMP. The third objective addresses local community and Aboriginal concerns regarding the safety of consuming fish and the quality of consumed fish that are captured in the Athabasca oil sands region.

To meet the specific component objectives, RAMP conducts a range of core monitoring activities that are intended to assess and document ecological characteristics of fish populations, chemical burdens, and habitat use in the Athabasca oil sands region. The core elements of the Fish Population component are:

- fish inventories;
- tissue sampling for organic and inorganic chemicals;
- monitoring of fish health through evaluation of performance indicators (physical condition, population age, and length/weight comparisons) in sentinel fish species; and
- monitoring of spring spawning use of tributary habitat.

Specific key indicator fish species (or key indicator resources, KIRs) have been identified for the Athabasca River and selected tributaries. These species were selected through consultation with Aboriginal peoples, government and industry representatives, and include goldeye, lake whitefish, longnose sucker, white sucker, northern pike, trout-perch, and walleye (CEMA 2001, RAMP 2009b). Although the Fish Population component 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.

General fish inventories are conducted to monitor and assess temporal and spatial changes in species presence, relative abundance and population variables in selected watercourses. In the Athabasca and Clearwater rivers, the inventory is conducted annually in the spring, summer (as of 2008 in the Athabasca and 2009 in the Clearwater) and fall and is designed to assess populations of large-bodied key indicator species in the vicinity of focal projects. 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 Fish Population component. In addition to their scientific value, the fish inventories provide useful information to local stakeholders on species diversity, the relative strength of age classes, and the incidence of fish anomalies.

RAMP conducts fish tissue assessments to quantify and monitor chemical levels in relation to the suitability of the fish resource for human consumption and to identify potential risk related to fish health. RAMP data are provided to Albert Health and Wellness to develop fish consumption guidelines for waterbodies within the RAMP RSA (GOA 2009b). As part of the ongoing program, muscle tissues are collected from lake whitefish and walleye from the Athabasca River and northern pike from the Clearwater and Muskeg rivers. Tissues are analyzed for metals, including mercury, and specific organic compounds known to cause tainting of fish flesh. Fish tissue analyses (mercury only) also are conducted in conjunction with sampling programs conducted by other agencies (e.g., Alberta Sustainable Resources Development [ASRD]), either through opportunistic sampling, or in conjunction with fisheries investigations mandated separately from RAMP. The program, known as the "Regional Lakes Program", has to date included analysis of fish tissue from Gregoire (Willow) Lake (2002, 2007), Lake Claire (2003), Christina Lake (2003), Winefred Lake (2004), Namur (Moose)

Lake (2007), Gardiner (Buffalo) Lake (2008), Big Island Lake (2008) and Unnamed (Jackson) Lake (2009).

Sentinel fish species monitoring is part of the Fish Population component to assess the potential effects of stressors on populations of fish species that have limited movement relative to the location of the potential stressors. The approach evaluates the performance (characterized by growth, survival, condition, and reproduction) of a specific sentinel species in *test* areas downstream of development relative to *baseline* 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 population of that species resides. The approach has also been included as part of the federal government's EEM programs under the pulp and paper (Environment Canada 2005) and metal mining (Environment Canada 2002, 2003) effluent regulations. Sentinel species monitoring is conducted at regular intervals at several sites in the Athabasca River (trout-perch), as well as several Athabasca tributaries including the Muskeg and Steepbank Rivers (slimy sculpin), and the Ells River (longnose dace).

Fish fence monitoring by RAMP is conducted on the Muskeg River and is used to obtain information on the biology and use of habitat by spawning populations of large-bodied fish species that use the Muskeg River and its tributaries. These data assist in the identification and quantification of local and watershed-level environmental changes in the Muskeg River drainage.

1.4.5.5 Acid-Sensitive Lakes

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

The Acid-Sensitive Lakes (ASL) component of RAMP was initiated in 1999 to conduct annual monitoring of water chemistry in regional lakes to determine long-term changes in these lakes in response to acid deposition on these lakes and their catchment basins. The objectives of the ASL component are to:

- establish a database of water quality to detect and assess cumulative effects and regional trends which would provide specific measurement endpoints capable of detecting incipient lake acidification;
- collect scientifically defensible *baseline* and historical data (both chemical and biological) to characterize the natural variability of these measurement endpoints in the regional lakes;
- collect data on the regional lakes against which predictions contained in environmental impact assessments (EIAs) could be verified; and
- quantify and document individual lake sensitivity to acidification.

Lakes are monitored for various chemical and biological variables that are capable of indicating long-term trends in acidification, including: pH; total alkalinity and Gran alkalinity (acid-neutralizing capacity); base cations; sulphate; chloride; nitrates; dissolved organic carbon; dissolved inorganic carbon; and chlorophyll.

The ASL component contains the following features:

- The locations of the lakes are selected to represent a gradient in acid deposition from both current and anticipated developments in the RAMP FSA.
- For scientific validity, the lake selection includes lakes in the Caribou Mountains and Canadian Shield that are distant from the sources of acidifying emissions.
- Certain regional lakes, which have been the subject of long-term monitoring by AENV, are included to maintain the continuity of their data and to provide additional information on potential trends.
- The lakes selected for monitoring exhibit moderate to high sensitivity to acidification as defined by a total alkalinity less than 400 μeq/L.
- Sampling occurs in the fall season. While fall sampling captures a picture of lake water chemistry after conditions have stabilized after high spring flows, it does not necessarily capture any acidification at other times of the year such as spring pulses of acidity during snowmelt.
- In recent surveys, small waterbodies (ponds) have been included in the ASL component because of their proximity to focal projects and the possibility that they might be low in alkalinity and therefore more sensitive to acid deposition.

1.4.6 Overall Analytical Approach for 2009

For the 2009 RAMP Technical Report, the overall analytical approach builds on analytical approaches used in RAMP in previous years and as described in the RAMP Technical Design and Rationale (RAMP 2009b) (Figure 1.4-1). Key features of the overall analytical approach are as follows.

First, the analysis of RAMP results for 2009 is conducted for the Athabasca River and ARD, as well as at the watershed/river basin level.

Second, the analysis for each RAMP component uses a set of measurement endpoints (Table 1.4-1) representing the health and integrity of valued environmental resources within the component. These are the same measurement endpoints that were used in the RAMP 2004 to 2008 Technical Reports (RAMP 2005, RAMP 2006, RAMP 2007, RAMP 2008, and RAMP 2009a).

Third, a set of criteria are used for determining whether or not there has been a change in the values of the measurement endpoints between: (i) *test* stations; and (ii) *baseline* conditions outside of the range of natural variability (Table 1.4-1).

Fourth, the magnitude of these changes in the values of the measurement endpoints is summarized, and locations or watersheds with moderate or high levels of change become candidate sites for additional studies to identify the causes of the changes being measured.

Figure 1.4-1 Overall analytical approach for RAMP 2009.

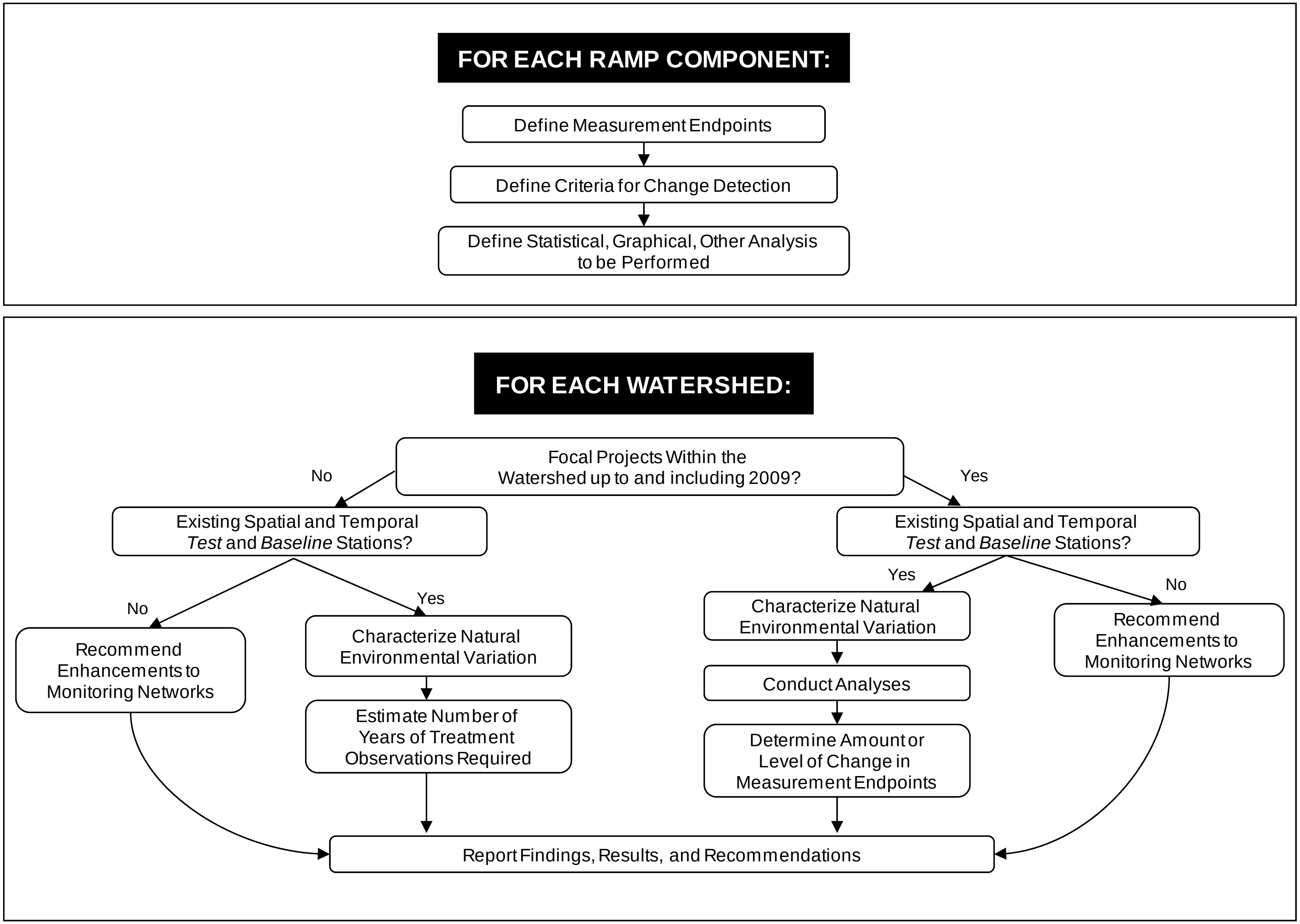


Table 1.4-1 Measurement endpoints and criteria for determination of change used in the analysis for the RAMP 2009 Technical Report.

RAMP Component	Measurement Endpoints Used in 2009 Technical Report[1]	Criteria for Determining Change Used in 2009 Technical Report
Climate and Hydrology	Mean open-water season discharge Mean winter discharge Annual maximum daily discharge Open-water season minimum daily discharge	Differences between observed *test* and estimated *baseline* hydrographs (i.e., the hydrograph that would have been observed had focal projects and other oil sands developments not occurred in the drainage, so that changes in water withdrawals, discharges, and diversions are accounted for) as follows: Negligible-Low: ± 5% ; Moderate: ± 15%;High: > 15%.
Water Quality	pH Total suspended solids Dissolved phosphorus Total nitrogen and nitrate-nitrite Various ions (sodium, chloride, sulphate) Total alkalinity, Total dissolved solids Dissolved organic carbon Total and dissolved aluminum Total arsenic, Total boron Total molybdenum, Total strontium Ultra-trace mercury, Naphthenic acids Overall ionic composition	Comparison to range of regional *baseline* conditions. Comparison to CCME and other water quality guidelines. Calculation of water quality index based on CCME water quality index found at http://www.ccme.ca/ourwork/water.html?category_id=102 , with water quality index scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions 60 to 80: Moderate difference from regional *baseline* conditions Less than 60: High difference from regional *baseline* conditions
Benthic Invertebrate Communities	Abundance Richness (number of taxa) Simpson's Diversity Evenness Abundance of EPT (mayflies, stoneflies, caddisflies) Axes of Correspondence Analysis ordination	Exceedance of regional range of *baseline* variability for the selected measurement endpoints based on the mean and standard deviation, with regional range defined as $\bar{X} \pm 2SD$, and statistically significant differences between measurement endpoints in *test* reaches/lakes as compared to *baseline* reaches/lakes; 1. Negligible-Low: no statistically significant difference in any measurement endpoint between *test* and *baseline* reaches/lakes 2. Moderate: statistically significant difference in one any measurement endpoint between *test* and *baseline* reaches/lakes, with low "noise" in the statistical test, but no measurement endpoint outside *baseline* range of natural variation 3. High: statistically significant difference in one any measurement endpoint between *test* and *baseline* reaches/lakes and either: (i) at least three measurement endpoints outside *baseline* range of natural variation or (ii) at least one measurement endpoint outside *baseline* range of natural variation for three consecutive years
Sediment Quality	Particle size distribution (clay, silt and sand) Total organic carbon Total hydrocarbons (CCME and Alberta Tier 1) Various PAH end-points, including: Total PAHs Total Low-Molecular Weight PAHs Total High-Molecular Weight PAHs Naphthelene, Retene Total dibenzothiophenes Predicted PAH toxicity Metals, Chronic toxicity	Comparison to CCME Interim Sediment Quality Guidelines (ISQG) and other guidelines. Calculation of sediment quality index based on CCME water quality index found at http://www.ccme.ca/ourwork/water.html?category_id=103, with sediment quality index scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions 60 to 80: Moderate difference from regional *baseline* conditions Less than 60: High difference from regional *baseline* conditions

Table 1.4-1 (Cont'd.)

RAMP Component	Measurement Endpoints Used in 2009 Technical Report	Criteria for Determining Change Used in 2009 Technical Report
Fish Populations: Fish Inventory	Relative abundance (catch per unit effort) Length-frequency Percent composition Condition factor	The RAMP fish inventory activity is generally considered to be a stakeholder-driven activity that is best suited for assessing general trends in abundance and population parameters for large-bodied species. It is not specifically designed for assessing environmental effects of focal project activities.
Fish Populations: Fish Tissue Sampling	Range of metals (including mercury) and tainting compounds (PAHs) in fish muscle tissue	**Risk to Human Health** Negligible-Low: Fish tissue concentrations for all variables below USEPA and Health Canada criteria for recreational and subsistence fishers and the general consumer. High (subsistence): Fish tissue concentrations for one or more variables above USEPA and Health Canada criteria for subsistence fishers, but below criteria for recreational fishers and general consumers. High (general consumer): Fish tissue concentrations for one or more variables above USEPA and Health Canada criteria for general consumers, and recreational and subsistence fishers. **Risk to Fish Health** Negligible-Low: Fish tissue concentrations for all variables below literature-based criteria for sublethal and lethal effects on fish. Moderate: Fish tissue concentration for one variable above literature-based criteria for sublethal effects. High: Fish tissue concentrations for more than one variable above literature-based criteria for effects on fish. **Tainting** Negligible-Low: Fish tissue concentrations for tainting compounds below criteria for palatability of fish (Jardine and Hrudey 1988). Moderate-High: Fish tissue concentrations for tainting compounds above criteria for palatability of fish.
Fish Populations: Regional Lakes Fish Tissue	Mercury concentration in food fish muscle tissue	**Risk to Human Health** Negligible-Low: Fish tissue concentrations for mercury below USEPA and Health Canada criteria for recreational and subsistence fishers and the general consumer. High (subsistence): Fish tissue concentrations for mercury above USEPA and Health Canada criteria for subsistence fishers, but below criteria for recreational fishers and general consumers. High (general consumer): Fish tissue concentrations for mercury above USEPA and Health Canada criteria for general consumers, and recreational and subsistence fishers.
Fish Populations: Sentinel Species Monitoring	Condition Factor	Comparison to Environment Canada's Environmental Effects Monitoring (EEM) criteria (Environment Canada 2005) where an effect is determined by a difference of ± 10% in condition of fish at the *test* reach relative to fish condition at the *baseline* reach. Negligible-Low: no exceedance greater than ± 10% in condition of fish at *test* site compared to condition of fish at *baseline* site Moderate: exceedance greater than ± 10% in condition of fish at *test* site compared to condition of fish at *baseline* site, but not in three successive years of sampling including the current year High: exceedance greater than ± 10% in condition of fish at *test* site compared to condition of fish at *baseline* site, and exceedance observed in three successive years of sampling including the current year
Acid-Sensitive Lakes	Critical Load of acidity pH Gran alkalinity Base cation concentrations Nitrate plus nitrite concentrations DOC Aluminum	Exceedance of Critical Load of acidity of a particular lake by the measured or modeled value of the Potential Acid Input (PAI) to that lake. A statistically significant change in any of the measurement endpoints beyond natural variability, resulting in a reduction of lake pH, Gran alkalinity, Critical Load or base cation concentrations or an increase in nitrates or aluminum concentrations. For each lake, mean and standard deviation calculated for each of seven measurement endpoints over all the monitoring years. The number of lakes in 2009 within each subregion with endpoint values greater than two standard deviations from the mean is calculated. Negligible-Low: subregion has <2% endpoint-lake combinations exceeding ± 2SD criterion. Moderate: subregion has 2% to 10 % endpoint-lake combinations exceeding ± 2SD criterion. High: subregion has > 10% of endpoint-lake combinations exceeding ± 2SD criterion.

[1] The measurement endpoints do not include a complete list of variables that were analyzed for water and sediment quality. A complete list can be found in Table 3.2-4 and Table 3.3-5.

1.5 ORGANIZATION OF THE RAMP 2009 TECHNICAL REPORT

Together with this Introduction, the RAMP 2009 Technical Report contains ten sections within which the results of the 2009 RAMP monitoring program developed by the RAMP Technical Program Committee and implemented by the Hatfield Team are presented.

Section 2: Activities in the RAMP Focus Study Area in 2009 – This section contains:

- a description of the activities in 2009 for each of the focal projects;
- a list of projects owned by 2009 industry members of RAMP that were in the application stage as of 2009, or which received approval in 2009 (or earlier) but were not in the construction phase as of 2009; and
- a list of active oil sands projects in the RAMP study areas owned or operated by companies that were not members of RAMP in 2009.

This provides a synthesis of information related to development pressures that may be influencing aquatic environmental resources within RAMP FSA.

Section 3: 2009 RAMP Monitoring Activities – This section of the report contains concise descriptions of the RAMP monitoring program that was conducted in 2009 for each RAMP component, and includes:

- an overview of the 2009 program;
- a description of any other information that was obtained (i.e., information from regulatory agencies, 2009 industry members of RAMP, RAMP stakeholders and other oil sands operators, knowledge obtained from local communities, and other sources);
- an overview of field methods;
- a description of changes in monitoring network from the 2009 field program;
- a description of the challenges and issues encountered during 2009 and the means by which these challenges and issues were addressed; and
- a summary of the component data that are now available.

Each component section of Section 3 contains a description of the detailed approach used for analyzing the RAMP data, including:

- a description and explanation of the measurement endpoints that were selected;
- a description and explanation of the criteria that were used in assessing whether or not changes in the selected measurement endpoints have occurred; and
- a description of the statistical, graphical, or other analyses that were performed on the monitoring data to assess whether or not changes in the selected measurements endpoints have occurred.

Section 4: Climatic and Hydrologic Characterization of the RAMP Focus Study Area in 2009 – This section of the report describes the 2009 hydrologic year and how 2009 compares with previous years with respect to climatic and hydrologic conditions. This helps set the context for the results, analyses, and assessments presented in Section 5.

Section 5: Assessment of 2009 Results – This is the main results section of the RAMP 2009 Technical Report, consisting of three major parts:

- Section 5.1 is the report of 2009 findings for the mainstem Athabasca River and the Athabasca River Delta; and
- Sections 5.2 to 5.12 are watershed-level reports of the 2009 findings for hydrology, water quality, benthic invertebrate communities and sediment quality, and fish populations.

Each of these sections presents the RAMP results following the analytical approaches contained in each of the component sections of Section 3, as described above. Each section begins with a summary assessment of the overall status of aquatic environmental resources and possible relation to focal projects.

Section 6: Special Studies – This section of the report contains studies that are not part of the core-monitoring program but were initiated in this reporting year to aid in improving the monitoring program or to gain additional information on issues related to aquatic resource monitoring in relation to oil sands development.

Section 7: Regional Synthesis – This section of the report presents regional assessments of the status of aquatic environmental resources within the scope of monitoring under RAMP and the possible influence of focal projects at the regional level. This section also presents the results of the ASL component for 2009 given the regional nature of this component.

Section 8: Conclusions and Recommendations – This section of the report contains a summary of the findings, conclusions, and recommendations from RAMP 2009. The recommendations include proposed changes to the RAMP monitoring network for future years based on the results for 2009.

Throughout the report, where possible and appropriate, recommendations are made for refinements to RAMP based on findings and conclusions.

The main report concludes with **Section 9: References** and **Section 10: Glossary and List of Acronyms**. In addition, the report is supported by a series of technical appendices that present the detailed analytical results and supporting material for each RAMP component.

2.0 SUMMARY OF FOCAL PROJECT ACTIVITIES IN 2009

This section provides the information on oil sands and other developments in the RAMP Focus Study Area (FSA) needed to conduct the assessment of 2009 monitoring results. Four sets of information are provided: development status of focal projects; development status of other oil sands projects in the RAMP FSA; summary of focal project activities in 2009; and RAMP FSA land change analysis for 2009.

2.1 DEVELOPMENT STATUS OF FOCAL PROJECTS

The development status of all projects as of the end of 2009 in the RAMP FSA owned by industry members of RAMP is presented in Table 2.3-1. Areas of the RAMP FSA downstream of focal projects that have started land disturbance are designated as *test*. Data obtained from sampling stations in these *test* areas are also designated as *test* for the purposes of analysis, assessment, and reporting (Section 1.4.4). Conversely, areas of the RAMP FSA that are upstream of focal projects or downstream of focal projects that have no specified year of first disturbance are designated as *baseline*. Data obtained from sampling stations in these *baseline* areas are also designated as *baseline* for the purposes of analysis, assessment, and reporting. Additional information provided in Table 2.3-1 is used to interpret the 2009 monitoring results for all RAMP components.

2.2 DEVELOPMENT STATUS OF OTHER OIL SANDS PROJECTS

There were eight approved oil sands projects active in the RAMP FSA in 2009 whose operators were not members of RAMP in 2009 (Table 2.3-2). This information is used in specific analyses conducted in the Water Quality component (Section 3.2.7.2, Table 3.2-4) and Benthic Invertebrate Communities component (Section 3.3.1.8, Table 3.3-2).

2.3 SUMMARY OF FOCAL PROJECT ACTIVITIES IN 2009

The information provided in this section is used to interpret the 2009 monitoring results for all RAMP components. Water discharge and withdrawal information provided in this section is used for the analysis, assessment, and reporting in the Climate and Hydrology component (Section 3.1.7.3).

2.3.1 Suncor Energy Inc.

Development activities had occurred for twelve of Suncor's 18 focal projects as of 2009 (i.e., projects with a specified first year of disturbance, Table 2.3-1). Suncor focal project activities in 2009 included:

- Steepbank, Millennium, and Voyageur projects: water discharge of approximately 3.1 million m^3 of water from holding ponds and site drainage at the Voyageur Upgrader to the Athabasca River and withdrawal of approximately 40.38 million m^3 of water from the Athabasca River.
- Fort Hills Project: muskeg dewatering activities from January to December in Fort Creek and from April to November in the watershed of an unnamed creek; water withdrawal of 500m^3 from a sedimentation pond; and discharge to Fort Creek of approximately 3.96 million m^3 of settling pond water collected from site runoff and dewatering activities.
- Suncor MacKay River: land clearing and construction, and withdrawal of 0.02 million m^3 from the MacKay River and Poplar Creek reservoir.

Table 2.3-1 Status and activities of developments owned by 2009 industry members of RAMP in the RAMP Focus Study Area.

2009 RAMP Industry Member	Development	Focal Projects	Location: Oil Sands Leases	Location: Township and Range	Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2009 Status
Suncor Energy Inc.	Lease 86/17	√	Lease 86, Lease 17	23-92-10-W4M	mine	280,000	1964	1967	**Closed in 2002**
	Steepbank Mine	√	Leases 97, 19, 25 and Fee Lots 1 and 3	91-9-W4M and 92-9-W4M	mine	294,000	1996	1997	**Operational**
	Millennium Mine	√	Leases 25, 19 and Fee Lots 3 and 4	91,92-9-W4M	mine		1998	2000	**Operational**
	Steepbank Debottleneck Phase 3	√			equipment upgrade	4,000		2007	**Operational**
	North Steepbank Mine Extension	√	Lease 25, Lease 97, Fee Lot 1	92,93-9-W4M	mine	180,000	2006	2007	**Construction**
	Millennium Debottleneck	√			equipment upgrade	23,000		2008	**Operational**
	Voyageur: Voyageur Upgrader	√	Fee Lot 2, Lease 23	91,92-10-W4M	mine	550,000[2]	2005	2007	**On hold**
	Voyageur: South Phase 1	√			mine	120,000	2007	--	**Application**
	South Tailings Pond	√	Lease 25, Lease 19	90,91-8-W4M, 91-9-W4M	tailings		2003	2005	**Construction**
	Firebag (Phases 1 &2, cogeneration and expansion)	√	Lease 85	19, 20, 29 to 32-94-5-W4M; 22 to 36-94-6-W4M; W25 36-94-7-W4M; 6 to 8, 17 to 20, 29 to 32-95-5-W4M; 95-6-W4M; 4 to 6-96-6-W4M	*in situ*	95,000	2000	2002	**Operational**
	Firebag Phase 3	√			*in situ*	52,500		2004	**On hold**
	Firebag Phase 4	√			*in situ*	62,500	--	--	**Application**
	Firebag Phase 5	√			*in situ*	62,500	--	--	**Application**
	Firebag Phase 6	√			*in situ*	62,500	--	--	**Application**
	Firebag Stages 2-6 Debottlenecking	√			*in situ*	23,500	--	--	**On hold**
	Fort Hills (Phase 1)	√	7598060T05, 7281020T52, 7400120008	96-11-W4M, 97,98-10-W4M	mine	165,000	2001	2005	**On hold**
	Fort Hills Debottleneck				equipment upgrade	25,000		--	**Approved**
	MacKay River Phase 1	√	7282030T75	92, 93-12-W4M	*in situ*	33,000	1998	2000	**Operational**
	MacKay River Expansion (Phase 2)		7282030T75, 728004AT22, 7187060328	92, 93-12-W4M	*in situ*	40,000	2006	--	**Approved**
	Meadow Creek	√	7281010T58, 7283010T81	84,85-8,9,10-W4M	*in situ*	80,000	2001	--	**On hold**
Syncrude Canada Ltd.	Mildred Lake and Aurora Stages 1 & 2	√	Lease 10, Lease 12, Lease 17, Lease 22 Lease 34	6-93-10-W4M; 96-9,10,11-W4M	mine	290,700	1973	1973	**Operational**
	Mildred Lake and Aurora Stage 3 Expansion	√	Lease 10, Lease 12, Lease 17, Lease 22 Lease 34	6-93-10-W4M; 96-9,10,11-W4M	mine	116,300	2001	unknown	**Operational**

Note: Information in this table obtained from Oilsands review (November 2009), Strategy West Inc. (2009), Government of Alberta (2009a), Alberta Labour Market Information (2009), ERCB (2009), ERCB project approvals, project EIA documents, and company websites.

1 Unless otherwise stated, units are in bpd (barrels per day).

2 Suncor's total planned upgrading capacity once Voyageur begins operations.

3 As of 2009, Shell Canada Ltd. and Albian Sands Energy Inc. became known as Shell Albian Sands for all oil sands operations; Birch Mountain Resources Ltd. became Hammerstone Corp.; Petro-Canada merged with Suncor to be Suncor; and Nexen became the operator of Long Lake and subsequent phases.

Table 2.3-1 (Cont'd.)

2009 RAMP Industry Member	Development	Focal Projects	Location		Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2009 Status
			Oil Sands Leases	Township and Range					
Shell Albian Sands	Muskeg River Mine	√	Lease 13	95-10-W4M	mine	155,000	1997	2000	**Operational**
	Muskeg River Mine Expansion & Debottlenecking	√	Lease 13, Lease 90	95-8,9-W4M, 94-10-W4M	mine	115,000	2005	2009	**Construction**
	Jackpine Mine (Phase 1A)	√	Lease 13	95-8-W4, 95-9-W4	mine	100,000	2002	2006	**Construction**
	Jackpine Mine (Phase 1B)				mine	100,000		--	**Approved**
	Jackpine Mine Phase 2		Lease 13, Lease 88, 89, Lease 035, 631, AT36	95,96,97-9,8-W4M	mine	100,000	2007	--	**Application**
	Pierre River Mine		Lease 309, 310, 351, 352	97,98,99-10,11-W4M	mine	200,000	2007	--	**Application**
Canadian Natural	Horizon Phase 1	√	Lease 18	96-11/12-W4M, 96-13-W4M, 97-11-W4M, 97-12-W4M, 97-13-W4M	mine	135,000	2002	2004	**Operational**
	Horizon Phase 2/3	√			mine	135,000		--	**Approved**
Imperial Oil Resources	Kearl Lake (Phases 1,2 & 3)	√	Leases 6, 87, 36 31A, 88	95,96,97-6-W4M, 95,96,97-7-W4M, 95,96,97-8-W4M	mine	300,000	2005	2009	**Construction**
Nexen Inc.	Long Lake (Phase 1)	√	Lease 27	85-6-W4M	*in situ*	70,000	2000	2004	**Operational**
	Long Lake South (Phase 2)				*in situ*	70,000	2005	--	**Approved**
	Long Lake South (Phase 3)					70,000			**Approved**
Total E&P Canada Ltd.	Joslyn, SAGD Phase 1		7280060T24, 7404110452, 7405070799	94,95,96-11-W4M, 94-12-W4M	*in situ*	2,000	unknown	2003	**Operational**
	Joslyn, SAGD Phase 2	√			*in situ*	10,000	2004	2005	**Operational**
	Joslyn, SAGD Phase 3a				*in situ*	15,000	2005	--	**Withdrawn**
	Joslyn North Mine Project				mine	100,000	2006	--	**Application**
	Northern Lights		Lease 15, Lease 16, Lease 789	98 and 99-5 to 7-W4M	mine	100,000	2006	--	**Withdrawn**
Husky Energy	Sunrise	√	728704AT87, 728103AT49, 740101A022, 740012A006, 7401100015, 7002080057, 742080006	94-97-6,7-W4M	*in situ*	200,000	2004	2007	**Construction**
	Phase 1					50,000		--	**Approved**
	Phase2					50,000		--	**Approved**
	Phase 3					50,000		--	**Approved**
	Phase 4					50,000		--	**Approved**
Hammerstone Corp.	Muskeg Valley Quarry	√	MAIM Leases 9494070001, 9494070002, 9403120367, 9499030555, and 9400080004	94,95-10-W4M	quarry	limestone product, 7 million t/yr	2004	2005	**Operational**
	Hammerstone Quarry		MAIM Leases 9494070001, 9494070002, 9403120367, 9499030555, and 9400080004	94-10-W4M	quarry	limestone product,18 million t/yr	2006	--	**Approved**

Note: Information in this table obtained from Oilsands review (November 2009), Strategy West Inc. (2009), Government of Alberta (2009a), Alberta Labour Market Information (2009), ERCB (2009), ERCB project approvals, project EIA documents, and company websites.

1 Unless otherwise stated, units are in bpd (barrels per day).

2 Suncor's total planned upgrading capacity once Voyageur begins operations.

3 As of 2009, Shell Canada Ltd. and Albian Sands Energy Inc. became known as Shell Albian Sands for all oil sands operations; Birch Mountain Resources Ltd. became Hammerstone Corp.; Petro-Canada merged with Suncor to be Suncor; and Nexen became the operator of Long Lake and subsequent phases.

Table 2.3-2 Approved oil sands projects within the RAMP FSA operated by non-RAMP members, as of 2009.

Operator	Field or Area	Location (Township and Range)	Recovery Method
EnCana	Christina Lake	11 to 16,E17,24-76-6W4M, 1, 2-20-76-6W4M, 1 to 4-21-76-6W4M, 1 to 4-22-76-6W4M, 1 to 4-23-76-6W4M	SAGD
Japan Canada	Hangingstone	NW26, N27, N28, 33, 34, W35-84-11W4M	SAGD
ConocoPhillips	Surmont	24-83-7W4M	Steam Stimulation
Devon Canada	Jackfish	19 to 21, 28 to 33-75-6W4M, 4 to 6-76-6W4M	SAGD
MEG Energy	Christina Lake	7 to 9, 16 to 18, N19 to N21-77-5W4, E12, E13, E24-77-6W4	SAGD
Petrobank Whitesands	Whitesands	12, 13-77-9W4M	Toe to Heel Air Injection
Statoil Canada Kai Kos Dehseh	Leismer Demonstration	19 to 21, 26, 28, 29 to 33-78-9W4M	SAGD
Connacher	Great Divide and Algar	NW16, NE17, SE20, 21-82-12W4	SAGD

Information obtained from ERCB (2009).

2.3.2 Syncrude Canada Ltd.

Syncrude's focal projects in 2009 were the Mildred Lake and Aurora Stages 1 and 2, and the Mildred Lake and Aurora Stage 3 Expansion (Table 2.3-1). Syncrude focal project activities in 2009 included:

- land clearing in the Athabasca River, Muskeg River and MacKay River watersheds;
- muskeg dewatering activities from January to December with a discharge of 4.3 million m^3 to Stanley Creek;
- withdrawal of 37.49 million m^3 from the Athabasca River;
- discharge of 0.27 million m^3 of treated domestic sewage to the Athabasca River;
- instream work and alteration to the Daphne Slough in the Muskeg River watershed from January to March; and
- a diversion of 4.96 million m^3 of water to Stanley Creek as part of the Aurora Clean Water Diversion system.

2.3.3 Shell Albian Sands

Shell Albian Sands focal projects in 2009 were the Muskeg River Mine, Muskeg River Mine expansion and debottlenecking operation, and Jackpine Mine (Phase 1A) (Table 2.3-1). Shell Albian Sands focal project activities in 2009 included:

- land clearing in the Muskeg River watershed adjacent to Muskeg Creek;
- muskeg dewatering of 103 ha in the Muskeg River watershed;
- Muskeg River Mine: water withdrawal from the Athabasca River totaling 15.2 million m^3. In 2009, the Muskeg River Mine facility was a zero water-discharge operation, with tailings water and local drainage being recycled for project operations; and

- Jackpine Mine: release of water collected from site runoff and muskeg dewatering from settling ponds as follows: 4.0 million m^3 of water discharged into Shelley Creek; 0.66 million m^3 of water discharged into Jackpine Creek; and 0.58 million m^3 of water discharged into Khahago Creek.

2.3.4 Canadian Natural Horizon Project

The Canadian Natural Horizon project was operational in 2009 (Table 2.3-1); Horizon project activities in 2009 included:

- land clearing in the Tar River watershed;
- instream work in the Tar River during May (2 days) and July (2 days);
- muskeg dewatering activities from January to November in areas adjacent to the Tar River;
- permanent alteration of the main channel drainage pattern of the Tar River to a diversion channel from the compensation lake around the plant to the lower Tar River (construction of the diversion occurred in 2008);
- water withdrawal of 13.2 million m^3 from the Athabasca River; and
- water discharge from the wastewater treatment plant to the Tar River of 0.2 million m^3.

2.3.5 Nexen Long Lake Phase 1 Project

The Nexen Inc. Long Lake Phase 1 project was operational in 2009 (Table 2.3-1). Long Lake Phase 1 project activities in 2009 included:

- land clearing in the Christina River watershed;
- instream work, including a culvert installation in an unnamed tributary to Robert Creek during the month of September; and
- water withdrawal of 2.28 million m^3 from groundwater sources.

2.3.6 Imperial Oil Resources Kearl Project

The Imperial Oil Resources Kearl Project was under construction in 2009 (Table 2.3-1); Kearl Project activities in 2009 included:

- exploratory drilling and land clearing in the Muskeg River, Athabasca River and Kearl Lake watersheds;
- instream work in the Athabasca River at the water intake (beginning in September and ongoing), Fort Creek (September and October), and four unnamed tributaries to the Athabasca River (March, April, July and August);
- alteration of an unnamed tributary to the Muskeg River with the construction of a ditch from March to June;
- muskeg dewatering activities from January to December, with a discharge of approximately 3.5 million m^3 of water to the Muskeg River, 0.03 million m^3 of water to the Athabasca River, and 0.02 million m^3 to Wapasu Creek in the Muskeg River watershed; and
- water withdrawal of 0.12 million m^3 from the Muskeg River and 0.014 million m^3 from Kearl Lake and 0.11 million m^3 from the Athabasca River.

2.3.7 Total E&P Joslyn Phase II Project

The Total E&P Canada Ltd. (Total E&P) Joslyn Phase II Project was operational in 2009 (Table 2.3-1); Joslyn Phase II Project activities in 2009 included:

- land clearing and project construction in the Ells River/Joslyn Creek watershed;
- water discharge of approximately 0.002 million m^3 from the industrial runoff pond; and
- groundwater withdrawals of approximately 0.03 million m^3.

2.3.8 Husky Energy Sunrise Project

The Husky Energy Sunrise Project was under construction in 2009 (Table 2.3-1); Sunrise Project activities in 2009 included:

- land clearing in the Muskeg River watershed and project construction in the Wapasu Creek drainage; and
- water discharge of 0.3 million m^3 from site run off to the Wapasu Creek headwaters.

2.3.9 Hammerstone Muskeg Valley Quarry

The Hammerstone Muskeg Valley Quarry Project was operational in 2009 (Table 2.3-1) with water discharges of approximately 0.16 million m^3 into the Muskeg River in 2009.

2.4 LAND CHANGE RELATED TO DEVELOPMENT ACTIVITIES IN 2009

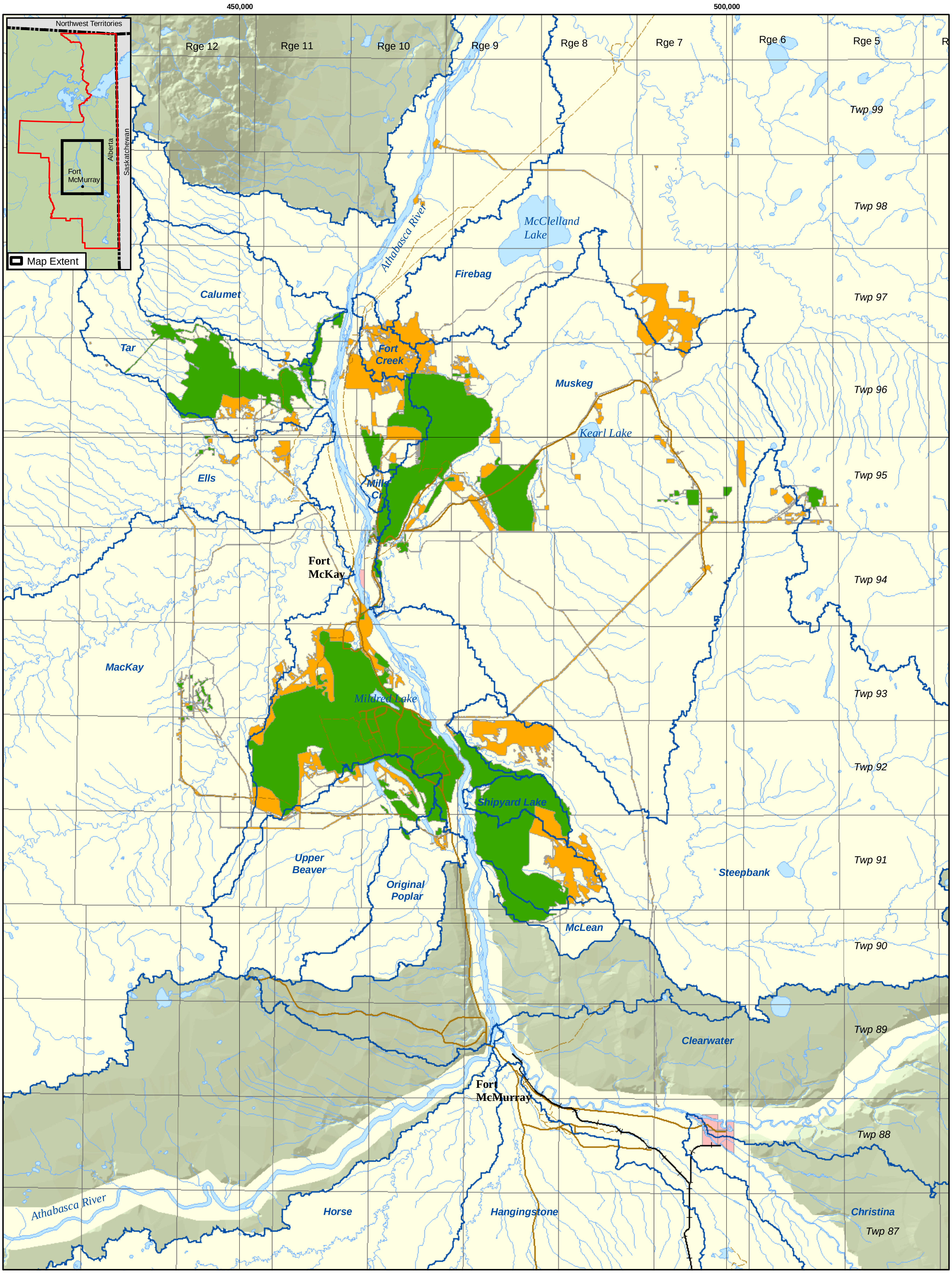
Land change was estimated with satellite imagery in conjunction with more detailed maps of operations provided by a number of RAMP industry members. These sources of data were used to estimate the amount of land change for a number of land change classes in each of the main RAMP FSA watersheds in 2009.

Seven SPOT-5 10m resolution images (three north of Fort McMurray and four south of Fort McMurray) taken on June 13, July 17, August 7, and August 11, 2009 and two SPOT-2 20 m resolution images (south of Fort McMurray) taken on June 13 and August 7, 2009 were obtained. A land change classification protocol was developed and applied to the imagery to identify and delineate two types of land change in 2009 from the projects listed in Table 2.3-1 and Table 2.3-2 (Appendix A). Developed areas where there is no natural exchange of water with the rest of the watershed (e.g. tailings ponds) are designated as hydrologically closed-circuited. Developed areas where there is natural exchange of water with the rest of the watershed (e.g. cleared land) are designated as not hydrologically closed-circuited.

Because of the resolution of the satellite imagery, SAGD well pads were about the smallest oil sands development entity that was delineated. Details of the land change estimation procedure are provided in Appendix A. Drafts of the land change maps were provided to RAMP members for review, and recommendations for revision of the maps were used to produce the final set of 2009 land change maps.

Land change area as of 2009 is presented in Figure 2.4-1 and Figure 2.4-2 for north and south of Fort McMurray, respectively.

Figure 2.4-1 RAMP land change classes derived from SPOT-5 satellite imagery of August 2009, north of Fort McMurray.



RAMP Regional Aquatics Monitoring Program

Data Sources:

a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, First Nation Reserve, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land change areas delineated from 10m SPOT-5 (August 2009) multispectral imagery.

Township and Range designations are relative to W4M.

LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area, not Hydrologically Closed-Circuited
- Land Change Area, Hydrologically Closed-Circuited

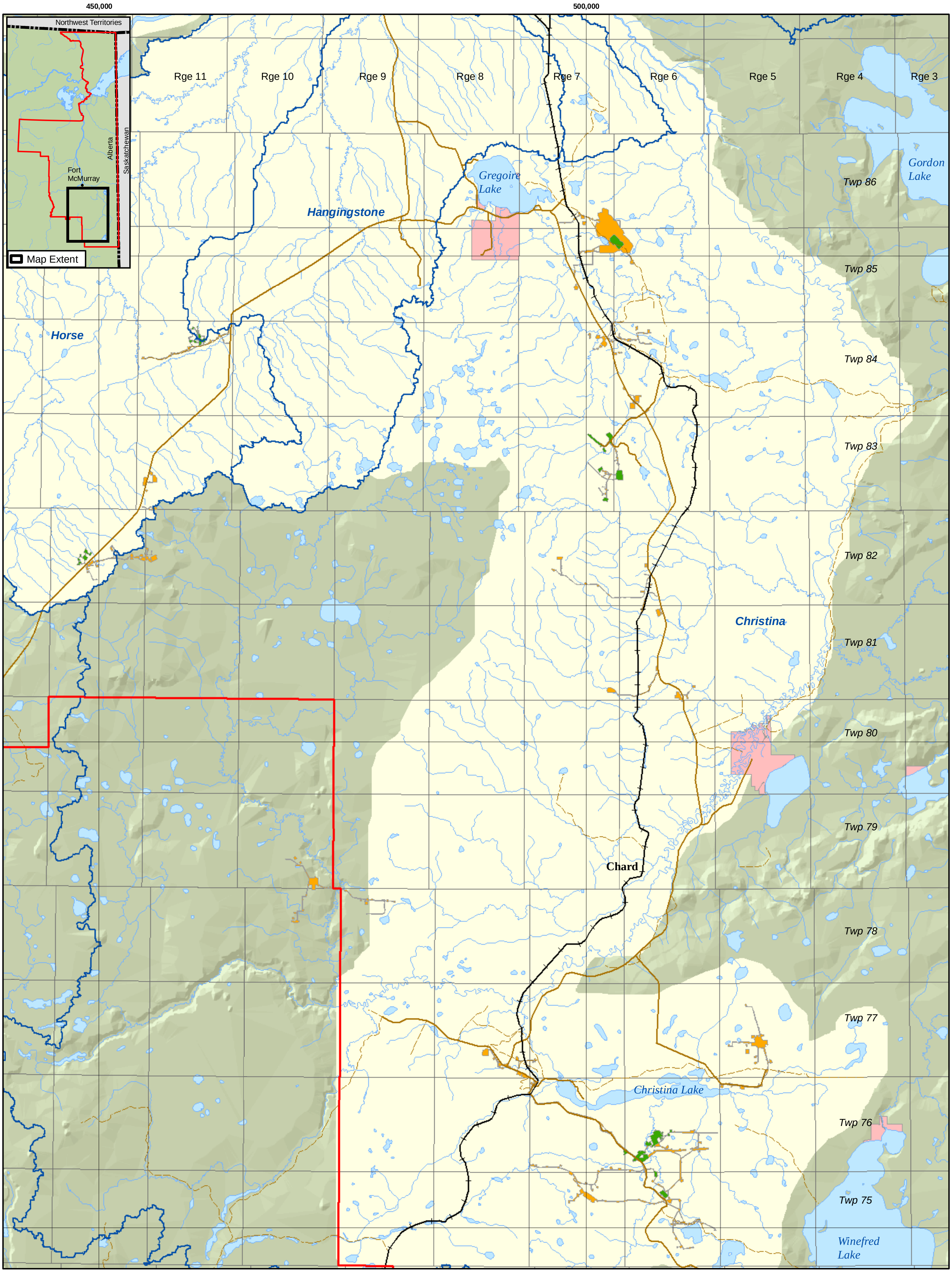
0 5 10 20 Km

Scale 1:425,000

Projection: UTM Zone 12 NAD83

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_B_LCNorthVector_20100106.mxd

Figure 2.4-2 RAMP land change classes derived from SPOT-5 satellite imagery of June, July and August 2009, south of Fort McMurray.



RAMP
Regional Aquatics Monitoring Program

LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area, not Hydrologically Closed-Circuited
- Land Change Area, Hydrologically Closed-Circuited

0 5 10 20 Km
Scale 1:425,000
Projection: UTM Zone 12 NAD83

Data Sources:
a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, First Nation Reserve, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land change areas delineated from 10m SPOT-5 (June, July, and August 2009) multispectral imagery.

Township and Range designations are relative to W4M.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_C_LCSouthVector_20100106.mxd

Table 2.4-1 and Table 2.4-2 provide tabular summaries of the land changes in each of the main watersheds by each land change type, for focal projects and non-RAMP oil sands projects within the RAMP FSA. Land change as of 2009 within the RAMP FSA is estimated at approximately 79,000 ha for focal projects and slightly more than 3,400 ha for oil sands projects operated by companies who were not members of RAMP in 2009 for a total of approximately 83,000 ha. This represents approximately 2.3% of the area of the RAMP FSA. The percentage of the area of watersheds with land change as of 2009 varies from less than 1% for many watersheds (MacKay, Ells, Christina, Hangingstone, Horse, and Firebag rivers), to 5% to 10% for the Upper Beaver watershed, to more than 10% for the Muskeg River, Fort Creek, Mills Creek, Tar River, Shipyard Lake, and McLean Creek watersheds, as well as the smaller Athabasca River tributaries from Fort McMurray to the confluence of the Firebag River.

Table 2.4-1 Area of watersheds with land change in 2009.

Watershed	Total Watershed Area (ha)	Watershed Area with Land Change (ha)						
		Focal Projects		Other Oil Sands Developments in RAMP FSA		Total		Watershed Total
		Not-Closed Circuited	Closed-Circuited	Not-Closed Circuited	Closed-Circuited	Not-Closed Circuited	Closed-Circuited	
Minor Athabasca River Tributaries[1]	160,730	8,510	25,750			8,510	25,750	34,260
Mills Creek	890	47	207			47	207	255
Shipyard Lake	4,047	546	3,208			546	3,208	3,753
Calumet	17,354	39	184			39	184	223
Christina	1,303,805	1,245	112	2,431	540	3,675	652	4,327
Ells	245,000	766	162			766	162	927
Firebag	568,174	3,454	255			3,454	255	3,709
Fort Creek	3,193	1,966	30			1,966	30	1,996
Hangingstone	106,641			9	47	9	47	56
Horse	215,741			284	104	284	104	388
MacKay	557,000	1,332	290			1,332	290	1,622
McLean	4,712	83	1,103			83	1,103	1,187
Muskeg	146,000	4,763	11,451			4,763	11,451	16,215
Original Poplar[2]	13,856	139	307			139	307	446
Steepbank	135,491	3,079	430			3,079	430	3,509
Tar	33,261	811	6,441			811	6,441	7,252
Upper Beaver[2]	28,711	783	1,936			783	1,936	2,719
FSA Total	**3,544,606**	**27,562**	**51,867**	**2,723**	**692**	**30,285**	**52,559**	**82,844**

Only land changes within the RAMP FSA were delineated.

[1] Refers to Athabasca River tributaries from Fort McMurray to the mouth of the Firebag River excluding the watersheds explicitly listed in this table. All land change areas in the minor Athabasca River tributaries in 2009 were above RAMP hydrology station S24.

[2] Original Poplar refers to the Poplar Creek watershed prior to the Beaver Creek diversion, while "Upper Beaver" refers to that part of the Beaver Creek drainage that now drains into Poplar Creek as a result of the Beaver Creek diversion. Drainage boundaries were estimated from maps provided in Syncrude Canada Ltd. (1977).

Table 2.4-2 Percent of total watershed areas with land change in 2009.

Watershed	Total Watershed Area (ha)	Watershed Area with Land Change (%)						
		Focal Projects		Other Oil Sands Developments in RAMP FSA		Total		Watershed Total
		Not-Closed Circuited	Closed-Circuited	Not-Closed Circuited	Closed-Circuited	Not-Closed Circuited	Closed-Circuited	
Minor Athabasca River Tributaries[1]	160,730	5.29	16.02			5.29	16.02	21.32
Mills Creek	890	5.31	23.31			5.31	23.31	28.62
Shipyard Lake	4,047	13.48	79.26			13.48	79.26	92.75
Calumet	17,354	0.22				0.22	1.06	1.28
Christina	1,303,805	0.10	0.01	0.19	0.04	0.28	0.05	0.33
Ells	245,000	0.31	0.07			0.31	0.07	0.38
Firebag	568,174	0.61	0.04			0.61	0.04	0.65
Fort Creek	3,193	61.57	0.93			61.57	0.93	62.50
Hangingstone	106,641			0.01	0.04	0.01	0.04	0.05
Horse	215,741			0.13	0.05	0.13	0.05	0.18
MacKay	557,000	0.24	0.05			0.24	0.05	0.29
McLean	4,712	1.77	23.42			1.77	23.42	25.19
Muskeg	146,000	3.26	7.84			3.26	7.84	11.11
Original Poplar[2]	13,856	1.00	2.22			1.00	2.22	3.22
Steepbank	135,491	2.27	0.32			2.27	0.32	2.59
Tar	33,261	2.44	19.37			2.44	19.37	21.80
Upper Beaver[2]	28,711	2.73	6.74			2.73	6.74	9.47
FSA Total	**3,544,606**	**0.78**	**1.46**	**0.08**	**0.02**	**0.85**	**1.48**	**2.34**

Only land changes within the RAMP FSA were delineated.

[1] Refers to Athabasca River tributaries from Fort McMurray to the mouth of the Firebag River excluding the watersheds explicitly listed in this table. All land change areas in the minor Athabasca River tributaries in 2009 were above RAMP hydrology station S24.

[2] Original Poplar refers to the Poplar Creek watershed prior to the Beaver Creek diversion, while "Upper Beaver" refers to that part of the Beaver Creek drainage that now drains into Poplar Creek as a result of the Beaver Creek diversion. Drainage boundaries were estimated from maps provided in Syncrude Canada Ltd. (1977).

3.0 2009 RAMP MONITORING ACTIVITIES

This section contains a description of RAMP monitoring conducted in 2009 and includes the following for each RAMP component:

- Summary of 2009 monitoring activities and field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, owners and operators of the 2009 focal projects, knowledge obtained from local communities, and other sources);
- Description of changes in the monitoring network from the 2008 program;
- Description of the challenges and issues encountered during 2009 and the means by which these challenges and issues were addressed;
- Summary of the component data that are now available; and
- A description of the approach used for analyzing the RAMP data, including:
  - A description and explanation of the measurement endpoints that were selected;
  - A description and explanation of the criteria that were used to assess whether or not changes in the selected measurement endpoints have occurred; and
  - A description of the statistical, graphical, or other analyses that were performed on the monitoring data to assess whether or not changes in the selected measurement endpoints have occurred.

Monitoring activities for all RAMP components in 2009 were implemented according to the monitoring protocols, field methods, and Standard Operating Procedures (SOPs) for the RAMP components as outlined in the RAMP Technical Design and Rationale (RAMP 2009b). Any changes in monitoring protocols, field methods and SOPs from those contained in RAMP (2009b) are noted below.

Quality Assurance and Quality Control (QA/QC) procedures were employed throughout and for all aspects of the monitoring conducted under RAMP in 2009. Appendix B contains a detailed description of the QA/QC procedures used for RAMP monitoring in 2009.

All 2009 monitoring data collected under RAMP have been added to the RAMP database, which is located in the RAMP member's area website. The 2009 data tables are included on the CD-ROM accompanying the final 2009 technical report.

3.1 CLIMATE AND HYDROLOGY COMPONENT

3.1.1 Overview of 2009 Activities

The Climate and Hydrology component monitoring in 2009 consisted of:

- climate monitoring (Table 3.1-1, Figure 3.1-1):
  - monitoring air temperature, relative humidity, total precipitation, wind speed and direction, solar radiation, and snow depth at the Aurora and Horizon Climate stations, with the Horizon Climate station also recording barometric pressure; and

- monitoring precipitation at three additional stations, two of which also measured air temperature;

- snow survey monitoring (Figure 3.1-1):
  - three regional snowcourse surveys at 16 stations in four distinct bio-geographic locations, conducted in February, March, and April;

- streamflow monitoring (Table 3.1-1, Figure 3.1-2):
  - 14 year-round stations;
  - 15 open-water stations;
  - six winter-only stations jointly operated with Water Survey of Canada (WSC), which monitors during the open-water season;
  - water temperature monitoring at nine of the streamflow stations; and
  - total suspended solids sampling throughout the open-water season at all streamflow stations during each visit;

- water level monitoring at three lake/wetland stations (Table 3.1-1, Figure 3.1-2).

Appendix C provides complete information for all climate and hydrology stations in the 2009 program.

3.1.2 Field Methods

3.1.2.1 General

Field crews conducted ten visits in 2009 for the Climate and Hydrology component:

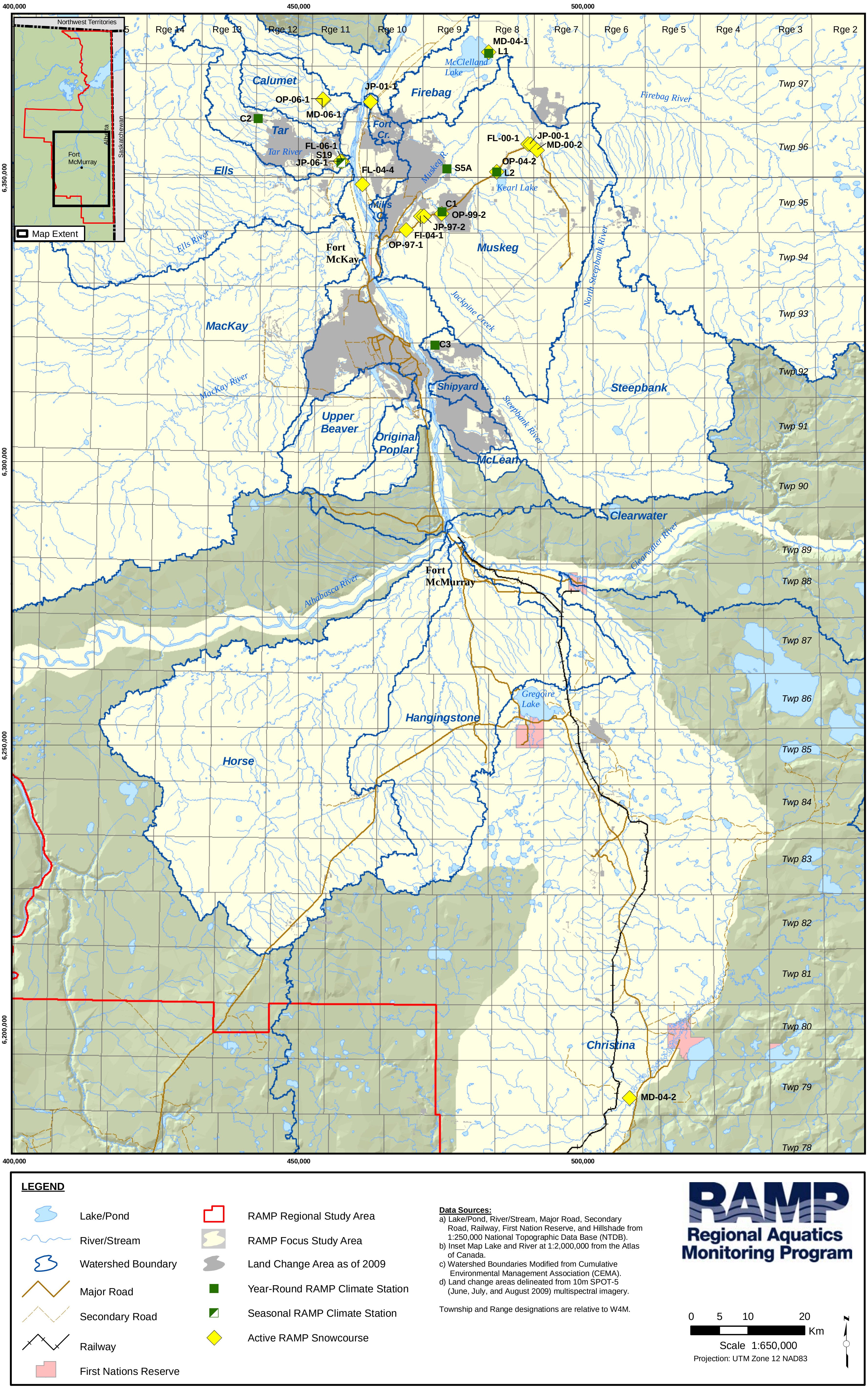
- five field visits during the open-water season at the RAMP year-round and open-water stations; and
- five visits during the winter season to all year-round RAMP stations and all seasonal WSC stations, three of five winter visits included a regional snowcourse survey.

Field visits included manual measurements of streamflow and water level, data retrieval, and station maintenance. Data retrieval from data loggers was conducted using a General Dynamics Go Book which is designed for reliability under extreme field conditions. Stage-discharge relationships were developed and refined using the manual streamflow and water level data collected during the field visits.

3.1.2.2 Streamflow Measurement

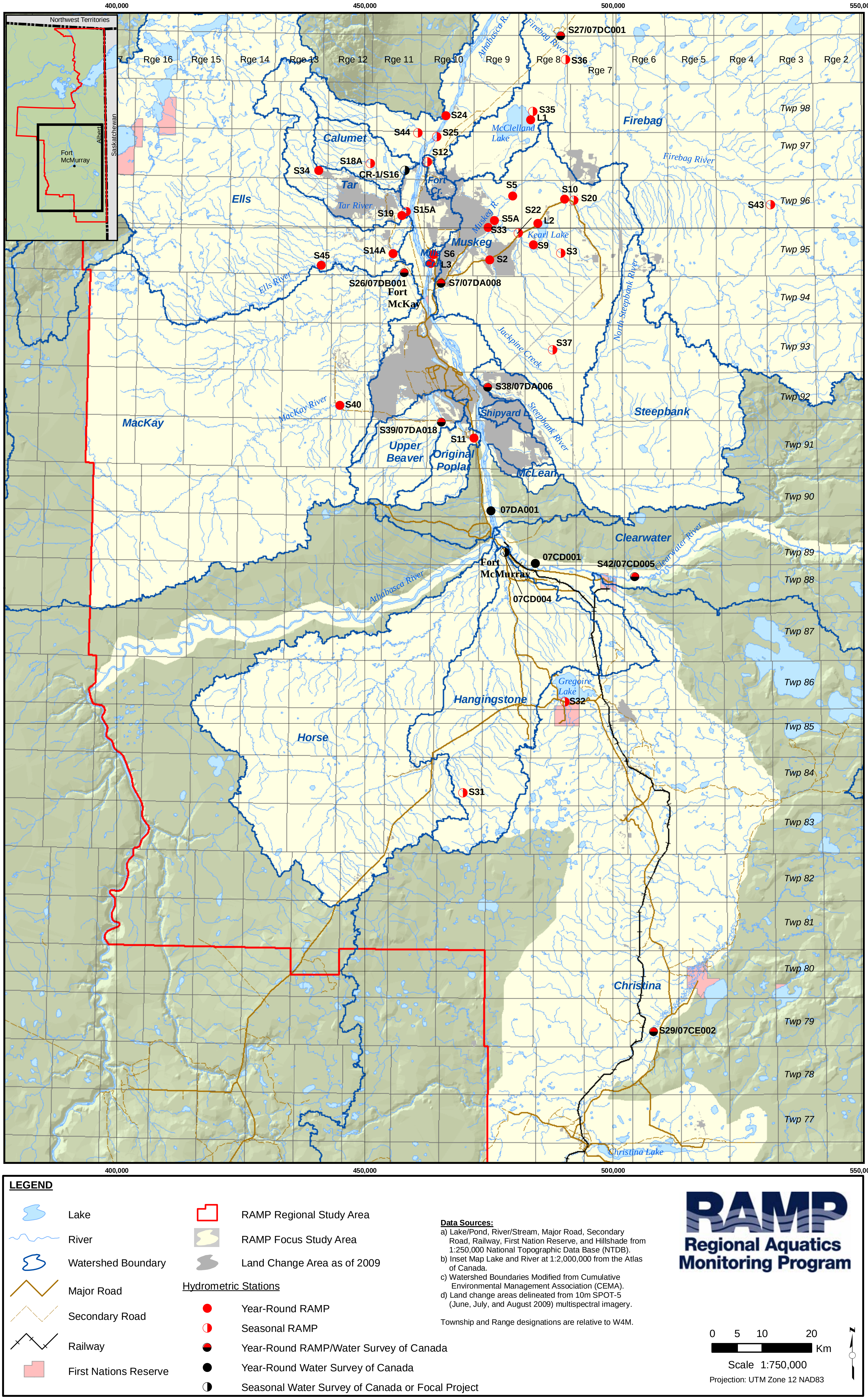
Streamflow measurement procedures and standards used in the Climate and Hydrology Component are consistent with Water Survey of Canada (WSC 2001), United States Geological Survey (USGS 1982), and BC Ministry of Environment (BC MOE 2009) recommendations and protocols, and are presented in the RAMP Design and Rationale Document (RAMP 2009b). Quality assurance and quality control procedures are provided in Appendix B of this report.

Figure 3.1-1 Locations of RAMP climate stations and snowcourse survey stations, 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_D_Climate_20100211.mxd

Figure 3.1-2 Locations of RAMP and government hydrometric stations, 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_E_Hydro_20100225.mxd

Measurement standards are summarized below:

- Number of verticals: 20, or at a spacing of 0.10 m in small streams;
- Number of readings in the vertical for an open-water measurement: 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;
- Number of readings in the vertical for a measurement under ice: one at 60% of the depth below the surface for depths of 1.0 m or less; otherwise one at 20% and one at 80% of the depth; and
- Velocity averaging: at least 20-second averages for the Acoustic Doppler (Sontek FlowTracker ADV) and electromagnetic meters (Marsh McBirney Flo-Mate 2000); and 45 seconds for mechanical meters.

3.1.2.3 Water Level Surveys

Field crews conducted water level surveys at both streamflow and lake/wetland stations to reference the continuous water level record to the surface water level. Procedures for conducting the water level survey were derived from standards in BC MOE (2009):

1. Level readings using a transit were made to the nearest 0.001 m.
2. Surveys were made using two independent benchmarks.
3. Each survey was conducted using two set-ups the difference between the set-ups required to be <0.005 m.

3.1.2.4 Climate Station Visits

Field crews visited climate stations to conduct data logger downloads, preliminary quality assurance to check station function, data reliability, and maintenance needs. Precipitation gauges were inspected to assure sufficient levels of anti-freeze and hydraulic fluid were present.

3.1.2.5 Snowcourse Surveys

Snowcourse survey procedures were developed from principles outlined in the British Columbia Ministry of Environment Procedure Manual (Volume 6, Section 9, Subsection 01, Page 5 of 72) (BC MOE 1982):

1. 40 snow depths were measured in each study plot.
2. Snow depth and the mass of a vertical profile of the snowpack were measured four times in each plot to calculate snow density.

Table 3.1-1 RAMP climate and hydrometric stations operating in 2009.

RAMP Station	Name	UTM Coordinates[1]		Operating Season	Variables Measured
		Easting	Northing		
C1	Aurora Climate Station	475230	6344049	all year	air temperature, total precipitation, humidity, solar radiation, snow on the ground, wind speed and direction
C2	Horizon Climate Station	442890	6360695	all year	air temperature, total precipitation, humidity, solar radiation, snow on the ground, barometric pressure, wind speed and direction
C3	Steepbank Climate Station			all year[2]	total precipitation
L1	McClelland Lake	483430	6371950	all year	water level, total precipitation, humidity, air temperature, water temperature
L2	Kearl Lake	484856	6351061	all year	water level, total precipitation, humidity, air temperature, water temperature
L3	Isadore's Lake	463297	6342987	all year	water level
S2	Jackpine Creek at Canterra Road	475132	6343680	all year	level, discharge, water temperature
S3	Iyinimin Creek above Kearl Lake	489491	6345029	open-water	level, discharge
S5	Muskeg River above Stanley Creek	479820	6356551	all year	level, discharge
S5A	Muskeg River above Muskeg Creek	476100	6351600	all year	level, discharge, barometric pressure, water temperature
S6	Mills Creek at Highway 63	463829	6344743	all year	level, discharge
S7	Muskeg River near Fort McKay (07DA008)	465408	6338944	winter[3]	level, discharge
S9	Kearl Lake Outlet	483980	6346750	all year	level, discharge
S10	Wapasu Creek at Canterra Road	490272	6355942	all year	level, discharge, water temperature
S11	Poplar Creek at Highway 63 (07DA007)	471998	6307667	all year	level, discharge, water temperature
S12	Fort Creek at Highway 63	462600	6363400	open-water	level, discharge
S14A	Ells River at the Canadian Natural Bridge	455748	6344947	all year	level, discharge, water temperature
S15A	Tar River near the Mouth	458395	6353391	open-water	level, discharge, water temperature
S18A	Calumet River Upland Tributary	452702	6367295	open-water	level, discharge
S19	Tar River Lowland Tributary near the Mouth	457502	6352663	open-water	level, discharge
				open-water	total precipitation
S20	Muskeg River Upland	492106	6355709	open-water	level, discharge
S22	Muskeg Creek near the Mouth	480970	6349071	open-water	level, discharge
S24	Athabasca River below Eymundson Creek	466313	6372760	all year	level, discharge
S25	Susan Lake Outlet	464491	6368503	open-water	level, discharge
S26	MacKay River near Fort McKay (07DB001)	458120	6341037	winter[3]	level, discharge
S27	Firebag River near the mouth (07DC001)	489553	6388830	winter[3]	level, discharge
S29	Christina River near Chard (07CE002)	508195	6187926	winter[3]	level, discharge
S31	Hangingstone Creek near the Mouth	469784	6236095	open-water	level, discharge
S32	Surmont Creek at Highway 31	490310	6254473	open-water	level, discharge, water temperature
S33	Muskeg River at the Aurora/Albian Boundary	474876	6350204	all year	level, discharge
S34	Tar River above Canadian Natural Lake	440729	6361689	all year	level, discharge, water temperature
S35	McClelland Lake Outlet below McClelland Lake	502047	6369724	open-water	
S36	McClelland Lake Outlet above Firebag River	490626	6384064	open-water	level, discharge
S37	East Jackpine Creek near the 1300 m contour	485905	6338825	open-water	level, discharge
S38	Steepbank River near Fort McMurray (07DA006)	474777	6318112	winter[3]	level, discharge
S39	Beaver River above Syncrude (07DA018)	465547	6311437	winter[3]	level, discharge
S40	Mackay River at Petro-Canada Bridge	444888	6314179	all year	level, discharge, water temperature
S42	Clearwater River above Christina River (07DC005)	504427	6279665	winter[3]	level, discharge
S43	Firebag River upstream of Suncor Firebag	531528	6354782	open-water	level, discharge
S44	Pierre River near Fort McKay (Formerly 07DA013)	460775	6369400	open-water	level, discharge
S45	Ells River above Joslyn Creek Diversion	440605	6342459	all year[4]	level, discharge, water temperature
07DA001	Athabasca River below Fort McMurray	475439	6293000	all year	discharge
07CD001	Clearwater River at Draper	484367	6282383	all year	discharge
07CD004	Hangingstone River at Fort McMurray	478196	6284606	all year	discharge
CR-1/S16	Calumet River near the Mouth[5]	458152	6361693	open-water	discharge

[1] UTM coordinate datum is NAD83 Zone 12V.
[2] Station began operating in August 2009.
[3] WSC monitors water level and discharge at these stations during the open-water season.
[4] Station began operating in June 2009.
[5] Station was operated as RAMP S16 from 2001 to 2004 and as CR-1 from 2005 to 2009 by Canadian Natural.

3.1.3 Changes in Monitoring Network from 2008

3.1.3.1 New Monitoring Stations

Climate Station

The Steepbank Climate Station (Station C3) was established in the lower Steepbank River watershed (Figure 3.1-1) to provide total precipitation measurements in a geographic region between Fort McMurray and the Aurora Climate Station (Station C1). The station was constructed in summer 2009 and began operating in August 2009.

Streamflow Stations

Four new streamflow stations were established in 2009:

1. Station S42, Clearwater River above Christina River, is operated by WSC (07DC005) from March to October and was added to the RAMP network during the winter months beginning in 2009.

2. Station S43, Firebag River upstream of Suncor Firebag, was established as an open-water level and discharge station in the spring of 2009 with the intention of becoming a year-round station.

3. Station S44, Pierre River near Fort McKay, was a WSC station (07DA013) from 1975 to 1977. RAMP water level and discharge monitoring began at this station in spring 2009.

4. Station S45, Ells River above the Joslyn Creek Diversion, is a year-round monitoring station for water level, discharge, and water temperature and started operating in June 2009.

3.1.3.2 Modified Stations

The following modifications and upgrades were made to stations and field equipment in 2009:

1. A new weighing-style precipitation gauge was installed at station C1, Aurora Climate, to more accurately determine year-round precipitation in this area.

2. Stations L1 (McClelland Lake) and L2 (Kearl Lake) were upgraded with new equipment to provide more reliable data collection and remote download capability (L2 station only).

3. Five stations: S2 (Jackpine Creek at Canterra Road), S10 (Wapasu Creek at Canterra Road), S14A (Ells River at the Canadian Natural Bridge), S37 (East Jackpine Creek near the 1300 m contour), and S40 (MacKay River at Petro-Canada Bridge) received solar panels to improve the power supply and data collection reliability.

4. Seven stations: S2 (Jackpine Creek at Canterra Road), S5 (Muskeg River above Stanley Creek), S5A (Muskeg River above Muskeg Creek), S19 (Tar River Lowland Tributary near the mouth), S31 (Hangingstone Creek near the mouth), S33 (Muskeg River at the Aurora/Albian Boundary), and S36 (McClelland Lake Outlet above Firebag River) received an additional benchmark for stage-discharge curve reliability and station security in case of damage.

5. Three data logger enclosure masts were installed at stations S2 (Jackpine Creek at Canterra Road), S3 (Iyinimin Creek above Kearl Lake), and S36 (McClelland Lake Outlet above Firebag River).

6. Station S40, MacKay River at Petro-Canada Bridge, and Station S12, Fort Creek at Highway 63, were relocated 50 m downstream to avoid bridge and road construction.

3.1.4 Challenges Encountered and Solutions Applied

Data Logger Malfunctions and Attrition

The long-term status of RAMP has resulted in the increasing age of equipment at a number of stations. Consequently, equipment at some stations have malfunctioned and become unreliable. Below is a summary of issues experienced in 2009. An assessment of station equipment is provided in Appendix C.

Station C2, Horizon Climate Station, had a malfunctioning resistor for the GEONOR precipitation gauge since its installation in late 2008. This unit was diagnosed and replaced on June 10, 2009. A wire on the air temperature and relative humidity probe was damaged in January 2009 causing sporadic recording of these variables between January 14 and March 10, 2009 when it was repaired, resulting in a data loss for 55 days. In addition, two data logger malfunctions occurred from April 15 to April 17, 2009 and from May 19 to May 26, 2009 resulting in two and six days of data loss, respectively. The station has been fully functional since June 2009.

Station C1, Aurora Climate Station, experienced a number of data logger malfunctions in 2009: from April 29 to May 8, June 8 to June 21, and October 15 to November 3 resulting in data loss of 29 days in total. The cause of these malfunctions has not been determined; however, it is believed that the age of this data logger (i.e., > ten years) is considered as a potential factor. A new data logger will be purchased and installed in 2010 for this station. An additional data loss of 16 days occurred from December 15 to December 31, 2009 due to power failure at this station.

The data logger at Station S3, Iyinimin Creek above Kearl Lake, stopped working shortly after it was re-installed for the open-water season in May 2009. A temporary replacement data logger was used for the 2009 open-water season; however, this data logger was not equipped to measure rainfall. Water level and discharge data were lost in May 2009 to June 2009 for a total of 43 days. A new data logger that has the capability to measure both water level and rainfall has been acquired for the 2010 open-water season.

The backup data logger at Station S5A, Muskeg River above Muskeg Creek, reached the end of its life and created an electrical short. The electrical short drained the battery of the primary data logger as both data loggers were operating from the same power supply. The malfunction resulted in a data loss of 38 days from May 5 to June 14, 2009. The backup data logger was removed and the primary data logger was re-started for this station.

The data logger at Station S19, Tar River Lowland Tributary near the mouth, malfunctioned and did not collect water level data from May 5 to June 10, 2009 (36 days). The problem was diagnosed and data logger function was restored.

The data logger that was re-installed for the 2009 open-water season at the S36, McClelland Lake Outlet above the Firebag River, malfunctioned and caused a loss of data for 42 days from May 5 to June 12, 2009. This data logger was replaced.

Station S44, Pierre River near Fort MacKay, did not record data due to a power supply malfunction from September 19, 2009 until it was removed for the winter period on September 25, 2009 (31 days).

Wildlife and Environmental Challenges

Stations S2, Jackpine Creek at Canterra Road, S33, Muskeg River at Aurora/Albian Boundary, and S45, Ells River above the Joslyn Creek Diversion, were damaged by beaver activity causing data losses of 62, 21, and 60 days, respectively. Following these damages, protective conduit was installed at all stations to prevent future data losses.

Station S18A, Calumet River Upland Tributary, was damaged by wildlife twice during the 2009 open water season. This damage resulted in a loss of data of 22 days in May and June, and 34 days in August and September.

A wildfire destroyed the data logger at Station S31, Hangingstone Creek at North Star Road, in June 2009. As a result of this damage data were not recorded for 56 days. The data logger was replaced in August and water level recording resumed for the remainder of the 2009 open-water season.

Human Damage to Stations

Station S11, Poplar Creek at Hwy 63, was damaged by a vehicle. The data logger was still connected to the pressure transducer; however, the vehicle impact resulted in data logger damage and data were lost at this station from August 7 to September 21 for a total of 45 days. A functioning data logger was installed in September 2009 for the remainder of the 2009 open-water season.

3.1.5 Other Information Obtained

Streamflow data and climate data from WSC, Meteorological Service of Canada (MSC), and AENV were obtained and incorporated into the RAMP database. Some of these data received are provisional and are flagged as such in the database. All provisional data will be updated and replaced in the RAMP database with the final data in 2010.

3.1.6 Summary of Component Data Now Available

Table 3.1-2 summarizes the available climate and hydrology data collected to date for RAMP. This table includes and identifies data collected by government agencies at combined government/RAMP stations.

Table 3.1-2 Summary of RAMP data available for the Climate and Hydrology component, 1997 to 2009.

see symbol key at bottom

Location	Station Number	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
Climate Stations																													
Aurora Climate Station	C1	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
Horizon Climate Station	C2																												
Steepbank Climate Station	C3																												
McClelland Lake	L1																						a	a	a		a	a	
Kearl Lake	L2																												
Iyinimin Creek above Kearl Lake	S3						a	a	a		a	a	a						a	a	a		a	a	a		a		
Muskeg River above Muskeg Creek	S5A																					e	e	e	e	e	e	e	e
Mills Creek at Highway 63	S6														e	e	e												
Kearl Lake Outlet	S9										e	e	e																
Calumet River near the Mouth	S16																						h	h	h	cf	cf	cf	cf
Tar River Lowland Tributary near the Mouth	S19																						a	a	a		a	a	a
Christina River near Chard	S29																						a	a	a		a	a	a
Muskeg River Basin Snowcourse Survey			d				d				d				d				d										
Fort Creek Basin Snowcourse Survey															d														
CNRL Area Snowcourse Survey																			d				d				d		
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		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	2		2	2	2
Fort Creek at Highway 63	S12														2	2	2		2	2	2		2	2	2				
Ells River above Joslyn Creek	S14																		2	2	2		2	2	2		2	2	2
Ells River at CNRL Bridge	S14A																												
Tar River near the Mouth	S15																		2	2	2		2	2	2		2	2	2
Tar River near the Mouth	S15A																												
Calumet River near the Mouth	S16																		2	2	2		2	2	2		2t	2t	2t
Tar River Upland Tributary	S17																		2	2	2		2	2	2		2	2	2
Upland Calumet River	S18																		2	2	2								
Calumet River Upland Tributary	S18A																						2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19																		2	2	2		2	2	2		2	2	2
Susan Lake Outlet	S25																						2	2	2				
MacKay River near Fort McKay (07DB001)	S26		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	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	2	4	4	4	2	4	4	4
Tar River above CNRL Lake	S34																												
McClelland Lake Outlet at McClelland Lake	S35																												
McClelland Lake Outlet above Firebag River	S36																												
Steepbank River near Fort McMurray (07DA006)	S38		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
Beaver River above Syncrude (07DA018)	S39		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
MacKay River at Petro-Canada Bridge	S40																												
Firebag River upstream of Suncro Firebag	S43																												
Pierre River near Fort MacKay (formerly 07DA013)	S44																												
Ells River above Joslyn Creek Diversion	S45																												
Athabasca River Mainstem																													
Athabasca River below Eymundson Creek	S24																		2	2	2	2	2	2	2	2	2	2	2

Location	Station Number	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
Climate Stations																									
Aurora Climate Station	C1	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
Horizon Climate Station	C2																				h	he	he	he	he
Steepbank Climate Station	C3																							c	c
McClelland Lake	L1		a	a	a						c	c	cg	i	i	i	i	i	i	i	i	i	i	i	i
Kearl Lake	L2																i	i	i	i	i	i	i	i	i
Iyinimin Creek above Kearl Lake	S3						a	a			a	a	a			a			a	a	a				
Muskeg River above Muskeg Creek	S5A	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e
Mills Creek at Highway 63	S6																								
Kearl Lake Outlet	S9																								
Calumet River near the Mouth	S16	f	cf	cf	cf	cf	cf	f																	
Tar River Lowland Tributary near the Mouth	S19		a	a	a		a	a	a	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	
Christina River near Chard	S29		a	a	a																				
Muskeg River Basin Snowcourse Survey																									
Fort Creek Basin Snowcourse Survey																									
CNRL Area Snowcourse Survey																									
Wide-Area Snowcourse Survey		d				d				d				d				d				d			
Athabasca River Tributaries																									
Mills Creek at Highway 63	S6		2	2	2		2	2	2	2	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	2	2t	2t	2t	2	2t	2t	2t
Fort Creek at Highway 63	S12										2	2	2		2	2	2		2	2	2		2	2	2
Ells River above Joslyn Creek	S14		2	2	2		2	2	2		2	2	2		2	2	2								
Ells River at CNRL Bridge	S14A				2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2	2t	2t	2t	2	2t	2t	2t
Tar River near the Mouth	S15		2	2	2		2	2	2		2	2	2												
Tar River near the Mouth	S15A														2	2	2		2t	2t	2t		2t	2t	2t
Calumet River near the Mouth	S16		2	2	2t																				
Tar River Upland Tributary	S17		1	1	1																				
Upland Calumet River	S18																								
Calumet River Upland Tributary	S18A		2	2	2		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		2	2	2
Susan Lake Outlet	S25										2	2	2		2	2	2		2	2	2		2	2	2
MacKay River near Fort McKay (07DB001)	S26	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Firebag River near the Mouth (07DC001)	S27	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Tar River above CNRL Lake	S34						2	2	2		2	2	2	2	2	2	2	2	2t	2t	2t	2	2t	2t	2t
McClelland Lake Outlet at McClelland Lake	S35																		2	2	2		2	2	2
McClelland Lake Outlet above Firebag River	S36																		2	2	2		2	2	2
Steepbank River near Fort McMurray (07DA006)	S38		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4
Beaver River above Syncrude (07DA018)	S39		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4
MacKay River at Petro-Canada Bridge	S40																	2	2t	2t	2t	2t	2t	2t	2t
Firebag River upstream of Suncro Firebag	S43																						2	2	2
Pierre River near Fort MacKay (formerly 07DA013)	S44																						2	2	2
Ells River above Joslyn Creek Diversion	S45																						2t	2t	2t
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	2	2	2	2

Legend

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

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

Test (downstream of focal projects)
Baseline (upstream of focal projects)

Table 3.1-2 (Cont'd.)

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
Muskeg River Basin																																																					
Alsands Drain	S1		2	2			2	2	2		2	2	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	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t
Iyinimin Creek above Kearl Lake	S3		2	2	2		2	2	2		2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Blackfly Creek near the Mouth	S4		2	2	2		2	2	2																																												
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	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	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2	2	2	2	2	2t	2t	2t	2	2t	2t	2t
Muskeg River near Fort McKay (07DA008)	S7		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Stanley Creek near the Mouth	S8											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		2	2	2		2	2	2	2	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	2	2	2	2	2	2	2	2	2	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		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth	S21																		1	1	1		1	1	1		1	1	1																								
Muskeg Creek near the Mouth	S22																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		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		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	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
East Jackpine Creek near the 1300 m Contour	S37																																												2		2	2	2		2	2	2
Muskeg River High Water Gauging				3				3				3				3				3																																	
Jackpine Creek High Water Gauging				3				3												3																																	
Clearwater River Mainstem																																																					
Clearwater River above Christina River (07CD005)	S42		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	4		4	4	4	2	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	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
Clearwater River Tributaries																																																					
Christina River near Chard (07CE002)	S29																					2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Hangingstone River at Highway 63	S30																						2	2	2																												
Hangingstone Creek near the Mouth	S31																						2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Surmont Creek at Highway 881	S32																						2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2t	2t	2t		2t	2t	2t
Wetlands																																																					
McClelland Lake	L1			2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2		2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1t	1t
Kearl Lake	L2										1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1t	1t	1t	1t	1t	1t	1t	1t	1t
Isadore's Lake	L3													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	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																																		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Compilation of WBEA data																																										√	√	√	√	√	√	√	√	√	√	√	√

Legend

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

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

Test (downstream of focal projects)
Baseline (upstream of focal projects)

3.1.7 Analytical Approach

3.1.7.1 Overall Approach

The analysis of the hydrologic data utilized a water balance approach to develop a *baseline* and *test* hydrograph for each watershed with focal projects. The *test* hydrographs were observed at hydrometric stations, while the *baseline* hydrographs were developed using land change information and water withdrawal and discharge information for the focal projects. This approach identifies the influence of focal projects on the 2009 hydrograph. Additional details regarding this analytical approach are found in (RAMP 2009b).

3.1.7.2 Analytical Approach for 2009

The RAMP 2009 hydrology analysis consisted of:

- establishing *test* hydrographs for all operating stations in 2009 using Aquatic Informatics Aquarius software;
- estimating the 2009 *baseline* hydrographs;
- reviewing and selecting hydrologic measurement endpoints and calculation of endpoint values from the *baseline* and *test* hydrographs; and
- applying criteria to be used in assessing change in the hydrologic measurement endpoints.

3.1.7.3 Estimation of 2009 *Baseline* Hydrographs

2009 *baseline* hydrographs are defined for this analysis as the hydrographs that would have been observed in 2009 had there been no focal projects in the watershed. Additional influences may be incorporated in the 2009 *baseline* hydrograph due to development activities from non-focal projects in the watershed. Therefore, the *baseline* hydrograph is derived for the purpose of assessing any change due to focal projects, and should not be considered as a fully naturalized hydrograph. The equation provided below describes the method used to calculate the 2009 *baseline* hydrographs for the outlet of each major watershed:

$$Hyd_B = Hyd_O + I_w - I_r + R_n - R_i$$

where:

Hyd_B is the *baseline* hydrograph for 2009;

Hyd_O is the *test* hydrograph which was observed in 2009;

I_w are the focal project withdrawals from the watershed;

I_r are the focal project releases to the watershed;

R_n is the natural runoff that would have occurred in the watershed, but was intercepted or closed-circuited by focal projects in 2009; and

R_i is the incremental increase in runoff caused by land cleared within the basin.

This approach excludes influences from groundwater inputs to surface water and does not address changes in catchment responsiveness caused by changes in catchment area. In addition, this approach assumes that land-change areas not closed-circuited have an increased runoff of 20%. This value is based on the professional judgment of the Climate and Hydrology Component subgroup under the RAMP Technical Program Committee. This value does not include changes in runoff timing, catchment responsiveness, or storage properties that could be associated with activities such as land clearing. This approach indentifies the approximate magnitude of changes in the measurement endpoints at the mouth of major watercourses in the RAMP FSA.

3.1.7.4 Review, Selection, and Generation of Hydrologic Measurement Endpoints

The RAMP Technical Design and Rationale document (RAMP 2009b) outlines the following measurement endpoints to be used in the analysis of the hydrologic data:

- Mean open-water season (May 1 to approximately October 31, 2009) discharge;
- Mean winter (January 1 to March 31, 2009 and November 1 to December 31, 2009) discharge;
- Annual maximum daily discharge; and
- Open-water season minimum daily discharge.

These measurement endpoints are hydrologic measurement endpoints used in various oil sands project EIAs (RAMP 2009b) that can be computed from one year of data, and were selected for the analysis of the 2009 data. Values for each of these four measurement endpoints were calculated for the *test* and *baseline* hydrographs and a percent change in the measurement endpoints between the *test* and *baseline* values was calculated.

3.1.7.5 Classification of Results

The percent difference between the *test* and *baseline* values of the hydrologic measurement endpoints were used to classify results as follows: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High. These ranges were derived from criteria for determining effects on hydrologic measurement endpoints in a number of EIAs prepared for oil sands projects (RAMP 2009b).

3.2 WATER QUALITY COMPONENT

3.2.1 Summary of 2009 Monitoring Activities

Monitoring activities for the Water Quality component were conducted in four sampling campaigns in 2009: winter (March 23 to 24); spring (May 11 to 15); summer (July 13 to 16); and fall (September 9 to 18).

Water quality sampling focused on the Athabasca River and its major tributaries in the RAMP FSA, as well as regionally important lakes and wetlands. Additional data were contributed by AENV and operators of individual projects for some locations (primarily on the Muskeg River). Water quality was sampled at 50 RAMP stations in 2009. Table 3.2-1 summarizes the location of 2009 water quality sampling stations, seasonal distribution of the sampling effort, and water quality variables measured at each station. Figure 3.2-1 provides the locations of water quality sampling in 2009. Sampling intensity was greatest during the fall campaign, with samples collected from all 2009 RAMP monitoring stations in that season. RAMP's standard protocol for newly-established water quality stations is to sample seasonally for three years and then to sample once in the fall in subsequent years (Table 3.2-1).

3.2.2 Summary of Field Methods and Sample Analysis

Station locations were identified using GPS coordinates, Alberta Forestry, Lands and Wildlife Resource Access Maps, and where applicable, written descriptions from past RAMP reports. Stations were accessed by boat, helicopter, or four-wheel drive vehicle.

At all water quality stations, *in situ* measurements of dissolved oxygen (DO), temperature, pH and conductivity were collected using an YSI Model 85 multi-probe water meter or a handheld thermometer (temperature), a handheld pH/conductivity meter (pH and conductivity) and a LaMotte portable Winkler titration kit (dissolved oxygen).

Field sampling involved collection of grab samples of water from smaller creeks or rivers, collection of cross-channel composite samples or bank-adjacent grab samples in large rivers, and collection of single grab samples in lakes and 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. The only exception to this was the oil and grease sample, which was taken from the surface of the water. The ultra-trace mercury bottle was triple-rinsed using this procedure prior to the final sample collection, following guidance from the analytical laboratory.

A composite sample was collected at station ATR-FR, Athabasca River upstream of the Firebag River, where an average concentration of monitored variables was desired. The composite was collected through combining a series of 2-L grabs collected at spaced intervals into a triple-rinsed polymer bucket. Samples were removed from the composite bucket with a certified-clean bottle 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. As with single grabs, ultra-trace mercury bottles were triple-rinsed prior to sample collection, all other bottles were not triple-rinsed.

Samples taken at mouths of tributaries were collected approximately 100 m upstream of the confluence where possible to avoid influences of mainstem water on sampled water quality at each station. Similarly, stations located on river mainstems near tributaries were sampled approximately 100 m upstream of the 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 (all waterbodies sampled during other seasons were free of ice). Water was collected through holes in the river/lake ice drilled using a gas-powered auger. For grab samples, one hole was drilled at the estimated stream thalweg. Samples were collected from approximately 0.2 m below the bottom of the ice layer using a triple-rinsed polymer bucket. Water was transferred to individual sample bottles and then preserved as required. All intermediate sampling equipment was triple-rinsed prior to final sample collection.

One HOBO® Water Temp Pro automatic temperature sensor/data logger for the collection of open-water temperature data was deployed at station FOC-1, Fort Creek, on May 13, 2009, during the spring sampling campaign. The sensor was attached to a steel rod anchored in the stream substrate in a pool that was expected to contain water for the entire monitoring period. The sensor was programmed to collect temperature data at 15-minute intervals for the duration of the installation. The sensor was retrieved on September 18, 2009 during the fall sampling program.

All water samples were collected, preserved and shipped according to protocols specified by consulting laboratories. Samples collected for analysis of dissolved organic carbon (DOC) were filtered in the field. All water quality samples taken in 2009 were analyzed for the RAMP standard variables (Table 3.2-2) in all sampling seasons. All analyses were conducted by ALS Environmental Ltd. (Fort McMurray and Edmonton, Alberta) except total and dissolved metals (including ultra-trace mercury) and naphthenic acids, which were analyzed by Alberta Research Council (ARC) in Vegreville, Alberta. Samples collected from regional lakes were analyzed for chlorophyll *a* by ALS.

Table 3.2-1 Summary of sampling for the RAMP 2009 Water Quality component.

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	Winter	Spring	Summer	Fall	
Athabasca River								
ATR-DC-E	Athabasca River upstream of Donald Creek (east bank)	475039	6298354	1	-	-	1	East bank grab
ATR-DC-W	Athabasca River upstream of Donald Creek (west bank)	474744	6298523	1	-	-	1	West bank grab
ATR-DD-E	Athabasca River downstream of all development (east bank)	463703	6367784	1	1	1	1	East bank grab
ATR-DD-W	Athabasca River downstream of all development (west bank)	463444	6368247	1	1	1	1	West bank grab
ATR-FR	Athabasca River upstream of the Firebag River	478066	6399907	-	-	-	1	Cross-channel composite
ATR-MR-E	Athabasca River upstream of the Muskeg River (east bank)	463418	6332225	-	-	-	1	East bank grab
ATR-MR-W	Athabasca River upstream of the Muskeg River (west bank)	463046	6332058	-	-	-	1	West bank grab
ATR-SR-E	Athabasca River upstream of the Steepbank River (east bank)	471022	6319599	-	-	-	1	East bank grab
ATR-SR-W	Athabasca River upstream of the Steepbank River (west bank)	470728	6319264	-	-	-	1	West bank grab
Tributaries to the Athabasca River (Southern)								
HOR-1	Horse River	427377	6246956	-	-	-	1	Mid-channel grab
Clearwater River								
CLR-1	Clearwater River upstream of Fort McMurray	480766	6284028	-	-	-	1	Mid-channel grab
CLR-2	Clearwater River upstream of Christina River	496495	6280425	-	-	-	1	Mid-channel grab
Christina River								
CHR-1	Christina River upstream of Fort McMurray	496481	6280190	-	-	-	1	Mid-channel grab
CHR-2	Christina River upstream of Janvier	511666	6192362	-	-	-	1	Mid-channel grab
Tributaries to the Athabasca River (Eastern)								
FOC-1	Fort Creek	461592	6363113	-	-	-	7	Mid-channel grab
MCC-1	McLean Creek (mouth)	474638	6306051	-	-	-	1	Mid-channel grab
Steepbank River								
NSR-1	North Steepbank River	497364	6324535	-	-	-	1	Mid-channel grab
STR-1	Steepbank River (mouth)	471100	6320118	1	-	-	1	Mid-channel grab
STR-2	Steepbank River upstream of Suncor Millennium	485833	6309340	-	-	-	1	Mid-channel grab
STR-3	Steepbank River upstream of North Steepbank River	495010	6300228	-	-	-	1	Mid-channel grab
Muskeg River and Muskeg River Tributaries								
MUR-1	Muskeg River (mouth)	463401	6332370	-	-	-	1	Mid-channel grab
MUR-6	Muskeg River upstream of Wapasu Creek	492111	6355706	-	-	-	1	Mid-channel grab
JAC-1	Jackpine Creek (mouth)	474982	6344012	-	-	-	1	Mid-channel grab
JAC-2	Jackpine Creek (upstream)	480783	6324619	-	-	-	1	Mid-channel grab
SHC-1	Shelley Creek (mouth)	474975	6349024	-	-	-	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477360	6356665	-	-	-	1	Mid-channel grab
WAC-1	Wapasu Creek at Canterra Road crossing	490288	6355920	-	-	-	1	Mid-channel grab
Firebag River								
FIR-1	Firebag River (mouth)	479033	6400142	-	-	-	1	Mid-channel grab
FIR-2	Firebag River upstream of Suncor Firebag	531551	6354770	-	-	-	1	Mid-channel grab

Table 3.2-1 (Cont'd.)

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	Winter	Spring	Summer	Fall	
Tributaries to the Athabasca River (Western)								
BER-1	Beaver River (mouth)	463630	6330898	-	-	-	1	Mid-channel grab
POC-1	Poplar Creek (mouth)	473001	6308781	-	-	-	1	Mid-channel grab
BER-2	Beaver River (upper)	465475	6311289	1	1	1	1	Mid-channel grab
CAR-1	Calumet River (mouth)	460698	6363159	-	-	-	1	Mid-channel grab
CAR-2	Calumet River (upper river)	453995	6366522	-	-	-	1	Mid-channel grab
ELR-1	Ells River (mouth)	459222	6351505	-	-	-	1	Mid-channel grab
ELR-2	Ells River (upstream)	455813	6344942	-	-	-	1	Mid-channel grab
TAR-1	Tar River (mouth)	458835	6353496	-	1	1	1	Mid-channel grab
TAR-2	Tar River upstream of Canadian Natural Horizon	440251	6361784	-	1	1	1	Mid-channel grab
MacKay River								
MAR-1	MacKay River (mouth)	461541	6336018	1	1	1	1	Mid-channel grab
MAR-2	MacKay River upstream of Suncor MacKay	444822	6314088	1	1	1	1	Mid-channel grab
MAR-2a	MacKay River upstream of Suncor Dover	449741	6320046	1	1	1	1	Mid-channel grab
DUR-1	Dunkirk River	396224	6301629	-	-	-	1	Mid-channel grab
Lakes and Wetlands								
ISL-1	Isadore's Lake	463571	6343843	-	-	-	16	Mid-lake grab
KEL-1	Kearl Lake	485437	6349388	-	-	-	16	Mid-lake grab
MCL-1	McClelland Lake	478204	6371304	-	-	-	16	Mid-lake grab
SHL-1	Shipyard Lake	473544	6313095	-	-	-	16	Mid-lake grab
QA/QC[1]								
-				1	1	1	1	Trip and field blanks, split, duplicate
Government and Industry Monitoring Stations Contributing Data to RAMP								
ATR-UFM	Athabasca River upstream of Fort McMurray (monthly)	474901	6286327	13	11	13	11	AENV sampling
ATR-OF	Athabasca River at Old Fort (monthly)	470205	6474330	12	12	12	12	AENV Sampling
MUR-2	Muskeg River upstream of Canterra Road crossing	466576	6340478	4	4	4	4	Industry sampling
MUR-2	Muskeg River downstream of Canterra Road crossing	465545	6338322	15	15	15	14	AENV sampling
MUR-4	Muskeg River upstream of Jackpine Creek	474379	6349075	4	10	10	10	Industry sampling
MUR-5	Muskeg River upstream of Muskeg Creek	476043	6351800	10	10	10	10	Industry sampling

[1] Results of the QA/QC analysis for the Water Quality component are presented in Appendix B.

Legend to Analytical Packages:

1. *RAMP standard (conventionals, major ions, nutrients, tot./dissolved metals, recoverable hydrocarbons, naphthenic acids, phenols)*
2. *RAMP standard + toxicity*
3. *RAMP standard + PAHs*
4. *RAMP standard + PAHs + toxicity*
5. *OPTI Lakes analytical package*
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*
16. *RAMP standard + chlorophyll a*

Figure 3.2-1 Locations of RAMP water quality sampling stations, 2009.

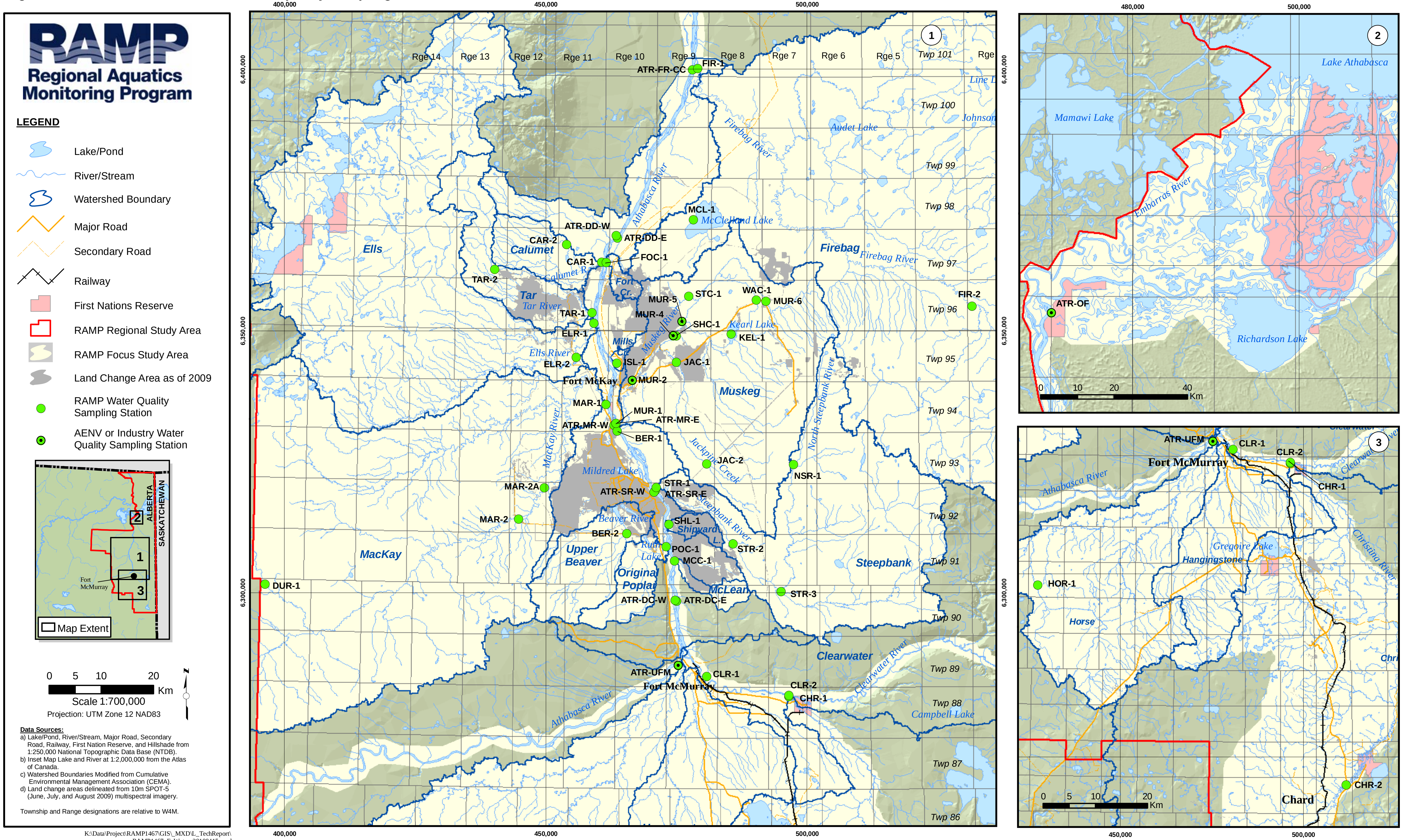


Table 3.2-2 RAMP standard water quality variables.

Group	Water Quality Variable	
Conventional variables	Colour	Total dissolved solids (TDS)
	Dissolved organic carbon (DOC)	Total hardness
	pH	Total organic carbon
	Conductivity	Total suspended solids
	Total alkalinity	
Major ions	Bicarbonate	Potassium
	Calcium	Sodium
	Carbonate	Sulphate
	Chloride	Sulphide
	Magnesium	
Nutrients	Nitrate + nitrite	Phosphorus – total
	Ammonia nitrogen	Phosphorus – total dissolved
	Total Kjeldahl nitrogen	Chlorophyll *a*[1]
Biological oxygen demand	Biochemical oxygen demand	
Organics	Naphthenic acids	Total recoverable hydrocarbons
	Total phenolics	
Total and dissolved metals	Aluminum (Al)	Lithium (Li)
	Antimony (Sb)	Manganese (Mn)
	Arsenic (As)	Mercury, ultra-trace[2] (Hg)
	Barium (Ba)	Molybdenum (Mo)
	Beryllium (Be)	Nickel (Ni)
	Bismuth (Bi)	Selenium (Se)
	Boron (B)	Silver (Ag)
	Cadmium (Cd)	Strontium (Sr)
	Calcium (Ca)	Thallium (Tl)
	Chlorine (Cl)	Thorium (Th)
	Chromium (Cr)	Tin (Sn)
	Cobalt (Co)	Titanium (Ti)
	Copper (Cu)	Uranium (U)
	Iron (Fe)	Vanadium (V)
	Lead (Pb)	Zinc (Zn)

[1] Chlorophyll *a* sampled at lotic (lake) sampling locations only. In rivers with erosional substrates, chlorophyll *a* in periphyton was also measured (see Section 3.3.1.2).

[2] Total mercury (Hg) measured with a detection limit of 1.2 ng/L (0.0000012 mg/L).

3.2.3 Changes in Monitoring Network from 2008

The 2009 monitoring network for the Water Quality component was the same as the 2008 monitoring network with the following exceptions:

1. MacKay River (mid-river, upstream of Suncor Dover), station MAR-2A, was added to serve as a *baseline* station for the lower MacKay River *test* station MAR-1 and to add a water quality station to the already existing benthic reach (MAR-E-2) at that location.
2. Dunkirk River, station DUR-1, was added to serve as a *baseline* station to harmonize with the Fish Population component.
3. Horse River, station HOR-1, was added to serve as a *baseline* station to harmonize with the Fish Population component.
4. Hangingstone River station (HAR-1) and Muskeg Creek station (MUC-1) were not sampled based on program design.
5. The Nexen lakes were surveyed in 2009.

3.2.4 Changes in Analytical Chemistry Methods from 2008

Until 2008, analysis of naphthenic acids was undertaken by ALS Environmental (previously Enviro-Test Laboratories), using an analytical method that achieved a method detection limit (MDL) of 1 mg/L. Recent investigations of water chemistry from tributaries of the lower Athabasca using other methods has indicated that background concentrations of naphthenic acids in the lower Athabasca region typically fall between 0 and 1 mg/L (Dr. J. Martin, University of Alberta, *pers. comm.*, 2009).

After investigation of alternative methods at various laboratories, in 2009 RAMP naphthenic acids analysis was shifted to ARC, who used an Electron-Ionization GC/MS method that initially provided an MDL of 0.1 mg/L (winter, spring and summer 2009), and then was further refined to 0.02 mg/L for analysis of water samples collected by RAMP in fall 2009. This method is undergoing further development at ARC, with additional assessments of accuracy and precision expected in 2010.

3.2.5 Challenges Encountered and Solutions Applied

Access to certain stations on the Athabasca River was difficult due to out of date navigational charts, which necessitated slower and more cautious boating to ensure safety. Due to a laboratory power outage, BOD samples were compromised for the summer sampling event. The laboratory has introduced new alternate power sources (i.e., back-up generators) to reduce the risk of power outages happening in the future.

3.2.6 Other Information Obtained

Sampling for the Water Quality component in 2009 was conducted by the RAMP implementation team, with the exception of:

- two stations on the mainstem Muskeg River (stations MUR-2 and MUR-4) that were sampled by Shell Albian Sands (Table 3.2-1); and
- two stations on the mainstem Athabasca River (stations ATR-UFM, ATR-OF) and two stations on the mainstem Muskeg River (station MUR-2 and MUR-5) that were sampled by AENV (Table 3.2-1).

3.2.7 Summary of Component Data Now Available

Water quality data collected to date by RAMP are summarized in Table 3.2-3. Table 3.2-3 does not include data collected by AENV and RAMP industry members.

3.2.8 Analytical Approach

The analytical approach used in 2009 for the Water Quality component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2009b) and consisted of:

- reviewing and selecting particular water quality variables as water quality measurement endpoints;
- reviewing and selecting criteria to be used in detecting changes in water quality measurement endpoints;
- updating regional *baseline* data ranges for each water quality measurement endpoint; and
- presenting results in tabular and graphical format comparing 2009 concentrations of water quality measurement endpoints, historical concentrations of each endpoint at each station, water quality regional *baseline* conditions, and selected criteria for determining change in water quality.

3.2.8.1 Review and Selection of Water Quality Measurement Endpoints

The selection of water quality measurement endpoints was guided by:

- water quality measurement endpoints used in the EIAs of oil sands projects (RAMP 2009b);
- a draft list of water quality variables of concern in the lower Athabasca region developed by CEMA (2004);
- water quality variables of interest listed in the RAMP 5-year report (Golder 2003a);
- results of correlation analysis of the RAMP 1997-2007 water quality dataset indicating significant inter-correlation of various water quality variables, particularly metals (RAMP 2008); and
- discussions within the RAMP Technical Program Committee about:
    - the importance of various water quality variables to assist in interpreting results of the Benthic Invertebrate Community component and the Fish Population component; and
    - appropriate analytical strategies for the Water Quality component.

Table 3.2-4 presents the water quality variables listed in these various sources.

The water quality measurement endpoints used in 2009 are:

- *pH:* an indicator of acidity;
- *Conductivity*: basic indicator of overall ion concentration;

- *Total suspended solids (TSS):* a variable strongly associated with several other measured water quality variables, including total phosphorus, total aluminum and numerous other metals;

- *Dissolved phosphorus, total nitrogen and nitrate+nitrite:* indicators of nutrient status. Dissolved phosphorus rather than total phosphorus is included because it is the primary biologically-available species of phosphorus and because total phosphorus levels are strongly associated with TSS (RAMP 2006);

- *Various ions (sodium, chloride, calcium, magnesium, sulphate):* indicators of ion balance, which could be affected by discharges or seepages from focal projects or by changes in the water table and changes in the relative influence of groundwater;

- *Total alkalinity:* an indicator of the buffering capacity and acid sensitivity of waters;

- *Total dissolved solids (TDS) and dissolved organic carbon (DOC):* indicators of total ion concentrations and dissolved organic matter (particularly humic acids), respectively;

- *Total and dissolved aluminum:* aluminum is mentioned as a variable of interest in some oil sands EIAs, by CEMA, and in the RAMP 5-year report (Table 3.2-4). Total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with TSS (Golder 2003a). Dissolved aluminum more accurately represents biologically available forms of aluminum that may be toxic to aquatic organisms (Butcher 2001);

- *Total boron, total molybdenum, total strontium*: three metals found in predominantly-dissolved form in waters of the RAMP FSA (RAMP 2004) and which may be indicators of groundwater influence in surface waters;

- *Total arsenic and total mercury (ultra-trace)*: metals of potential importance to the health of aquatic life and human health;

- *Naphthenic acids*: relatively-labile hydrocarbons associated with oil sands deposits and processing that have been identified as a potential toxicity concern; and

- In addition to the above water quality measurement endpoints, overall ionic composition at each station was assessed graphically using Piper diagrams (Section 3.2.8.3).

Table 3.2–3 Summary of RAMP data available for the Water Quality component. (Page 1 of 2)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000			
		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
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1												
(west bank) [b]	ATR-DC-W								1								1
(east bank) [b]	ATR-DC-E								1								1
(middle)	ATR-DC-M																1
Upstream of the Steepbank River (middle)	ATR-SR-M																1
(west bank)	ATR-SR-W																1
(east bank)	ATR-SR-E																1
Upstream of the Muskeg River (middle)	ATR-MR-M																1
(west bank) [b c]	ATR-MR-W								1								1
(east bank) [b c]	ATR-MR-E								1								1
Upstream Fort Creek (cross channel)	ATR-1		1	1	1												
(west bank) [b c]	ATR-FC-W								1								1
(east bank) [b c]	ATR-FC-E								1								1
(middle)	ATR-FC-M																1
Downstream of all development (cross channel)	ATR-DD																
(east bank)	ATR-DD-E																
(west bank)	ATR-DD-W																
Upstream of mouth of Firebag River	ATR-FR																
Upstream of the Embarras River (cross channel)	ATR-ER																1
Embarras River	EMR-1																
At Old Fort (grab) [d]	ATR-OF													11	11	11	11
Athabasca River Delta																	
Big Point Channel [e]	ARD-1											1					1
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1											6	7		6	6	9
(100 m upstream)	MCC-2											6	6				
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1
(upstream of Project Millennium)	STR-2																
(upstream of Nt. Steepbank)	STR-3																
North Steepbank River (upstream of Suncor Lewis)	NSR-1																
Fort Creek (mouth)	FOC-1														7	7	9
Muskeg River																	
Mouth [f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1
Upstream of Canterra Road Crossing [f]	MUR-2									2	9	9	9	10	10	10	10
AENV sampling [g]						13	13	13	11	13	13	13	11	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
Upstream of Muskeg Creek [f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10
Upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9

Waterbody and Location	Station	2001				2002				2003				2004			
		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
Upstream Donald Creek (cross channel)	ATR-DC-CC								1				3				1
(west bank) [b]	ATR-DC-W				3				1				1				1
(east bank) [b]	ATR-DC-E				3				1				1				1
(middle)	ATR-DC-M																
Upstream of the Steepbank River (middle)	ATR-SR-M																
(west bank)	ATR-SR-W				1				1				1				1
(east bank)	ATR-SR-E				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																
(west bank) [b c]	ATR-MR-W				1				1				1				1
(east bank) [b c]	ATR-MR-E				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1																
(west bank) [b c]	ATR-FC-W				3				1				1				
(east bank) [b c]	ATR-FC-E				3				1				1				
(middle)	ATR-FC-M																
Downstream of all development (cross channel)	ATR-DD					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3
(east bank)	ATR-DD-E																
(west bank)	ATR-DD-W																
Upstream of mouth of Firebag River	ATR-FR								1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER				3												
Embarras River	EMR-1												1				
At Old Fort (grab) [d]	ATR-OF	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																	
Big Point Channel [e]	ARD-1				1								1				1
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1		6	6	9	1	6	6	7		6	6	7		6	6	9
(100 m upstream)	MCC-2																
Steepbank River (mouth)	STR-1				1	1			1				1				1
(upstream of Project Millennium)	STR-2					1			1				1				1
(upstream of Nt. Steepbank)	STR-3													1	1	1	1
North Steepbank River (upstream of Suncor Lewis)	NSR-1					1	1	1	1	1	1	1	1	1	1	1	1
Fort Creek (mouth)	FOC-1		6	6	7	1	6	6	7		6	6	7				
Muskeg River																	
Mouth [f]	MUR-1				1				1				1				1
Upstream of Canterra Road Crossing [f]	MUR-2	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling [g]		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	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek [f g]	MUR-5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6		6	6	9		6	6	9		6	6	7		6	6	9

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
Athabasca River																					
Upstream of Fort McMurray (grab) [a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	11	13	11	13	11	13	11	13
Upstream Donald Creek (cross channel)	ATR-DC-CC	1	1	1	1	1			1				1								
(west bank) [b]	ATR-DC-W	1	1	1	1				1				1	1			1	1			1
(east bank) [b]	ATR-DC-E	1	1	1	1				1				1	1			1	1			1
(middle)	ATR-DC-M																				
Upstream of the Steepbank River (middle)	ATR-SR-M																				
(west bank)	ATR-SR-W				1				1				1				1				1
(east bank)	ATR-SR-E				1				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																				
(west bank) [b c]	ATR-MR-W				1				1				1				1				1
(east bank) [b c]	ATR-MR-E				1				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1																				
(west bank) [b c]	ATR-FC-W				1																
(east bank) [b c]	ATR-FC-E				1																
(middle)	ATR-FC-M																				
Downstream of all development (cross channel)	ATR-DD	1,1	1	1	1																
(east bank)	ATR-DD-E					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
(west bank)	ATR-DD-W					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Upstream of mouth of Firebag River	ATR-FR				1				1				1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER																				
Embarras River	EMR-1																				
At Old Fort (grab) [d]	ATR-OF	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																				
Athabasca River tributaries (Eastern)																					
McLean Creek (mouth)	MCC-1		6	6	9		6	6	9				9				1				1
(100 m upstream)	MCC-2																				
Steepbank River (mouth)	STR-1				1				1				1	1			1	1			1
(upstream of Project Millennium)	STR-2				1				1				1				1				1
(upstream of Nt. Steepbank)	STR-3	1	1	1	1		1	1	1		1	1	1				1				1
North Steepbank River (upstream of Suncor Lewis)	NSR-1		1	1	1				1				1				1				1
Fort Creek (mouth)	FOC-1						6	6	7				7		6	6	7		6	6	7
Muskeg River																					
Mouth [f]	MUR-1				1				1				1				1				1
Upstream of Canterra Road Crossing [f]	MUR-2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling [g]		15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	15	15	15	15	14
Downstream of Alsands Drain	MUR-3																				
Upstream of Jackpine Creek [f g h]	MUR-4	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	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		6	6	9		6	6	7				7		6	6	7				1

Legend

1 = standard water quality parameters (conventionals, major ions, nutrients, total & dissolved metals, recoverable hydrocarbons and naphthenic acids)
2 = standard w.q. + chronic toxicity testing (*Selenastrum capricornutum, Ceriodaphnia dubia,* Pimephales promelusfathead minnow)
3 = standard watr quality + PAHs
4 = standard water quality + chronic tox testing + PAHs
5 = standard water quality for OPTI lakes (routine paramters and arsenic)
6 = thermograph
7 = thermograph + standard water quality
8 = thermograph + standard water quality + PAHs
9 = thermograph + standard water quality + chronic tox. testing
10 = thermograph + standard water quality + 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
16 = standard water quality + chlorophyll-a

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] All testing, with the exception of thermographs, is conducted by individual industry
[g] AENV collects/collected nine samples throughout the year, although only three are/were analyzed for PAHs
[h] In 1999, MUR-4 was located upstream of Shelley Creek

Test (downstream of focal projects)
Baseline (upstream of focal projects)
Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

√ = allowance made for potential TIE

Table 3.2–3 (Cont'd.) (Page 2 of 2)

See symbol key below.

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
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	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10																				
Jackpine Creek (mouth) [g]	JAC-1					13	13	13	11	13	13	13	11,1				1				1				1				1				1				1				1				1				1				1
(upper)	JAC-2																																																1				1
Shelley Creek (mouth)	SHC-1								11				11,1																												1				1								1
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1				1				1				1		1	1	1				1				1	1	1	1	1				
Stanley Creek (mouth)	STC-1								11				11,1								1	1	1	1	1	1	1	1	1				1		1	1	1				1				1				1				1
Iyinimin Creek (mouth)	IYC-1																																											1	1				1				
Wapasu Creek (Canterra Road Crossing)	WAC-1					2			11	2			11,1																				1				1				1				1				1				1
Athabasca River tributaries (Western)																																																					
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1				1				1				1				1				1
Beaver River (mouth)	BER-1																												1				1			1	1				1				1				1				1
(upper)	BER-2																																													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	1	1	1	1
(upstream of Suncor MacKay)	MAR-2																					1			1	1	1	1	1				1				1				1				1	1	1	1	1	1	1	1	1
(mid-river, upstream of Suncor Dover)	MAR-2a																																																	1	1	1	1
Dunkirk River (Fish program support)	DUC-1																																																				1
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11				1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2				1				1				1				1
(upstream of Canadian Natural Lease 7)	ELR-2														11	11	11	14												1	1	1	2		1	1	2		1	1	1		1	1	1				1				1
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	1	1
(upstream of Canadian Natural Horizon)	TAR-2																													1	1	1	1		1	1	1		1	1	2		1	1	2				1		1	1	1
Calumet River (mouth)	CAR-1																					1	1	1	2	1	1	1	2	1	1	1	2		1	1	2				1				1				1				1
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2																																		1	1	2		1	1	2	1	1	1	2				1				1
Firebag River (mouth)	FIR-1																					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				1
Athabasca River tributaries (Southern)																																																					
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		7	7	7				1				1
(upstream of Christina River)	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8		6	6	7	1	7	7	7		6	6	7		7		7				1				1
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				1				1
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	1				1	1			1				1				1
(mid)	CHR-2A																																									1			1								
Hangingstone River (upstream of Fort McMurray)	HAR-1																														1	1	1		1	1	1		1	1	1		1	1	1				1				
Horse River (Fish program support)	HOR-1																																																				1
Wetlands (Lakes)																																																					
Kearl Lake (composite)	KEL-1							1									1			1	1				1	1			1			1	1			1	1				16			16	16				16				16
Isadore's Lake (composite)	ISL-1							1									1			1	1												1			1	1			16	16			16	16			16	16				16
Shipyard Lake (composite)	SHL-1							1			1	1	1			1	1			1	1			1	1			1	1			1	1			1	1			16	16			16	16			16	16				16
McClelland Lake (composite)	MCL-1																1			1	1				1																16				16				16				16
Additional Sampling (Non-Core Programs)																																																					
Unnammed Creek north of Ft. Creek (mouth)	UNC-1															1	1																																				
Nexen Lakes	-																		5		5		5		5							5	5		5		5		5		5										5		5
Potential TIE	-																								√				√				√																				
QA/QC																																																					
Field and trip blanks, one split and duplicate	-														1	1	1			1	1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	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, total & dissolved metals, recoverable hydrocarbons and naphthenic acids)
2 = standard w.q. + chronic toxicity testing (*Selenastrum capricornutum, Ceriodaphnia dubia,* Pimephales promelusfathead minnow)
3 = standard watr quality + PAHs
4 = standard water quality + chronic tox testing + PAHs
5 = standard water quality for OPTI lakes (routine paramters and arsenic)
6 = thermograph
7 = thermograph + standard water quality
8 = thermograph + standard water quality + PAHs
9 = thermograph + standard water quality + chronic tox. testing
10 = thermograph + standard water quality + 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
16 = standard water quality + chlorophyll-a

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] All testing, with the exception of thermographs, is conducted by individual industry
[g] AENV collects/collected nine samples throughout the year, although only three are/were analyzed for PAHs
[h] In 1999, MUR-4 was located upstream of Shelley Creek

Test (downstream of focal projects)
Baseline (upstream of focal projects)
Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

√ = allowance made for potential TIE

Table 3.2-4 Potential water quality measurement endpoints.

Group	RAMP (2009b) Variables Listed in EIAs	CEMA Variables of Concern (CEMA 2004)	RAMP 5-year Report (Golder 2003a)	Variables to Support Other RAMP Components[1]	Additional Suggested Variables[2]
Physical Variables	Temperature TSS Dissolved oxygen Conductivity pH	(None)	pH TSS	Temperature Dissolved oxygen pH TSS Conductivity	
Nutrients	Ammonia-N Total nitrogen Total phosphorus	Ammonia-N Total nitrogen Total phosphorus	Dissolved organic carbon Total Kjeldahl nitrogen Total phosphorus	Dissolved phosphorus Nitrate+nitrite	
Ions and Ion Balance	Chloride Sulphide TDS	Sodium Chloride Potassium **Fluoride** Sulphate	TDS Sulphate Total alkalinity	Total alkalinity Hardness	Carbonate Bicarbonate Magnesium Calcium
Dissolved and Total Metals	Aluminum Arsenic Barium Boron Cadmium Chromium Copper Iron Manganese Mercury Molybdenum Selenium Silver Zinc	Aluminum Antimony Boron Cadmium Chromium Lithium Molybdenum Nickel Strontium Vanadium	Total chromium Total boron Total aluminum	Total & dissolved copper Total & dissolved lead Total & dissolved nickel Total & dissolved zinc Ultra-trace mercury	Total strontium Total arsenic
Organics/ Hydrocarbons	Oil and grease Naphthenic acids Total phenolics	Oil and grease Total hydrocarbons Naphthenic acids **Toluene** **Xylene**	(None)	(None)	(None)
PAHs	Benzo(a)anthracene Benzo(a)pyrene Miscellaneous PAHs	**Naphthalene** **Biphenyl** **Acenapthene** **Acenaphthylene** **Fluorene** **Fluoranthene** **Alkyl-naphthalenes** **Alkyl-biphenyls** **Alkyl-acenaphthene** **Alkyl-benzo(a)anthracene** **Alkyl-fluorenes** **Alkyl-phenanthrenes** **Dibenzothiophene** **Alkyl-dibenzothiophenes**	(None)	(None)	(None)
Effects-based Endpoints	Acute toxicity Chronic toxicity	Acute toxicity Chronic toxicity **Fish tainting**			

All variables are currently monitored by RAMP except those in **bold**.

[1] Primarily Benthic Invertebrate Communities and Fish Population components (inferred).

[2] Suggested by the RAMP Technical Program Committee, February 2006 and February 2008, and from ongoing review of stakeholder concerns.

3.2.8.2 Development of Regional Water Quality Baselines

Multivariate data analysis is used to develop descriptions of regional *baseline* water quality that are then used to screen water quality measurements from *baseline* and *test* stations. In this approach, water quality data from all RAMP *baseline* water quality stations from 2002 to 2009 were pooled using Objective Classification Analysis (OCA). This analysis involved multivariate data reduction of the RAMP total metals, dissolved metals and major ions dataset using Principal Component Analysis (PCA), followed by application of hierarchical and k-means clustering algorithms to define groups of stations exhibiting similar water quality characteristics. Similar approaches to consolidation and analysis of large water quality datasets are presented and discussed by Jones and Boyer (2002) and Güler *et al.* (2004). The analytical methodology is similar to that of the Reference Condition Approach to biomonitoring (Bailey *et al.* 2004) also used in the RAMP benthic invertebrate communities component, and incorporates elements of control charting (Morrison 2008), which also is a feature of RAMP benthic invertebrate communities and acid-sensitive lakes components. This approach is more fully described in the RAMP Technical Design and Rationale document (RAMP 2009b).

Water quality data collected prior to 2002 were excluded from this analysis because metals data from 1997 to 2001 had higher analytical detection limits than 2002 onwards. Use of the earlier data in previous reports required upward adjustment of all later data and eliminated important variability. Also, only the dissolved value was included in the PCA for any total and dissolved metals that were clearly co-linear, metals that were present predominantly in dissolved form and therefore exhibited very similar or identical values as both total and dissolved measurements. Detailed methods and results of the OCA of the RAMP water quality data are provided in Appendix D.

Results of this analysis of the RAMP 2002 to 2009 dataset indicated three major groups of stations with similar water quality types (Table 3.2-5):

- Athabasca River mainstem and delta, plus Clearwater, Christina and Horse rivers;
- Eastern tributaries, including Steepbank, Muskeg, Firebag rivers, Fort Creek and regional lakes, as well as McLean Creek; and
- Western tributaries, including Beaver River, Poplar Creek, MacKay River, Ells, Tar and Calumet rivers, as well as Hangingstone River.

For most stations included in the cluster analysis, samples from different years clustered closely together, indicating that water quality at these stations was consistent at specific locations across years of sampling (i.e., spatial variation was more important than temporal variation in defining cluster membership). Where multiple years of data from a station fell across different clusters, data from all years for that station were placed in a single cluster that either: (i) represented the most years of data; or (ii) included other stations from the watershed within which that station was located.

Within each cluster, data from stations designated as *baseline* (i.e., those stations located in areas of watersheds that are not being influenced by focal project activities) were pooled to develop descriptions of regional *baseline* water quality, against which RAMP data from stations designated as *test (i.e.,* downstream of focal project activities) and *baseline* were assessed. Table 3.2-6 lists the stations from which *baseline* data from 2002 to 2009 were pooled to develop these *baseline* descriptions. The numbers of observations in regional *baseline* datasets varied by cluster and by water quality measurement endpoint.

Table 3.2-5 Classification of groups of RAMP water quality monitoring stations with similar water quality, from 2002 to 2009 data.

Region	Waterbody	Total # of Station/Year Combinations	Cluster		
			1	2	3
Athabasca River and Delta					
	Athabasca	81	79	-	-
	Delta/Embarras River	3	3	-	-
Eastern Tributaries					
	McLean Creek	8	-	1	7
	Shipyard Lake	8	-	8	-
	Steepbank River	22	-	22	-
	- North Steepbank River	8	-	8	-
	Muskeg River	16	-	16	-
	- Iyinimin Creek	2	1	1	-
	- Jackpine Creek	10	-	10	-
	- Muskeg Creek	7	-	5	2
	- Shelley Creek	3	-	1	2
	- Stanley Creek	8	-	8	-
	- Wapasu Creek	6	-	6	-
	- Kearl Lake	8	-	8	-
	Isadore's Lake	6	-	6	-
	Fort Creek	6	-	3	3
	Firebag River	16	-	16	
	- McClelland Lake	6	-	6	-
Western Tributaries					
	Beaver River	9	-	-	9
	- Poplar Creek	8	-	-	8
	MacKay River	17	-	-	17
	- Dunkirk River	1	-	-	1
	Ells River	14	-	-	14
	Tar River	14	-	-	14
	Calumet River	13	-	-	13
Southern Tributaries					
	Clearwater River	16	16	-	-
	- Christina River	16	7	5	4
	Hangingstone River	5	-	-	5
	Horse River	1	1	-	-
Total		**338**	**115**	**132**	**89**

Bold entries refer to sum of station-year combinations in each group of waterbodies.

Shaded entries denote the cluster designated for each waterbody. Totals include all stations following cluster designation.

Table 3.2-6 Regional *baseline* water quality data groups and station comparisons.

Regional *Baseline* Grouping (Cluster)	*Baseline* Stations Used in Creating Regional Comparison[1]	*Test* Stations (2009) Compared Against Regional *Baseline*
1. Athabasca and Clearwater rivers	ATR-DC-E, ATR-DC-W, CHR-2[2], CHR-2A[2], CLR-2[2], HOR-1[2]	ATR-DC-E, ATR-DC-W, ATR-DD-E, ATR-DD-W, ATR-FR-CC, ATR-MR-E, ATR-MR-W, ATR-SR-E, ATR-SR-W, CLR-1
2. Eastern tributaries and lakes	FIR-2, FIR-2X, FOC-1, KEL-1, MCL-1, JAC-1, JAC-2, MUC-1, SHC-1, STC-1, WAC-1, NSR-1, MUR-6, STR-2, STR-3, IYC-1	FIR-1, FIR-2, FOC-1, ISL-1, KEL-1, MCL-1, SHL-1, JAC-1, JAC-2, MUR-1, MUR-6, SHC-1, STC-1, WAC-1, NSR-1, STR-1, STR-2, STR-3, IYC-1
3. Western tributaries	BER-2, CAR-1, CAR-2, DUR-1, ELR-1, ELR-2, MAR-1, MAR-2, MAR-2, TAR-1, TAR-2, HAR-1[2]	MCC-1, BER-1, BER-2, CAR-1, CAR-2, DUR-1, ELR-1, ELR-2, MAR-1, MAR-2, MAR-2[a], POC-1,TAR-1, TAR-2

[1] See Table 3.2-3 for classification of station status by year. Where station status changed from *baseline* to *test* during 1997-2009, only *baseline* data were used in the determination of regional water quality characteristics.

[2] Station classified as *baseline* due to no focal projects upstream, but excluded from regional *baseline* range calculations due to other oil sands developments in upstream watershed.

3.2.8.3 Tabular and Graphical Presentation of Results

Comparison to Water Quality Guidelines and Historical Data

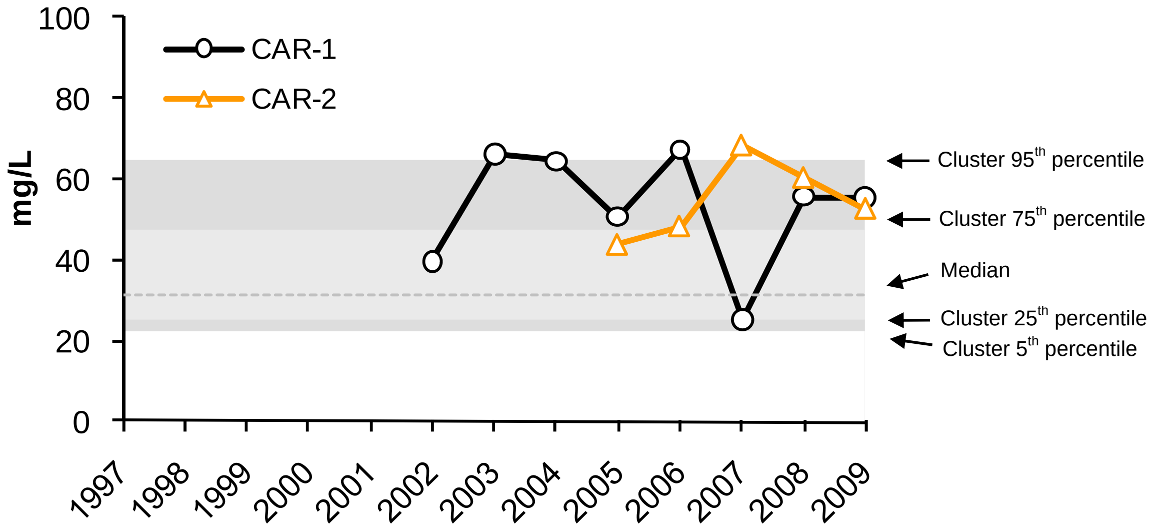
The fall 2009 value of each water quality measurement endpoint was tabulated for each station sampled. Historical variability was presented for each water quality measurement endpoint, represented by minimum, maximum and median values observed, as well as the number of observations, at each station from 1997 to 2009 (fall observations only). All cases, in which concentrations of water quality variables, including water quality measurement endpoints and any other monitored water quality variables, exceeded relevant guidelines, were also reported.

Comparison to Natural Variation in Baseline Conditions

To allow a regional comparison, untransformed data for fifteen of the 21 water quality measurement endpoints from all *baseline* stations sampled by RAMP from 1997 to 2009 (fall only) were pooled from each cluster of similar stations (Table 3.2-5). Descriptive statistics describing natural water quality characteristics for each group were calculated; for each water quality cluster (Table 3.2-5), the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined for comparison against station-specific data. The number of observations varied by cluster for each of the fifteen selected water quality measurement endpoints (Table 3.2-7). The median rather than the mean was used as an indicator of typical conditions; given water quality data are characteristically positively skewed.

Data for the fifteen selected water quality measurement endpoints were presented graphically in the context of relevant regional variability by presenting data for each station for all years of sampling by RAMP to allow assessment of any temporal trends (Figure 3.2-2). Where possible, stations located upstream and downstream on specific watersheds were presented together, to allow assessment of any differences in values or trends between upstream/downstream locations.

Figure 3.2-2 Example of a comparison of RAMP data from a specific watershed[1] against regional *baseline* data and water quality guidelines.



[1] In this case, Total Dissolved Solids at stations CAR-1 (*test*) and CAR-2 (*baseline*) of the Calumet River.

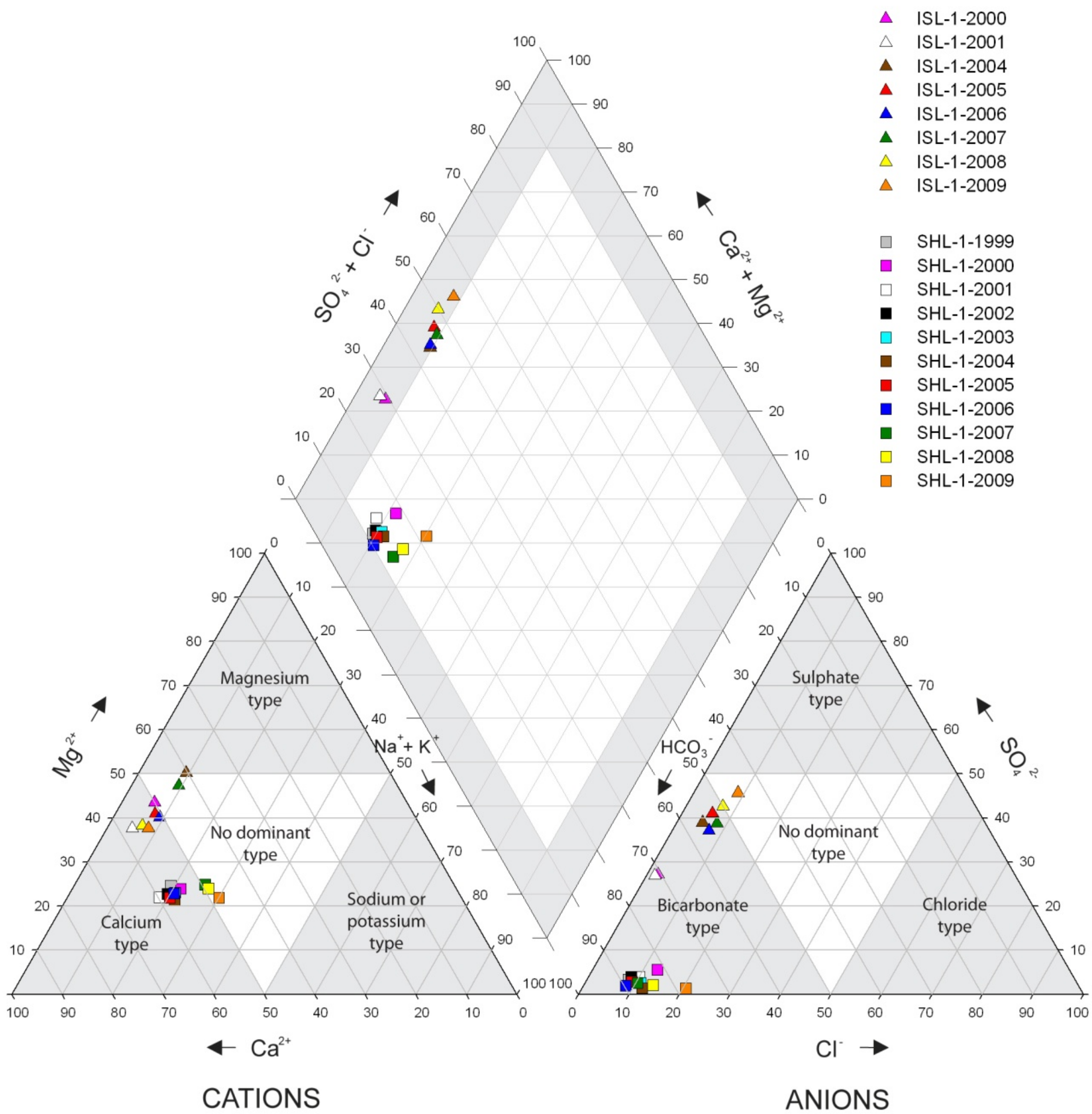
Table 3.2-7 Number of observations available for determining regional *baseline* water quality.

Water Quality Measurement Endpoint	Number of Observations (Station-Year Combinations) for *Baseline* Regional Water Quality		
	Cluster 1	Cluster 2	Cluster 3
Total Suspended Solids (TSS)	55	90	39
Total Dissolved Solids (TDS)	55	90	39
Dissolved phosphorus	55	91	39
Total nitrogen	55	91	39
Total strontium	55	91	39
Total boron	55	91	39
Total Mercury (ultra-trace)	41	58	31
Total Arsenic	55	91	39
Naphthenic acids	55	90	39
Calcium	55	90	39
Magnesium	55	90	39
Sodium	55	90	39
Potassium	55	90	39
Chloride	55	90	39
Sulphate	55	90	39

Ion Balance

Piper diagrams were used to examine ion balance at each station, or at multiple stations within a watershed, to assess temporal or spatial differences in ion balance. Piper diagrams display the relative concentrations of major cations and anions on two separate ternary (triangular) plots, together with a central diamond plot where points from the two ternary plots are projected to describe the overall character, or type of water (Güler *et al*. 2004) (Figure 3.2-3).

Figure 3.2-3 Example Piper diagram, illustrating relative ion concentrations in waters from Isadore's Lake and Shipyard Lake (1997 to 2009).



Trend Analysis

Statistical trend analysis was undertaken on water quality data for the Athabasca River, which has been monitored continuously by Alberta Environment since 1976. Trend analysis was undertaken on data from: Athabasca River upstream of Fort McMurray (station ATR-UFM, approximately 100 m upstream of the Horse River); and Athabasca River at Old Fort (station ATR-OF), located in the Athabasca River Delta, downstream of the Embarras River distributary. Trend analysis was conducted on specific water quality measurement endpoints (Section 3.2.8.1), including total suspended solids, total dissolved solids, dissolved phosphorus, total nitrogen, total boron, naphthenic acids, total strontium, calcium, chloride, magnesium, potassium, sodium, sulphate and total arsenic, from the period of RAMP sampling (1997 to 2009), to assess trends potentially related to development between the two stations during this time period. Trend analysis also was conducted on the water quality measurement endpoints at those sampling stations where there were at least seven consecutive years of fall water quality data. A Mann-Kendall trend analysis was conducted on RAMP fall data (Seasonal Mann-Kendall for monthly AENV Athabasca River data) using the program WQStat Plus, with a level of significance of α=0.05. Values were not flow-averaged before trend analysis, given a lack of concurrent hydrometric data for most sampling stations.

Regional Analysis of Water Quality

In addition to watershed-level analyses, this report includes regional-level analyses of water quality, based on comparisons of water quality in different regional groups (clusters) of water quality stations described above. Specific comparisons include those between historical regional *baseline* data and regional *baseline* data collected in 2009, and between data from *test* stations and regional *baseline* data from 2009 and historically. Results of these comparisons are included in Section 7.

3.2.8.4 Classification of Results

Three criteria for classifying water quality results were used:

- **Comparison to Water Quality Guidelines**: All water quality data collected by RAMP in 2009 in any season were screened against Alberta acute and chronic water quality guidelines for the protection of aquatic life (AENV 1999b) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2007). Variables for which there are no AENV or CCME guidelines were screened against applicable guidelines from other jurisdictions where appropriate (Table 3.2-8). All values that exceeded these guidelines are reported explicitly in the body of the RAMP report.

- **Comparison to Natural Variation in *Baseline* Conditions**: 2009 water quality data for each of the selected water quality measurement endpoints were assessed against a rigorously defined range of natural variability in concentration of each of these measurement endpoints.

- **Calculation of a Water Quality Index**: Described below.

Water quality at each RAMP monitoring station in fall 2009 was summarized into a single index value, ranging from 0 to 100, using an approach based on the CCME Water Quality Index[1]. This index is calculated using comparisons of observed water quality against user-specified benchmark values, such as water quality guidelines or background concentrations. It considers three factors: (i) the percentage of variables with values that exceed a given user-specified benchmark; (ii) the percentage of comparisons that exceed a given user-specified benchmark; and (iii) the degree to which observed values exceed user-specified benchmark values.

[1] A detailed description of the index is found at http://www.ccme.ca/ourwork/water.html?category_id=102.

Table 3.2-8 Water quality guidelines used to screen data collected by the RAMP Water Quality Component, 2009.

Water Quality Variable	Units	AENV[2]		CCME[1]	Other Jurisdictions[3]
		Acute	Chronic		
Conventional variables		-	-	-	-
pH	pH units	-	-	6.5 to 9.0	-
Dissolved oxygen	mg/L	5.0 (min)	6.5 (7-day mean)[j]	5.5 to 9.5[h]	-
Temperature	^oC	-	-[g]	-	-
Suspended Solids	mg/L	-	> 10 mg/L[m]	-	-
Turbidity	NTU	-	-	-	-
Major ions		-	-	-	-
Sulphate	mg/L	-	-	-	100['3]
Sulphide (as H_2S)	mg/L	-	-	-	2['3]
Chloride (Cl)	mg/L	-	-	-	230 (BC), 860 (USEPA)
Nutrients		-	-	-	-
Total Kjeldahl Nitrogen (TKN)	mg/L	-	-	-	-
Ammonia	mg/L	-	-	0.043 to 153[g]	-
Nitrate-N	mg/L	-	-	13	-
Nitrite-N	mg/L	-	-	0.060	-
Total Nitrogen	mg/L	-	1.0	-	-
Total Dissolved Phosphorus	mg/L	-	-	-	-
Total Phosphorus	mg/L	-	0.05	-	-
Organics		-	-	-	-
Total phenols	mg/L	-	0.005	-	0.05[l]
Naphthenic acids	mg/L	-	-	-	-
Total and dissolved metals					
Aluminum (Al)	mg/L	-	-	0.005, 0.1[a]	0.05 (dissolved)[i]
Antimony (Sb)	mg/L	-	-	-	0.023
Arsenic (As)	mg/L	-	-	0.0050	-
Barium (Ba)	mg/L	-	-	-	53
Beryllium (Be)	mg/L	-	-	-	-
Bismuth (Bi)	mg/L	-	-	-	-
Boron (B)	mg/L	-	-	-	1.23
Cadmium (Cd)	mg/L	-	-	0.000017[b]	-
Calcium (Ca)	mg/L	-	-	-	-
Chromium III (Cr^{3+})	mg/L	-	-	0.0089	-
Chromium VI (Cr^{6+})	mg/L	-	-	0.0010	-
Cobalt (Co)	mg/L	-	-	-	0.113
Copper (Cu)	mg/L	-	-	0.002 to 0.004[c]	-
Iron (Fe)	mg/L	-	-	0.300	-
Lead (Pb)	mg/L	-	-	0.001 to 0.007[d]	-
Lithium (Li)	mg/L	-	-	-	5
Magnesium (Mg)	mg/L	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	0.8 to 3.8[j]
Mercury (Hg)[e]	mg/L	0.000013	0.000005	-	-
Molybdenum (Mo)	mg/L	-	-	0.073	-
Nickel (Ni)	mg/L	-	-	0.025 to 0.150[f]	-
Phosphorus (P)	mg/L	-	-	-	-
Potassium (K)	mg/L	-	-	-	-
Selenium (Se)	mg/L	-	-	0.0010	-
Silver (Ag)	mg/L	-	-	0.0001	-
Sodium (Na)	mg/L	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-
Sulphur (S)	mg/L	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.0008	-
Tin (Sn)	mg/L	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	0.130
Uranium (U)	mg/L	-	-	-	0.330
Vanadium (V)	mg/L	-	-	-	-
Zinc (Zn)	mg/L	-	-	0.030	-

[1] CCME (2007).

[2] AENV (1999b).

[3] All from British Columbia (2006), except chloride (USEPA 1999), and sulphide (USEPA 1999)

a: 0.005 at pH<6.5; $[Ca^{2+}]$<4 mg/L; DOC<2 mg/L; 0.100 at pH>=6.5; $[Ca^{2+}]$>=4 mg/L; DOC>=2 mg/L

b: Hardness-dependant. Guideline = $10^{(0.86[\log(hardness)]-3.2)/1000}$

c: 0.002 at $[CaCO_3]$=0 to 120 mg/L; 0.003 at $[CaCO_3]$=120 to 180 mg/L; 0.004 at $[CaCO_3]$>180 mg/L

d: 0.001 at $[CaCO_3]$=0 to 60 mg/L; 0.002 at $[CaCO_3]$=60 to 120 mg/L; 0.004 at $[CaCO_3]$=120 to 180 mg/L; 0.007 at $[CaCO_3]$>180 mg/L

e: for inorganic mercury

f: 0.025 at $[CaCO_3]$=0 to 60 mg/L; 0.065 at $[CaCO_3]$=60 to 120 mg/L; 0.110 at $[CaCO_3]$=120 to 180 mg/L; 0.150 at $[CaCO_3]$>180 mg/L

g: Guidelines for total ammonia are temperature and pH dependent; see CCME (2007) for additional information.

h: For cold-water biota, 9.5 mg/L for early life stages, 6.5 mg/L for other life stages. For warm-water biota, 6.0 mg/L for early life stages, 5.5 mg/L for other life stages.

i: For dissolved Al at pH>=6.5. At pH<6.5, guidelines are $e^{1.209-2.426*pH+0.286*pH2}$ (maximum concentration) and $e^{1.6-3.327*median\ pH+0.402*pH2}$

j: Hardness-dependant. Guideline = 0.01102*hardness+0.54.

k: 0.2 at hardness <=50 mg/L $CaCO_3$, 0.3 at hardness >=50 mg/L

l: For all pnenolic compounds except 3- and 4-hydroxyphenol, which have separate guidelines.

Index calculations for RAMP water quality data used regional *baseline* conditions, calculated and described in Section 3.2.8.2, as the benchmarks for comparison. Specifically, individual water quality observations were compared to the 95th percentiles of *baseline* concentrations (for the appropriate water quality station cluster) for each water quality variable.

Variables included in the calculation of the water quality index included all RAMP water quality measurement endpoints (Section 3.2.8.1) except total nitrogen, which was excluded because of autocorrelation with nitrate+nitrite and ammonia, both of which were included in index calculations. Index values were calculated for all *baseline* and *test* stations. Calculation of water quality index values for all stations sampled by RAMP in fall since 1997 (n=420) yielded index values ranging from 38.4 to 100.0. It should be noted that historical index values calculated for specific observations may change annually, given 95th percentile values for individual variables included in the index may change with addition of new *baseline* data to the RAMP data record.

Water-quality-index scores were classified using the following scheme:

- 80 to 100: Negligible-Low difference from regional *baseline* conditions;
- 60 to 80: Moderate difference from regional *baseline* conditions; and
- Below 60: High difference from regional *baseline* conditions.

This classification scheme, based on similarity to regional *baseline* conditions, differs somewhat from that used by CCME to classify water quality based on water-quality guidelines. Specifically, only three categories were used (versus five used by CCME), to ensure consistency with classification schemes used for other RAMP components. A classification of "Negligible-Low" difference from *baseline,* corresponds with CCME guideline-based index classes "Good" and "Excellent"; RAMP classification of "Moderate" difference from *baseline* generally corresponds with CCME class "Fair"; and RAMP classification of "High" difference from *baseline* corresponds with CCME classes "Marginal" and "Poor". Although the CCME index is typically calculated using comparisons against water quality guidelines, it is customized for each station where it is applied to suit local conditions and concerns, and the use of regional norms as benchmarks, as is done by RAMP, is an appropriate use of this index (Government of Canada 2008, S. Pappas, Environment Canada, *pers. comm.* 2009).

3.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY COMPONENT

3.3.1 Benthic Invertebrate Communities

3.3.1.1 Summary of 2009 Monitoring Activities

Benthic invertebrates were collected from September 9 to 20, 2009. A total of 240 samples were collected from 22 river reaches and four lakes (Figure 3.3-1, Table 3.3-1). As in previous years, river-reach samples were collected in the dominant habitat type found in each reach (Table 3.3-1). Habitats were defined as being either depositional (dominated by fine sediment deposits and low to no current) or erosional (dominated by rocky substrates and frequent riffle areas).

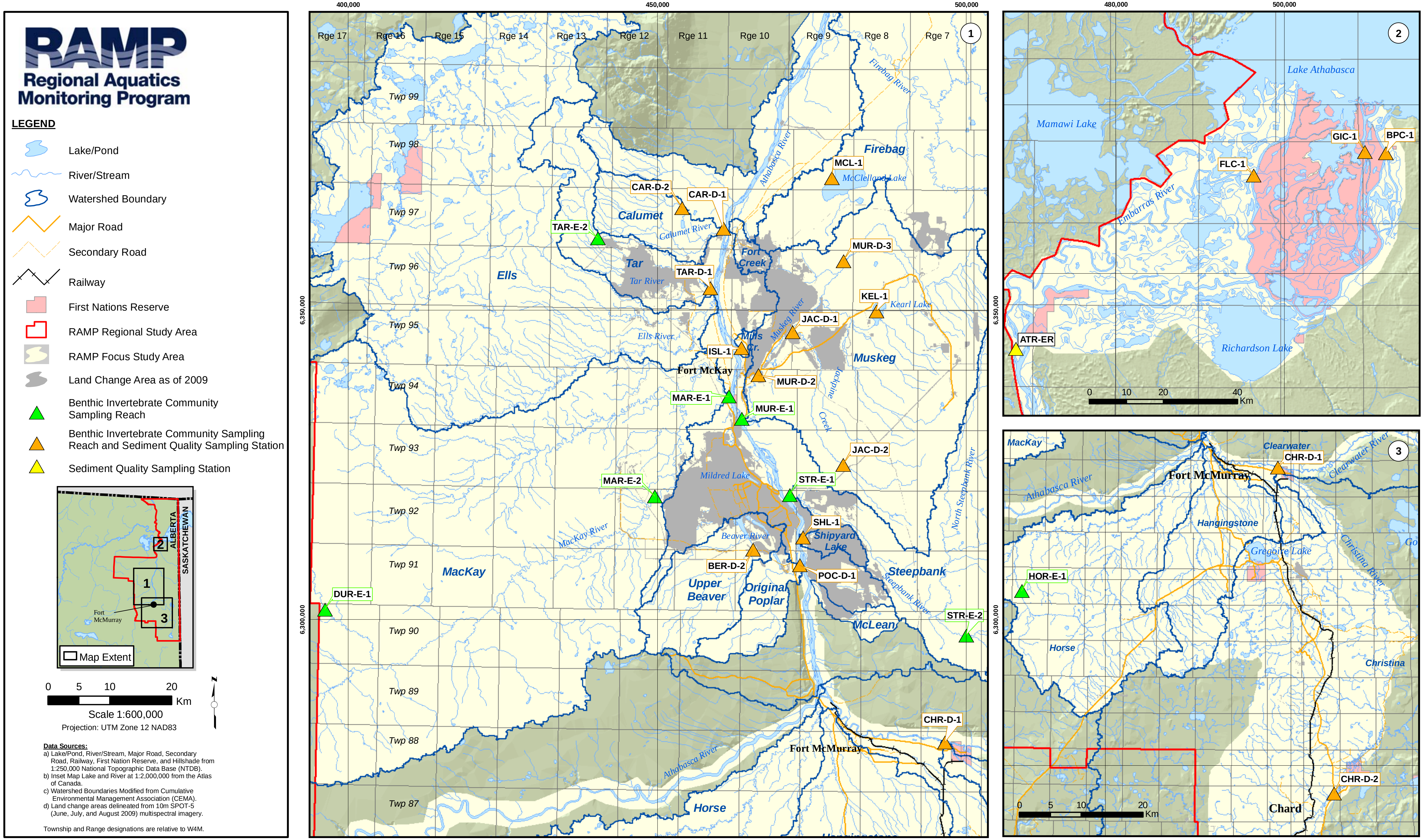
Table 3.3-1 Summary of sampling locations for the RAMP 2009 Benthic Invertebrate Communities component.

Waterbody and Location	Habitat[1]	Reach or Station	UTM Coordinates (NAD 83, Zone 12)			
			Downstream Limit of Reach		Upstream Limit of Reach	
			Easting	Northing	Easting	Northing
Athabasca River Delta						
Goose Island Channel	depositional	BPC	510963	6496226	510934	6496382
Big Point Channel	depositional	FLC	496445	6491625	496509	6491770
Fletcher Channel	depositional	GIC	508179	6495947	508014	6495925
Steepbank River						
Lower Reach	erosional	STR-E-1	471390	6320166	472401	6319888
Upper Reach	erosional	STR-E-2	499961	6297509	501114	6297814
Muskeg River						
Lower Reach	erosional	MUR-E-1	463643	6332493	464557	6332299
Middle Reach	depositional	MUR-D-2	466295	6339500	466596	6340498
Upper Reach	depositional	MUR-D-3	480075	6357945	482104	6359791
Jackpine Creek						
Lower Reach	depositional	JAC-D-1	471862	6346430	473071	6346317
Upper Reach	depositional	JAC-D-2	480086	6324999	480788	6324619
Beaver River						
Upper Reach	depositional	BER-D-2	465475	6311289	465221	6311024
Poplar Creek						
Lower Reach	depositional	POC-D-1	473047	6308837	472427	6308501
MacKay River						
Lower Reach	erosional	MAR-E-1	461548	6336018	460679	6336703
Upper Reach	erosional	MAR-E-2	449883	6319957	448855	6318837
Tar River						
Lower Reach	depositional	TAR-D-1	458573	6353573	458086	6353579
Upper Reach	erosional	TAR-E-2	440357	6361662	4398870	6362093
Calumet River						
Lower Reach	depositional	CAR-D-1	460698	6363156	459583	6362803
Upper Reach	depositional	CAR-D-2	453995	6366522	453996	6366265
Christina River						
Lower Reach	depositional	CHR-D-1	496481	6280190	497744	6278488
Upper Reach	depositional	CHR-D-2	511666	6192362	510845	6192005
Dunkirk River						
Lower Reach	erosional	DUR-E-1	396208	6301643	395706	63202687
Horse River						
Lower Reach	erosional	HOR-E-1	427377	6246956	427269	6246262
Lakes[2]						
Kearl Lake	lake	KEL-1	484417	6349805		
McClelland Lake	lake	MCL-1	478204	6371304		
Shipyard Lake	lake	SHL-1	473552	6313264		
Isadore's Lake	lake	ISL-1	463571	6343843		

[1] Sediment quality sampling was conducted at depositional reaches and in lakes.

[2] UTM coordinates of first station.

Figure 3.3-1 Locations of RAMP benthic invertebrate community reaches and sediment quality sampling stations, 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_G_BenthosSed_20100415.mxd

3.3.1.2 Summary of Field Methods

Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003a, RAMP 2009b), which were developed from Alberta Environment (1990), Environment Canada (1993), Klemm *et al.* (1990) and Rosenberg and Resh (1993). A Neill-Hess cylinder (0.093-m^2 opening and 210-µm mesh) was used for collection of benthic invertebrates in erosional areas. An Ekman grab (0.023 m^2, 6″ x 6″) was used for benthic invertebrate collections in depositional habitats and was deployed using a rope and messenger in lakes.

Ten replicate samples were collected from within pre-established 2 to 4 km long river reaches. Five replicate samples were collected from ARD channels. Samples were selected from within the reach, based on habitat availability and approximately equal spacing. Ten replicate samples were randomly selected in lakes from littoral areas based on a controlled depth range of 0.5 m to 3 m. Samples collected at depositional stations were sieved in the field using a 250-µm screen, preserved in 10% buffered formalin, and bottled for transport.

As in previous years, a series of measurements were recorded as supporting information:

- Wetted and bankfull channel widths – visual estimate (for rivers/streams only); field water quality measurements – dissolved oxygen, conductivity, temperature, and pH. The instrument used to measure conductivity and pH was calibrated according to manufacturer's instructions; dissolved oxygen was measured by field titrations;
- Current velocity – determined by measuring the time for a semi-submerged object to travel a known distance (2 m);
- Water depth at the benthic sample location – measured with a graduated device (pole or Hess cylinder);
- Amount of benthic algae at erosional stations (for chlorophyll *a* measurement) – obtained by scraping of a 1 cm x 1 cm square from three randomly-selected cobbles and combining these 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;
- An additional Ekman grab sample collected at depositional stations for analysis of total organic carbon (TOC, as a dry weight percentage), metals, PAHs, and particle size (% sand, silt and clay, as dry weight);
- Geographical position – using a hand-held Magellan Global Positioning System (GPS) unit; and
- General station appearance.

Laboratory Methods

ALS Laboratories (Edmonton, Alberta) conducted the chlorophyll *a* analyses for erosional stations and analysis of TOC and particle size distribution for depositional stations.

Dr. Jack Zloty in Summerland, BC performed sorting and taxonomic identifications, as in previous years. Samples were sieved in the laboratory using a 250-µm mesh sieve to remove the preservative and any remaining fine sediments. The 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 sub-sampled using a modification of the method described by Wrona *et al*. (1982) in which fine materials were scanned for invertebrates with the aid of a dissecting microscope at a magnification of 6X to 10X. All sorted material was preserved for random checks of removal efficiency. QA/QC procedures related to sample processing for benthic invertebrate communities are discussed in Appendix B.

Organisms were identified to lowest practical taxonomic levels using up-to-date taxonomic literature, and as per the guidelines in Appendix E.

3.3.1.3 Changes in Monitoring Network from 2008

Benthic invertebrates were collected from the Horse River (*baseline* reach HOR-E-1) and the Dunkirk River (*baseline* reach DUR-E-1) for the first time in 2009 to harmonize with the Fish Population component.

3.3.1.4 Challenges Encountered and Solutions Applied

All samples were collected as planned in 2009.

3.3.1.5 Other Information Obtained

No additional or supplementary information was obtained as part of the 2009 Benthic Invertebrate Communities component.

3.3.1.6 Summary of Component Data Now Available

As of 2009, 2,271 benthic invertebrate community samples have been collected under RAMP. The distribution of stations and reaches, and the time-series of data available for individual locations are presented in Table 3.3-2.

3.3.1.7 Analytical Approach and Methods

The analytical approach used in 2009 for the Benthic Invertebrate Community component was based on the analytical approach described in the RAMP Technical Design and Rationale (RAMP 2009b) and consisted of:

- selecting benthic invertebrate community measurement endpoints;
- developing criteria to be used in detecting changes in benthic invertebrate community measurement endpoints; and
- detailed data analysis, consisting of:
    - analysis of variance testing for differences between upstream *baseline* and downstream *test* reaches, and/or differences in time trends; and
  - calculation of normal ranges of variability for the benthic invertebrate community measurement endpoints, and comparison of data from reaches designated as *test* to reaches designated as *baseline* to determine how the communities compare to natural variability.

Table 3.3-2 Summary of RAMP data available for the Benthic Invertebrate Communities component.

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	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 Delta																																																							
Athabasca River Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1								1,1				1,1				1,1
Calumet River																																																							
Lower Reach	1,2[1]	depositional	CAR-D-1																				2				1				1				1				1																1,2
Upper Reach	1	depositional	CAR-D-2																												1				1				1				1,2												1,2
Christina River																																																							
Lower Reach	1	depositional	CHR-D-1																								1				1				1				1				1,2				1								1,2
Middle Reach	1	erosional	CHR-E-2A																																												1								
Upper Reach	1	depositional	CHR-D-2																								1				1				1				1				1,2												1,2
Clearwater River																																																							
Downstream of Christina River	1	depositional	CLR-D-1																				1				1				1				1				1												1				
Upstream of Christina River	1	depositional	CLR-D-2																				1				1				1				1				1												1				
Ells River																																																							
Lower Reach	1	depositional	ELR-D-1																												1				1				1				1,2				1								
Upper Reach	1	erosional	ELR-E-2																												1				1				1				1												
Firebag River																																																							
Lower Reach	1	erosional	FIR-D-1																												1				1				1				1,2				1								
Upper Reach	1	depositional	FIR-E-2																												1				1				1				1				1								
Fort Creek																																																							
Lower Reach	1	depositional	FOC-D-1												2								1				1				1								1,2				1,2				1,2				1,2				
Hangingstone River																																																							
Lower Reach	1	erosional	HAR-E-1																																1				1				1				1				1				
Horse River																																																							
Upper Reach	1	erosional	HOR-E-1																																																				1
Jackpine Creek																																																							
Lower Reach	1	depositional	JAC-D-1																								1				1				1				1				1,2				1				1				1,2
Upper Reach	1	depositional	JAC-D-2																												1				1				1				1,2				1				1				1,2
MacKay River																																																							
Lower Reach	1	erosional	MAR-E-1																1				1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	MAR-E-2																								1				1				1				1				1				1				1				1
Dunkirk River																																																							
Upper Reach	1	erosional	HAR-E-1																																																				1
Muskeg River																																																							
Lower Reach	1	erosional	MUR-E-1																1				1				1				1				1				1				1				1				1				1
Middle Reach	1	depositional	MUR-D-2																1				1				1				1				1				1				1,2				1,2				1,2				1
Upper Reach	1	depositional	MUR-D-3																								1				1				1				1				1,2				1,2				1,2				1
Steepbank River																																																							
Lower Reach	1	erosional	STR-E-1																1				1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	STR-E-2																												1				1				1				1				1				1				1
Tar River																																																							
Lower Reach	1[1]	depositional	TAR-D-1																				2				1				1				1				1				1,2												1,2
Upper Reach	1	erosional	TAR-E-2																												1				1				1				1												1

Type Legend:

1 = RAMP station

2 = Sampled outside of RAMP (data available to RAMP)

,1 = RAMP standard sediment quality variables (carbon, particle size, total hydrocarbons, metals, PAHs, alkylated PAHs)

,2 = RAMP standard sediment quality + sediment toxicity (*Chironomus tentans, Hyalella azteca*)

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

[1] sampled outside of RAMP in 2001, became RAMP station in 2002

[2] sampled outside of RAMP in 1999, became RAMP station in 2000

Table 3.3-2 (Cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	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
Beaver River																																																							
Lower Reach	1	depositional	BER-D-2																																																1				1,2
Poplar Creek																																																							
Lower Reach	1	depositional	POC-D-1																																																1				1,2
Wetlands and Lakes																																																							
Isadore's Lake	1	lake	ISL-1																																						1,2				1,2				1,2				1,1
Kearl Lake	1	lake	KEL-1																				1				1				1				1				1				1,2				1,2				1,2				1,1
McClelland Lake	1	lake	MCL-1																								1				1												1,2				1,2				1,2				1,1
Shipyard Lake	1	lake	SHL-1																1				1				1				1				1				1				1,2				1,2				1,2				1,1
Historical Data																																																							
Historical Data Review																1	1	1	1					1	1	1	1																												
5-Year Summary Report																																																							
Summary Report																								1	1																														
Locations No Longer in Sample Design																																																							
Athabasca River																																																							
Near Fort Creek (east bank)	1	depositional	ATR-B-A1 to A3				1																																																
(west bank)	1	depositional	ATR-B-A4 to A6				1																																																
Near Donald Creek (east bank)	1	depositional	ATR-B-B1 to B3				1																																																
(west bank)	1	depositional	ATR-B-B4 to B6				1																																																
Suncor near-field monitoring	2	depositional	-																				2																																
MacKay River																																																							
200 m upstream of mouth	1	erosional	MAR-1								1																																												
500 m upstream of mouth	1	erosional	MAR-2								1																																												
1.2 km upstream of mouth	1	erosional	MAR-3								1																																												
Muskeg River																																																							
50 m upstream of mouth	1	erosional	MUR-1								1																																												
200 m upstream of mouth	1	erosional	MUR-2								1																																												
450 m upstream of mouth	1	erosional	MUR-3								1																																												
Steepbank River																																																							
50 m upstream of mouth	1	erosional	STR-1								1																																												
150 m upstream of mouth	1	erosional	STR-2								1																																												
300 m upstream of mouth	1	erosional	STR-3								1																																												

Type Legend:
1 = RAMP station
2 = Sampled outside of RAMP (data available to RAMP)

,1 = RAMP standard sediment quality variables (carbon, particle size, total hydrocarbons, metals, PAHs, alkylated PAHs)
,2 = RAMP standard sediment quality + sediment toxicity (*Chironomus tentans, Hyalella azteca*)

Test (downstream of focal projects)
Baseline (upstream of focal projects)
Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

[1] sampled outside of RAMP in 2001, became RAMP station in 2002
[2] sampled outside of RAMP in 1999, became RAMP station in 2000

Selection of Benthic Invertebrate Community Measurement Endpoints

For each sample, the following benthic invertebrate community measurement endpoints were based on Environment Canada's Environmental Effects Monitoring (EEM) guidelines developed for the metal mining and pulp and paper sectors (Environment Canada 2005) and calculated:

- Abundance (total number of individuals/m^2);
- Taxon richness (number of distinct taxa);
- Simpson's Diversity Index (D), where

  $$D = 1 - \sum (p_i)^2$$

  and p_i is the proportion that taxon i contributes to the total number of invertebrates in a sample;
- Evenness, where

  $$\text{Evenness} = \frac{D}{D_{max}}$$

  $$D_{max} = 1 - \left(\frac{1}{S}\right)$$

  and S is the total number of taxa in the sample. In cases where S = 1 (i.e., only one taxon was identified in a sample), evenness was set to 1; and
- Percent EPT (Ephemeroptera, Plecoptera, Trichoptera).

The percent EPT presented in tabular format is the total number of individuals in these taxa from all ten samples taken from a reach, as a percentage of the total number of individuals taken from all ten samples at a reach. The percent EPT presented in graphical format against regional *baseline* conditions, is the average percentage across the ten sampled taken from a reach.

In addition to these core benthic invertebrate community endpoints the data were also ordinated using Correspondence Analysis (CA) to provide a multivariate assessment of spatial and temporal variations in composition (see Appendix E for a full description of the method). Separate ordinations were carried out for benthos from the Delta, lakes, erosional river reaches, and depositional river reaches, because these four classes of habitat can be anticipated to produce unique fauna, and on the basis of previous analyses that had demonstrated differences in composition among those four habitat types.

All benthic invertebrate community measurement endpoints were determined for each sample and then averaged for each reach or lake for the purpose of illustrating time trends. The measurement endpoints were computed for all RAMP data dating from 1998 onward to evaluate trends in these measures over time.

3.3.1.8 Detailed Data Analysis

Determination of Regional Baseline Conditions

Regional *baseline* conditions were defined as the normal range of variability for measurement endpoints across all *baseline* reaches/lakes. The normal range of variability for measurements endpoints was calculated as between the 5th percentile and 95th percentile of the measurement endpoint values. These calculations were made separately for each measurement endpoint and for each habitat type.

Baseline data have been identified for lake and river habitats. The normal range of variation was non-parametrically computed as the range of values that included the 5th and 95th percentiles for each of abundance, number of taxa, Simpson's diversity, evenness and percent EPT for lake, erosional river and depositional river habitats (Figure 3.3-2). The ordination axis scores were treated somewhat differently. The normal range of variation was depicted as an ellipse in a biplot of the first two CA axes with the normal range being defined parametrically as the region enclosing the 95% region, equivalent to a non-parametric estimate of the 95th percentile (Figure 3.3-3). The Delta was considered unique in the analysis because there are no true regional *baseline* reaches that provide a truly adequate comparison. In this report, the *baseline* condition for the Delta habitat was considered to be all of the previous data from 1998 to 2008. This approach to estimating *baseline* conditions is roughly equivalent to control charting techniques that are designed to determine when processes are "out of control" (Shewart, 1931).

Figure 3.3-2 Example of a comparison of benthic invertebrate community data against regional *baseline* data, in this case, for erosional reaches in the RAMP FSA.

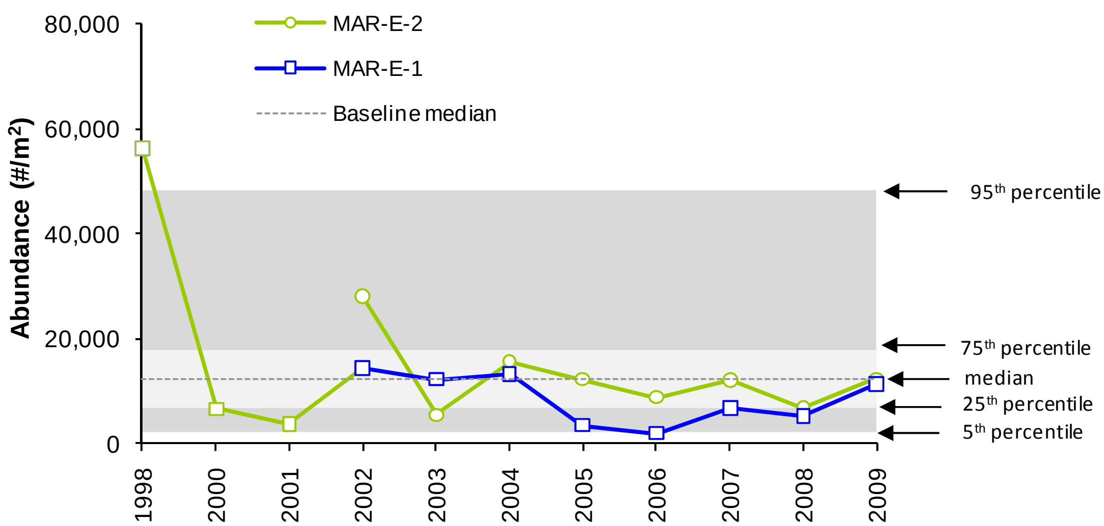
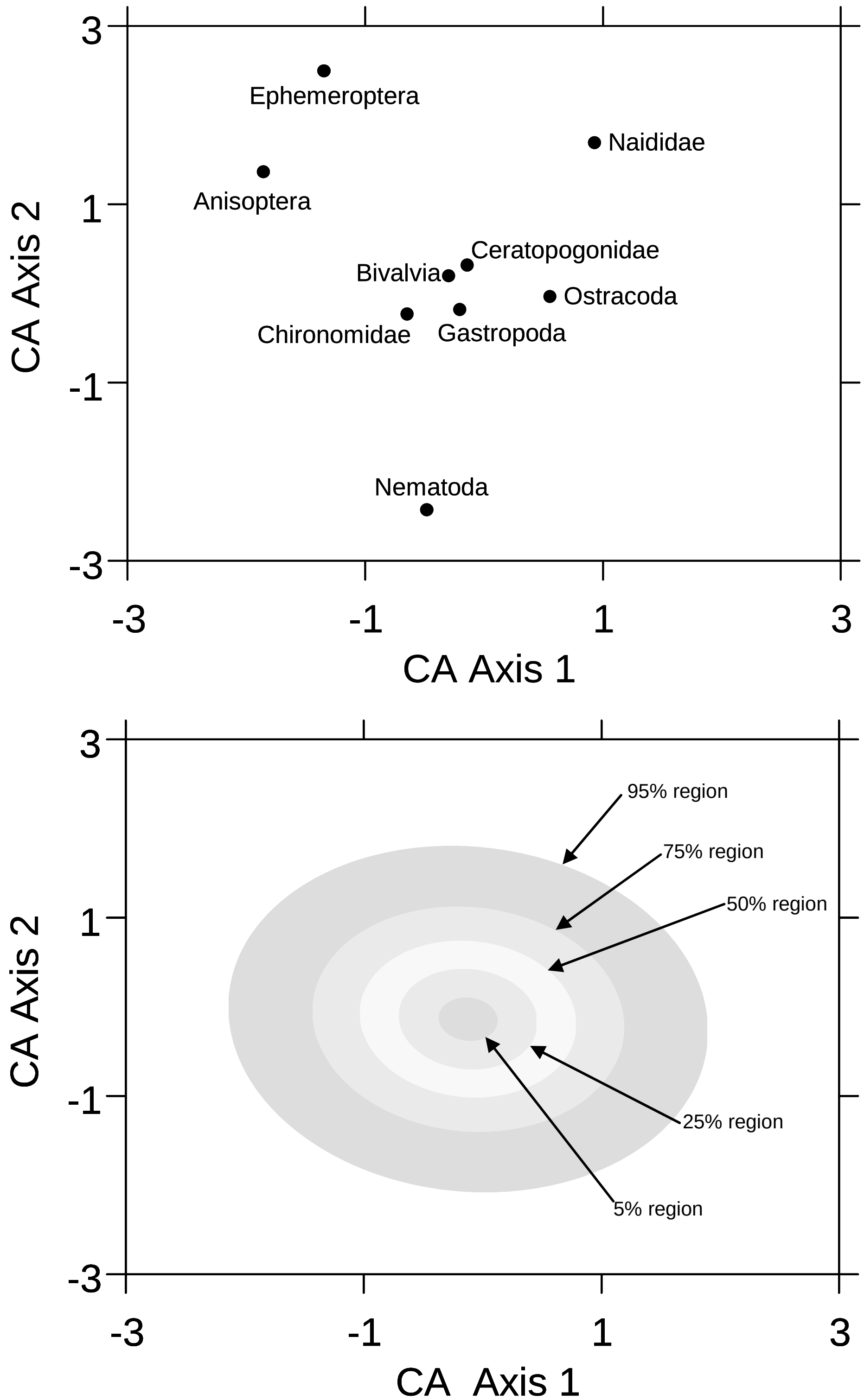


Figure 3.3-3 Example of a biplot of benthic invertebrate community CA Axis scores against the range of *baseline* conditions, in this case, for benthic invertebrate community data from the Athabasca River Delta.



Evaluating Potential Changes in Benthic Invertebrate Communities

Possible changes in benthic invertebrate communities were evaluated by comparing benthic invertebrate community measurement endpoints in reaches designated as *test* to upstream *baseline* reaches and/or to pre-development conditions with analysis of variance (ANOVA). When necessary, the measurement endpoints were $\log_{10}$-transformed to meet assumptions of normality and homogeneity of variances. One-way ANOVAs were conducted for each benthic invertebrate community measurement endpoint with each reach-year (or lake-year, as appropriate) combination as the factorial variable. Planned linear orthogonal contrasts (Hoke *et al*. 1990) were then used to identify differences between *baseline* and *test* reaches (or lakes), between *baseline* and *test* periods, and differences in time trends between lower *test* reaches and upper *baseline* reaches (or lakes, as appropriate). In all cases, the comparisons were tested against the residual error of the overall one-way ANOVA.

Reaches designated as *test* and reaches designated as *baseline* within a watercourse were not always the same habitat type (e.g., Muskeg River, reach MUR-E-1 and reach MUR-D-3). In these cases it was expected that trends over time should be the same in both reaches unless focal projects were influencing the lower reach differently than the upstream reach.

The statistical power associated with these various hypothesis testing procedures is high with an error-degrees-of-freedom that is frequently > 100. The ability to detect differences is quite substantive, with the detectable effect sizes much less than the within-reach-standard deviation (i.e., small differences, Cohen 1988, Kilgour *et al.* 1998). Statistically significant differences; therefore, may be minor, subtle, or otherwise trivial. The nature of statistically significant differences was therefore examined to determine if the difference was consistent with a "negative" impact. A reduction in taxa richness, Simpson's Diversity, Evenness and %EPT would each be considered a negative change or difference. Abundance might increase or decrease with an impact. Excessively high abundances (i.e., on the order of 100's of thousands of organisms per m^2) would be considered a negative impact if the fauna was dominated by one or a few taxa (see Kilgour *et al*. 2005), and might be consistent with a nutrient enrichment effect (Lowell *et al*. 2003). In addition, non-effect-related variation was tested for significance. This was determined by testing the "remainder" variation, which is based on the remaining treatment sums of squares, left over after considering the specific effects-based contrasts. A significant "remainder" test indicates that there is a considerable amount of noise in the data and can put into question other contrasts that may be statistically significant, but that do not account for as much of the total variation (DFO and EC 1995).

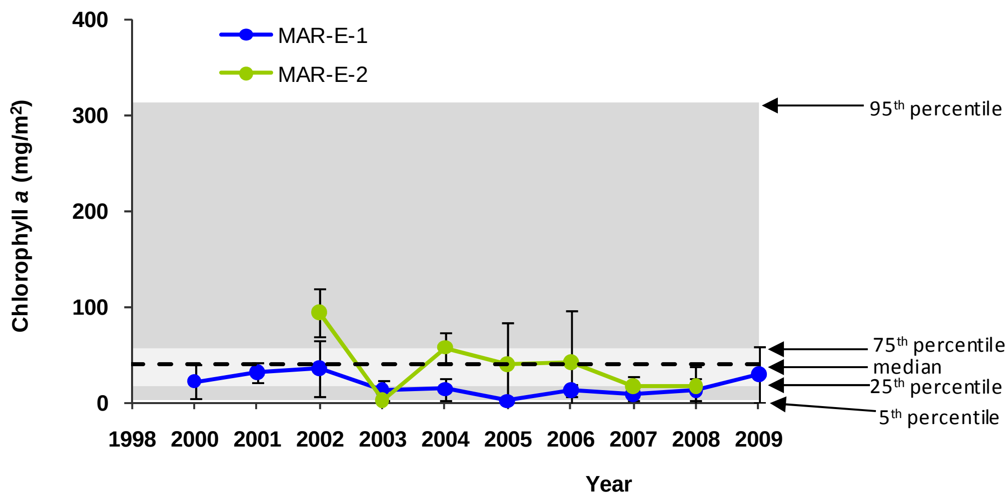
3.3.1.9 Environmental Variables

A number of environmental variables, including physical substrate condition and water temperature, chemistry, and flow velocities were measured at each station (Section 3.3.1.2). These environmental variables were measured because they influence the kinds of benthic invertebrate fauna found at a reach or in a lake. Where benthic invertebrate communities are shown to vary over time in a manner consistent with the development of focal projects, the variation may be attributed to changes in one or more of these environmental variables. An examination of these potential associations was made if the criteria for determination of change in benthic invertebrate communities were met.

In addition, some general conclusions about the condition of a reach (or lake) can be made using a number of the environmental variables:

- Dissolved oxygen is typically above concentrations considered critical for the protection of aquatic life (5.0 mg/L; AENV 1999b). Concentrations below this guideline are indicative of potential risks to aquatic life, especially if those concentrations are observed during the day, which is the typical time of sampling for RAMP; and
- Chlorophyll *a*, one of the environmental variables measured in erosional reaches, was identified early in the Alberta Oil Sands Environmental Research Program (AOSERP) studies as a potential indicator of oil sands activity (Barton and Lock 1979) (i.e., removal of cover over a watercourse through development would increase chlorophyll *a* concentrations). The limits of the normal range of chlorophyll *a* values from reaches designated as *baseline* was determined (Appendix E) and is provided in figures that illustrate trends over time in chlorophyll *a* values.

Figure 3.3-4 Example of periphyton chlorophyll *a* data against the range of regional *baseline* concentrations, in this case, for the MacKay River reaches.



3.3.1.10 Classification of Results

The criterion used for classifying results of benthic invertebrate communities was whether or not the benthic invertebrate community measurement endpoints at a given location (i.e., river reach or lake) that is designated as *test* exceed regional *baseline* conditions. The determination of regional *baseline* conditions is described below.

Measured changes were classified as Negligible-Low, Moderate and High on the basis of the strength of the statistical signal from a reach/lake, and whether values produced by the reach (lake) tend to fall within or outside the normal range of variation for reaches/lakes in a *baseline* condition (Table 3.3-3). Strong statistical signals are considered here to be differences that are statistically significant ($p < 0.05$), and that are as strong as or stronger than the background "noise" in reach-year variations (see Section 3.3.1.8 for a discussion of how the "noise" is assessed). There are seven benthic community metrics assessed (abundance, species richness, Simpson's Diversity, evenness, %EPT, and the two axes from the CA ordination). If any one of those metrics produces a strong signal of an effect, then this criterion will be considered to have been met. Allowing any one of the seven measurement endpoints to trigger this criterion assumes that each measurement endpoint represents an attribute of the community that is important. The second criterion will be considered to be met (producing a "yes" in Table 3.3-3) if any measurement endpoint has fallen outside of the normal range of variation of *baseline* conditions for three years in a row. The criterion will also be considered to be met when values for three of the seven measurement endpoints fall outside the normal range of variation within the current year. This is particularly relevant for the assessment of waterbodies (reaches or lakes) for which there is not at least a three-year data record. For watercourses where the upstream and downstream reaches are different habitat types (i.e., depositional versus erosional), only the second criterion for classifying results was used.

Table 3.3-3 Classification of results for Benthic Invertebrate Community component.

Criterion	Classification			"Yes"
	Negligible-Low	Moderate	High	
Statistical significance	No	Yes	Yes	Strong statistical signal on any one of seven measurement endpoints, with difference from reach-specific *baseline* reach implying a decrease in quality of benthic invertebrate community.
Exceed normal range of variation	No	No	Yes	Any three of seven measurement endpoints with values outside normal range in current year, or any one measurement endpoint with a value outside normal range for three successive years including the current year.

3.3.2 Sediment Quality

3.3.2.1 Overview of 2009 Program

Sediment samples were collected from September 9 to 20, 2009 at the most downstream replicate sampling location in each depositional reach sampled for benthic invertebrate communities (total of 14 depositional reaches), one station in the Athabasca River that was not sampled for benthic invertebrates, and four regionally-important lakes (Table 3.3-4, Figure 3.3-1).

3.3.2.2 Summary of Field Methods and Sample Shipping and Analysis

Sediment sampling locations were identified from historical GPS coordinates and, when available, station descriptions recorded for benthic invertebrate community sampling locations. Stations were accessed by helicopter, jet boat, all-terrain vehicle or four-wheel drive vehicle.

At each station, sediment 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 collected 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 cleaned with a metal-free soap (i.e., Liquinox), rinsed with hexane and acetone, and triple-rinsed with ambient water at each station prior to sampling.

Table 3.3-4 Summary of sampling for the RAMP Sediment Quality component, September 2009.

Station Identifier and Location		UTM Coordinates (NAD83, Zone12)		Analytical Package
		Easting	Northing	
Athabasca River				
ATR-ER	Athabasca River at Embarras River	468117	6471259	3
Athabasca Delta				
FLC-1	Fletcher Channel	496379	6491663	3
GIC-1	Goose Island Channel	509600	6494185	3
BPC-1	Big Point Channel	512092	6494124	3
Tributaries to the Athabasca River (Western)				
BER-D-2	Beaver River (upper reach)	465475	6311289	3
CAR-D-1	Calumet River (lower reach)	460698	6363156	
CAR-D-2	Calumet River (upper reach)	453995	6366522	3
TAR-D-1	Tar River (lower reach)	458573	6353573	3
POC-D-1	Poplar Creek	473047	6308837	1
Tributaries to the Athabasca River (Southern)				
CHR-D-1	Christina River (lower reach)	496481	6280190	3
CHR-D-2	Christina River (upper reach)	571666	6192362	3
Muskeg River				
MUR-D-2	Muskeg River (middle reach)	466295	6339500	1
MUR-D-3	Muskeg River (upper reach)	480075	6357945	1
JAC-D-1	Jackpine Creek (lower reach)	471862	6346430	3
JAC-D-2	Jackpine Creek (upper reach)	480086	6324999	3
Regional Lakes				
KEL-1	Kearl Lake	485417	6349805	1
MCL-1	McClelland Lake	478204	6371304	1
SHL-1	Shipyard Lake	473552	6313264	1
ISL-1	Isadore's Lake	463571	6343843	1
QA/QC				
-	Two sets of split and duplicate samples			1
-	One rinsate blank			Metals, PAHs

Legend to Analytical Packages:

1. RAMP standard variables (carbon, particle size, total hydrocarbons, metals, PAHs, alkylated PAHs)
3. RAMP standard variables + toxicity (*Chironomus tentans, Hyalella azteca*)

Homogenized samples were transferred into labeled, sterilized glass jars for chemical analyses, sealable plastic bags for particle size and TOC analyses, and to a sealable plastic bucket for chronic toxicity testing. All samples were stored on ice or refrigerated prior to and during shipment to analytical laboratories.

All chemical and physical (e.g., particle size, TOC) analyses were conducted by ALS (Edmonton, Alberta) except PAHs, which were analyzed by AXYS Analytical Services Ltd. (Sidney, British Columbia). Evaluation of sediment toxicity was undertaken by HydroQual Laboratories Ltd. (Calgary, Alberta).

Sediments were analyzed for the RAMP standard sediment quality variables (Table 3.3-5), with sediment toxicity to aquatic organisms test at a selection of stations sampled. Sediment toxicity tests are conducted every three years at each station and annually for the stations in Athabasca River Delta.

3.3.3 Changes in Monitoring Network from 2008

Given the three-year sampling rotation, stations CHR-D-1 (lower reach on Christina River), CHR-D-2 (upper reach on Christina River), TAR-D-1 (lower reach on Tar River), CAR-D-1 (lower reach on Calumet River), CAR-D-2 (upper reach on Calumet River) were sampled in 2009 and not in 2008 and stations FOC-D-1 (lower reach on Fort Creek), CLR-D-1 (lower reach on Clearwater River) and CLR-D-2 (upper reach on Clearwater River) were not sampled in 2009.

3.3.4 Challenges Encountered and Solutions Applied

At station MCL-1, McClelland Lake, it was difficult to collect sediment replicates at all ten benthic invertebrate community sampling replicates due to dense vegetation. Therefore, for the analyses, particle size fractions and TOC concentrations were averaged from the available replicates taken (4 replicates for particle size and 9 replicates for TOC concentrations).

3.3.5 Other Information Obtained

No additional sediment quality information for 2009 was obtained.

3.3.6 Summary of Component Data Now Available

Table 3.3-6 summarizes historical sediment quality sampling undertaken by RAMP since 1997.

3.3.7 Analytical Approach

The analytical approach undertaken for the sediment quality component in 2009 was similar to that of recent previous years, and consisted of:

- review and selection of particular sediment quality variables as sediment quality measurement endpoints, including predicted toxicity of sediments due to PAHs (calculated using an equilibrium-partitioning model);
- tabular presentation of 2009 results, comparing 2009 concentrations of the sediment quality measurement endpoints to concentrations previously observed within the reach, where data were available, and sediment quality guidelines; and
- analysis of the relationship between various sediment quality measurement endpoints and benthic invertebrate community measurement endpoints, using correlation analysis.

Table 3.3-5 RAMP standard sediment quality variables.

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	CCME 4-fraction total hydrocarbons:	
	- BTEX (Benzene, Toluene, Ethylene, Xylene)	
	- F1 (C6-C10)	
	- F2 (C10-C16)	
	- F3 (C16-C34)	
	- F4 (C34-C50)	
	- Total hydrocarbons (C6-C50)	
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
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]	
Sublethal toxicity testing	Survival and growth of the amphipod *Hyalella azteca*	
	Survival and growth of *Chironomus tentans* midge larvae	

[1] Any summations of total PAHs did not include retene, as it is also accounted for in total C4-substituted phenanthrene/anthracene.

Table 3.3-6 Summary of RAMP data available for the Sediment Quality component.

See symbol key below.

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																				
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				3				3								1				3				1				3				1																				
(east bank)[a]	ATR-DC-E				3				3								1				3				1				3				1																				
Upstream of Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1																				
(east bank)	ATR-SR-E																1				3				1				3				1																				
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								3								1				3				1				3				1																				
(east bank)[a b]	ATR-MR-E								3								1				3				1				3				1																				
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				3				3								1				3				1				3																								
(east bank)[a b]	ATR-FC-E				3				3								1				3				1				3																								
Testing inter-site variability (3 composite samples)	-																1								1																												
Downstream of all development (west bank)	ATR-DD-W																								1				3				1																				
(east bank)	ATR-DD-E																								1				3				1																				
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1																				
(east bank)	ATR-FR-E																								1				3				1																				
Upstream of the Embarras River	ATR-ER																3				1				1				3				1				1								1				3				3
Athabasca Delta / Lake Athabasca																																																					
Delta composite[c]	ARD-1												3				3																																				
Big Point Channel	BPC												3				3				3				3				3								1								1				3				3
Goose Island Channel	GIC																				3				3				3								1								1				3				3
Fletcher Channel	FLC																				3				3				3								1								1				3				3
Flour Bay	FLB-1																3																																				
Athabasca River Tributaries (South of Fort McMurray)																																																					
Clearwater River (upstream of Fort McMurray)	CLR-1/CLR-D-1																				1				3				3																				3				
(upstream of Christina River)	CLR-2																				1				3				3																				3				
Christina River (upstream of Fort McMurray)	CHR-1																								1				3				3																				
(upstream of Janvier)	CHR-2																								1				3				3																				
(benthic reach at mouth)	CHR-D-1																																								3				1								3
benthic reach at upper Christina River)	CHR-D-2																																								3												3
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																3				3																
Athabasca River Tributaries (North of Fort McMurray)																																																					
McLean Creek (mouth)	MCC-1												3				3				1				3												3																
Beaver River	BER-D-2																																																3				3
Poplar Creek (mouth)	POC-1/POC-D-1				1																				3								3																3				3
Steepbank River (mouth)	STR-1				1				1																3												3																
(upstream of Suncor Project Millennium)	STR-2				1																				3												3																
(upstream of North Steepbank)	STR-3																																				3																
North Steepbank River (upstream of Suncor Lewis)	NSR-1																								3				3				1				1																
MacKay River (mouth)	MAR-1				1				1												3				3								3																				
(upstream of Suncor MacKay)	MAR-2																				1				3								3																				

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 sediment quality + toxicity testing

√ = allowance made for potential TIE

* Sediment program integrated with Benthic Invertebrate Community component in 2006.

Footnotes

[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the ARD 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

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

Table 3.3-6 (Cont'd.)

See symbol key below.

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 Tributaries (North of Fort McMurray) (cont'd)																																																					
Ells River (mouth)	ELR-1								1																3				3				3				1																
(benthic reach at mouth)	ELR-D-1																																								3				3								
(upstream of CNRL Lease 7)	ELR-2																																3				1																
Tar River (mouth)	TAR-1								1																3				3				1				1																
(benthic reach at mouth)	TAR-D-1																																								3												3
(upstream of Canadian Natural Horizon)	TAR-2																																1				1																
Calumet River (mouth)	CAR-1																								3								3				3																
(benthic reach at mouth)	CAR-D-1																																								3												3
(upstream of Canadian Natural)	CAR-2																																				3																
(benthic reach at upper Calumet)	CAR-D-2																																								3												3
Fort Creek (mouth)	FOC-1																1								3																												
(benthic reach at mouth)	FOC-D-1																																				3				3				3				3				
Firebag River (mouth)	FIR-1																								3				3				1				1																
(benthic reach at mouth)	FIR-D-1																																								3				1								
(upstream of Suncor Firebag)	FIR-2																								3				3				1				1																
Muskeg River																																																					
Mouth	MUR-1				1				1				3				1				1				3				3				3																				
1 km upstream of mouth	MUR-1b																1												1																								
Upstream of Canterra Road Crossing	MUR-2																1												3				3				3																
Upstream of Jackpine Creek	MUR-4				1												1												1																								
Upstream of Muskeg Creek	MUR-5																1												1																								
Upstream of Stanley Creek	MUR-D-2																												3				3				3																
Upstream of Wapasu Creek	MUR-6																1												1																								
(benthic reach - downstream of Jackpine Creek)	MUR-D-2																																								3				3				3				1
(benthic reach - upstream of Stanley Creek)	MUR-D-3																																								3				3				3				1
Muskeg River Tributaries																																																					
Jackpine Creek (mouth)	JAC-1				1																												3																				
(benthic reach at mouth)	JAC-D-1																																								3				1				3				3
(benthic reach at upper Jackpine Creek)	JAC-D-2																																								3				1				3				3
Stanley Creek (mouth)	STC-1																												1																								
Wetlands																																																					
Kearl Lake (composite)	KEL-1																				1												1								3				3				3				1
Isadore's Lake (composite)	ISL-1																				1																				3				3				3				1
Shipyard Lake (composite)	SHL-1																				1				3				1				3								3				3				3				1
McClelland Lake (composite)	MCL-1																								1				1												3				3				3				1
Additional Sampling (Non-Core Programs)																																																					
Potential TIE	-																				√																																
QA/QC																																																						
One split and one duplicate sample	-																1				1				1				1				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 sediment quality + toxicity testing

√ = allowance made for potential TIE

* Sediment program integrated with Benthic Invertebrate Community component in 2006.

Footnotes

[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the ARD 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

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Baseline (excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities)

3.3.7.1 Selection of Sediment Quality Measurement Endpoints

The selection of sediment quality measurement endpoints was guided by:

- sediment quality measurement endpoints listed in the environmental impact assessments of oil sands projects as being potentially affected by oil sands development activities (RAMP 2009b);
- sediment quality variables of interest listed in the RAMP 5-year report (Golder 2003a);
- results of correlation analysis of the RAMP 1997-2004 sediment quality dataset indicating significant inter-correlation of various sediment quality variables; and
- discussions within the RAMP Technical Program Committee about:
  - the importance of various sediment quality variables to interpreting the results of the Benthic Invertebrate Community component; and
  - approaches and appropriate analytical strategies for the Sediment Quality component.

Table 3.3-7 Potential sediment quality measurement endpoints.

Variable Group	EIA Review: Variables Listed in EIAs	RAMP 5-Year Report (Golder 2003a)	Variables to Support Other RAMP Components[1]	Additional Suggested Variables[2]
Physical Variables	(None)	(None)	Particle size distribution	-
Carbon Content	(None)	(None)	Total organic carbon	Total inorganic carbon Total organic carbon
Total Hydrocarbons	(None)	Total recoverable hydrocarbons	CCME F1, F2	CCME F1 to F4 +BTEX
Metals	(None)	Total metals	Total metals	Total arsenic and metals that exceed sediment quality guidelines
PAHs	General PAHs	Naphthalene C1-Naphthalene	Total PAHs LMW PAHs (parent+alkylated)	LMW PAHs HMW PAHs Naphthalene Dibenzothiophenes Retene
Effects-Based Endpoints	Sublethal toxicity	-	Sublethal toxicity	-

1 Primarily Benthic Invertebrate Communities component (inferred).

2 Suggested by the RAMP Technical Program Committee and from ongoing review of stakeholder concerns.

The final sediment quality measurement endpoints selected for use are the following:

- *Particle size distribution (clay, silt and sand)*: sediment particle size is an indicator of depositional regime at a given station, and an important factor affecting organic chemical sorption;
- *Total organic carbon*: an indicator of organic matter in sediment, including hydrocarbons;

- *Total hydrocarbons (CCME fractions)*: Indicators of the total hydrocarbon content of sediments, with each indicator (fraction) capturing hydrocarbon compounds of different molecular weights (specifically, number of carbon atoms), based on methods presented by CCME (2001);
- *Various PAH measurement endpoints,* including*:*
  - *Total PAHs:* a sum of concentrations of all PAHs measured in a given sample, including parent and alkylated forms;
  - *Total parent PAHs:* a sum of concentrations of all non-alkylated PAHs measured in a given sample;
  - *Total alkylated PAHs:* a sum of concentrations of all alkylated PAHs measured in a given sample;
  - *Naphthalene:* a volatile, low-molecular-weight PAH that may cause toxicity when dissolved in water;
  - *Total dibenzothiophenes:* a sulphonated PAH (parent and alkylated forms) that is associated with bitumen (i.e., petrogenic);
  - *Retene:* an alkylated phenanthrene generated through decomposition of plant materials (i.e., biogenic rather than petrogenic); and
  - *Predicted PAH toxicity:* an estimate of the cumulative toxicity of all PAHs in a sediment sample (the methodology for calculating predicted PAH toxicity is presented in Appendix F);
- *Metals:* With the exception of total arsenic (see below), only metals in sediment that exceeded CCME Interim Sediment Quality Guideline (ISQG) values (CCME 2002) were presented, as metals in sediments are not listed in oil sands EIAs as being potentially affected by development (RAMP 2009b);
- *Total arsenic:* In analyses of sediment quality in the ARD (Section 5.1) and in regional analyses of sediment quality in tributaries (Section 6), data for total arsenic in sediments are presented, given recent stakeholder concerns regarding arsenic in regional sediments; and
- *Sublethal toxicity:* sublethal toxic effects of whole sediment samples on the survival and growth of the amphipod (seed-shrimp) *Hyalella azteca* (14-day test) and the midge *Chironomus tentans* (10-day test).

3.3.7.2 Tabular Presentation of 2009 Sediment Quality Results

2009 sediment quality data for each sediment quality measurement endpoint were tabulated for each station sampled. Historical variability also was presented for each measurement endpoint, represented by minimum, maximum and median values observed (as well as number of observations) from 1997 to 2009. Concentrations of any sediment quality measurement endpoint and any metal that exceeded relevant guidelines were also reported.

3.3.7.3 Correlation with Benthic Invertebrate Community Measurement Endpoints

Spearman's rank correlations were used to evaluate the relationships among benthic invertebrate community measurement endpoints and selected sediment quality measurement endpoints. Correlations were calculated for all depositional stations, sampled at the lowest (most downstream) end of the reach. Correlations greater than r_s of |0.232| were indicative of statistically-significant relationships for n=72 (number of depositional stations) (α=0.05, two-tailed test). Moderate correlations were defined as those ranging from |0.50| to |0.75|, while strong correlations were defined as those ranging from |0.75| to |1.00|.

3.3.7.4 Classification of Results

Sediment quality in each depositional benthic-invertebrate sampling reach in fall 2009 was summarized using the CCME Sediment Quality Index calculator, (http://www.ccme.ca/ourwork/water.html?category_id=103). This index uses an identical calculation to that developed by CCME for water quality (see Section 3.2.8.4), also yielding a single index value ranging from 0 to 100.

Like the CCME Water Quality Index, the sediment-quality index is calculated using comparisons of observed sediment quality against benchmark values, such as guidelines or background concentrations. It considers three factors: (i) the percentage of variables with values that exceed a given benchmark; (ii) the percentage of comparisons that exceed a given benchmark; and (iii) the degree to which observed values exceed benchmark values. Further details describing this calculation may be found at the CCME website listed above.

Index calculations for RAMP sediment quality data used regional *baseline* conditions, calculated and described in Section 3.2.8.4, as benchmarks for comparison. Specifically, 5^{th} or 95^{th} percentiles of *baseline* values for all variables included in the index were used as benchmarks against which individual sediment quality observations were compared. All sediment quality data collected by RAMP since 1997 at stations classified as *baseline* was used to develop *baseline* ranges of sediment quality.

Seventy-eight sediment-quality variables were included in calculation of the index, including total and fractional hydrocarbons, all parent and alkylated PAH species, all metals measured consistently in sediments by RAMP since 1997, and sediment-toxicity endpoints. For hydrocarbons and metals, data were compared against the 95^{th} percentile of *baseline* data, while for sediment-toxicity endpoints, data were compared against the 5^{th} percentile. Index values were calculated for all *baseline* and *test* stations. For all sediment-quality station observations from 1997 to 2009 (n=262), sediment quality index values of 81.5 to 97.7 were calculated.

Sediment-quality-index scores were classified using the following scheme:

- 80 to 100: Negligible-Low difference from regional *baseline* conditions;
- 60 to 80: Moderate difference from regional *baseline* conditions; and
- Below 60: High difference from regional *baseline* conditions.

3.4 FISH POPULATION COMPONENT

3.4.1 Overview of 2009 Monitoring Activities

The following monitoring activities were conducted in 2009 for the Fish Population component:

- Full-span fish fence program on the Muskeg River (spring);
- Spring, summer, and fall fish inventories on the Athabasca and Clearwater rivers;
- Tissue analyses and health evaluations on northern pike in the Clearwater River (fall sampling);
- Sentinel species program using non-lethal sampling methods on the following Athabasca tributaries: Steepbank, Horse, Dunkirk and Muskeg rivers (summer and fall sampling); and
- Tissue analyses on target fish species in an unnamed regional lake, but locally known as "Jackson" Lake (fall sampling).

Table 3.4-1 summarizes the watercourses sampled and the target fish species for each monitoring activity; sampling locations are presented in Figure 3.4-1. Common and scientific names for each fish species noted in this report are listed in Appendix G.

Table 3.4-1 Summary of 2009 Fish Population component monitoring activities.

Watercourse	Fish Population Component Activity			
	Fish Fence	Fish Inventory	Fish Tissue	Sentinel Species
Athabasca River		spring, summer and fall, fish community		
Clearwater River		spring, summer and fall, fish community	fall, northern pike	
Muskeg River	spring, fish community			
Muskeg, Steepbank, Horse and Dunkirk rivers				summer and fall, slimy sculpin
"Jackson" Lake			fall, lake whitefish, walleye and northern pike	

3.4.2 Summary of Field Methods

3.4.2.1 Muskeg River Fish Fence

The objectives of the 2009 Muskeg River fish fence were to:

- generate ongoing data on the biology and movement of large-bodied fish species that use the Muskeg River watershed;
- use these data to assist in identifying and quantifying local and watershed-level environmental effects in the Muskeg River watershed; and
- document the current use of the Muskeg River by spawning fish populations from the Athabasca River.

Fish Fence Location and Construction

The location of the Muskeg River fish fence was selected on the basis of 2002 fish fence reconnaissance studies (Golder 2003b) and the location of the 2003 and 2006 fish fence deployments (RAMP 2004, RAMP 2007). The selected location represents optimal hydraulic conditions, acceptable cross-sectional depth profile and substrate features, and good access and safety characteristics. The site is located on the Muskeg River mainstem approximately 800 m upstream from its confluence with the Athabasca River (464049 E, 6332081 N, Zone 12, NAD83).

Flow conditions in the Muskeg River during the 2009 sampling period were generally within the RAMP protocol for fence deployment at the end of April into the beginning of May (i.e., < 9 m^3/s, RAMP [2009b]).

In order to capture the largest portion of the spring spawning runs of large-bodied fish (i.e., northern pike, longnose sucker, white sucker), 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 9 m^3/s. Field crews monitored ice conditions in the lower Muskeg River daily in April 2009 to assist in determining the earliest date for fence installation. Fish fence components and other equipment were transported by helicopter to the site on April 23, 2009, and installation of the fence began on April 30, 2009. Installation was completed by May 3, 2009, and the fish fence was operational from May 4 to June 1, 2009 for a total of 29 days.

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 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 (Figure 3.4-2). Channels were supported by brackets attached to 2.1 m high x 5 cm diameter aluminum poles and "two by four" wooden A-frames, held in place by rock and 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 wooden "two-by-fours", were located on opposite sides of the river, and connected by a single centre wing. 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 3.4-1 Locations of RAMP fish monitoring activities for the 2009 Fish Population component.

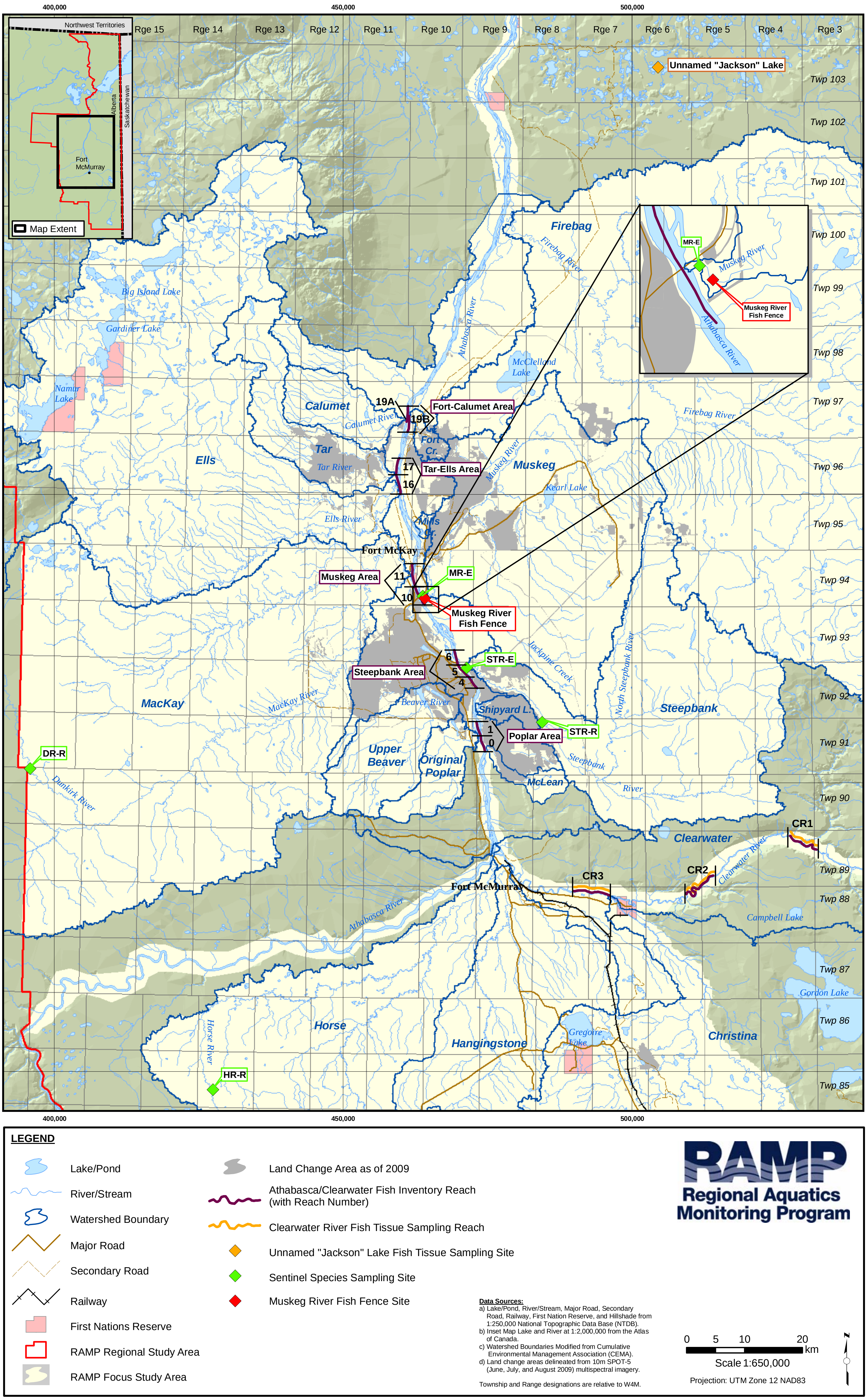


Figure 3.4-2 View of full-span Muskeg River Fish Fence, spring 2009.

Fish Sampling and Handling

A two-person crew monitored the fish fence daily. The two trap boxes were checked periodically throughout the day between 0700 and 1900. Floy tags with a unique identification number (specific to the RAMP Fish Population Component) were inserted into the posterior end of the dorsal fin of captured northern pike and walleye. The Floy tag number was recorded for all captured fish that were already tagged.

All fish were released unharmed in the direction they were moving when captured.

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); and fish weight (± 10.0 g using an electronic hanging scale) were recorded from all fish recovered from the trap boxes. These data were recorded on field data sheets and later transferred to an electronic database for analysis.

An external assessment was conducted to evaluate the general health of each fish. The examination was conducted using a coding system, modified from the inventory-specific coding system (Appendix G), with values associated to the severity of the external pathology (one to four with one being normal), if applicable. External assessments were conducted on the following structures: body (form and surface); opercles; fins; gills; pseudobranchs; and eyes.

A mean external pathology score was then calculated for each species by summing the values for all individuals of each species and dividing by the total number of fish captured per species.

Age Determination

Appropriate non-lethal ageing structures (fin rays and scales) were collected from the first fifty individuals captured each day for longnose and white sucker and for all sportfish using the protocols in MacKay *et al.* (1990). The ageing structures were placed in scale envelopes and dried for age determination.

North/South Consultants Inc. of Winnipeg analyzed all ageing structures. All collected ageing structures for species other than white sucker were submitted for analysis. However, due to the large number of captured white sucker, a weighted sub-sample (n=282) of collected ageing structures was submitted for analysis based on the species-specific length frequency distribution. Furthermore, to ensure that the selected ageing structures would not be biased to any one period of the spawning run, ageing structures for a given length class were randomly selected from the pool of all ageing structures of the given length class collected over the entire period of operation of the fish fence.

Water Quality Measurements

Daily i*n situ* water quality measurements were taken throughout operation of the Muskeg River fish fence at a location immediately upstream of the fish fence. Temperature, specific conductance, pH and dissolved oxygen were recorded using a hand-held probe (LaMotte Tracer Pocketester) or LaMotte winkler titration kit. Other environmental variables, such as general weather conditions and air temperature, were also recorded on a daily basis. Water temperature was recorded between April 20, 2006 and June 3, 2009 using a HOBO® Water Temp Pro automatic data logger that was installed on the right downstream bank of the river approximately 20 m upstream of the fish fence. Average readings were generated every fifteen minutes and results were recorded in degrees Celsius (± 0.2°C).

3.4.2.2 Athabasca River and Clearwater River Fish Inventories

The objectives of the 2009 Athabasca River and Clearwater River inventories were to:

- document information about fish populations (both resident and seasonal); and
- respond to concerns and needs of the various stakeholders and local communities using the fish resources.

In 2009, spring, summer and fall inventories of the fish community focusing on the following RAMP key indicator fish species (analogous to Key Indicator Resources, KIRs) were conducted on the Athabasca and Clearwater rivers:

- Walleye (*Sander vitreus*);
- Northern pike (*Esox lucius*);
- Longnose sucker (*Catostomus catostomus*);
- White sucker (*Catostomus commersoni*);
- Lake whitefish (*Coregonus clupeaformis*);
- Goldeye (*Hiodon alosoides*); and
- Trout-perch (*Percopis omiscomaycus*).

Spring, summer, and fall sampling was conducted between May 12 and June 2, 2009, July 22 and August 6, 2009, and September 21 and October 6, 2009, respectively. Seven days of sampling on the Athabasca River and two days of sampling on the Clearwater River were conducted in each of the three seasons.

Sampling on the Athabasca River was implemented within ten reaches specifically established for the RAMP fish inventory, all of which have been sampled annually since 1997, and a number of which have been sampled annually since 1989 by Syncrude Canada Ltd. (Figure 3.4-1, Table 3.4-2). These ten reaches fall within key areas of the river within the RAMP FSA:

- Poplar Area (Reaches 0 and 1);
- Steepbank Area (Reaches 4, 5, and 6);
- Muskeg Area (Reaches 10 and 11);
- Tar-Ells Area (Reaches 16 and 17); and
- Fort-Calumet Area (Reach 19).

Sampling in the Clearwater River was conducted at three reaches (CR1, CR2, and CR3) of the river (Figure 3.4-1, Table 3.4-2). Northern pike captured during the fall survey in all three reaches on the Clearwater River were also used to support fish tissue monitoring studies (Section 3.4.2.3).

Sampling was primarily conducted on both rivers safely in areas conducive to electrofishing, primarily in shallow river margins deep enough to be accessible by boat.

Fish were sampled using a Smith-Root model SR-18 electrofishing boat equipped with a 5.0 GPP electrofishing unit, configured with two anode boom arrays and multiple dropper cables. Stunned fish were captured with dip nets and held in an on-board flow-through live well. Fish observed but not captured were enumerated by species.

Captured fish were measured for fork length (±1 mm) and weight (±1 g), and sex and state of maturity were recorded when discernible by external examination. An external assessment was conducted to evaluate the general health (e.g., presence of disease, incidence of parasites, physical abnormalities, etc.) of each fish. The examination was conducted using an inventory-specific coding system (Appendix G) that focused on the following structures: body (form and surface); lips and jaws; snout; barbels; anus; opercles; isthmus; fins; gills; pseudobranchs; thymus; eyes; and urogenital area.

In order to ensure consistency with external health assessments performed for the other Fish Population Component activities, the results were re-coded using the Health Assessment Index (HAI) scoring system developed by Adams *et al.* (1993) (Appendix G). Accordingly, the condition of each external structure was assigned an index code and an associated value representing degree of severity ranging from 0 to 30, where 0 indicated no signs of pathology. A mean HAI score by season was then calculated for each species by summing the index values for all individuals of each species and dividing by the total number of fish captured per species.

The HAI system ranks abnormalities with severe pathology with higher scores. Therefore, an external pathology assessment was completed by calculating the percentage of pathological abnormalities, including growths, tumors, and parasites from the total number of fish captured for each species by year.

Adults and larger juvenile walleye and northern pike were fixed with RAMP Floy tags prior to their live release. Floy tags were inscribed with a discrete identification number and a contact phone number to facilitate tracking in the event of a recapture during future inventories, and to encourage anglers to report them.

Table 3.4-2 Fish inventory sampling locations on the Athabasca and Clearwater rivers, 2009.

Area	Reach Number	Subreach Number	UTM Coordinates (NAD 83, Zone 12)	
			Upstream Boundary	Downstream Boundary
Athabasca River				
Poplar Area	00B		474646 E / 6305438 N	473932 E / 6308141 N
	01A		473480 E / 6307893 N	473103 E / 6310531 N
Steepbank Area	04A		472890 E / 6316361 N	471314 E / 6318285 N
	04B		471314 E / 6318285 N	469636 E / 6320525 N
	05A		469636 E / 6320525 N	468911 E / 6323011 N
	05B		473156 E / 6316650 N	471877 E / 6318562 N
	06A		471877 E / 6318562 N	470153 E / 6320420 N
Muskeg Area	10B		464172 E / 6330904 N	462582 E / 6334464 N
	11A		462220 E / 6333918 N	462025 E / 6337965 N
Tar-Ells Area	16A		459425 E / 6350065 N	458958 E / 6353380 N
	17A		458958 E / 6353380 N	459360 E / 6356213 N
Fort-Calumet Area	19A		461057 E / 6362604 N	460943 E / 6365216 N
	19B		461181 E / 6360892 N	461417 E / 6363621 N
Clearwater River	CR1	CR1A	531982 E / 6288505 N	529592 E / 6289549 N
		CR1B	529592 E / 6289549 N	527714 E / 6291560 N
Clearwater River	CR2	CR2A	514112 E / 6283950 N	512193 E / 6282517 N
		CR2B	512193 E / 6282517 N	510345 E / 6281510 N
		CR2C	510345 E / 6281510 N	509500 E / 6280700 N
Clearwater River	CR3	CR3A	496071 E / 6280509 N	493022 E / 6280960 N
		CR3B	493022 E / 6280960 N	489943 E / 6281368 N

3.4.2.3 Fish Tissue Studies

Clearwater River Tissue Study

The objectives of the fish tissue studies in RAMP are to assess the suitability of fisheries resources for human consumption and the health of the fish in waterbodies within in the oil sands region.

The 2009 fish tissue study on the Clearwater River targeted northern pike. Tissue samples were acquired from fish captured in all sampled reaches of the Clearwater River in October 2009 (Figure 3.4-1). Captured northern pike selected for tissue sampling were kept in river water and transported back to a protected facility to minimize contamination from precipitation, wind, and debris. Non-lethal and lethal sampling tissue sampling and analyses was conducted using the methods described below.

Non-Lethal Tissue Analysis for Mercury A target of 25 individuals was set for non-lethal mercury tissue analysis, with specific targets of five fish (irrespective of sex) in each of five size classes of 100 mm increments in fork length from 200 mm to 700 mm. These size classes were selected in order to:

- ensure adequate representation of typical size ranges for northern pike observed in the fall during past inventories on the river (RAMP 2004 to RAMP 2009a);
- ensure an even distribution of tissue samples across a wide range of fish sizes and ages; and
- ensure consistency with those size classes targeted in the fall during past tissue programs on the Clearwater river (RAMP 2005, 2007, 2008), and to allow comparisons with historical data.

Prior to tissue sampling, each fish was measured for fork length (± 1 mm) and total weight (± 1 g), and an external health assessment was conducted using the methods described in Section 3.4.2.2.

Muscle tissue was then sampled non-lethally from northern pike for mercury analysis using a clean, unused 4 mm dermal biopsy punch (Acuderm Inc.), a method that was first used in the Fish Population component in 2005 (RAMP 2006). A few scales were removed from the fish and the dermal punch was then positioned on the surface of the skin over the dorsal musculature. The punch was then pushed into the dorsal musculature, using pressure and a twisting motion moderate enough to penetrate the muscle, but not to penetrate through to the fish cavity. Upon extraction, the punch was rotated in a twisting motion using slight angular pressure in order to assist in obtaining the muscle plug sample. The tissue plug was then blown through the hollow punch into a sterile, pre-labeled, pre-weighed (± 0.001 g) 4 mL externally-threaded cryovial. The wet weight of the plug was then recorded (± 0.001 g) for the calculation of total mercury concentration, and was placed immediately on dry ice in a cooler. After extraction of the punch, the void left in the fish was filled with a waterproof "bandage" sealant (Nexaband S/C, Topical Tissue Adhesive, Formulated Cyanoacrylate) following methods described by Baker *et al*. (2004), in order to decrease the risk of infection. All sampling equipment was rinsed using metals-free soap and distilled water, hexane, then acetone, and re-rinsed with deionized water after each fish to avoid cross-contamination.

Following mercury tissue sampling, all individuals not designated for lethal dissections were released immediately into the calm margins of the river to limit additional handling and confinement stress. Tissue samples were transported in a cooler on dry ice and held in the Hatfield freezer (Fort McMurray) before being shipped on dry ice to Flett Research (Winnipeg) for mercury analysis.

Lethal Dissections and Tissue Analysis for Tainting Compounds and Metals A target of five fish (target male fork length: 450 mm to 500 mm; target female fork length: 500 mm to 550 mm) was set for dissection and comprehensive tissue sampling for tainting compounds (organics) and metals analysis. These sex/length combinations were set as targets in an attempt to minimize potential variability associated with size and age, and to allow for direct comparisons with data from previous tissue surveys conducted on northern pike (RAMP 2005, 2007, 2008).

The size-class distribution of fish captured for tissue analysis for metals and tainting compounds is provided in Table 3.4-3. Because of difficulties in capturing male northern pike within the targets size class, fish from the next size class were also included to ensure sufficient tissue for analyses.

Table 3.4-3 Sex/length combinations of northern pike captured for fish tissue analyses of metals and organics, Clearwater River 2009.

Species	Sex	Size Class	Number Captured
Northern pike	Male	450-500 mm (target)	3
		500-550 mm	2
	Female	500-550 mm (target)	4

Each captured fish was measured for fork length and weight, given an external health assessment (Section 3.4.2.2), and sampled for mercury analysis as described above. The fish were then sacrificed for dissections and comprehensive tissue sampling.

Each sacrificed fish was dissected and an internal assessment was conducted to evaluate general health (e.g., presence of disease, incidence of parasites, physical and other abnormalities) based on the following structures and characteristics: liver; kidney; spleen; hindgut; gall bladder; fat content; and the presence of parasites.

For each fish, the sex, stage of maturity, liver weight (± 0.01 g), gonad weight (± 0.01 g), and carcass weight (total weight minus the internal organs, ± 1 g) were recorded. Ageing structures (cleithra and two leading rays from the left pelvic fin) were then collected, dried, and stored in labeled coin envelopes to be sent to North/South Consultants Inc. (Winnipeg) for analysis.

Tissues were then removed from the musculature above the lateral line and posterior to the dorsal fin on the left side of each fish for analysis of tainting compounds, and from the right side of each fish for assessing metals (RAMP 2009b). Minimum muscle tissue requirements per fish were 20 g (50 to 100 g preferred) for tainting compounds analyses and 2 g (5 g preferred) for metals analyses. Skin and bone were removed from the muscle tissue. Samples collected for organics analysis were individually wrapped in solvent-rinsed aluminum foil, and samples collected for metals analysis were individually placed in clean, sealable plastic bags. All samples were labeled, and placed immediately on dry ice in a cooler for transportation to the Hatfield deep-freeze (Fort McMurray) where they were held prior to being shipped on ice to ALS Laboratory Group Edmonton (via the Fort McMurray ALS office) for chemical analysis.

Organics and metals analyses were performed on the composite samples of female and male target-sized fish in order to compare 2009 results with results from previous surveys. The composites were prepared at ALS by combining an equal weight of muscle tissue from each fish. Two sets of each composite were prepared for the following analyses:

- Metals: aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, uranium, vanadium, and zinc; and
- Tainting Compounds (PAHs): thiophene, toluene, M+P-xylenes, 1,3,5-trimethylbenzene, and naphthalene.

Methods and detection limits used for all chemical analyses, including tainting compounds, metals, and mercury are presented in Table 3.4-4. All remaining tissue samples were archived at the testing laboratory for additional analyses, if required.

Regional Lakes Tissue Studies

In 2009, tissue studies were performed on a sacrificed subsample of fish captured during Alberta Sustainable Resource Development's (ASRD's) fish population survey (lake whitefish, walleye and northern pike) in an unnamed lake known locally as "Jackson" Lake located in the Richardson backcountry north of Fort McMurray (Figure 3.4-1).

Sampling in the lake took place between September 14 and September 20, 2009 during the Fall Walleye Index Netting (FWIN) program conducted by ASRD. Targets of 25 walleye, 25 northern pike, and 25 lake whitefish were set for mercury tissue analysis, with specific targets of five fish (irrespective of sex) in each of five size classes of 100 mm increments in fork length from 200 mm to 700 mm. These five length classes were selected in order to ensure consistency with those size classes targeted in past tissue programs for these species on other regional lakes. These classes were originally selected based on typical size ranges observed for each species during past lake inventories, and were therefore considered to be representative of a wide range of fish sizes and ages within the population of each species. The distribution of fish captured from "Jackson" Lake for tissue analysis for mercury is provided in Table 3.4-5.

Fish tissues from the lake were analyzed for mercury, but were collected and sampled lethally using a modified protocol. Fish were collected by ASRD using experimental multi-mesh gill nets, sacrificed, measured on-site for fork length (± 1 mm) and total weight (± 1 g), and evaluated for sex and stage of maturity. The tail sections (between the last rib and end of the caudal peduncle) were then removed, placed on dry ice, and transported to Hatfield (Fort McMurray) where they were stored in a deep-freeze and sampled for mercury analysis. Ageing structures were taken from each individual of walleye and northern pike and analyzed by personnel at ASRD.

Skinless, boneless, interior muscle tissues were sampled from each fish peduncle for mercury analysis using clean, stainless steel dissection equipment. Tissues from each fish were collected individually in sterile, pre-labelled, pre-weighed (± 0.001 g) 4 mL externally-threaded cryovials. Tissue sample wet weights were recorded (± 0.001 g) for the calculation of total mercury concentration, and samples were held in the Hatfield deep-freeze (Vancouver) before being shipped on dry ice to Flett Research (Winnipeg, Manitoba) for mercury analysis. All sampling equipment was rinsed using metals-free soap and distilled water, hexane, then acetone, and re-rinsed with de-ionized water in between each fish to avoid cross contamination.

Methods and detection limits used by Flett for mercury analysis are presented in Table 3.4-4.

Table 3.4-4 Methods of analyses and detection limits for mercury, metals, and tainting compounds in Clearwater River fish tissues, 2009.

Variable	Detection Limit (mg/kg)	Method of Analysis
Metals		
Aluminum (Al)	2	EPA 200.3/200.8-ICPMS
Antimony (Sb)	0.01	EPA 200.3/200.8-ICPMS
Arsenic (As)	0.002	APHA 3114 C-AAS – Hydride
Barium (Ba)	0.02	EPA 200.3/200.8-ICPMS
Beryllium (Be)	0.05	EPA 200.3/200.8-ICPMS
Bismuth (Bi)	0.06	EPA 200.3/200.8-ICPMS
Cadmium (Cd)	0.1	EPA 200.3/200.8-ICPMS
Chromium (Cr)	0.1	EPA 200.3/200.8-ICPMS
Cobalt (Co)	0.1	EPA 200.3/200.8-ICPMS
Copper (Cu)	0.1	EPA 200.3/200.8-ICPMS
Iron (Fe)	1	EPA 200.3/200.7-ICPOES
Lead (Pb)	0.02	EPA 200.3/200.8-ICPMS
Lithium (Li)	0.1	EPA 200.3/200.8-ICPMS
Manganese (Mn)	0.05	EPA 200.3/200.7-ICPOES
Mercury (Hg)[1]	0.002	Cold Vapor Atomic Fluorescence Spectraphotometry (CVAFS)
Molybdenum (Mo)	0.01	EPA 200.3/200.8-ICPMS
Nickel (Ni)	0.1	EPA 200.3/200.8-ICPMS
Selenium (Se)	0.004	APHA 3114 C-Auto Continuous Hydride
Strontium (Sr)	0.05	EPA 200.3/200.8-ICPMS
Thallium (Tl)	0.01	EPA 200.3/200.8-ICPMS
Tin (Sn)	0.05	EPA 200.3/200.8-ICPMS
Titanium (Ti)	0.1	EPA 200.3/200.7-ICP-OES
Uranium (U)	0.002	EPA 200.3/200.8-ICPMS
Vanadium (V)	0.06	EPA 200.3/200.8-ICPMS
Zinc (Zn)	0.1	EPA 200.3/200.8-ICPMS
Tainting Compounds (PAHs)		
1,3,5-Trimethylbenzene	0.004	EPA 5021/8260-Headspace GC/MS
M+P-Xylenes	0.008	EPA 5021/8260-Headspace GC/MS
Naphthalene[2]	0.05	EPA 3540/8270-GC/MS
Thiophene	0.0004	EPA 5021/8260-Headspace GC/MS
Toluene	0.004	EPA 5021/8260-Headspace GC/MS

[1] Analyzed by Flett Research (all other variables analyzed by ALS).

[2] Naphthalene was analyzed for three target compounds, 1-Methylnaphthalene, 2,6-Dimethylnaphthalene, 2,3,5-Trimethylnaphthalene, all with the same detection limit and all using the same analytical method.

Table 3.4-5 Lengths of lake whitefish, walleye and northern pike captured for fish tissue analyses of mercury, "Jackson" Lake, 2009.

Species	Size Class (mm)				
	200-300	301-400	401-500	501-600	601-700
Lake whitefish	2	6	8	1	0
Walleye	3	6	6	5	2
Northern pike	0	1	0	0	0

3.4.2.4 Non-Lethal Tributary Sentinel Fish Species Monitoring

The objective of the sentinel species monitoring program in 2009 is to monitor potential changes in fish populations due to stressors resulting from focal project development by assessing growth, reproduction and survival. Sentinel species monitoring in 2009 was carried out at a total of five sites on tributaries of the Athabasca River (Table 3.4-6, Figure 3.4-1). Three of these sites, lower Steepbank River (site STR-E), lower Muskeg River (site MR-E), and the upper Steepbank River (site STR-R) are designated as *test,* while the remaining two sites, Horse River (site HR-R) and Dunkirk River (site DR-R), are designated as *baseline*. Slimy sculpin (*Cottus cognatus*) was the sentinel species for non-lethal tributary sentinel fish species monitoring, with a target of 100 individuals to be captured per site for each sample period.

Table 3.4-6 Tributary sentinel fish species monitoring sites, 2009.

Watershed	Site Code	Location Description	UTM Coordinates (NAD83, Zone 12)[1]
Steepbank River	STR-E	*Test* site approximately 0.3 to 1.0 km upstream of the confluence with the Athabasca River.	D/S: 471017 E / 6319955 N U/S: 471448 E / 6320230 N
	STR-R	*Test* site approximately 15 km upstream of the confluence with the Athabasca River.	D/S: 484400 E / 6310590 N U/S: 484393 E / 6310494 N
Muskeg River	MR-E	*Test* site approximately 0.2 to 0.6 km upstream of the confluence with the Athabasca River.	D/S: 463511 E / 6332462 N U/S: 463829 E / 6332456 N
Horse River	HR-R	*Baseline* site approximately 140 km upstream of the confluence with the Athabasca River.	D/S: 427575 E / 6246900 N U/S: 427480 E / 6246775 N
Dunkirk River	DR-R	*Baseline* site approximately 25 km upstream of the confluence with the MacKay River.	D/S: 395841 E / 6302502 N U/S: 395793 E / 6302640 N

[1] U/S-upstream end of each reach; D/S-downstream end of reach.

Fish Sampling and Handling

The two sampling campaigns for the 2009 non-lethal tributary sentinel species monitoring study were August 18 to 20, 2009 and October 1 to 3, 2009. All fish sampling was carried out by a two-person field crew using a Smith-Root 12B-POW battery-powered electrofishing unit and a standard dip net, which was deployed downstream of the anode prior to and during the application of electrical current. The dip net was fitted with a fine mesh net (32 mm) to ensure that young-of-year fish could be captured. Fish sampling was conducted from one wetted bank to the other within each site until the 100 fish sentinel species target was reached or until conditions such as deepwater did not permit continued backpack electrofishing.

All captured sculpin were identified to species using the RAMP Sculpin Field ID Card (Appendix G), measured for total length (± 1.0 mm) and weight (± 0.01 g) using an electronic balance that was calibrated prior to each measurement. An external pathology examination was also performed (described in Section 3.4.2.1). The fish were then revived in fresh water, with monitoring at regular intervals to ensure full recovery, and then released back into the watercourse near the original capture location.

Water Quality Measurements and Habitat Assessments

The August sampling campaign included habitat assessment at each site in addition to the fish sampling outlined above. Habitat assessment methods involved measuring and recording a range of variables relating to channel morphology, substrate, water quality, and stream cover similar to that outlined in RAMP (2009b) (examples of the habitat assessment field data sheets are presented in Appendix G). Water quality was measured in both sampling campaigns. Water quality variables measured included temperature, dissolved oxygen, and specific conductance, and were measured either with a hand-held probe (LaMotte Tracer Pocketester) (temperature, conductivity, pH) and a titration kit (LaMotte Winkler) (DO). Basic water quality data were also collected during the October field campaign. A HOBO® Water Temp Pro automatic data logger deployed at each site in August 2009 and retrieved during the October 2009 sampling campaign to provide information on the thermal regime of the sampled site.

3.4.2.5 Fish Tag Return Assessment

Tagging of key indicator fish species has been a part of the Fish Population component since 1999. RAMP fish tags are uniquely identified by a colour and ID number (for tracking the fish in the event of recapture), as well as a contact phone number that anglers can use to report catch information to the ASRD. Tag number, tag colour, species, basic morphology (fish length and weight), maturity, sex (if possible), external health condition, date, and location were recorded at the time of tagging.

3.4.3 Changes in Monitoring Network from 2008

2009 Fish Population component monitoring activities differed from those carried out during 2008 in the following ways:

- The Muskeg River fish fence was implemented successfully in 2009, following unsuccessful implementation in 2008 due to high water levels;
- A summer fish inventory program was conducted for the first time in 2009 on the Clearwater River;
- Tissue sampling for northern pike was conducted on the Clearwater River in 2009 as compared to sampling for lake whitefish and walleye on the Athabasca River in 2008;
- The regional lakes fish tissue program was implemented on “Jackson” Lake in 2009 as compared to Gardiner (Moose) and Big Island lakes in 2008; and
- A sentinel species monitoring program was conducted in 2009.

3.4.4 Challenges Encountered and Solutions Applied

All monitoring activities implemented under the 2009 Fish Population component were completed successfully without significant difficulties.

3.4.5 Other Information Obtained

Two fish (lake trout and lake whitefish) were submitted to the Fish Population component as part of the Fish Health program. The samples were submitted to the Canadian Cooperative Wildlife Health Centre at the University of Saskatchewan for analyses. Pathology results from the fish samples are reported in Appendix G.

3.4.6 Summary of Component Data Now Available

Fish Population component data collected to date by RAMP are summarized in Table 3.4-7.

3.4.7 Analytical Approach and Methods

The analytical approach used in 2009 for the Fish Population component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2009b) and consisted of:

- selecting fish population measurement endpoints;
- conducting analysis of variance on fish population measurement endpoints to test for differences between baseline and test reaches, and/or differences in time trends;
- presenting results in tabular and graphical format comparing 2009 fish population measurements endpoints to historical results in the same reach; and
- selecting and using criteria to assess change in fish population measurement endpoints both spatially and temporally.

3.4.7.1 Muskeg River Fish Fence

Selection of Measurement Endpoints

Measurement endpoints for large-bodied fish species captured at the Muskeg River fish fence are:

- relative abundance of migrants (fence count data by species);
- percent species composition (relative to all fish captured);
- onset and peak timing of spawning runs;
- residency time in the spawning tributary (out-migration was monitored).
- length/age-frequency distributions;
- condition factor;
- sex ratio; and
- incidence of external health abnormalities.

Detailed Data Analysis

Measurement endpoints calculated from data collected during the fish fence program on the Muskeg River were used to evaluate general trends in fish abundance and population characteristics, with a focus on large-bodied KIR species (i.e., walleye, northern pike, white sucker, longnose sucker, and Arctic grayling).

Species Composition and Relative Abundance All fish captured at the fish fence were summarized by percent species composition (relative to total abundance for all species). These measurement endpoints were calculated for fish species migrating upstream and downstream with timing of migration presented graphically to compare species migration patterns throughout the time period of the fish fence.

Timing of spawning runs for each species will be displayed graphically with temporal comparisons (2003, 2006 and 2009) to evaluate changes in fish populations using the Muskeg River for spawning purposes.

Length-Frequency Distributions Length-frequency distributions (i.e. number of fish per fork length class or age class) were calculated for each large-bodied KIR species captured during the Muskeg River fish fence. Length classes were divided into 50 mm increments for all species captured. Length-frequency distributions were displayed graphically in order to evaluate trends in dominant length classes over time. Length-at-age relationships were also compared for each species captured.

Condition Factor Fish condition was evaluated over time as a measure of change in energy storage for large-bodied KIR species captured during the Muskeg River fish fence. In order to be consistent with past analyses, 2009 analyses were restricted to fish of the following species-specific minimum lengths: walleye >400 mm; northern pike >400 mm; longnose sucker >350 mm; and white sucker >350 mm.

The following analyses were performed in order to evaluate condition for fish captured on both rivers:

- Fish condition (or "fatness") was compared among years (2003, 2006, 2009) using analysis of covariance (ANCOVA; α=0.05), with body weight ($\log_{10}$ transformed) as the dependent variable, site/year as the independent variable, and fork length ($\log_{10}$ transformed) as the covariate. The first step in the analysis was to compare slopes of length-weight regressions from different years, and the second step was to compare the intercepts of the regressions; and

- Fulton's Condition Factor was calculated as K= (body weight/fork length^3 x 10^5), and used in tabular and graphical presentations showing condition for each species, per season, over time.

Sex Ratio The ratio of males to females moving up the Muskeg River to spawn were displayed graphically and in tabular form by date for the period of the fish fence operation.

Incidence of External Health Abnormalities Incidence of external fish health abnormalities were evaluated for all large-bodied KIR species captured in the Muskeg River fish fence using the following analyses:

- Number of external abnormalities (with severity score) was calculated relative to total number of fish captured during each season; and

- Key types of abnormalities were identified.

Table 3.4-7 Summary of RAMP data available for the Fish Population component.

		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
Athabasca River																																																					
Poplar Area	0/1[a]		1	1,5	1,5		1,6	1,5	1,3,6														1								1		1		1		1		1		1		1		1		1	1	1,6		1	1	1
Steepbank Area	4[a]/5[a]/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		1		1,6		1		1		1		1		1	1	1,6		1	1	1
Muskeg Area	10/11		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		1		1,6		1		1		1		1		1	1	1,6		1	1	1
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7					1								1		1		1		1		1		1		1		1		1	1	1		1	1	1
Fort-Calumet Area	19[a]																																						1		1		1		1		1	1	1		1	1	1
CNRL/TrueNorth Area (Fort/Asphalt reaches)																							1																														
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												10,3				10															3	3								
Below Muskeg River	AR-MR												1,3												10,3				10															3	3								
Reference site upstream of Ft. McMurray STP																									3				10															3	3								
Reference site between STP and Suncor	AR-R												1,3												3				10															3	3								
Downstream of Development (near Firebag River)																													10,6															3	3								
Athabasca River Tributaries																																																					
Fort Creek (mouth)															1,8,5,9	1																																					
Poplar Creek (mouth)	POC-F1																																																				10
Beavery River (upper)	BER-F2																																																				10
Tar River (mouth)	TAR-F1																																																				10
Clearwater River Reach	CR1																										1		1		1		1,6		1		1		1		1,6		1		1,6		1		1		1	1	1,6
Clearwater River Reach	CR2																										1		1		1				1				1		1,6		1		1,6		1		1		1	1	1,6
Clearwater River Reach	CR3																										1	10	1		1				1				1		1,6		1		1,6		1		1		1	1	1,6
Christina River[i]																																	1																				
Ells River																																																					
Upper Ells River[h]													1,3																		4		3		4		3							3	3								
Lower Ells River[h]													1,3																		4		3		4		3							3	3								
Mackay River																																																					
Lower reach (85 km section from bridge to mouth)[j]	MAR-1		1																				1					10			4																						10
Muskeg River																																																					
Lower 35 km below Jackpine Creek confluence	MUR-F2			1			4						1,3		2,8	2	2	2	2	1	6			1	6							1	6							1	6												10
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1												1,3						4		3		4		4		4						3						4	3	3										4	3	3,10
Reference sites (Steepbank, Horse and Dunkirk rivers)																	3				3												3							3	3											3	3,10
Upper Muskeg River (near Wapasu Creek Confluence)																							1,4		1,4																												
Muskeg River Tributaries																																																					
Alands Drain																																																					
Jackpine Creek (upper portion of the creek)	JAC-F2																																																				10
Jackpine Creek (accessable areas of lower creek)	JAC-F1														8					1				1								1																					10
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																												
Steepbank River																																																					
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																																																	
Vicinity of Steepbank Mine	SR-E												1,3								3												3							3	3											3	3,10
Baseline site in vicinity of Bitumin Heights	SR-R												1,3																																								
Upstream sentinel site[g]	SR-EC												1,3				3				3												3							3	3											3	3
Sentinel baseline sites (Horse and Dunkirk rivers)																	3				3												3							3	3											3	3,10
Regionally-Important Lakes																																																					
Various lakes in water/air emissions pathway																													6				6											6	6				6				6

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; 1998-1999: longnose sucker (Athabasca River)
2002-2009: trout-perch (Atha. River); slimy sculpin (Muskeg, Steepbank, Dunkirk, Horse)
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 (Muskeg River), northern pike (Clearwater River), northern pike, walleye and lake whitefish (lakes)
7 = winter fish habitat sampling
8 = spawning survey
9 = benthic drift survey
10 = fish assemblage monitoring - pilot/test program

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] In 2004 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. In 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers.
[i] Reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing.
[j] In 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers.

Test (downstream of focal projects)
Baseline (upstream of focal projects)

3.4.7.2 Fish Inventories

Selection of Measurement Endpoints

Measurement endpoints for the Athabasca River and Clearwater River fish inventories are:

- percent species composition (relative to all fish captured);
- relative abundance (catch per unit effort – CPUE);
- length-frequency distributions;
- condition factor;
- incidence of external health abnormalities; and
- recruitment to the sport fishery (Athabasca River only).

Detailed Data Analysis

Measurement endpoints calculated from data collected during the fish inventories on the Athabasca and Clearwater rivers were used to evaluate general trends in fish abundance and population characteristics, with a focus on large-bodied Key Indicator Resource (KIR) species (i.e., walleye, northern pike, white sucker, longnose sucker, and lake whitefish).

Only capture data were used to calculate measurement endpoints; data on fish observed were reported separately for each river, but not included in the analyses.

Species Composition and Relative Abundance (CPUE) All fish captured in the Athabasca River and Clearwater River fish inventories were summarized by percent species composition (relative to total abundance for all species), and relative abundance for each species (catch per unit effort - CPUE). These measurement endpoints were calculated for all combined reaches on a river, for each season. Temporal comparisons were graphically presented in order to compare species composition between 1997 and 2008 for each of the large-bodied KIR species, for each season (with the exception of lake whitefish, because of insufficient spring and summer data). Mean CPUE of KIR species was compared against mean discharge rates for May, July, and August at the Water Survey of Canada hydrology station at Fort McMurray on the Athabasca River (07DA001, Figure 3.1-2) from 1997 to 2009 to assess variability in relative abundance of KIR species to fluctuations in discharge rates in the Athabasca River across time.

Correspondence Analysis (CA) was conducted to interpret similarities and trends between years using relative species abundance and species composition. The analyses followed similar methods to the analyses conducted for the benthic invertebrate community analyses in Section 3.3.1.8. Years that are close together in the CA have similar fauna with similarities decreasing with increasing distance between years. Four analyses were conducted: (i) all species in spring; (ii) all species in fall; (iii) KIR species in spring; and (iv) KIR species in fall.

Length-Frequency Distributions Trends in dominant length classes over time were evaluated using length-frequency distributions (i.e. number of fish per fork length class) calculated for each large-bodied KIR species captured during the Athabasca River and Clearwater River fish inventories (spring and fall combined). Length classes were divided into 25 mm increments for goldeye and 50 mm increments for walleye, longnose sucker, white sucker, and northern pike. Comparisons of length-frequency were made among years for KIR species from the spring inventory using the Kolmogorov-Smirnov test (K-S test) ($\alpha = 0.05$).

Condition Factor Fish condition was evaluated over time as a measure of change in energy storage for large-bodied KIR species captured on the Athabasca River and Clearwater River. The following analyses were performed in order to evaluate fish condition:

- Fish condition (or "fatness") was compared among years (1997 to 2009) for each season using analysis of covariance (ANCOVA; $\alpha = 0.05$), where body weight ($\log_{10}$ transformed) as the dependent variable, year as the independent variable, and fork length ($\log_{10}$ transformed) as the covariate; and

- Fulton's Condition Factor was calculated as K= (body weight/fork length^3 x 10^5), and used in tabular and graphical presentations showing condition for each species, per season, over time.

In order to be consistent with past analyses, 2009 analyses were restricted to fish of the following species-specific minimum lengths: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; longnose sucker >350 mm; and white sucker >350 mm.

Spring, summer, and fall condition for each KIR species has evaluated over time, with the exception of lake whitefish for which only fall condition was evaluated over time due to insufficient sample sizes in the spring (Golder 2002).

Incidence of External Health Abnormalities Incidence of external fish health abnormalities were evaluated for all large-bodied KIR species captured in the Athabasca River and Clearwater River fish inventories using the following analyses:

- Mean annual HAI scores were calculated relative to total number of fish captured during each season for each species across years; and

- Key types of abnormalities were identified.

Recruitment to the Sport Fishery Fish captured in the Athabasca River inventory were used to estimate recruitment of walleye and northern pike to the sport fishery. The ratios of under-size to legal-size fish were calculated and compared over time (1997 to 2009) for each species. Although fork length is the standard measure of length used in RAMP fish population studies, ASRD legal catch size limits for the Athabasca River in the Northern Boreal Zone 3 are given in total length (walleye ≥ 430 mm; northern pike ≥ 630 mm). Using regression equations for each species, the associated fork length limits were estimated to be 370 mm for walleye and 600 mm for northern pike.

3.4.7.3 Fish Tag Return Assessment

RAMP and ASRD maintain records of tagged fish recaptured by anglers or during RAMP fish inventories. In general, information reported and recorded from angler recaptures has been limited to the recapture date, tag number, species, and a description of the geographical recapture location. This information is compared to data compiled at the time of tagging and used to analyze patterns of fish movements over time. Information reported and recorded from RAMP program recaptures can include re-evaluations of fish length and weight, and external health. These data can be used to analyze changes over time in basic morphology and health.

A spatial presentation of tag return information (location tagged and location recaptured) was prepared for the tag returns received by anglers in 2009.

3.4.7.4 Fish Tissue Studies

Selection of Measurement Endpoints

Measurement endpoints for the Clearwater River fish tissue program are weight/length-standardized tissue concentrations of metals (including mercury) and tainting compounds and the incidence of external/internal health abnormalities.

Whole-organism metrics (fork length, body weight and age) and mercury burden (both concentration and concentration standardized to fish weight) were the measurement endpoints used to analyze fish tissues results from "Jackson" Lake.

Detailed Data Analysis

Measurement endpoints calculated from data collected during the fish tissue programs on the Clearwater River and regional lakes (i.e., "Jackson" Lake) were used to evaluate temporal trends in fish tissue chemical concentrations and fish health.

Whole-organism Metrics Whole-organism metrics (i.e., fork length, body weight, age) were reported along with fish sex and stage for northern pike collected during the tissue program on the Clearwater River. These metrics were also reported for lake whitefish, walleye, and northern pike collected during the tissue program on "Jackson" Lake; ageing structures were not analyzed for lake whitefish.

Mercury Mercury results were reported for fish collected during tissue programs on the Clearwater River and "Jackson" Lake. Scatterplots were then used to initially assess relationships between mercury concentrations and fork length, body weight, and age for each species. Linear regression was used to further evaluate significant correlations. Assumptions of regression models were tested and, if necessary, analyses were performed using $\log_{10}$-transformed or ranked data. Mercury concentrations among years (2004, 2006, 2007 and 2009) for the Clearwater River program were compared graphically and statistically using analysis of covariance (ANCOVA; α=0.05), with mercury concentration ($\log_{10}$ transformed) as the dependent variable, year as the independent variable, and fork length ($\log_{10}$ transformed) as the covariate.

Mercury concentrations adjusted to fish weight in fish tissue samples from the Clearwater River and "Jackson" Lake were compared to fish tissue mercury concentrations from lakes in the region (AOSERP 1977, Grey *et al.* 1995, NRBS 1996, Golder 2004, RAMP 2003, RAMP 2004, RAMP 2008, RAMP 2009a) to assess temporal and spatial differences.

Total Metals and Organic Compounds Results for total metals and tainting compounds were reported for northern pike collected in the Clearwater River fish tissue program. Results were compared temporally to northern pike tissue studies previously completed on the Clearwater River (2004, 2006, 2007).

Incidences of Health Abnormalities Incidences of abnormalities observed during external and internal health assessments were reported for northern pike collected and dissected during the fish tissue program on the Clearwater River. Mean HAI scores were calculated for all external abnormalities and included in the Clearwater River fish inventory summary.

3.4.7.5 Sentinel Species Monitoring

Selection of Measurement Endpoints

Fish population measurement endpoints selected for RAMP non-lethal sentinel species monitoring on selected Athabasca River tributaries are summarized in Table 3.4-8. These are based on Environment Canada's Environmental Effects Monitoring (EEM) guidelines developed for the metal mining and pulp and paper sectors (Environment Canada 2005).

Table 3.4-8 Measurement endpoints for non-lethal sentinel species tributary monitoring.

	Measurement Endpoints
Survival	*Length-frequency distribution *Proportion of young-of-year to adult individuals
Growth	*Length / weight of young-of-year at end of growth period Size of 1+ fish
Condition	*Body weight vs. length (k)

***** Measurement endpoints used for determining effects. Other endpoints used for supporting analyses.

Detailed Data Analysis

For testing for possible differences in survival between *baseline* and *test* sampling sites, sculpin length-frequency distributions were generated using 2 mm length classes and then compared using the Kolmogonov-Smirnov test ($\alpha = 0.05$). The young-of-year (YOY) size class was determined as the first peak in the bimodal distribution and the abundance of YOY individuals from August to October was assessed as an indicator of survival and reproductive success within the sculpin population.

For testing for possible differences in growth between *baseline* and *test* sampling sites, young-of-year and adult sculpin lengths and weights and were $\log_{10}$-transformed and compared among sites across time (between sampling periods) using ANOVA ($\alpha = 0.05$).

For testing for possible differences in condition between *baseline* and *test* sampling sites, sculpin condition factor was compared among sites using ANCOVA ($\alpha = 0.05$), where weight represented the dependent variable, site the independent variable, and length the covariate.

3.4.7.6 Classification of Results

Criteria were selected and used for classifying results as described by the measurement endpoints calculated from the Fish Population component data.

Muskeg River Fish Fence Study

The Muskeg River fish fence study has been implemented in three non-consecutive years (2003, 2006, 2009). While data from fish fences are well suited for assessing time trends in abundance and population variables for each spawning species, the high level of natural annual variability common in spawning run strength means it is necessary to collect a large number of sampling years before observed trends and possible changes in fish populations due to development activities can be described with confidence. In addition, fish fences in the Muskeg River have only been implemented during low flow years due to safety concerns. Therefore the three years of the RAMP fish fence do not provide a comprehensive assessment of fish use of the Muskeg River for spawning across variable hydrologic years which influence spawning run timing and fish abundance. Therefore, no criteria are applied to the results of the 2009 Muskeg River fish fence study.

Fish Inventories

As indicated in Section 1.4.4.4, the RAMP fish inventories are considered to be stakeholder-driven activities best suited for assessing general trends in abundance and population variables for large-bodied species. They are not specifically designed for assessing change potentially due to focal project activities and; therefore, no criteria were used to classify measurement endpoints calculated from the results of the Athabasca River and Clearwater River fish inventories.

Fish Tissue Studies

Metals (including mercury) and tainting compounds measured in fish collected from the Clearwater River were used to evaluate potential risk to human health, fish, and palatability (tainting).Mercury in fish collected from Unnamed "Jackson" Lake was used to evaluate potential risk to human health and fish health.

Potential Risk to Human Health To assess potential risk to human health due to ingestion of fish tissues, fish tissue data were screened against the following criteria:

- Health Canada Guidelines for general fish consumption (Health Canada 2007, last updated July 2007) and subsistence level fish consumption (Health and Welfare Canada 1979, INAC 2003, updated June 2006) (Table 3.4-9);
- Government of Alberta Human Health Risk Assessment for Mercury in Fish in the RAMP area (GOA 2009b);
- Region III USEPA risk-based criteria for consumption of fish tissue for recreational and subsistence fishers (USEPA 2000, updated October 2007); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000, updated November 2000).

Mercury is the only RAMP fish tissue endpoint that currently has a Health Canada consumption guideline, both for general and subsistence consumers. USEPA criteria exist for a larger number of RAMP fish tissue measurement endpoints, and are risk-based values that take into account the toxicity (including carcinogenicity) of the contaminant, body weight of the consumer, and exposure rate. National USEPA criteria have been developed for both recreational (general) and subsistence consumers, and are available for arsenic, selenium, and mercury. Regional USEPA criteria apply to general adult exposure, and exist for several total metals, mercury, and toluene, tainting compound. The Government of Alberta has recently released new fish consumption guidelines for fish captured within the RAMP FSA developed through a risk assessment of fish mercury data collected through RAMP (GOA 2009b). Although the consumption limits are for fish species from specific waterbodies previously sampled by RAMP and ASRD, they are used in this analysis for comparisons and conservative guidelines for waterbodies sampled in the 2009 RAMP fish tissue programs.

While Health Canada's mercury guidelines are for total mercury, the USEPA's mercury guidelines are for methylmercury. Both guidelines make the conservative assumption that, for the purposes of screening for human health risks, 100% of total mercury in edible fish tissues is present as methylmercury (USEPA 2000, Health Canada 2007). Guidance accompanying mercury guidelines from both countries recommends that most health risk assessments employ the less costly method of analyzing for total mercury, while screening against methylmercury and mercury guidelines interchangeably.

Health Canada's guideline for general consumption of total mercury in fish (Health Canada 2007) is less conservative than its guideline for subsistence-level consumption of total mercury (INAC 2003), which was originally derived from various studies on toxicity of methylmercury to Aboriginal consumers (Health and Welfare Canada 1979). Similarly, the USEPA methylmercury guideline for recreational fishers is less conservative than the guideline developed for subsistence level fishers. Overall, the National USEPA mercury guideline for subsistence fishers is the most stringent value used for evaluating RAMP fish tissue concentrations; the screening concentration is four times lower than Health Canada's guideline for subsistence fishers.

Summary indicators of 2009 fish tissue mercury results were developed for determining risk to human health based on the exceedances of subsistence fisher and general consumer consumption guidelines, and criteria outlined in the RAMP Technical Design and Rationale Document (RAMP 2009b). Summary indicators of fish tissue results were classified taking into account the consumption differences between general consumers and subsistence fishers and the variance in mercury concentrations across size classes of individual fish to accurately assess the risk to human health in relation to the amount of fish consumed and in the size of fish consumed. Table 3.4-11 provides the classification of results for risk to human health for subsistence fishers and general consumers. The classification specifies the corresponding size class for each species for which fish tissue studies were conducted in 2009 (see Section 3.4.2.3). A Moderate classification is not defined for subsistence fishers given that the consumption guideline is low due to larger quantities of fish consumed by this group which poses a higher risk to human health.

Potential Risk to Fish Health To assess potential risk to fish health, fish tissue data were screened against minimum lethal (survival) and non-lethal (growth and reproduction) effects and no-effects thresholds (Table 3.4-12) derived from laboratory-based studies summarized in Jarvinen and Ankley (1999). These criteria were only available for some of the RAMP fish tissue measurement endpoints, including several total metals and mercury, but not for any of the tainting compounds. The thresholds were developed based on ranges of fish tissue residue concentrations linked to both effects and a lack of effects on both sublethal (e.g. growth) and lethal (survival) measurement endpoints; the lowest (i.e., most conservative) concentrations were used to evaluate risk.

The classification of fish tissue results for risk to fish health is as follows:

- Negligible-Low - all metal concentrations below criteria for sublethal and lethal effects on fish;
- Moderate – concentration of one metal exceeds the sublethal effects criteria; and
- High - concentration of more than one metal exceeding the lethal effects criteria.

The classification was provided for each watershed where fish tissue studies were conducted in 2009.

Table 3.4-9 Criteria used for evaluating potential risk of fish consumption to human health.

Measurement Endpoint[1]	Units	Health Canada		National USEPA[4]		Region III USEPA[5]
		General[2]	Subsistence[3]	Recreational	Subsistence	Risk-based Criteria
Total Metals						
Antimony (Sb)	mg/kg	nc	nc	nc	nc	0.54
Arsenic (As)	mg/kg	nc	nc	0.026	0.00327	0.0021
Barium (Ba)	mg/kg	nc	nc	nc	nc	270
Beryllium (Be)	mg/kg	nc	nc	nc	nc	2.7
Cadmium (Cd)	mg/kg	nc	nc	nc	nc	1.4
Chromium (Cr)	mg/kg	nc	nc	nc	nc	4.1
Copper (Cu)	mg/kg	nc	nc	nc	nc	54
Iron (Fe)	mg/kg	nc	nc	nc	nc	410
Lithium (Li)	mg/kg	nc	nc	nc	nc	27
Manganese (Mn)	mg/kg	nc	nc	nc	nc	190
Mercury (Hg)[6]	mg/kg	0.5	0.2	0.4	0.049	0.14
Molybdenum (Mo)	mg/kg	nc	nc	nc	nc	6.8
Nickel (Ni)	mg/kg	nc	nc	nc	nc	27
Selenium (Se)	mg/kg	nc	nc	20	2.457	6.8
Silver (Ag)	mg/kg	nc	nc	nc	nc	6.8
Strontium (Sr)	mg/kg	nc	nc	nc	nc	810
Thallium (Tl)	mg/kg	nc	nc	nc	nc	0.095
Tin (Sn)	mg/kg	nc	nc	nc	nc	810
Vanadium (V)	mg/kg	nc	nc	nc	nc	1.4
Zinc (Zn)	mg/kg	nc	nc	nc	nc	410
Tainting Compounds						
Toluene	mg/kg	nc	nc	nc	nc	110

1 Measurement endpoints listed are for variables that have human health criteria under Health Canada or National USEPA.

2 Last updated July 2007; found at http://www.hc-sc.gc.ca/fn-an/securit/chem-chim/contaminants-guidelines-directives_e.html

3 Last updated June 2006; found at http://www.ainc-inac.gc.ca/nth/ct/ncp/pubs/hig/hil-eng.pdf

4 Last updated November 2000; found at http://www.epa.gov/waterscience/fishadvice/volume1/index.html (see Chapter 5).

5 Last updated October 2007; found at http://www.epa.gov/reg3hwmd/risk/human/index.htm

6 Criteria are for total mercury and methylmercury, assuming equivalence.

nc – no criterion.

Table 3.4-10 Criteria used for evaluating potential risk of fish consumption to human health for watercourses within the RAMP FSA (GOA 2009b).

Waterbody	Species	Weight (g)*	Consumption Limit (serving/week)**			
			Women	Child (1-4yr)	Child (5-11yr)	Adult +
Athabasca River (downstream of Fort McMurray)	Walleye	908	2	0.5	1	8
Clearwater River	Walleye	908	2	0.5	1	8
	Northern pike	908	8	2	4	no limit
Muskeg River	Northern pike	908	8	2	4	no limit
Christina Lake	Walleye	1,816	2	0.5	1	8
	Northern pike	3,632	2	0.5	1	8
Gregoire Lake	Walleye	908	8	2	4	no limit
	Northern pike	908	8	2	4	no limit
Winefred Lake	Walleye	1,362	8	2	4	no limit

* 454 g = 1 lb

** 1 serving=75g, 1/2 cup, 2.5 ounces, or a piece of cooked fish that fits into the palm of a hand.

"Women" refers to women of child-bearing age (15-49 yr) and pregnant women.

"Adult +" refers to adults and children over 12 yrs.

Table 3.4-11 Classification of fish tissue results for risk to human health.

Classification	Subsistence Fishers	General Consumers
Negligible-Low	Average mercury concentration below the subsistence fisher guideline (0.2 mg/kg)	Average mercury concentration below the subsistence fisher guideline (0.2 mg/kg)
Moderate	-	Average mercury concentration above the subsistence fisher guideline and below the general consumer guideline (0.2 to 0.5 mg/kg)
High	Average mercury concentration above the subsistence fisher guideline (0.2 mg/kg)	Average mercury concentration above the general consumer guideline (0.5 mg/kg)

Potential Influence on Palatability Elevated concentrations of tainting compounds may cause undesirable odors or flavours in fish that can decrease their palatability. The potential influence of chemicals on tissue palatability was assessed by evaluating tainting compound data based on a method developed by Jardine and Hrudey (1988), whereby compounds present at concentrations above 1 mg/kg have the potential to result in detectable undesirable odor or taste.

The classification of fish tissue results for potential effects on palatability is as follows:

- Negligible-Low - all tainting compound concentrations below their guideline;
- Moderate – concentrations of one tainting compound exceeding their guideline; and
- High – concentrations of more than one tainting compound exceeding their guidelines.

The classification scheme was provided for each watershed where fish tissue studies were conducted in 2009.

Table 3.4-12 Criteria used for evaluating potential risk to fish health based on concentrations of metals that have lethal, sublethal, or no effects on freshwater fish.

Variable	Endpoint		Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Route	(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
Cadmium	Survival	no effects	0.02 - 2.8	muscle	rainbow trout, brook trout	150 -200 g, adult	water, ip injection[2]	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
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
Lead	Survival	no effects	4.0	carcass	rainbow trout	under-yearlings (6.5 g)	water	224

- = no data; [1] methylated forms of mercury; [2] ip = intraperitoneal injection is the injection of a substance into the body cavity.

Only thresholds derived from the most relevant studies were used to screen the RAMP fish tissue data; those derived from studies on small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, were excluded. Effects concentrations associated with acute exposures were only included for contaminants where few other data existed.

Table 3.4-12 (Cont'd.)

Variable	Endpoint		Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Route	(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[2], oral, water	15 - 273
		effects	3.7 - 31	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, subadult (100 - 150 g),	ip injection[2], oral,	186 - 273
					northern pike	yearling-adult, adult	water	
	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,	larvae-swim-up, egg-juvenile,	water, oral	28 - 308
					largemouth bass	fingerling-juvenile, juvenile		
		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,	oral	60 - 308
						fingerling-juvenile, juvenile		
		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
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; [2] ip = intraperitoneal injection is the injection of a substance into the body cavity.

Only thresholds derived from the most relevant studies were used to screen the RAMP fish tissue data; those derived from studies on small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, were excluded. Effects concentrations associated with acute exposures were only included for contaminants where few other data existed.

Sentinel Species Monitoring

The selected criterion for determining change in a measurement endpoint for a non-lethal sentinel species study is a ± 10% difference in condition in fish collected at a *test* site from condition of fish collected at a *baseline* site, based on Environment Canada's Environmental Effects Monitoring (EEM) criteria (Environment Canada [2005]).

The criterion used for classifying results of non-lethal sentinel species monitoring was a ±10% difference in condition of fish at a *test* site compared to condition in fish at *baseline* sites. This effects criterion was established for the Pulp and Paper Environmental Effects Monitoring (EEM) Program (Environment Canada 2005) as a measure for determining change in a sentinel fish species population.

There are two steps in determining the classification of the effects criterion as Negligible-Low, Moderate, or High (Table 3.4-13):

- an exceedance observed at a *test* site compared to at least one of the *baseline* sites in the current sampling year; and
- an exceedance at a *test* site in three consecutive years of sampling, including the current year.

The exceedance over three consecutive years of sampling is an indication that condition in fish at a *test* site is outside of the *baseline* range of variation of sentinel species monitoring sites in the RAMP FSA.

Table 3.4-13 Classification of results for the sentinel species monitoring program.

Criteria	Negligible-Low	Moderate	High	"Yes"
Exceedance in current sampling year	No	Yes	Yes	exceedance greater than ±10% in condition of fish at *test* site compared to condition of fish at *baseline* site.
Exceed *baseline* range of variation	No	No	Yes	exceedance in three successive years of sampling including the current year.

3.5 ACID-SENSITIVE LAKES COMPONENT

The 2009 Acid-Sensitive Lakes (ASL) component consisted of monitoring 50 lakes and ponds within and beyond the RAMP RSA for water quality variables during late August, 2009. The locations of each lake are presented in Figure 3.5-1, along with each lake's acid sensitivity based on three separate classification systems: (i) Gran alkalinity; (ii) pH; and (iii) critical load (CL). Table 3.5-1 presents the three classification systems and the number of lakes that are classified as highly acid-sensitive, moderately acid-sensitive, of low acid-sensitivity and least acid-sensitive.

Table 3.5-1 Acid sensitivity criteria for Alberta lakes.

Acid Sensitivity Category	Gran Alkalinity[1] (μeq/L)	No. of RAMP ASL Lakes in Alkalinity Category	pH[1] (Units)	No. of RAMP ASL Lakes in each pH Category	Critical Load[2] (CL) Keq H^+/ha/y	No. of RAMP ASL Lakes in each CL Category
High Sensitivity	Negative to 199	25	4.0 to 6.49	17	<0.249	19
Moderate Sensitivity	200 to 399	12	6.5 to 6.99	14	0.250 to 0.499	10
Low Sensitivity	400 to 799	8	7.0 to 7.49	13	0.500 to 0.999	8
Least Sensitive	> 800	5	> 7.5	6	>1.00	13

[1] Erickson (1987), Saffron and Trew (1996).

[2] CASA 1996.

[3] CL calculated from isotopically derived estimates of runoff for 2009.

The most acid-sensitive lakes are found in upland areas, in particular the Stony Mountains, and the Muskeg River Uplands (Figure 3.5-1). The least acid-sensitive lakes are found scattered throughout the region with a high concentration in the area west of Fort McMurray (Figure 3.5-1).

The date of sampling and the UTM coordinates of each lake are presented in Table 3.5-2. The unique identification number listed in Table 3.5-2 is that ascribed to each lake by the NO_xSO_x Monitoring Working Group (NSMWG) lake sensitivity mapping program (WRS 2004).

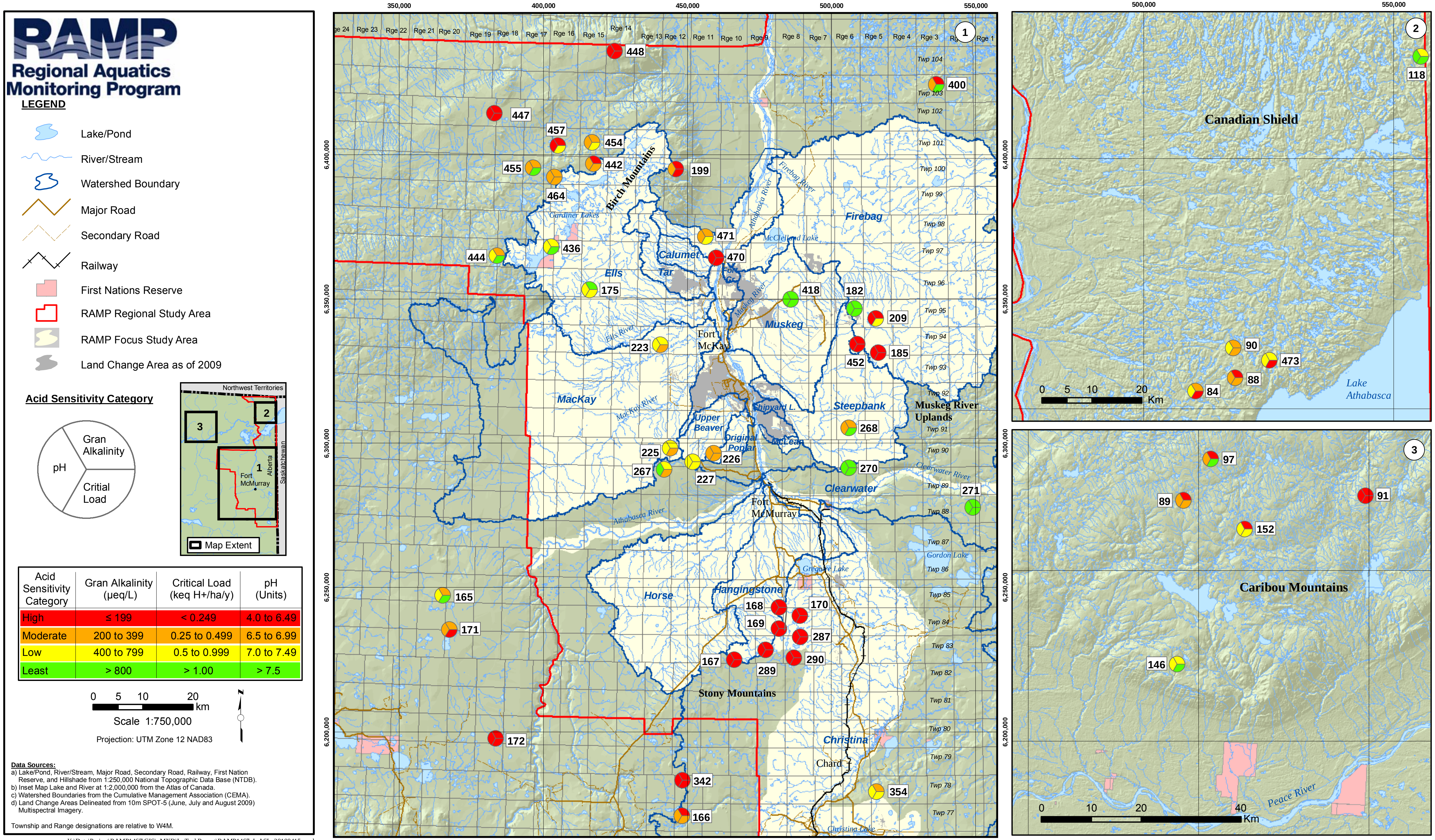
3.5.1 Summary of Field Methods

AENV provided the sampling equipment and logistical support for the lake sampling. A float plane was used to access the majority of study lakes while a helicopter with floats was used to reach the smaller lakes.

AENV water quality sampling protocols were used as the basis for the field methods (AENV 2006). Water samples were collected (approximately 10 L of water in total) from the euphotic zone (defined as twice the Secchi disk depth) at a single deep-water site in each major basin of a lake using weighted Tygon tubing. 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 1-L grab samples collected at 0.5 m depth along a transect dictated by wind direction (upwind to downwind shore). Samples taken from a given lake were then combined to form a single composite sample.

Vertical profiles of dissolved oxygen, temperature, conductivity and pH were measured at the deepest location using a field-calibrated Hydrolab Minisonde 5 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, and analyzed for the water quality variables listed in Table 3.5-3.

Figure 3.5-1 Locations and acid sensitivity of ASL lakes sampled in 2009.



Acid Sensitivity Category	Gran Alkalinity (µeq/L)	Critical Load (keq H+/ha/y)	pH (Units)
High	≤ 199	< 0.249	4.0 to 6.49
Moderate	200 to 399	0.25 to 0.499	6.5 to 6.99
Low	400 to 799	0.5 to 0.999	7.0 to 7.49
Least	> 800	> 1.00	> 7.5

Table 3.5-2 Lakes sampled in 2009 for the Acid-Sensitive Lakes component.

Lake Identification			Lake Area (km²)	UTM Coordinates (NAD83, Zone12)		Sampling Date
Unique ID[1]	Original Name	AENV Designation		Easting	Northing	m/d
Stony Mountains Sub-Region						
168	A21	SM 10	1.38	483819	6235130	08/21
169	A24	SM 9	1.45	484387	6230872	08/21
170	A26	SM 6	0.71	489502	6230877	08/21
167	A29	SM 5	1.05	466180	6224950	08/21
166	A86	SM 7	1.44	448014	6170896	08/19
287	25	SM 8	2.18	487594	6229281	08/21
289	27	SM 3	1.83	477248	6228400	08/21
290	28	SM 4	0.54	487068	6225576	08/21
342	82	SM 2	1.97	448271	6183205	08/19
354	94	SM 1	2.50	515689	6179207	08/19
Birch Mountains Sub-Region						
436	L18/Namur	BM 2	43.39	402704	6368016	08/20
442	L23/Otasan	BM 9	3.44	417321	6396959	08/20
444	L25/Legend	BM 1	16.80	383849	6364923	08/20
447	L28	BM 6	1.30	382996	6414339	08/17
448	L29/Clayton	BM 7	0.65	424694	6435790	08/17
454	L46/Bayard	BM 8	1.20	416941	6404239	08/20
455	L47	BM 4	4.37	396500	6395456	08/20
457	L49	BM 5	2.61	404995	6403111	08/20
464	L60	BM 3	0.91	403796	6392247	08/20
175	P13	BM 10	0.38	416003	6353212	08/21
199	P49	BM 11	2.61	446002	6394961	08/21
Northeast of Fort McMurray Sub-Region						
452	L4 (A-170)	NE 1	0.61	508990	6334305	08/22
470	L7	NE 2	0.33	461006	6368512	08/22
471	L8	NE 3	0.56	460931	6369481	08/22
400	L39/E9/A-150	NE 4	1.12	536495	6424234	08/18
268	E15	NE 5	1.87	506092	6305335	08/22
182	P23	NE 6	0.28	509000	6346712	08/21
185	P27	NE 7	0.09	508300	6333712	08/21
209	P7	NE 8	0.15	515399	6343212	08/21
270	4	NE 9	3.44	506113	6291421	08/22
271	6	NE 10	4.31	549064	6277789	08/19
418	Kearl	NE 11	5.34	485939	6349881	08/18
West of Fort McMurray Sub-Region						
165	A42	WF 1	3.20	365015	6247322	08/19
171	A47	WF 2	0.47	367321	6235430	08/19
172	A59	WF 3	2.06	383467	6197733	08/19
223	P94	WF 4	0.03	440557	6334112	08/21
225	P96	WF 5	0.21	444002	6295513	08/21
226	P97	WF 6	0.16	456002	6296463	08/21
227	P98	WF 7	0.08	451762	6293513	08/21
267	1	WF 8	2.22	441917	6290884	08/19
Caribou Mountains Sub-Region						
146	E52/ Fleming	CM 1	1.60	243692	6522556	08/17
91	O-1/E55	CM 5	2.70	298955	6571856	08/17
97	O-2/E67	CM 4	0.56	253582	6582654	08/17
152	E59/Rocky I.	CM 2	9.53	263546	6562225	08/17
89	E68 Whitesand	CM 3	2.46	245596	6570610	08/17
Canadian Shield Sub-Region						
473	A301	S 4	1.40	525150	6559733	08/18
118	L107/Weekes	S 1	3.73	555469	6620456	08/18
84	L109/Fletcher	S 2	1.29	510321	6553552	08/18
88	O-10	S 5	0.70	518279	6556260	08/18
90	R1	S 3	0.55	517889	6562197	08/18

[1] Derived from the Lake Sensitivity Mapping Program conducted by NSMWG (WRS 2004).

One blind field blank was collected using de-ionized water from the Limnology Laboratory, University of Alberta. Two duplicate samples were additionally assessed by the University of Alberta laboratory. Quality control samples were analyzed for all variables listed in Table 3.5-3 (Appendix B).

Subsamples of 150 mL were taken from the composite samples for phytoplankton taxonomy and preserved using Lugol's solution. One or two replicate zooplankton samples were also collected from 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 soda water. Plankton samples were archived at AENV and the zooplankton samples were sent to Environment Canada for analysis.

Table 3.5-3 Water quality variables analyzed in 2009 in lake water sampled for the Acid-Sensitive Lakes component.

pH	bicarbonate	total dissolved nitrogen
turbidity	Gran bicarbonate	ammonia
colour	chloride	nitrite + nitrate
total suspended solids	sulphate	total Kjeldahl nitrogen
total dissolved solids	calcium	total nitrogen
dissolved organic carbon	potassium	total phosphorus
dissolved inorganic carbon	sodium	total dissolved phosphorus
conductivity	magnesium	chlorophyll *a*
total alkalinity (fixed point titration to pH 4.5)	iron	
Gran alkalinity	silicon	

3.5.2 Changes in Monitoring Network from 2008

All 50 lakes were sampled in 2009, including the lake (Lake 267, AENV WF 8) where logistical difficulties prevented sampling in 2008.

3.5.3 Challenges Encountered and Solutions Applied

There were no exceptional challenges encountered in implementing field activities under the ASL component in 2009.

3.5.4 Other Information Obtained

AENV collected additional water samples for metals analyses from each ASL lake surveyed during the 2009 field season (Table 3.5-2). These water samples were sent to the Alberta Research Council, Vegreville, Alberta for analysis of both total and dissolved metal fractions (Table 3.5-4). The results of the metals analyses are reported in Appendix H.

Table 3.5-4 Metals analyzed in 2009 in lake water sampled for the Acid-Sensitive Lakes component.

silver	copper	selenium
aluminum	iron	tin
arsenic	mercury	strontium
barium	lithium	thorium
beryllium	manganese	titanium
bismuth	molybdenum	thallium
cadmium	nickel	uranium
cobalt	lead	vanadium
chromium	antimony	zinc

3.5.5 Summary of Component Data Now Available

The selection of lakes sampled during the eleven years of the ASL component is summarized in Table 3.5-5.

3.5.6 Analytical Approach

The analytical approach used in 2009 for the ASL component was in accordance with the overall analytical approach outlined in the RAMP Technical Design and Rationale (RAMP 2009b) and consisted of:

- selecting ASL measurement endpoints;
- developing criteria to be used in detecting changes in ASL measurement endpoints; and
- detailed data analysis of 2009 results.

3.5.6.1 Measurement Endpoints

The measurement endpoints for the ASL component in 2009 were as follows:

- pH;
- Gran alkalinity;
- Base cation concentrations;
- Nitrate plus nitrite;
- Sulphate;
- Dissolved organic carbon; and
- Dissolved aluminum.

Gran alkalinity and pH are considered the principal ASL measurement endpoints. Sulphate is included in the list of ASL measurement endpoints but, unlike most lakes in eastern North America, sulphate and acidity (H^+) in Alberta lakes are poorly correlated because of the abundance of neutral sulphate compounds in wet and dry deposition (AEP 1990, Lau 1982, Legge 1988). The poor correlation between sulphate and H^+ in the RAMP ASL lakes was demonstrated in RAMP (2004). However, sulphate is included as an endpoint, given acidification in a lake likely results from decreasing sulphate in the water.

Table 3.5-5 Summary of lakes sampled in the Acid-Sensitive Lakes component, 1999 to 2009.

NO_xSO_x GIS No.	Original RAMP Designation	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
168	A21	+	+	+	+	+	+	+	+	+	+	+
169	A24	+	+	+	+	+	+	+	+	+	+	+
170	A26	+	+	+	+	+	+	+	+	+	+	+
167	A29	+	+	+	+	+	+	+	+	+	+	+
166	A86	+	+		+	+	+	+	+	+	+	+
287	25 (287)				+	+	+	+	+	+	+	+
289	27 (289)				+	+	+	+	+	+	+	+
290	28 (290)				+	+	+	+	+	+	+	+
342	82 (342)				+	+	+	+	+	+	+	+
354	94 (354)				+	+	+	+	+	+	+	+
165	A42	+	+	+	+	+	+	+	+	+	+	+
171	A47	+	+	+	+	+	+	+	+	+	+	+
172	A59	+	+	+	+	+	+	+	+	+	+	+
223	P94 (223)				+	+	+	+	+	+	+	+
225	P96 (225)				+	+	+	+	+	+	+	+
226	P97 (226)				+	+	+	+	+	+	+	+
227	P98 (227)				+	+	+	+	+	+	+	+
267	1 (267)				+	+	+	+	+	+		+
452	L4	+	+	+	+	+	+	+	+	+	+	+
470	L7	+	+	+	+	+	+	+	+	+	+	+
471	L8	+	+	+	+	+	+	+	+	+	+	+
400	L39	+	+	+	+	+	+	+	+	+	+	+
268	E15 (268)		+	+	+	+	+	+	+	+	+	+
182	P23 (182)				+	+	+	+	+	+	+	+
185	P27 (185)				+	+	+	+	+	+	+	+
209	P7 (209)				+	+	+	+	+	+	+	+
270	4 (270)				+	+	+	+	+	+	+	+
271	6 (271)				+	+	+	+	+	+	+	+
418	Kearl Lake					+	+	+	+	+	+	+
+436	L18 Namur	+	+	+	+	+	+	+	+	+	+	+
442	L23 Otasan	+	+	+	+	+	+	+	+	+	+	+
444	L25 Legend	+	+	+	+	+	+	+	+	+	+	+
447	L28	+	+	+	+	+	+	+	+	+	+	+
448	L29 Clayton	+		+	+	+	+	+	+	+	+	+
454	L46 Bayard	+	+	+	+	+	+	+	+	+	+	+
455	L47	+	+	+	+	+	+	+	+	+	+	+
457	L49	+	+	+	+	+	+	+	+	+	+	+
464	L60	+	+	+	+	+	+	+	+	+	+	+
175	P13 (175)				+	+	+	+	+	+	+	+
199	P49 (199)				+	+	+	+	+	+	+	+
473	A301			+	+	+	+	+	+		+	+
118	L107 Weekes		+	+	+	+	+	+	+	+	+	+
84	L109 Fletcher	+	+	+	+	+	+	+	+	+	+	+
88	O-10	+	+	+	+	+	+	+	+		+	+
90	R1	+	+	+	+	+	+	+	+	+	+	+
146	E52 Fleming	+	+	+	+	+	+	+	+	+	+	+
152	E59 Rocky Is.	+	+	+	+	+	+	+	+	+	+	+
89	E68 Whitesand		+	+	+	+	+	+	+	+	+	+
91	O-1	+	+	+	+	+	+	+	+	+	+	+
97	O-2	+	+	+	+	+	+	+	+	+	+	+
428	L1	+										
83	O3/E64	+										
85	R2	+										
86	R3	+										
310	A300			+								

3.5.6.2 Details of Data Analysis

Primary Analyses

The emphasis in the data analysis was placed on the detection and evaluation of potential trends in the ASL measurement endpoints in the RAMP ASL lakes that would indicate incipient changes in the buffering capacity and acid sensitivity of the lakes. In this regard, four specific data analyses were conducted.

Among-Year Comparisons of Measurement Endpoints An Analysis of Variance (ANOVA) was conducted to determine whether there have been any significant changes in the concentrations of the ASL measurement endpoints in the 50 RAMP lakes, as a group, during the eight years when all 50 lakes were sampled (2002 to 2009). An ANOVA was run after testing for the homogeneity of the variance of each variable between years. When the variance of a variable was found to be non-homogeneous, a non-parametric test (Kruskal-Wallis one-way analysis of variance) was applied to detect changes in the median concentrations. Tukey's post-hoc test was used to examine individual differences in mean values among years when the ANOVA indicated significant differences. Any observed changes were discussed in relation both to acidification and natural variability.

Calculation of Critical Loads of Acidity and Comparison to Modeled Potential Acid Input The critical loads (CL), 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; it represents a measure of a lake's sensitivity to acidification. CLs for the RAMP lakes in 2009 were calculated using the Henriksen steady state water chemistry model (Henriksen and Posch 2001, Henriksen *et al*. 2002, Forsius *et al*. 1992, Rhim 1995) modified for the effects of organic acids on buffering and acid sensitivity (RAMP 2009b).

As in previous years, the runoff to each lake, a term in the Henriksen model, was calculated both from traditional hydrometric methods and from analysis of heavy isotopes of oxygen (^{18}O) and (^{2}H) in each lake. In the latter technique, the natural evaporative enrichment of ^{18}O and ^{2}H in the lakes is used to partition water losses between evaporation and liquid outflow and hence derive an estimate of runoff (Gibson 2002, Gibson *et al*. 2002, Gibson and Edwards 2002). This technique utilizes a different set of assumptions from the hydrometric method which extrapolates water yields from one or more gauged catchments to the ungauged lake catchments. Water yields were provided by Dr. John Gibson (University of Victoria) from a research project funded by CEMA. The catchment areas of the 50 SAL lakes were also recalculated by Dr. Gibson using digital elevation data. Potential inaccuracies in the hydrometric method, especially in low-relief catchments, have long been recognized (WRS 2004). The isotopically-derived values of runoff were taken from a recent study by Bennett *et al.* (2008). Critical loads were calculated using both estimates of runoff and the values for comparisons. Detailed results of the isotopically-derived runoff values are provided in Appendix H.

The critical loads for each lake were compared with levels of the Potential Acid Input (PAI) to each lake basin taken as the modeled rate of acid deposition (Planned Development Case) for each lake published in the most recent environmental impact assessment for an oil sands development for which air modeling was conducted (RAMP 2009b). As listed values of PAI are generally unavailable for lakes in the Caribou Mountains and the Shield region, they were estimated from background PAI values (no industrial input) determined from RELAD modeling conducted by Alberta Environment in 2002.

Trends in Measurement Endpoints in Individual Lakes Potential trends in the ASL measurement endpoints were examined for all 50 lakes. The analysis involved Mann-Kendall trend analysis for each endpoint and lake using the MAKSENS program (Salmi *et al.* 2002). Significant trends were examined and discussed in relation to previous hydrological events and the logical consistencies (or inconsistencies) of these observed trends. The program calculates the Mann-Kendall statistic S on lakes having fewer than ten years of data. For lakes having at least ten years of data, a normal approximation test is applied to calculate the test statistic Z. Significant trends detected in the trend analysis were plotted in control charts as described below. The Mann-Kendall test is a non-parametric test which subtracts successive values and ranks the differences as negative or positive. Small monotonic increases or decreases in measurement endpoints that may not be significant ecologically or are within the range of analytical error can result in a false conclusion that a significant trend is occurring. To assist in interpreting the results of the trend analyses, control charts are provided of measurement endpoints in those lakes where significant changes occur in a direction indicative of acidification.

Control Charting of Measurement Endpoints in Individual Lakes pH, Gran alkalinity, sulphate, sum of base cations and nitrates, and dissolved organic carbon were charted in Shewhart control plots for the ten lakes deemed most at risk to acidification. Ten lakes were selected for control charting on the basis of a high ratio of PAI to CL, the greater is the risk for acidification. The control plots follow standard analytical control chart theory where control limits representing two and three standard deviations are plotted on the graphs with the points and the mean value (Gilbert 1987). The lines at two standard deviations represent warning limits while the lines at three standard deviations identify distinct outliers. A trend in the value of a measurement endpoint is often assumed if three consecutive points fall on the same side outside of the two standard deviation warning limits or one point outside of the three standard deviation control limit.

Supporting Analyses

The following supporting data analyses were also conducted, the results of which are presented in Appendix H:

- Analysis of variance (ANOVA) using the general linear model was also applied to the data to examine trends in measurement endpoints over time. The model was applied to the population of 50 lakes as well as subsets of the 50 lakes that included the various physiographic regions and those lakes determined as most likely to suffer acidification (high potential acid input/low critical load; see below). Finally the correlation coefficients of the endpoints regressed over time for each lake were examined and related to lake location and potential acid input at each location;

- Update of the ASL database, calculation of summary statistics, identification of lakes with unusual chemical characteristics and comparisons of the chemistry of the RAMP lakes in 2009 to the range of chemical characteristics of lakes within the Athabasca oil sands region; and

- Analysis of metals in the individual RAMP lakes with emphasis on those (e.g., aluminum) that are known to increase with acidification.

Update of the ASL Database, Summary Statistics and Comparisons of RAMP ASL Chemistry to Regional Lake Chemistry The chemical data from years when ASL monitoring was conducted were tabulated and summarized statistically. Lakes with unusual chemical characteristics were identified based on exceedances of the 5th and 95th

percentiles in values of measurement endpoints. The chemical characteristics of the ASL component lakes were compared to those of 450 regional lakes reported in the lake sensitivity mapping study produced for the NOxSOx Management Working Group (NSMWG; WRS 2004). Comparisons involved:

- Examination of the ranges, medians and mean values of key chemical variables for 2009 in the RAMP lakes relative to the regional dataset;
- Graphical presentation of both datasets in box plots; and
- Statistical comparison of chemical variables between the RAMP ASL lakes and the regional dataset.

Principal Components Analysis of the Regional Lake Database and the RAMP ASL Data Principal Components Analysis (PCA) was applied to the NSMWG regional lake database and the RAMP lakes in order to group the lakes into specific lake types or categories based on lake chemistry. These groupings were compared to those identified in Piper plots.

Analysis of Metal Concentrations in the RAMP ASL Lakes The total and dissolved metal fractions from eight years of monitoring by AENV (2001, 2003 to 2009) were tabulated and summarized statistically. Lakes having extreme mean metal concentrations were identified as those exceeding the 95th percentile concentration for individual metals; exceedances of the Alberta and CCME surface water quality guidelines were also identified (CCME 2007, AENV 1999b).

3.5.6.3 Classification of Results

A summary of the state of the ASL component lakes in 2009 with respect to the potential for acidification was prepared for each physiographic subregion by examining deviations from the mean chemical concentrations of the measurement endpoints for each lake within each subregion. The measurement endpoint and the relevant trend that is indicative of acidification are as follows: Gran alkalinity (downwards); pH (downwards); sum base cations (upwards); nitrates (upwards); dissolved organic carbon (downwards); sulphate (upwards); aluminum (upwards).

For each lake, the mean and standard deviation were calculated for each measurement endpoint over all the monitoring years. The number of lakes in 2009 within each subregion having measurement endpoint values greater than two standard deviations (SD) (above or below the mean as indicated above) was calculated. The number of such endpoint-lake exceedances was expressed as a percentage of the total number of lake-endpoint combinations for each subregion. The results were classified as follows:

- Negligible-Low: subregion has <2% endpoint-lake combinations exceeding ± 2 SD criterion;
- Moderate: subregion has 2% to 10 % endpoint-lake combinations exceeding ± 2 SD criterion; and
- High: subregion has > 10% of endpoint-lake combinations exceeding ± 2 SD criterion.

4.0 CLIMATIC AND HYDROLOGIC CHARACTERIZATION OF THE ATHABASCA OIL SANDS REGION IN 2009

The following characterization of the 2009 climate and hydrology of the Athabasca oil sands region and comparison with long-term values provides context for the results of the 2009 RAMP monitoring program. The comparison is based primarily on federal and provincial hydrologic monitoring stations because of the long data record available at those stations, but also relies on a number of the RAMP climate and snowpack monitoring stations for additional information.

4.1 PRECIPITATION AND SNOWPACK

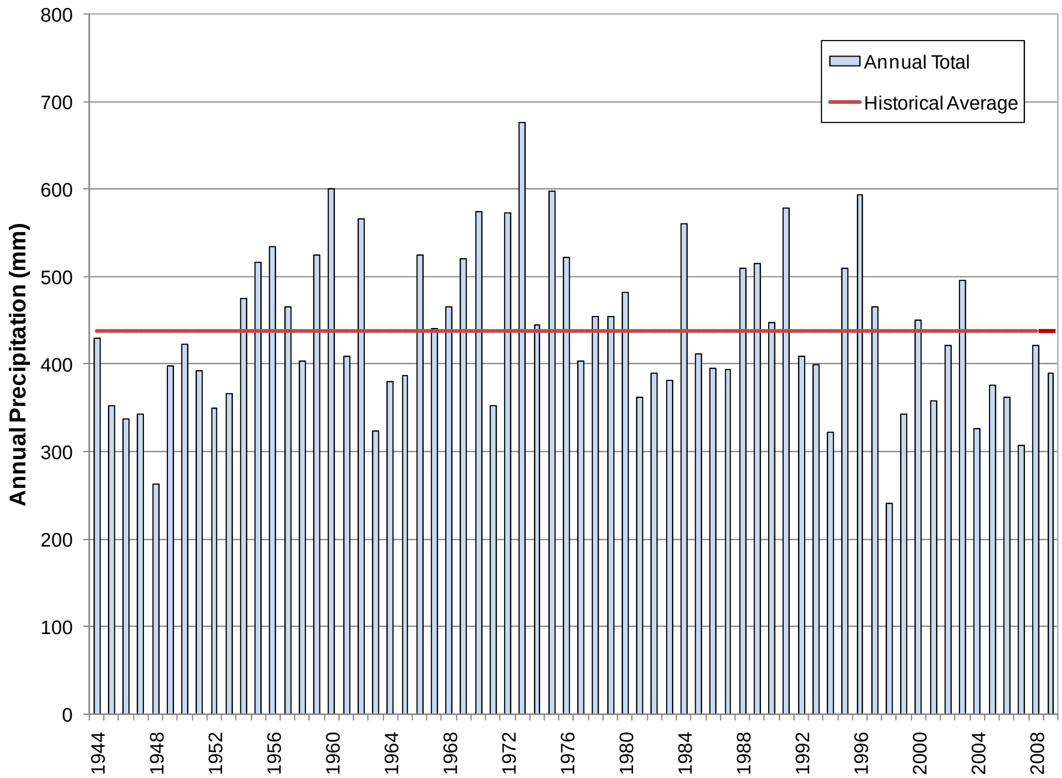
Precipitation records are available for Fort McMurray from 1944 to 2009 at Environment Canada station 3062693, Fort McMurray A, until July 2008 and EC station 3062700, Fort McMurray AWOS A thereafter. Total precipitation measured at this station in 2009 was 390 mm (Figure 4.1-1), which is 11% lower than the long-term annual average (from 1944 to 2008) of 438 mm, and represents the sixth consecutive year in which precipitation at this station was below average. Monthly total precipitation was below average in eight of 12 months in 2009 (January to March; May; July; and October to December) and was near historical minimum values in February and December 2009 (Figure 4.1-2).

Precipitation records for RAMP Stations C1–Aurora Climate Station, C2–Horizon Climate Station, L1–McClelland Lake Station, L2–Kearl Lake Station and S19–Tar River Lowland Station provide additional insight used to characterize 2009 conditions throughout the region. Daily precipitation and cumulative values at each of these stations is shown in Figure 4.1-3, including the 2009 and long-term average precipitation data from the EC Fort McMurray stations. No clear pattern of precipitation amount was evident through the entire year. Between January and mid-June, the most northerly climate station (L1–McClelland Lake Station) recorded consistently more precipitation than at other stations, but measurements ceased at this station on June 10. Many stations recorded their daily maximum precipitation amount on June 22, including 71 mm at L2–Kearl Lake Station, and 52 mm at C1–Aurora Climate Station, which was higher than at Fort McMurray AWOS A (32 mm). This amount at L2–Kearl Lake Station (also north of Fort McMurray) was sufficient to raise the cumulative precipitation amount beyond that of Fort McMurray AWOS A, until August 4.

A rainfall event of 38 mm occurred at Fort McMurray AWOS A on September 4, which did not exceed 5 mm at any other station. This raised the cumulative total at Fort McMurray AWOS A beyond the cumulative values at all other stations, to equal the long-term cumulative total at Fort McMurray A and AWOS A for September 4 (329 mm). Precipitation and cumulative amounts in the remaining months were lower than average at Fort McMurray AWOS A, and the final cumulative value for 2009 was 390 mm. Corresponding values at L2–Kearl Lake Station, C2–Horizon Climate Station, and C1–Aurora Climate Station were 335 mm, 332 mm and 310 mm; with values 14%, 15% and 20% respectively, lower than the Fort McMurray AWOS A value in 2009.

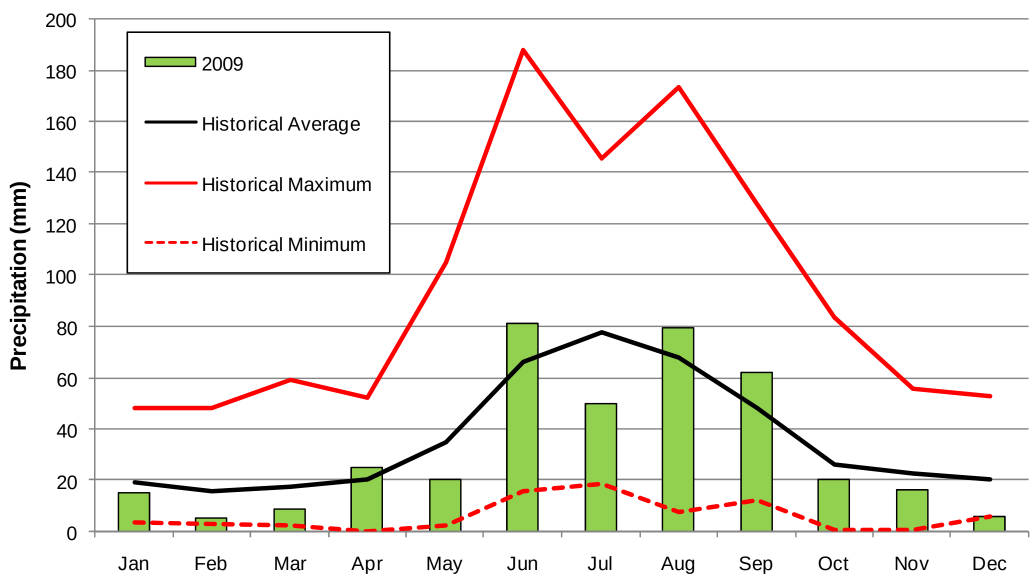
Snowpack amounts (in terms of snow water equivalent, SWE) were measured at 16 locations in February, March and April 2009 (Figure 3.1-1), including four surveys at each of four land category types. The maximum SWE values recorded for each category are presented in Figure 4.1-2, for each year since measurements began in 2004. Depending on land category, the 2009 maximum SWE amounts were 6% to 26% higher than the average maximum SWE values calculated from the 5-year period of historical record (2004 to 2008). The difference between land categories was also consistent when comparing the 2009 and 5-year historical averages, with most SWE occurring in flat low-lying areas, the least occurring in open land/lake areas, and intermediate amounts occurring in the two sub-canopy categories (mixed deciduous and jackpine stands).

Figure 4.1-1 Historical annual precipitation at Fort McMurray (1944 to 2009).



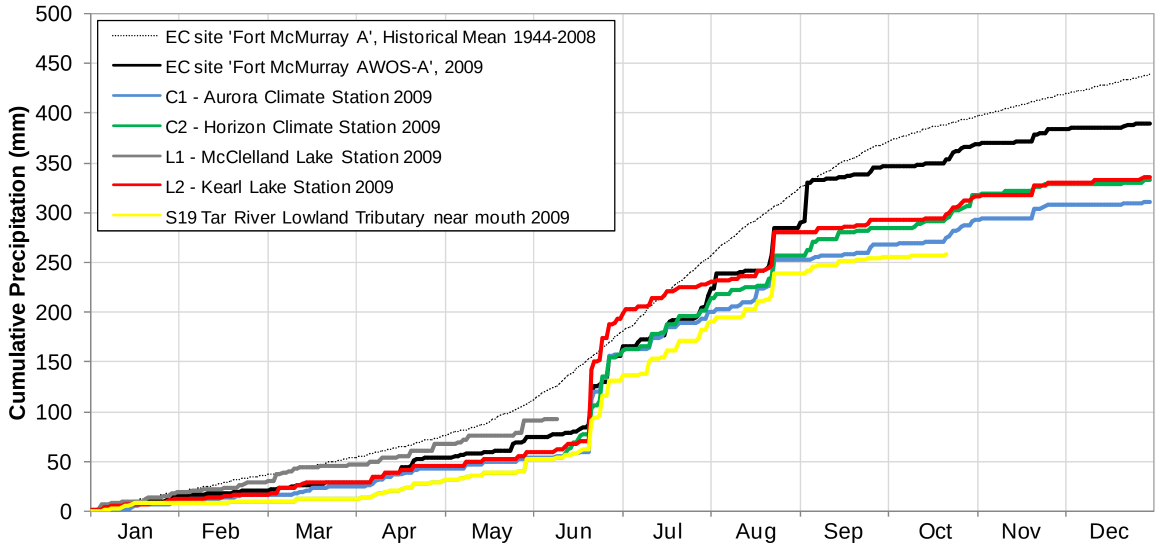
Note: Data recorded at Environment Canada (EC) station 3062693 (Fort McMurray A) from 1944 until July 2008, and then at EC station 3062700 (Fort McMurray AWOS A) thereafter.

Figure 4.1-2 Monthly precipitation at Fort McMurray in 2009.



Note: 2009 data recorded at Environment Canada station 3062700 (Fort McMurray AWOS A); historical values based on data from EC station 3062693 (Fort McMurray A) from 1944 until July 2008, and at AWOS A until December 31, 2008.

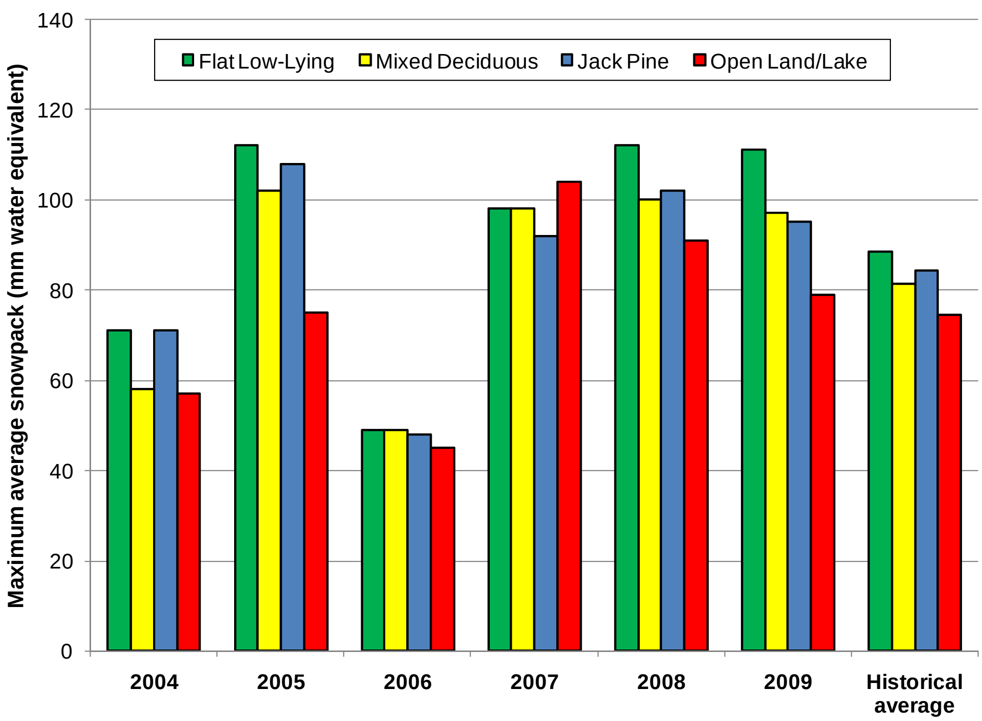
Figure 4.1-3 Cumulative total precipitation at climate stations in the Athabasca oil sands region in 2009.



Note: 2009 measurements began at station C2, Horizon Climate Station, on June 11. Until this date, precipitation was estimated for this station using the data from station S19, Tar River Lowland Tributary, located near station C2 and also within the Tar River watershed.

Note: Data were measured at station L1, McClelland Lake, until June 10.

Figure 4.1-4 Historical maximum measured snowpack amounts in the Athabasca oil sands region (2004 to 2009).



Note: Data from RAMP regional snowcourse surveys. Four snowcourses were sampled in each of four land categories (Figure 3.1-1), usually in February, March and April of each winter. The water equivalent values shown here represent the maximum monthly values recorded for each land category and year.

4.2 STREAMFLOW

2009 provisional hydrographs for four Water Survey of Canada (WSC) stations are presented and compared to long-term runoff statistics in order to characterize the 2009 hydrological conditions in four main areas of interest in the RAMP FSA:

- WSC Station 07DA001, Athabasca River below McMurray, representing the Athabasca River;
- WSC Station 07DA008, Muskeg River near Fort McKay, representative of watersheds east of the Athabasca;
- WSC Station 07DB001, MacKay River near Fort McKay, representative of watersheds west of the Athabasca; and
- WSC station 07CE002, Christina River near Chard, representative of watersheds south of Fort McMurray.

4.2.1 Athabasca River

The total annual runoff volume for the Athabasca River measured at WSC Station 07DA001, Athabasca River below McMurray, was 14,890 million m^3 in 2009 (Table 4.2-1). This is 24% less than the long-term average value of 19,653 million m^3 over the station's 52-year recording period (1958 to 2009), and is the eighth lowest-value to occur (Figure 4.2-1). Since 1991, all annual runoff values have been lower than this long-term average, with the exception of 1996, 1997 and 2005.

The flow measured at this station was lower than historical median values from January until mid-April (Figure 4.2-2). Melting of the snowpack in basins upstream of this station likely caused the sharp increase in flow measured in late April, peaking at 1,650 m^3/s on April 27. Thereafter, flow dropped below the median level again, until mid-July when the annual maximum daily flow of 1,780 m^3/s was recorded on July 14. This annual maximum value occurred approximately three weeks after the heavy rainfall event around June 22, and was 29% lower than the long-term average maximum daily flow value of 2,513 m^3/s. Flows from August 2009 onward were consistently at or below the historical lower quartile values. The 2009 open-water period (May 1 to October 31) minimum daily flow of 259 m^3/s recorded on October 21 was 39% lower than the historical average of 427 m^3/s (Table 4.2-1).

4.2.2 Muskeg River

The total seasonal (March to October) runoff volume for the Muskeg River watershed, recorded at WSC Station 07DA008, Muskeg River near Fort McKay, was 128 million m^3 (Table 4.2-1). This is 9% higher than the long-term average total seasonal runoff volume of 117 million m^3 over the station's 35-year recording period (Figure 4.2-3). The hydrograph for this location is typically dominated by the spring freshet following snowmelt (Figure 4.2-4), but this was not the case in 2009. During the freshet period, flow peaked at 13 m^3/s on April 25, approximately two weeks earlier than the normal freshet date in this basin. The maximum daily flow of 41.7 m^3/s occurred on July 2 shortly after the late-June rainfall event (Figure 4.2-4), which was 63% higher than the long-term average maximum daily flow of 25.6 m^3/s (Table 4.2-1). Streamflow from August to October was between the lower and upper quartile. The 2009 March to October minimum daily flow of 0.26 m^3/s recorded on March 10 was similar to the historical average of 0.27 m^3/s (Table 4.2-1).

4.2.3 MacKay River

The total seasonal (March to October) runoff volume for the MacKay River watershed recorded at WSC Station 07DB001, MacKay River near Fort McKay, was 509 million m^3 (Table 4.2-1). This is the highest-recorded total seasonal runoff volume since 1997, although total season runoff volume was similar in 2005 and 2008, and is 19% greater than the long-term average of 428 million m^3 (Figure 4.2-5). The spring freshet recorded for the MacKay River was more distinct than for the Muskeg River, with a maximum-recorded flow of 99 m^3/s on April 25 (Figure 4.2-6). The annual maximum daily flow of 120 m^3/s occurred following the rainfall event in late June and was slightly higher than the annual maximum daily flows recorded at this station (Table 4.2-1). Following the late June event, flows dropped below median flow values on July 27 and remained below median flows until the end of October, with the exception of four days in late August (Figure 4.2-6). The 2009 March to October minimum daily flow of 0.65 m^3/s recorded on March 10 was almost double the historical average minimum daily flow of 0.35 m^3/s (Table 4.2-1).

4.2.4 Christina River

The total seasonal (March to October) runoff volume for the Christina River watershed recorded at WSC station 07CE002, Christina River near Chard, was 495 million m^3 (Table 4.2-1). This is 18% higher than the long-term average total seasonal runoff volume of 411 million m^3 over the 26-year recording period, and is the sixth consecutive year of above-average seasonal runoff volumes recorded at this station (Figure 4.2-7). Melting of the spring snowpack dominated the hydrograph in this basin (Figure 4.2-8), and the annual maximum daily flow of 129 m^3/s recorded on April 25 was the highest daily streamflow ever recorded for April at this station (Figure 4.2-8). This flow was 60% higher than historical average maximum daily flows recorded at this station (81 m^3/s, Table 4.2-1).

Flows receded through May, until the end of May when a small rise was recorded, which was not observed at the Muskeg River or MacKay River stations. Additionally, there was no discernable rise in the Christina River hydrograph following the late June rainfall event, which dominated the hydrograph at these other stations. These features suggest that precipitation patterns experienced for this period in the Christina River watershed may have been different than at other locations in the Athabasca River basin. From mid-June until the end of October (Figure 4.2-8), streamflow was near historical median flows. The 2009 March to October minimum daily flow of 2.65 m^3/s recorded on March 11 was 15% higher than the historical average minimum daily flow of 2.30 m^3/s (Table 4.2-1).

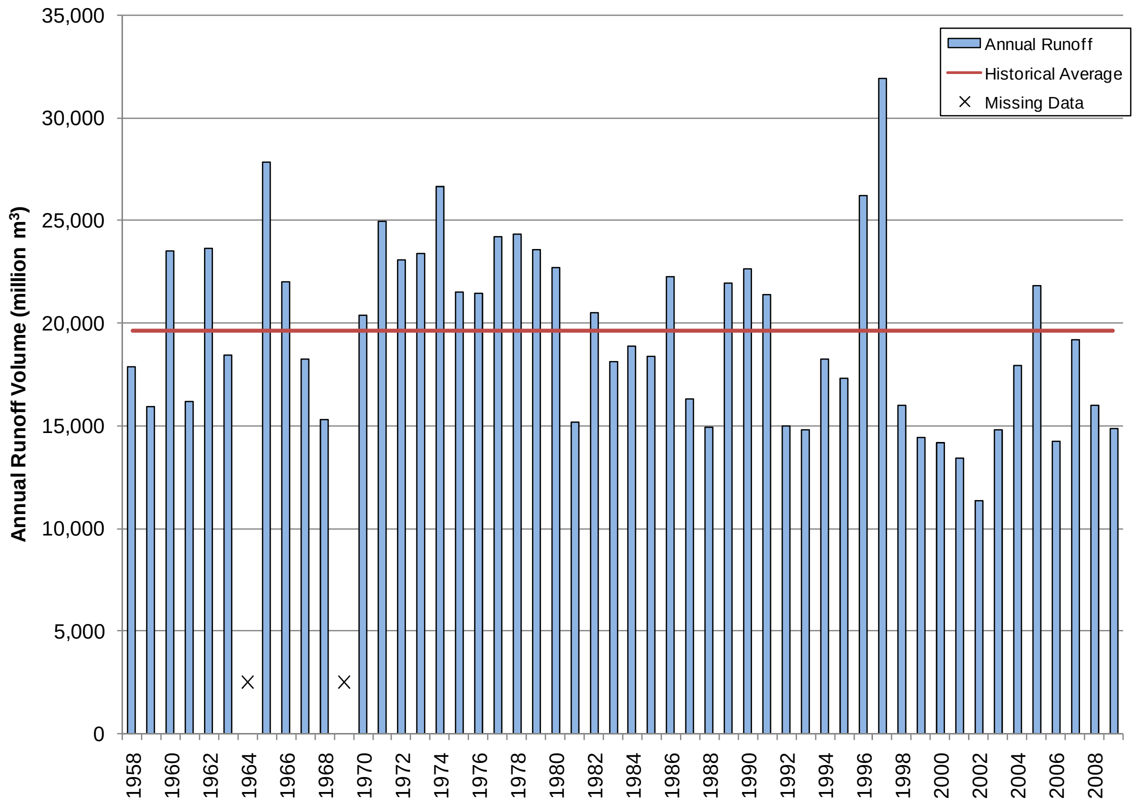
Table 4.2-1 Summary of 2009 streamflow variables compared to historical values measured in the Athabasca oil sands region.

	Athabasca River below Fort McMurray (07DA001)	Muskeg River near Fort McKay (07DA008)	MacKay River near Fort McKay (07DB001)	Christina River near Chard (07CE002)
Effective Drainage Area (km^2)	132,585	1,457	5,569	4,863
Period of Record	1958 - 2009	1974 - 2009	1973 - 2009	1983 - 2009
Runoff Volume[1]				
Historical mean (million m^3)	19,653	117	428	419
2009 (million m^3)	14,890	128	509	495
Maximum Daily Discharge[1]				
Historical mean (m^3/s)	2,513	25.6	116.6	80.6
2009 (m^3/s)	1,780	41.7	120.0	129.0
Minimum Daily Discharge[2]				
Historical mean (m^3/s)	132	0.27	0.35	2.30
2009 (m^3/s)	111	0.26	0.65	2.65

[1] Annual runoff volume and maximum daily discharge provided for the Athabasca River below Fort McMurray (07DA001), while seasonal (March to October) runoff volume and maximum daily flow are provided for the other three stations.

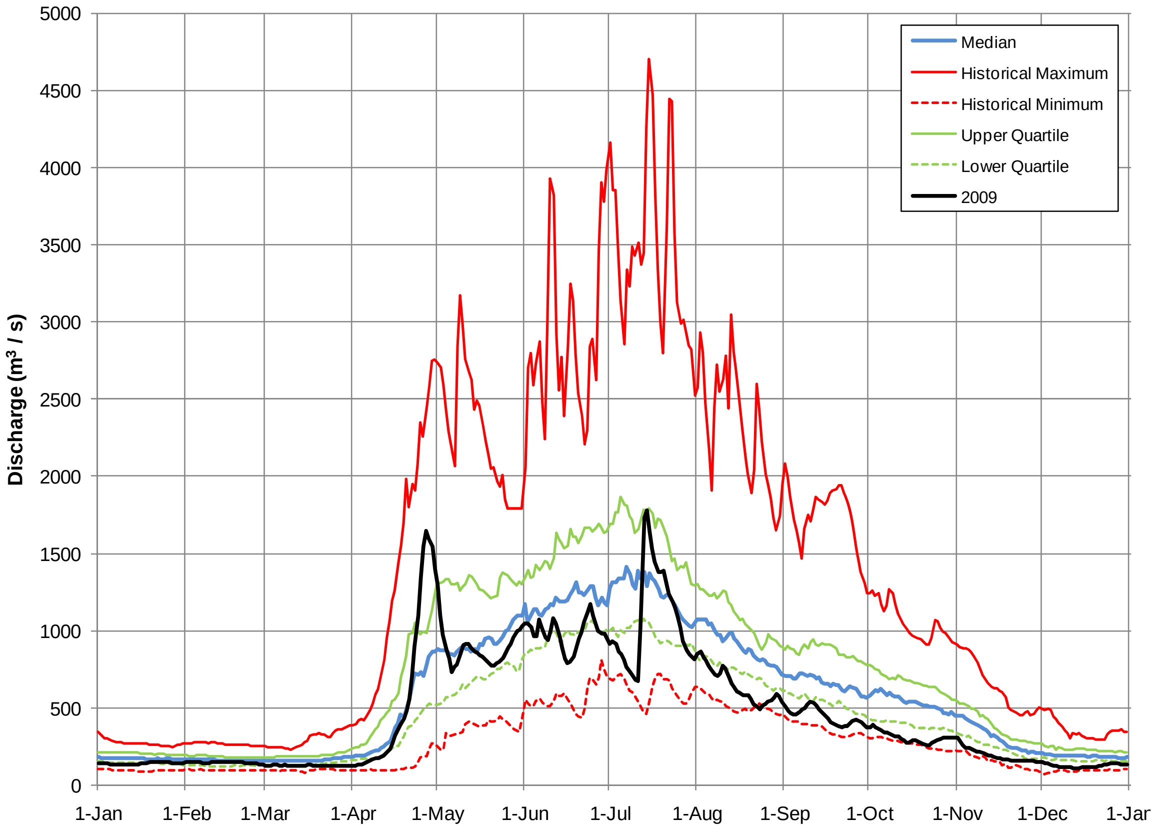
[2] Open-water (May to October) minimum daily discharge provided for the Athabasca River below Fort McMurray (07DA001), while seasonal (March to October) minimum daily discharge are provided for the other three stations.

Figure 4.2-1 Historical annual runoff volume in the Athabasca River basin, 1958 to 2009.



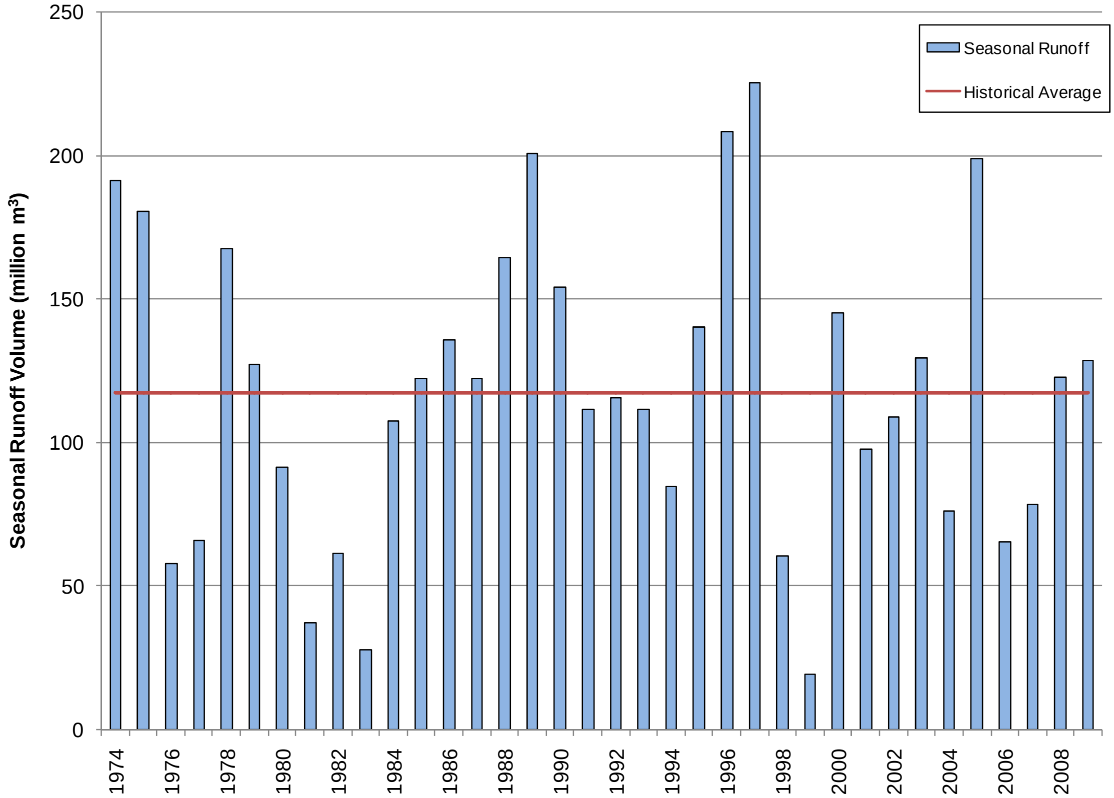
Note: Based on provisional data recorded from 1958 to 2009 at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2.

Figure 4.2-2 The 2009 Athabasca River hydrograph compared to historical values.



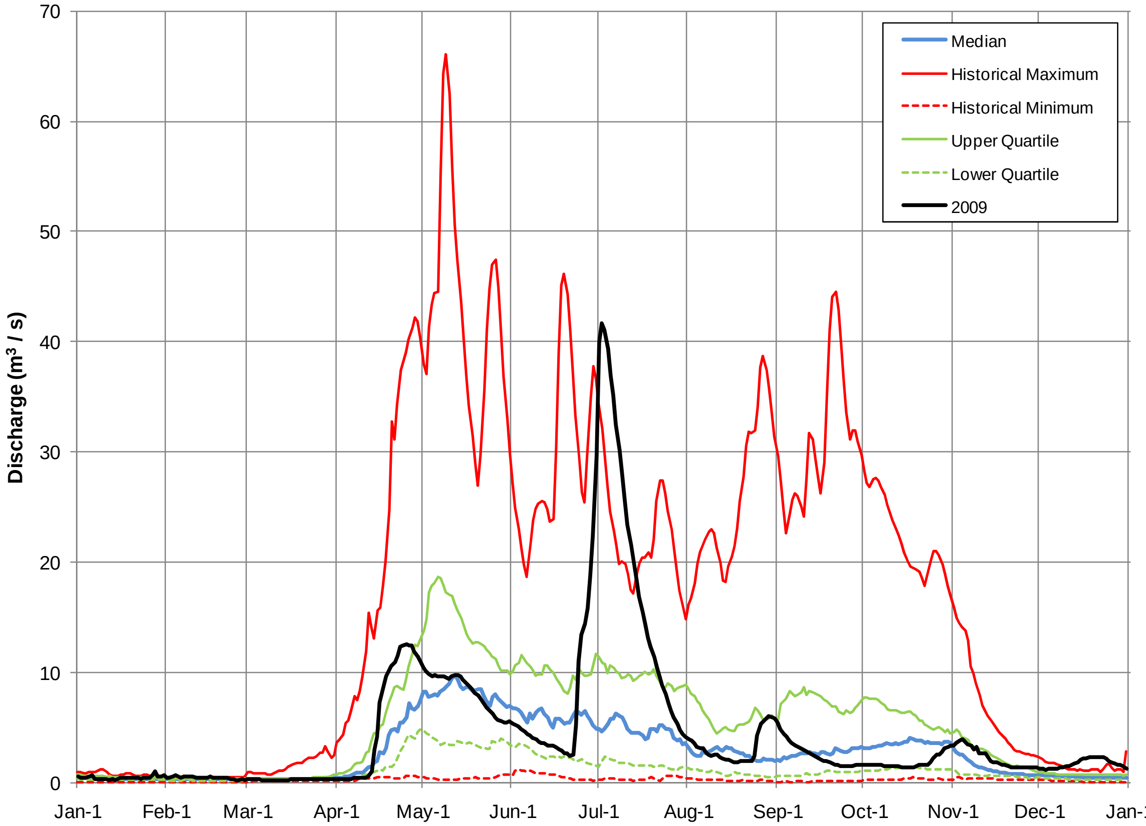
Note: Based on provisional data recorded at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2. Historical values were calculated for the period 1958 to 2008.

Figure 4.2-3 Historical seasonal (March to October) runoff volume in the Muskeg River basin, 1974 to 2009.



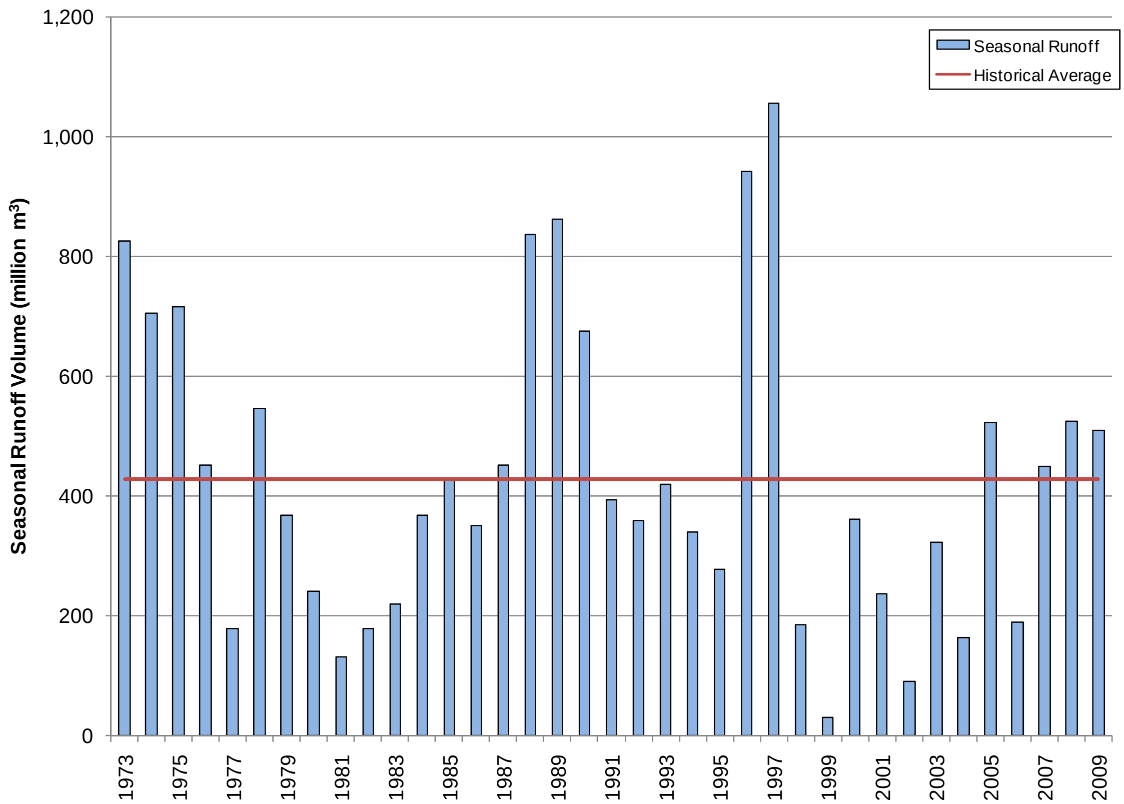
Note: Based on provisional data recorded from 1974 to 2009 at WSC Station 07DA008, Muskeg River near Fort MacKay; the upstream drainage area is 1,457 km^2.

Figure 4.2-4 The 2009 Muskeg River hydrograph compared to historical values.



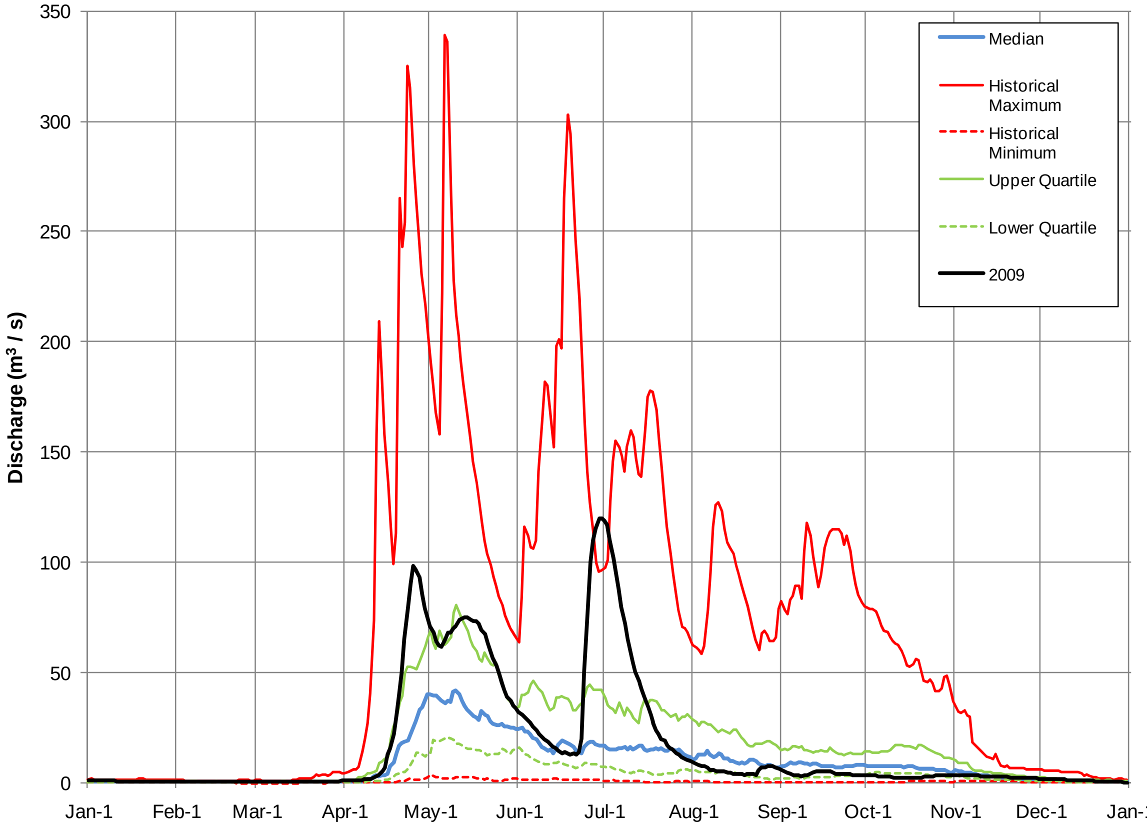
Note: Based on provisional data recorded at WSC Station 07DA008, Muskeg River near Fort MacKay; the upstream drainage area 1,460 km^2. Historical values were calculated for the period 1974 to 2008.

Figure 4.2-5 Historical seasonal (March to October) runoff volume in the MacKay River basin, 1973 to 2009.



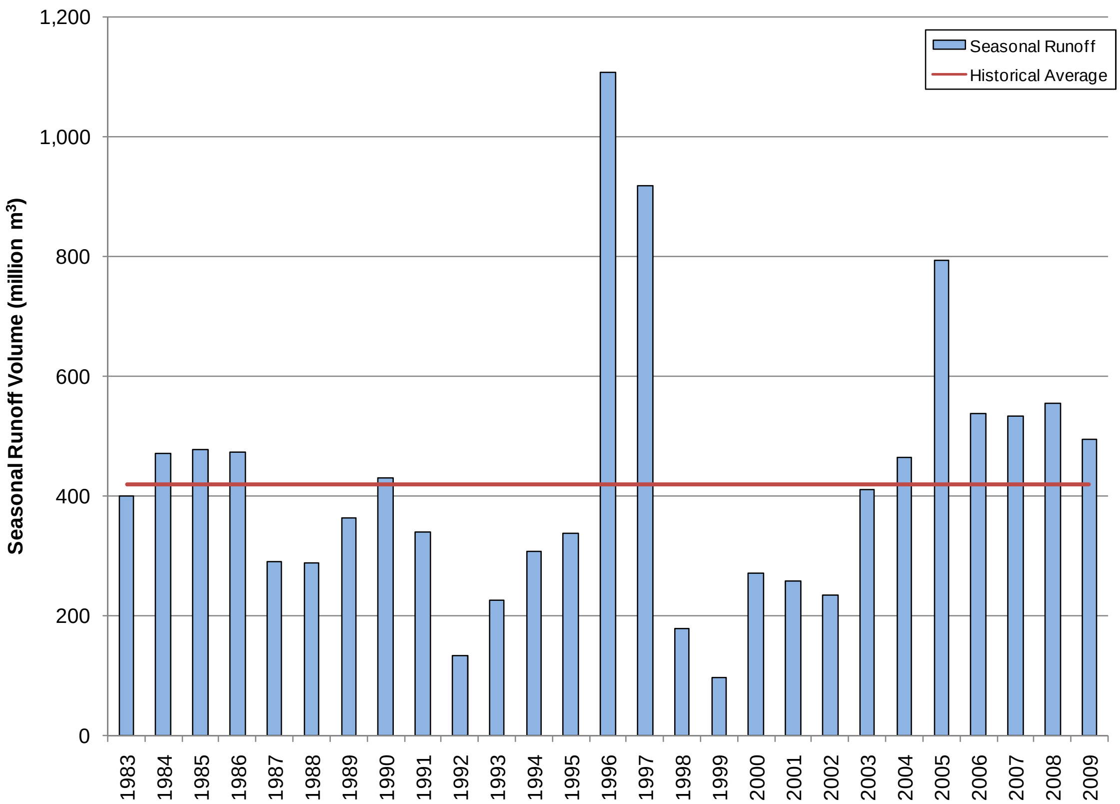
Note: Based on provisional data recorded from 1973 to 2009 at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2.

Figure 4.2-6 The 2009 MacKay River hydrograph compared to historical values.



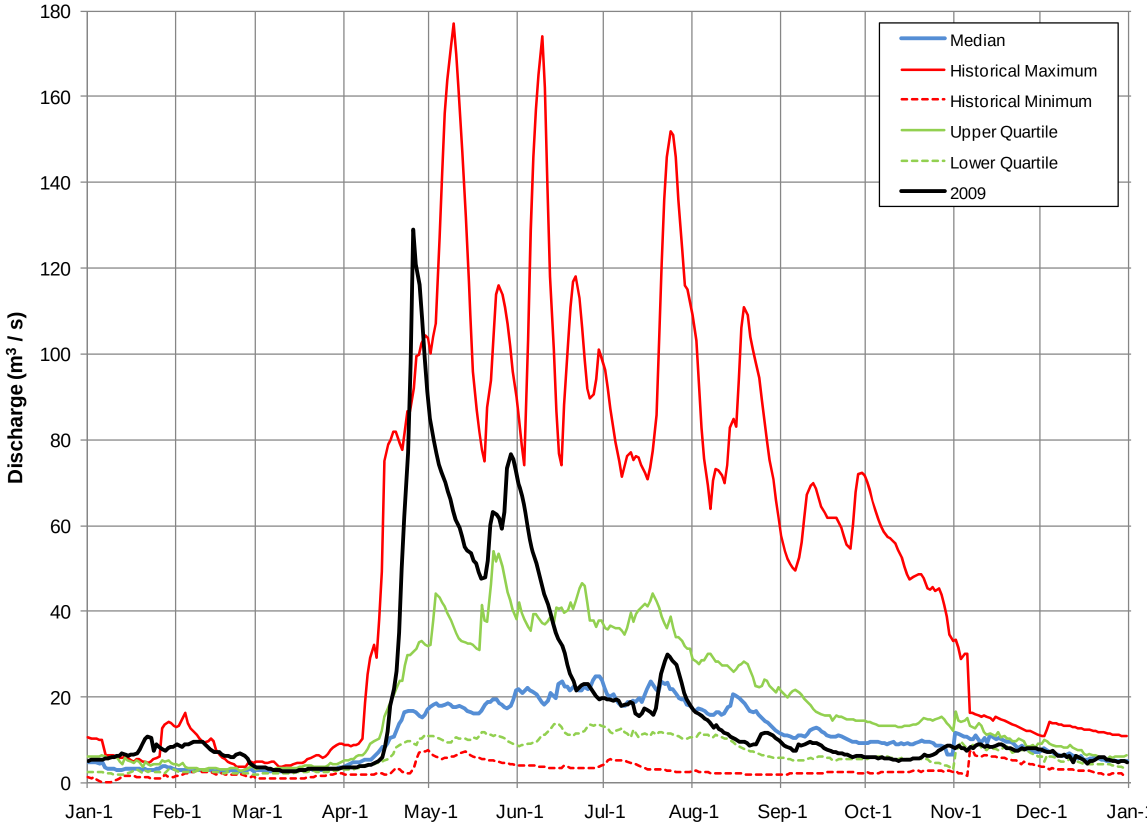
Note: Based on provisional data recorded at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2. Historical values were calculated for the period 1973 to 2008.

Figure 4.2-7 Historical seasonal (March-October) runoff volume in the Christina River basin, 1983 to 2009.



Note: Based on provisional data recorded from 1983 to 2009 at WSC Station 07CE002, Christina River near Chard; the upstream drainage area is 4,863 km^2.

Figure 4.2-8 The 2009 Christina River hydrograph compared to historical values.



Note: Based on provisional data recorded at WSC Station 07CE002, Christina River near Chard; the upstream drainage area is 4,863 km^2. Historical values were calculated for the period 1983 to 2008.

4.3 SUMMARY

In summary, climate and hydrology in the RAMP FSA in 2009 was characterized by:

1. Annual precipitation measured at Fort McMurray that was slightly lower than the historical average, with monthly total precipitation below average in eight of 12 months and near historical minimum values in February and December 2009 with the largest precipitation event of 2009 occurring on June 22.

2. A runoff volume for WSC Station 07DA001, Athabasca River below McMurray, which was the eighth-lowest in the 52-year record period, continuing a trend of below average annual flows for much of the past two decades.

3. Average total runoff volumes that were slightly above historical seasonal average values for the Muskeg, MacKay and Christina River watersheds, with annual maximum daily flows that were determined by snowmelt (Christina River), summer rainfall (Muskeg River), or a combination of snowmelt and rainfall (MacKay River).

4. Annual minimum and maximum daily flow values recorded for the Muskeg, MacKay and Christina River basins that were between average and almost double the corresponding long-term average values observed for these locations.

5.0 2009 RESULTS FOR INDIVIDUAL WATERSHEDS

This is the main results section of the RAMP 2009 Technical report. Section 5.1 presents 2009 results for the Athabasca River and the Athabasca River Delta; Sections 5.2 to 5.11 present 2009 results for the major tributaries of the Athabasca River in the RAMP Focus Study Area (FSA); Section 5.12 contains the 2009 results for miscellaneous aquatic systems throughout the RAMP FSA that were monitored in 2009.

Table 5-1 Page number guide to watersheds and RAMP component reports.

	Athabasca River and Delta	Muskeg	Steepbank	Tar	MacKay	Calumet	Firebag	Ells	Clearwater-Christina	Hangingstone	Horse	Miscellaneous Aquatic Systems
Climate and Hydrology	5-6	5-84	5-169	5-209	5-232	5-259	5-281	5-305	5-318	5-368	5-374	5-386
Water Quality	5-7	5-86	5-170	5-210	5-232	5-260	5-282	5-306	5-319	-	5-374	5-386
Benthic Invertebrate Communities	5-10	5-89	5-172	5-211	5-234	5-261	5-283	5-306	5-321	-	5-375	5-386
Sediment Quality	5-11	5-93	5-172	5-211	5-235	5-262	5-284	5-306	5-322	-	5-376	5-386
Fish Populations	5-13	5-95	5-173	5-213	5-236	5-263	5-285	5-307	5-323	-	5-376	5-386

Definitions for Monitoring Status

The RAMP 2009 Technical Report uses the following definitions for monitoring status:

- ***Test*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches) downstream of a focal project; data collected from these locations are designated as *test* for the purposes of analysis, assessment, and reporting. The use of this term does not imply or presume that effects are occurring or have occurred, but simply that data collected from these locations are being tested against *baseline* conditions to assess potential changes; and

- ***Baseline*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 2009) or were (prior to 2009) upstream of all focal projects; data collected from these locations are to be designated as *baseline* for the purposes of data analysis, assessment, and reporting. The terms *test* and *baseline* depend solely on the location of the aquatic resource in relation to the location of the focal projects to allow for long-term comparison of trends between *baseline* and *test* stations.

5.1 ATHABASCA RIVER AND ATHABASCA RIVER DELTA

Table 5.1-1 Summary of Results for Athabasca River and Athabasca River Delta.

Athabasca River and Delta	Summary of 2009 Conditions												
	Athabasca River									*Athabasca Delta*			
Climate and Hydrology													
Criteria							**S24** below Eymundson Creek			no stations sampled			
Mean open-water season discharge							○						
Mean winter discharge							○						
Annual maximum daily discharge							○						
Minimum open-water season discharge							○						
Water Quality													
Criteria	**ATR-DC-E** upstream of Donald Creek (east bank)	**ATR-DC-W** upstream of Donald Creek (west bank)	**ATR-SR-E** upstream of Steepbank River (east bank)	**ATR-SR-W** upstream of Steepbank River (west bank)	**ATR-MR-E** upstream of Muskeg River (east bank)	**ATR-MR-W** upstream of Muskeg River (west bank)	**ATR-DD-E** downstream of all development (east bank)	**ATR-DD-W** downstream of all development (west bank)	**ATR-FR-CC** upstream of Firebag River	no stations sampled			
Water Quality Index	○	○	○	○	○	○	○	○	○				
Benthic Invertebrate Communities and Sediment Quality													
Criteria	no reaches sampled									**FLC** Fletcher Channel	**GIC** Goose Island Channel	**BPC** Big Point Channel	**ATR-ER** Athabasca River downstream of Embarras River
Benthic Invertebrate Communities										○	○	○	n/a
Sediment Quality Index										○	○	○	○
Fish Populations													
No Fish Population component fish tissue activities conducted in 2009													

Legend and Notes

○ Negligible-Low

● Moderate

● High

baseline (green)

test (blue)

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

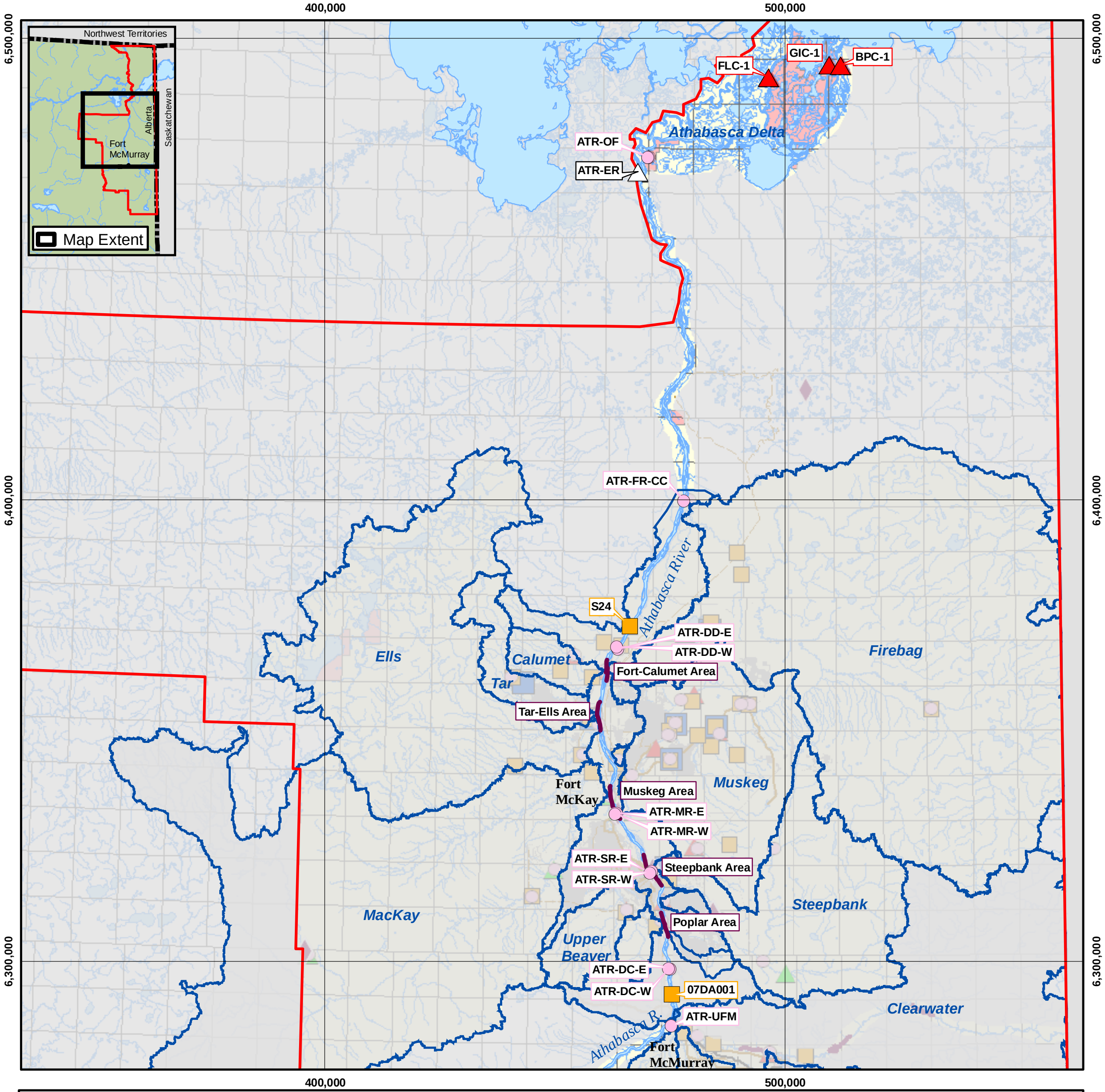
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Figure 5.1-1 Athabasca River and Athabasca River Delta.



LEGEND

Lake/Pond	Climate Station
River/Stream	Hydrometric Station
Watershed Boundary	Water Quality Sampling Station
Major Road	Benthic Invertebrate Community Sampling Reach
Secondary Road	Benthic Invertebrate Community Sampling Reach and Sediment Quality Sampling Station
Railway	Sediment Quality Sampling Station
First Nations Reserve	Fish Sampling Site
RAMP Regional Study Area	Fish Sampling Reach
RAMP Focus Study Area	
Land Change Area	

RAMP
Regional Aquatics Monitoring Program

0 10 20 40 Km

Scale 1:1,400,000

Projection: UTM Zone 12 NAD83

Land Change Areas Delineated from 10m SPOT-5 (June, July and August 2009) Multispectral Imagery.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K01_Mainstem_20100415.mxd

Figure 5.1-2 Representative monitoring stations of the Athabasca River and Athabasca River Delta, fall 2009.

Benthic and Sediment Quality Station BPC-1: Athabasca River Delta – Big Point Channel

Benthic and Sediment Quality Station FLC-1: Athabasca River Delta – Fletcher Channel

Benthic and Sediment Quality Station GIC-1: Athabasca River Delta – Goose Island Channel

Water Quality Station ATR-FR-W: Athabasca River upstream of Firebag River

Water Quality Station ATR-DC-W: Athabasca River at Donald Creek

Water Quality Station ATR-SR-W: Athabasca River downstream of Steepbank River

Water Quality Station ATR-MR-W: Athabasca River downstream of Muskeg River

Water Quality Station ATR-MR-E: Athabasca River upstream of Muskeg River

5.1.1 Summary of 2009 Conditions

As of 2009, approximately 2.3% (82,000 ha) of the RAMP FSA had undergone land change from focal projects and other oil sands developments (Table 2.4-2). Approximately 21% (34,000 ha) of the minor Athabasca River tributary watersheds had undergone land change as of 2009 from focal projects and other oil sands developments (Table 2.4-2) For 2009, the confluence of McLean Creek with the Athabasca River demarcates the *baseline* (upstream) and *test* (downstream) portions of the Athabasca River.

Table 5.1-1 is a summary of the 2009 assessment for the Athabasca River and Athabasca River Delta, while Figure 5.1-1 denotes the location of the monitoring stations for each RAMP component and the land change area for 2009. Figure 5.1-2 contains fall 2009 photos of a number of monitoring stations in the Athabasca River and Athabasca River Delta.

Hydrology The observed 2009 discharge for the Athabasca River is estimated to be 0.85% less than the *baseline* discharge would have been in the absence of focal projects. The mean open-water period (May to October) discharge, open-water minimum daily discharge, annual maximum daily discharge, and mean winter discharge calculated from the observed *test* hydrograph are 0.7%, 1.2%, 0.4% and 1.7% lower, respectively, than from the estimated *baseline* hydrograph. These differences are all classified as **Negligible-Low**. The results of the hydrologic assessment are the essentially identical to these results in the case in which focal projects plus other oil sands developments are considered.

Water Quality In fall 2009, water quality at *test* and *baseline* stations in the Athabasca River were assessed as having **Negligible-Low** differences from regional *baseline* water quality conditions. Concentrations of water quality measurement endpoints at *test* stations were similar to those at *baseline* stations and were consistent with regional *baseline* concentrations. There were no consistent patterns between *baseline* and *test* stations in the selected water quality measurement endpoints. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem was consistent with previous sampling years, showing little year-to-year variation.

Benthic Invertebrate Communities and Sediment Quality The variations in benthic invertebrate community measurement endpoints in the ARD reaches are classified as **Negligible-Low** because the measurement endpoints in fall 2009 were within the range of historical values for these reaches, and there are no trends over time in the measurement endpoints indicating a degradation of community composition. Sediment quality at stations in the ARD exhibited **Negligible-Low** differences from regional *baseline* sediment quality conditions because concentrations of sediment quality endpoints in fall 2009 were generally within previously-measured ranges.

Fish Populations Seasonal patterns were observed in species dominance among years with white sucker dominating the spring catch over the last three years, and the increasing dominance of goldeye in summer since 1997. Goldeye and walleye have dominated the catch in fall among years. As of 2009, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, length-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition and length-frequency distribution for all KIR species. However, the variability of these measurement endpoints among years does not indicate consistent negative or positive changes in the fish populations and likely reflect natural variability across time.

5.1.2 Hydrologic Conditions

2009 Hydrologic Conditions: Station S24, Athabasca River below Eymundson Creek
The annual runoff volume for the Athabasca River watershed, recorded at Station S24 was 16,321 million m^3. The open-water period (May to October) runoff volume of 11,767 million m^3 was 17% lower than the historical average open-water runoff volume. Flows from January 1 until mid-March were above the historical upper quartile and were recorded above historical maximum values for eight days in January (Figure 5.1-3). Flows during April increased due to snowmelt, reaching a peak of 1,542 m^3/s on April 22 that was close to the previous maximum value recorded on this date. Flows in May and June were generally between historical lower quartile to median values, and increased to reach the annual maximum value of 1,766 m^3/s on July 14. This flow was 17% lower than the mean historical annual maximum daily flow recorded at this station. Flows then generally decreased from the beginning of August until the end of the year, and were typically below historical median values, with four and 20 days below historical minimum values in August and October, respectively. The minimum open-water daily flow of 278 m^3/s recorded on October 23 was 25% lower than the corresponding historical average.

2009 flows at Station S24 were consistent with those observed upstream at WSC Station 07DA001, Athabasca River below Fort McMurray (see Section 4.2.1). The runoff volume, open-water minimum and annual maximum daily flow at WSC Station 07DA001 in 2009 were also below corresponding historical values for this station.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph
The estimated water balance at Station S24 in 2009 is presented for two different cases in Table 5.1-2. The first case considers changes from focal projects and the second case considers changes from focal projects plus other oil sands developments. The second case can be considered as the cumulative hydrologic assessment in 2009 for all oil sands developments in the Athabasca River watershed upstream of Station S24. In both cases land changes in the Firebag River watershed were included even though the confluence of the Firebag River with the Athabasca River is below Station S24. This approach is conservative in that differences between the observed *test* and estimated *baseline* hydrographs for Station S24 presented below are greater than they would actually be because of the assumptions made about Firebag River flows.

A summary of the inputs to the water balance model for the Athabasca River for the focal projects is provided below and in Table 5.1-2:

1. The closed-circuited area from focal projects in the minor Athabasca River tributaries, McLean Creek, Shipyard Lake and upper Beaver River as of 2009 is estimated at 320 km^2 (Table 2.4-1). The loss of flow to the Athabasca River that would have otherwise occurred from this land area is estimated at 36.1 million m^3.

2. The land area not closed-circuited from focal projects in the minor Athabasca River tributaries, McLean Creek, Shipyard Lake and upper Beaver River as of 2009 was estimated at 99.2 km^2 (Table 2.4-1). The increase in flow to the Athabasca River that would not have otherwise occurred from this land area is estimated at 2.2 million m^3.

3. Water withdrawals directly from the Athabasca River by focal projects in 2009 are reported at 106.3 million m^3.

4. Water discharges directly to the Athabasca River by focal projects in 2009 are reported at 3.4 million m^3.

5. The discharge into the Athabasca River in 2009 in the major Athabasca River tributaries (Calumet River, Christina River, Ells River, Firebag River, Fort Creek, MacKay River, Mills Creek, Muskeg River, Poplar Creek, Steepbank River, and Tar River) is estimated to be 3.1 million m^3 less than it would have been in the absence of focal projects in those watersheds.

The estimated cumulative effect is a loss of flow of 139.9 million m^3 at Station S24 from what the estimated *baseline* flow would have been in the absence of focal projects. The estimated *baseline* hydrograph is presented in Figure 5.1-3.

The mean open-water period (May to October) discharge, open-water minimum daily discharge, annual maximum daily discharge, and mean winter discharge calculated from the observed *test* hydrograph are 0.7%, 1.2%, 0.4% and 1.7% lower, respectively, than from the estimated *baseline* hydrograph (Table 5.1-3). These differences are all classified as **Negligible-Low** (Table 5.1-1).

The inputs to the water balance model for the Athabasca River for the second case - focal projects plus other oil sands developments are the same as the first case (focal projects only) plus the effects of other oil sands developments in the Horse River, Hangingstone River and Christina River watersheds, which are the only watersheds in the RAMP FSA that contained other oil sands developments under construction or operational as of 2009 (Table 2.4-1).

The estimated cumulative effect is a loss of flow of 140.0 million m^3 at Station S24 from what the estimated *baseline* flow would have been in the absence of focal projects plus oil sands developments (Figure 5.1-3); this compares to 139.9 million m^3 when considering focal projects only. The changes to the hydrologic measurement endpoints are essentially identical between the two cases (Table 5.1-3); the differences caused by focal projects plus other oil sands developments are classified as **Negligible-Low** (Table 5.1-1).

5.1.3 Water Quality

In 2009, water quality samples were taken from:

- upstream of Donald Creek, east and west banks, in winter and fall (*baseline* stations ATR-DC-E, ATR-DC-W, data available most years from 1997 to 2009);
- upstream of the Steepbank River, east and west banks, in fall (*test* stations ATR-SR-E and ATR-SR-W, data available from 2000 to 2009);
- upstream of the Muskeg River, east and west banks, in fall (*test* stations ATR-MR-E and ATR-MR-W, data available most years from 1998 to 2009);
- "downstream of development" (near Susan Lake), east and west banks, in winter, spring, summer and fall (*test* stations ATR-DD-E and ATR-DD-W, data available from 2002 to 2009); and
- upstream of the Firebag River, cross-channel composite sample, in fall (*test* station ATR-FR-CC, data available from 2002 to 2009).

Concentrations of water quality measurement endpoints measured in fall 2009 in the Athabasca River mainstem are provided in Table 5.1-4. Historical trends in selected measurement endpoints (1997 to 2009), relative to regional *baseline* conditions, are shown in Figure 5.1-4 to Figure 5.1-7. Table 5.1-5 lists all seasonal water quality guideline exceedances observed in 2009. Stations ATR-DD-W and ATR-DD-E, are the only stations in the Athabasca River that were sampled by RAMP in all seasons in 2009 (monthly sampling of Athabasca River water quality is undertaken by AENV, upstream of Fort McMurray and near the Athabasca River Delta (ARD) at Old Fort, as discussed later in this section). Figure 5.1-8 presents the ionic composition of water sampled in the Athabasca River under RAMP from 1997 to 2009. Table 5.1-6 and Figure 5.1-9 contains graphical and tabular results, respectively, of the trend analysis conducted on water quality measurement endpoints at AENV water quality monitoring stations in the Athabasca River mainstem. Table 5.1-7 contains calculated 2009 water quality index values for the Athabasca River mainstem stations.

2009 Results Relative to Historical Ranges and Regional *Baseline* Concentrations Concentrations of most water quality measurement endpoints in the Athabasca River mainstem in fall 2009 were within the range of historical observations, and within the range of regional *baseline* concentrations (Table 5.1-4, Figure 5.1-4 to Figure 5.1-7), with the following exceptions:

1. Total nitrogen exceeded previously-measured maximum concentration at *baseline* station ATR-DC-E and *test* station ATR-MR-W.

2. Total boron at *test* station ATR-MR-W was approximately twice as high as historical median concentrations.

3. Naphthenic acids at all stations in the Athabasca River were below the historical minima, but this was due to greatly improved detection limits for this analysis in 2009.

4. Total strontium and calcium at baseline station ATR-DC-W exceeded the 95th percentile of regional *baseline* concentrations.

5. Total nitrogen at *test* station ATR-MR-E exceeded the 95th percentile of regional *baseline* concentrations.

6. Dissolved phosphorus at *baseline* station ATR-DC-W and *test* station *ATR*-SR-W were below the 5th percentile of regional *baseline* concentrations.

Differences in water quality are evident between the west and east banks of the Athabasca River, likely due to the influence of the Clearwater River, which joins the Athabasca River along its east bank at Fort McMurray and mixes slowly into the Athabasca River. The differences in water quality generally persists for long distances downstream, only becoming indiscernible in 2009 in data collected by the Water Quality component at *test* stations ATR-DD, which is located downstream of Fort Creek and the Calumet River (Figure 5.1-1).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of all water quality measurement endpoints were below water quality guidelines in fall 2009 with the exception of total aluminum at all water quality stations in the Athabasca River mainstem and total nitrogen at *test* station ATR-MR-E (Table 5.1-4).

Other Water Quality Guideline Exceedances The other water quality guideline exceedances measured in the Athabasca River mainstem in fall 2009 were total iron at all

Athabasca River mainstem stations and sulphide at *test* stations ATR-DD-E, ATR-DD-W, and ATR-FR-CC (Table 5.1-5).

The water quality guideline exceedances in the Athabasca River mainstem in winter 2009 were dissolved selenium, total selenium, total iron at *test* stations ATR-DD-E and ATR-DD-W and total aluminum at *baseline* station ATR-DC-E (Table 5.1-5).

The water quality guideline exceedances in the Athabasca River mainstem in spring 2009 were sulphide, total phenolics, total phosphorus, total aluminum, and total iron at *test* station ATR-DD-E and sulphide, total phenolics, total phosphorus, total Kjeldahl nitrogen, total nitrogen, total aluminum, and total iron at *test* station ATR-DD-W (Table 5.1-5).

The water quality guideline exceedances in the Athabasca River mainstem in summer 2009 were total phenolics, total Kjeldahl nitrogen, total nitrogen, total aluminum, total iron and total phosphorus at *test* station ATR-DD-E and total aluminum, total iron and total phosphorus at *test* station ATR-DD-W (Table 5.1-5).

Ion Balance The ionic composition of water sampled in fall 2009 at all stations in the Athabasca River was consistent with the ionic composition of the Athabasca River mainstem since 1997, and was dominated by calcium and bicarbonate (Figure 5.1-8). Periodically, including fall 2009, water samples collected near the east bank of the Athabasca River, especially from *baseline* station ATR-DC-E, had a greater proportion of sodium and chloride ions compared to other stations in the Athabasca River, which is likely related to the incomplete mixing of the Clearwater River into the Athabasca River mainstem flow at this station (see Section 5.9 for a description of the ionic composition of water from Clearwater River).

Trend Analysis The following significant trends in water quality measurement endpoints were calculated from the fall data for the RAMP Athabasca River mainstem water quality stations ($\alpha = 0.05$):

- an increasing trend in the concentration of total nitrogen at *baseline* station ATR-DC-E and *test* station ATR-MR-E;
- decreasing trends in concentrations of total strontium and sulphate at *baseline* station ATR-DC-E; and
- a decreasing trend in the concentration of sodium at *test* station ATR-SR-E.

The following significant trends in water quality measurement endpoints were calculated from the monthly data for the AENV Athabasca River mainstem water quality stations ($\alpha = 0.05$):

- increasing trends in pH and total aluminum, and a decreasing trend in total phosphorus at both ATR-UFM and ATR-OF;
- at ATR-UFM only, increasing trends in dissolved aluminum and total arsenic; and
- an increasing trend in sulphate and decreasing trend in molybdenum at ATR-OF.

Long-term trends in water quality in the Athabascsa River mainstem and delta were also examined in recent publications by Hebben (2009), Glozier *et al.* (2009) and Squires *et al.* (2010). Comparisons of these results and results of trend analyses presented in this section are discussed further in Section 7.2.

In 2009, the concentration of total dissolved phosphorus (TDP) measured by AENV at Old Fort was consistently higher than historical observations and higher than concentrations measured upstream of Fort McMurray (Figure 5.1-9). These differences, however, are suspect, given total phosphorus measurements measured in the same samples from Old Fort were consistent between stations, and lower than TDP measurements.

Water Quality Index The water quality at all stations in the Athabasca River mainstem in fall 2009 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.1-7). The WQI values for all Athabasca River stations for fall 2009 were 100, with the exception of ATR-DC-W with a WQI value of 94.6 due to concentrations of calcium and strontium in fall 2009 that exceeded regional *baseline* concentrations (Figure 5.1-4).

Summary In fall 2009, water quality at *test* and *baseline* stations in the Athabasca River were assessed as having **Negligible-Low** differences from regional *baseline* water quality conditions. Concentrations of water quality measurement endpoints at *test* stations were similar to those at *baseline* stations and were consistent with regional *baseline* concentrations. There were no consistent patterns between *baseline* and *test* stations in the selected water quality measurement endpoints. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem was consistent with previous sampling years, showing little year-to-year variation.

5.1.4 Benthic Invertebrate Communities and Sediment Quality

5.1.4.1 Benthic Invertebrate Communities in the Athabasca River Delta

Benthic invertebrate community samples were taken from three depositional reaches in the ARD in fall 2009: Fletcher Channel (*test* reach FLC), Goose Island Channel (*test* reach GIC), and Big Point Channel (*test* reach BPC).

2009 Habitat Conditions The three ARD reaches at which benthic invertebrate communities were sampled in fall 2009 had similar habitat characteristics (Table 5.1-8), with slightly alkaline water, flow velocity between 0.2 and 0.3 m/s, water depth between 1.6 and 1.7 m, a substrate dominated by sand, levels of total organic carbon in sediments that reflect natural organic detritus, and concentrations of dissolved oxygen that were at or near the chronic guideline for protection of aquatic life (AENV 1999b).

Relative Abundance of Benthic Invertebrate Community Taxa in 2009 The benthic invertebrate communities at all three reaches in fall were generally similar (Table 5.1-9), dominated numerically by tubificid worms and chironomids. The tubificid worms were not identified below the Family level, but the high number is not uncommon in the shifting-sand environment typical of the ARD (Barton and Locke 1979). Fingernail clams (Bivalvia), ostracods, naidid worms and gastropods (snails) were generally sub-dominant at all three reaches. As in previous years, the dominant chironomids were *Polypedilum, Tanytarsus* and *Procladius*. The snail *Amnicola* was common to all three reaches.

The variations in the benthic invertebrate community measurement endpoints for the ARD (Table 5.1-9) were compared to the range of variation observed in previous years (Figure 5.1-10):

1. Historically, total abundance in ARD reaches has ranged from approximately 4,400 to 73,000 individuals per m^2. Abundance in 2009 was within this range, varying between 13,000 (*test* reach GIC) and 23,000 (*test* reach BPC).

2. Historically, the average number of taxa in ARD reaches has ranged from 9.5 to 14 taxa per sample. Observed taxa richness per sample was within that range in 2009, with 10, 11, and 15 taxa in *test* reach FLC, *test* reach BPC, and *test* reach GIC, respectively.

3. Simpson's diversity and evenness have varied in ARD reaches over the data record, and diversity and evenness values for 2009 were within the historical range of observations for these reaches.

4. %EPT (mayflies, stoneflies and caddisflies) has generally been low in the ARD, ranging from 0 to 6.2% on average. This low range of values is not unusual for a large river with a shifting-sand substrate (Barton 1980a; Barton and Smith, 1984) which provides unsuitable habitat for large insect larvae (including mayflies and caddisflies). Values of %EPT for 2009 are at the lower end of the historical range of observations for all three ARD reaches.

The results of the Correspondance Analysis (CA ordination, Figure 5.1-11) indicate that the composition of the benthic invertebrate community at all three reaches was similar in 2009 to historical observations. The benthic invertebrate communities in fall 2009 did, however, produce higher CA Axis 1 scores than previous years indicating a higher relative abundance of Ostracods and lower relative abundance of Anisoptera (dragonfly larvae) and Ephemeroptera (mayfly larvae). These variations were subtle because dragonflies and mayflies have typically always comprised a small fraction (~1%) of the total benthic invertebrate community composition for any reach in any year (Table 5.1-9).

5.1.4.2 Sediment Quality

In fall 2009, sediment quality was sampled in the ARD at Goose Island Channel, GIC-1, Big Point Channel, BPC-1, and Fletcher Channel, FLC-1 in the same location as the benthic invertebrate community sampling reaches, as well as in the Athabasca River mainstem, immediately upstream of the Embarrass River (ATR-ER). All four stations are designated as *test* for 2009. Results from 2009 and earlier for sediment quality measurement endpoints at these stations are presented in Table 5.1-10 to Table 5.1-13 and Figure 5.1-12 to Figure 5.1-15).

2009 Results and Historical Ranges of Concentration Sediment quality at the station in the Athabasca River mainstem and the three stations in the ARD in fall 2009 was generally similar to that observed in previous years (Table 5.1-10 to Table 5.1-13):

1. Sediments at all four stations in fall 2009 were dominated by silt and sand. Total organic carbon in sediments at all stations was relatively low (<2.5%), but exceeded the previously-measured maximum concentration at *test* station BPC-1.

2. Concentrations of total metals in sediments in fall 2009, expressed either in absolute terms and normalized to percent fine sediments, were similar to those observed in previous years (Figure 5.1-12 to Figure 5.1-15).

3. Concentrations of total hydrocarbon were within the range of historical previous measurements at all stations with the exception of *test* station BPC-1, where concentrations of high-molecular-weight hydrocarbons (i.e., CCME fractions 3 and 4) exceeded the previously-measured maximum concentrations (Table 5.1-13).

4. Absolute concentrations of PAHs at *test* stations BPC-1 and FLC-1 exceeded previously-measured maxima at these stations. However, when normalized to organic content, PAH concentrations at these stations were similar to or lower than normalized concentrations in previous sampling years (Figure 5.1-14, Figure 5.1-15)[1].

5. At all sampled stations in 2009, PAHs were dominated by alkylated species, indicating these compounds have a petrogenic origin.

6. Potential toxicity of PAHs in sediments at each station[2] were within the range of historical values at *test* station ATR-ER (Table 5.1-10) and *test* station BPC-1 (Table 5.1-13) below the previously-calculated minimum value at *test* station GIC-1 (Table 5.1-11), and greater than the previously-calculated maximum value at *test* station FLC-1 (Table 5.1-12).

7. Direct measures of sediment toxicity to invertebrates indicated good survival (i.e., 80% survival or greater of test organisms) of the amphipod *Hyalella* at all stations, and poor to moderate survival (i.e., 60% survival or less of test organisms) of the midge *Chironomus* at all stations (Table 5.1-10 to Table 5.1-13).

8. Ten-day growth of the midge *Chironomus* and 14-day growth of the amphipod *Hyalella* were within the range of previous values at all stations with the exception of *test* station FLC-1 where *Chironomus* growth was lower than previously-measured minimum growth.

Comparison with Sediment Quality Guidelines No hydrocarbon fraction, specific PAHs, or total metals measured at the four stations had concentrations that exceeded relevant sediment or soil quality guidelines in fall 2009, with the exception CCME F3 hydrocarbons at *test* stations FLC-1 (Table 5.1-12) and BPC-1 (Table 5.1-13).

Regional Context Absolute and carbon-normalized concentrations of total PAHs and total hydrocarbons (i.e., sum of F1-F4), and absolute concentrations of a representative metal, total arsenic, in sediments collected from the Athabasca River mainstem and ARD since 1997 are presented in Figure 5.1-16 to Figure 5.1-20[3]. Historically, the highest concentrations of PAHs and total hydrocarbons in sediments sampled from the Athabasca River mainstem and from the ARD have been measured consistently at *baseline* station ATR-DC (upstream of Donald Creek) which is located near a bitumen outcrop. Generally, lower concentrations of PAHs and total hydrocarbons in sediments have been observed at other Athabasca River mainstem stations, with the exception of a number of high concentrations of individual hydrocarbons and PAHs measured in sediments at *test* stations ATR-FC and ATR-DD. Concentrations of PAHs and hydrocarbons at all stations in the ARD have been generally stable across sampling years. Concentrations of PAHs in sediments at the ARD stations in fall 2009 remained low but variable, with the highest absolute concentrations of total PAHs measured in fall 2009 at two of four stations (*test* stations BPC-1 and FLC-1) (Figure 5.1-14 and Figure 5.1-15), and

---

1 As hydrophobic compounds, PAHs may preferentially adsorb to organic particles. Therefore, both absolute and carbon-normalized concentrations of PAHs and other hydrophobic compounds are important to consider in monitoring. Carbon-normalized data may provide a better measure of change over time, as these data exclude the potentially confounding influence of sediment carbon content on PAH concentration.

2 Calculated using the solubility and aquatic toxicity of each PAH species, and total hydrocarbons in each sample.

3 RAMP sampling of sediments from the Athabasca River between Fort McMurray and the ARD was discontinued in 2004, given the generally non-depositional nature of mainstem sediments, and the confounding effects of variable river wetted widths and eroding bitumen-bearing soils along the river bank at some stations.

lowest concentrations of carbon-normalized total PAH measured in 2009 at the other two stations (*test* stations GIC-1 and ATR-ER) (Figure 5.1-13 and Figure 5.1-12).

Concentrations of total arsenic in sediments of the Athabasca River mainstem and ARD have generally been similar among all stations and across years, with concentrations below the CCME interim sediment quality guideline (5.9 mg/kg) at nearly all locations in all years of sampling (Figure 5.1-20).

Sediment Quality Index The SQI values of 94.9, 93.8, 88.9, and 94.2 at *test* stations ATR-ER, FLC-1 BPC-1, and GIC-1, respectively, indicated **Negligible-Low** differences from regional *baseline* sediment quality conditions.

5.1.4.3 Summary

The variations in benthic invertebrate community measurement endpoints in the ARD reaches are classified as **Negligible-Low** because the measurement endpoints in fall 2009 were within the range of historical values for these reaches; and there are no trends over time in the measurement endpoints indicating a degradation of community composition. Sediment quality at stations in the ARD exhibited **Negligible-Low** differences from regional *baseline* sediment quality conditions because concentrations of sediment quality endpoints in fall 2009 were generally within previously-measured ranges.

5.1.5 Fish Populations

Fish population monitoring in 2009 on the Athabasca River consisted of a spring, summer, and fall fish inventory and a fish tag return assessment.

5.1.5.1 Fish Inventory

A total of 3,207 fish were captured in the ten standardized reaches (Figure 3.4-2) during the spring, summer, and fall fish inventories on the Athabasca River in 2009, of which:

- 1,055 fish representing 14 species were caught in the spring (Table 5.1-14);
- 1,005 fish representing 15 species were caught in the summer (Table 5.1-14); and
- 1,147 fish representing 13 species were caught in the fall (Table 5.1-14).

Species Composition

Key features of the species composition of the Athabasca River fish inventory for 2009 and in comparison to previous years are as follows:

1. A total of 16 species were captured in 2009 compared to 21 species captured in 2008 and 22 species captured in 1997, which represents the highest species richness documented to date of the Athabasca River inventory (RAMP 1998).

2. The most abundant large-bodied species captured were white sucker and walleye, goldeye and flathead chub, and lake whitefish and goldeye in spring, summer, and fall, respectively.

3. The dominant large-bodied species in 2009 were consistent with inventory results from 2008 for all seasons. The most abundant small-bodied fish in each season was trout-perch (Table 5.1-14).

4. KIR species composition in 2009 was generally similar to 2008 and 2007 across sampling seasons (Figure 5.1-21 to Figure 5.1-23). White sucker has

been the most commonly-captured species in spring from 2007 to 2009 with walleye dominating the total catch in most years prior to 2007. The number of walleye captured in 2009 was similar to 2008 and lower than many years previous to 2008.

5. The number of goldeye captured in the summer has increased across sampling years (Figure 5.1-22).
6. In fall 2009, approximately equal numbers of white sucker, walleye, and goldeye were captured. The dominant KIR species captured during the fall survey has varied between walleye and goldeye (Figure 5.1-23), however, the dominant species captured in fall is lake whitefish across most years given this species is a fall-spawner.
7. Among sampling years, species richness in spring, summer, and fall ranges from two (fall 2000) to 19 (fall 2007) (Figure 5.1-24). Species richness in 2009 was close to the historical average in fall (13 species) and spring (14 species), and above average in summer (12 species).

Catch per Unit Effort

The total catch per unit effort (CPUE), as a measure of relative abundance, for all KIR species combined (Figure 5.1-25) was:

- higher in spring 2009 than most historical sampling years, with the exception of 1997, 2000, and 2008;
- lower in summer 2009 than summer 2008 but similar to the historical average; and
- lower in fall 2009 than fall 2008 but within the upper range of CPUE in historical sampling years.

As in 2008, CPUE in 2009 decreased from spring to fall, likely a result of the use of the Athabasca River in spring as a migration route to spawning grounds for many of the KIR species. This trend was not observed in 1998, 2004, and 2006, where CPUE in fall exceeded spring CPUE (Figure 5.1-25).

Spring, summer and fall CPUE for key indicator (KIR) species in 2009 is presented in Figure 5.1-26. With the exception of a general increase in the relative abundance of white sucker across all seasons in recent years (2008 and 2009) and the increase in goldeye in summer in 2008 and 2009, there is no obvious increasing or decreasing temporal trends in CPUE for individual KIR species.

Spring, summer and fall CPUE for key indicator (KIR) species relative to the mean discharge rate in the Athabasca River in May, July, and September is presented in Figure 5.1-27. Instream Flow Needs (IFN) guidelines for the Athabasca River specify discharge rates for the ecological protection of the system and fish species using the system (AENV 2007). Therefore, water withdrawals from oil sands development are monitored and regulated to ensure IFN guidelines are met. Mean monthly discharges at the Water Survey of Canada hydrology station (07DA001) on the Athabasca River below Fort McMurray (Figure 3.1-2) for May, July, and September when the fish inventories were conducted were compared to relative fish abundance from 1997 to 2009.

The relationship between discharge and CPUE was highly variable. CPUE of walleye and white sucker in spring and goldeye in fall generally increased with increased discharge rate (Figure 5.1-27). There were no relationship between CPUE for longnose sucker or northern pike in any season, but CPUE was generally consistent across the flow range indicating very little direct influence of fluctuations in discharge rate on relative abundance of these species. The small amount of data collected during the summer inventories was not adequate to assess if there are any relationships between mean CPUE of KIR species and discharge rate; however the existing data shows little variation in CPUE of all KIR species relative to the mean discharge rate (Figure 5.1-27).

Results for the Correspondence Analysis (Figure 5.1-28) are as follows:

1. In spring 2009 (Figure 5.1-28), relative abundance of species was similar to 2007 and 2008 and clustered near white sucker indicating that the relative abundance of this species was dominant in these three years. Northern pike, goldeye, and walleye clustered together with high relative abundance in all years prior to 2007.

2. In summer 2009 (Figure 5.1-29), relative abundance of species was similar to 2008, driven primarily by goldeye CPUE. Relative abundance of walleye and northern pike dominated the similarities among 1997, 2003, and 2005 while relative abundance of white sucker and longnose sucker were high and similar in 1998, 2000, and 2001.

3. In fall 2009 (Figure 5.1-30), relative abundance of species were similar to 2008, determined largely by the high relative abundance of white sucker and goldeye. Relative abundance has been variable with no clear trends among years or in species dominance in the fall inventory.

Length-Frequency Analysis

Length-frequency distributions (1997-2009) for the KIR species are presented in Figure 5.1-31 to Figure 5.1-35. Comparisons in length-frequency distributions across years were conducted using a two sample K-S test (two-sided, $\alpha=0.05$) for each species.

The length-frequency distribution of goldeye in 2009 was similar to 2008 with a dominant length class of 151-175 mm; the 2009 length distribution is significantly different than all other years ($p<0.01$). Similar to 2008, 2009 has a large peak of smaller individuals that is much greater than any peak in any year (Figure 5.1-31). The fish in the peak between 100 and 200 mm are juveniles captured in the summer; each season in 2009 was distinct in length distribution ($p<0.01$). Some of the juveniles were still present in the Athabasca River in the fall.

The length-frequency distribution of longnose sucker in 2009 was significantly different from all previous sampling years ($p<0.01$) with the exception of 2001, 2003, 2006, and 2008 ($p\geq0.12$). The co-dominant length classes in 2009 were 100 to 150 mm and 401 to 450 mm, the dominant length class in 2007 and 2008 was also 401 to 450 mm (Figure 5.1-32). The increase of catch in the smaller length class is likely attributed to juvenile fish capture in summer.

The length-frequency distribution of northern pike was not significantly different between 2009 and all historical sampling years with the exception of 1998 ($p=0.02$). There was a significant difference between the seasonal length-frequency distributions in 2009 with a decreasing shift in length from spring to fall (Figure 5.1-33). Smaller fish recorded during the fall survey are likely juveniles migrating from the nursery areas in the tributaries into the Athabasca River mainstem while spring catch was likely dominated by pre-spawning adults.

The length-frequency distribution of walleye in 2009 was significantly different from 1997, 1999, and 2001 to 2007 ($p \leq 0.01$) (Figure 5.1-34). Two distinct modes were apparent in the 2009 distribution, similarly to previous sampling years. These two modes are age-related and become more obvious when examining the seasonal data from 2009. The length distributions of fish in 2009 for each season are statistically distinct ($p \leq 0.012$). Longer fish captured in spring are the spawning adult population with juveniles captured in summer and fall.

The length-frequency distributions of white sucker were significantly different in 2009 compared to all years, with the exception of 2008 ($p \leq 0.01$). The dominant length class in 2009 was 401 to 500 mm, similarly to most historical sampling years (Figure 5.1-35). In summer, a higher number of smaller juvenile sucker were captured relative to spring and fall (Figure 5.1-35).

Condition Factor

Mean condition factor for KIR fish species captured in the Athabasca River from 1997 to 2009 in spring, summer and fall are presented in Figure 5.1-36. Statistical differences among years with a season were tested using analysis of covariance (ANCOVA). Given the number of statistical tests performed comparing years, adjusted significance levels were calculated (adjusted $\alpha=0.0008$ for testing differences in slope and $\alpha=0.0042$ for testing differences in the intercept). Generally, condition of all KIR species was within the 5th and 95th percentiles of values measured from 1997 to 1998 (Figure 5.1-36). Species-specific results are as follows:

1. Condition in goldeye in spring 2009 was significantly lower compared to 2000, 2004, and 2007 ($p \leq 0.002$). Condition in goldeye in summer 2009 was significantly higher compared to 2000 and 2008 ($p \leq 0.001$) and condition of goldeye in fall 2009 was significantly lower than 1997, 2003, 2005, and 2006 ($p \leq 0.001$);

2. There were no significant differences in longnose sucker condition among years in spring and summer ($p \geq 0.060$, $p \geq 0.005$, and $p \geq 0.005$, respectively);

3. There were no significant differences in northern pike condition among years in spring and fall ($p \geq 0.060$ and $p \geq 0.007$, respectively). Northern pike condition in summer 2009 was significantly higher compared to 2008 ($p<0.001$);

4. Condition in walleye in spring 2009 was significantly higher compared to most historical sampling years (1997, 1998, 2002, 2003, 2005, 2006, and 2008) ($p \leq 0.002$; Figure 5.1-36). Walleye condition in summer 2009 was significantly higher compared to 2008 ($p<0.001$); slopes of condition were significantly different between 1998 and 2009 so an ANCOVA could not be performed ($p=0.001$; Figure 5.1-36). There were no significant differences in condition of walleye among years during the fall inventory survey ($p \geq 0.007$); and

5. Condition in white sucker in spring 2009 was significantly higher compared to 1997, 1998, 2000, and 2002 ($p=0.002$). There were no significant differences in condition of white sucker among years in summer ($p>0.005$) and fall ($p \geq 0.007$).

Currently only condition has an established criterion for determining change for the large-bodied species in the Athabasca River fish inventory. Environment Canada (2005) has defined a critical effect size for fish condition as ± 10% relative to *baseline* fish. From this perspective, a >10% change in condition is considered important suggesting a need for further evaluation (e.g., confirmation over time, follow-up studies, etc.). For the Athabasca River fish inventory, however, there are no reaches classified as *baseline* because all reaches are downstream of focal projects for all years that fish inventories have been conducted by RAMP. In addition, the mobility of most large-bodied fish species in the lower Athabasca River presents a challenge in identifying a *baseline* reach that is inaccessible from fish of the *test* reach (and vice versa).

Recruitment to the Sport Fishery[4]

The ratio of undersize (i.e., < 400 mm) to legal size (i.e., > 400 mm) walleye, an index of the rate of recruitment to the sport fishery, was 1.32 in 2009, meaning that there were 1.32 undersize walleye for every legal-sized fish. The value in 2008 was 1.64 and the average recruitment rate across historical sampling years is 1.80 suggesting that there was 0.48 fewer undersize fish for every adult in 2009 compared to the historical average. Although lower than the mean recruitment rate, the 2009 rate is within the historical range of values for this ratio (Figure 5.1-37).

The ratio of undersize (i.e., < 600 mm) to legal size northern pike (i.e., >600 mm) was 3.18 in 2009, indicating that recruitment rate was high in 2009 for this species in the Athabasca River, with approximately three undersize fish for every legal-sized fish. The recruitment rate was 3.45 in 2008 with an historical average of 3.17, indicating that 2009 was an average recruitment year (Figure 5.1-38).

External Health Assessment

Observed abnormalities were primarily associated with minor skin aberrations or wounds and scars and fin erosion. In 2009, 172 out of 1,055 (16.3%) in spring, 58 out of 1,005 (5.7%) in summer, 64 out of 1,147 (5.6%) in fall were found to have some type of external wound, scar or fin erosion. The percentage of external abnormalities observed in 2009 are lower than 2008 for spring, slightly higher for summer (36% in summer 2008 [RAMP 2009a]) and similar in fall. The mean health assessment index (HAI) for all KIR species by season and year are presented in Table 5.1-16. 2009 index scores for each species in each season were within the historical range with the exception of walleye in the spring and white sucker in the summer, when the mean HAI in 2009 exceeded the maximum historical score recorded in spring 1998 for walleye and summer 1997 for white sucker.

For fish pathology, only 50 (33 [66%] in the spring, 11 [22%] in spring, and 7 [14%] in fall) out of 3,207 fish (1.6%) exhibited some form external pathology, including parasites, growths, lesions or body deformities, in 2009. A summary of the percentage of fish by species, season and year with some form of pathology is presented in Table 5.1-17. The percentage of external pathology in KIR species in 2009 is generally within the historical range with the exception of walleye captured in spring and white sucker captured in summer. There were only eight white sucker captured in the summer, two of which exhibited some form of external pathology, resulting in a high percentage given the small sample size.

[4] Data from all seasons were included in this recruitment analyses to account for spring spawning adults and juveniles captured primarily in summer and fall.

Improvement to standardizing the assessment of external pathology has been developed in the most recent sampling year (i.e., 2008 and 2009). Therefore, the differences in HAI scores and percent external pathology between the initial years of sampling and the more recent years may be a result of changes in assessment protocols.

Summary Assessment for the Fish Inventory

As outlined in RAMP (2009b), the Athabasca River fish inventory is generally considered to be a community-driven activity, primarily suited for assessing generally trends in abundance and population variables for large-bodied species, rather than detailed community structure. Seasonal patterns were observed in species dominance among years with white sucker dominating the spring catch over the last three years and an increasing dominance of goldeye in summer since 1997. Goldeye and walleye have dominated the catch in fall among years.

As of 2009, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, length-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition and length-frequency distribution for all KIR species. However, the variability of these measurement endpoints among years does not indicate consistent negative or positive changes in the fish populations and likely reflect natural variability over time.

5.1.5.2 Fish Tag Return Assessment

RAMP Floy Tags

A total of four RAMP Floy tags were submitted to the Alberta Sustainable Resource Development (ASRD), Fort McMurray office by anglers in 2009. Information provided with each tag return included tag number, species, approximate capture location, date of capture.

Figure 5.1-39 shows the locations of first capture and tagging by RAMP and the location of recapture by the angler, as well as the most direct travel route, for three of the four fish for which tags were returned in 2009 (one record was incomplete). The 2009 fish tag returns were for three walleye and one northern pike (Table 5.1-18). A cumulative summary of RAMP tags returned to date is presented in Table 5.1-19 for comparison by species.

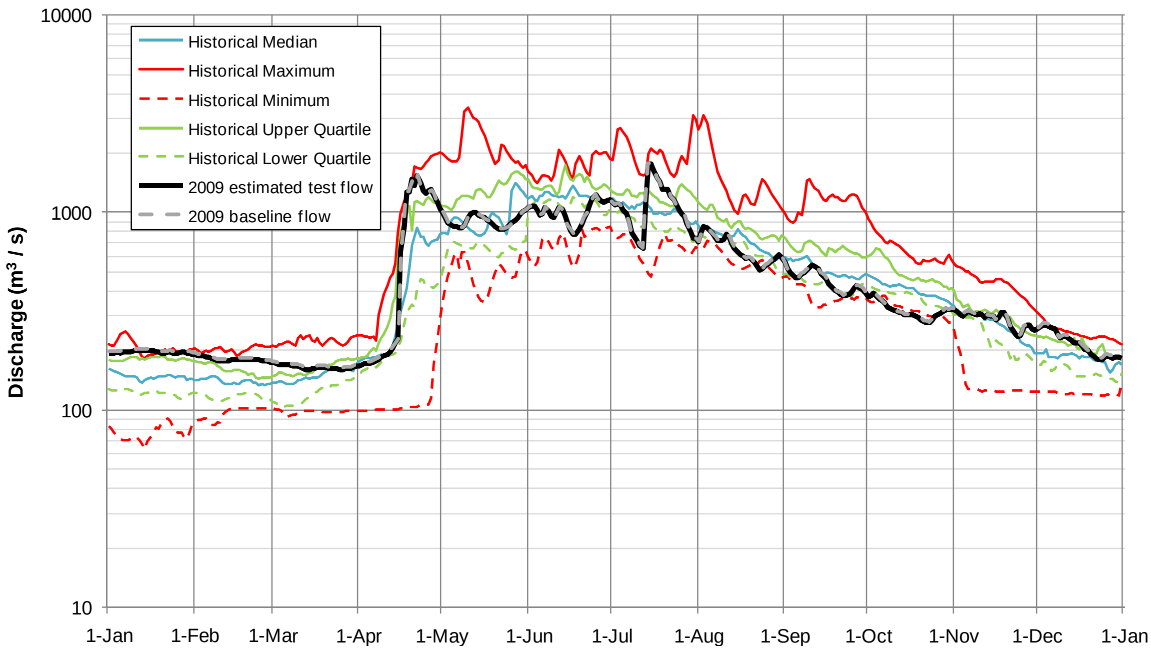
RAMP Tags During Fish Inventory and Muskeg River Fish Fence Activities

Walleye and northern pike are tagged during RAMP fish inventory programs and in the 2003, 2006, and 2009 Muskeg River fish fence programs White sucker were also tagged during the 2003 and 2006 Muskeg River fish fence programs. During the 2009 Athabasca River fish inventories, six walleye and one white sucker were recaptured that had been previously tagged (Table 5.1-18). All walleye were captured in the same river reach where they were originally tagged; four of the six walleye were originally tagged in 2008 and one was tagged in 2002. The white sucker was tagged during the Muskeg River fish fence in 2003.

During the Clearwater River 2009 fish inventories, 21 fish were captured that had been tagged during previous Clearwater inventories. Of these 21 fish, 15 were northern pike and six were walleye. All walleye were marked and captured within 2009 but in different seasons and were re-captured within the same reach as they were originally caught. Two northern pike recaptures were originally tagged in 2009 and seven northern pike recaptures were recaptured within the same reach. The trends observed in tag recaptured for walleye and northern pike suggest that they have a strong homing tendency during spawning periods (Miller *et al.* 2001).

Data collected during the spring 2009 Athabasca River fish inventory suggest that this river is an important migration route for spawning fish, moving from Lake Athabasca to upstream tributaries to spawn. Several walleye that were captured in previous RAMP programs were recaptured in either the same sub-reach or the same section of the Athabasca River, indicating that fish continuously use tributaries as spawning grounds in the section of the river near oil sands development. Northern pike, walleye, and white sucker (although more variably) may home to specific locations in waterbodies for spawning (Miller *et al.* 2001, Olson and Scidmore 1962, Olson and Scidmore 1963).

Figure 5.1-3 Athabasca River: 2009 hydrograph and historical context.



Note: Based on 2009 provisional data from Station S24, Athabasca River below Eymundson Creek. The upstream drainage area is 146,000 km^2. Historical data are calculated from eight years of record (June 21, 2001 to December 31, 2008).

Note: For clarity, the estimated *baseline* flow resulting from focal projects in the Athabasca River watershed is only shown here; differences between this and the estimated *baseline* hydrograph resulting from other oil sands developments in the Athabasca River watershed are negligible and not detectable on this graph.

Table 5.1-2 Estimated water balance at Station S24, Athabasca River below Eymundson Creek, 2009.

Component	Volume (million m^3)		Basis and Data Source
	Focal Projects	Focal Projects Plus Other Oil Sands Developments	
Observed *test* hydrograph (total discharge)	**16,321.2**		**Sum of observed daily discharges obtained from Station S24, Athabasca River below Eymundson Creek.**
Closed-circuited area water loss from the observed hydrograph	-36.1	-36.2	321 km^2 (320 km^2 focal projects only) of land estimated to have been closed-circuited as of 2009 (Table 2.4-1), in the cumulative area upstream of S24, including (from Table 2.41): minor Athabasca River tributaries, McLean Creek, upper Beaver River, and Shipyard Lake
Incremental runoff form land clearing (not closed-circuited area)	+2.2	+2.3	102 km^2 (99.2 km^2 focal projects only) of land estimated to have undergone land change by focal projects as of 2009 but are not closed-circuited (Table 2.4-1), in the cumulative area upstream of S24, including (from Table 2.41): minor Athabasca River tributaries, McLean Creek, upper Beaver River, and Shipyard Lake.
Water withdrawals from the Athabasca River watershed from focal projects	-40.4		Withdrawals by Suncor (annual total in Section 2.3; constant daily values assumed).
	-37.5		Withdrawals by Syncrude (monthly total in Section 2.2; constant daily values assumed).
	-15.2		Withdrawals by Shell Albian Sands (daily values provided, Section 2.3).
	-13.2		Withdrawals by Canadian Natural (annual total in Section 2.3; constant daily total assumed).
	-0.1		Withdrawals by Imperial (annual total in Section 2.3; constant daily total assumed).
Water releases in the Athabasca River watershed from focal projects	+0.3		Releases by Syncrude (monthly values in Section 2.3, constant daily total assumed).
	+3.1		Releases by Suncor (annual total in Section 2.3; constant daily total assumed).
The difference between *test* and *baseline* hydrographs on tributary streams	-3.1	-3.2	Net sum of incremental volume results from the major tributaries as listed in Section 5.2 to Section 5.12[1].
Estimated *baseline* hydrograph (total discharge)	**16,461.1**	**16,461.2**	**Estimated *baseline* discharge at Station S24, Athabasca River below Eymundson Creek.**
Incremental flow (change in total discharge)	-139.9	-140.0	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-0.85%**	**-0.85%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Data and assumptions are discussed in Section 3.1.7.3.

Note: Based on the provisional 2009 data for Station S24, Athabasca River below Eymundson Creek.

Note: Some rounding of results occurs due to the use of a maximum of one decimal point.

[1] It is assumed that discharges entering the Athabasca River mainstem from the Upper Beaver watershed via the Poplar Creek spillway would have entered the Athabasca River mainstem via the Original Beaver River watershed, and so the incremental changes of the Beaver Creek diversion on the Athabasca River mainstem flows are assumed to be zero.

[2] The Horse River, Hangingstone River and Christina River watersheds are the only watersheds in the RAMP FSA that contained other oil sands developments under construction or operation as of 2009 (Table 2.4-1).

Table 5.1-3 Calculated change in hydrologic measurement endpoints for the Athabasca River in 2009, for focal project and cumulative assessment cases[1].

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	745	740	-0.7%
Mean winter discharge	213	209	-1.7%
Annual maximum daily discharge	1,773	1,766	-0.4%
Open-water season minimum daily discharge	281	278	-1.2%

Note: Based on the provisional 2009 data for Station S24, Athabasca River below Eymundson Creek.

[1] Differences in results between the focal project and focal project plus other oil sands developments, only exist when presented at two (three) decimal places for *baseline* (relative change) values.

Table 5.1-4 Concentrations of water quality measurement endpoints, Athabasca River mainstem, fall 2009.

Measurement Endpoint	Units	Guideline	Upstream of Fort McMurray (ATR-UFM) Fall AENV data, 1997-2009				Upstream of Donald Creek (ATR-DC-E, ATR-DC-W)		Upstream of Steepbank River (ATR-SR-E, ATR-SR-W)		Upstream of Muskeg River (ATR-MR-E, ATR-MR-W)		Downstream of Development (ATR-DD-E, ATR-DD-W)		Upstream of Firebag River (ATR-FR-CC)
			n	min	median	max	East[1]	West	East	West	East	West	East	West	Cross-channel
Physical variables															
pH	pH units	6.5-9.0	52	7.3	8.1	8.4	7.9	8.18	8.1	8.17	8.11	8.19	8.0	7.97	8.07
Total suspended solids	mg/L	-	48	1	8.6	344	17	12	24	22	17	34	15	14	13
Conductivity	µS/cm	-	49	150	284	446	204	295	254	284	248	268	253	254	265
Nutrients															
Total dissolved phosphorus	mg/L	0.05[2]	35	0.003	0.006	0.025	0.018	0.0025	0.0088	0.0043	0.0082	0.0049	0.0083	0.0086	0.0074
Total nitrogen*	mg/L	1.0	47	0.133	0.393	**1.903**	0.901	0.495	0.571	0.371	**1.011**	0.641	0.531	0.641	0.621
Nitrate+nitrite	mg/L	1.0	53	0.001	0.003	0.843	<0.071	0.085	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071
Dissolved organic carbon	mg/L	-	48	2.5	7.85	25	11.7	5.2	8.6	5.3	8.8	6.4	8.2	8.7	8.1
Ions															
Sodium	mg/L	-	50	4	10.3	20	16.9	10.6	12.9	10.2	12.7	10.9	13.3	13.5	14.7
Calcium	mg/L	-	53	19.4	35.5	50.5	20.2	38.8	25.2	31.6	29.8	34	29	30.3	28.3
Magnesium	mg/L	-	51	5.4	9.45	14.2	5.74	9.92	7.34	9.48	7.85	8.9	6.82	7.02	7.44
Chloride	mg/L	230, 860[3]	53	1	2.8	7.2	18.3	3.37	12.3	4.72	9.52	6.24	10.3	10.1	11.9
Sulphate	mg/L	100[4]	52	13	29.15	53.1	7.75	33.3	19.3	33.6	20.2	27.4	19.2	19.5	22.5
Total dissolved solids	mg/L	-	44	109	171	263	131	176	143	174	171	169	151	167	178
Total alkalinity	mg/L		53	64.3	119	176	62.9	111	86.5	101	88.7	97.5	90.3	90.7	90.6
Organic compounds															
Naphthenic acids	mg/L	-	-	-	-	-	0.127	0.035	0.08	0.082	0.069	0.066	0.065	0.047	0.043
Selected metals															
Total aluminum	mg/L	0.1	16	0.07	**0.2065**	**1.29**	**0.618**	**0.549**	**0.965**	**0.928**	**0.775**	**1.04**	**0.581**	**0.567**	**0.433**
Total arsenic	mg/L	0.005	18	0.0003	0.000565	0.0019	0.000595	0.000561	0.000749	0.000732	0.001	0.001	0.000682	0.00676	0.001
Dissolved aluminum	mg/L	0.1[2]	9	0.004	0.11	0.02	0.0108	0.0139	0.012	0.0127	0.013	0.0132	0.0131	0.0133	0.0109
Total boron	mg/L	1.2[5]	12	0.01	0.0271	0.04	0.024	0.0314	0.024	0.0254	0.0272	0.0406	0.0295	0.0307	0.029
Total molybdenum	mg/L	0.073	18	0.00066	0.000865	0.018	0.000179	0.000814	0.000477	0.000762	0.000575	0.000668	0.0005	0.000532	0.0006
Total mercury (ultra-trace)	ng/L	5, 13[6]	7	0.6	0.81	2.4	2.6	1.2	2	<1.2	1.7	1.8	1.2	1.6	<1.2
Total strontium	mg/L	-	12	0.22	0.288	0.355	0.091	0.295	0.187	0.257	0.201	0.241	0.199	0.204	0.208
Other variables that exceeded CCME/AENV guidelines in 2009															
Total Phosphorus	mg/L	0.05	51	0.006	0.023	**0.35**	-	-	-	-	-	-	-	-	-
Sulphide	mg/L	0.002[7]	-	-	-	-	-	-	-	-	-	-	**0.0025**	**0.0024**	**0.0021**
Total iron	mg/L	0.3	16	0.168	**0.338**	**3.29**	**1.04**	**0.439**	**1.06**	**0.794**	**0.881**	**1.12**	**0.757**	**0.772**	**0.583**
Dissolved iron	mg/L	0.3[2]	-	-	-	-	**0.401**	-	-	-	-	-	-	-	-
Total Zinc	mg/L	0.03	20	<0.001	0.003395	**0.034**	-	-	-	-	-	-	-	-	-

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

[1] Denotes sampling location. East=east bank; West=west bank; Cross-channel=cross-channel composite.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA guideline for continuous and maximum concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H2S (B.C. 2006).

Table 5.1-5 Water quality guideline exceedances in the Athabasca River mainstem, downstream of development (ATR-DD), 2009.

Parameter	Units	Guideline	Upstream of Donald Creek (ATR-DC-E, ATR-DC-W)		Upstream of Steepbank River (ATR-SR-E, ATR-SR-W)		Upstream of Muskeg River (ATR-MR-E, ATR-MR-W)		Downstream of Development (ATR-DD-E, ATR-DD-W)		Upstream of Firebag River (ATR-FR-CC)
			East[1]	West	East	West	East	West	East	West	Cross-channel
Winter											
Dissolved Selenium	mg/L	0.001	-	-	ns	ns	ns	ns	**0.00135**	**0.00119**	ns
Total Selenium	mg/L	0.001	-	-	ns	ns	ns	ns	**0.00136**	**0.0012**	ns
Total aluminum	mg/L	0.1	**0.103**	-	ns	ns	ns	ns	**-**	**-**	ns
Total iron	mg/L	0.3	-	-	ns	ns	ns	ns	**0.49**	**0.476**	ns
Spring											
Sulphide	mg/L	0.002[2]	ns	ns	ns	ns	ns	ns	**0.007**	**0.0102**	ns
Total phenolics	mg/L	0.004	ns	ns	ns	ns	ns	ns	**0.0042**	**0.0061**	ns
Phosphorus, Total	mg/L	0.05	ns	ns	ns	ns	ns	ns	**0.132**	**0.159**	ns
Dissolved iron	mg/L	0.3	ns	ns	ns	ns	ns	ns	**-**	**-**	ns
Total Kjeldahl Nitrogen	mg/L	1.0	ns	ns	ns	ns	ns	ns	**-**	**1.35**	ns
Total nitrogen	mg/L	1.0	ns	ns	ns	ns	ns	ns	**-**	**1.421**	ns
Total aluminum	mg/L	0.1	ns	ns	ns	ns	ns	ns	**3.18**	**4.16**	ns
Total iron	mg/L	0.3	ns	ns	ns	ns	ns	ns	**3.65**	**4.21**	ns
Summer											
Total phenolics	mg/L	0.004	ns	ns	ns	ns	ns	ns	**0.0046**	**-**	ns
Total Kjeldahl Nitrogen	mg/L	1.0	ns	ns	ns	ns	ns	ns	**1.03**	**-**	ns
Total nitrogen	mg/L	1.0	ns	ns	ns	ns	ns	ns	**1.101**	**-**	ns
Total Aluminum	mg/L	0.1	ns	ns	ns	ns	ns	ns	**2.93**	**2.88**	ns
Total iron	mg/L	0.3	ns	ns	ns	ns	ns	ns	**3.16**	**2.93**	ns
Dissolved iron	mg/L	0.3[2]	ns	ns	ns	ns	ns	ns	**-**	**-**	ns
Total phosphorus	mg/L	0.05	ns	ns	ns	ns	ns	ns	**0.114**	**0.128**	ns
Fall											
Dissolved iron	mg/L	0.3[2]	**0.401**	-	-	-	**-**	-	-	-	-
Total nitrogen	mg/L	1.0	-	-	-	-	**1.011**	-	-	-	-
Sulphide	mg/L	0.002 [2]	-	-	-	-	**-**	-	**0.0025**	**0.0024**	**0.0021**
Total Aluminum	mg/L	0.1	**0.618**	**0.549**	**0.965**	**0.928**	**0.775**	**1.04**	**0.581**	**0.567**	**0.433**
Total iron	mg/L	0.3	**1.04**	**0.439**	**1.06**	**0.794**	**0.881**	**1.12**	**0.757**	**0.772**	**0.583**

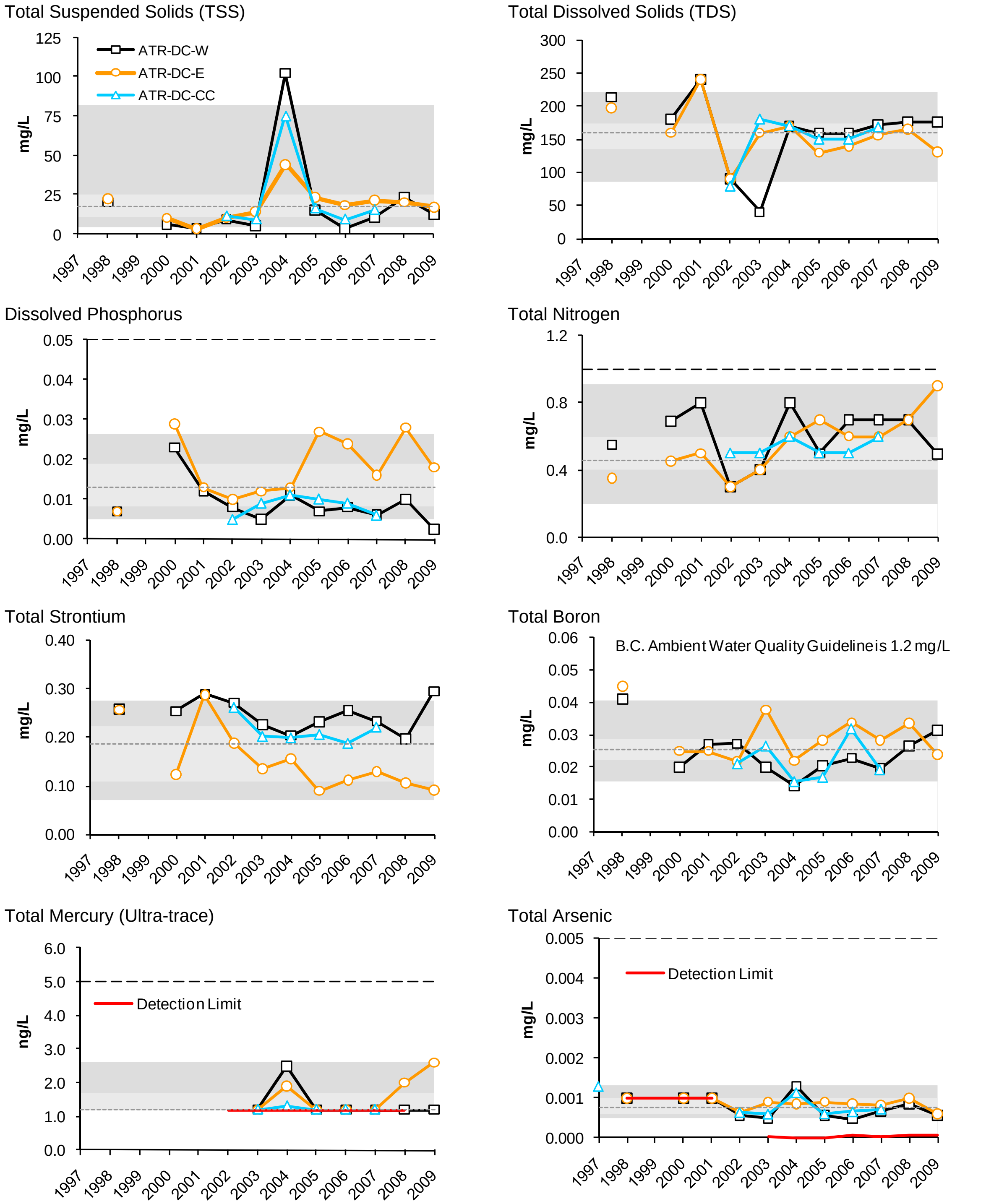
ns = not sampled

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

[1] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[2] B.C. Working Water Quality Guideline (2006).

Figure 5.1-4 Concentrations of selected water quality measurement endpoints (fall data) relative to regional *baseline* fall concentrations, Athabasca River mainstem, upstream of Donald Creek (ATR-DC).



Non-detectable values are shown at the detection limit.

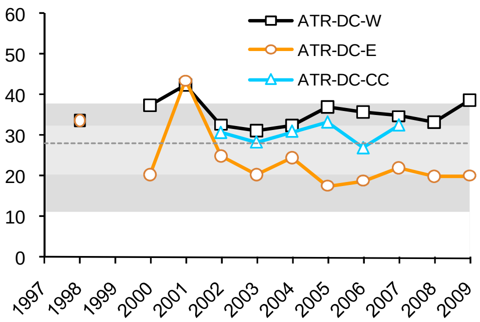
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

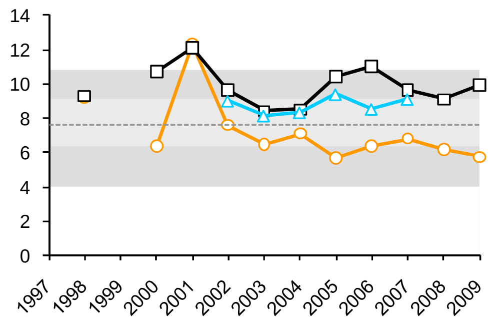
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-4 (Cont'd.)

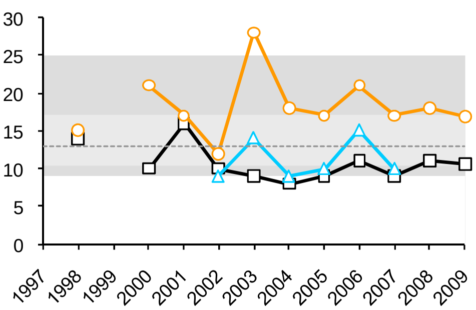
Calcium



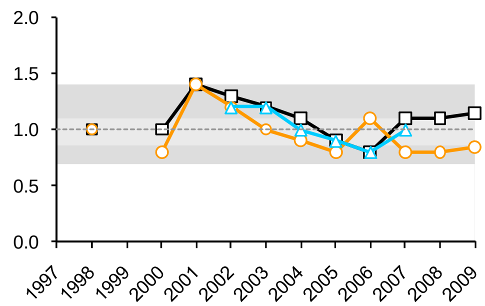
Magnesium



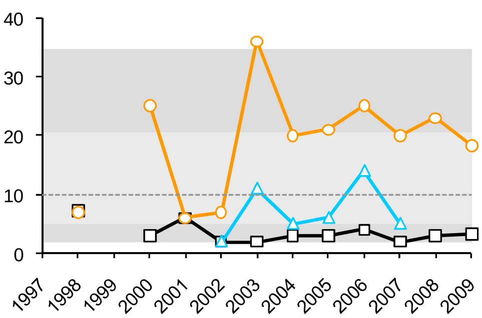
Sodium



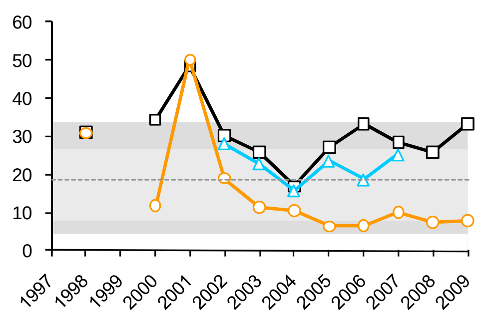
Potassium



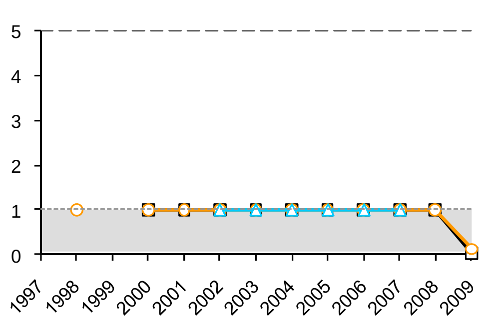
Chloride



Sulphate



Naphthenic Acids[1]



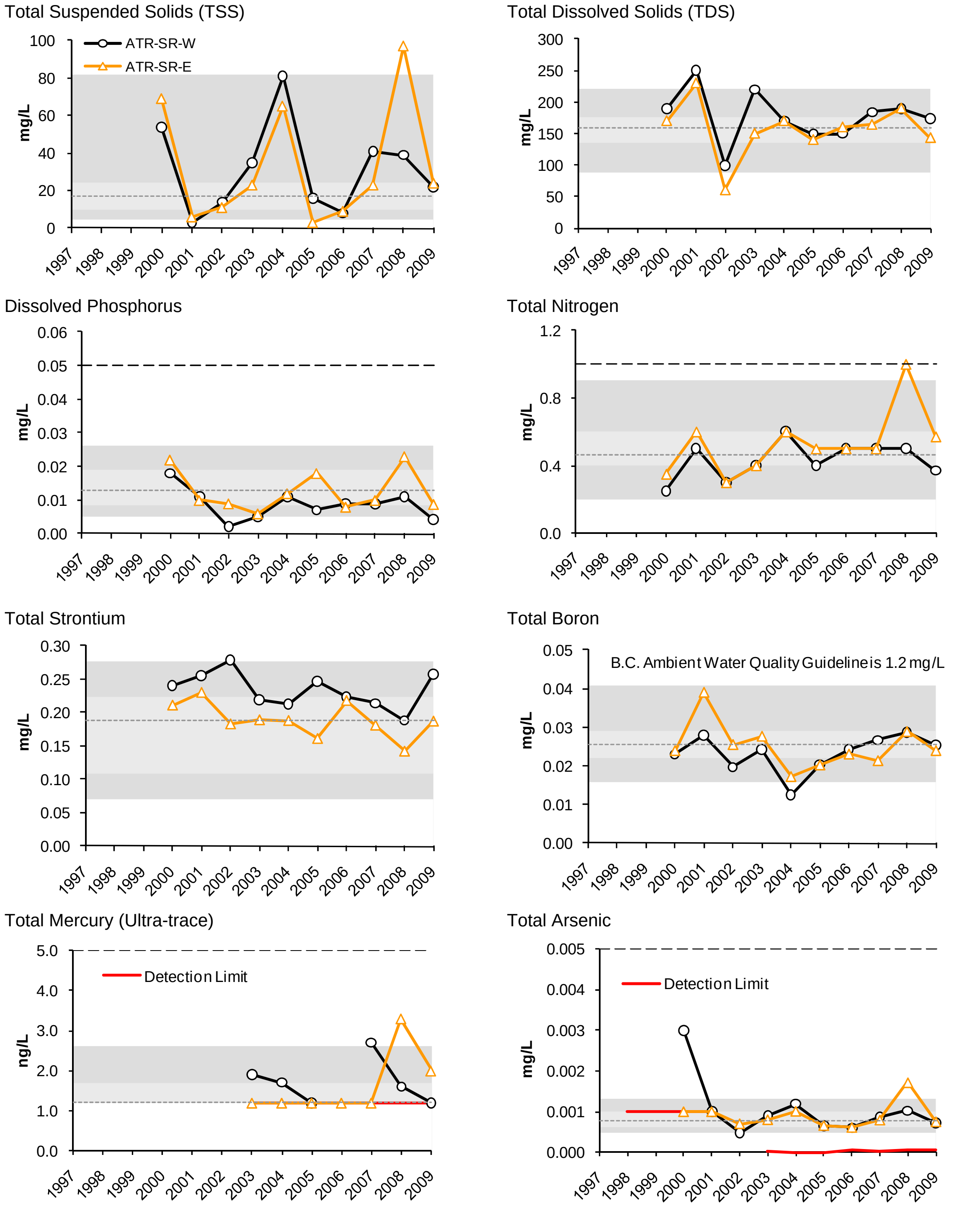
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-5 Concentrations of selected water quality measurement endpoints (fall data) relative to regional *baseline* fall concentrations, Athabasca River mainstem, upstream of the Steepbank River (ATR-SR).



Non-detectable values are shown at the detection limit.

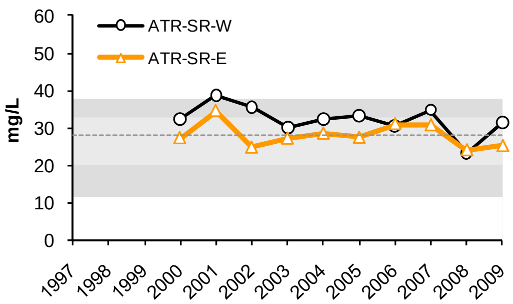
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

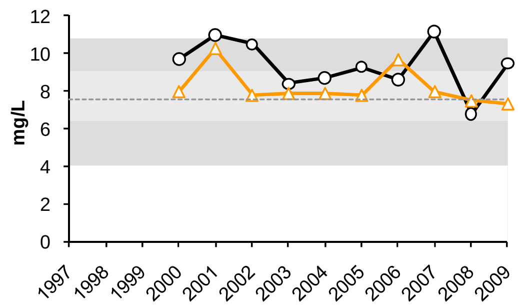
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-5 (Cont'd.)

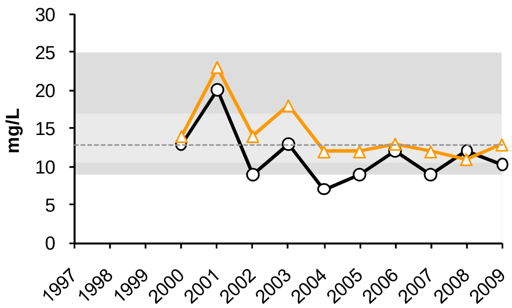
Calcium



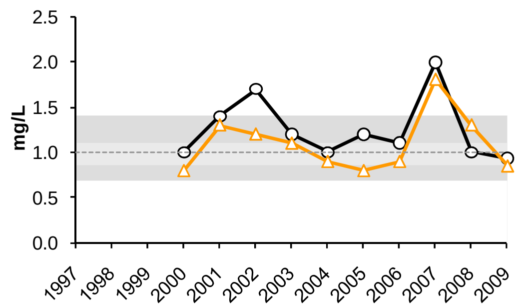
Magnesium



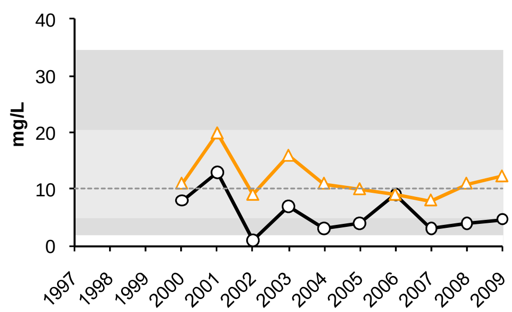
Sodium



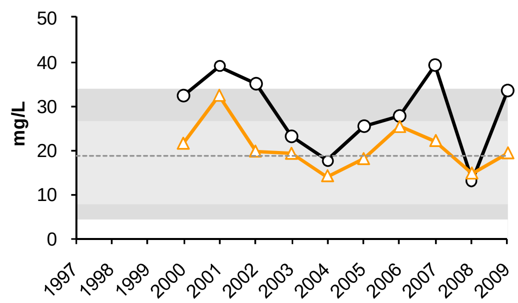
Potassium



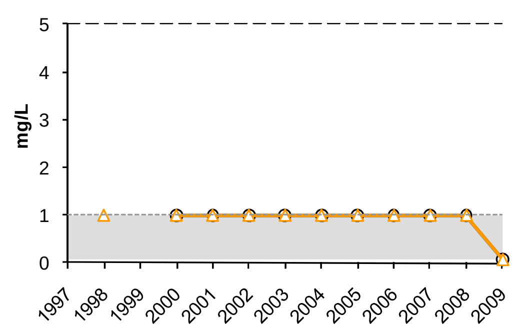
Chloride



Sulphate



Naphthenic Acids[1]



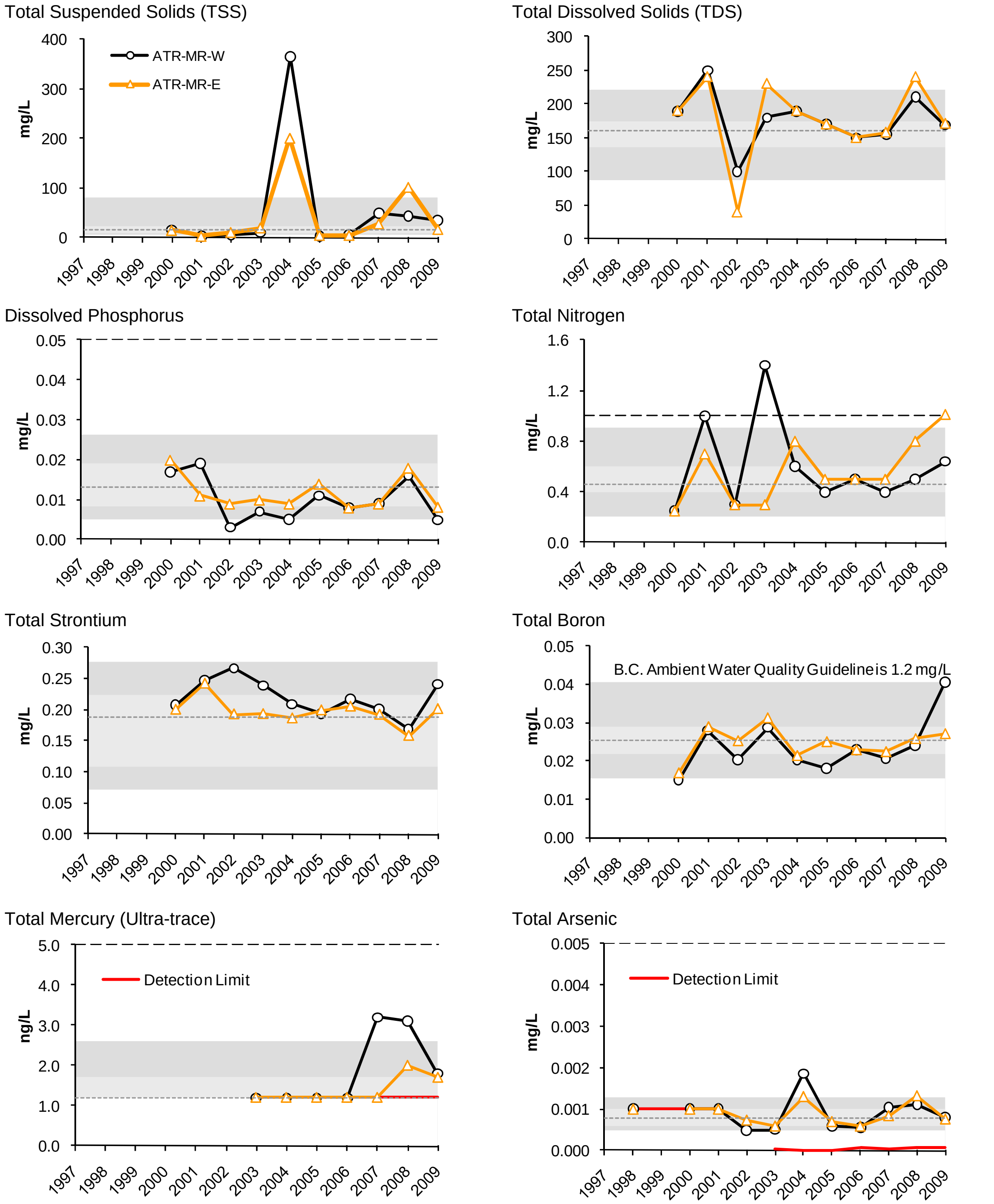
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-6 Concentrations of selected water quality measurement endpoints (fall data) relative to regional *baseline* fall concentrations, Athabasca River mainstem, upstream of the Muskeg River (ATR-MR).



Non-detectable values are shown at the detection limit.

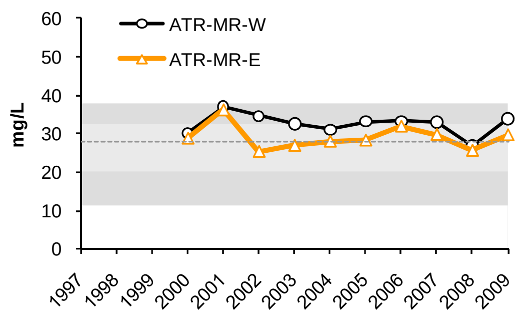
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

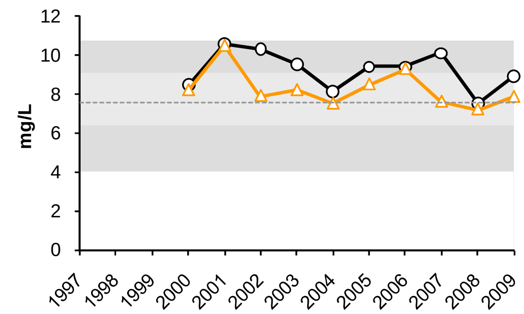
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-6 (Cont'd.)

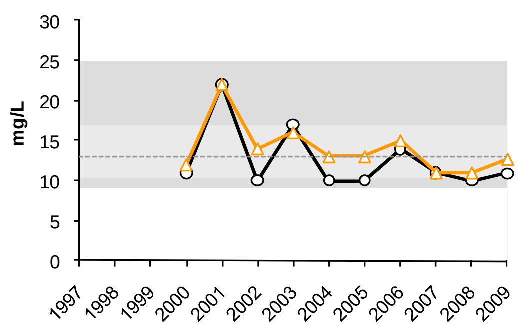
Calcium



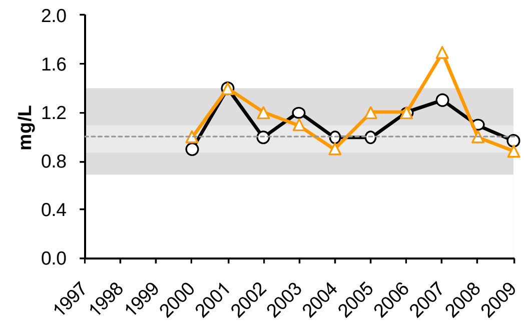
Magnesium



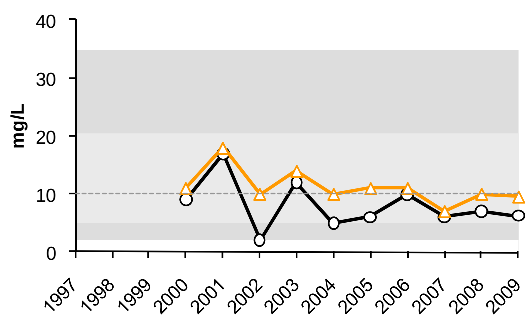
Sodium



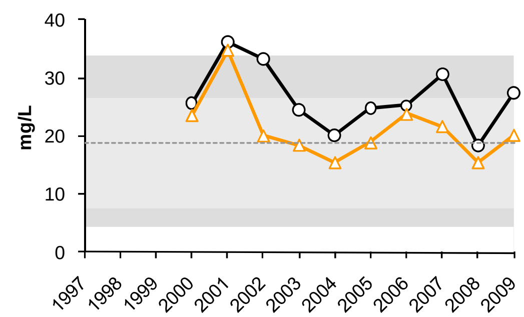
Potassium



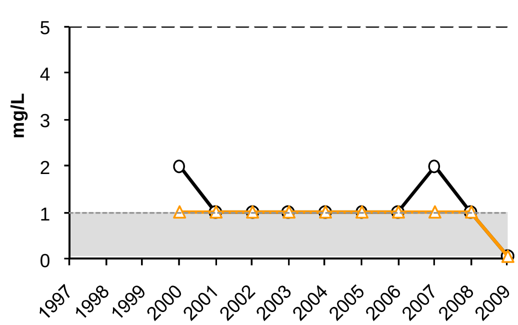
Chloride



Sulphate



Naphthenic Acids[1]



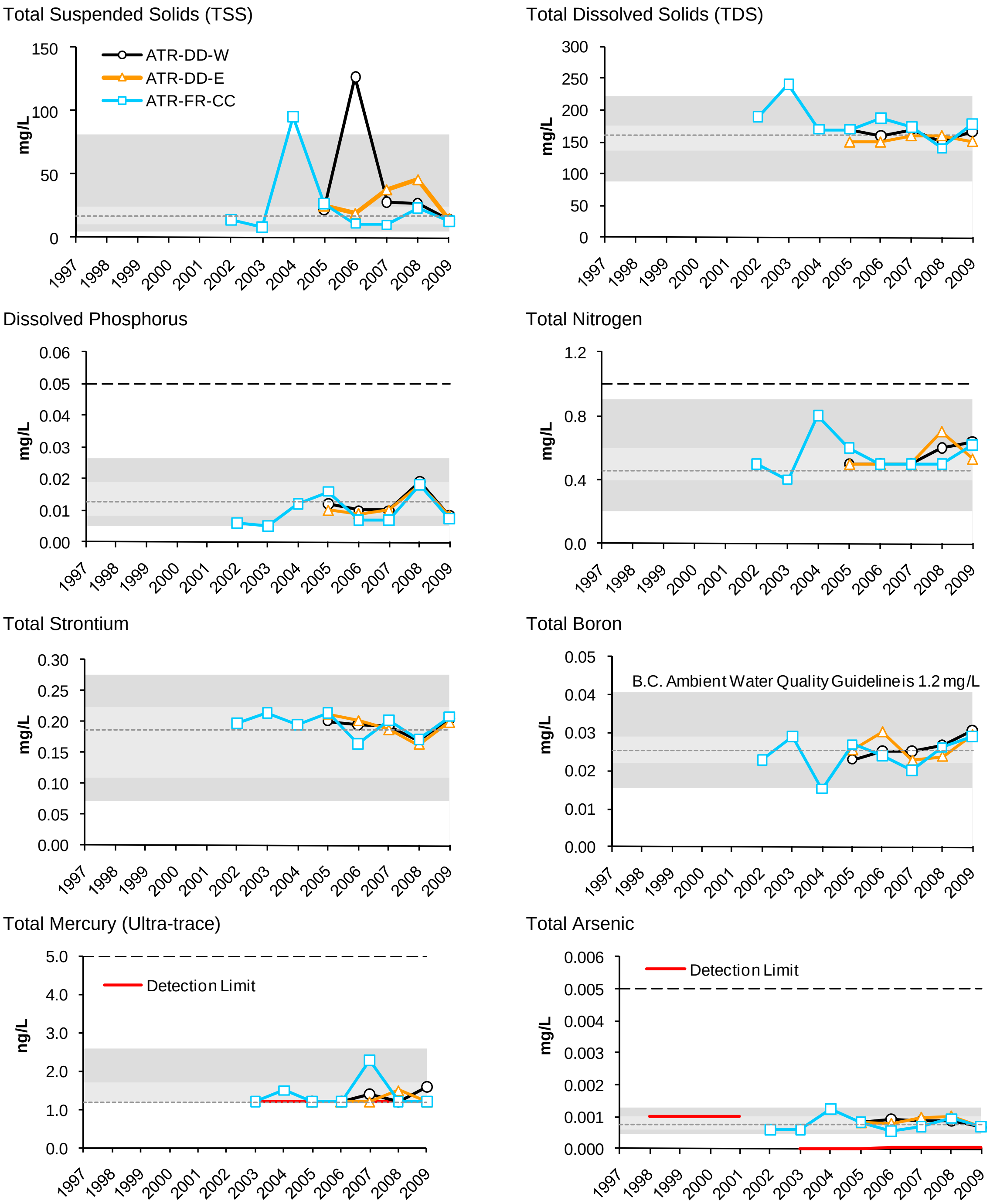
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-7 Concentrations of selected water quality measurement endpoints (fall data) relative to regional *baseline* fall concentrations, Athabasca River mainstem, downstream of development (ATR-DD) and upstream of the Firebag River (ATR-FR).



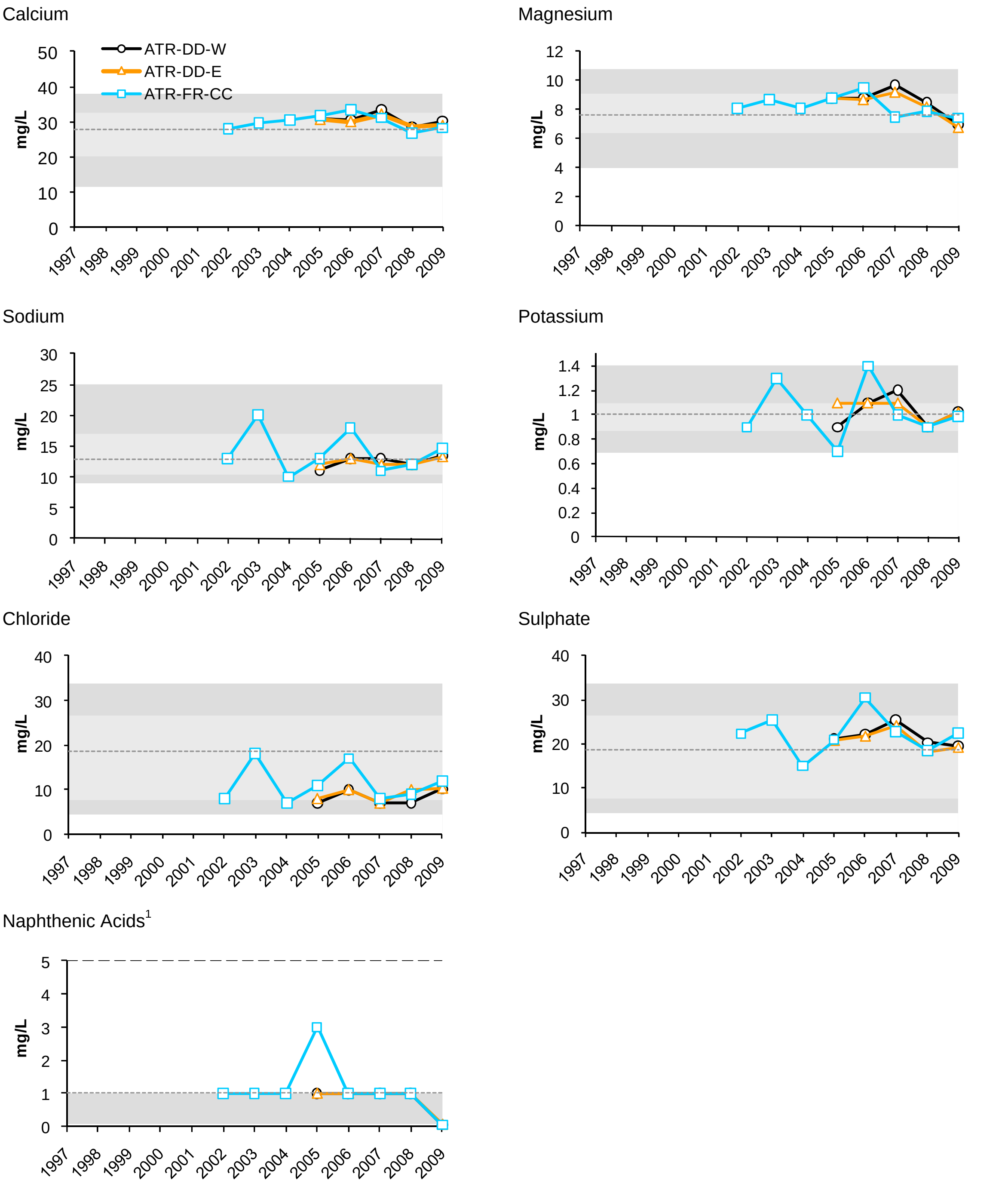
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-7 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-8 Piper diagram of ion concentrations in Athabasca River mainstem, fall 1997 to 2009.

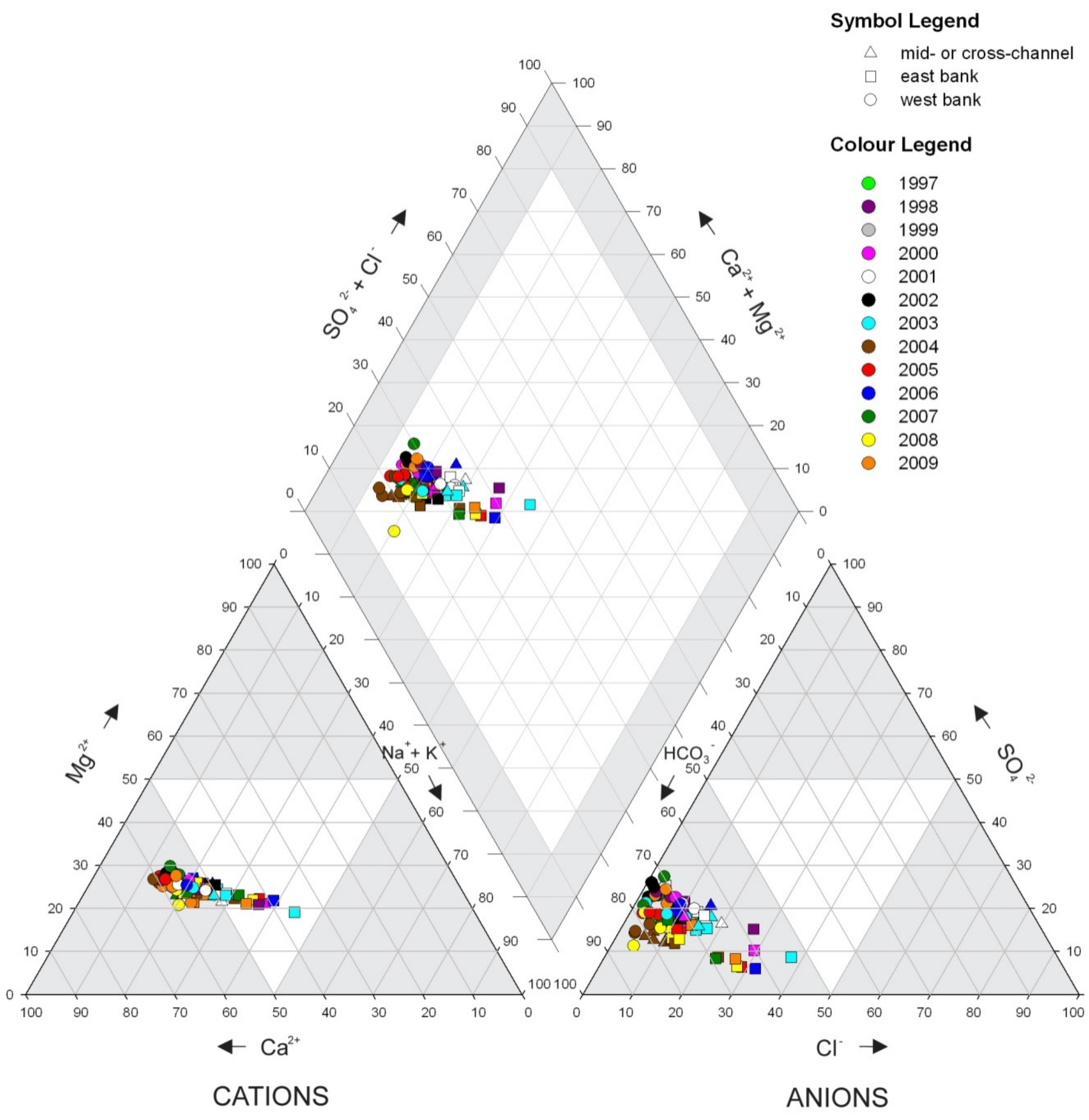
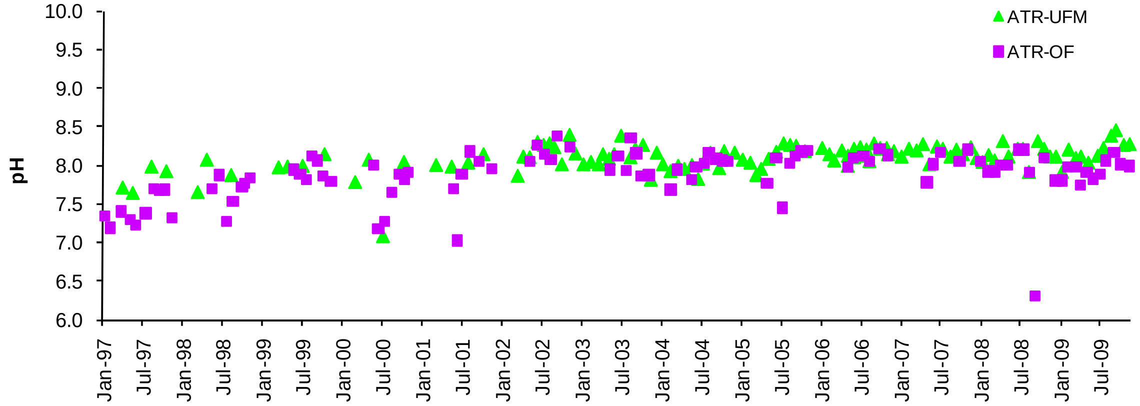


Figure 5.1-9 Water quality measurement endpoints, 1997 to 2009 AENV data for the Athabasca River mainstem.

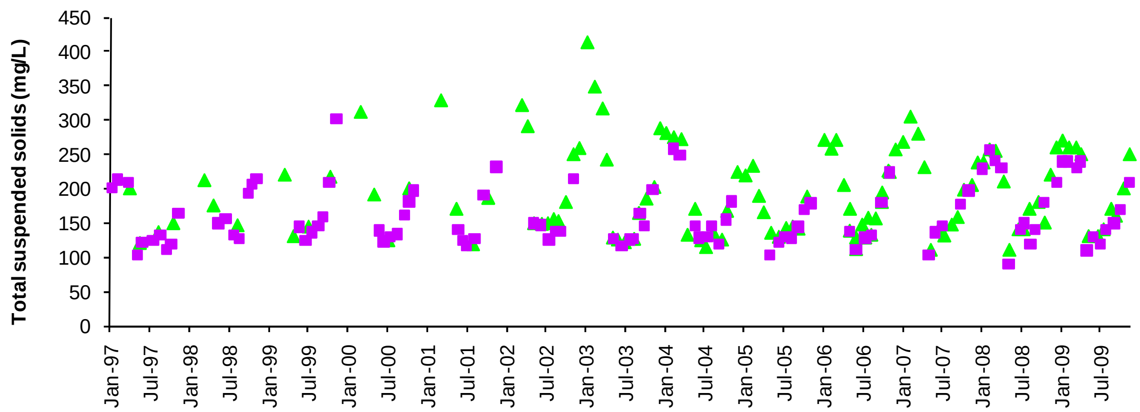
pH

Trend at ATR-UFM: up Trend at ATR-OF: up



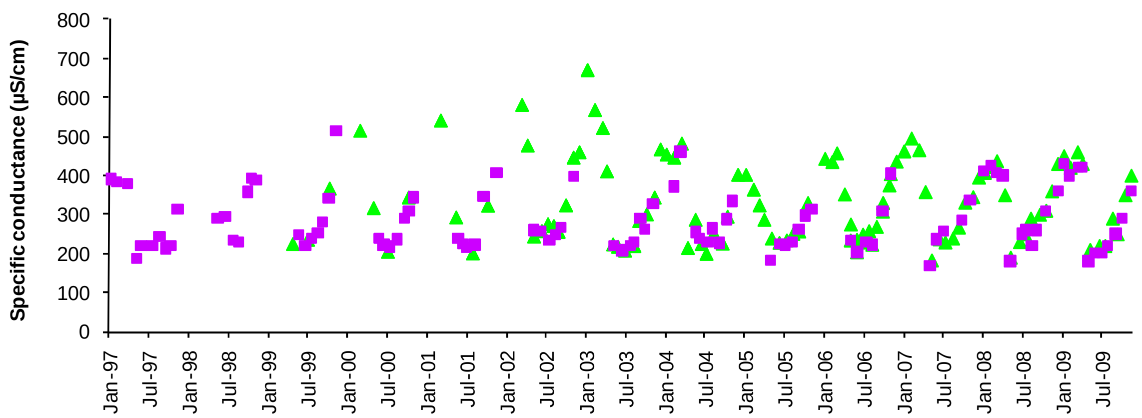
Total dissolved solids

Trend at ATR-UFM: none Trend at ATR-OF: none



Specific conductance

Trend at ATR-UFM: none Trend at ATR-OF: none

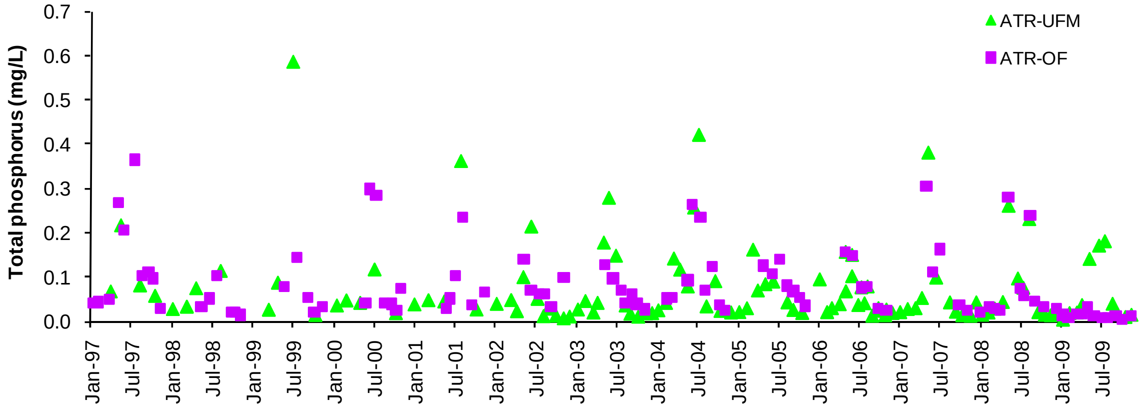


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

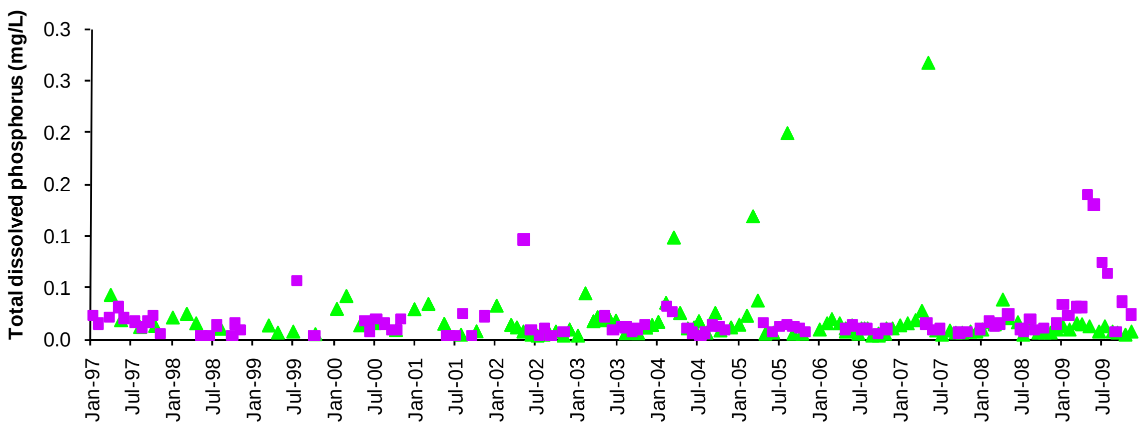
Total phosphorus

Trend at ATR-UFM: down   Trend at ATR-OF: down



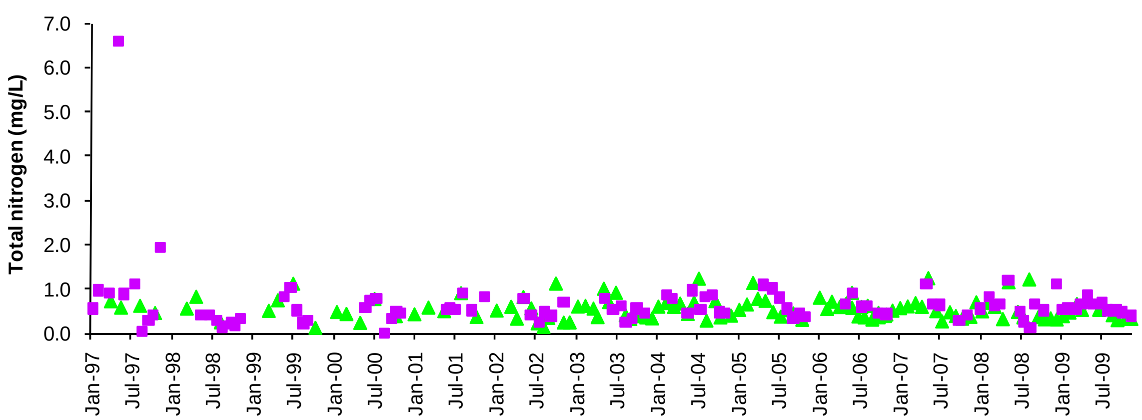
Total dissolved phosphorus

Trend at ATR-UFM: none   Trend at ATR-OF: none



Total nitrogen

Trend at ATR-UFM: none   Trend at ATR-OF: none

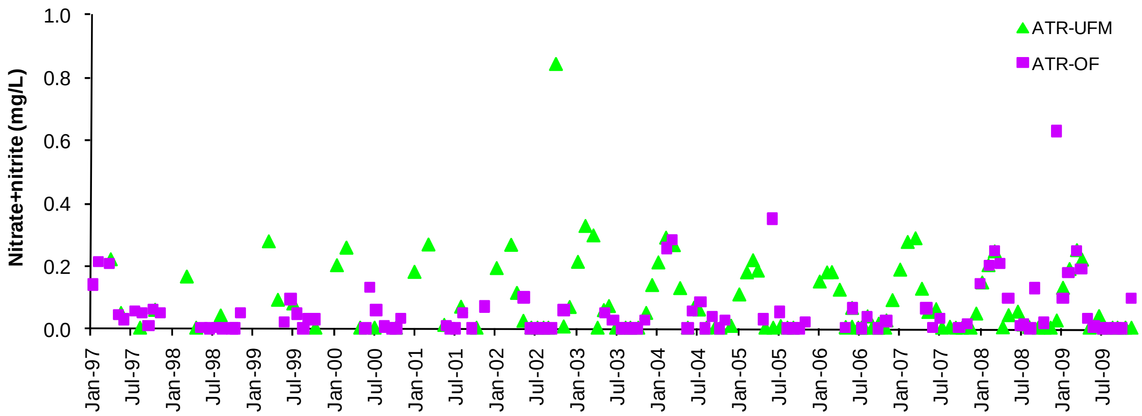


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

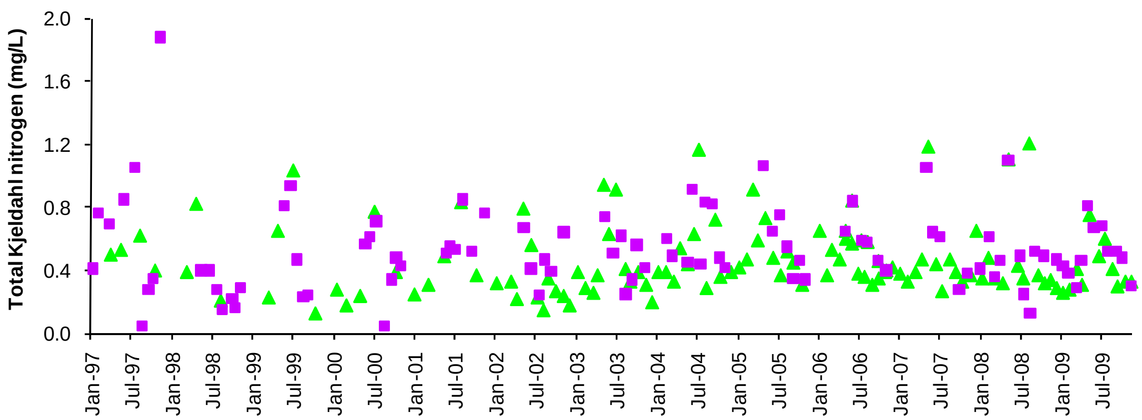
Nitrate + Nitrite

Trend at ATR-UFM: none Trend at ATR-OF: none



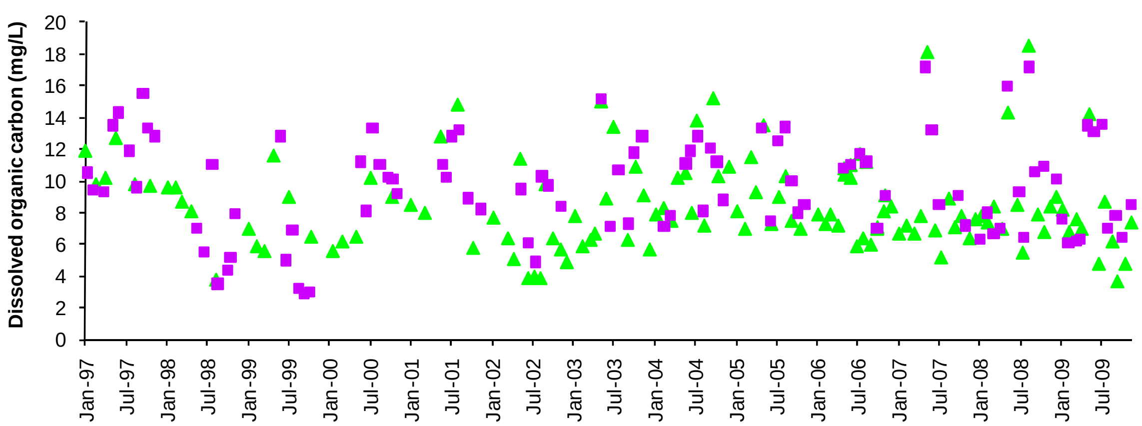
Total Kjeldahl nitrogen

Trend at ATR-UFM: none Trend at ATR-OF: none



Dissolved organic carbon

Trend at ATR-UFM: none Trend at ATR-OF: none

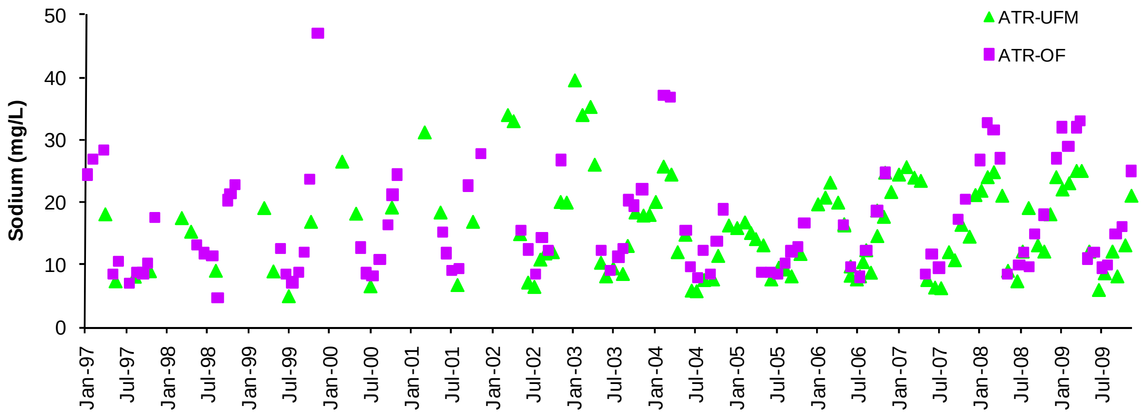


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

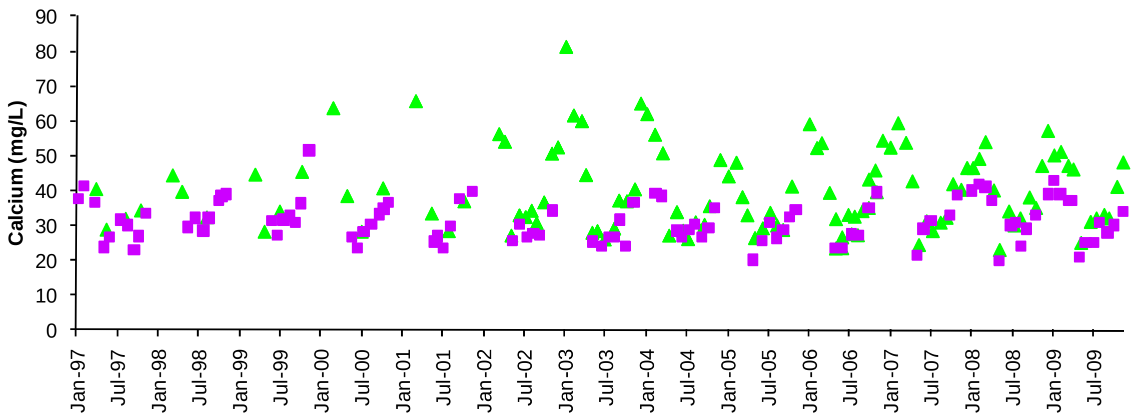
Sodium

Trend at ATR-UFM: none   Trend at ATR-OF: none



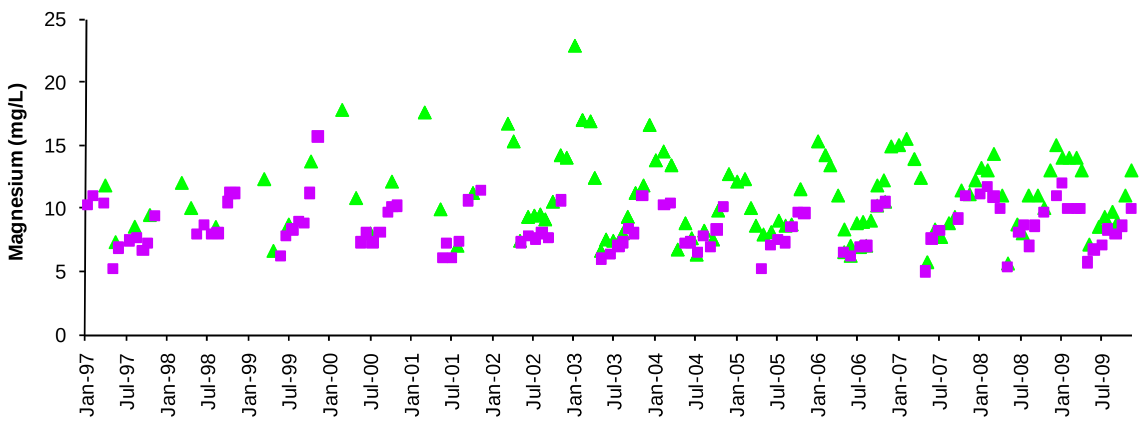
Calcium

Trend at ATR-UFM: none   Trend at ATR-OF: none



Magnesium

Trend at ATR-UFM: none   Trend at ATR-OF: none

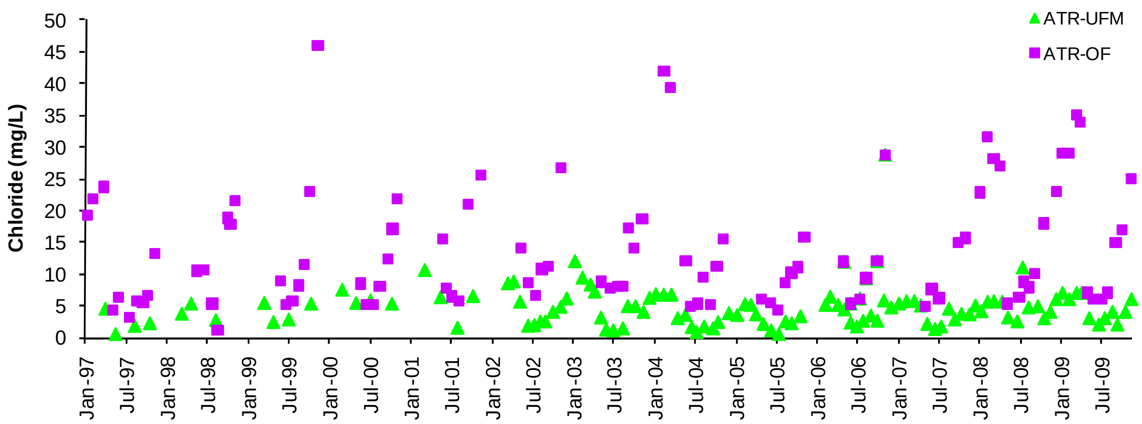


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

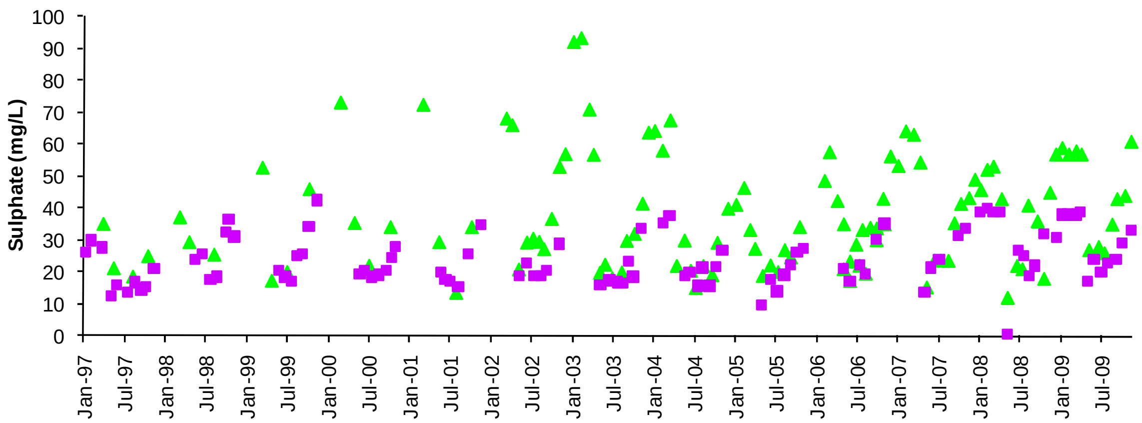
Chloride

Trend at ATR-UFM: none   Trend at ATR-OF: none



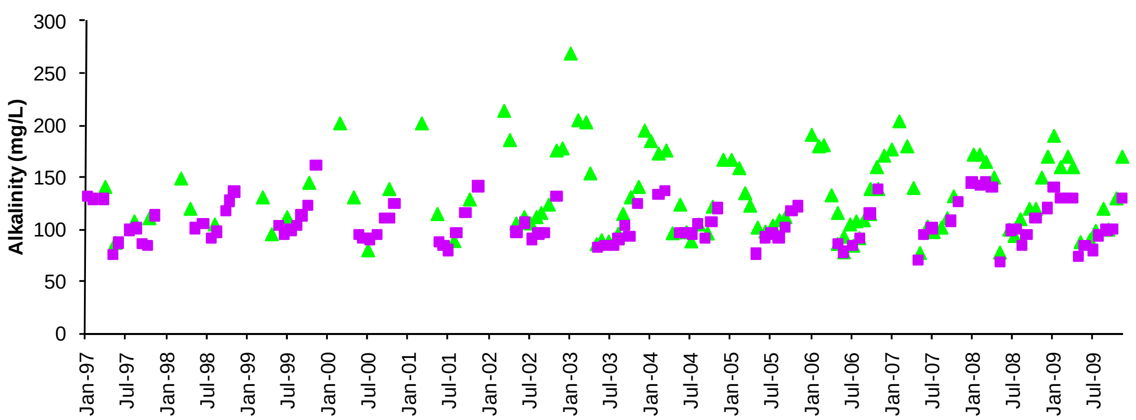
Sulphate

Trend at ATR-UFM: none   Trend at ATR-OF: up



Alkalinity (as $CaCO_3$)

Trend at ATR-UFM: none   Trend at ATR-OF: none

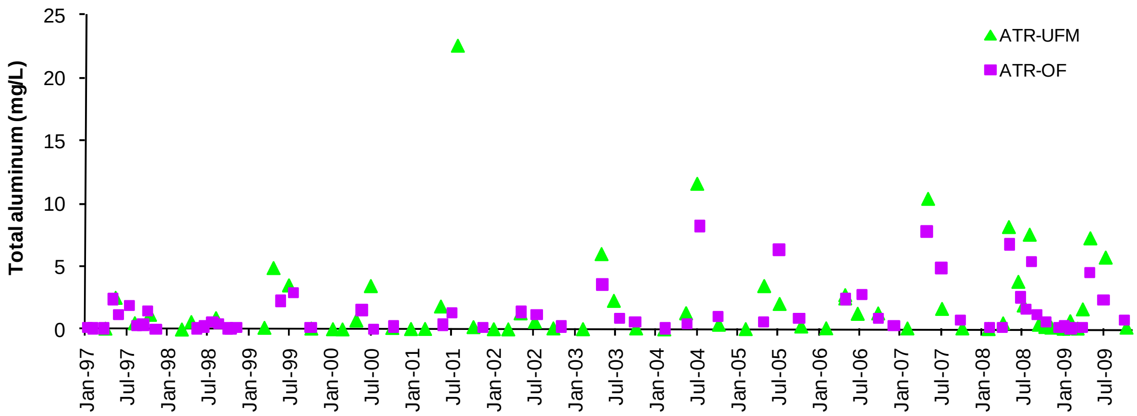


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

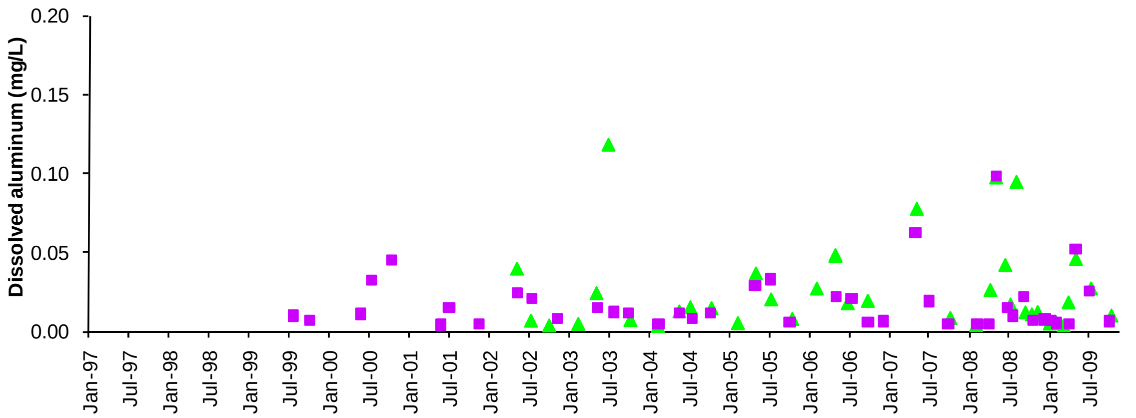
Total aluminum

Trend at ATR-UFM: up Trend at ATR-OF: up



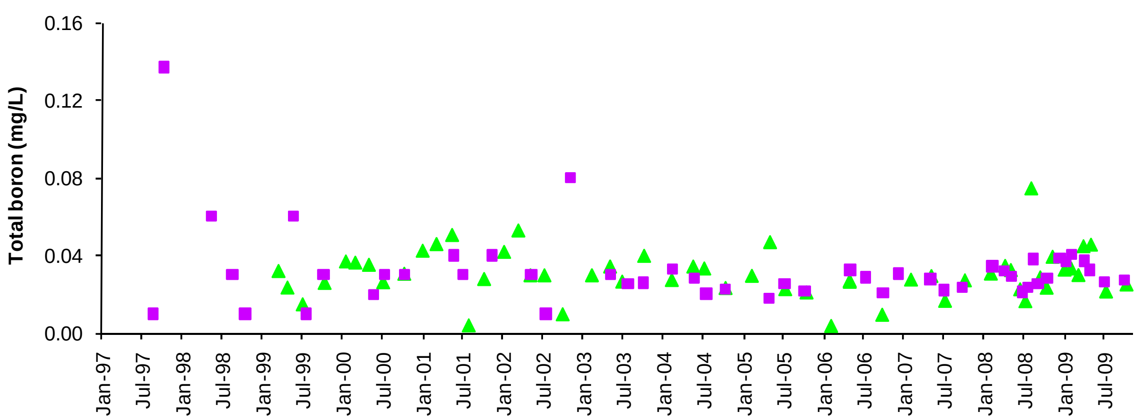
Dissolved aluminum

Trend at ATR-UFM: up Trend at ATR-OF: none



Total boron

Trend at ATR-UFM: none Trend at ATR-OF: none

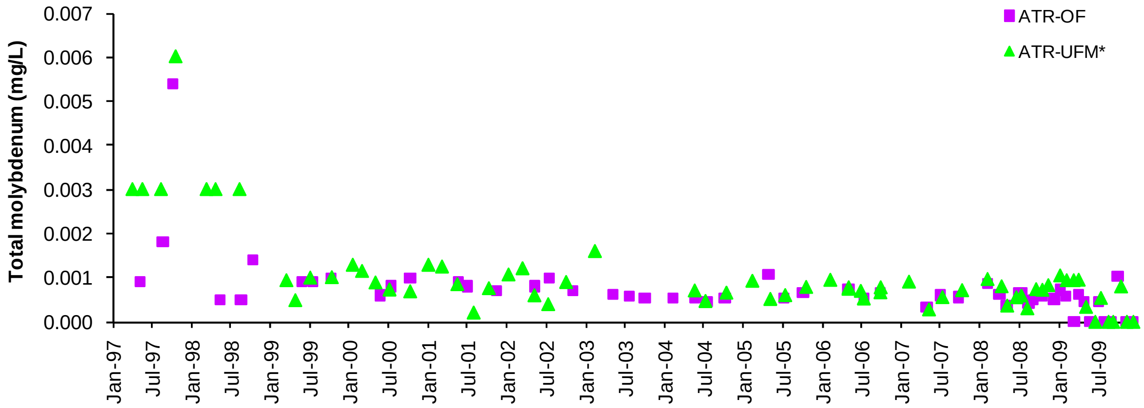


Non-detectable results are shown at the detection limit.

Figure 5.1-9 (Cont'd.)

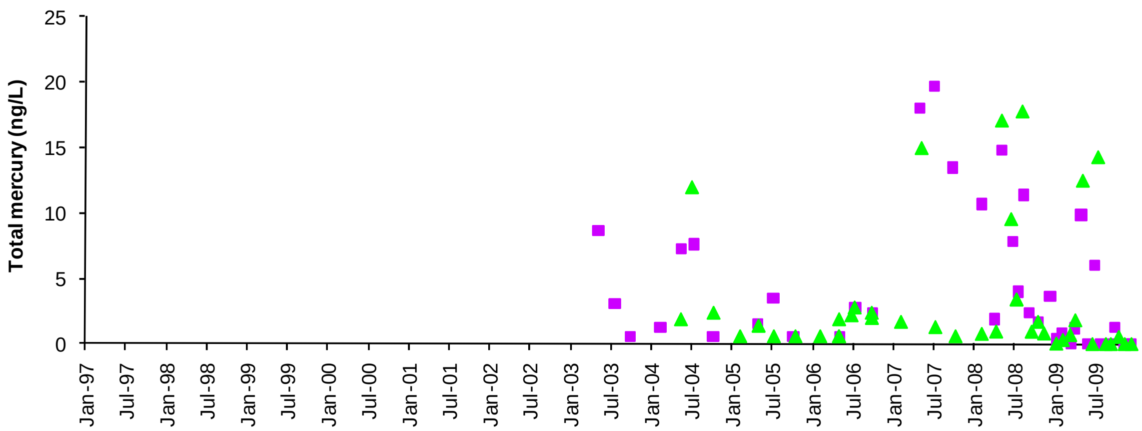
Total molybdenum

Trend at ATR-UFM: none Trend at ATR-OF: down



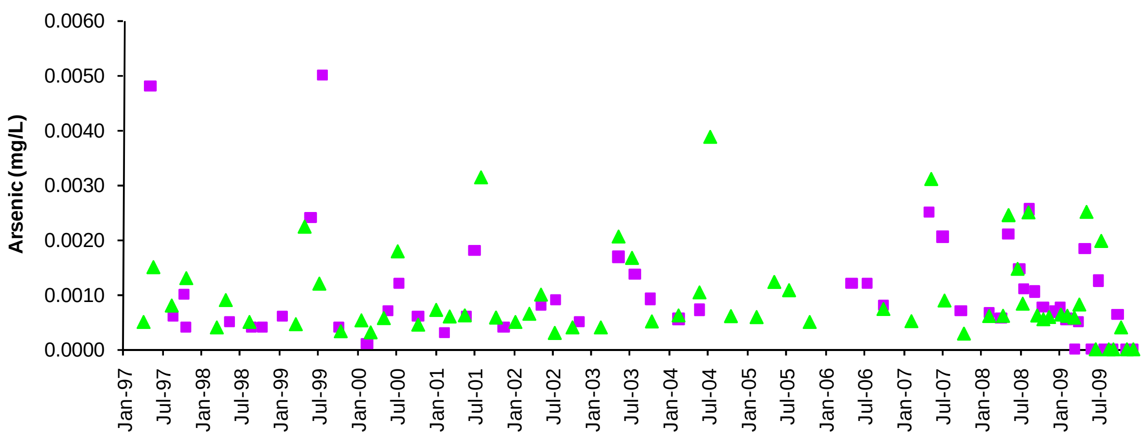
Total mercury (ultra-trace)

Trend at ATR-UFM: none Trend at ATR-OF: none



Total Arsenic

Trend at ATR-UFM: up Trend at ATR-OF: none



Non-detectable results are shown at the detection limit.

Table 5.1-6 Trend analysis of water quality measurement endpoints for Athabasca River mainstem stations.

AENV Water Quality Variable	Upstream of Fort McMurray 1997 - 2009 (station ATR-UFM)			At Old Fort 1997 - 2009 (station ATR-OF)		
	n	Trend Direction	Slope Estimate[1] (units per year)	n	Trend Direction	Slope Estimate[1] (units per year)
Physical variables						
pH	110	up	0.0183	105	up	0.0313
Specific conductance	102	-	-	105	-	-
Nutrients						
Total phosphorus	112	down	-0.0009	102	down	-0.0023
Total dissolved phosphorus	113	-	-	99	-	-
Total nitrogen	113	-	-	103	-	-
Nitrate+nitrite	113	-	-	104	-	-
Total Kjeldahl nitrogen	113	-	-	102	-	-
Dissolved organic carbon	118	-	-	103	-	-
Ions						
Sodium	110	-	-	105	-	-
Calcium	110	-	-	105	-	-
Magnesium	110	-	-	105	-	-
Chloride	109	-	-	105	-	-
Sulphate	109	-	-	105	up	0.3796
Total dissolved solids (calculated)	110	-	-	105	-	-
Alkalinity (as $CaCO_3$)	110	-	-	105	-	-
Selected metals						
Total aluminum	62	up	0.0071	62	up	0.0636
Dissolved aluminum	36	up	0.0006	43	-	-
Total boron	55	-	-	50	-	-
Total molybdenum	51*	-	-	51	down	-0.00003
Total mercury (ultra-trace)	31	-	-	32	-	-
Total Arsenic	59	up	0.00002	48	-	-

Critical value at 95% confidence level = 1.960.

[1] Trend analyzed from 1999 to 2009 due to high detection limits in 1997 and 1998.

Table 5.1-7 Water quality index (fall 2009) for Athabasca River mainstem stations.

Station Identifier	Location	2009 Designation	Water Quality Index	Classification
ATR-DC-E	Upstream of Donald Creek, East Bank	*baseline*	100.0	Negligible-Low
ATR-DC-W	Upstream of Donald Creek, West Bank	*baseline*	94.6	Negligible-Low
ATR-SR-E	Upstream of the Steepbank River, East Bank	*test*	100.0	Negligible-Low
ATR-SR-W	Upstream of the Steepbank River, West Bank	*test*	100.0	Negligible-Low
ATR-MR-E	Upstream of the Muskeg River, East Bank	*test*	100.0	Negligible-Low
ATR-MR-W	Upstream of the Muskeg River, West Bank	*test*	100.0	Negligible-Low
ATR-DD-E	Downstream of all development, East Bank	*test*	100.0	Negligible-Low
ATR-DD-W	Downstream of all development, West Bank	*test*	100.0	Negligible-Low
ATR-FR-CC	Upstream of the Firebag River, Cross-Channel	*test*	100.0	Negligible-Low

Note: see Figure 5.1-1 for the locations of these water quality stations.

Note: see Section 3.2.7.4 for a description of the Water Quality Index.

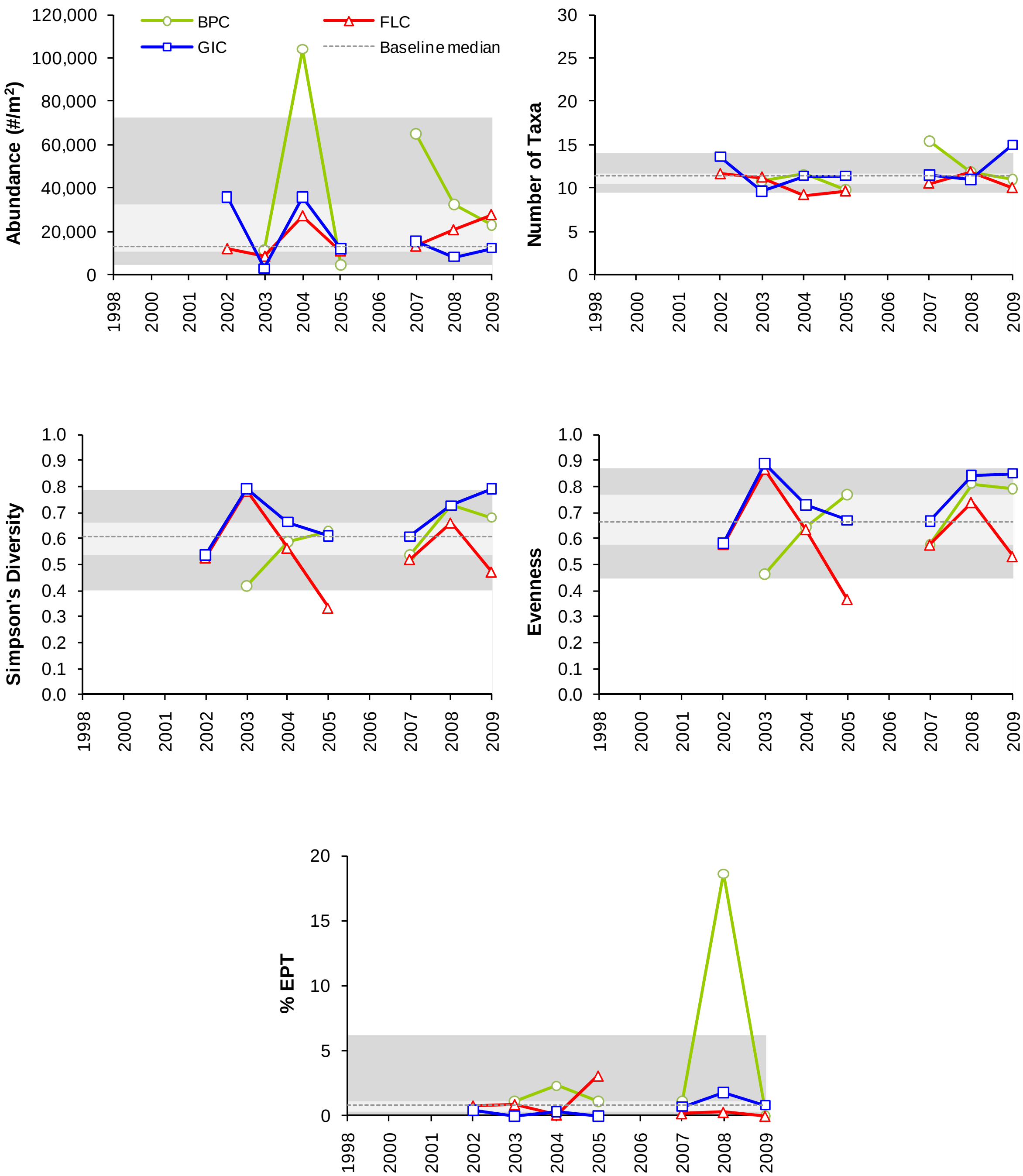
Table 5.1-8 Average habitat characteristics of benthic invertebrate community sampling locations of the Athabasca River Delta.

Variable	Units	Big Point Channel	Fletcher Channel	Goose Island Channel
Sample Date	-	Sept. 19, 2009	Sept. 19, 2009	Sept. 19, 2009
Habitat	-	Depositional	Depositional	Depositional
Water Depth	m	1.6	1.7	1.6
Current Velocity	m/s	0.23	0.22	0.31
Field Water Quality				
Dissolved Oxygen	mg/L	8.8	9.4	9.0
Conductivity	µS/cm	193	308	295
pH	pH units	8.2	8.2	8.2
Water Temperature	°C	15.9	16.1	15.5
Sediment Composition				
Sand	%	25	28	39
Silt	%	52	53	45
Clay	%	23	19	15
Total Organic Carbon	%	2.2	2.2	1.8

Table 5.1-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in *test* reaches of the Athabasca River Delta.

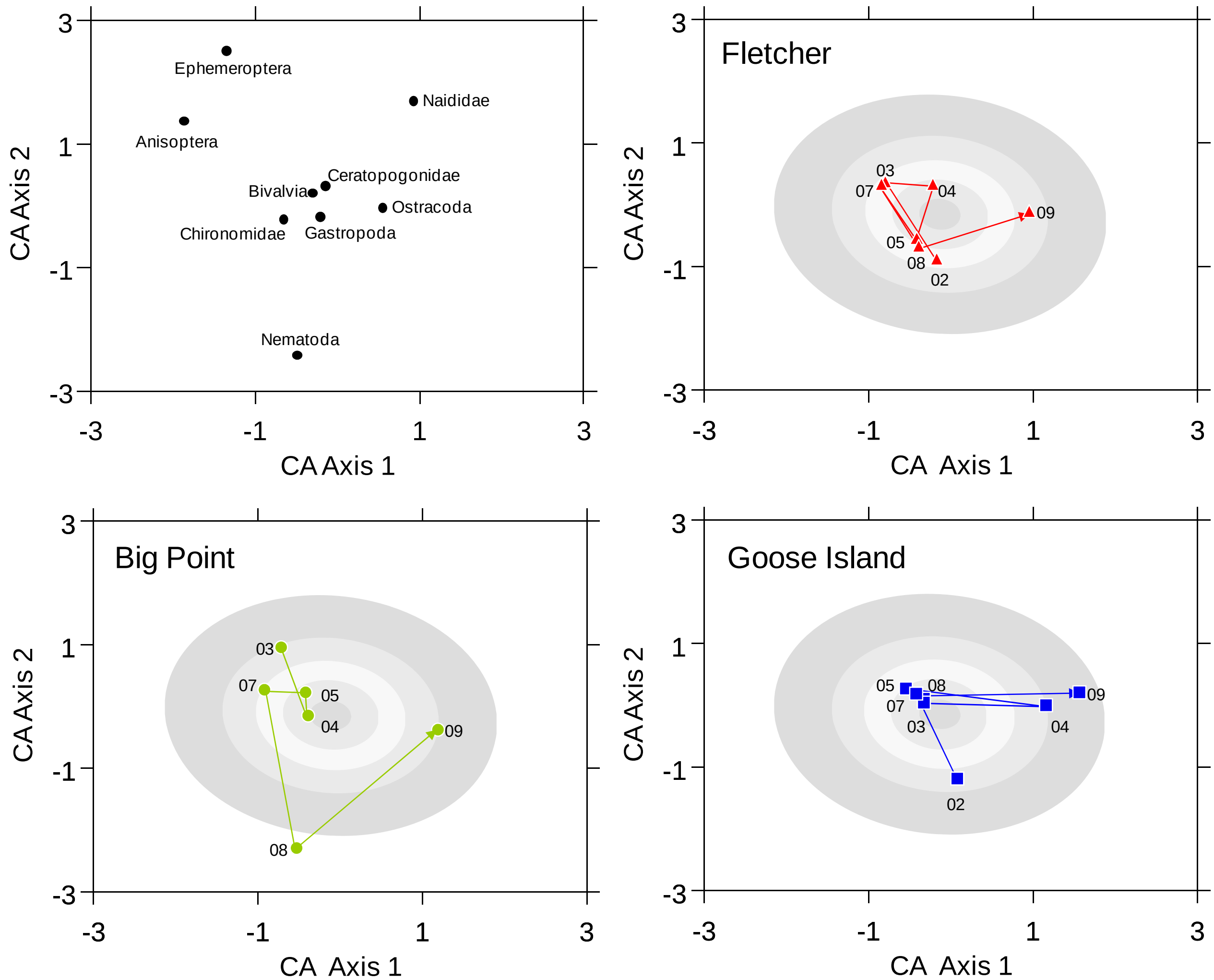
Taxon	Percent Major Taxa Enumerated in Each Year																			
	Big Point Channel						Fletcher Channel							Goose Island Channel						
	2003	2004	2005	2007	2008	2009	2002	2003	2004	2005	2007	2008	2009	2002	2003	2004	2005	2007	2008	2009
Amphipoda		<1	2																	
Anisoptera	<1	<1	<1	<1	<1			<1	<1	<1	<1			<1	<1	<1		<1	<1	
Bivalvia	10	1	8	37	12	8	1	13	3	3	2	1	2	13	4	2	3	2	4	2
Ceratopogonidae	1	<1	7	1	1	2	2	10	5	2	8	6	<1	1	17	3	2	2	3	1
Chironomidae	6	40	31	3	11	23	86	13	27	4	18	52	11	74	28	64	13	24	27	55
Copepoda				<1		1							<1	<1			1		<1	2
Empididae					<1	4	<1													<1
Ephemeroptera	<1	<1	1	<1			<1	1	<1	<1	<1	<1				<1	<1		1	<1
Erpobdellidae		<1																		
Gastropoda	4	<1	1	2	12	<1	1	14	<1	2	1	1	2	5	11	<1	<1	1	24	1
Heteroptera	<1	<1						<1	<1						<1					
Hydracarina	<1				<1					<1				<1	<1		<1			
Lumbriculidae															<1	<1				
Macrothricidae							<1			<1				<1	2		2			
Megaloptera		<1																		
Naididae	1	<1	2	1	<1	7	<1	15	3		2	1	2			<1	7	2	<1	<1
Nematoda	<1	<1	1	1	7	<1	5	5	<1	<1	1	22	<1	5		<1	2	2	1	<1
Ostracoda	<1	2	2	<1	<1	5	3	2	4	4	1	7	4	1	9	3	8	9	2	13
Plecoptera				<1	<1					<1										
Tabanidae								<1												
Tipulidae	<1																			<1
Trichoptera	1	2	1	1	4			<1	<1	2	1			<1				1	2	
Tubificidae	75	52	46	54	52	49	2	26	58	81	66	10	72	<1	27	27	62	57	36	24
Benthic Invertebrate Community Measurement Endpoints																				
Total Abundance (No./m^2)	11,552	103,983	4,757	64,933	32,419	22,905	11,897	8,328	27,207	10,843	13,055	20,696	27,801	36,000	2,914	35,776	12,243	15,348	8,270	12,374
Richness	11	12	10	15	12	11	12	11	9	10	11	12	10	14	10	11	11	12	11	15
Simpson's Diversity	0.42	0.59	0.63	0.54	0.73	0.68	0.53	0.78	0.56	0.33	0.52	0.66	0.47	0.54	0.79	0.66	0.61	0.61	0.73	0.79
Evenness	0.46	0.64	0.77	0.57	0.81	0.79	0.58	0.86	0.63	0.37	0.57	0.74	0.53	0.58	0.89	0.73	0.67	0.67	0.84	0.85
% EPT	1	2	1	1	19	0	1	1	<1	3	<1	<1	0	<1	0	<1	<1	1	2	<1

Figure 5.1-10 Variation in benthic invertebrate community measurement endpoints in the Athabasca River Delta, 2002 to 2009.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.1-11 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Athabasca River Delta.



Note: The upper left panel is the scatterplot of taxa scores while the other three panels are the sample scores. The ellipses represent the range of CA axis scores that the three ARD reaches have produced from 1997 to 2008, and serves as a range of values against which to compare the 2009 data.

Table 5.1-10 Concentrations of sediment quality measurement endpoints, Athabasca River mainstem upstream of Embarras River (ATR-ER).

Measurement Endpoints	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	8.4	8	10	13.5	22
Silt	%	-	27.6	8	29	33	42
Sand	%	-	64	8	36	53.5	61
Total organic carbon	%	-	1.0	8	0.8	1.1	1.7
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	4	11	26	39
Fraction 3 (C16-C34)	mg/kg	300[1]	161	4	220	295	**570**
Fraction 4 (C34-C50)	mg/kg	2800[1]	141	4	180	215	340
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.006	8	0.005	0.008	0.037
Retene	mg/kg	-	0.064	8	0.031	0.046	0.081
Total dibenzothiophenes	mg/kg	-	0.234	8	0.092	0.238	0.749
Total PAHs	mg/kg	-	1.175	8	0.816	1.192	2.482
Total Parent PAHs	mg/kg	-	0.073	8	0.084	0.114	0.156
Total Alkylated PAHs	mg/kg	-	1.102	8	0.660	1.088	2.355
Predicted PAH toxicity[3]	H.I.	-	1.050	8	0.397	0.993	1.500
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	3.4	4	7.0	7.7	8.6
Chironomus growth - 10d	mg/organism	-	1.3	4	1.2	2.2	3.5
Hyalella survival - 14d[4]	# surviving	-	9.4	2	7.0	9.1	10.0
Hyalella growth - 14d[4]	mg/organism	-	0.3	2	0.1	0.1	0.3

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

4 Pre-2003 *Hyalella* test based off 10-day test period.

Table 5.1-11 Concentrations of sediment quality measurement endpoints, Goose Island Channel (GIC-1).

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only GIC-1)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	14	6	12	20	28
Silt	%	-	34	6	44	53	58
Sand	%	-	53	6	17	30	44
Total organic carbon	%	-	1.4	6	1.1	1.8	2.4
Total hydrocarbons							
BTEX	mg/kg	-	<10	3	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[2]	<10	3	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[2]	<20	3	<5	8	17
Fraction 3 (C16-C34)	mg/kg	300[2]	216	3	180	280	**360**
Fraction 4 (C34-C50)	mg/kg	2800[2]	176	3	88	110	200
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.0058	6	0.005	0.009	0.015
Retene	mg/kg	-	0.035	6	0.027	0.049	0.078
Total dibenzothiophenes	mg/kg	-	0.238	6	0.202	0.241	0.412
Total PAHs	mg/kg	-	1.184	6	1.016	1.390	2.161
Total Parent PAHs	mg/kg	-	0.077	6	0.082	0.123	0.177
Total Alkylated PAHs	mg/kg	-	1.107	6	0.935	1.269	1.984
Predicted PAH toxicity[4]	H.I.	-	0.810	6	0.933	1.104	1.263
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	5.8	4	4.0	7.5	8.4
Chironomus growth - 10d	mg/organism	-	1.6	4	1.3	2.7	4.2
Hyalella survival - 14d[1]	# surviving	-	8.2	2	7.0	9.0	10.0
Hyalella growth - 14d[1]	mg/organism	-	0.2	2	0.1	0.1	0.3

Values in **bold** indicate concentrations exceeding guidelines.

1 Pre-2003 *Hyalella* test based on 10-day test period

2 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

3 Interim sediment quality guideline (ISQG) (CCME 2002).

4 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.1-12 Concentrations of sediment quality measurement endpoints, Fletcher Channel (FLC-1).

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	10.8	6	10	15	18
Silt	%	-	42.6	6	18	36.5	72
Sand	%	-	46.6	6	11	47.5	70
Total organic carbon	%	-	1.3	6	0.6	1.2	1.6
Total hydrocarbons							
BTEX	mg/kg	-	<20	3	<5	<5	30
Fraction 1 (C6-C10)	mg/kg	30[2]	<20	3	<5	<5	30
Fraction 2 (C10-C16)	mg/kg	150[2]	30	3	<5	18	23
Fraction 3 (C16-C34)	mg/kg	300[2]	**389**	3	110	290	**430**
Fraction 4 (C34-C50)	mg/kg	2800[2]	242	3	53	170	280
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.016	6	0.003	0.008	0.011
Retene	mg/kg	-	0.105	6	0.020	0.041	0.048
Total dibenzothiophenes	mg/kg	-	0.591	6	0.132	0.178	0.260
Total PAHs	mg/kg	-	2.703	6	0.594	1.116	1.357
Total Parent PAHs	mg/kg	-	0.160	6	0.048	0.095	0.109
Total Alkylated PAHs	mg/kg	-	2.543	6	0.546	1.022	1.247
Predicted PAH toxicity[4]	H.I.	-	1.168	6	0.488	0.773	0.993
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	3.4	4	6.0	6.5	9.4
Chironomus growth - 10d	mg/organism	-	1.7	4	2.0	2.7	3.6
Hyalella survival - 14d[1]	# surviving	-	8.0	2	9.0	9.3	9.6
Hyalella growth - 14d[1]	mg/organism	-	0.2	2	0.1	0.1	0.3

Values in **bold** indicate concentrations exceeding guidelines.

1 Pre-2002 *Hyalella* test based on 10-day test period

2 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

3 Interim sediment quality guideline (ISQG) (CCME 2002).

4 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.1-13 Concentrations of sediment quality measurement endpoints, Big Point Channel (BPC-1).

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	27.8	8	10	18.5	32
Silt	%	-	56.6	8	26	48	64
Sand	%	-	15.6	8	10	37	64
Total organic carbon	%	-	2.2	8	<0.1	1.2	1.8
Total hydrocarbons							
BTEX	mg/kg	-	<21	3	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<21	3	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	21	3	<5	<5	23
Fraction 3 (C16-C34)	mg/kg	300[1]	**307**	3	110	190	210
Fraction 4 (C34-C50)	mg/kg	2800[1]	199	3	33	100	120
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.009	8	0.005	0.010	0.024
Retene	mg/kg	-	0.071	7	0.041	0.051	0.096
Total dibenzothiophenes	mg/kg	-	0.358	8	0.150	0.228	0.31
Total PAHs	mg/kg	-	1.821	8	1.045	1.340	1.54
Total Parent PAHs	mg/kg	-	0.119	8	0.096	0.107	0.21
Total Alkylated PAHs	mg/kg	-	1.702	8	0.945	1.235	1.33
Predicted PAH toxicity[3]	H.I.	-	0.98	8	0.830	1.221	2.59
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	4.6	6	3.2	7.3	9.0
Chironomus growth - 10d	mg/organism	-	1.3	6	0.9	1.9	3.6
Hyalella survival - 14d[4]	# surviving	-	8.2	2	6.6	8.0	9.0
Hyalella growth - 14d[4]	mg/organism	-	0.2	2	0.0	0.1	0.2

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

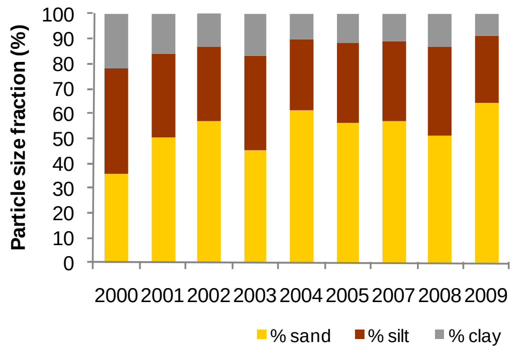
[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

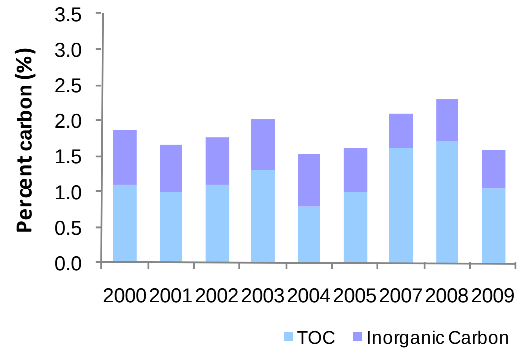
[4] Pre-2003 *Hyalella* test based on 10 day test period

Figure 5.1-12 Characteristics of sediment collected in the Athabasca River upstream of Embarras River, 2000-2009 (fall data only).

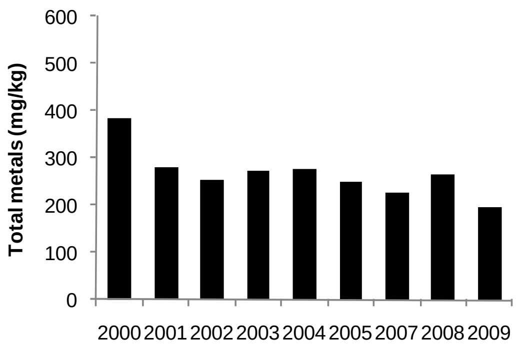
Particle size distribution



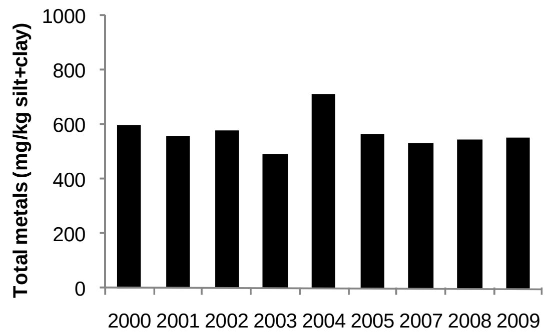
Carbon Content



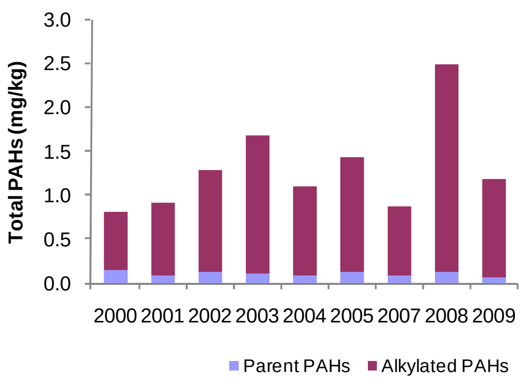
Total Metals*



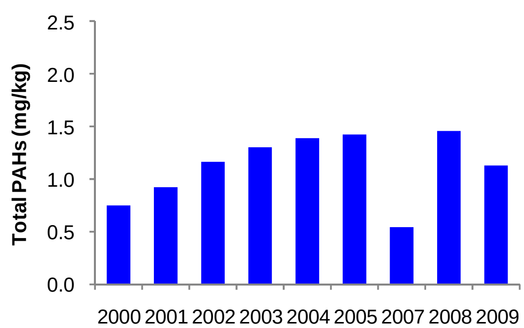
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



Total PAHs



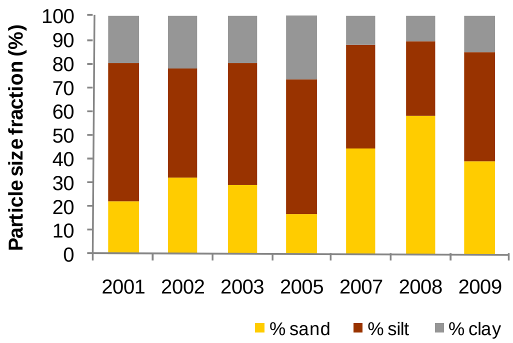
Total PAHs normalized to 1% TOC



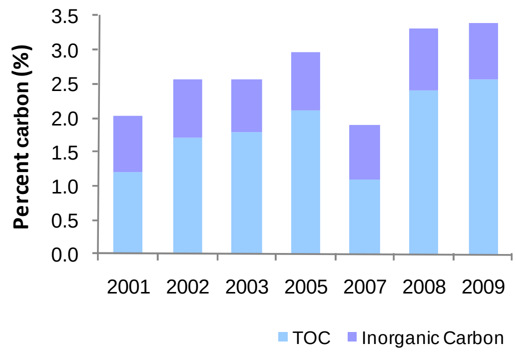
* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, U, V, Zn (measured in all years).

Figure 5.1-13 Characteristics of sediment collected in Goose Island Channel (GIC-1), 2001-2009 (fall data only).

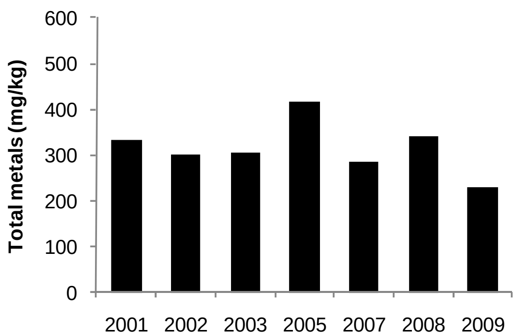
Particle size distribution



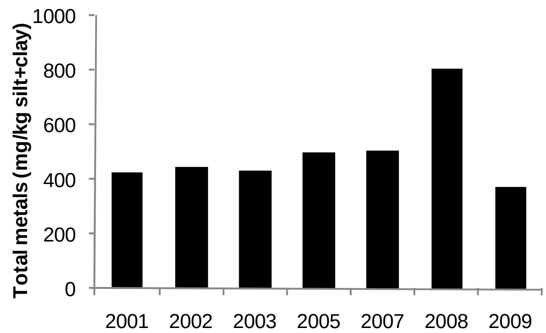
Carbon Content



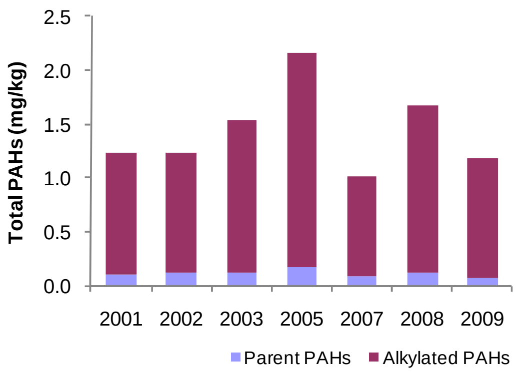
Total Metals*



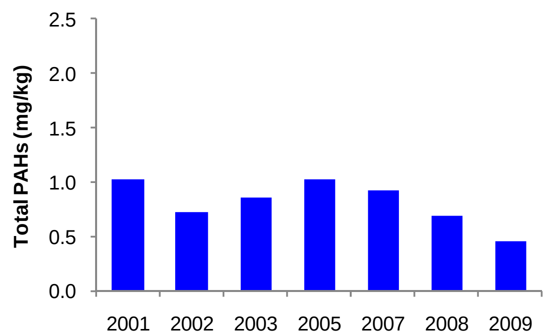
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



Total PAHs



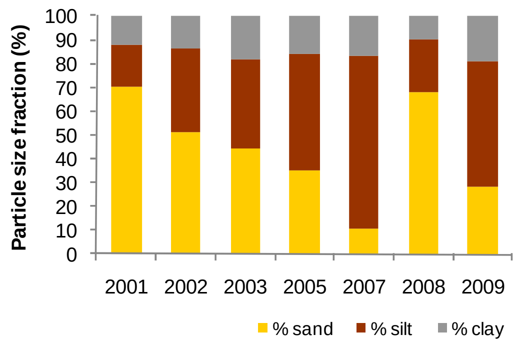
Total PAHs normalized to 1% TOC



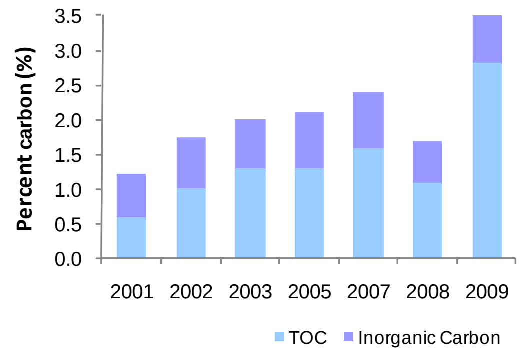
* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, U, V, Zn (measured in all years).

Figure 5.1-14 Characteristics of sediment collected in Fletcher Channel (FLC-1), 2001-2009 (fall data only).

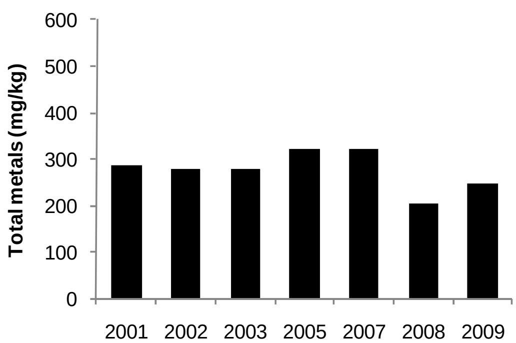
Particle size distribution



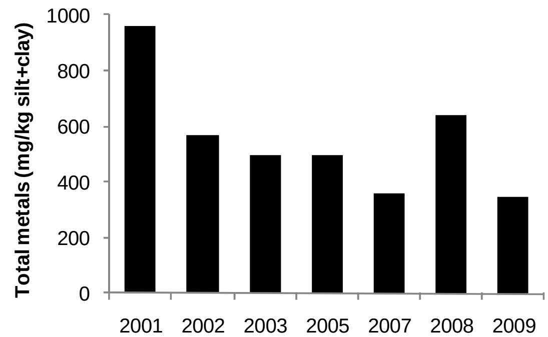
Carbon Content



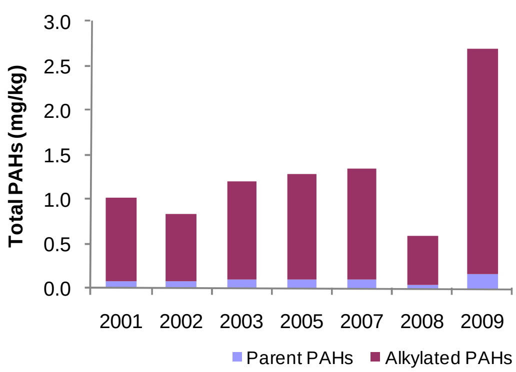
Total Metals*



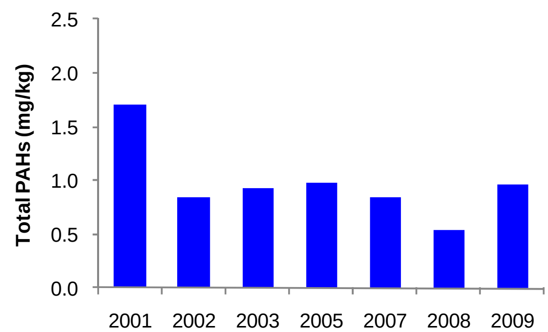
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



Total PAHs



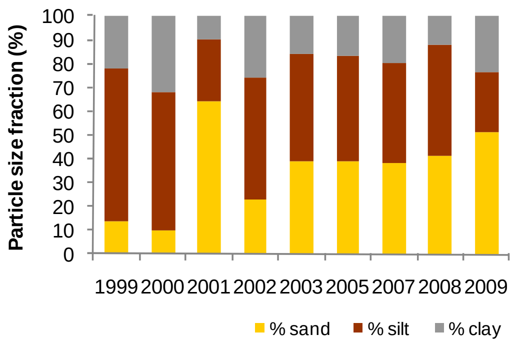
Total PAHs normalized to 1% TOC



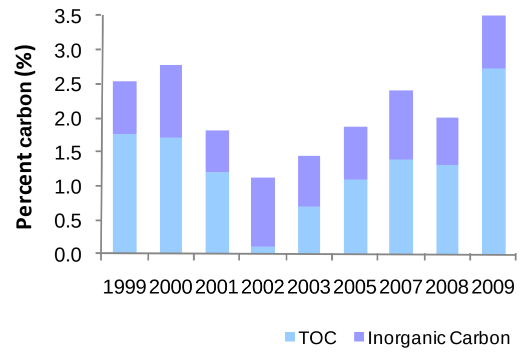
* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, U, V, Zn (measured in all years).

Figure 5.1-15 Characteristics of sediment collected in Big Point Channel (BPC-1), 1999-2009 (fall data only).

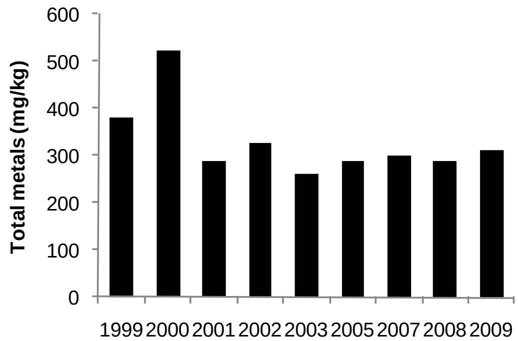
Particle size distribution



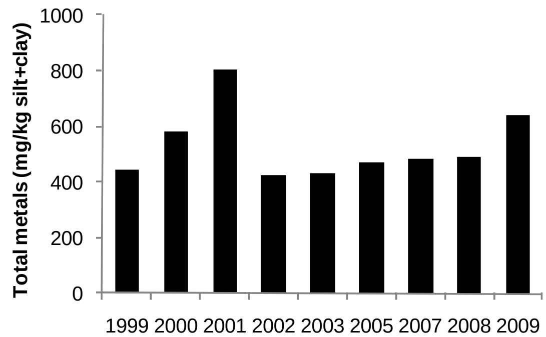
Carbon Content



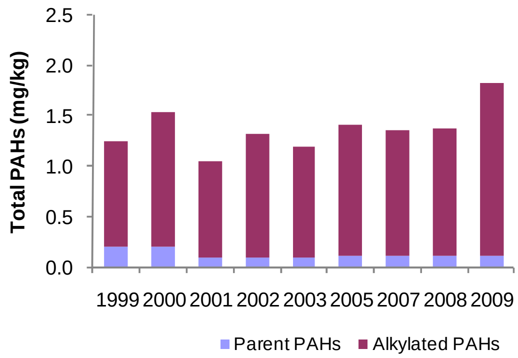
Total Metals*



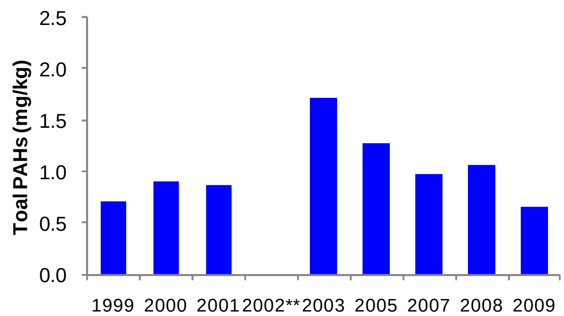
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



Total PAHs



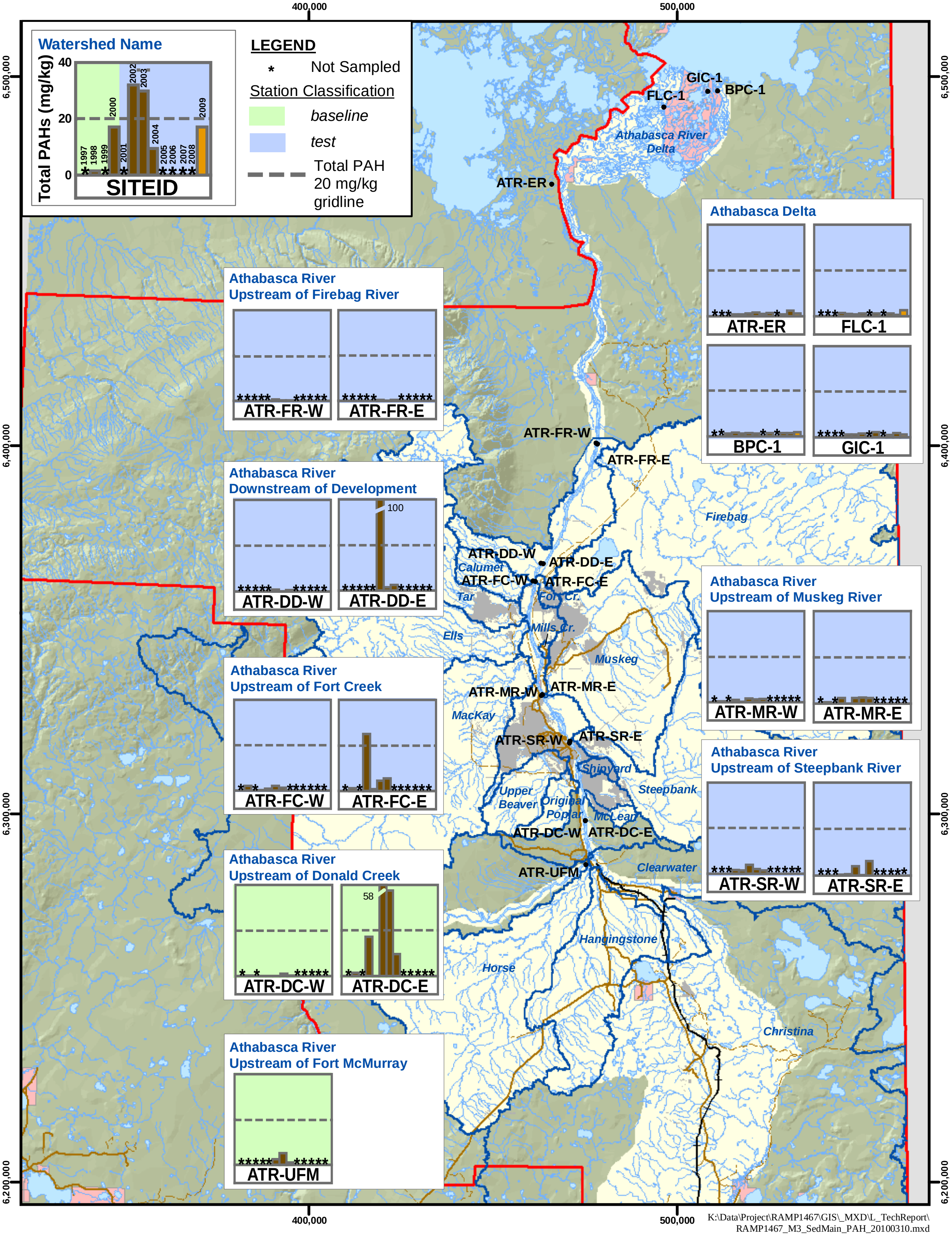
Total PAHs normalized to 1% TOC



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Ag, U, V, Zn (measured in all years).

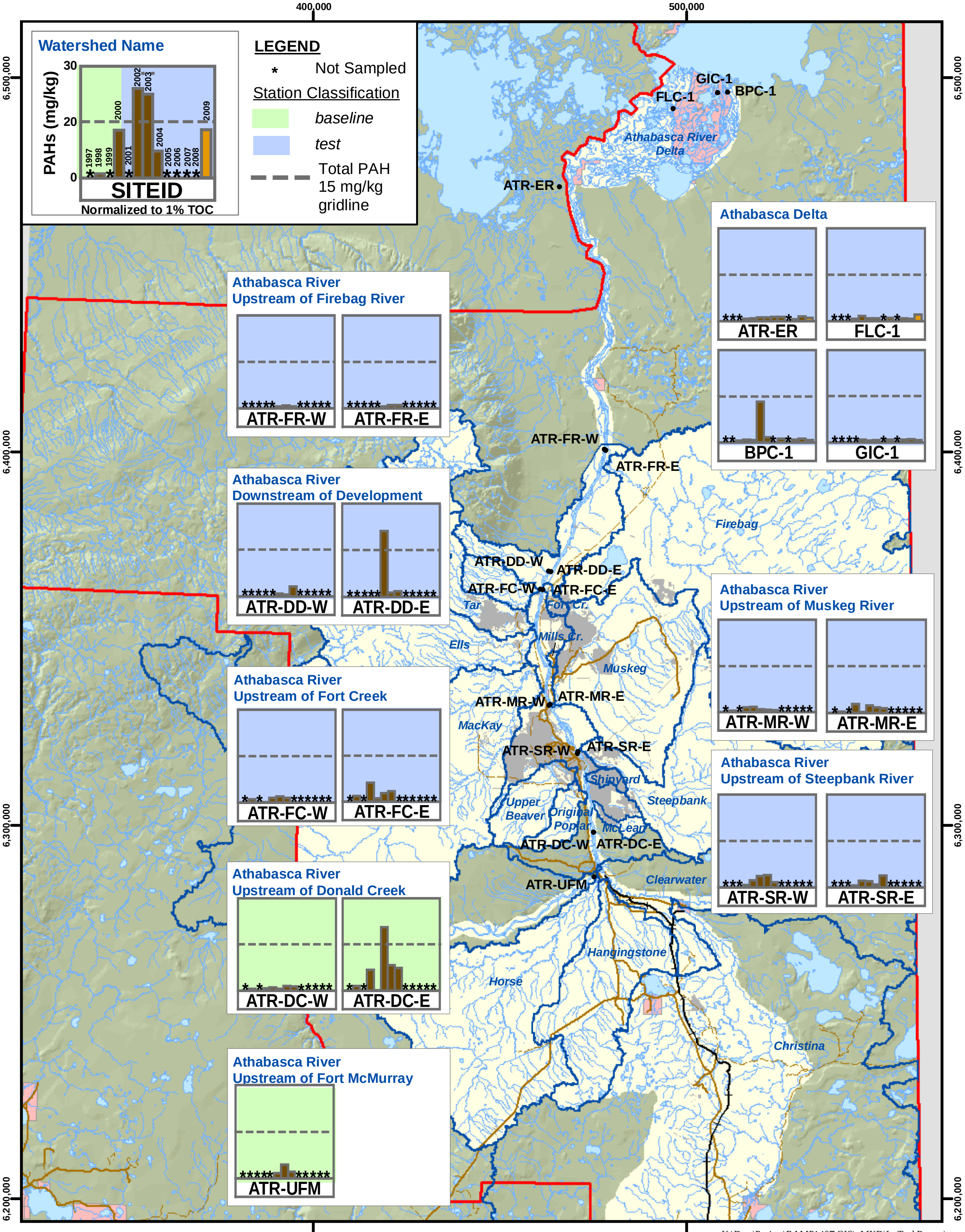
** Non-detectable level of total organic carbon in 2002 (<0.1%).

Figure 5.1-16 Concentrations of total PAHs in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2009.



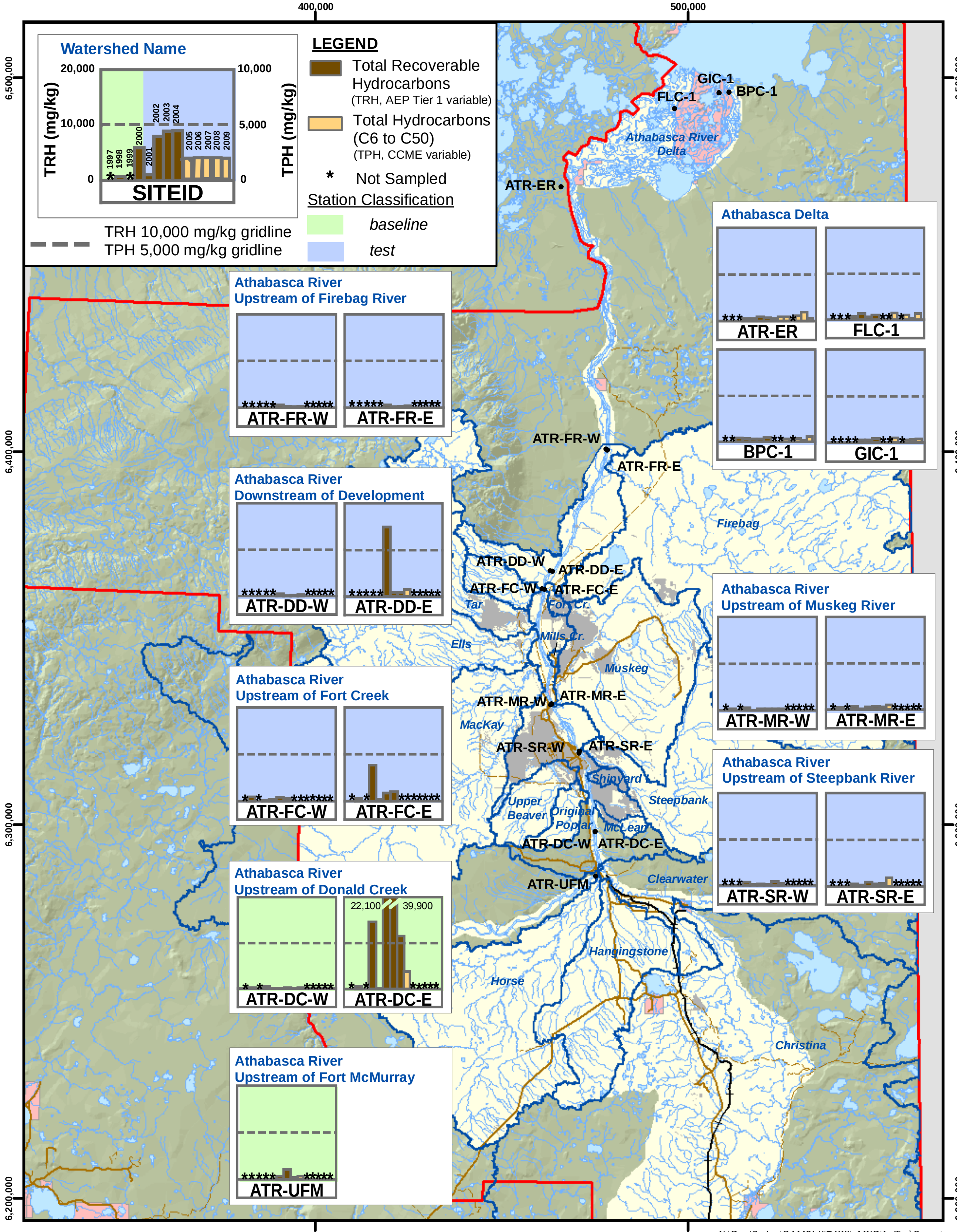
K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_M3_SedMain_PAH_20100310.mxd

Figure 5.1-17 Carbon-normalized concentrations of total PAHs in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2009.



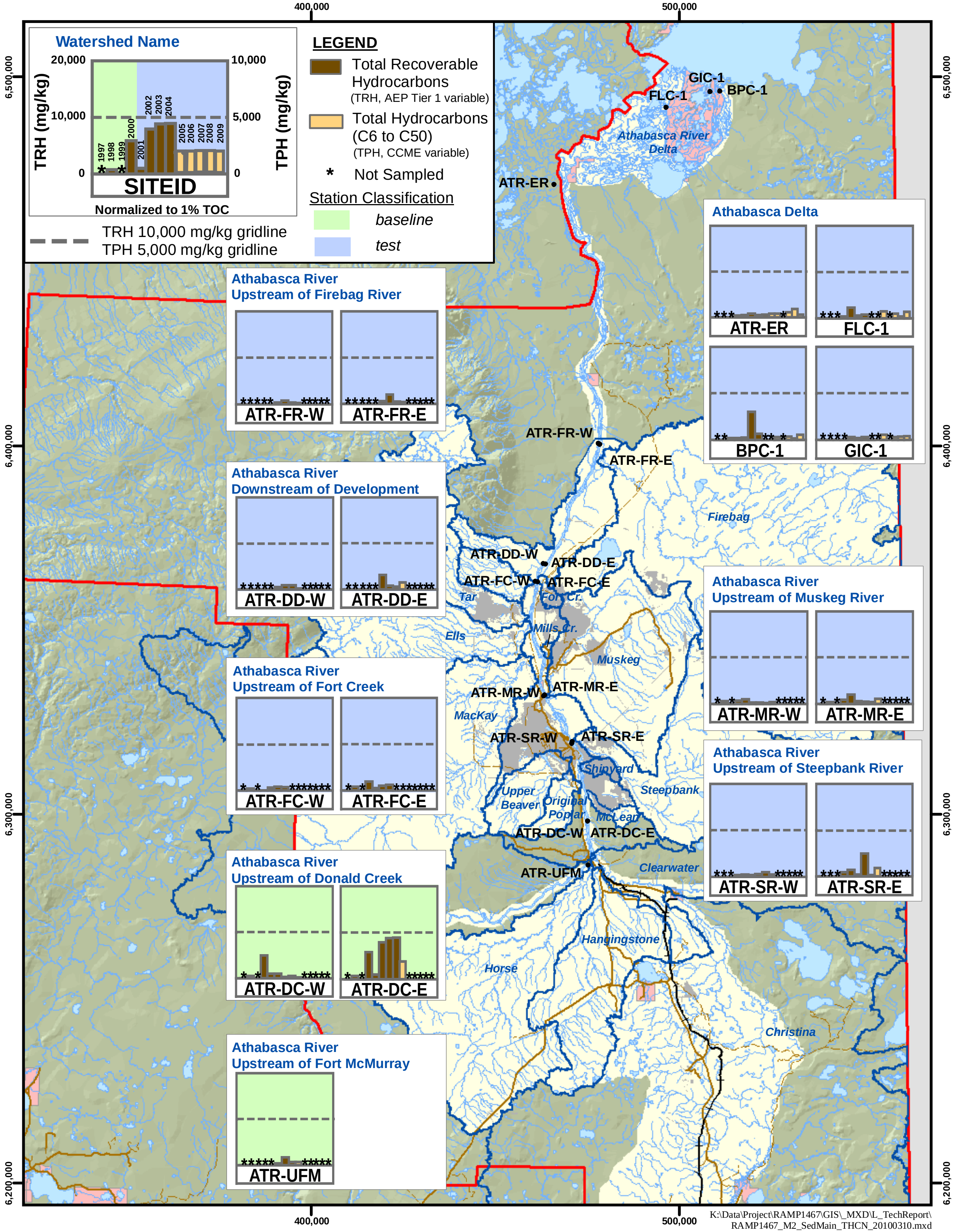
K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_M4_SedMain_PAHCN_20100310.mxd

Figure 5.1-18 Concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2009.



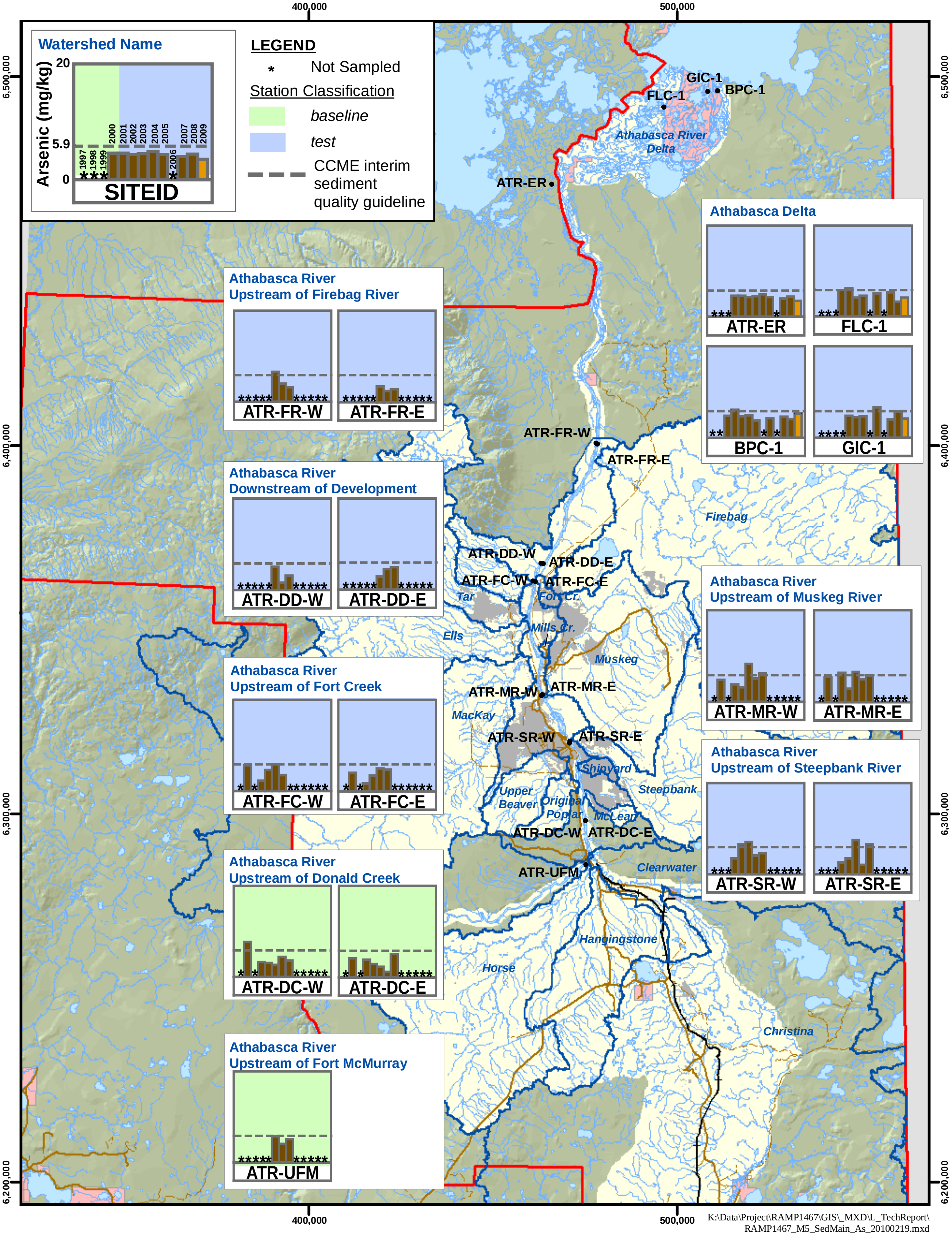
K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_M1_SedMain_TH_20100310.mxd

Figure 5.1-19 Carbon-normalized concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_M2_SedMain_THCN_20100310.mxd

Figure 5.1-20 Concentrations of total arsenic in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_M5_SedMain_As_20100219.mxd

Table 5.1-14 Species composition of the Athabasca River during spring, summer, and fall, 2009.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
burbot	1	0.1	2	0.2	2	0.8
emerald shiner	12	1.1	81	8.1	21	1.8
flathead chub	71	6.7	157	15.6	43	3.8
goldeye	112	10.6	382	38.0	128	11.2
lake chub	16	1.5	30	3.0	10	0.9
lake whitefish	11	1.0	9	0.9	431	37.6
longnose sucker	14	1.3	17	1.7	45	3.9
mountain whitefish	0	0.0	3	0.3	1	0.1
northern redbelly dace	1	0.1	0	0.0	0	0.0
northern pike	19	1.8	16	1.6	12	1.1
slimy sculpin	3	0.3	1	0.1	0	0.0
spottail shiner	1	0.1	6	0.6	9	0.8
trout-perch	319	30.2	196	19.5	246	21.5
walleye	223	21.1	96	9.6	112	9.8
white sucker	252	23.9	8	0.8	87	7.6
yellow perch	0	0.0	1	0.1	0	0.0
Total	1,055	100.0	1,005	100.0	1,147	100.0

Table 5.1-15 Species composition of the Athabasca River observed but not captured during the Athabasca River fish inventory in, spring, summer, and fall, 2009.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
burbot	2	0.5	1	0.2	0	0.0
emerald shiner	0	0.0	5	0.9	0	0.0
flathead chub	14	3.1	26	4.8	18	1.7
fathead minnow	0	0.0	0	0.0	0	0.0
goldeye	47	10.5	178	32.7	62	5.7
lake chub	1	0.2	0	0.0	0	0.0
lake whitefish	1	0.2	3	0.6	612	56.6
longnose sucker	0	0.0	0	0.0	1	0.1
mountain whitefish	0	0.0	1	0.2	0	0.0
northern pike	8	1.8	21	3.9	11	1.0
trout-perch	180	40.2	267	49.0	279	25.8
unknown sp.	2	0.5	4	0.7	0	0.0
walleye	79	17.6	26	4.8	39	3.6
white sucker	114	25.5	10	1.8	59	5.5
yellow perch	0	0.0	3	0.6	0	0.0
Total	448	100.0	545	100.0	1,081	100.0

Figure 5.1-21 Percent composition of KIR species caught during the Athabasca River spring inventory, 1997-2009.

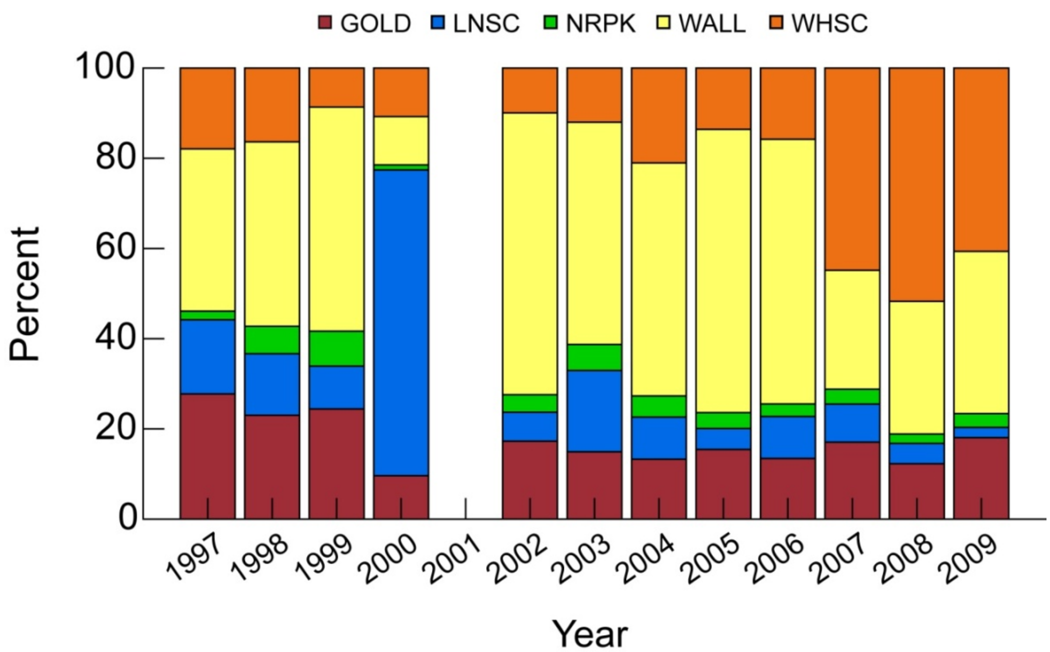


Figure 5.1-22 Percent composition of KIR species caught during the Athabasca River summer inventory, 1997-2009.

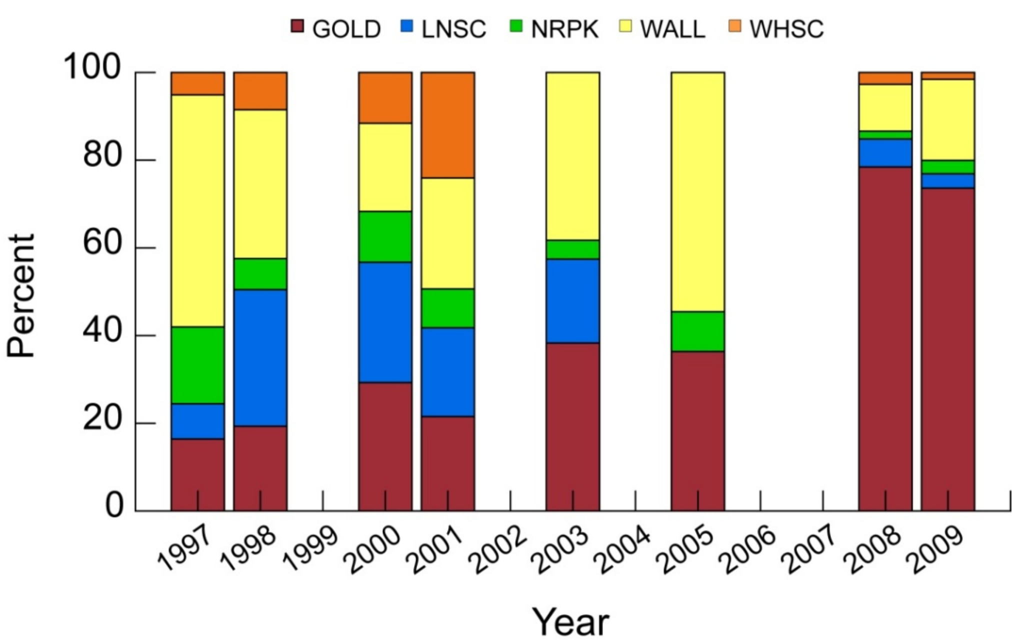


Figure 5.1-23 Percent composition of KIR species caught during the Athabasca River fall inventory, 1997-2009.

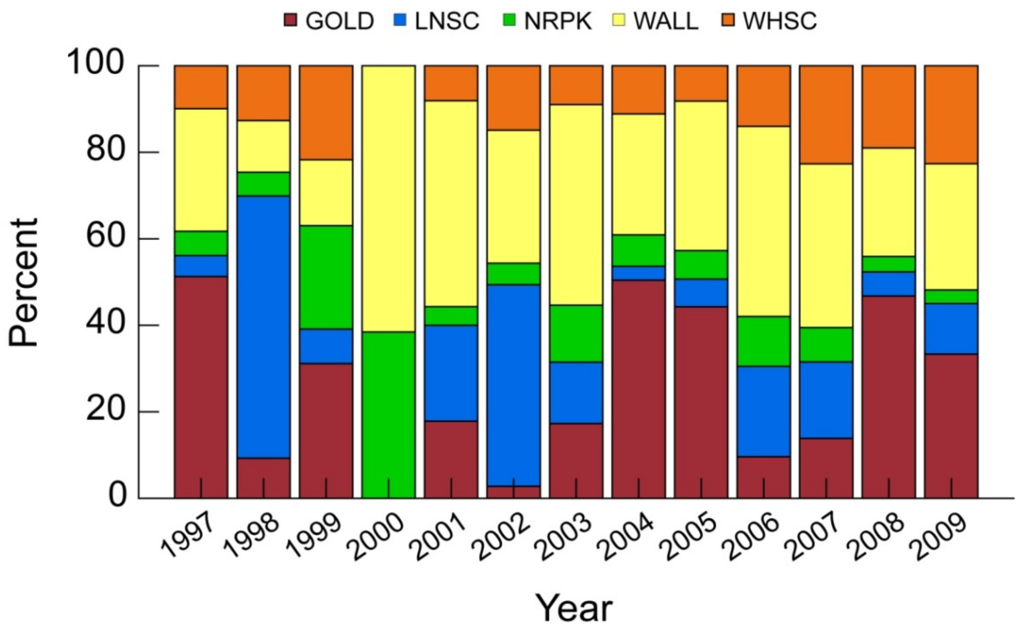


Figure 5.1-24 Species richness in the spring, summer, and fall Athabasca Inventories, 1997-2009.

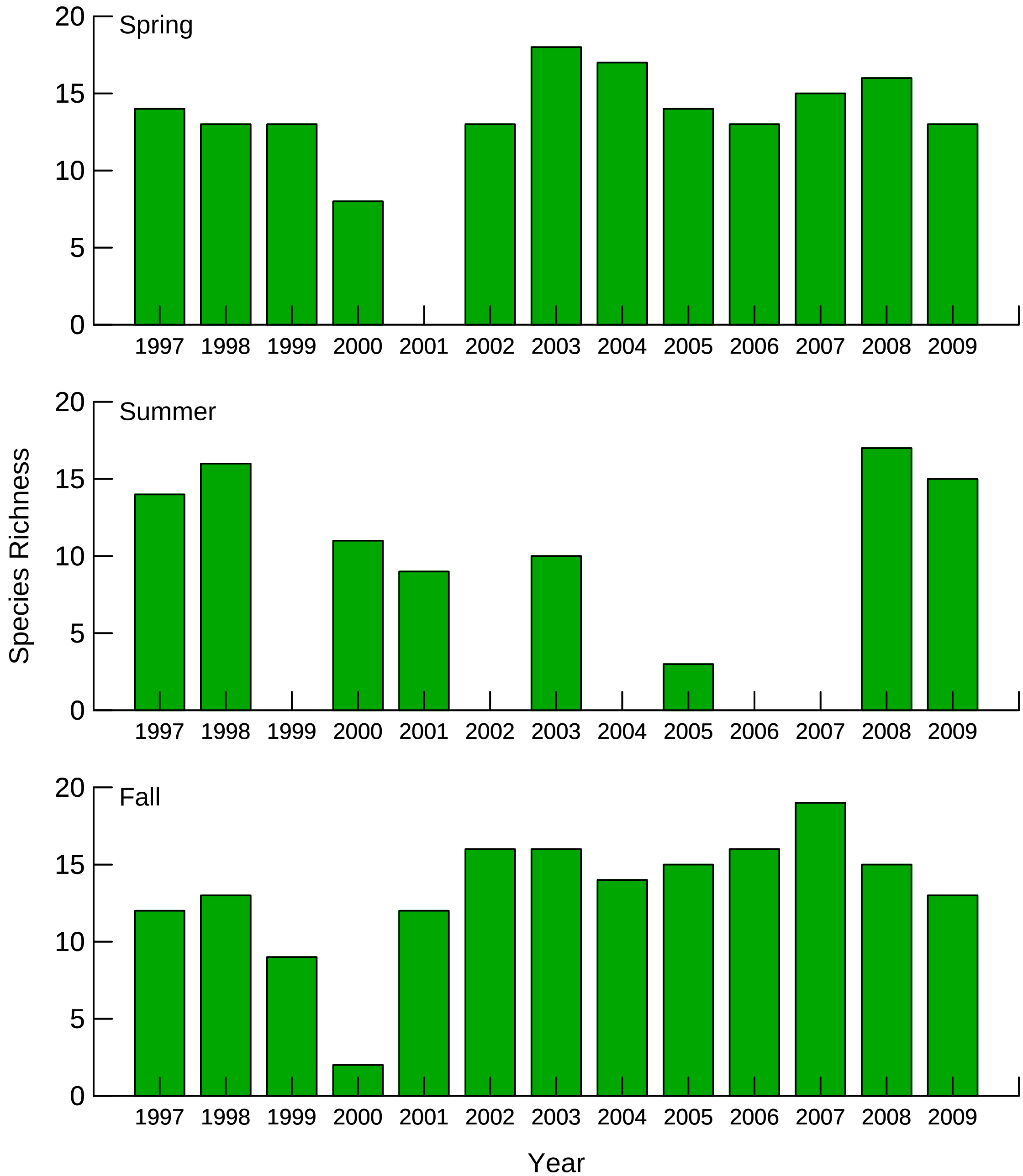


Figure 5.1-25 Seasonal mean CPUE for captured fish, all KIR species combined, Athabasca River spring, summer, and fall inventory, 1997-2009.

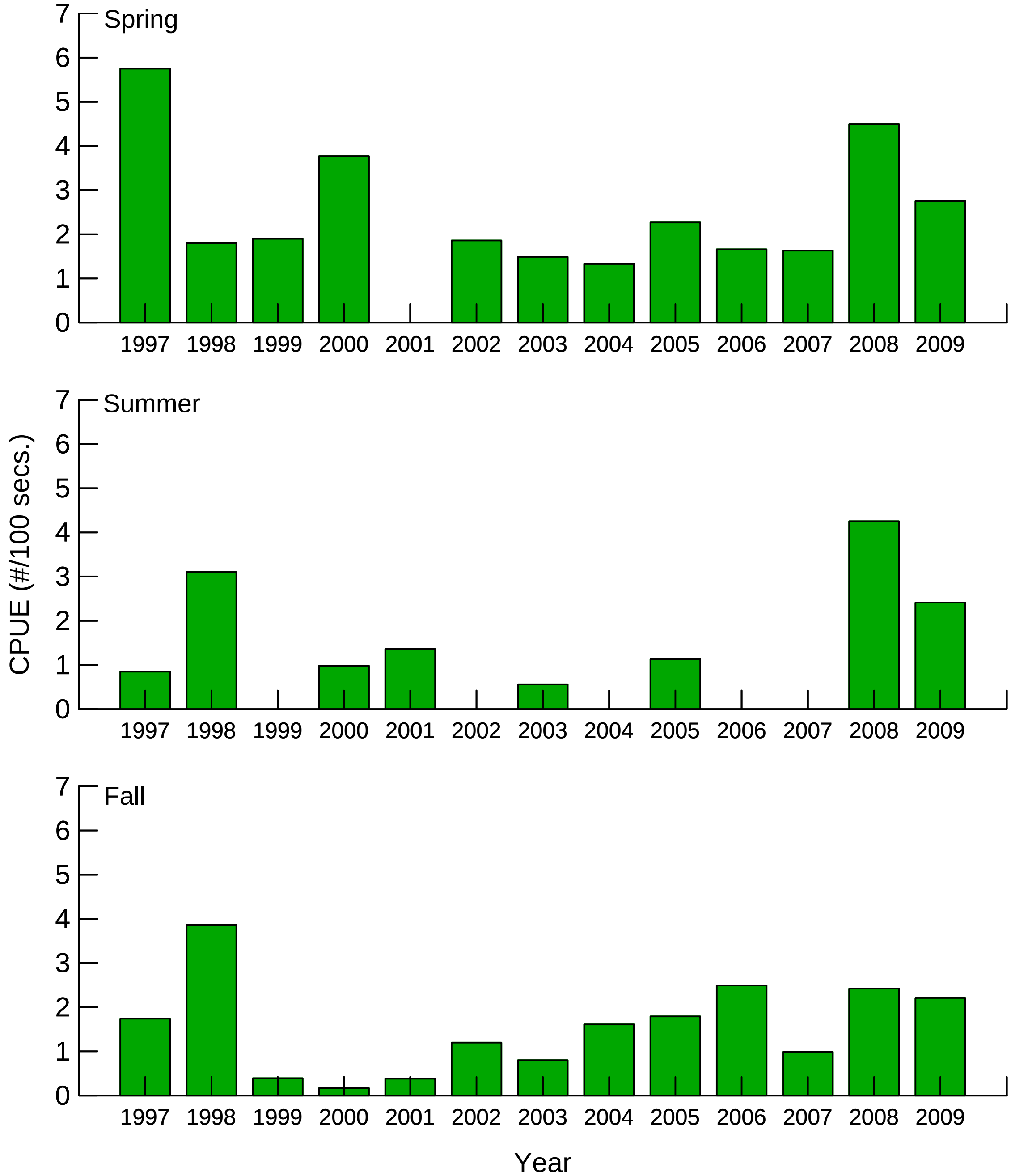


Figure 5.1-26 Spring, summer, and fall CPUE for each KIR species, Athabasca River fish inventory, 1997-2009.

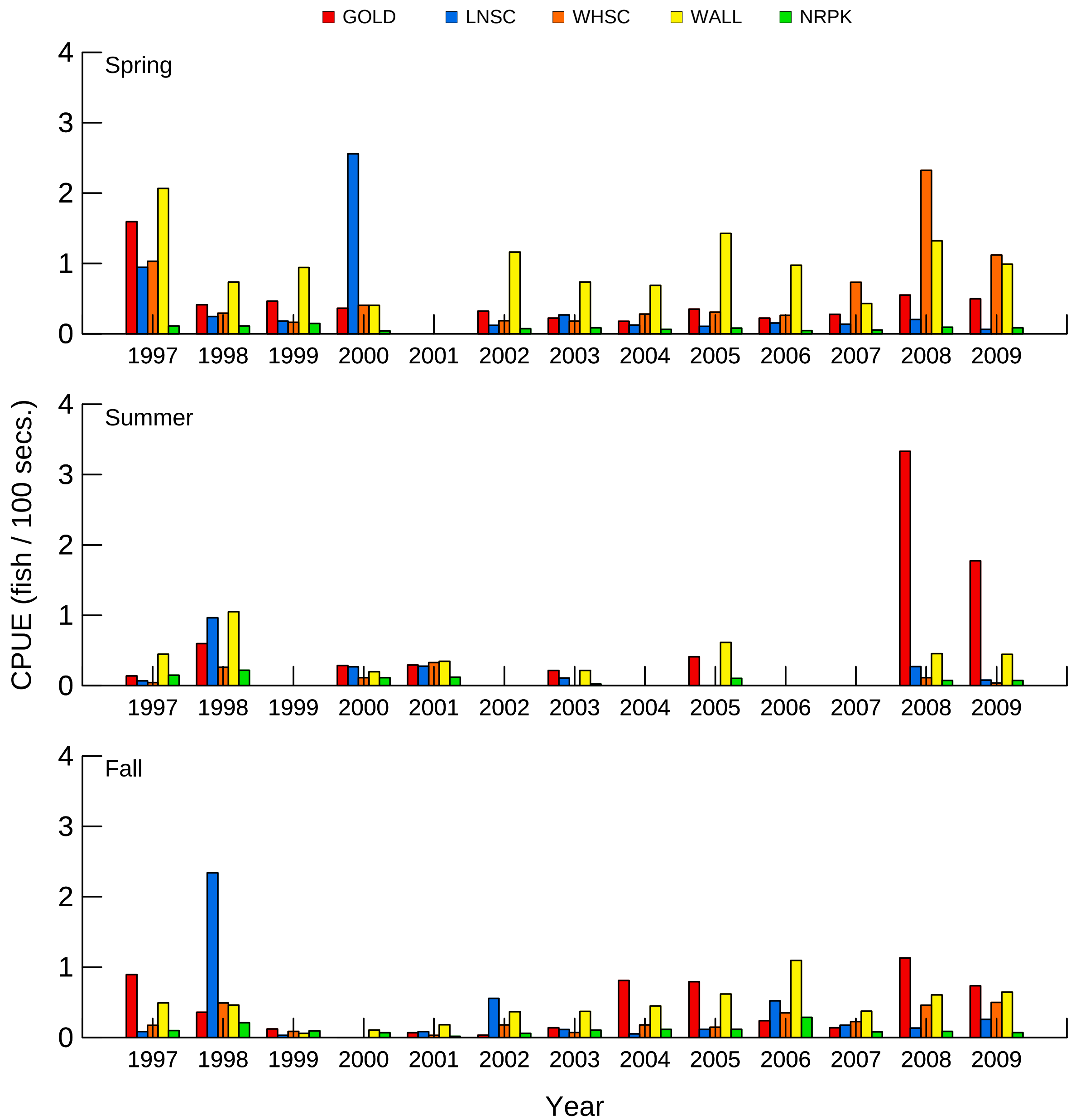


Figure 5.1-27 Seasonal mean CPUE for KIR species relative to mean discharge rate for May, July, and September in the Athabasca River, 1997-2009.

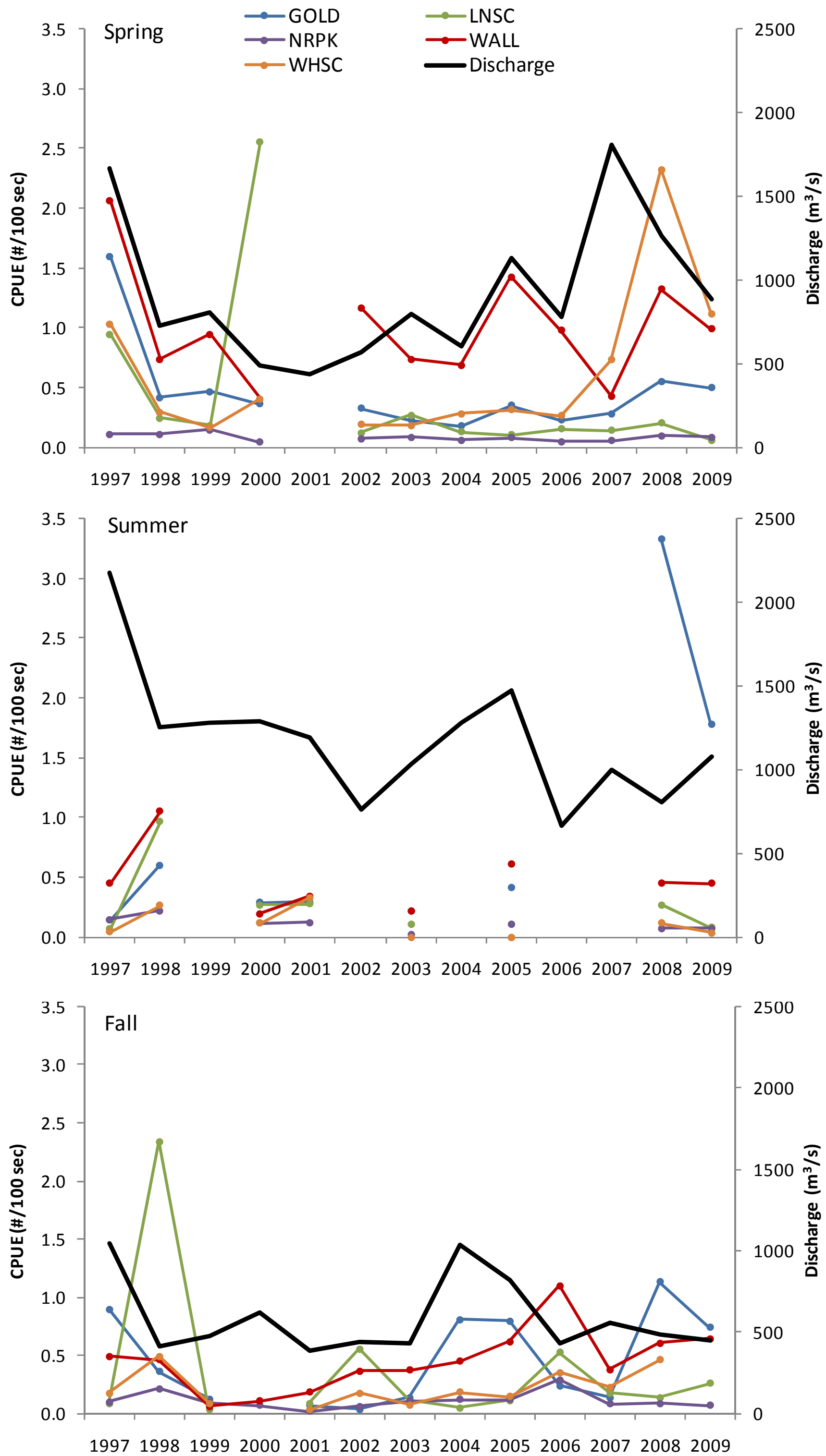


Figure 5.1-28 Correspondence analysis for KIR species captured in the spring Athabasca inventory, 1997-2009.

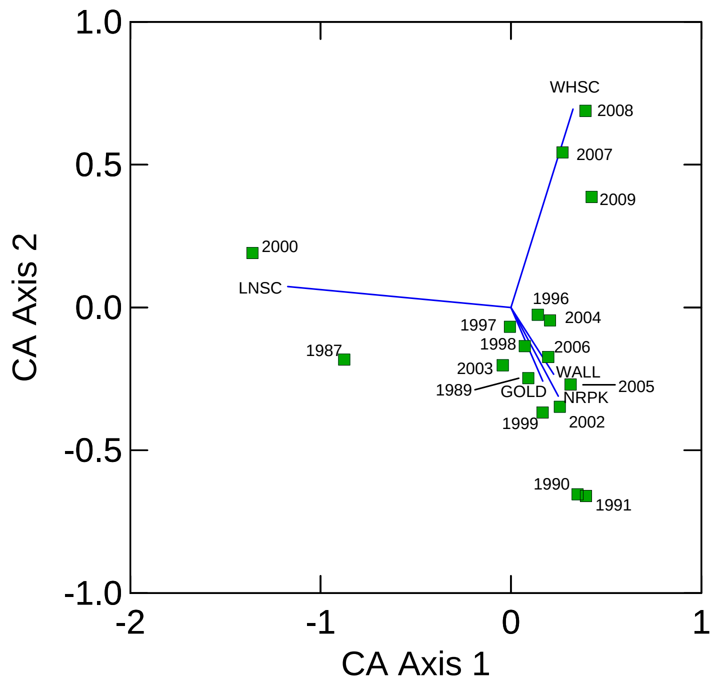


Figure 5.1-29 Correspondence analysis for KIR species captured in the summer Athabasca inventory, 1997-2009.

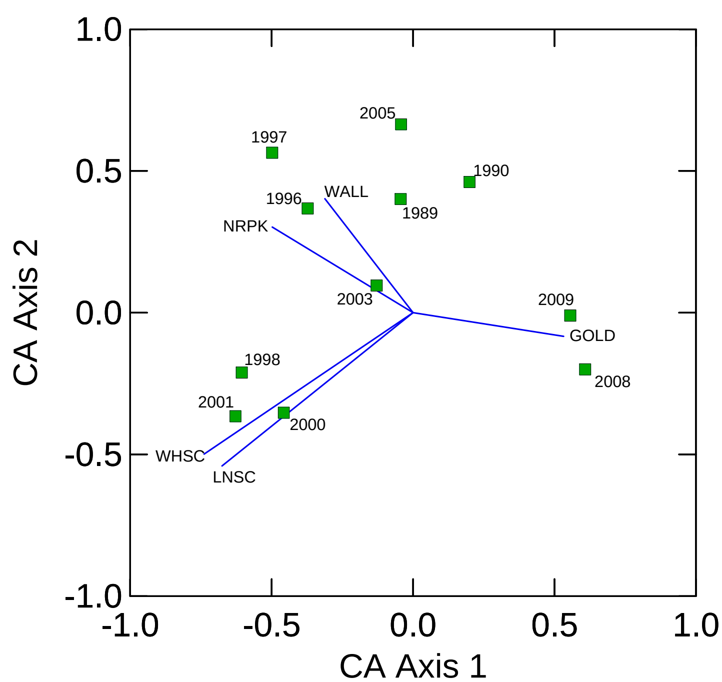


Figure 5.1-30 Correspondence analysis for KIR species captured in the fall Athabasca inventory, 1997-2009.

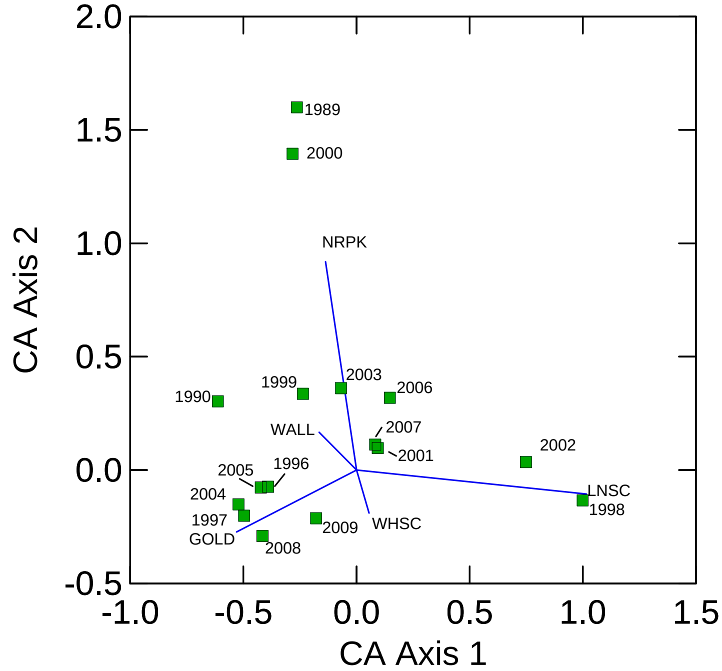


Figure 5.1-31 **Relative length-frequency distribution for goldeye captured in the Athabasca River, all seasons combined from 1997 to 2009 (upper pane) and for spring, summer, and fall 2009 (lower pane).**

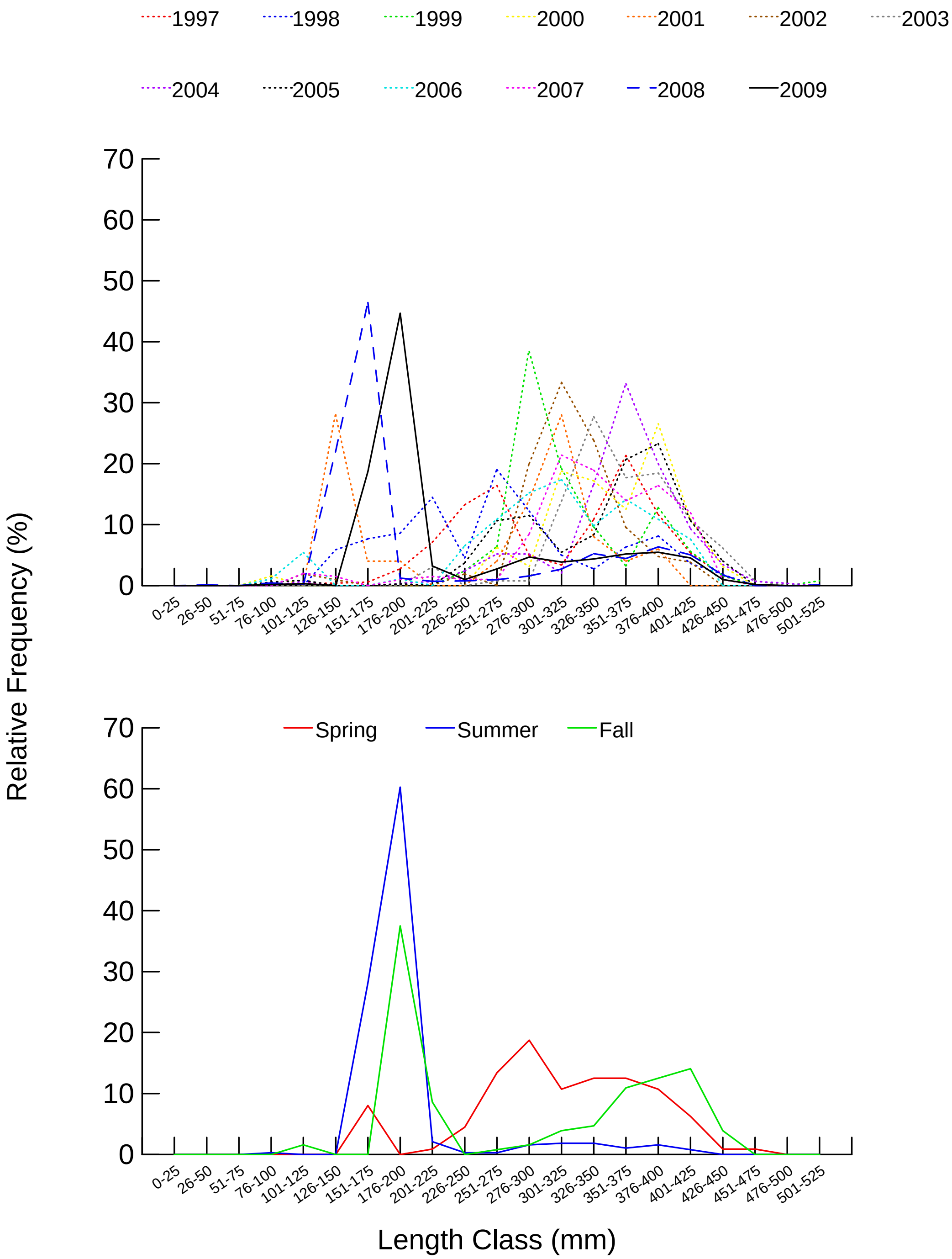


Figure 5.1-32 **Relative length-frequency distribution for longnose sucker captured in the Athabasca River, all seasons combined from 1997 to 2009 (upper pane) and for spring, summer, and fall 2009 (lower pane).**

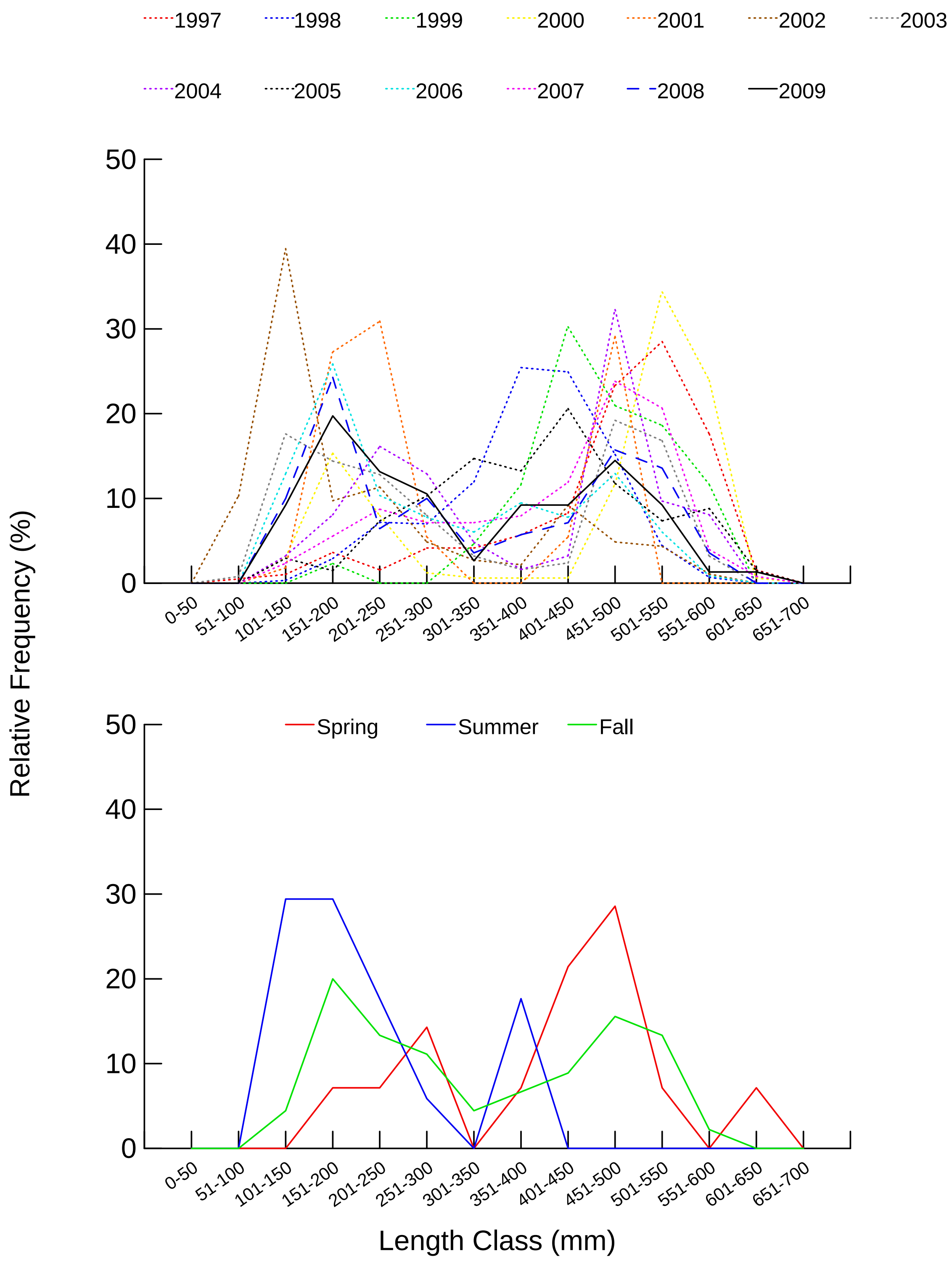


Figure 5.1-33 Relative length-frequency distribution for northern pike captured in the Athabasca River, all seasons combined from 1997-2009 (upper pane) and for spring, summer, and fall 2009 (lower pane).

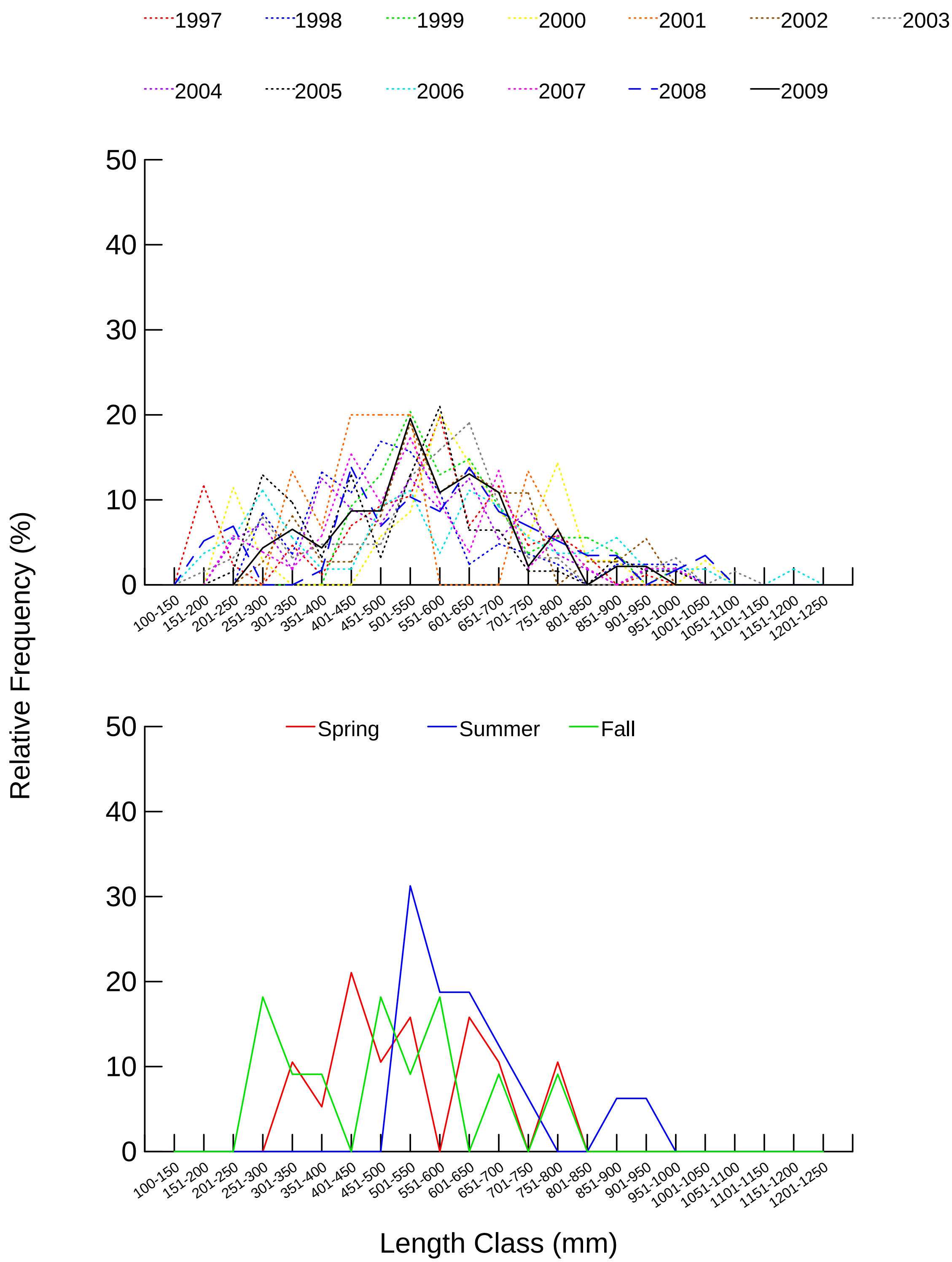


Figure 5.1-34 Relative length-frequency distribution for walleye captured in the Athabasca River, all seasons combined from 1997-2009 (upper pane) and for spring, summer, and fall 2009 (lower pane).

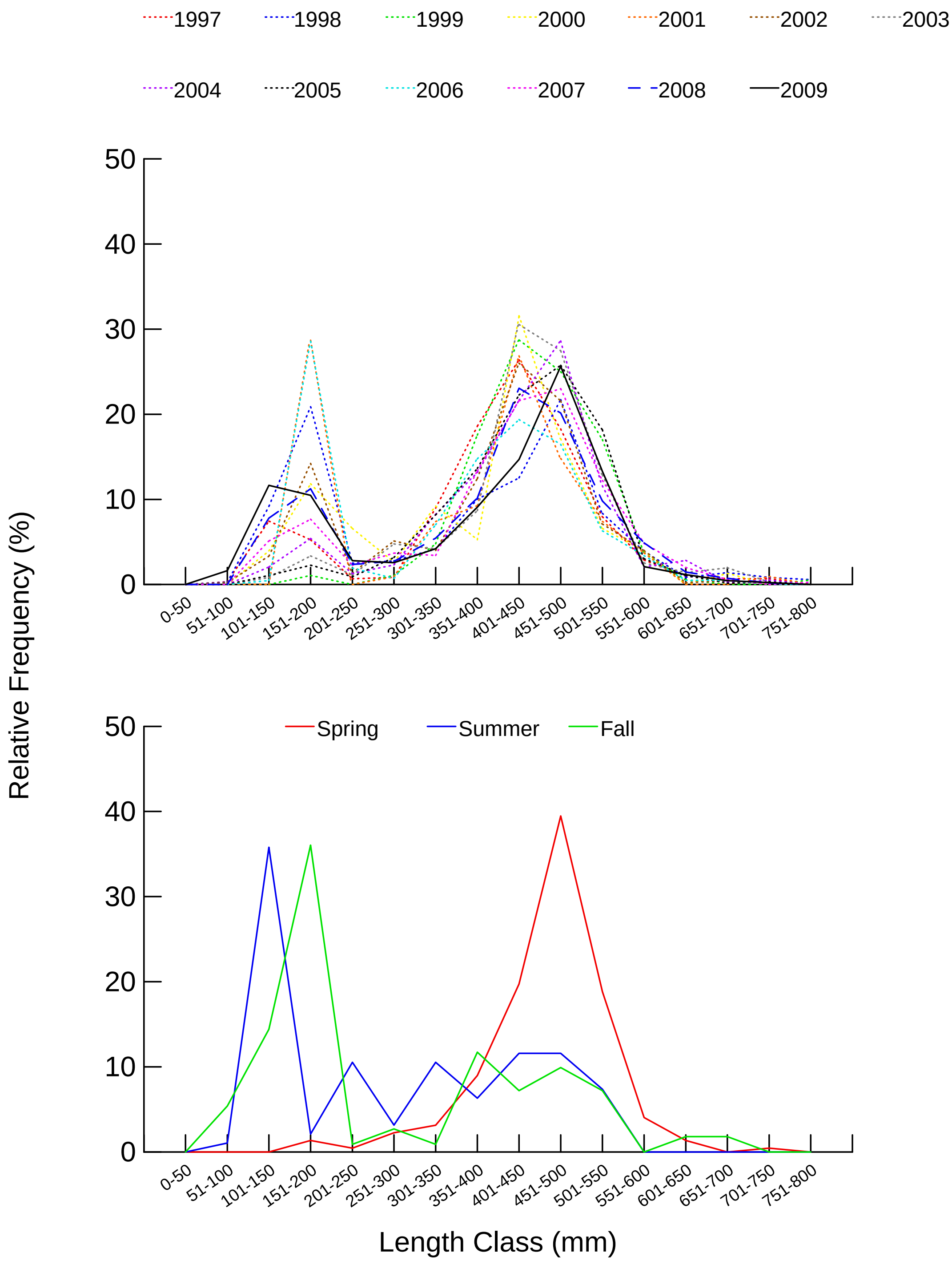


Figure 5.1-35 Relative length-frequency distribution for white sucker captured in the Athabasca River, all seasons combined from 1997-2009 (upper pane) and for spring, summer, and fall 2009 (lower pane).

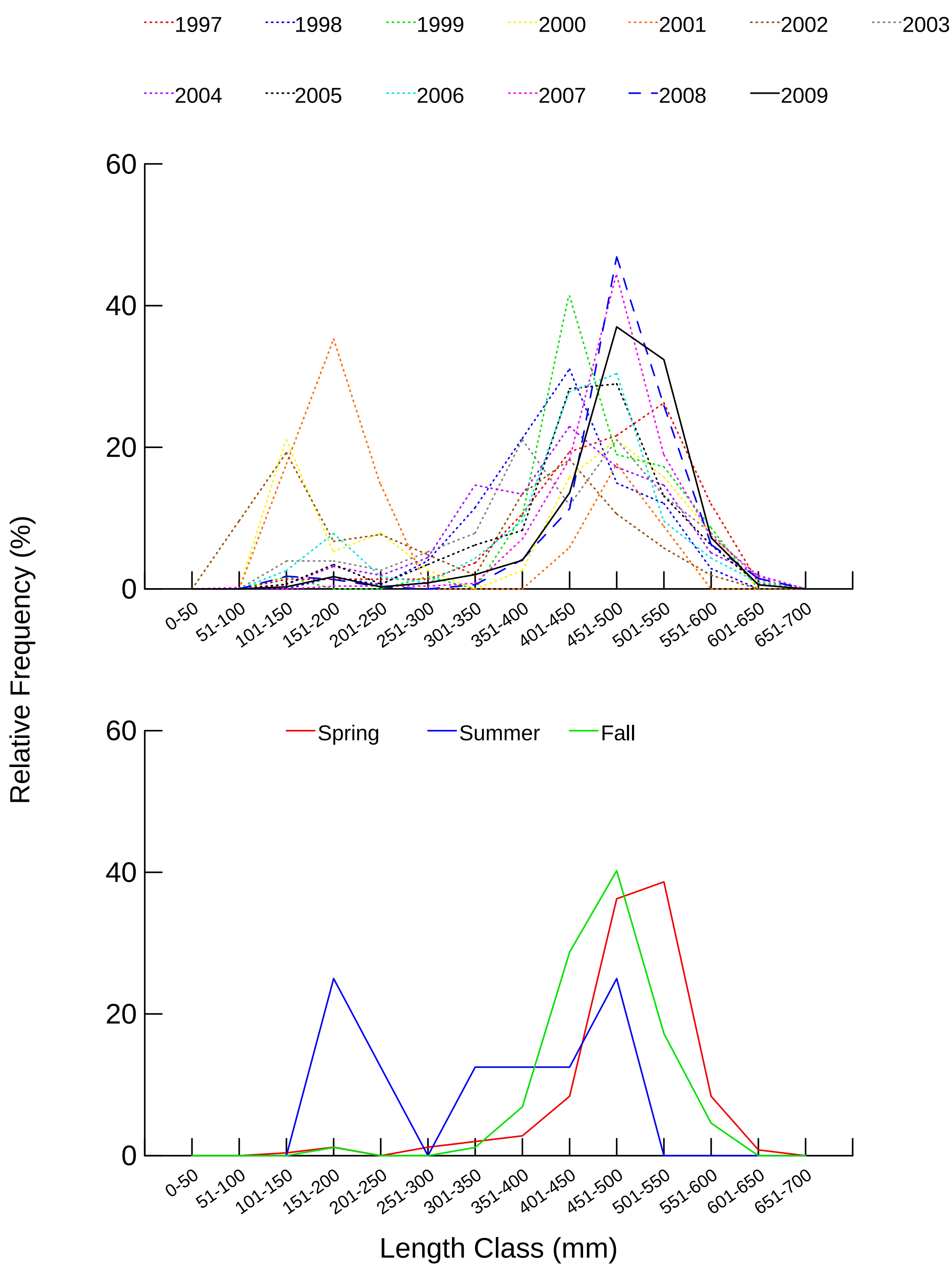
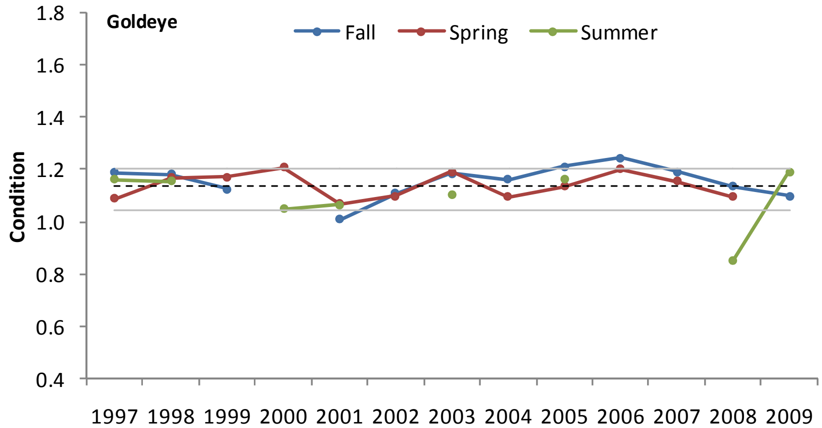
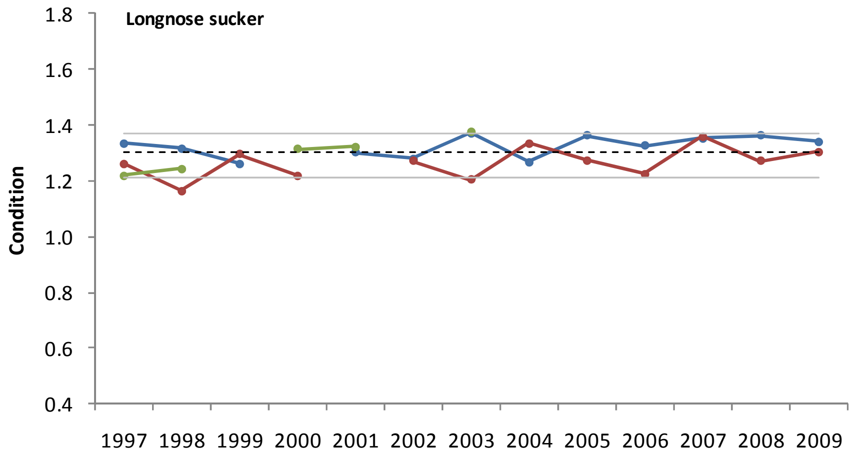
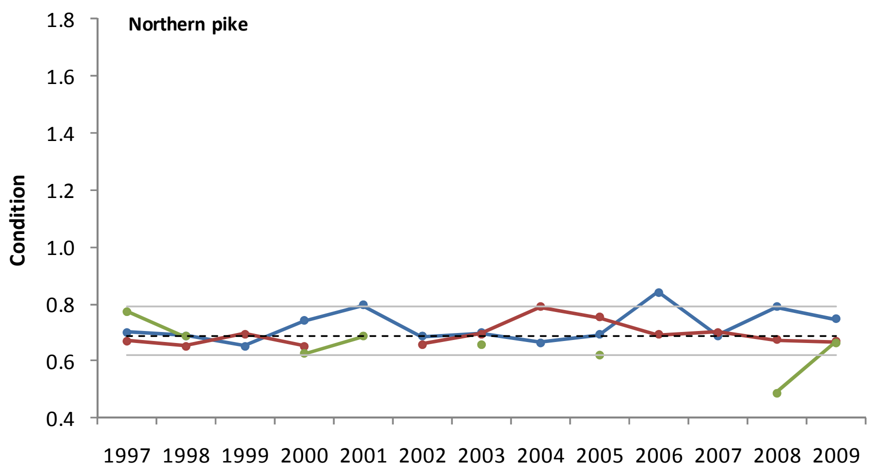


Figure 5.1-36 Mean condition (± 1SE) of KIR species captured during the spring, summer, and fall inventories relative to regional *baseline* values in the Athabasca River, 1997-2009.

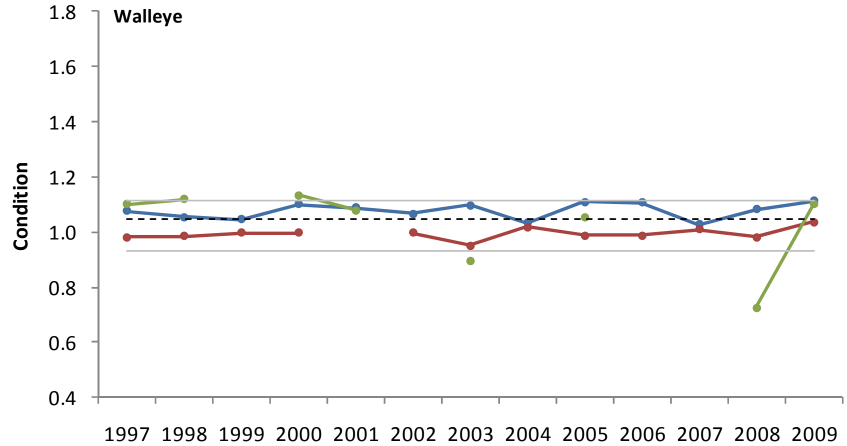


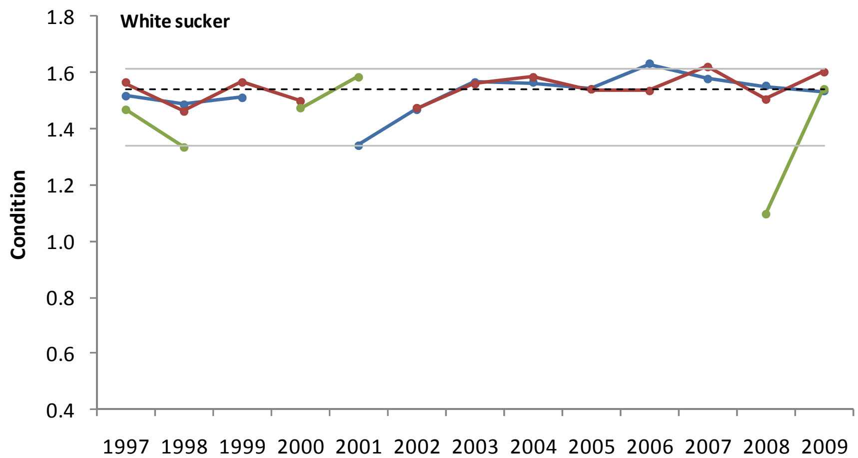




Note: The solid lines indicate the 5^{th} and 95^{th} percentiles from 1997 to 2008. The dashed line is the median from 1997 to 2008.

Figure 5.1-36 (Cont'd.)





Note: The solid lines indicate the 5th and 95th percentiles from 1997 to 2008. The dashed line is the median from 1997 to 2008.

Figure 5.1-37 Recruitment of walleye to the sport fishery captured during the Athabasca River inventories, 1997-2009.

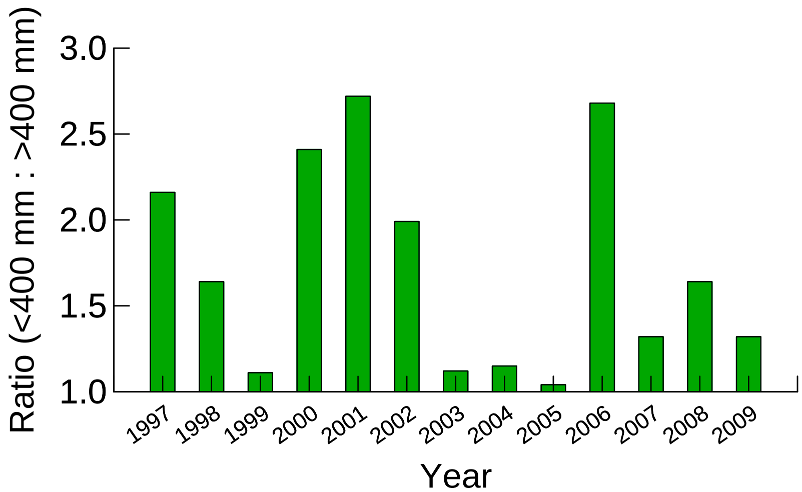


Figure 5.1-38 Recruitment of northern pike to the sport fishery captured during the Athabasca River inventories, 1997-2009.

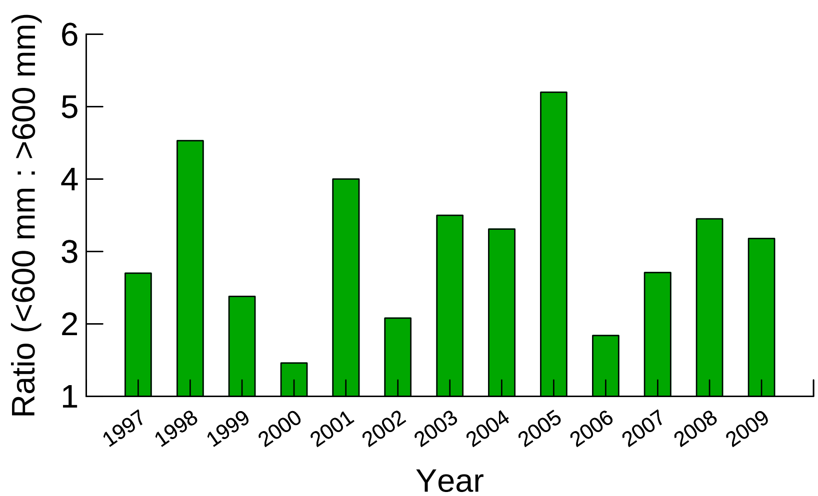


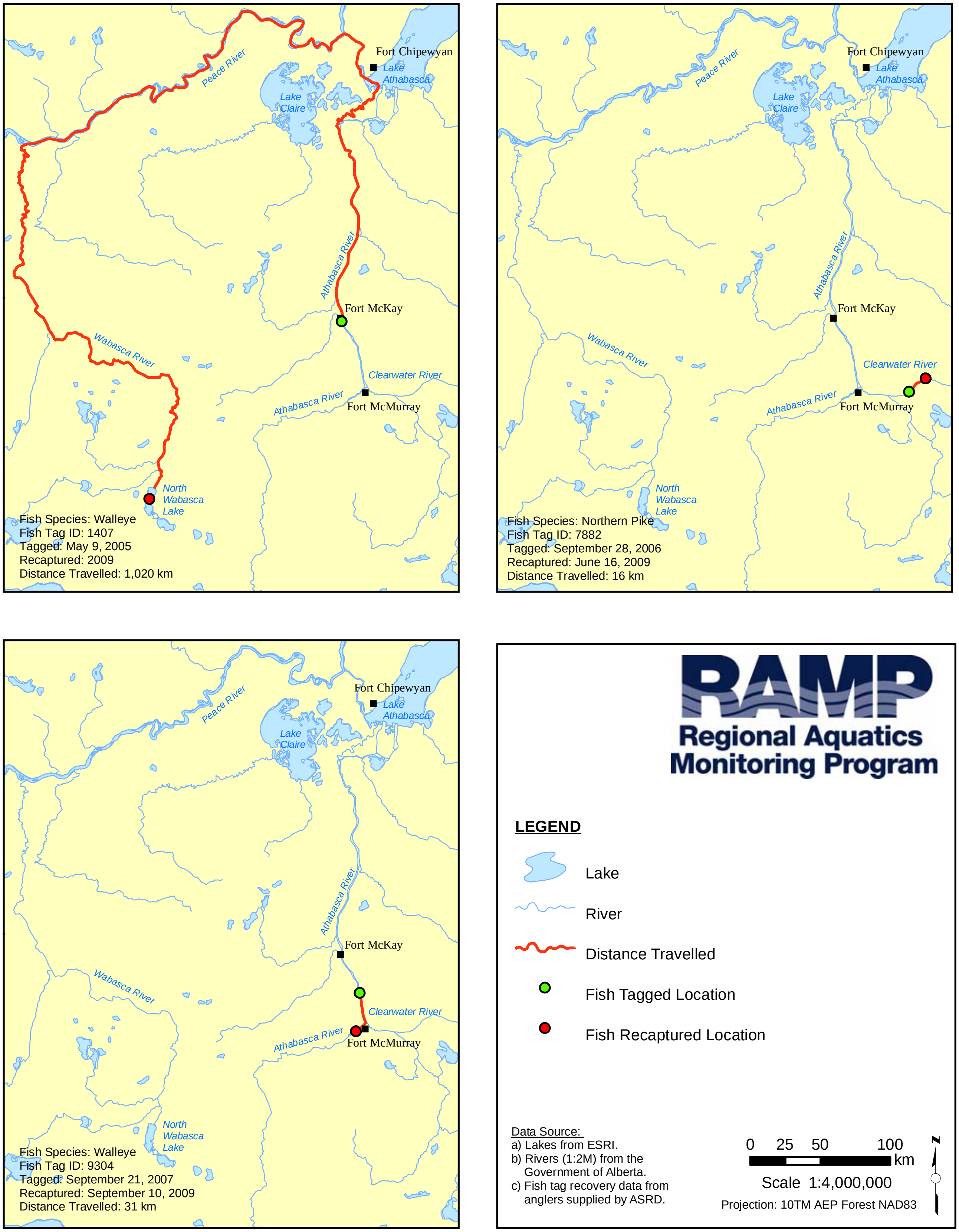
Table 5.1-16 Summary of mean health assessment index (HAI) values for five KIR fish species, Athabasca River, spring, summer, and fall, 1997-2009.

Year	Goldeye			Longnose Sucker			Northern Pike			Walleye			White Sucker		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
1997	4.0	5.3	2.7	5.3	4.5	1.1	6.7	7.7	3.2	1.4	1.0	0.9	6.7	10.0	3.3
1998	1.6	1.3	2.5	1.6	0.9	2.0	4.5	1.7	2.2	2.0	0.2	1.9	10.7	3.1	4.7
1999	5.0	-	1.9	6.3	-	2.7	4.6	-	4.5	2.4	-	0.0	3.1	-	3.7
2000	0.6	5.2	-	6.3	0.0	-	0.0	5.8	0.7	0.5	0.9	0.4	3.2	1.6	-
2001	-	1.2	0.3	-	1.3	0.7	-	5.7	0.0	-	1.5	0.7	-	4.2	4.7
2002	0.6	-	1.1	0.8	-	0.6	0.9	-	0.6	1.2	-	0.4	2.7	-	0.4
2003	1.0	0.0	0.2	0.1	0.0	1.5	1.3	5.0	2.4	0.4	0.0	1.2	1.4	-	2.7
2004	0.4	-	0.9	1.5	-	5.0	1.3	-	3.1	2.5	-	1.4	2.7	-	1.4
2005	0.8	0.0	0.1	2.0	-	0.6	0.7	10.0	2.4	0.9	0.0	1.5	2.0	-	0.7
2006	0.7	-	0.3	0.5	-	0.7	0.8	-	1.0	1.0	-	0.0	1.8	-	2.0
2007	1.5	-	2.1	2.5	-	1.0	2.4	-	0.5	1.3	-	1.3	3.6	-	3.5
2008	1.7	0.4	0.5	6.4	1.1	0.3	2.7	1.8	1.0	2.6	0.4	0.6	5.2	5.0	2.1
2009	1.8	0.8	0.2	0.0	3.5	1.1	3.7	5.0	1.7	6.2	0.4	0.1	4.2	15.0	2.0

Table 5.1-17 Percent of KIR species captured with some form of external pathology, Athabasca River, spring, summer, and fall, 1997-2009.

Year	Goldeye			Longnose Sucker			Northern Pike			Walleye			White Sucker		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
1997	3.5	2.2	0.0	10.4	18.2	0.0	0.0	12.5	9.1	3.0	2.1	0.0	12.5	0.0	0.0
1998	0.0	1.2	3.2	2.2	0.0	2.4	0.0	0.0	8.1	3.0	0.0	3.7	16.7	0.0	3.5
1999	3.7	0.0	0.0	6.3	0.0	0.0	7.7	0.0	15.2	2.4	0.0	0.0	10.3	0.0	0.0
2000	5.9	0.0	0.0	5.8	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	10.5	0.0
2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.8	0.0	1.0	3.6	0.0	0.0
2003	0.0	0.0	0.0	0.0	0.0	4.9	4.2	0.0	2.6	0.0	0.0	3.7	0.0	0.0	7.7
2004	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	3.8	0.0	0.0	6.5	0.0	0.0
2005	0.9	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	1.7	0.0	2.8	2.9	0.0	0.0
2006	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	1.5	0.0	0.0
2007	0.0	0.0	3.0	2.4	0.0	0.0	0.0	0.0	0.0	1.9	0.0	3.3	2.5	0.0	5.6
2008	0.8	0.0	1.1	12.8	1.6	0.0	4.5	0.0	0.0	3.9	1.0	2.1	9.1	7.7	2.8
2009	0.9	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	6.7	0.0	0.0	6.3	25.0	4.6

Figure 5.1-39 Fish tag recovery locations, 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_J_FishTag_20100310.mxd

Table 5.1-18 Results of RAMP fish tag return analysis, 2009.

Variable	Fish Species		
	Walleye	Northern Pike	White Sucker
No. of Fish Recaptured	12	15	1
Minimum Distance Travelled (km)	0	0	1
Maximum Distance Travelled (km)	4	52	1

Table 5.1-19 Results of RAMP fish tag return analysis, 1999-2009.

Variable	Fish Species				
	Lake Whitefish	Longnose Sucker	Northern Pike	Walleye	White Sucker
No. of Fish Captured	1	2	35	86	4
Minimum Distance Travelled (km)	271	5.3	0	0	1
Maximum Distance Travelled (km)	271	236	57	715	241

This page intentionally left blank for printing purposes.

5.2 MUSKEG RIVER WATERSHED

Table 5.2-1 Summary of results for Muskeg River watershed.

Muskeg River Watershed	**Summary of 2009 Conditions**									
	Muskeg River			***Jackpine Creek***		***Other***				
Climate and Hydrology										
Criteria	**S7** near Fort McKay								**L2** Kearl Lake	**S9** Kearl Lake Outlet
Mean open-water season discharge	🟡								not measured	not measured
Mean winter discharge	🟤								not measured	not measured
Annual maximum daily discharge	🟠								not measured	not measured
Minimum open-water season discharge	🟤								not measured	not measured
Water Quality										
Criteria	**MUR-1** at the mouth	no station sampled	**MUR-6** upstream of Wapasu Creek	**JAC-1** at the mouth	**JAC-2** upper station	**STC-1** Stanley Creek at the mouth	**SHC-1** Shelley Creek at the mouth	**WAC-1** Wapasu Creek at Canterra Road	**KEL-1** Kearl Lake	no station sampled
Water Quality Index	🟡		🟡	🟡	🟡	🟡	🟤	🟡	🟡	
Benthic Invertebrate Communities and Sediment Quality										
Criteria	**MUR-E-1** lower reach	**MUR-D-2** middle reach	**MUR-D-3** upper reach	**JAC-D-1** lower reach	**JAC-D-2** upper reach	no reach sampled	no reach sampled	no reach sampled	**KEL-1** Kearl Lake	no reach sampled
Benthic Invertebrate Communities	🟡	🟡	🟡	🟡	n/a				🟡	
Sediment Quality Index	n/a	🟡	🟡	🟡	🟡				🟡	
Fish Populations										
Criteria	**MUR-E-1** lower reach									
± 10% difference in condition of *test* fish versus *baseline* fish	🟠									

Legend and Notes

🟡 Negligible-Low — *baseline*
🟠 Moderate — *test*
🟤 High

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with *baseline* reaches.

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

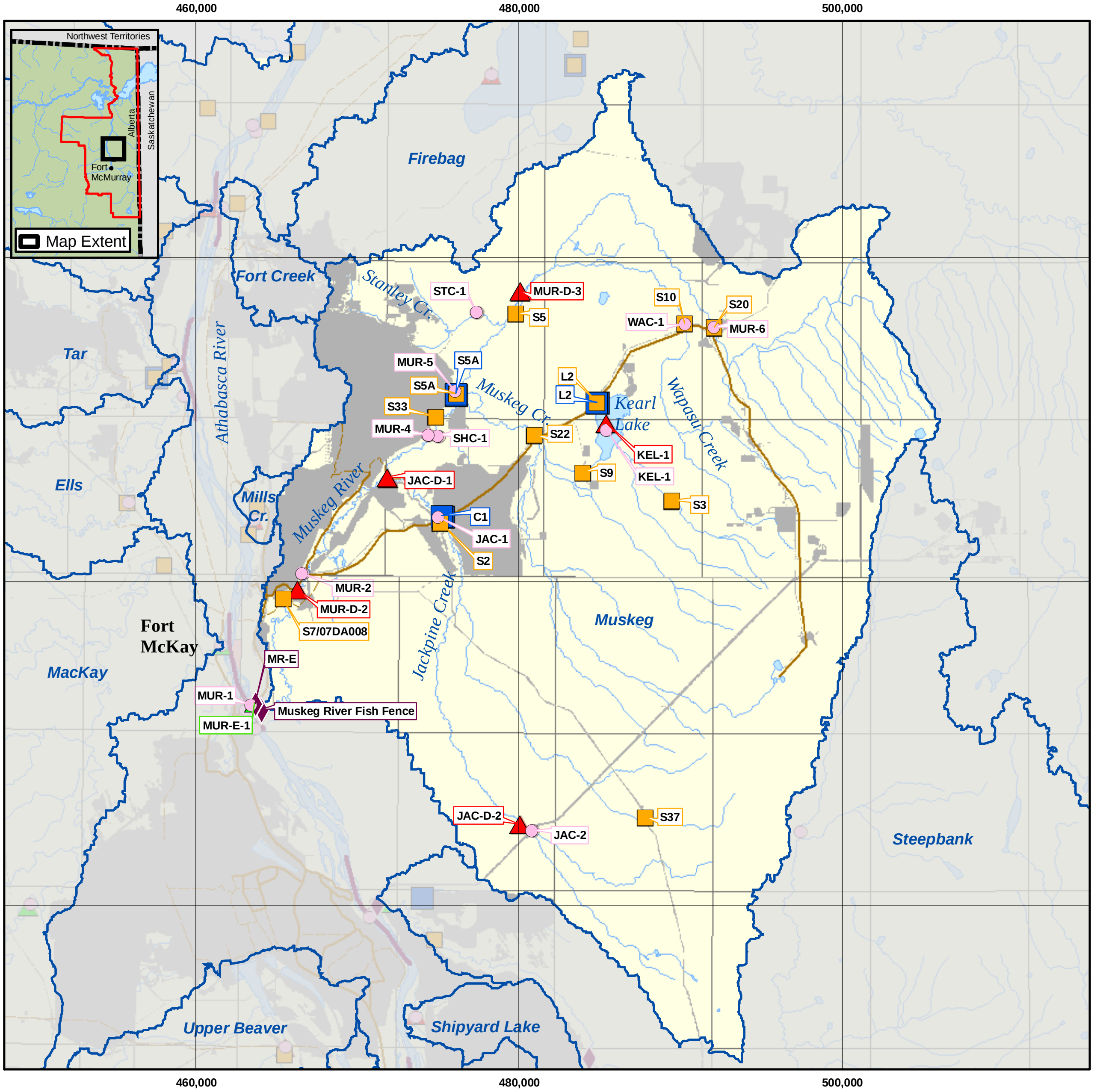
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Fish Populations: Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2005), see Section 3.4.7.3 for a detailed description of the classification methodology. See Section 5.3.4 for the results of the 2009 sentinel species monitoring.

Figure 5.2-1 Muskeg River watershed.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area
- Climate Station
- Hydrometric Station
- Water Quality Sampling Station
- Benthic Invertebrate Community Sampling Reach
- Benthic Invertebrate Community Sampling Reach and Sediment Quality Sampling Station
- Sediment Quality Sampling Station
- Fish Sampling Site
- Fish Sampling Reach

RAMP Regional Aquatics Monitoring Program

0 2.5 5 10 Km

Scale 1:400,000

Projection: UTM Zone 12 NAD83

Land Change Areas Delineated from 10m SPOT-5 (June, July and August 2009) Multispectral Imagery.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K02_Muskeg_20100415.mxd

Figure 5.2-2 Representative monitoring stations of the Muskeg River watershed, 2009.

Water Quality Station MUR-1 (Muskeg River): Left Downstream Bank

Fish Fence Location (Muskeg River): Right Downstream Bank

Water Quality Station MUR-6 (Muskeg Creek): Centre of Channel, facing upstream

Water Quality Station JAC-2 (Jackpine Creek): Left Downstream Bank

Water Quality Station JAC-1 (Jackpine Creek): Right Downstream Bank

Water Quality Station SHC-1 (Shelley Creek): Right Downstream Bank

Water Quality Station WAC-1 (Wapasu Creek): Left Downstream Bank

Water Quality Station KEL-1: Kearl Lake

5.2.1 Summary of 2009 Conditions

As of 2009, approximately 11% (16,200 ha) of the Muskeg River watershed had undergone land change from focal projects (Table 2.4-2). The designations of specific areas of the watershed are as follows:

- The Muskeg River from upstream of Wapasu Creek to the mouth, as well as the lower part of Stanley Creek, Muskeg Creek (including Kearl Lake), Jackpine Creek and Wapasu Creek drainages in the Husky Sunrise, Shell Albian Muskeg River Mine and Shell Albian Jackpine Mine leases are designated as *test*; and
- The remainder of the watershed, including Iyinimin Creek, and the upper portion of Jackpine Creek, is designated as *baseline*.

Table 5.2-1 is a summary of the 2009 assessment of the Muskeg River watershed, and Figure 5.2-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009 in the Muskeg River watershed. Figure 5.2-2 contains spring and fall 2009 photos of a number of the monitoring stations in the watershed.

Hydrology The mean open-water discharge and the annual maximum daily flow calculated from the observed *test* hydrograph are 2.5% and 6.4% lower, respectively, than from the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low** and **Moderate,** respectively. The mean winter discharge and the open-water period minimum daily discharge calculated from the observed *test* hydrograph are 31.6% and 17.3% higher, respectively, from the estimated *baseline* hydrograph; these differences are classified as **High**.

Water Quality In fall 2009, water quality at most stations in the Muskeg River watershed was generally consistent with regional *baseline* conditions with the exception of Shelley Creek as measured at *test* station SHC-1. Differences in water quality in fall 2009 at seven of the eight stations monitored in the Muskeg River watershed as compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**. Differences in water quality in Shelley Creek as measured at *test* station SHC-1 as compared to regional *baseline* conditions was assessed as **High** because concentrations of several measurement endpoints in fall 2009 were outside regional *baseline* concentrations; however, similarly high concentrations of these endpoints also fell outside the range of regional *baseline* concentrations in previous sampling years at this station in the late 1990s, prior to any development in the Shelley Creek watershed, suggesting that the difference in water quality may be naturally occurring.

Benthic Invertebrate Communities and Sediment Quality The difference in the condition of benthic invertebrate communities in *test* reach MUR-E-1 as compared to regional *baseline* conditions is classified as **Negligible-Low** on the basis that none of the benthic invertebrate community measurement endpoints have had a significant time trend relative to background variation as of 2009, and all benthic invertebrate community measurement endpoints in fall 2009 were within the range of values for *baseline* erosional reaches. The difference in the condition of benthic invertebrate communities in *test* reach MUR-D-2 as compared to regional *baseline* conditions is classified as **Negligible-Low** for the same reasons as for *test* reach MUR-E-1, summarized above. The difference in the condition of benthic invertebrate communities in *test* reach MUR-D-3 as compared to regional *baseline* conditions is classified as **Negligible-Low** because none of the benthic invertebrate community measurement endpoints were significantly different between the years in which the reach has been designated as *test* from years it was designated as *baseline*.

The data from Jackpine Creek support a conclusion that the benthic invertebrate communities in *test* reach JAC-D-1 have changed over time with increases in number of taxa, diversity, and evenness that were not observed in *baseline* reach JAC-D-2. The variation in benthic invertebrate community measurement endpoints in *test* reach JAC-D-1 are classified as **Negligible-Low** on the basis that although there was a significant decrease in %EPT in 2009 compared to 2008, %EPT in 2009 was greater or similar to previously-measured values at this reach, and within regional *baseline* conditions and. Significant increases in diversity and evenness were also observed at *test* reach JAC-D-1 that does not imply a negative change in benthic invertebrate communities. All other measurement endpoints were within the range of regional *baseline* conditions.

The differences in benthic invertebrate community measurement endpoints between Kearl Lake and McClelland Lake in the RAMP FSA are classified as **Negligible-Low.** None of the seven measurement endpoints of benthic invertebrate community composition provided strong evidence of a change related to *test* conditions. All of the measurement endpoints were within the range of expected *baseline* lake conditions in the RAMP FSA.

Sediment quality at all Muskeg River watershed stations sampled in 2009 was generally consistent with that of previous years, and largely within historical concentrations and regional *baseline* conditions. Differences in sediment quality in fall 2009 at all five stations monitored in the Muskeg River watershed as compared to regional *baseline* conditions are assessed as **Negligible-Low** (Table 5.2-1).

Fish Populations The 2009 Muskeg River fish fence results were compared to results of the 2003 and 2006 Muskeg River fish fences. Key findings include:

- Although the Muskeg River continues to be utilized by populations of a number of species, dominated by white sucker, longnose sucker, and northern pike, significantly higher numbers of white sucker and much lower numbers of all other species were observed in 2009 compared to the previous two sampling years;
- The timing of migration for sucker species in 2009 was different from 2003 and 2006 given the runs were not dictated by an initial temperature threshold of about 10°C;
- Mean age of the dominant species between years was significantly different with younger fish being captured in 2009 compared to 2003 and 2006, and narrower age ranges of fish captured in 2009; and
- The weight-length relationship in dominant species was generally consistent between sampling years but sex-specific differences were observed between male and female white sucker in all three years (i.e., female were heavier than males).

Based on the intermittent operation of fish fence programs on the Muskeg River, any changes related to oil sands development remains undetectable from the natural variability in spawning runs of large-bodied fish species.

5.2.2 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay The open-water runoff volume recorded in 2009 at WSC Station 07DA008 (RAMP Station S7) was 141.3 million m^3, 24% higher than the historical mean open-water runoff. Flows generally remained below 1 m^3/s until mid-April, and then increased due to snowmelt, peaking at 13 m^3/s on April 25 (Figure 5.2-3). This date was approximately two weeks earlier than the normal freshet date in this watershed. The maximum recorded daily flow of 41.7 m^3/s occurred on July 2, shortly after the late June rainfall event, and was 85% higher than the mean historical maximum daily flow of 22.6 m^3/s. Flows from August to October were between the historical lower and upper quartile values. The minimum daily flow during the open-water period (May to October) was 1.4 m^3/s, recorded on October 16, 25% higher than the corresponding historical average of 1.1 m^3/s.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DA008 for 2009 is presented in Table 5.2-2 and described below:

1. The closed-circuited land area from focal projects as of 2009 was estimated at 114.5 km^2 (Table 2.4-1). The loss of flow to the Muskeg River that would have otherwise occurred from this land area is estimated at 11.09 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 47.6 km^2 (Table 2.4-1). The increase in flow to the Muskeg River that would not have otherwise occurred from this land area is estimated at 0.92 million m^3.

3. Syncrude's reported 4.96 million m^3 of water released into Stanley Creek via the Aurora Clean Water Diversion (CWD). As in previous water balance calculations involving the CWD (RAMP 2008, RAMP 2009a), the assumption was made in this analysis that none of the water released from the CWD would have reached the Muskeg River through other means.

4. 0.16 million m^3 of water released from the Hammerstone quarry.

5. 0.37 million m^3 of water released from the Husky treatment plant and well-pads.

6. 5.24 million m^3 of water released from ponds on the Shell Albian Sands lease.

7. 0.13 million m^3 of water withdrawn by Imperial from various ponds and Kearl Lake. Other releases were reported by Imperial.

The estimated cumulative effect of land change and water withdrawals and releases is an increase in flow of 0.21 million m^3 to the Muskeg River. The estimated *baseline* hydrograph is presented in Figure 5.2-1.

The mean open-water discharge and the annual maximum daily flow calculated from the observed *test* hydrograph are 2.5% and 6.4% lower, respectively, than from the estimated *baseline* hydrograph (Table 5.2-3); these differences are classified as **Negligible-Low** and **Moderate,** respectively (Table 5.2-1). The mean winter discharge and the open-water period minimum daily discharge calculated from the observed *test* hydrograph are 31.6% and 17.3% higher, respectively, than from the estimated *baseline* hydrograph (Table 5.2-3); these differences are classified as **High** (Table 5.2-1).

2009 Hydrologic Conditions: Station L2, Kearl Lake Lake levels measured at Station L2 remained relatively constant throughout 2009 (Figure 5.2-4). With the exception of the rise in lake level following the late June rainfall event, levels from January to late June and from mid August to late December were generally within the inter-quartile range of lake levels, between 331.80 and 331.94 m above sea level (asl). The maximum lake level recorded for 2009 of 332.14 m on July 6 was equal to the historical mean annual maximum level, and the minimum lake level recorded for 2009 of 331.80 m asl on April 16 was 7 cm higher than the historical mean annual minimum level.

5.2.3 Water Quality

In fall 2009, water quality samples were taken from:

- the Muskeg River near its mouth (*test* station MUR-1, sampled from 1997 to 2009);
- the Muskeg River upstream of Wapasu Creek (*test* station MUR-6, designated as *test* in 2008, sampled from 1998 to 2009);
- Jackpine Creek near its mouth (*test* station JAC-1, designated as *test* in 2006, sampled from 1998 to 2009);
- upper Jackpine Creek (*baseline* station JAC-2, sampled for the first time in 2008);
- Stanley Creek near its mouth (*test* station STC-1, designated as *test* in 2003, sampled from 1998 to 2009);
- Shelley Creek near its mouth (*test* station SHC-1, designated as *test* in 2006, sampled intermittently from 1998 to 2009);
- Wapasu Creek near its mouth (*test* station WAC-1, designated as *test* in 2007, sampled intermittently from 1998 to 2009); and
- Kearl Lake (*test* station KEL-1, designated as *test* in 2009, sampled from 1998-2009).

2009 Results Relative to Historical and Regional *Baseline* Concentrations
Concentrations of water quality measurement endpoints in the mainstem of the Muskeg River, at *test* stations MUR-1 and MUR-6, in fall 2009 were within historical and regional *baseline* ranges of concentration with the following exceptions:

1. Concentrations of total nitrogen exceeded previously-measured maximum concentrations at *test* stations MUR-1 and MUR-6 and exceeded its regional range of *baseline* concentrations at *test* station MUR-6 (Table 5.2-4, Table 5.2-5, Figure 5.2-5).
2. The concentration of dissolved organic carbon exceeded its regional range of *baseline* concentrations at *test* station MUR-6 (Figure 5.2-5).
3. The concentration of naphthenic acids at all stations in the Muskeg River was below the regional *baseline*, but this was due to greatly improved detection limits for this analysis in 2009.

Concentrations of water quality measurement endpoints were generally similar between *test* stations MUR-1 and MUR-6 (Table 5.2-4, Table 5.2-5, Figure 5.2-5).

Concentrations of water quality measurement endpoints in the mainstem of the Muskeg River, at *test* station JAC-1 and *baseline* station JAC-2, in fall 2009 were within historical and regional *baseline* ranges of concentration with the following exceptions:

1. Concentrations of total nitrogen and total mercury exceeded previously-measured maximum concentrations at *test* station JAC-1, although

concentrations of both measurement endpoints were within the range of regional *baseline* concentrations (Table 5.2-6 and Figure 5.2-6).

2. The concentration of sulphate at *test* station JAC-1 was below the 5th percentile of regional *baseline* concentrations.

3. Concentrations of naphthenic acids at both *test* station JAC-1 and *baseline* station JAC-2 were below the regional range of *baseline* concentrations, but this was due to an improved detection limit for this analysis in 2009.

4. The concentration of chloride was lower than its previously-measured minimum concentration at *test* station JAC-1 (Table 5.2-6).

5. Concentrations of all water quality measurement endpoints at *baseline* station JAC-2 represented historical minimum or maximum concentrations, as 2009 was only the second year of sampling at this station (Table 5.2-7).

6. Concentrations of all selected water quality measurement endpoints at *baseline* station JAC-2 were within the range of regional *baseline* concentrations (Figure 5.2-6).

Concentrations of water quality measurement endpoints in the other Muskeg River tributaries in fall 2009 were within historical and regional *baseline* ranges of concentration (Table 5.2-8 to Table 5.2-11 and Figure 5.2-6 to Figure 5.2-7) with the following exceptions:

1. Concentrations of naphthenic acids at all stations in the other Muskeg River tributaries, with the exception of *test* station SHC-1 were below the regional range of *baseline* concentrations, but this was due to an improved detection limits for this analysis in 2009.

2. At *test* station STC-1, concentrations of total dissolved phosphorus and dissolved organic carbon were greater than their previously-measured maximum concentrations for this station, and the concentration of sulphate was lower than its previously-measured minimum concentration for this station (Table 5.2-8). Concentrations of all these measurement endpoints were within their regional *baseline* concentrations (Figure 5.2-6). In addition, concentrations of total arsenic were lower than its regional *baseline* concentrations (Figure 5.2-6) but within its historical range for *test* station STC-1(Table 5.2-8).

3. At *test* station SHC-1, concentrations of several water quality measurement endpoints, including pH, nitrate+nitrite, dissolved organic carbon, calcium, magnesium, sulphate, total dissolved solids, and total molybdenum were at or outside their previously-measured ranges of concentration for this station because 2009 was only the third year of water quality sampling at *test* station SHC-1 (Table 5.2-9). Concentrations of suspended and dissolved solids, total nitrogen, strontium, boron, calcium, magnesium, sodium, potassium, chloride, and sulphate exceeded their 95th percentile of regional *baseline* concentrations (Figure 5.2-6).

4. At *test* station WAC-1, concentrations of total nitrogen, dissolved organic carbon, total aluminum, dissolved aluminum, total arsenic, and total molybdenum were greater than their previously-measured maximum concentrations for this station, while the concentration of chloride was

below its previously-measured minimum concentration (Table 5.2-10). In addition, the concentration of total nitrogen exceeded its 95th percentile of *baseline* concentrations (Figure 5.2-6).

5. At *test* station KEL-1, concentrations of sodium, and mercury exceeded their previously-measured maximum concentrations for this station, while concentrations of dissolved organic carbon and sulphate were below their previously-measured minimum concentrations (Table 5.2-11).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines In fall 2009, concentrations of all water quality measurement endpoints at Muskeg watershed stations were below water quality guidelines with the exception of total nitrogen, with concentrations that exceeded its water quality guideline at all stations with the exception of *test* station STC-1 (Table 5.2-8) and *test* station SHC-1 (Table 5.2-9) and total aluminum, with concentrations that exceeded its water quality guideline at *baseline* station JAC-2 (Table 5.2-7).

Other Water Quality Guideline Exceedances The following are other water quality guideline exceedances observed in the Muskeg River watershed in fall 2009 (Table 5.2-12):

- sulphide, total nitrogen and total and dissolved iron at *test* station MUR-1;
- sulphide, total phenols, and total and dissolved iron at *test* station JAC-1;
- sulphide, total phenols, and total and dissolved iron at *baseline* station JAC-2;
- sulphide, total iron, and sulphate at *test* station SHC-1;
- sulphide at *test* station STC-1 and *test* station MUR-6;
- sulphide, total phenols, and total iron at *test* station WAC-1; and
- sulphide, total Kjeldahl nitrogen, and total phenols at *test* station KEL-1.

Ion Balance The ionic composition throughout the Muskeg River watershed in fall 2009 was similar to that measured in previous years (Figure 5.2-8). The ionic composition at *test* station SHC-1 has had the greatest variability over the sampling period and in fall 2009 had a higher proportion of calcium and sulphate than in most previous years. The ionic composition of Kearl Lake in fall 2009 was consistent with that of previous years of sampling, with anions dominated by calcium bicarbonate and low concentrations of sodium and potassium chloride (Figure 5.2-8).

Trend Analysis A significant downward trend in sulphate was calculated for *test* stations MUR-6 and JAC-1 over the sampling period ($\alpha = 0.05$). There have been no significant trends in water quality measurement endpoints at *test* stations MUR-1, STC-1, WAC-1, and *test* station KEL-1. Trend analyses could not be completed for *baseline* stations JAC-2 or SHC-1 due to an insufficient number of sampling years.

Water Quality Index The WQI values for all stations in the Muskeg River watershed in fall 2009 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.2-13), with the exception of *test* station SHC-1 which in fall 2009 had water quality conditions that indicated **High** differences from regional *baseline* water quality conditions. This is a result of the concentrations of a number of measurement endpoints at *test* station SHC-1 in fall 2009, including suspended and dissolved solids, total nitrogen, strontium, boron, calcium, magnesium, sodium, potassium, chloride, and sulphate, being outside regional *baseline* concentrations (Figure 5.2-6).

Summary In fall 2009, water quality at most stations in the Muskeg River watershed was generally consistent with regional *baseline* conditions with the exception of Shelley Creek as measured at *test* station SHC-1. Differences in water quality in fall 2009 at seven of the eight stations monitored in the Muskeg River watershed compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**. Differences in water quality in Shelley Creek as measured at *test* station SHC-1 compared to regional *baseline* conditions is assessed as **High**, as a result of the concentrations of a number of measurement endpoints at *test* station SHC-1 in fall 2009 being outside regional *baseline* concentrations.

5.2.4 Benthic Invertebrate Communities and Sediment Quality

5.2.4.1 Benthic Invertebrate Communities

Muskeg River Mainstem

Benthic invertebrate community samples were collected from three reaches on the Muskeg River in 2009:

- A lower erosional reach near the mouth of the Muskeg River (reach MUR-E-1, designated as *test* for its entire data record beginning in 2000);
- A middle depositional reach near the Canterra Road crossing (reach MUR-D-2, designated as *test* for its entire data record beginning in 2000); and
- An upper depositional reach located upstream of the Muskeg River and Aurora North oil sands developments (reach MUR-D-3, designated as *test* for the first time in 2008, sampled since 2002).

2009 Habitat Conditions for *Test* Reach MUR-E-1 *Test* reach MUR-E-1 in fall 2009 was 0.4 m deep and had fast currents, a substrate dominated by large gravel and small cobble, no macrophyte cover, and a concentration of dissolved oxygen that was greater than the chronic guideline for protection of aquatic life (AENV 1999b) (Table 5.2-14). Periphyton biomass averaged about 62 mg/m^2, which was within the range of periphyton biomass for regional *baseline* erosional reaches (Figure 5.2-9).

Relative Abundance of Benthic Invertebrate Community Taxa for *Test* Reach MUR-E-1 The benthic invertebrate community of *test* reach MUR-E-1 was dominated by chironomids (52%), and mayflies (Ephemeroptera, 29%, Table 5.2-15). The chironomids were diverse, consisting of many common forms such as *Tanytarsus*, and *Rheotanytarsus,* as well as other forms that are more restricted to clean and cold water such as *Tvetenia* and *Lopesocladius*. Mayfly taxa included the common forms *Baetis* and *Acerpenna*, as well as *Ephemerella* and *Heptagenia*, which require water of higher quality. The caddisfly taxa were dominated numerically by Hydropsychidae. Stoneflies (Plecoptera) included *Taeniopteryx*, *Skwala*, and *Classenia sabulosa*.

Abundance, taxa richness, Simpson's diversity, evenness, and %EPT in fall 2009 were within the range of regional *baseline* values for erosional reaches (Figure 5.2-10). In addition, the results of the Correspondence Analysis indicated that *test* reach MUR-E-1 in fall 2009 had a benthic invertebrate community composition that was within the range of regional *baseline* erosional reaches in the RAMP FSA (Figure 5.2-11).

None of the benthic invertebrate community measurement endpoints for *test* reach MUR-E-1 had a significant time trend with the exception of CA Axis 2 (Table 5.2-16). The "remainder (noise)" term, however, is larger than the time trend term for CA Axis 2 scores, indicating that this time trend is not strong and is therefore considered negligible.

2009 Habitat Conditions for *Test* Reach MUR-D-2 *Test* reach MUR-D-2 was relatively deep in fall 2009, with a substrate dominated by sand, little macrophyte cover, and a concentration of dissolved oxygen that was between the acute and chronic guidelines for protection of aquatic life (AENV 1999b, Table 5.2-17).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community in *test* reach MUR-D-2 was dominated by chironomids (48%) and tubificid worms (21%, Table 5.2-18). Fingernail clams (bivalves, 5%), ceratopogonids (3%), and various other worms (Lumbriculidae and Naididae) were sub-dominant. The most dominant chironomids included the common *Tanytarsus*, *Micropsectra*, *Stempellinella* and *Procladius*, as well as the cold-water form *Heterotrissocladius*. Mayflies (Ephemeroptera) including *Leptophlebia*, *Tricorythodes*, *Callibaetis* and *Baetis* were present, as was the caddisfly (Trichoptera, *Hydroptila*).

Abundance, Simpson's diversity, evenness, and %EPT in fall 2009 at *test* reach MUR-D-2 were within the range of regional *baseline* values for depositional reaches (Figure 5.2-12). The number of taxa was above the 95th percentile of the regional *baseline* values for depositional reaches, implying robust and healthy benthic invertebrate communities at *test* reach MUR-D-2 (Figure 5.2-12). In addition, the results of the Correspondence Analysis indicated that *test* reach MUR-D-2 in fall 2009 had a benthic invertebrate community composition that was within the range of regional *baseline* depositional reaches in the RAMP FSA (Figure 5.2-13).

None of the benthic invertebrate community measurement endpoints for *test* reach MUR-D-2 exhibited a significant trend over time with the exception of abundance and CA Axis 1 scores (Table 5.2-19). Abundance decreased from approximately 60,000 individuals/m^2 in 2000 and 2001 to approximately 30,000 individuals/m^2 in 2009 (Table 5.2-18, Figure 5.2-12). The trend in CA Axis 2 score reflected an increase in relative abundance of fingernail clams (bivalves) over time. The "remainder (noise)" term, however, is larger than the time trend term for both these measurement endpoints, indicating that these time trends are not strong and therefore, can be considered negligible.

2009 Habitat Conditions for *Test* Reach MUR-D-3 *Test* reach MUR-D-3 was relatively deep, had a substrate dominated by sand, sediments that contained high amounts of organic carbon, sparse macrophyte cover and a concentration of dissolved oxygen that was lower than both the acute and chronic guideline for protection of aquatic life (AENV 1999) (Table 5.2-20).

Relative Abundance of Benthic Invertebrate Community Taxa for *Test* Reach MUR-D-3 The benthic invertebrate community of *test* reach MUR-D-3 in fall 2009 was dominated by chironomids (42%) and tubificid worms (23%) (Table 5.2-21). Fingernail clams (bivalves, 12%), and various other worms (Lumbriculidae and Naididae) were sub-dominant. The most dominant chironomids included the common forms *Micropsectra* and *Polypedilum*. Mayflies (Ephemeroptera) were sparse, but included *Leptophlebia.* The only caddisfly larva was *Nemotaulius*.

Abundance, taxa richness, diversity, evenness, and %EPT at *test* reach MUR-D-3 in fall 2009 were within the range of regional *baseline* values for depositional reaches (Figure 5.2-14). The CA ordination for *test* reach MUR-D-3 (Figure 5.2-15) illustrated a modest shift in benthic invertebrate community composition in 2009 relative to previous years, with a reduced relative abundance of mayflies (Ephemeroptera), snails (Gastropoda), and water mites (Hydracarina). The decreases in these taxa were relatively minor and *test* reach MUR-D-2 in fall 2009 had a benthic invertebrate community composition that was within the range of regional *baseline* depositional reaches in the RAMP FSA.

None of the benthic invertebrate community measurement endpoints for *test* reach MUR-D-3 were significantly different between the years in which the reach has been designated as *test* from years it was designated as *baseline* (Table 5.2-22, Figure 5.2-14).

Jackpine Creek

Benthic invertebrate community samples were collected from two reaches on Jackpine Creek:

- A lower depositional reach near the mouth of Jackpine Creek (reach JAC-D-1 designated as *test* in 2006, sampled since 2002); and
- An upper depositional reach (reach JAC-D-2, designated as *baseline* for its entire data record).

2009 Habitat Conditions *Test* reach JAC-D-1 in fall 2009 was moderately deep and had a substrate dominated by sand, some macrophyte cover, and a concentration of dissolved oxygen that was between the acute and chronic guidelines for protection of aquatic life (AENV 1999b, Table 5.2-23). *Baseline* reach JAC-D-2 was also relatively deep, with a substrate also dominated by sand, little macrophyte cover, and a concentration of dissolved oxygen that was above the chronic guideline for protection of aquatic life (AENV 1999b, Table 5.2-23).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community in *test* reach JAC-D-1 in fall 2009 was dominated by chironomids (80%) consisting primarily of *Tanytarsus*, *Stempellinella*, *Paratanytarus*, *Polypedilum*, *Paralauterbourniella* (Table 5.2-24). *Test* reach JAC-D-1 in fall 2009 also contained ceratopogonids, copepods, empidid fly larvae, and water mites (Hydracarina) in low numbers. Mayflies (Ephemeroptera) were also in low abundances, and were represented by *Tricorythodes*, *Leptophlebia* and *Caenis*, while caddisflies (Trichoptera) were represented by *Oxyethira* and early instar Limnephilidae.

The benthic invertebrate community in *baseline* reach JAC-D-2 in fall 2009 was dominated by chironomids (69%) consisting primarily of *Tanytarsus*, *Stempellinella* and *Paralauterbourniella* (Table 5.2-24). Sub-dominant groups included ceratopogonids (11%), Coleoptera (e.g., *Dubiraphia*), Ephemeroptera (7%, *Leptophlebia*, *Siphloplecton*, *Tricorythodes*, *Caenis*), and Tipulidae (2%). Caddisflies (Trichoptera, e.g., Lepidostoma and Hydroptilidae) were also present.

Taxa richness and diversity at *test* reach JAC-D-1 were above their range of regional *baseline* values in fall 2009 (Figure 5.2-16); values of all other benthic invertebrate community measurement endpoints for the two sampled reaches in Jackpine Creek were within their range of regional *baseline* values. In addition, the results of the Correspondence Analysis indicate that the benthic invertebrate community composition at both *test* reach JAC-D-1 and *baseline* reach JAC-D-2 in fall 2009 were within the range of regional *baseline* depositional reaches in the RAMP FSA (Figure 5.2-17).

Linear contrasts were used to test for:

- differences in values of benthic invertebrate community measurement endpoints between *test* reach JAC-D-1 and *baseline* reach JAC-D-2 from the period that reach JAC-D-1 was designated as *test* to the period it was designated as *baseline*, i.e., a test of the interaction between Before vs After (BA) and *Baseline* vs *Test* (BT) (BA x BT in Table 5.2-25); and

- differences in time trends of measurement endpoints for benthic invertebrate communities between *test* reach JAC-D-1 and *baseline* reach JAC-D-2 (i.e., TT x BT in Table 5.2-25).

There were significant differences in time trends of taxa richness, diversity, evenness, %EPT, CA Axis 1 score, and CA Axis 2 score between *test* reach JAC-D-1 and *baseline* reach JAC-D-2 (Table 5.2-25). Taxa richness, diversity, evenness, and %EPT increased in *test* reach JAC-D-1 over time during the period that it was designated as *test*, whereas these measurement endpoints remained stable in the *baseline* reach JAC-D-2 over the same period (Table 5.2-24, Figure 5.2-16). These are not consistent with a "negative" difference between *test* reach JAC-D-1 and *baseline* reach JAC-D-2.

There were significant differences in %EPT, CA Axis 1 score, CA Axis 2 score before and after reach JAC-D-1 was designated as *test*. %EPT initially declined in *test* reach JAC-D-1 once it was designated as *test* in 2006, increased in 2008, and then decreased again in 2009. The average %EPT decreased in *test* reach JAC-D-1 after it was designated as *test* compared to *baseline* reach JAC-D-2 producing a significant BAxBT contrast. Although a decrease in %EPT was observed at *test* reach JAC-D-1, diversity continues to increase at this reach. These variations over time in *test* reach JAC-D-1 do not indicate a negative change to the benthic invertebrate community. All of the measurement endpoints were within regional *baseline* conditions, with the exception of taxa richness and diversity, with increases indicative of a more robust and healthy community compared to *baseline* conditions.

Kearl Lake

Benthic invertebrate communities were sampled in fall 2009 in Kearl Lake (station KEL-1, depositional, sampled since 2001, classified as *baseline* from 2001 to 2008, and *test* in 2009).

2009 Habitat Conditions The substrate at *test* station KEL-1 in fall 2009 consisted of 35% organic carbon (Table 5.2-26). Substrate materials were described as almost 90% sand, but the material is principally rotting vegetation. The concentration of dissolved oxygen at *test* station KEL-1 in fall 2009 was between the acute and chronic guidelines for protection of aquatic life (AENV 1999b).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community taxa at *test* station KEL-1 in fall 2009 were dominated by copepods (56%) and chironomids (21%), with bivalve clams (6%), amphipods (8%) and tubificid worms (2%) subdominant (Table 5.2-27).

Abundance, taxa richness, diversity, evenness and %EPT have been relatively stable at *test* station KEL-1 throughout the sampling period (Figure 5.2-18); the values of all these measurement endpoints at *test* station KEL-1 in fall 2009 were within their range of regional *baseline* values In addition, the results of the Correspondence Analysis indicate that the benthic invertebrate community composition at *test* station KEL-1, with high relative abundance of copepods and chironomids, and including bivalves and amphipods and various worms, was similar in composition of benthic invertebrate communities in *baseline* lakes in the RAMP FSA (Figure 5.2-19).

Linear contrasts were used to test for a difference in the change from *baseline* to *test* periods for station KEL-1 as compared to *baseline* MCL-1, used to represent *baseline* lakes in the RAMP FSA. There were no significant differences in changes from *baseline* to *test* periods between station KEL-1 and MCL-1 for five of the seven measurement endpoints

(Table 5.2-28). Changes in abundance and number of taxa between *baseline* to *test* periods differed between the lakes, and these changes were statistically significant. The "remainder (noise)" term, however, is larger than the time trend term for both these measurement endpoints, indicating that these differences are not strong and therefore can be considered negligible.

5.2.4.2 Sediment Quality

Sediment quality was sampled in fall 2009 in depositional reaches/lakes of the Muskeg River watershed where benthic invertebrate communities were sampled, at:

- *test* station MUR-D-2 of the Muskeg River (designated as *test* for its entire data record beginning in 2000);
- *test* station MUR-D-3 of the Muskeg River (designated as *test* for 2008 and 2009. Sampled since 2002);
- *test* station JAC-D-1 on Jackpine Creek near its mouth (designated as *test* since 2006, sampled since 2002);
- *baseline* station JAC-D-2 on Jackpine Creek (designated as *baseline* for its entire data record, sampled since 2006); and
- *test* station KEL-1 in Kearl Lake (designated as *test* for the first time in 2009, sampled since 2001).

2009 Results and Historical Ranges of Concentration Sediment quality data sampled in 2009 from all stations in the Muskeg River watershed were taken from the same locations as those reaches sampled in 2006 through 2008. Prior to the integration of the Sediment Quality and Benthic Invertebrate Communities components in 2006, benthic invertebrate community reaches MUR-D-2 and MUR-D-3 correspond to pre-2006 sediment-quality stations MUR-2 and MUR-D2 respectively, reach JAC-D-1 corresponds with pre-2006 sediment quality station JAC-1, and reach JAC-D-2 was established in 2006 (Table 3.3-6).

Sediment quality at all stations was similar to that observed historically (Table 5.2-29 to Table 5.2-33). Particle size at all stations was dominated by sand, and concentrations of volatile, low-molecular-weight hydrocarbons (i.e., CCME fraction 1 and BTEX – benzene, toluene, ethylene and xylene) were below analytical detection limits at all stations in fall 2009. Concentrations of heavier hydrocarbon fractions in fall 2009 were within the range of previously-measured fall concentrations at all *test* stations. A further assessment of hydrocarbons and PAHs in sediments is discussed in Section 7.

Survival and growth of the midge *Chironomus* at both *test* station JAC-D-1 and *baseline* station JAC-D-2 were below previously-measured minimum values for these stations (Table 5.2-31 and Table 5.2-32). *Hyalella* growth in fall 2009 at *test* station JAC-D-1 and *baseline* station JAC-D-2 was higher and lower than previously-measured maximum and minimum growth, respectively. All other results of sediment toxicity tests that were conducted were within historical ranges of values (Table 5.2-29 to Table 5.2-33).

Values of potential toxicity of PAHs in sediments at each station[1] were within the range of historical values, with the exception of *baseline* station JAC-D-2 where the value of potential toxicity of PAHs was greater than the previously-measured maximum for this station (Table 5.2-32).

[1] Calculated using the solubility and aquatic toxicity of each PAH species, and total hydrocarbons in each sample, as described in Appendix F.

Qualitative Among-Reach Comparisons The following comparisons of sediment quality measurement endpoints among reaches in fall 2009 are noted as follows:

1. Sand and total organic carbon concentrations were higher at *test* station MUR-D-3 (98.0% and 22.2%, respectively) than at *test* station MUR-D-2 (88.0% and 1.1%, respectively).
2. Hydrocarbon concentrations (including PAHs) were higher at *test* stations MUR-D-2, MUR-D-3, and JAC-D-1 compared to *baseline* station JAC-D-2.
3. Survival and growth of *Chironomus* and *Hyalella* were similar between *test* station JAC-D-1 and *baseline* station JAC-D-2.

Comparison of Sediment Quality Guidelines Concentrations measured for CCME fraction-3 hydrocarbons exceeded relevant CCME soil-quality guidelines at all stations with the exception of *baseline* station JAC-D-2 (Table 5.2-29 to Table 5.2-33). No other hydrocarbon, PAH or metal concentrations measured at the five stations exceeded relevant sediment or soil quality guidelines in fall 2009 with the exception of copper at *test* station KEL-1 (Table 5.2-33).

Sediment Quality Index The SQI values for all stations in the Muskeg River watershed in fall 2009 indicated **Negligible-Low** differences in sediment quality conditions at these stations from regional *baseline* sediment quality conditions (Table 5.2-34).

5.2.4.3 Summary

The difference in the condition of benthic invertebrate communities in *test* reach MUR-E-1 compared to regional *baseline* conditions is classified as **Negligible-Low** on the basis that none of the benthic invertebrate community measurement endpoints have had a significant time trend relative to background variation as of 2009, and the values of all benthic invertebrate community measurement endpoints in fall 2009 were within the range of values for *baseline* erosional reaches.

The difference in the condition of benthic invertebrate communities in *test* reach MUR-D-2 compared to regional *baseline* conditions is classified as **Negligible-Low** for the same reasons as for *test* reach MUR-E-1, above.

The difference in the condition of benthic invertebrate communities in *test* reach MUR-D-3 compared to regional *baseline* conditions is classified as **Negligible-Low** because none of the benthic invertebrate community measurement endpoints were significantly different between the years in which the reach has been designated as *test* from years it was designated as *baseline*.

The data from Jackpine Creek support a conclusion that benthic invertebrate communities in *test* reach JAC-D-1 has changed over time with increases in number of taxa, diversity, and evenness that were not observed in *baseline* reach JAC-D-2. The variation in benthic invertebrate community measurement endpoints in *test* reach JAC-D-1 are classified as **Negligible-Low** on the basis that although there was a significant decrease in %EPT in 2009 compared to 2008, %EPT in 2009 was higher than when *test* reach JAC-D-1 was designated as *baseline*, and the value was within regional *baseline* conditions and greater or similar to previously-measured values at this reach. Significant increases in other measurement endpoints were also observed but these changes do not imply a negative change in benthic invertebrate communities. All other measurement endpoints were within the range of regional *baseline* conditions.

The differences in benthic invertebrate community measurement endpoints between Kearl Lake and McClelland Lake in the RAMP FSA are classified as **Negligible-Low.** None of the measurement endpoints of benthic invertebrate community composition provided strong evidence of a change related to *test* conditions. All of the measurement endpoints within the range of expected *baseline* lake conditions in the RAMP FSA.

Sediment quality at all Muskeg River watershed stations sampled in fall 2009 was generally consistent with that of previous years and largely within historical concentrations and regional *baseline* conditions. Differences in sediment quality in fall 2009 at all five stations monitored in the Muskeg River watershed as compared to regional *baseline* conditions are assessed as **Negligible-Low** (Table 5.2-1).

5.2.5 Fish Populations

Fish population component activities undertaken in the Muskeg River watershed in 2009 included a spring fish fence and a non-lethal sentinel species monitoring study. Activities related to sentinel species monitoring was part of a larger study undertaken in 2009 in a number of watersheds within the RAMP FSA, including the Steepbank River watershed. The results of the Muskeg River watershed portion of this study are presented in Section 5.3.

The Muskeg River fish fence in 2009 is the third year a fish fence operation was undertaken by RAMP with previous fish fence operations in 2003 and 2006. While data from fish fences are best suited for assessing time trends in abundance and population variables for each spawning species, the level of inter-, and intra-annual variability common with spawning run strength requires a large number of sampling events before observed trends and possible changes from oil sands developments can be determined with confidence. Therefore, the results focus on the 2009 spring fish fence study and comparison with results from spring fish fences conducted in 2003 (RAMP 2004) and 2006 (RAMP 2007), rather than an assessment of changes related to oil sands developments in the Muskeg River watershed.

The 2009 fish fence was operational from May 5 to May 31, 2009 similarly to the period of operation in 2003 (May 1 to May 28), and 2006 (April 19 to May 19). Temperature in the Muskeg River was recorded continuously using a datalogger installed upstream of the fish fence. Daily mean, minimum and maximum temperatures are presented in Figure 5.2-20.

5.2.5.1 Fish Counts and Species Composition

A total of 5,657 fish were counted at the fish fence in the Muskeg River in 2009 (Table 5.2-35) exceeding the total number of fish counted in 2003 (1,152) and 2006 (1,256). From the total number of fish counted, 3,904 fish were measured and weighed (Table 5.2-36). The majority of the fish captured in 2009 were white sucker (98.3%; *Catostomus commersoni*); followed by northern pike (1.0%; *Esox lucius*); and a small number of longnose sucker (<1%; *Catostomus catostomus*).

The proportion of the total catch moving upstream (55%) was slightly higher than the proportion moving downstream, strongly influenced by the upstream migration of white sucker. Approximately equal numbers of northern pike and longnose sucker were captured moving upstream and downstream (Table 5.2-35).

5.2.5.2 Recapture Rates

Mark-recapture data obtained at the 2009 fish fence provides information on yearly movement patterns, spawning-site fidelity, and the amount of time large-bodied species spend in the upper reaches of the Muskeg River (i.e., upstream of the fish fence location).

A total of 52 sportfishes were marked with Floy tags in 2009, including 50 northern pike, and two walleye. Of these fish, 21 northern pike, and both walleye were tagged moving upstream and 39 northern pike were tagged moving downstream. None of these fish were recaptured during the operation of the 2009 fish fence.

A total of 14 fish, including one longnose sucker, three northern pike, and ten white sucker were recaptured with Floy tags from previous RAMP monitoring activities: two fish initially tagged during the Athabasca River fish inventory and twelve fish initially tagged in previous fish fence operations resulting in a 0.25% rate of return, which is lower than previous sampling years (2003 and 2006).

5.2.5.3 Timing of Migration

White Sucker

A total of 5,560 white sucker were captured during the operation of the fish fence, accounting for the largest proportion of the migrant fish enumerated at the fence (Table 5.2-35). Of these, 3,069 fish were counted moving upstream in the fish fence with the majority captured between May 15 and May 24, 2009 (Figure 5.2-21). Within this period, three peaks in white sucker movement were recorded on May 15, May 18, and May 21. The 2009 fish fence successfully captured a very high proportion of the white sucker spring spawning migration with no fish captured during the first ten days of operation and none captured in the final day of the fish fence (Figure 5.2-22). The fish fence operations in 2003 and 2006 also appeared to have captured a high proportion of the white sucker spawning run with few fish captured in the first two days and no fish captured on the final day (Figure 5.2-22).

A peak in downstream movement began on May 26 and continued until the end of the fish fence study (May 31). Of the 2,491 white suckers that were captured moving downstream, 1,343 of these fish were captured on May 31. On the last day of fish fence operation, all of the individuals moving downstream were counted and released downstream before removing the fence from the Muskeg River. Most white sucker moving upstream remained within the vicinity of the fish fence prior to moving downstream (approximately 20 to 50 m upstream of the fish fence location). Given most white sucker moving downstream were spent, it is likely they were initially intercepted while migrating upstream.

Previous fish fences in the Muskeg River (RAMP 2004, RAMP 2007) and other fish fence operations in Alberta (Walton 1980, Hamel *et al.* 1997) indicated a strong relationship between temperature and the initiation of spawning runs for sucker species at a thermal cue of 10°C. Although, this temperature was reached between May 4 and May 11, the peak in white sucker movement upstream did not begin until May 15 when the maximum daily water temperature was 9.1°C (Figure 5.2-22). Following a decrease in mean water temperature below 10ºC from May 12 to 20, the thermal threshold of 10°C was reached for a second time on May 21 and continued to increase for the duration of the fish fence study. The peaks in white sucker movement on May 15, 18, and May 21, coincided with daily temperatures approaching 10°C and decreases in water temperatures between the peak runs coincided with a decrease in the intensity of the white sucker run (Figure 5.2-21). When the fish are separated by sex, females responded strongly to the 10°C cue when it was reached on May 21. After May 22, the number of white sucker moving upstream in the Muskeg River decreased irrespective of water temperature.

Water discharge can also be a factor in the timing of migration for spawning of white sucker (Walton 1980), with increases in discharge coinciding with peak runs. Discharge measured at Station S7, upstream of the location of the fish fence ranged from <1 to >10 m^3/s in April and May (Figure 5.2-3) with a continuous decrease in discharge throughout the period of fish fence operation, indicating no relationship with peak spawning runs of white sucker on May 15 and 21.

In 2009, the ratio of female to male white sucker migrating upstream was 1:1.3, in contrast to 2.5:1 in 2003 and 1.5:1 in 2006. There is a clear sex-related pattern in white sucker migration in both directions with males moving upstream prior to females and females moving back downstream before males (Figure 5.2-23). This pattern has been previously observed in studies by Walton (1980) and Dion *et al.* (1994). The first half of the peak run beginning on May 15 was predominantly males (five times more males than females) and then switched to predominantly female white sucker on May 21. On May 22, there were half as many males as females ascending the Muskeg River. A similar pattern was found in white sucker moving upstream in 2006, but not in 2003 (RAMP 2004, 2007). White sucker females dominated the downstream migration from May 26 to May 29, while males initiated downstream migration on May 30.

Reproductive status of fish is expected to shift from pre-spawning to post-spawning with a change in direction of migration (Figure 5.2-24). Most male and female white sucker were ripe or in a pre-spawning state when captured moving upstream while the majority of white sucker moving downstream were reproductively spent.

Longnose Sucker

Longnose sucker were captured at the Muskeg River fish fence throughout the study period in small numbers (Table 5.2-35). Two small peaks of longnose sucker moving upstream (less than 5 fish in both runs) were observed on May 15 and May 22 and two small peaks of longnose sucker moving downstream on May 19 (n=6) and May 31 (n=7) (Figure 5.2-21). The intensity of the 2009 longnose sucker run was only a small fraction of the runs in 2003 and 2006 (Figure 5.2-22).

In previous fish fence operations longnose sucker and white sucker spawning runs overlapped (RAMP 2007, 2004, Edwards 1983), indicating that it is unlikely that a large run was missed prior to the installation of the fish fence in 2009. It may be likely that longnose sucker moving upstream on the Athabasca River to spawn did not use the Muskeg River as spawning grounds in 2009. The is further supported by the absence of longnose sucker at the mouth of the Muskeg River during the spring 2009 Athabasca River fish inventory compared to high number of white sucker captured in this area.

As with white sucker, most longnose sucker moving upstream were in a pre-spawning state while downstream migrants were spent (Figure 5.2-24).

Northern Pike

Northern pike were captured throughout the duration of the Muskeg River fish fence operation in smaller numbers than either sucker species (Table 5.2-35). Minor downstream peaks in fish movement were observed on May 7 to 8 (n=4) and May 20 to 21 (n=3) (Figure 5.2-21). The number of northern pike captured in 2009 was lower than the previous two years of fish fence operations, with peak spawning runs between ten and fifteen fish observed prior to May 11 (Figure 5.2-22). The lower number could be attributed to the delay in installing the fish fence due to high flows. In previous years, most northern pike were captured in April. In 2009, the fish fence was not installed until May 4.

This shift in reproductive status from pre-spawning or ripe in upstream moving fish to spent in downstream moving fish was not in northern pike where most fish captured moving both upstream and downstream were pre-spawning (Figure 5.2-24).

5.2.5.4 Residency Time

The estimated residency time of spawning species is the time between initiation of fish moving upstream and fish moving downstream. A large proportion of white sucker in the initial upstream run on May 15 were male followed closely by females on May 21. On May 26 spent white sucker, both male and female, started to move downstream following spawning suggesting a maximum residency of 11 days for males and four days for females with a minimum residency of one day. Many of the fish captured moving downstream occurred only a short time after initial capture, processing, and release upstream of the fence suggesting that the short time between capture and recaptured could be a result of fish fatigue and stress related to handling at the fence.

Residency time could not be estimated for longnose sucker or northern pike given there were no recaptures moving downstream. Recaptures of longnose sucker could be identified by the absence of two leading fin rays on the pelvic fin taken during initial capture for ageing. Recaptures of northern pike could be identified by the presence of a tag.

Sucker species were not tagged in 2009, therefore, residency times were based on the timing between capture of pre-spawning individuals moving upstream and the capture of spent individuals moving downstream, providing low confidence in the estimates of residency time. Currently the Muskeg River fish fence is operated for 30 days after initial installation, but this duration is not sufficient to accurately characterize the out-migration of these dominant fish species, which have been observed to leave the Muskeg River in June (Bond and Machniak 1979).

5.2.5.5 Size and Age Composition of Migrants

White Sucker

Length-frequency distributions between sexes of white sucker were significantly different ($p<0.001$; Figure 5.2-25), with the average length of migrating female white sucker (467 mm) significantly longer than males (439 mm). Females were significantly longer at a given age than males ($p<0.001$; Figure 5.2-26).

Migrant white sucker ranged in age from 3 to 13 years in 2009, similar to the age range in 2006 (4 to 14 years). Mean age of white sucker was compared between years (2003, 2006, and 2009) of fish fence operation. There was a significant decrease in mean age of male and female white sucker from 2003 to 2009 ($p<0.001$; Figure 5.2-26 and Figure 5.2-27). The length-age relationship for white sucker is shown in Figure 5.2-28. Consistent with results from 2003 and 2006, female white sucker were longer at any given age relative to males ($p<0.001$).

The weight-length (i.e., condition) relationship of migrant white sucker is shown in Figure 5.2-29. Female white sucker were significantly heavier for a given length compared to male white sucker ($p<0.001$). Condition of white sucker moving downstream was significantly lower compared to fish moving upstream ($p<0.001$; Figure 5.2-30); condition of white sucker female was 13% lower in downstream moving fish and 6.1% lower in downstream moving males relative to upstream moving females and males, primarily due to the differences in reproductive stages of white sucker moving upstream (pre-spawning) and downstream (post-spawning).

Longnose Sucker

The length-frequency distribution was not significantly different between male and female longnose sucker ($p=0.20$), with average lengths of 420 mm and 395 mm for female and male longnose sucker, respectively.

Migrant longnose sucker ranged in age from 5 to 11 years in 2009 (mean of 8 years), a slightly narrower range than reported in 2003 (7 to 19 years) and 2006 (4 to 14 years). There were no significant differences in mean age ($p=0.43$) between male and female longenose sucker in 2009. The mean age of male longnose sucker in 2003 was significantly older than 2006 and 2009 ($p=0.002$), but there were no significant differences in the mean age of male longnose sucker between 2006 and 2009 ($p=0.99$). The mean age of female longnose sucker significantly decreased from 2003 to 2009 ($p=0.01$). The length-age relationship for longnose sucker is shown in Figure 5.2-28. Consistent with results from 2003 and 2006, female longnose sucker were longer at any given age relative to males ($p=0.005$).

There were no significant differences in the weight-length relationship between male female longnose sucker in 2009 ($p\geq0.22$) (Figure 5.2-29).

Northern Pike

Length-frequency distributions were significantly different between male and female northern pike captured in 2009 ($p=0.020$), with the average length of female northern pike (686 mm) significantly longer than male northern pike (545 mm).

Migrant northern pike ranged in age ranged from 3 to 13 years with a mean age of seven years. The mean age of male northern pike was significantly older in 2009 compared to 2006 ($p=0.003$), but similar to 2003 ($p>0.20$) (Figure 5.2-26). There were no significant differences in mean age of female northern pike between sampling years. The length-age relationship for northern pike is shown in Figure 5.2-28. In contrast to 2003 and 2006 where there were no significant differences in length-at-age relationships between male and female northern pike, in 2009, female northern pike were longer at any given age relative to males ($p=0.01$).

There were no significant differences in the weight-length (i.e., condition) relationship between male and female northern pike captured in 2009 ($p=0.53$) (Figure 5.2-29).

5.2.5.6 External Pathology

External pathology was recorded for each fish measured during the operation of the Muskeg River fish fence (3,898 fish). Most fish showed no external abnormalities (96%) (Table 5.2-37). Most incidences of external abnormalities occurred in the form of fin erosion and skin aberrations with few cases of eye damage (n=2 for WHSC), gill damage (n=3 for WHSC, n=1 for NRPK), and operculum erosion (n=8 for WHSC).

5.2.5.7 Other Fish Species

Three other large-bodied species were captured during the operation of the 2009 Muskeg River fish fence (Table 5.2-38). As in previous years (2003 and 2006), only two Arctic grayling (*Thymallus arcticus*) were captured, both moving downstream (age=3 years) as well as two lake whitefish (*Coregonus clupeaformis*) (one moving upstream, one moving downstream) and two walleye (*Sander vitreus*) (both moving upstream age=7 and 10 years).

5.2.5.8 Synthesis of Results of Muskeg River Fish Fences from RAMP and Other Studies

Fish fences have been installed in the Muskeg River watershed in various years from 1976 to 2009 (Bond and Machniak 1977, 1979, Golder 1996, O'neil 1982 cited in AXYS 2005, as well as in 2003, 2006, and 2009 under RAMP). Comparisons between results from the first (1976 and 1977) fish fence studies and fish fence studies conducted in more recent years suggest that the use of the Muskeg River during spring spawning by Arctic grayling, longnose sucker, northern pike, and mountain whitefish has declined over time (Table 5.2-39). In addition, the results of fish fence studies on Jackpine Creek in 1981 and 1984 indicate that migration during spring spawning by Arctic grayling, northern pike and longnose sucker in Jackpine Creek was lower in 2004 compared to 1981 in Jackpine Creek (O'neil 1982 cited in AXYS 2005). The decline in these species over time was evident in prior to 1996 when oil sands development first started in the Muskeg River watershed, indicating that the decline is not necessarily due to influence by focal projects.

The use of the Muskeg River during spring spawning by white sucker has increased over time, with the 2009 fish fence counts of white sucker comparable to counts from the 1976 and 1977 fish fences (Table 5.2-39). Observations from the 2009 fish fence indicated that white sucker spawned immediately upstream of the location of the fish fence itself indicating that this species may not migrate long distances up the Muskeg River for spawning or may be too tired/stressed from handling at the fish fence to migrate long distances. A supporting study from Walton (1980) also showed that the majority of white sucker spawning in Willow Creek in Alberta was found to occur within 3 km of a fish fence located on the creek only 600 m from its confluence with the Chain Lakes Reservoir. No fish tagged at this fish fence were captured at a second fish fence 15 km further upstream, and the counts of white sucker at the upper fish fence were 95% lower than at the lower fish fence, despite suitable habitat for white sucker at locations of both fences (Walton 1980). Short migration distances for white sucker in the Muskeg River are likely a result of habitat suitability. The lower portion of the Muskeg River is erosional and provides coarser substrate suitable for spawning compared to the upper portion of the Muskeg River which is depositional with fine sediments.

It is difficult to determine the cause of declines of some large-bodied fish species using the Muskeg River watershed for spawning and the increase by other fish species based on the available data from fish fence operations in the Muskeg River watershed.

Spawning runs have only been documented in years of relatively low spring freshets when fish fences could be safely installed; there is little migration information in years with high flows or over a period of consecutive years. Although flows during fish fence operations in 2009 were comparable to flows during fish fence operations in 2003 and 2006 (RAMP 2004, RAMP 2007), the effects of flow conditions on spawning runs in years when no fence was or could be installed are unknown. Hydrologic conditions may influence many aspects of stream ecology, including abundance of benthic invertebrates (Poff *et al.* 1997), growth and dispersion of fish (Danehy *et al.* 1998), and habitat quality, which in turn may influence the use of a watercourse by large-bodied fish species for spawning. Food availability is a factor in regulating spawning in several fish species (Rideout *et al.* 2005), including white sucker (Trippel and Harvey 1989). A larger dataset of fish fence operations across consecutive years under varying hydrologic conditions would be required to determine factors influencing the decline in abundance of some fish species during spring migration in the Muskeg River.

5.2.5.9 Summary

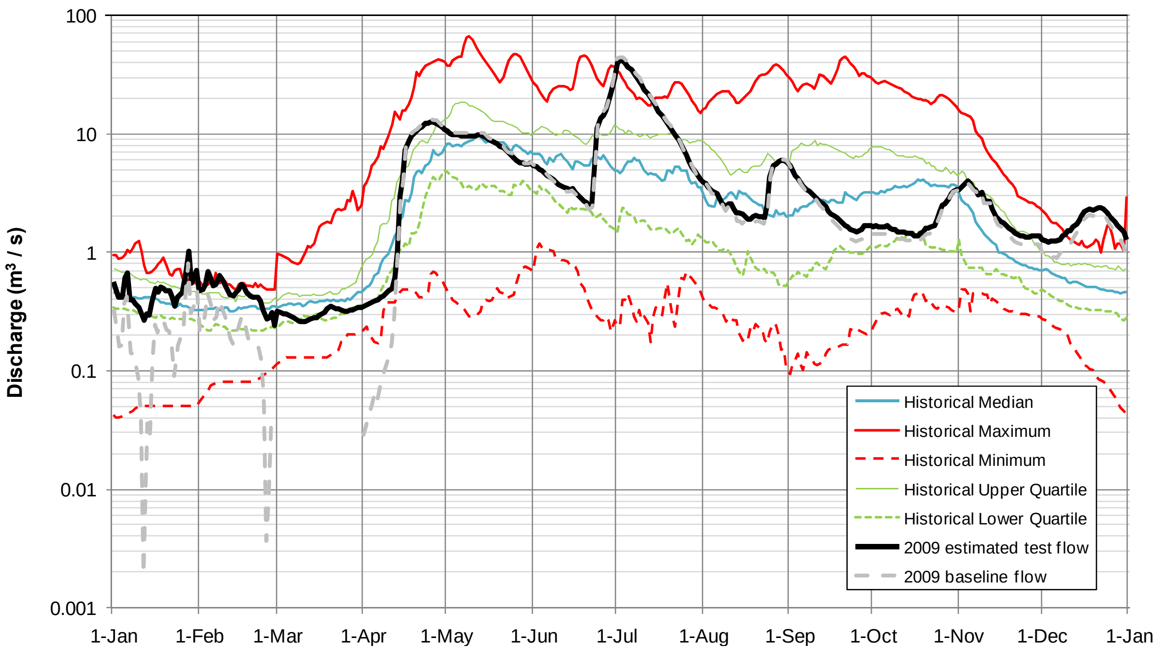
The 2009 fish fence in the Muskeg River represents the third and final year of fence operation undertaken by RAMP. In every year beginning in 2003, an attempt was made to install a fish fence in the Muskeg River. However, discharge rates above the safety threshold of 9 m^3/s prevented fish fence operations in 2004, 2005, 2007, and 2008. The frequency with which fish fences were installed in the Muskeg River is an important factor to consider when analysing the fish fence data and the differences between years. The use of the Muskeg River for spawning has only been measured in years when the spring freshet was below 10 m^3/s, resulting in three years of data for low-freshet spring seasons and no information on spawning runs in extreme flow conditions. However, despite the consistency in flows across the three years of fish fence operations, the magnitude of the runs of white sucker, longnose sucker and northern pike were variable. As mentioned above, this study was designed to compare results between the three years of fish fence operation rather than an assessment of changes related to oil sands developments.

The 2009 Muskeg River fish fence results were compared to results of the 2003 and 2006 Muskeg River fish fences. Key findings include:

- Although the Muskeg River continues to be utilized by populations of a number of species, dominated by white sucker, longnose sucker, and northern pike, significantly higher numbers of white sucker and much lower numbers of all other species were observed in 2009 compared to the previous two sampling years;
- The timing of migration for sucker species in 2009 was different from 2003 and 2006 given the runs were not dictated by an initial temperature threshold of about 10°C;
- Mean age of the dominant species between years was significantly different with younger fish being captured in 2009 compared to 2003 and 2006, with narrower age ranges of fish captured in 2009; and
- The weight-length relationship in dominant species was generally consistent between sampling years but sex-specific differences were observed between male and female white sucker in all three years (i.e., females were heavier than males).

Based on the intermittent operation of fish fence programs on the Muskeg River, any changes related to oil sands development remains undetectable from the natural variability in spawning runs of large-bodied fish species.

Figure 5.2-3 The observed (*test*) hydrograph for the Muskeg River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Based on provisional 2009 data from WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay. The upstream drainage area is 1,457 km^2. Historical values from March 1 to October 31 calculated from data collected from 1974 to 2008, and values for other months calculated from data collected from 1974 to 1986 and 1999 to 2008.

Note: *Baseline* flow values were computed to be less than zero between February 28 and March 31, when the net flows released by focal projects were estimated to be greater than the observed flows at WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay. In accordance with previous reports (e.g., RAMP 2009a), these negative *baseline* flow values were set to zero, but do not appear on the graph due to the logarithmic scale used.

Table 5.2-2 Estimated water balance at WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**141.33**	**Observed discharge at WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay**
Closed-circuited area water loss from the observed *test* hydrograph	-11.09	Estimated 114.5 km^2 of the Muskeg River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.92	Estimated 47.6 km^2 of the Muskeg River watershed with land change from focal projects as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the Muskeg River watershed from focal projects	-0.13	0.13 million m^3 withdrawn by Imperial from Kearl Lake and other ponds.
Water releases into the Muskeg River watershed from focal projects	10.72	Aurora Clean Water Diversion discharges to Stanley Creek (annual total provided by Syncrude), and other releases by Hammerstone, Husky and Shell Albian Sands.
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Muskeg River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**141.12**	**Estimated *baseline* discharge at RAMP Station S7 (WSC Station 07DA008), Muskeg River near Fort McKay**
Incremental flow (change in total discharge)	+0.21	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+0.15%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on provisional 2009 data from WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay.

Note: *Baseline* values shown in the table are likely underestimated, because they are based on the assumption that none of the releases from the Aurora Clean Water Diversion would have reached the Muskeg River naturally.

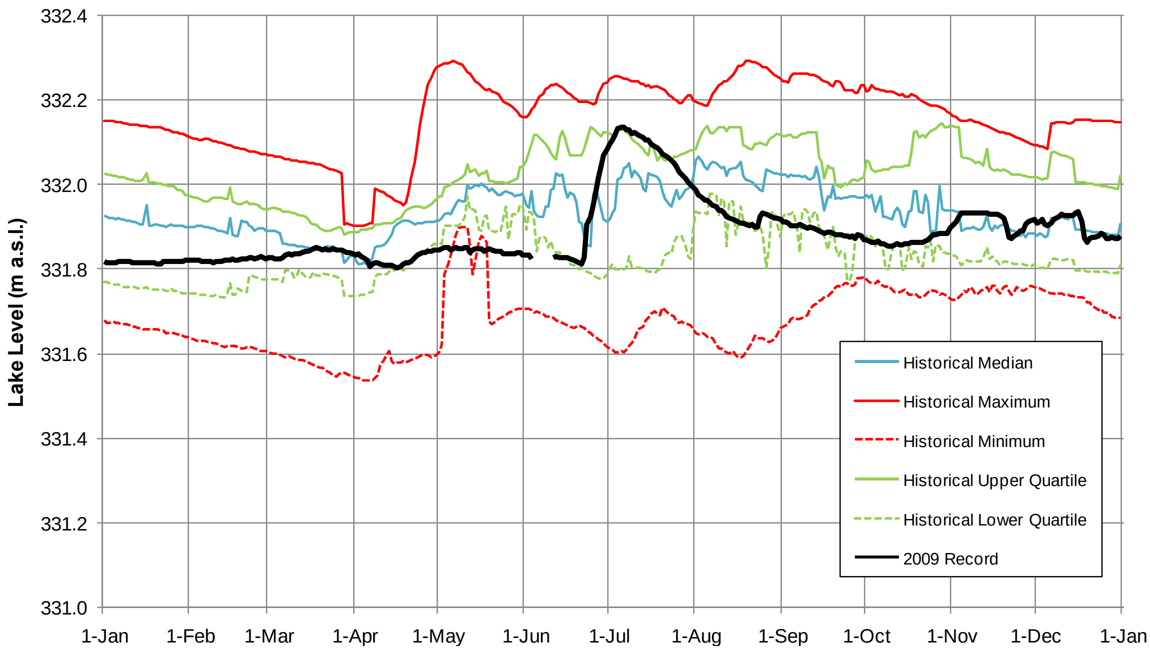
Table 5.2-3 Calculated changes in hydrologic measurement endpoints for the Muskeg River watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	7.24	7.05	-2.5%
Mean winter discharge	0.80	1.06	31.6%
Annual maximum daily discharge	44.56	41.70	-6.4%
Open-water season minimum daily discharge	1.16	1.36	17.3%

Note: Based on provisional 2009 data from WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay.

Note: *Baseline* values shown in the table are likely underestimated, because they are based on the assumption that none of the releases from the Aurora Clean Water Diversion would have reached the Muskeg River naturally.

Figure 5.2-4 Observed lake levels for Kearl Lake in 2009, compared to historical values.



Note: Observed 2009 lake levels based on 2009 provisional data for RAMP Station L2, Kearl Lake. Historical values calculated from 1999 to 2008, with periods of missing data present in most years.

Table 5.2-4 Concentrations of selected water quality measurement endpoints, mouth of Muskeg River (station MUR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.24	12	7.4	8.205	8.4
Total suspended solids	mg/L	-[1]	3	12	<3	3	70
Conductivity	µS/cm	-	323	12	220	331	671
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0128	12	0.004	0.014	0.03
Total nitrogen*	mg/L	1.0	**1.621**	12	0.4	0.9	**1.2**
Nitrate+nitrite	mg/L	1.0	0.071	12	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	25.6	12	15	21	29
Ions							
Sodium	mg/L	-	13.1	12	8	12.5	64
Calcium	mg/L	-	44.5	12	28.8	47.25	108
Magnesium	mg/L	-	12.3	12	7.1	11.8	18.9
Chloride	mg/L	230, 860[3]	2.38	12	1	3	36
Sulphate	mg/L	100[4]	6.1	12	0.6	5.3	91
Total dissolved solids	mg/L	-	236	12	170	280	405
Total alkalinity	mg/L		166	12	105	177	313
Organic compounds							
Naphthenic acids	mg/L	-	0.189	12	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0329	12	0.026	0.072	**1.2**
Dissolved aluminum	mg/L	0.1[2]	0.0033	12	0.0019	0.0067	0.030
Total arsenic	mg/L	0.005	0.0004	12	0.000251	0.0004	0.001
Total boron	mg/L	1.2[5]	0.048	12	0.032	0.043	0.15
Total molybdenum	mg/L	0.073	0.0001	12	<0.0001	0.0001	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.121	12	0.086	0.125	0.296
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0096**	12	<0.002	**0.004**	**0.022**
Dissolved iron	mg/L	0.3[2]	**0.398**	12	0.14	**0.34**	**1.02**
Total iron	mg/L	0.3	**0.66**	12	0.287	**0.625**	**1.81**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-5 Concentrations of selected water quality measurement endpoints, Muskeg River upstream of Wapasu Creek (station MUR-6), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.29	11	7.2	8.1	8.4
Total suspended solids	mg/L	-[1]	3	11	<3	3	25
Conductivity	µS/cm	-	303	11	233	320	441
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0141	11	0.011	0.014	0.029
Total nitrogen*	mg/L	1.0	**1.921**	11	0.3	0.80	**1.65**
Nitrate+nitrite	mg/L	1.0	0.071	11	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	31.9	11	13	18	24
Ions							
Sodium	mg/L	-	4.6	11	3	3	7
Calcium	mg/L	-	42.8	11	31.3	45.1	67.4
Magnesium	mg/L	-	14.4	11	11.6	15.9	21.4
Chloride	mg/L	230, 860[3]	0.5	11	<1	1	3
Sulphate	mg/L	100[4]	2.22	11	1.5	4.4	6.3
Total dissolved solids	mg/L	-	225	11	180	240	320
Total alkalinity	mg/L		166	11	120	184	235
Organic compounds							
Naphthenic acids	mg/L	-	0.05	11	<1	<1	12
Selected metals							
Total aluminum	mg/L	0.1	0.0118	11	0.0091	0.0203	**0.11**
Dissolved aluminum	mg/L	0.1[2]	0.0048	11	0.00168	0.0055	0.01
Total arsenic	mg/L	0.005	0.0005	11	0.000264	0.00036	<0.001
Total boron	mg/L	1.2[5]	0.0159	11	0.006	0.0112	0.01573
Total molybdenum	mg/L	0.073	0.0001	11	0.000069	0.0001	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0884	11	0.058	0.084	0.164
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total Kjeldahl Nitrogen	mg/L	1.0	**1.85**	11	0.2	0.7	**1.6**
Sulphide	mg/L	0.002[7]	**0.0046**	11	<0.002	**0.007**	**0.014**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-6 Concentrations of selected water quality measurement endpoints, Jackpine Creek (station JAC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.19	10	7.8	8.05	8.3
Total suspended solids	mg/L	-[1]	3	10	<3	3	8
Conductivity	µS/cm	-	237	10	183	239.5	413
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0205	10	0.006	0.014	0.026
Total nitrogen*	mg/L	1.0	**1.621**	10	0.7	0.900	**1.5**
Nitrate+nitrite	mg/L	1.0	0.071	10	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	28.9	10	18.6	22.5	30
Ions							
Sodium	mg/L	-	12.9	10	10	12	18
Calcium	mg/L	-	31.2	10	22.2	29.1	56.6
Magnesium	mg/L	-	8.47	10	6.6	8.0	14.2
Chloride	mg/L	230, 860[3]	0.89	10	1	2	6
Sulphate	mg/L	100[4]	0.53	10	0.5	2.8	4.3
Total dissolved solids	mg/L	-	206	10	110	200.5	234
Total alkalinity	mg/L		124	10	93	120	227
Organic compounds							
Naphthenic acids	mg/L	-	0.099	10	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0307	10	0.0179	0.068	**0.12**
Dissolved aluminum	mg/L	0.1[2]	0.0071	10	0.0033	0.00935	**0.17**
Total arsenic	mg/L	0.005	0.0006	10	0.0003	0.00052	0.0006
Total boron	mg/L	1.2[5]	0.0485	10	0.033	0.0422	0.066
Total molybdenum	mg/L	0.073	0.0001	10	0.0001	0.0001	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.5	10	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.119	10	0.085	0.105	0.171
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total Kjeldahl Nitrogen	mg/L	1.0	**1.55**	10	0.6	0.8	**1.4**
Sulphide	mg/L	0.002[7]	**0.0079**	10	**0.006**	**0.009**	**0.103**
Dissolved iron	mg/L	0.3[2]	**0.635**	10	0.19	**0.3285**	**0.699**
Total iron	mg/L	0.3	**0.793**	10	**0.38**	**0.569**	**1.57**
Total phenols	mg/L	0.004	**0.006**	10	<0.001	**0.0065**	**0.019**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-7 Concentrations of selected water quality measurement endpoints, upper Jackpine Creek (station JAC-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009 Value	September 2008 Value
Physical variables				
pH	pH units	6.5-9.0	7.98	8.0
Total suspended solids	mg/L	-[1]	3	6
Conductivity	µS/cm	-	216	213
Nutrients				
Total dissolved phosphorus	mg/L	0.05[2]	0.0143	0.017
Total nitrogen*	mg/L	1.0	**1.061**	0.9
Nitrate+nitrite	mg/L	1.0	0.071	<0.1
Dissolved organic carbon	mg/L	-	22.6	25
Ions				
Sodium	mg/L	-	11	10
Calcium	mg/L	-	30.5	26.9
Magnesium	mg/L	-	8.62	8.6
Chloride	mg/L	230, 860[3]	0.5	1
Sulphate	mg/L	100[4]	0.67	2
Total dissolved solids	mg/L	-	173	150
Total alkalinity	mg/L		113	110
Organic compounds				
Naphthenic acids	mg/L	-	0.100	<1
Selected metals				
Total aluminum	mg/L	0.1	**0.142**	0.202
Dissolved aluminum	mg/L	0.1[2]	0.00876	0.0104
Total arsenic	mg/L	0.005	0.0007	0.000676
Total boron	mg/L	1.2[5]	0.0453	**0.0571**
Total molybdenum	mg/L	0.073	0.0001	0.000111
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	<1.2
Total strontium	mg/L	-	0.121	0.104
Other variables that exceeded CCME/AENV guidelines in fall 2009				
Sulphide	mg/L	0.002[7]	**0.0081**	**0.007**
Dissolved iron	mg/L	0.3[2]	**0.448**	**0.411**
Total iron	mg/L	0.3	**0.689**	**0.698**
Total phenols	mg/L	0.004	**0.0058**	**0.012**

JAC-2 only sampled in 2008 and 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-8 Concentrations of selected water quality measurement endpoints, Stanley Creek (station STC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.12	8	7.6	8.0	8.2
Total suspended solids	mg/L	-[1]	5	8	<3	<3	6
Conductivity	µS/cm	-	392	8	271	408	760
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0332	9	0.01	0.02	0.03
Total nitrogen*	mg/L	1.0	0.501	9	0.3	0.4	**2.1**
Nitrate+nitrite	mg/L	1.0	0.071	9	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	12.2	8	6	8	10
Ions							
Sodium	mg/L	-	3.3	8	2	4	26
Calcium	mg/L	-	62.5	8	45.4	64.6	112
Magnesium	mg/L	-	12.5	8	11.1	14.1	20.5
Chloride	mg/L	230, 860[3]	0.5	8	<1	2	14
Sulphate	mg/L	100[4]	0.5	8	1.1	18.1	**126**
Total dissolved solids	mg/L	-	271	8	200	254	480
Total alkalinity	mg/L		216	8	157	206	260
Organic compounds							
Naphthenic acids	mg/L	-	0.1	9	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0067	9	<0.002	0.007	0.02
Dissolved aluminum	mg/L	0.1[2]	<0.001	9	<0.001	0.001	0.02
Total arsenic	mg/L	0.005	0.0001	9	0.0001	0.00015	<0.001
Total boron	mg/L	1.2[5]	0.0253	9	0.018	0.024	0.087
Total molybdenum	mg/L	0.073	0.00002	9	0.000008	0.000077	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.142	9	0.075	0.139	0.248
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total phosphorus	mg/L	0.05	**0.0545**	9	0.016	0.027	**0.08**
Total iron	mg/L	0.3	**0.41**	9	0.004	0.17	**1.54**
Sulphide	mg/L	0.002[7]	**0.0049**	9	**<0.003**	**0.004**	**0.013**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-9 Concentrations of selected water quality measurement endpoints, Shelley Creek (station SHC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1999-2006 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	3	7.16	7.9	7.9
Total suspended solids	mg/L	-[1]	33	3	3	5	39
Conductivity	µS/cm	-	738	3	419	495	1172
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0063	3	0.006	0.020	0.036
Total nitrogen*	mg/L	1.0	0.851	3	0.8	**1.2**	**3.9**
Nitrate+nitrite	mg/L	1.0	0.071	3	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	20.2	3	25	26	28.6
Ions							
Sodium	mg/L	-	33.9	3	27	32	96.2
Calcium	mg/L	-	96.5	3	44.9	59.1	83.5
Magnesium	mg/L	-	24	3	13.8	14.3	15.8
Chloride	mg/L	230, 860[3]	5.65	3	3	15	80.2
Sulphate	mg/L	100[4]	**118**	3	<0.5	10	10
Total dissolved solids	mg/L	-	504	3	276	340	500
Total alkalinity	mg/L		290	3	199	242	354
Organic compounds							
Naphthenic acids	mg/L	-	0.612	3	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0573	3	0.0095	0.060	0.088
Dissolved aluminum	mg/L	0.1[2]	<0.001	3	<0.001	0.0012	0.00315
Total arsenic	mg/L	0.005	0.0005	3	0.00039	0.0009	<0.001
Total boron	mg/L	1.2[5]	0.134	3	0.0776	0.0833	0.169
Total molybdenum	mg/L	0.073	0.000263	3	0.0001	0.00016	0.00016
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	3	<1.2	<1.2	1.2
Total strontium	mg/L	-	0.405	3	0.154	0.207	0.435
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[1]	**0.0682**	3	0.012	0.013	**0.053**
Total iron	mg/L	0.3	**0.973**	3	0.237	**2.5**	**5.3**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

Table 5.2-10 Concentrations of selected water quality measurement endpoints, Wapasu Creek (station WAC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.09	6	7.7	8.0	8.2
Total suspended solids	mg/L	-[1]	3	6	<3	<3	3
Conductivity	µS/cm	-	225	6	209	266	339
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0145	6	0.009	0.013	0.022
Total nitrogen*	mg/L	1.0	**1.841**	6	0.8	1.0	**1.1**
Nitrate+nitrite	mg/L	1.0	0.071	6	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	33.2	6	11	17.5	26
Ions							
Sodium	mg/L	-	7.8	6	6	6.5	9
Calcium	mg/L	-	30.4	6	29.1	38.6	53.8
Magnesium	mg/L	-	9.31	6	8.6	13.0	17.2
Chloride	mg/L	230, 860[3]	0.79	6	2	2	3
Sulphate	mg/L	100[4]	1.7	6	1.6	2.8	5.2
Total dissolved solids	mg/L	-	178	6	160	210	250
Total alkalinity	mg/L		118	6	103	146	197
Organic compounds							
Naphthenic acids	mg/L	-	0.059	6	<1	<1	<1
Selected metals							
Total aluminum	mg/L	0.1	0.074	6	0.014	0.015	0.02
Dissolved aluminum	mg/L	0.1[2]	0.0082	6	0.0037	0.0051	<0.01
Total arsenic	mg/L	0.005	0.0005	6	0.00025	0.0003	<.001
Total boron	mg/L	1.2[5]	0.0302	6	0.014	0.021	0.0316
Total molybdenum	mg/L	0.073	0.00005	6	0.000033	0.000043	<0.0001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	5	<1.2	<1.2	3.3
Total strontium	mg/L	-	0.0811	6	0.067	0.089	0.103
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0121**	6	**<0.003**	**0.0085**	**0.019**
Total Kjeldahl Nitrogen	mg/L	1.0	**1.77**	6	0.7	0.9	1
Total iron	mg/L	0.3	**0.45**	6	0.177	**0.348**	**0.6**
Total phenols	mg/L	0.004	**0.006**	6	0.002	**0.0085**	**0.016**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.2-11 Concentrations of selected water quality measurement endpoints, Kearl Lake (station KEL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.18	10	7.6	8.0	8.3
Total suspended solids	mg/L	-[1]	4	10	<3	5.5	19
Conductivity	µS/cm	-	174	10	133	175	183
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0062	10	0.002	0.008	0.013
Total nitrogen*	mg/L	1.0	**1.421**	10	0.45	**1.3**	**1.8**
Nitrate+nitrite	mg/L	1.0	0.071	10	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	9.8	10	15	21	24
Ions							
Sodium	mg/L	-	11.3	10	8	10	11
Calcium	mg/L	-	20	10	16.5	19.4	20.6
Magnesium	mg/L	-	6.52	10	5.7	6.85	7.6
Chloride	mg/L	230, 860[3]	0.5	10	<0.5	<1.0	3
Sulphate	mg/L	100[4]	2.35	10	2.7	4.75	5.7
Total dissolved solids	mg/L	-	152	10	94	155.5	220
Total alkalinity	mg/L		88.9	10	72	88	93
Organic compounds							
Naphthenic acids	mg/L	-	0.09	10	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0136	10	0.011	0.027	**0.13**
Dissolved aluminum	mg/L	0.1[2]	<0.001	10	<0.001	0.0025	0.03
Total arsenic	mg/L	0.005	0.0004	10	0.00029	0.00039	<0.001
Total boron	mg/L	1.2[5]	0.0463	10	0.012	0.047	0.0523
Total molybdenum	mg/L	0.073	0.0000	10	<0.0001	0.00011	0.0009
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.3	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0675	10	0.056	0.06495	0.215
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.005**	10	<0.002	**0.0055**	**0.01**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.4**	10	0.4	**1.2**	**1.7**
Total phenols	mg/L	0.004	**0.005**	10	<0.001	0.002	**0.012**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

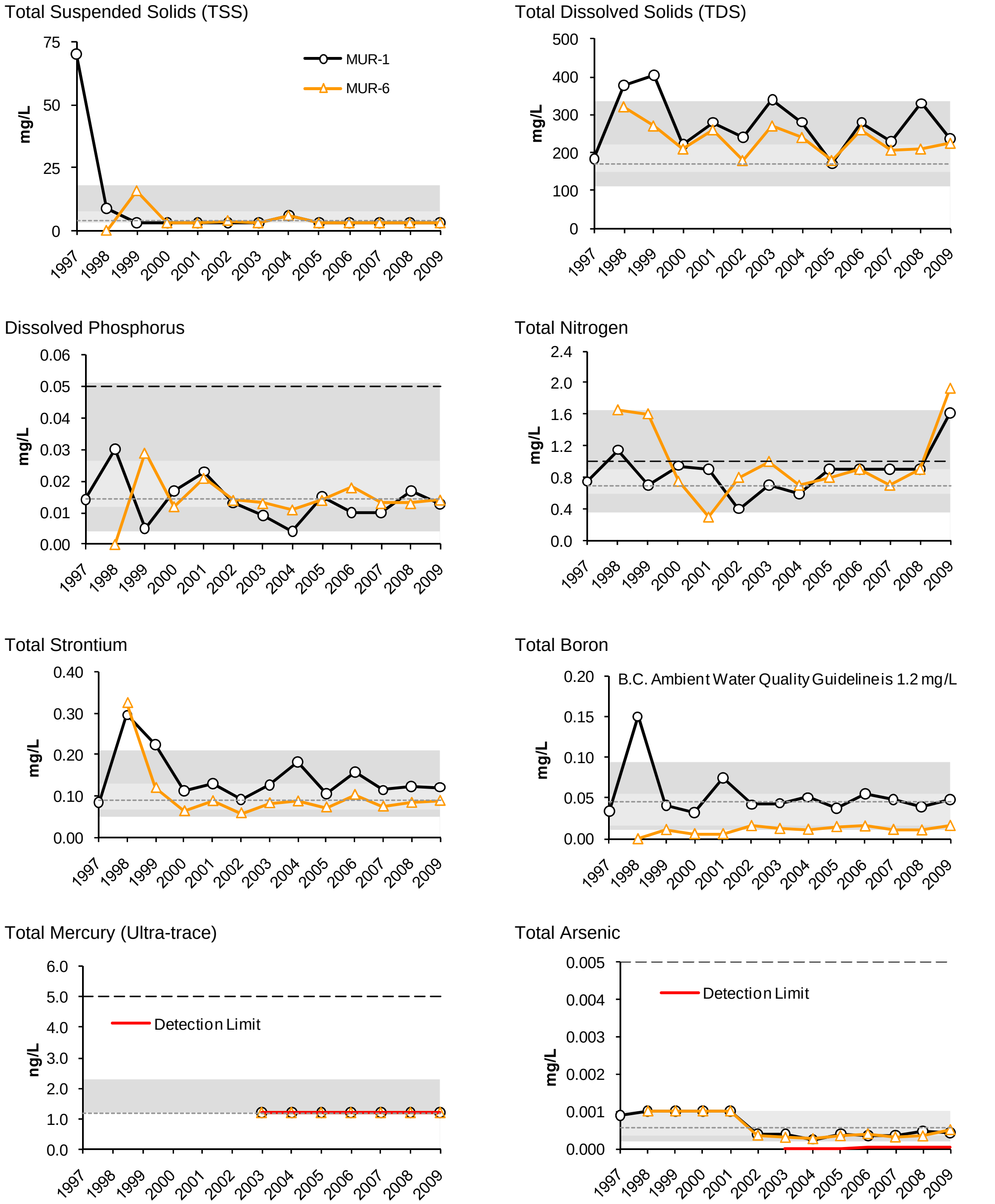
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Figure 5.2-5 Selected water quality measurement endpoints in the Muskeg River at the mouth (station MUR-1) and upstream of Wapasu Creek (station MUR-6) (fall 2009) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

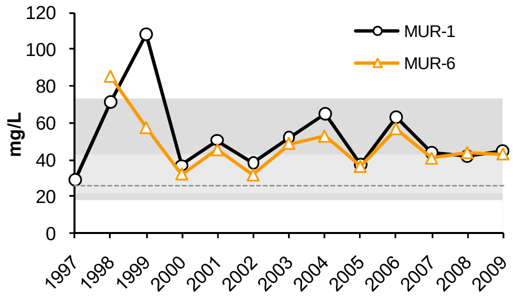
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

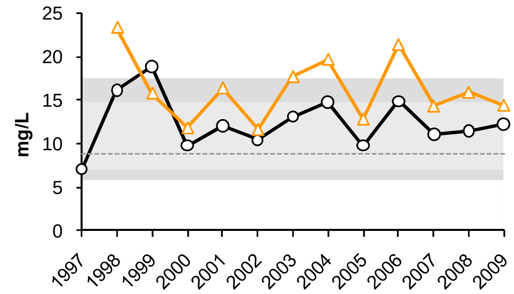
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-5 (Cont'd.)

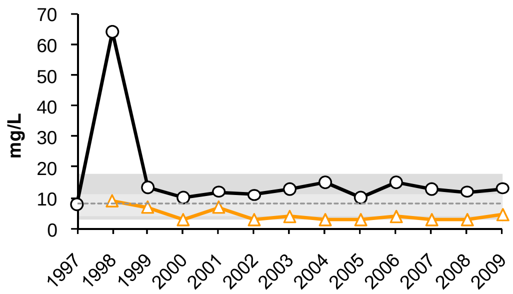
Calcium



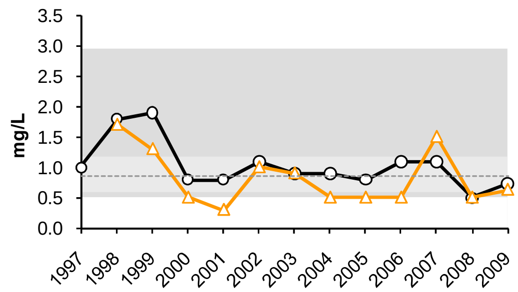
Magnesium



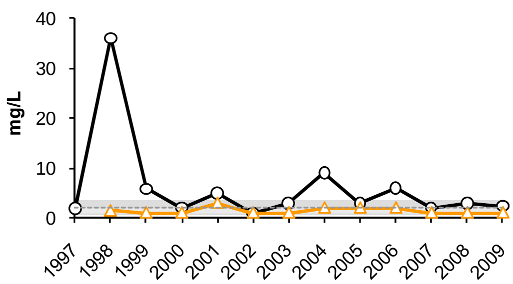
Sodium



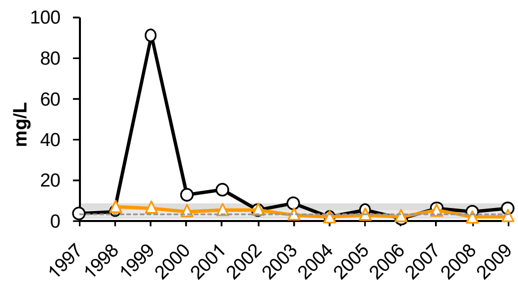
Potassium



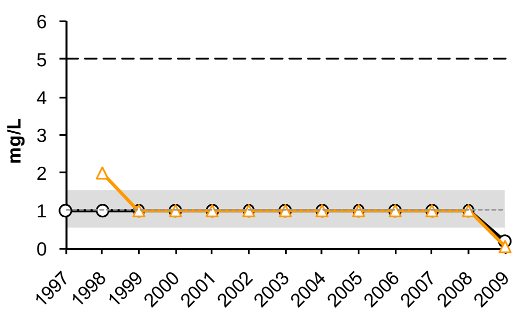
Chloride



Sulphate



Naphthenic Acids[1]



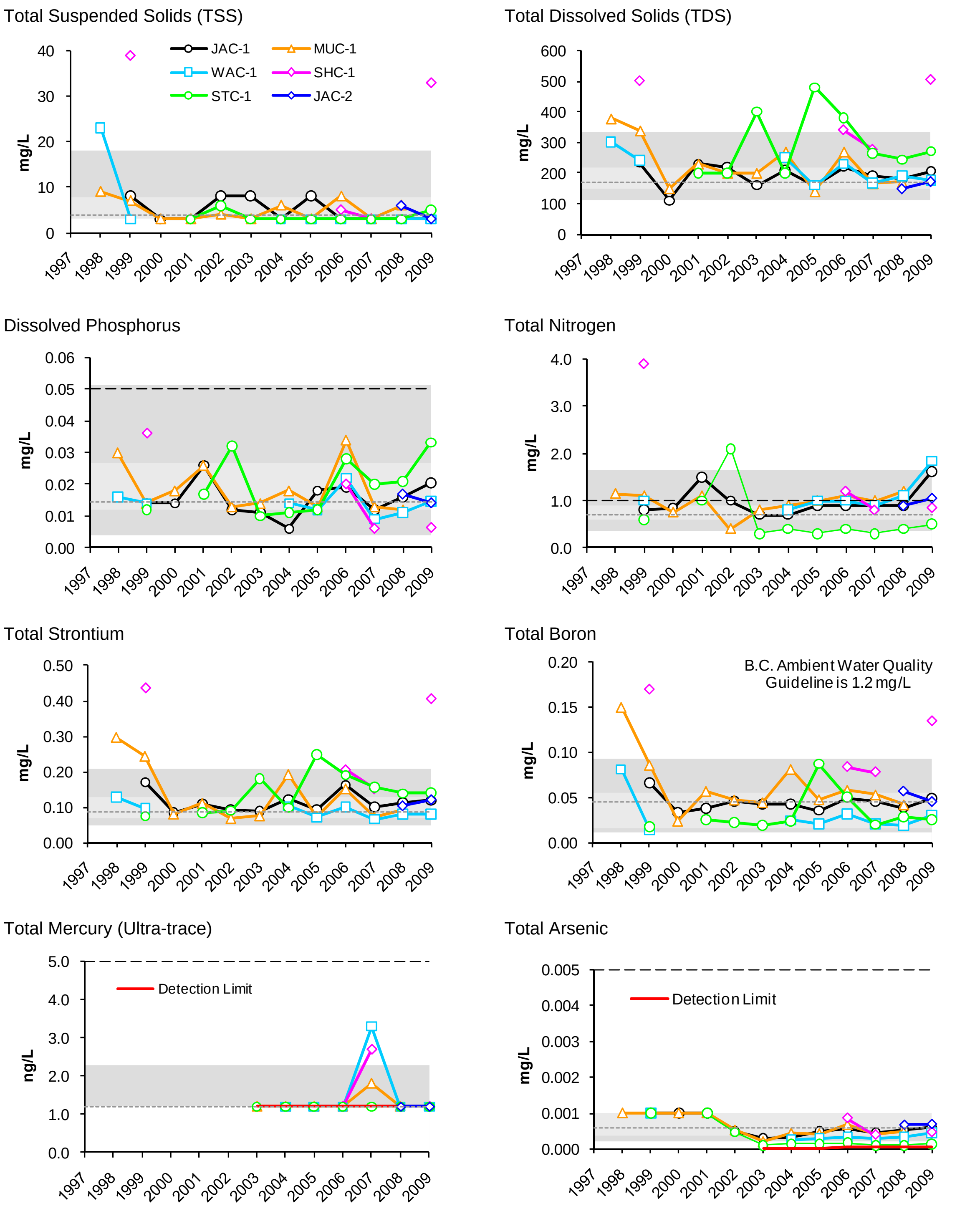
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-6 Selected water quality measurement endpoints in Muskeg River tributaries (fall 2009) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

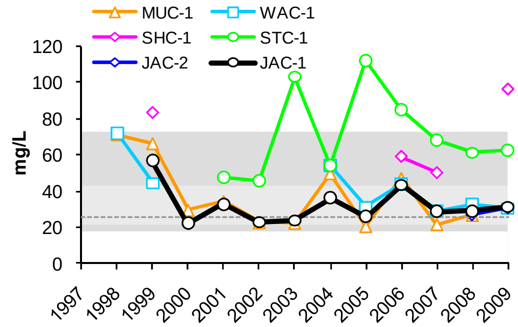
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

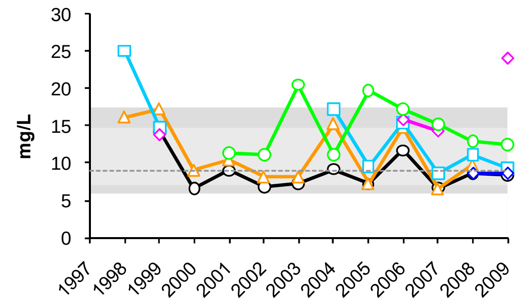
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-6 (Cont'd.)

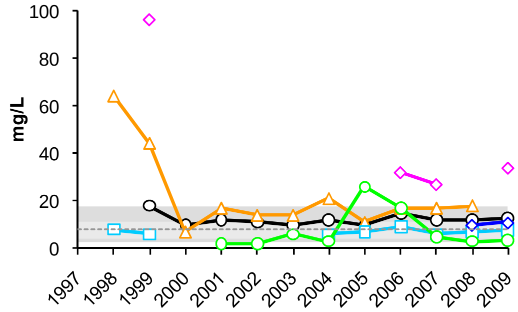
Calcium



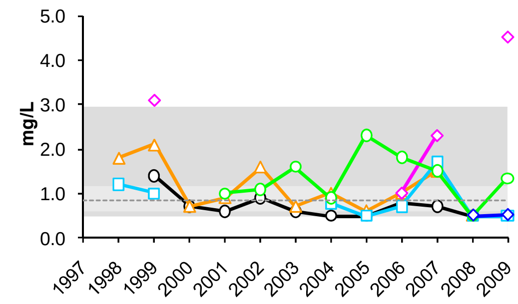
Magnesium



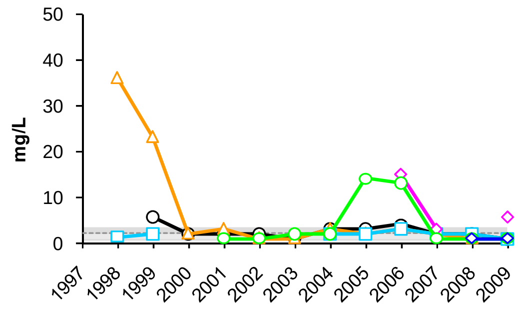
Sodium



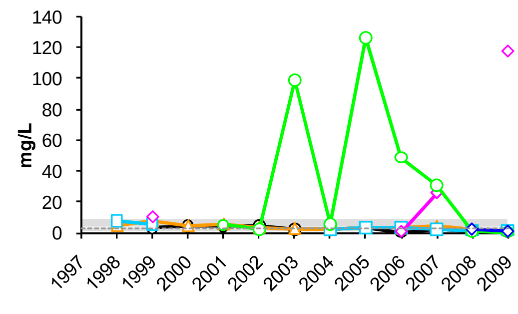
Potassium



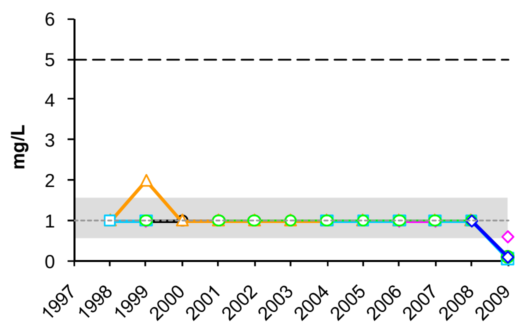
Chloride



Sulphate



Naphthenic Acids[1]



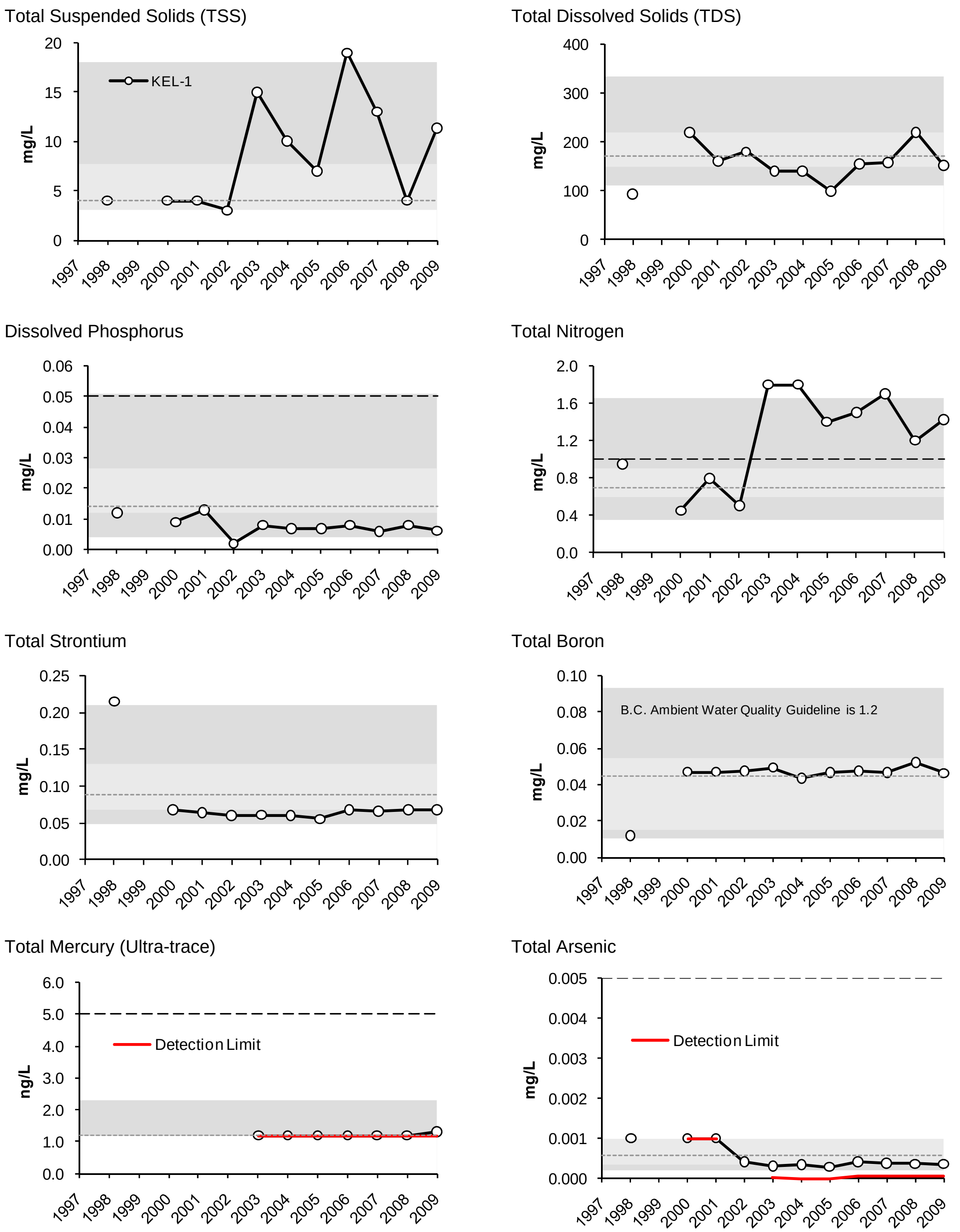
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-7 Selected water quality measurement endpoints in Kearl Lake (fall 2009) relative to regional *baseline* fall concentrations.



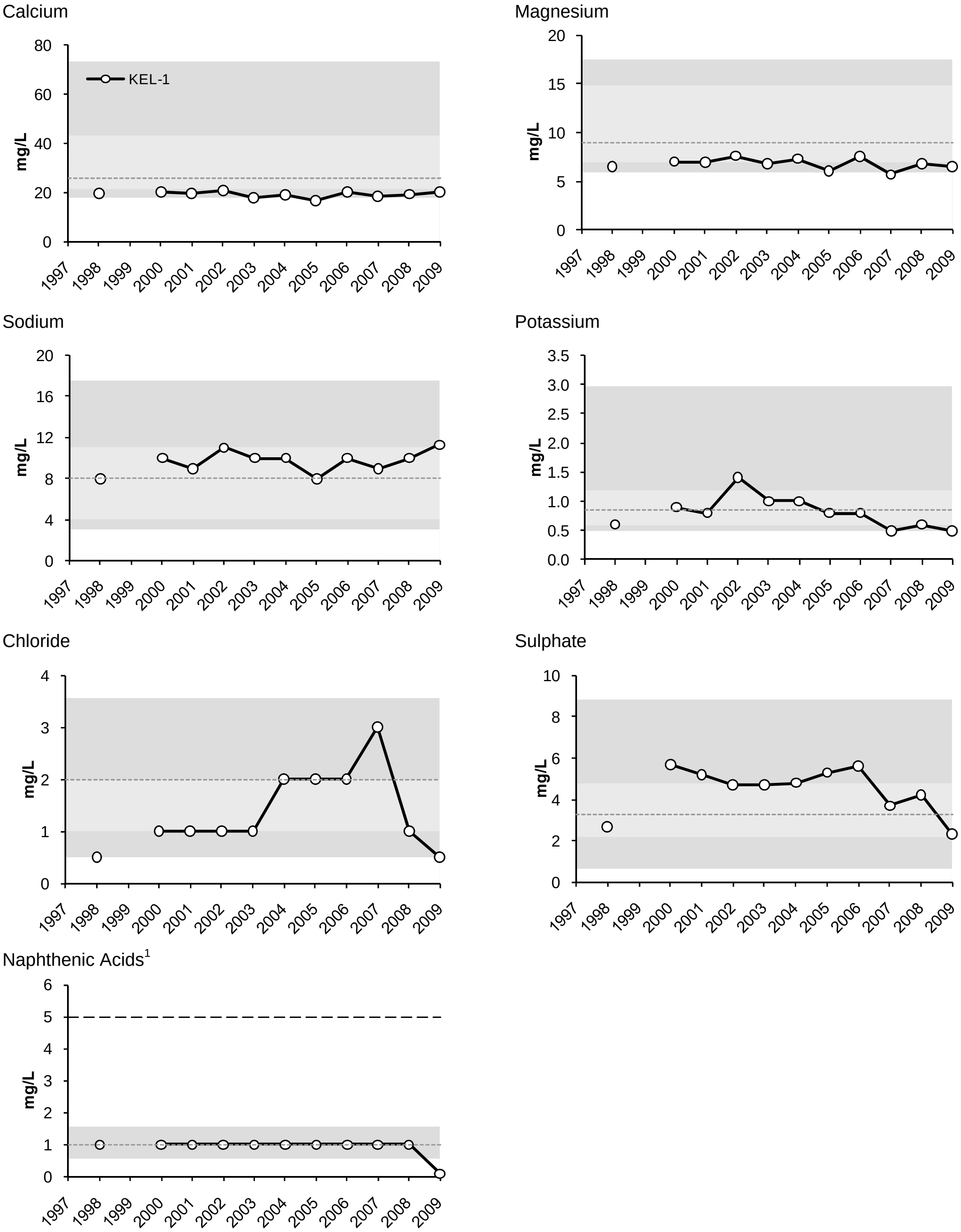
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-7 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.2-12 Water quality guideline exceedances, Muskeg River watershed, fall 2009.

Variable	Units	Guideline	JAC-1	JAC-2	MUR-1	MUR-6	STC-1	SHC-1	WAC-1	KEL-1
Sulphide	mg/L	0.002[1]	**0.0079**	**0.0081**	**0.0096**	**0.0046**	**0.0049**	**0.0682**	**0.0121**	**0.0047**
Sulphate	mg/L	50, 100 [2]	-	-	-	-	-	**118**	-	-
Total aluminum	mg/L	0.10	**-**	**0.142**	**-**	-	-	-	-	-
Dissolved iron	mg/L	0.3[3]	**0.635**	**0.448**	**0.398**	-	-	-	-	-
Total iron	mg/L	0.3	**0.793**	**0.689**	**0.66**	-	-	**0.973**	**0.45**	-
Total phenols	mg/L	0.004	**0.006**	**0.0058**	**-**	**-**	-	-	**0.006**	**0.0052**
Total Kjeldahl nitrogen	mg/L	1.0[4]	**-**	**-**	**-**	**-**	-	-	**-**	**1.35**
Total nitrogen	mg/L	1.0	**1.621**	**1.061**	**1.621**	**1.921**	-	-	**1.841**	**1.421**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[3] Guideline is for total metal (no guideline for dissolved species).

[4] Guideline is for total nitrogen (no guideline for TKN).

Figure 5.2-8 Piper diagram of fall ion concentrations in the Muskeg River, its tributaries, and Kearl Lake, 1997 to 2009.

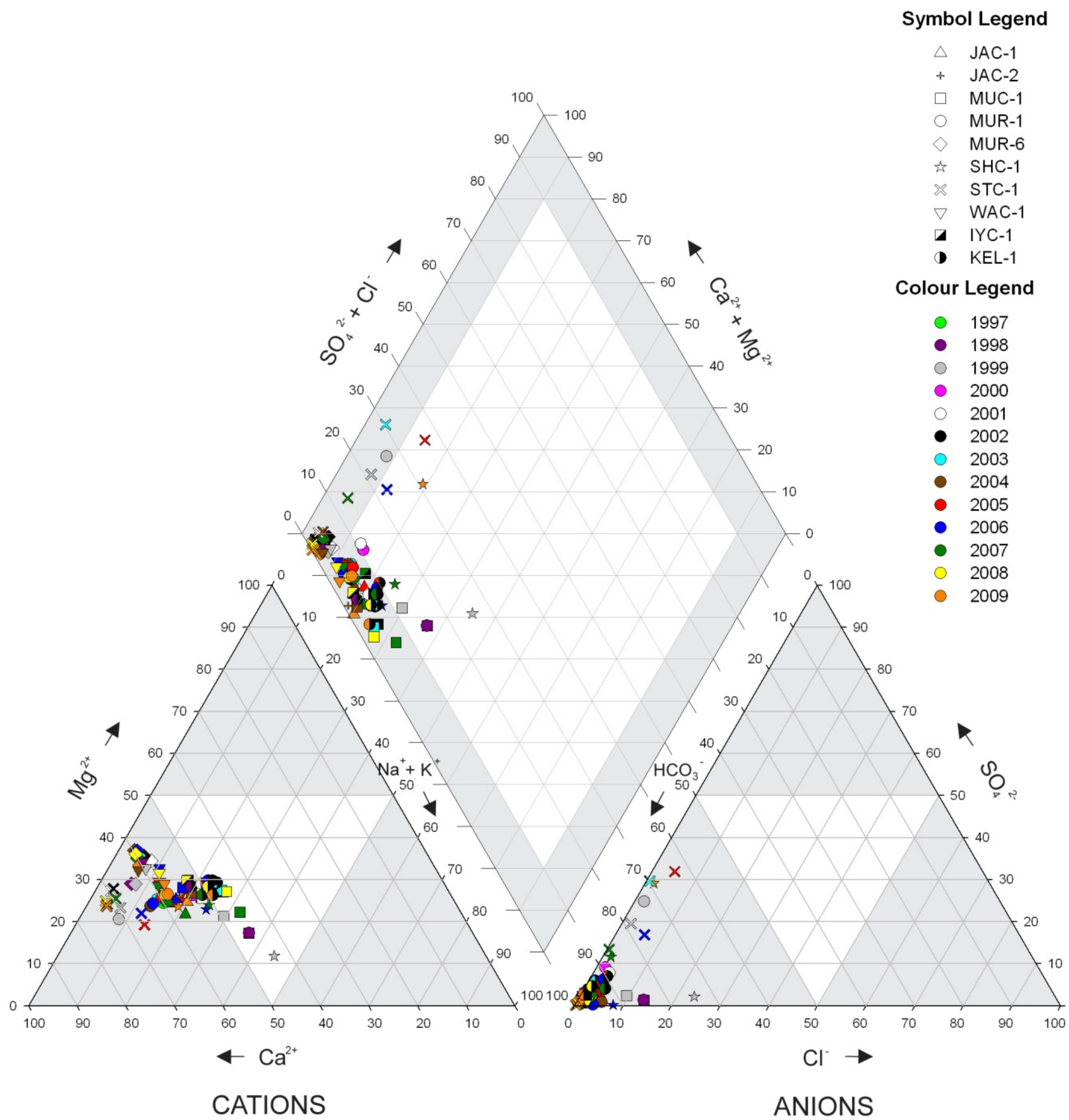


Table 5.2-13 Water quality index (fall 2009) for Muskeg River watershed stations.

Station Identifier	Location	2009 Designation	Water Quality Index	Classification
MUR-1	Lower Muskeg River	*test*	100.0	Negligible-Low
MUR-6	Upstream of Wapasu Creek	*test*	89.1	Negligible-Low
JAC-1	Near mouth of Jackpine Creek	*test*	89.1	Negligible-Low
JAC-2	Upper Jackpine Creek	*baseline*	100.0	Negligible-Low
SHC-1	Near mouth of Shelley Creek	*test*	38.4	High
STC-1	Near mouth of Stanley Creek	*test*	100.0	Negligible-Low
WAC-1	Near mouth of Wapasu Creek	*test*	89.0	Negligible-Low
KEL-1	Kearl Lake	*test*	100.0	Negligible-Low

Note: see Figure 5.2-1 for the locations of these water quality stations.
Note: see Section 3.2.7.4 for a description of the Water Quality Index.

Table 5.2-14 Average habitat characteristics of benthic invertebrate community in the lower sampling reach (MUR-E-1) of the Muskeg River, fall 2009.

Variable	Units	*Test* Reach MUR-E-1
Sample Date	-	Sept 10, 2009
Habitat	-	Erosional
Water Depth	m	0.4
Current Velocity	m/s	0.85
Macrophyte Cover	%	0
Field Water Quality		
Dissolved Oxygen	mg/L	10.4
Conductivity	µS/cm	362
pH	pH units	8.5
Water Temperature	°C	15.1
Sediment Composition		
Sand/Silt/Clay	%	4
Small Gravel	%	14
Large Gravel	%	30
Small Cobble	%	36
Large Cobble	%	15
Boulder	%	1
Bedrock	%	0

Figure 5.2-9 Periphyton chlorophyll *a* biomass in the lower *test* reach (MUR-E-1) of the Muskeg River.

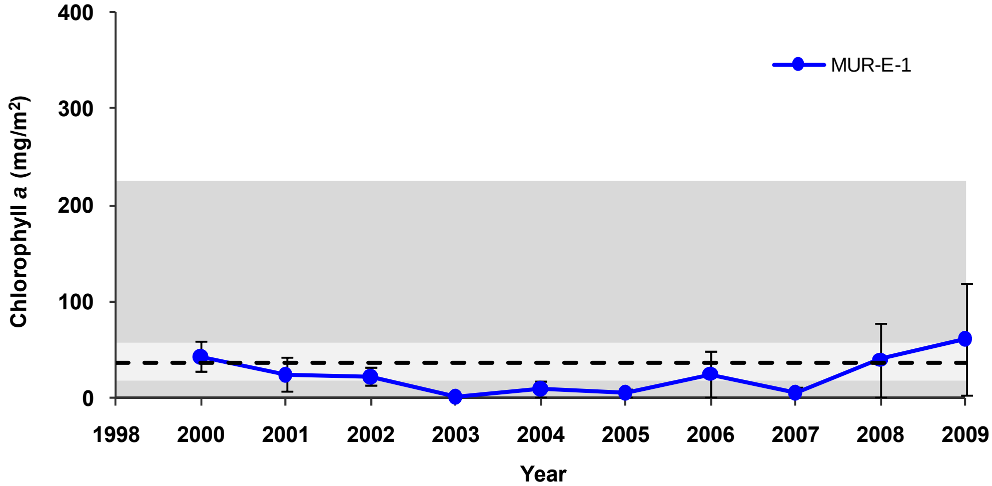
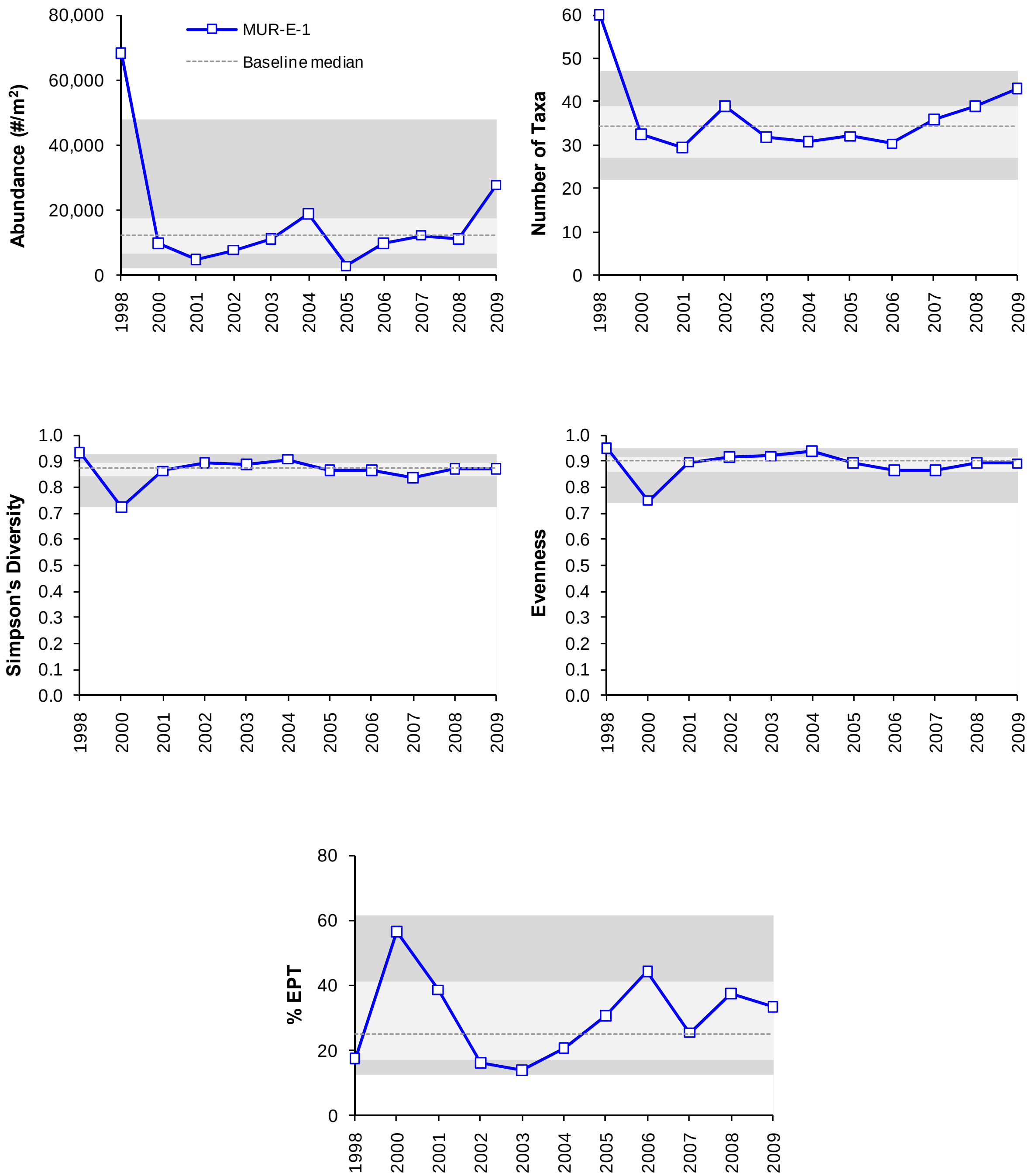


Table 5.2-15 Summary of major taxon abundances and benthic invertebrate community composition in the lower Muskeg River (MUR-E-1).

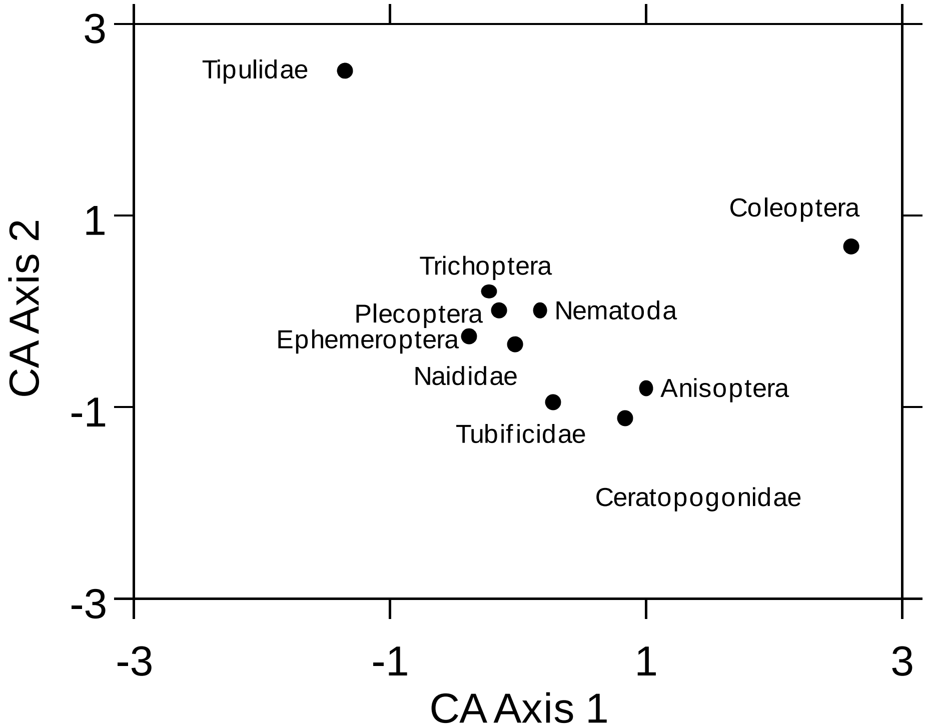
Taxon	Percent Major Taxa Enumerated in Each Year										
	Test Reach MUR-E-1										
	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Amphipoda		<1		<1	<1						
Anisoptera	<1	<1	2	1	1	2	<1	<1	1	2	<1
Bivalvia	6	1	3	5	1	3	2		5	4	1
Ceratopogonidae	1	<1	<1	1		<1	<1	1	2	<1	<1
Chironomidae	32	31	23	37	58	37	20	31	25	15	52
Coleoptera	5	1	2	1	3	10	5	3	2	1	1
Copepoda	<1	<1	<1	2	<1	<1	1		<1	<1	2
Empididae	4	<1	2	2	3	6	22	1	<1	<1	1
Enchytraeidae	<1	<1	1	<1	<1	1	1	<1		1	<1
Ephemeroptera	12	50	28	5	5	9	21	24	20	25	29
Erpobdellidae				<1							
Gastropoda	3	<1	<1	<1	<1				7	2	
Glossiphoniidae				<1							
Hydra		<1	<1	<1							
Hydracarina	14	6	15	13	13		10	11	17	8	3
Lumbriculidae				<1	<1	<1				<1	
Naididae	5	1	6	14	3	3	1	4	3	30	3
Nematoda	2	<1	4	2	3	5	2	1	1	<1	1
Ostracoda	3	1	<1	3	<1			<1	2	1	<1
Plecoptera	4	6	5	5	3	8	8	5	3	2	2
Simuliidae	<1							<1	<1		
Tabanidae	0	<1	<1			<1					
Tipulidae	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1
Trichoptera	2	1	8	5	4	4	2	16	3	2	4
Tubificidae	5	<1	<1	1	1	13	5		7	7	<1
Benthic Invertebrate Community Measurement Endpoints											
Total Abundance (No./m^2)	68,374	9,983	4,953	7,754	11,343	18,757	2,849	11,131	12,296	11,223	27,783
Richness	60	32	29	39	32	31	32	30	36	39	43
Simpson's Diversity	0.93	0.72	0.86	0.89	0.89	0.91	0.87	0.86	0.84	0.87	0.87
Evenness	0.95	0.75	0.89	0.92	0.92	0.94	0.89	0.86	0.86	0.89	0.89
% EPT	18	57	39	16	14	21	31	44	25	30	34

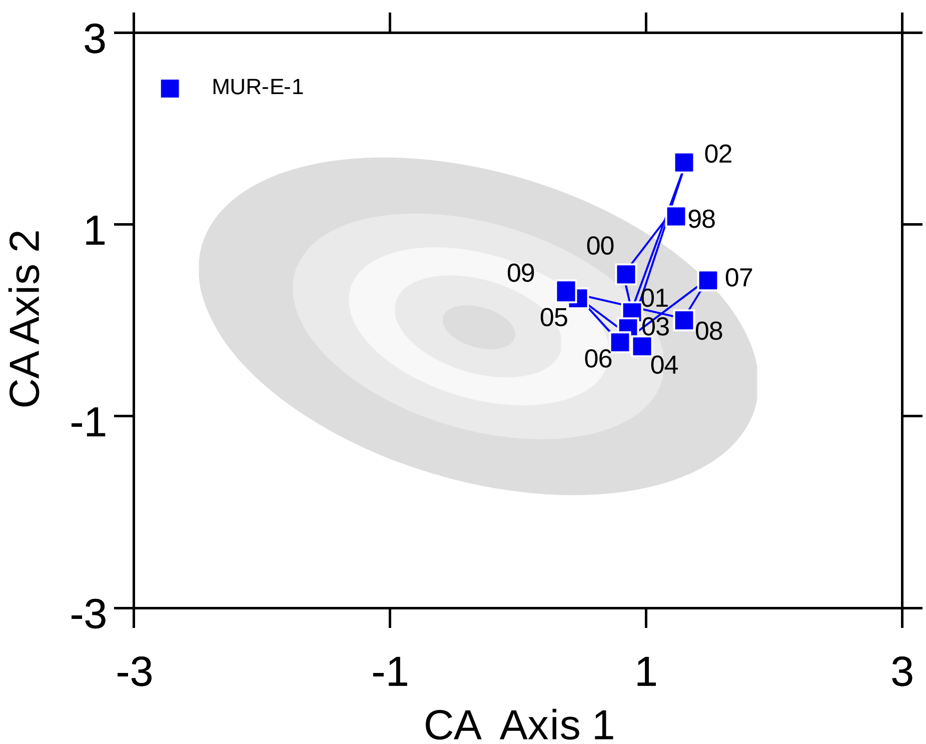
Figure 5.2-10 Variation in benthic invertebrate community measurement endpoints in the lower Muskeg River (MUR-E-1).



Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.2-11 Ordination (Correspondence Analysis) of benthic invertebrate communities in the lower Muskeg River (MUR-E-1).





Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* erosional reaches in the RAMP FSA.

Table 5.2-16 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, lower *test* reach (MUR-E-1).

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	8.563	10	0.856	10.58	0.000
	Time Trend (TT)	0.162	1	0.162	2.00	0.160
	Remainder (noise)	8.401	9	0.933	11.53	0.001
	Error	8.821	109	0.081		
Log Richness	Reach - Year	0.517	10	0.052	7.50	0.000
	Time Trend (TT)	0.007	1	0.007	1.06	0.306
	Remainder (noise)	0.510	9	0.057	8.22	0.005
	Error	0.752	109	0.007		
Diversity	Reach - Year	0.360	10	0.036	7.22	0.000
	Time Trend (TT)	0.001	1	0.001	0.19	0.661
	Remainder (noise)	0.359	9	0.040	8.00	0.006
	Error	0.544	109	0.005		
Evenness	Reach - Year	0.381	10	0.038	7.33	0.000
	Time Trend (TT)	0.000	1	0.000	0.08	0.779
	Remainder (noise)	0.380	9	0.042	8.14	0.005
	Error	0.566	109	0.005		
Log %EPT	Reach - Year	4.93	10	0.49	15.70	0.000
	Time Trend (TT)	0.06	1	0.06	1.84	0.178
	Remainder (noise)	4.87	9	0.54	17.25	0.000
	Error	3.42	109	0.03		
CA Axis 1	Reach - Year	10.41	10	1.04	6.89	0.000
	Time Trend (TT)	0.29	1	0.29	1.92	0.169
	Remainder (noise)	10.12	9	1.12	7.44	0.007
	Error	16.47	109	0.15		
CA Axis 2	Reach - Year	41.28	10	4.13	12.77	0.000
	Time Trend (TT)	4.24	1	4.24	13.11	0.000
	Remainder (noise)	37.04	9	4.12	12.74	0.001
	Error	35.22	109	0.32		

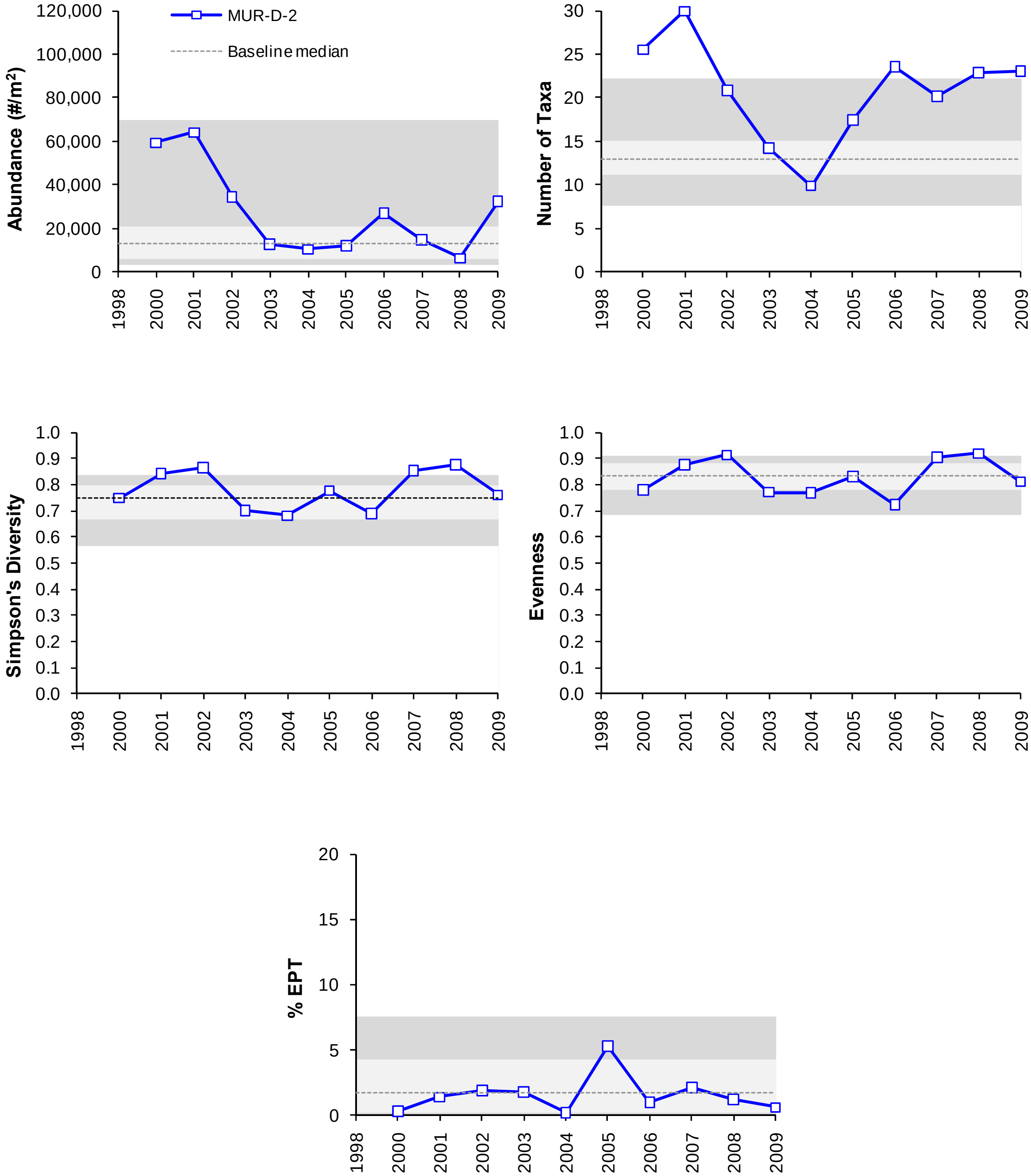
Table 5.2-17 Average habitat characteristics of benthic invertebrate sampling location in the Muskeg River, middle reach (MUR-D-2).

Variable	Units	*Test* Reach MUR-D-2
Sample Date	-	Sept 14, 2009
Habitat	-	Depositional
Water Depth	m	2.5
Current Velocity	m/s	0.21
Macrophyte Cover	%	1
Field Water Quality		
Dissolved Oxygen	mg/L	8.2
Conductivity	µS/cm	354
pH	pH units	8.1
Water Temperature	°C	14.4
Sediment Composition		
Sand	%	83
Silt	%	12
Clay	%	5
Total Organic Carbon	%	2.96

Table 5.2-18 Major taxon percent abundances and benthic invertebrate community measurement endpoints in the middle Muskeg River (MUR-D-2).

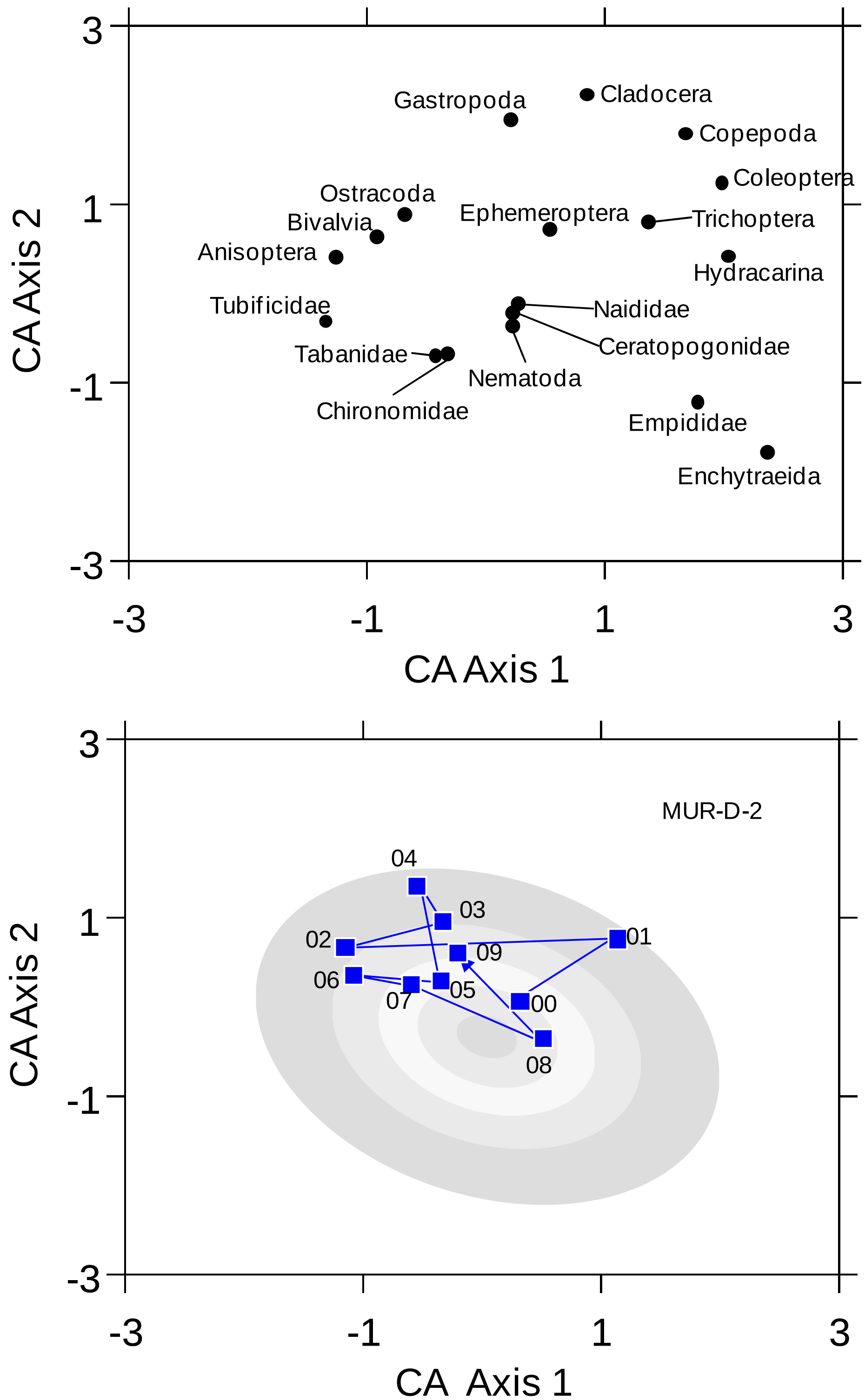
Taxon	Percent Major Taxa Enumerated in Each Year									
	Test Reach MUR-D-2									
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Amphipoda		<1	<1	1	<1	<1	<1	2		
Anisoptera	<1	<1	<1	<1		<1		<1	<1	<1
Bivalvia	4	1	3	1	1	<1		2	4	5
Ceratopogonidae	1	1	2	3	7	4	2	28	11	3
Chironomidae	75	84	69	81	74	44	55	32	56	48
Coleoptera	<1	<1	<1		<1	1	<1	<1		<1
Copepoda	<1	1	<1	<1	1	<1	<1	2	<1	3
Empididae	<1	<1	<1	<1	1	1	1		4	
Enchytraeidae	<1	1	2	2	3	3	<1	6	1	
Ephemeroptera	<1	1	2	1	<1	6	1	2	1	1
Erpobdellidae	<1	<1	<1	<1		<1		<1		
Gastropoda	<1	3	1	<1		<1	1	2	4	1
Glossiphoniidae	<1	<1	<1	<1			<1	<1	<1	<1
Hydra	<1	<1				<1	<1	1	<1	
Hydracarina	1	1	2	1	<1	<1	2	<1	3	1
Lumbriculidae	1	<1	<1	1		<1	<1	<1		7
Naididae	2	1	<1	2	1	11	1	4	4	6
Nematoda	2	1	6	3	3	6	1	6	5	2
Ostracoda	1	2	5		<1	10	<1	3	<1	1
Plecoptera	<1	<1	<1	<1		<1	<1		<1	
Simuliidae						1				
Tabanidae	<1	<1	<1	<1	<1	<1	<1		<1	<1
Tipulidae	1	<1			<1		<1	<1	1	
Trichoptera	<1	<1	<1	<1	<1	1	<1	<1	<1	
Tubificidae	10	<1	3	2	8	10	31	5	3	21
Benthic Invertebrate Community Measurement Endpoints										
Total Abundance (No./m^2)	59,328	64,032	34,672	12,635	10,440	11,948	27,123	14,796	6,322	32,196
Richness	26	30	21	14	10	17	24	20	23	23
Simpson's Diversity	0.75	0.84	0.86	0.7	0.68	0.78	0.69	0.85	0.87	0.76
Evenness	0.78	0.87	0.91	0.77	0.77	0.83	0.69	0.90	0.95	0.81
% EPT	<1	1	2	2	<1	5	1	2	1	1

Figure 5.2-12 Variation in benthic invertebrate community measurement endpoints in the Muskeg River, middle reach (MUR-D-2).



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.2-13 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River, middle reach (MUR-D-2).



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.2-19 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, middle *test* reach (MUR-D-2).

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	13.287	9	1.476	10.42	0.000
	Time Trend (TT)	3.219	1	3.219	22.71	0.000
	Remainder (noise)	10.069	8	1.259	8.88	0.004
	Error	16.301	115	0.142		
Log Richness	Reach - Year	2.408	9	0.268	10.33	0.000
	Time Trend (TT)	0.025	1	0.025	0.96	0.329
	Remainder (noise)	2.383	8	0.298	11.50	0.001
	Error	2.980	115	0.026		
Diversity	Reach - Year	0.646	9	0.072	5.11	0.000
	Time Trend (TT)	0.005	1	0.005	0.34	0.560
	Remainder (noise)	0.641	8	0.080	5.70	0.019
	Error	1.615	115	0.014		
Evenness	Reach - Year	0.600	9	0.067	4.98	0.000
	Time Trend (TT)	0.00	1	0.00	0.35	0.558
	Remainder (noise)	0.595	8	0.074	5.56	0.020
	Error	1.537	115	0.013		
Log %EPT	Reach - Year	2.88	9	0.32	4.80	0.000
	Time Trend (TT)	0.02	1	0.02	0.30	0.583
	Remainder (noise)	2.86	8	0.36	5.36	0.022
	Error	7.67	115	0.07		
CA Axis 1	Reach - Year	15.02	9	1.67	3.48	0.001
	Time Trend (TT)	4.13	1	4.13	8.61	0.004
	Remainder (noise)	10.9	8	1.362	2.84	0.095
	Error	55.13	115	0.48		
CA Axis 2	Reach - Year	37.23	9	4.14	5.73	0.000
	Time Trend (TT)	0.60	1	0.60	0.83	0.364
	Remainder (noise)	36.63	8	4.58	6.34	0.013
	Error	83.06	115	0.72		

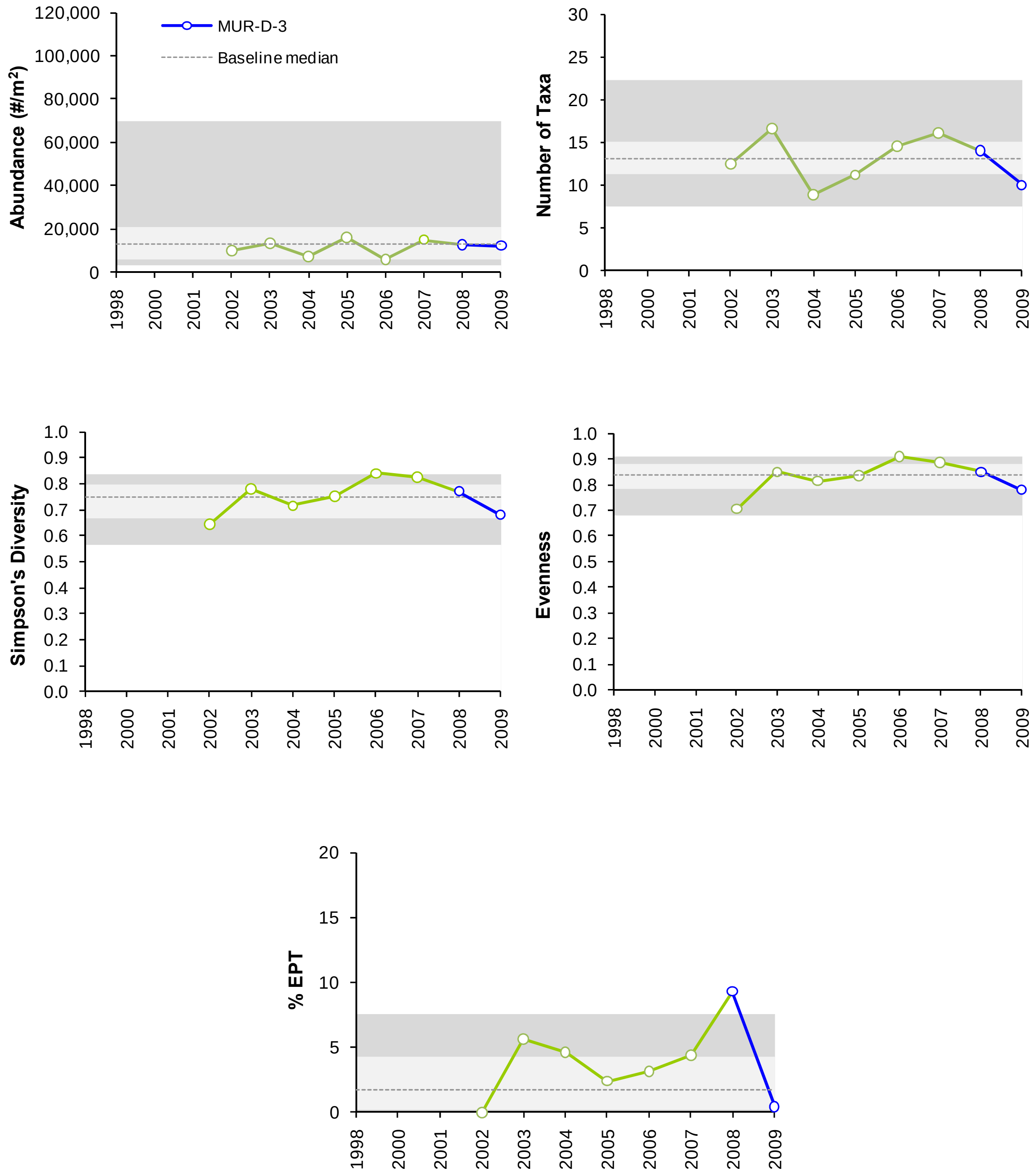
Table 5.2-20 Average habitat characteristics of benthic invertebrate sampling location in the upper reach (MUR-D-3) of the Muskeg River.

Variable	Units	*Test* Reach MUR-D-3
Sample Date	-	Sept 16, 2009
Habitat	-	Depositional
Water Depth	m	0.8
Current Velocity	m/s	0.14
Macrophyte Cover	%	5
Field Water Quality		
Dissolved Oxygen	mg/L	4.8
Conductivity	µS/cm	375
pH	pH units	7.6
Water Temperature	°C	14.4
Sediment Composition		
Sand	%	95
Silt	%	3
Clay	%	2
Total Organic Carbon	%	21.1

Table 5.2-21 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the upper Muskeg River (MUR-D-3).

Taxon	Percent Major Taxa Enumerated in Each Year							
	Test Reach MUR-D-3							
	2002	2003	2004	2005	2006	2007	2008	2009
Amphipoda	<1	1	5	<1	1	<1	<1	1
Anisoptera		<1	<1				<1	
Bivalvia	28	17	18	8		5	7	12
Ceratopogonidae	<1	2	2	1	1	1	1	
Chironomidae	66	65	27	79	54	60	48	42
Coleoptera		<1	<1			1	1	
Copepoda		1	3	1		<1	2	3
Empididae								
Enchytraeidae		<1	1	<1		<1	<1	
Ephemeroptera		5	5	2	3	3	7	<1
Erpobdellidae	<1	<1	<1	<1	<1	<1		<1
Gastropoda	<1	1	2	<1	<1	<1	<1	
Glossiphoniidae	<1	1	1	<1	3	<1	<1	
Hydra				<1	1	<1		
Hydracarina	<1	1	<1	<1		<1	15	
Lumbriculidae		<1	1		1	<1		2
Naididae	<1	1	1	2	2	7	2	2
Nematoda	1	2	6	3	4	5	2	<1
Ostracoda	4	1	7	1		2	3	2
Plecoptera						1		
Simuliidae				<1				
Tabanidae	<1	<1	<1	<1	<1	1	<1	
Tipulidae								2
Trichoptera	<1	<1	<1	1		<1	<1	<1
Tubificidae	<1	2	15	2	15	16	9	23
Benthic Invertebrate Community Measurement Endpoints								
Total Abundance (No./m^2)	9,905	13,566	7,190	15,887	6,087	15,001	12,779	12,295
Richness	12	17	9	11	15	16	14	10
Simpson's Diversity	0.64	0.78	0.71	0.75	0.84	0.82	0.77	0.68
Evenness	0.71	0.85	0.81	0.83	0.86	0.89	0.85	0.78
% EPT	<1	6	5	2	3	4	9	<1

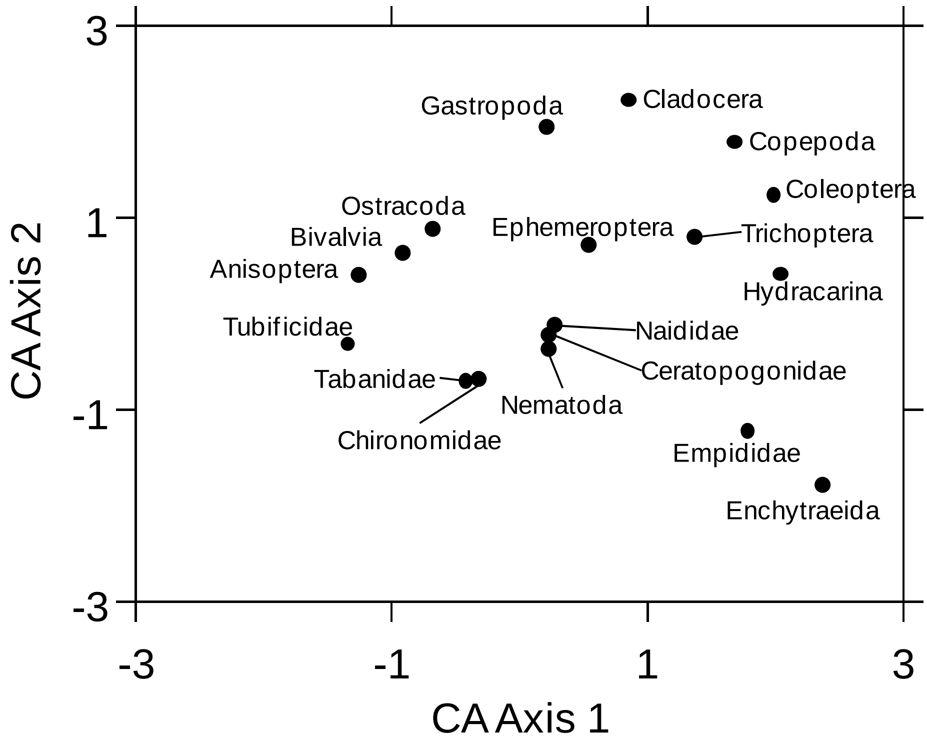
Figure 5.2-14 Variation in benthic invertebrate community measurement endpoints in the upper reach of the Muskeg River (MUR-D-3).

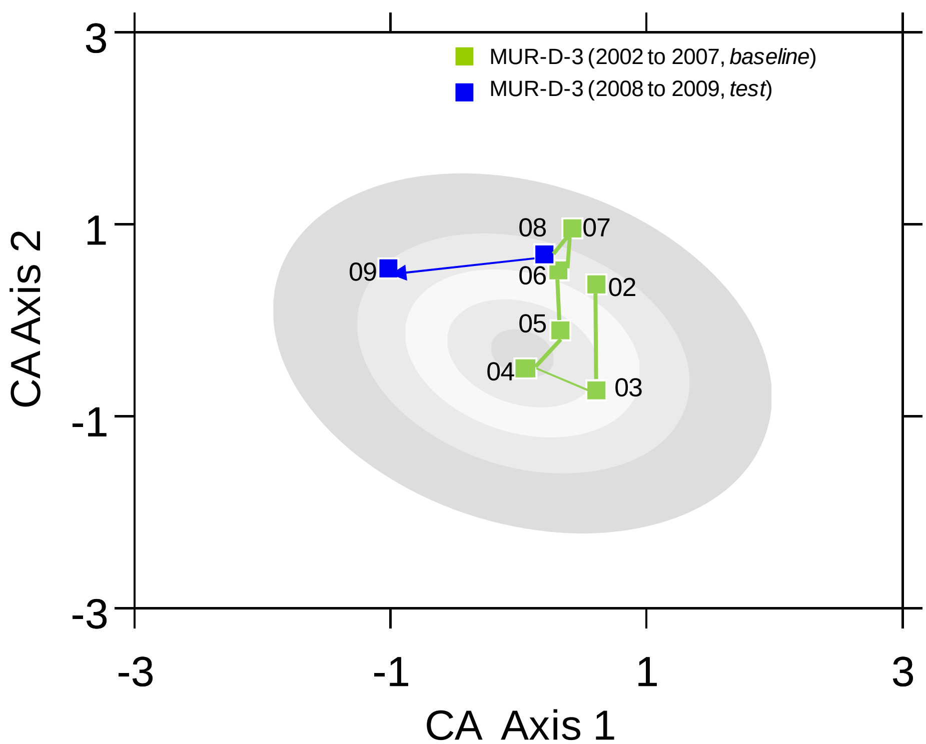


Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Note: The *test* reach MUR-D-3 was designated as *baseline* from 2002 to 2007.

Figure 5.2-15 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River, upper *test* reach (MUR-D-3).





Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.2-22 Analysis of variance (ANOVA) testing variations from before to after development in the upper Muskeg River catchment (MUR-D-3).

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	3.217	7	0.460	1.49	0.182
	Before to After (BA)	0.296	1	0.296	0.96	0.330
	Remainder (noise)	2.921	6	0.487	1.58	0.213
	Error	26.865	87	0.309		
Log Richness	Reach - Year	0.673	7	0.096	2.56	0.019
	Before to After (BA)	0.050	1	0.050	1.33	0.251
	Remainder (noise)	0.623	6	0.104	2.77	0.100
	Error	3.224	86	0.037		
Diversity	Reach - Year	0.383	7	0.055	3.01	0.007
	Before to After (BA)	0.015	1	0.015	0.84	0.361
	Remainder (noise)	0.368	6	0.061	3.37	0.070
	Error	1.562	86	0.018		
Evenness	Reach - Year	0.301	7	0.043	2.40	0.027
	Before to After (BA)	0.00	1	0.00	0.10	0.753
	Remainder (noise)	0.299	6	0.050	2.78	0.099
	Error	1.541	86	0.018		
Log %EPT	Reach - Year	4.01	7	0.57	2.88	0.010
	Before to After (BA)	0.02	1	0.02	0.10	0.758
	Remainder (noise)	3.99	6	0.67	3.34	0.071
	Error	17.13	86	0.20		
CA Axis 1	Reach - Year	16.62	7	2.37	5.46	0.000
	Before to After (BA)	1.06	1	1.06	2.43	0.122
	Remainder (noise)	15.6	6	2.594	5.96	0.017
	Error	37.44	86	0.44		
CA Axis 2	Reach - Year	12.46	7	1.78	2.73	0.013
	Before to After (BA)	0.01	1	0.01	0.01	0.917
	Remainder (noise)	12.46	6	2.08	3.18	0.078
	Error	56.16	86	0.65		

Table 5.2-23 Average habitat characteristics of benthic invertebrate community sampling locations in Jackpine Creek.

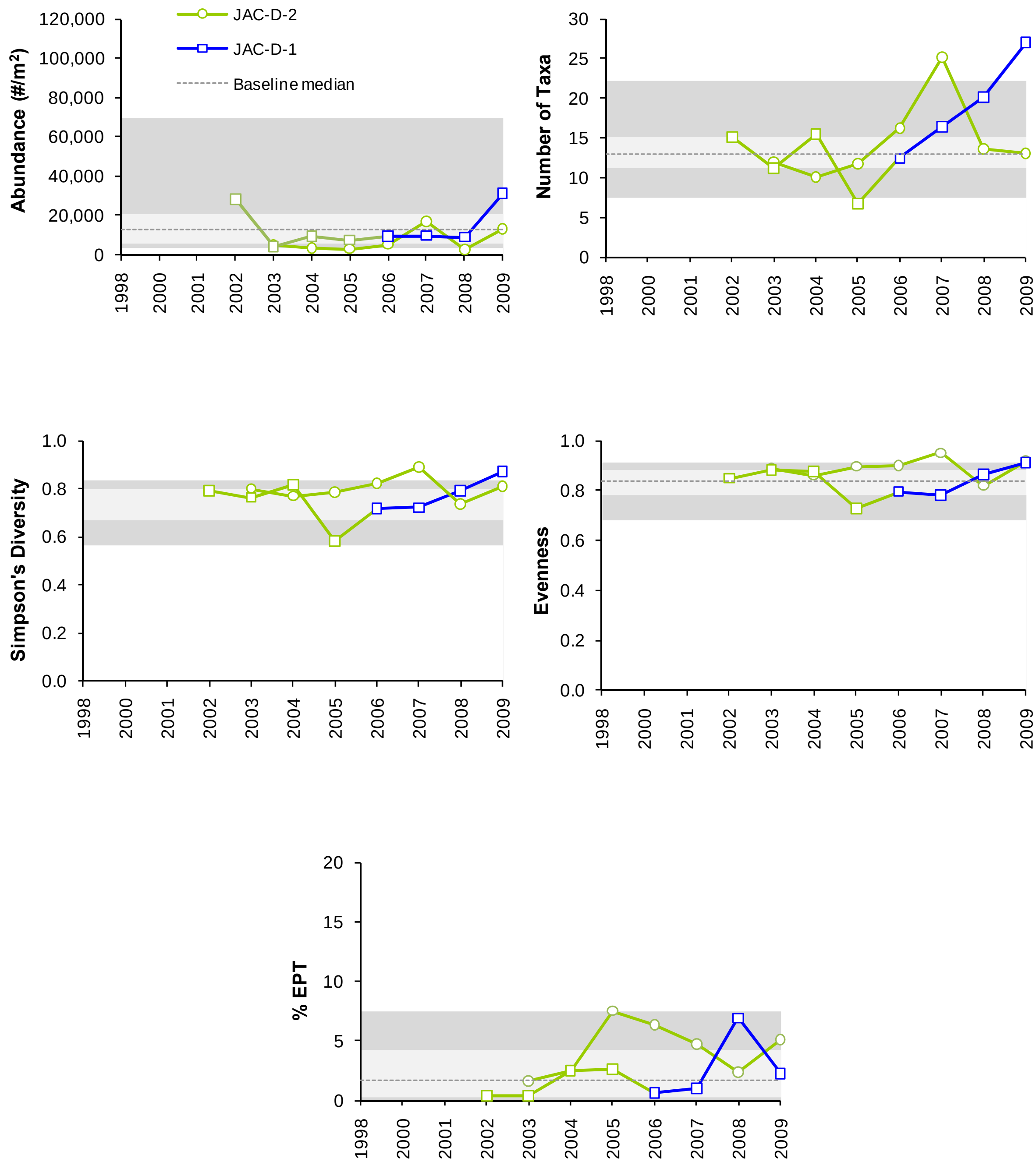
Variable	Units	*Test* Reach JAC-D-1	*Baseline* Reach JAC-D-2
Sample Date	-	Sept 15, 2009	Sept 11, 2009
Habitat	-	Depositional	Depositional
Water Depth	m	0.7	1.0
Current Velocity	m/s	0.28	037
Macrophyte Cover	%	16	4
Field Water Quality			
Dissolved Oxygen	mg/L	8.8	10.2
Conductivity	µS/cm	244	214
pH	pH units	8.11	8.12
Water Temperature	°C	16	12.0
Sediment Composition			
Sand	%	83	74
Silt	%	11	16
Clay	%	6	10
Total Organic Carbon	%	1.8	1.5

Table 5.2-24 Summary of major taxon abundances and benthic invertebrate community measurement endpoints composition in Jackpine Creek.

Taxon	Percent Major Taxa Enumerated in Each Year														
	Test Reach JAC-D-1								*Baseline* Reach JAC-D-2						
	2002	2003	2004	2005	2006	2007	2008	2009	2003	2004	2005	2006	2007	2008	2009
Amphipoda		<1	<1												
Anisoptera	<1	<1	<1		1	<1	<1	<1			<1				<1
Bivalvia	1	3	<1	<1		<1	1	<1	<1	<1	<1		<1	2	1
Ceratopogonidae	2	2	4		5	2	9	4	1	31	4	2	5	19	11
Chironomidae	88	66	69	69	86	66	57	80	67	3	44	63	66	60	69
Cladocera			8		<1	2	<1	<1		<1			<1		
Coleoptera		<1	<1				<1		6	3	6	1	2	3	6
Copepoda	<1	1	6	1		1		4		2	3		<1	<1	
Empididae	<1	2	2	4	2	1	1	2	1	<1	3	3	1		<1
Enchytraeidae	<1	4	<1			<1	1		1	1	1	2	<1	<1	<1
Ephemeroptera	<1		2	1	1	1	7	1	<1	2	1	6	4	3	7
Gastropoda	<1		<1			2	1	<1			<1	<1	<1	<1	1
Glossiphoniidae		<1												<1	
Hydra			<1										<1		
Hydracarina	1	1	1	8	1	5	4	3	<1	<1	18	1	2	<1	
Naididae	<1	2	2		1	<1	1	1	3	1	1	2	8	2	
Nematoda	5	6	1	4	2	2	6	1	6	4	2	4	5	3	<1
Ostracoda	<1		2	4		1	<1	<1	<1	1	3	1	<1	<1	
Plecoptera					1		<1		<1					<1	<1
Tabanidae	<1	<1	<1	<1	<1	<1	1	<1	1	2	<1	<1	<1	<1	<1
Tipulidae	<1	2	1	1	1	<1	<1		1	13	4	2	<1	<1	2
Trichoptera	<1	<1	<1	3	<1	<1	2	1	<1	1	7	1	2	1	1
Tubificidae	<1	<1	1	5	<1	17	8	1	2	5	1	2	5	2	1
Benthic Invertebrate Community Measurement Endpoints															
Total Abundance (No./m^2)	28,172	4,017	9,230	7,417	9,561	9,644	8,913	31,371	4,787	3,448	2,957	5,174	16,966	2,752	12,952
Richness	15	11	15	7	12	16	20	27	12	10	12	16	25	14	13
Simpson's Diversity	0.79	0.76	0.81	0.58	0.72	0.72	0.79	0.87	0.8	0.77	0.78	0.82	0.89	0.74	0.81
Evenness	0.85	0.88	0.88	0.73	0.73	0.78	0.82	0.91	0.89	0.86	0.9	0.86	0.95	0.87	0.92
% EPT	<1	<1	2	3	<1	1	2	2	2	2	7	6	5	6	5

Note: Reach JAC-D-1 has been designated as *test* since 2006.

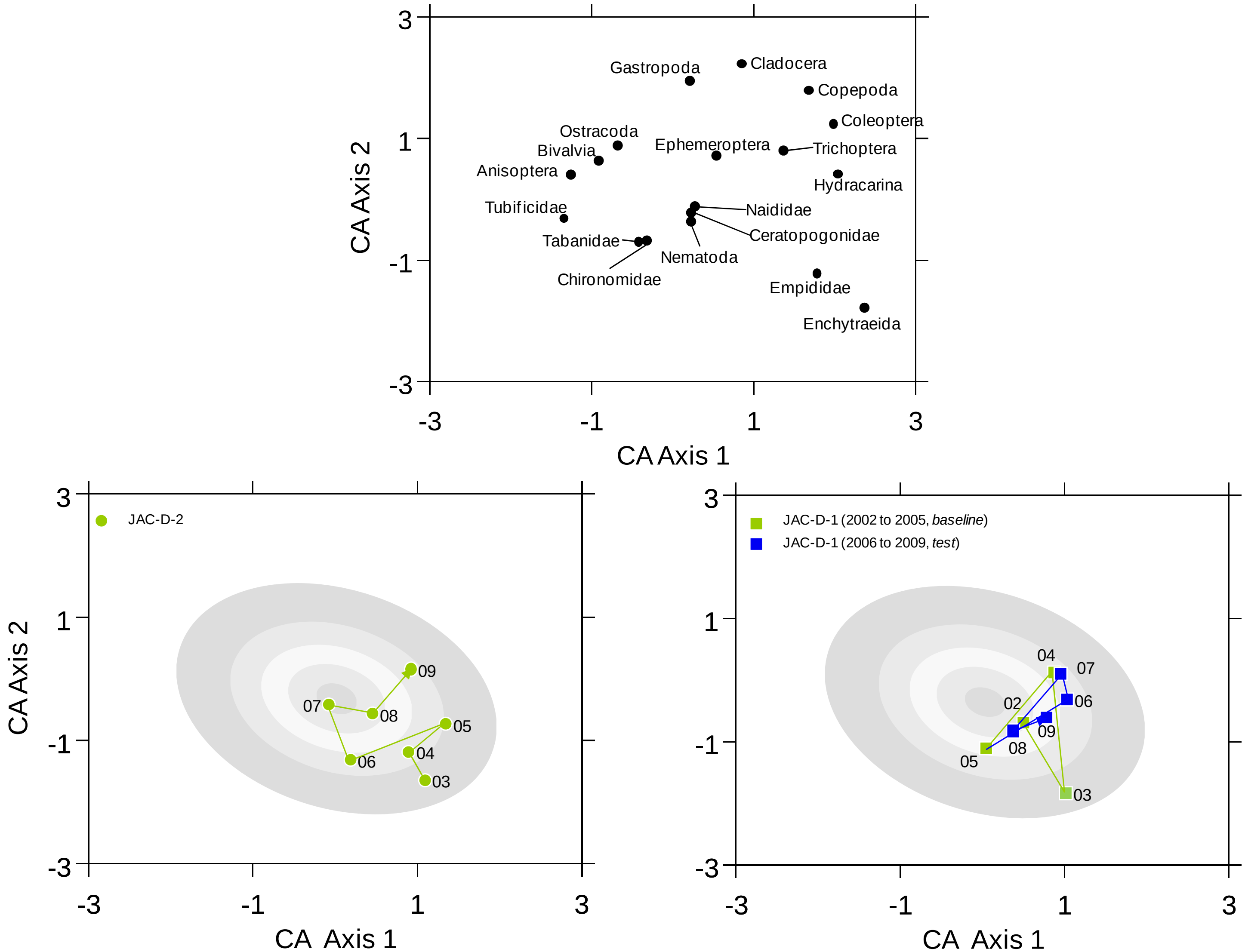
Figure 5.2-16 Variations in benthic invertebrate community measurement endpoints in *test* (JAC-D-1) and *baseline* (JAC-D-2) reaches of Jackpine Creek.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Note: The *test* reach JAC-D-1 was designated as *baseline* from 2002 to 2005.

Figure 5.2-17 Ordination (Correspondence Analysis) of benthic invertebrate community composition in *test* (JAC-D-1) and *baseline* (JAC-D-2) reaches of Jackpine Creek.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.2-25 Analysis of variance (ANOVA) between *test* (JAC-D-1) and *baseline* (JAC-D-2) reaches of Jackpine Creek.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	23.696	14	1.693	6.25	0.000
	BA x BT	1.853	2	0.926	3.42	0.035
	TT x BT	0.264	1	0.264	0.97	0.325
	Remainder (noise)	21.579	11	1.962	7.24	0.008
	Error	43.068	159	0.271		
Log Richness	Reach - Year	3.020	14	0.216	4.64	0.000
	BA x BT	0.163	2	0.081	1.75	0.177
	TT x BT	0.707	1	0.707	15.23	0.000
	Remainder (noise)	2.150	11	0.195	4.21	0.042
	Error	7.386	159	0.046		
Diversity	Reach - Year	0.751	14	0.054	2.66	0.002
	BA x BT	0.054	2	0.027	1.33	0.266
	TT x BT	0.127	1	0.127	6.29	0.013
	Remainder (noise)	0.570	11	0.052	2.57	0.111
	Error	3.210	159	0.020		
Evenness	Reach - Year	0.606	14	0.043	2.35	0.005
	BA x BT	0.06	2	0.03	1.57	0.212
	TT x BT	0.087	1	0.087	4.73	0.031
	Remainder (noise)	0.461	11	0.042	2.28	0.133
	Error	2.926	159	0.018		
Log %EPT	Reach - Year	7.62	14	0.54	3.55	0.000
	BA x BT	1.73	2	0.87	5.64	0.004
	TT x BT	1.39	1	1.39	9.09	0.003
	Remainder (noise)	4.50	11	0.41	2.67	0.104
	Error	24.38	159	0.15		
CA Axis 1	Reach - Year	26.47	14	1.89	2.06	0.016
	BA x BT	5.76	2	2.88	3.14	0.046
	TT x BT	4.12	1	4.12	4.50	0.035
	Remainder (noise)	16.6	11	1.508	1.65	0.201
	Error	145.64	159	0.92		
CA Axis 2	Reach - Year	67.24	14	4.80	4.37	0.000
	BA x BT	13.32	2	6.66	6.06	0.003
	TT x BT	9.14	1	9.14	8.31	0.004
	Remainder (noise)	44.77	11	4.07	3.70	0.056
	Error	174.87	159	1.10		

Note: BA x BT = before-after, *baseline-test*; TT x BT = Time Trend x *baseline* vs *test*

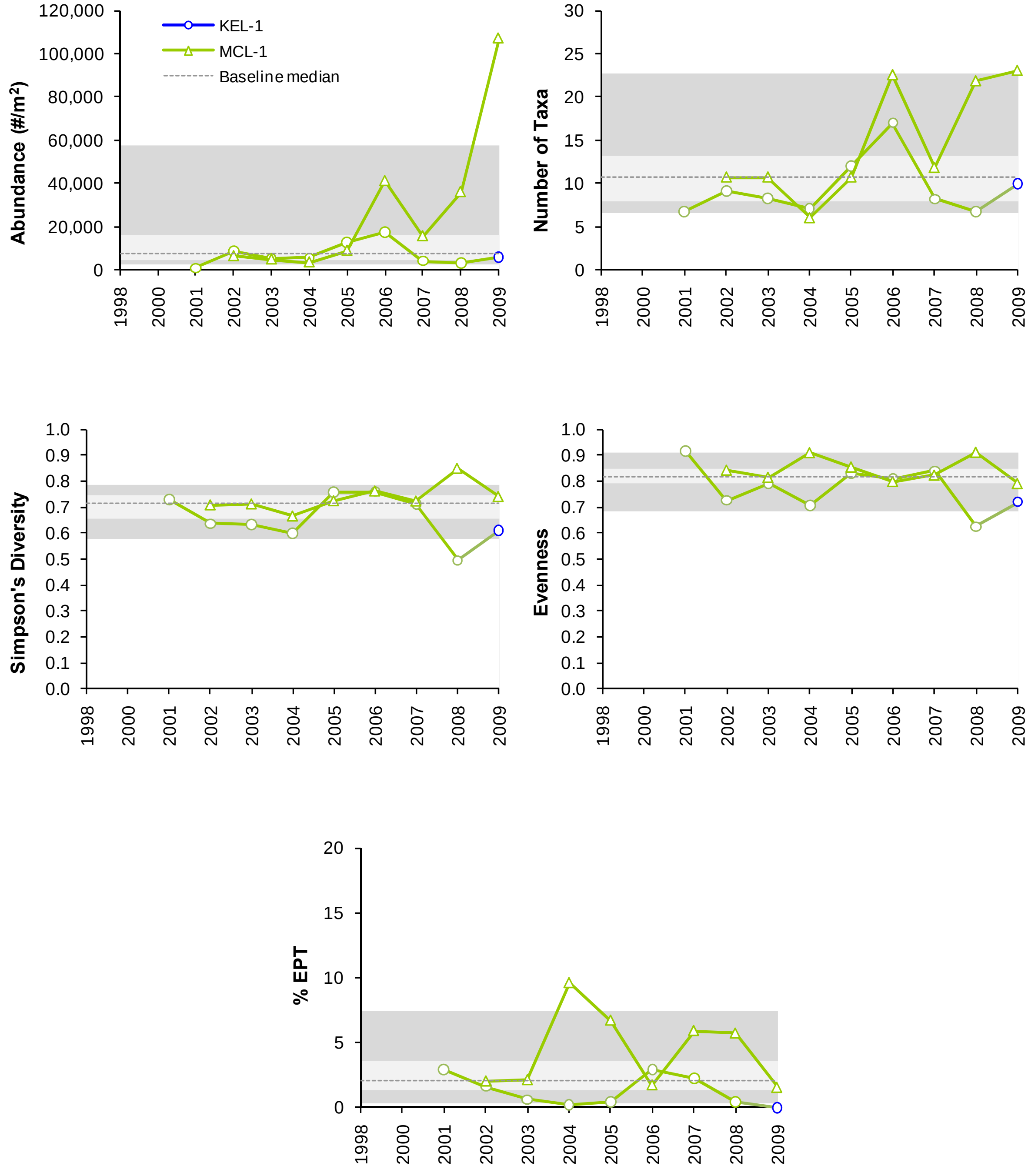
Table 5.2-26 Average habitat characteristics of benthic invertebrate community sampling locations in Kearl Lake (KEL-1).

Variable	Units	Kearl Lake (KEL-1)
Sample Date	-	Sept 13, 2009
Habitat	-	Depositional
Water Depth	m	N/A
Macrophyte Cover	%	N/A
Field Water Quality		
Dissolved Oxygen	mg/L	7.3
Conductivity	µS/cm	182
pH	pH units	8.3
Water Temperature	°C	15.3
Sediment Composition		
Sand	%	89
Silt	%	7
Clay	%	4
Total Organic Carbon	%	35

Table 5.2-27 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Kearl Lake (KEL-1).

Taxon	Percent Major Taxa Enumerated in Each Year								
	2001	2002	2003	2004	2005	2006	2007	2008	2009
Amphipoda	13	46	36	58	25	23	27	2	8
Anisoptera						<1			
Bivalvia	4	4	6	9	4	23	7	11	6
Ceratopogonidae		1	1			<1		<1	<1
Chaoboridae	1						<1	<1	<1
Chironomidae	6	42	46	20	45	42	24	28	21
Cladocera	1		<1	1	7	<1		1	<1
Copepoda	<1	<1		2	15	<1	31	38	56
Ephemeroptera	<1	1				2	1		
Erpobdellidae					<1	<1		<1	<1
Gastropoda	1	<1				<1		1	<1
Glossiphoniidae	<1	1	1	<1				<1	
Hydracarina	<1		<1				2	7	
Lumbriculidae						<1			
Naididae		<1	6	5	1	3	2	5	5
Nematoda					1	1	3	5	
Ostracoda	7	7	4	4	1	<1	1		<1
Trichoptera	2	1	1	<1	<1	1	2	1	
Tubificidae					1	2	1	<1	2
Zygoptera									
Benthic Invertebrate Community Measurement Endpoints									
Total Abundance (No./m^2)	891	8,706	5,366	5,690	12,691	17,405	4,217	3,209	5,900
Richness	7	9	8	7	12	17	8	7	10
Simpson's Diversity	0.73	0.64	0.63	0.6	0.76	0.76	0.71	0.49	0.61
Evenness	0.92	0.72	0.79	0.71	0.83	0.76	0.84	0.62	0.72
% EPT	3	2	1	<1	<1	2	2	<1	0

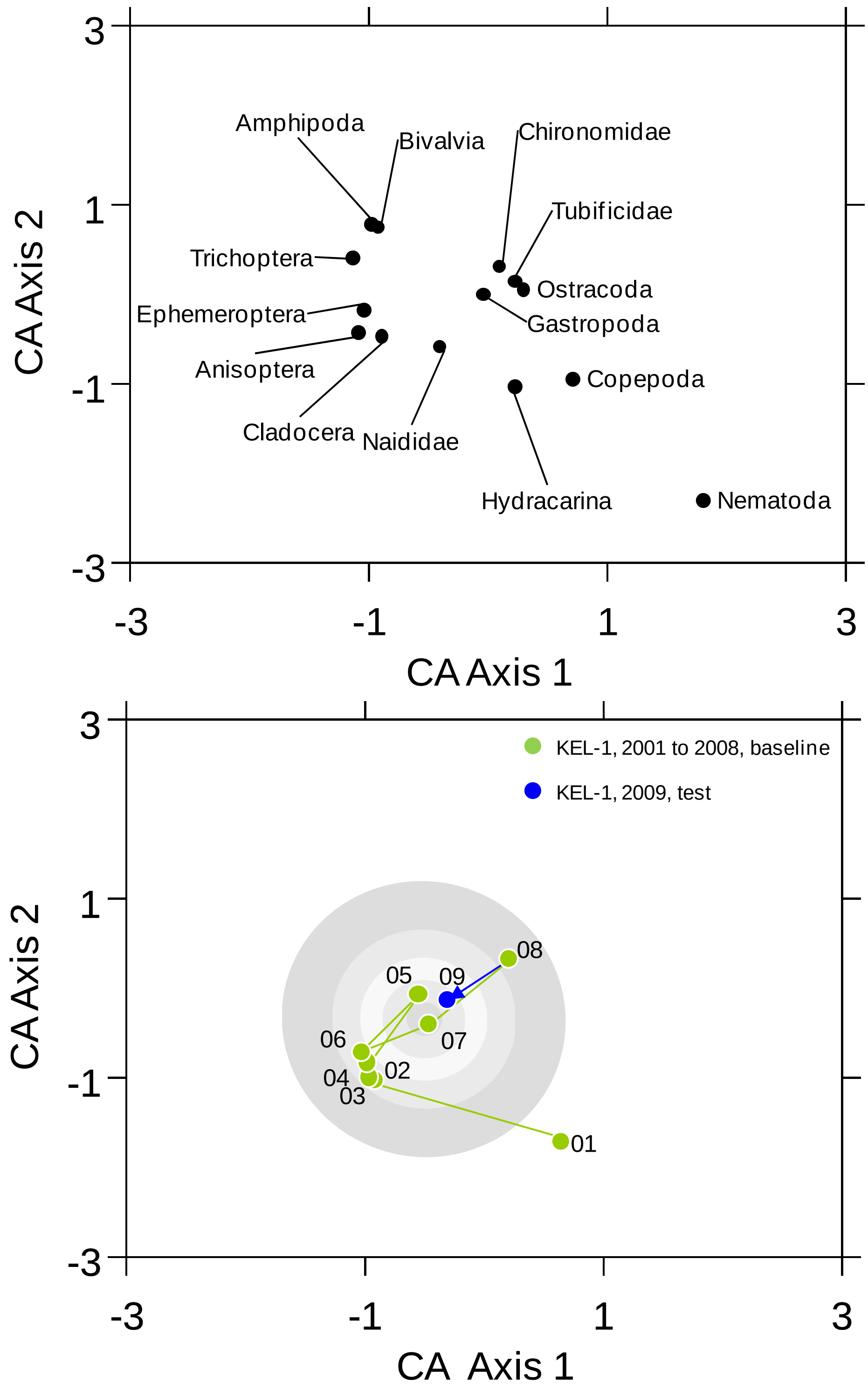
Figure 5.2-18 Variations in benthic invertebrate community measurement endpoints in Kearl Lake (KEL-1) relative to McClelland Lake (*baseline*, MCL-1).



Note: Regional *baseline* values reflect pooled results for all *baseline* lakes in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Note: Kearl Lake was designated as *baseline* from 2001 to 2008, shown in green up to 2009.

Figure 5.2-19 Ordination (Correspondence Analysis) of benthic invertebrate communities in Kearl Lake (KEL-1).



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* lakes in the RAMP FSA.

Table 5.2-28 Analysis of variance (ANOVA) between Kearl Lake (*test*, KEL-1) and McClelland Lake (*baseline*, MCL-1).

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Lake - Year	40.433	16	2.527	8.25	0.000
	BA x BT	3.685	1	3.685	12.03	0.001
	Remainder (noise)	36.749	15	2.450	8.00	0.005
	Error	46.573	152	0.306		
Log Richness	Lake - Year	5.796	16	0.362	6.52	0.000
	BA x BT	0.359	1	0.359	6.46	0.012
	Remainder (noise)	5.437	15	0.362	6.53	0.012
	Error	8.443	152	0.056		
Diversity	Lake - Year	1.081	16	0.068	2.72	0.001
	BA x BT	0.016	1	0.016	0.62	0.431
	Remainder (noise)	1.065	15	0.071	2.86	0.093
	Error	3.779	152	0.025		
Evenness	Lake - Year	0.993	16	0.062	3.06	0.000
	BA x BT	0.002	1	0.002	0.12	0.727
	Remainder (noise)	0.990	15	0.066	3.26	0.073
	Error	3.078	152	0.020		
Log %EPT	Lake - Year	5.12	16	0.32	2.14	0.009
	BA x BT	0.03	1	0.03	0.21	0.651
	Remainder (noise)	5.09	15	0.34	2.27	0.134
	Error	22.72	152	0.15		
CA Axis 1	Lake - Year	26.72	16	1.67	5.00	0.000
	BA x BT	0.40	1	0.40	1.20	0.276
	Remainder (noise)	26.3	15	1.755	5.26	0.023
	Error	50.39	151	0.33		
CA Axis 2	Lake - Year	48.40	16	3.03	7.33	0.000
	BA x BT	0.00	1	0.00	0.00	0.983
	Remainder (noise)	48.40	15	3.23	7.82	0.006
	Error	62.32	151	0.41		

Table 5.2-29 Concentrations of selected sediment quality measurement endpoints in the middle *test* reach (MUR-D-2) of the Muskeg River, fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only, station MUR-2)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	3	6	<1	6	12
Silt	%	-	8	6	<1	18	32
Sand	%	-	88	6	60	76.5	100
Total organic carbon	%	-	1.12	7	0.2	2.8	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	5	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	5	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	68	5	<5	110	**180**
Fraction 3 (C16-C34)	mg/kg	300[1]	**856**	5	110	**1800**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	743	5	62	1400	2100
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0014	7	0.0013	0.0034	0.0200
Retene	mg/kg	-	0.0715	7	<0.21	0.146	0.314
Total dibenzothiophenes	mg/kg	-	2.84	7	0.29	5.33	11.04
Total PAHs	mg/kg	-	8.02	7	0.90	15.33	30.44
Total Parent PAHs	mg/kg	-	0.16	7	0.03	0.41	1.30
Total Alkylated PAHs	mg/kg	-	7.86	7	0.87	15.01	29.76
Predicted PAH toxicity[3]	H.I.	-	1.41	7	0.93	1.50	1.73
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.6	6	2.6	7	8.6
Chironomus growth - 10d	mg/organism	-	1.554	6	0.68	2.155	2.5
Hyalella survival - 14d	# surviving	-	8.6	6	8	8	9.2
Hyalella growth - 14d	mg/organism	-	0.298	6	0.11	0.213	0.35

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.2-30 Concentrations of selected sediment quality measurement endpoints in the upper *test* reach (MUR-D-3) of the Muskeg River, fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay[4]	%	-	1	6	5	19	40
Silt[4]	%	-	1	6	10	18	29
Sand[4]	%	-	98	6	31	63	85
Total organic carbon	%	-	22.2	6	1.7	23.0	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<73	5	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<73	5	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	27	5	<5	7	130
Fraction 3 (C16-C34)	mg/kg	300[1]	**712**	5	52	**740**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	326	5	71	630	1800
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.003	6	0.003	0.007	0.015
Retene	mg/kg	-	0.349	6	0.131	0.369	0.522
Total dibenzothiophenes	mg/kg	-	0.11	6	0.05	0.13	0.19
Total PAHs	mg/kg	-	1.02	6	0.38	1.19	1.39
Total Parent PAHs	mg/kg	-	0.05	6	0.03	0.06	0.34
Total Alkylated PAHs	mg/kg	-	0.97	6	0.35	1.00	1.19
Predicted PAH toxicity[3]	H.I.	-	0.28	6	0.03	0.33	0.54
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 µm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[4] Sediment size measured at replicate 2 in 2009, as particle size analysis was not possible at replicate 1.

Table 5.2-31 Concentrations of selected sediment quality measurement endpoints in *test* reach (JAC-D-1) of Jackpine Creek, fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	9	5	<1	4	18.7
Silt	%	-	11	5	0.3	11	13
Sand	%	-	81	5	81	84	99
Total organic carbon	%	-	1.3	5	0.2	1.1	2.7
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	32	4	13	21	71
Fraction 3 (C16-C34)	mg/kg	300[1]	**592**	4	150	**480**	**790**
Fraction 4 (C34-C50)	mg/kg	2800[1]	734	4	210	640	820
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.00071	5	0.0007	0.0016	<0.003
Retene	mg/kg	-	0.037	4	0.007	0.052	0.951
Total dibenzothiophenes	mg/kg	-	0.491	5	0.105	0.715	1.639
Total PAHs	mg/kg	-	1.537	5	0.413	2.134	4.492
Total Parent PAHs	mg/kg	-	0.032	5	0.022	0.109	0.136
Total Alkylated PAHs	mg/kg	-	1.505	5	0.391	1.998	4.375
Predicted PAH toxicity[4]	H.I.	-	0.323	5	0.214	0.297	1.110
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	5.6	3	7	7.2	8.6
Chironomus growth - 10d	mg/organism	-	1.148	3	2.434	3.1	3.2
Hyalella survival - 14d	# surviving	-	9.2	3	7	9.4	9.6
Hyalella growth - 14d	mg/organism	-	0.314	3	0.14	0.268	0.272

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.2-32 Concentrations of selected sediment quality measurement endpoints in the *baseline* reach (JAC-D-2) of Jackpine Creek, fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	8	3	1.0	11	13
Silt	%	-	14	3	<1	21	23
Sand	%	-	78	3	66	66	98
Total organic carbon	%	-	1.0	3	0.1	1.4	1.9
Total hydrocarbons							
BTEX	mg/kg	-	<10	3	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	3	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	3	<5	<5	8
Fraction 3 (C16-C34)	mg/kg	300[1]	54	3	10	160	190
Fraction 4 (C34-C50)	mg/kg	2800[1]	48	3	<5	89	160
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.001	2	0.0012	0.0017	0.002
Retene	mg/kg	-	0.029	2	0.001	0.0171	0.033
Total dibenzothiophenes	mg/kg	-	0.0050	2	0.0019	0.0044	0.01
Total PAHs	mg/kg	-	0.097	2	0.0143	0.0671	0.12
Total Parent PAHs	mg/kg	-	0.007	2	0.0037	0.012	0.02
Total Alkylated PAHs	mg/kg	-	0.09	2	0.0106	0.0551	0.10
Predicted PAH toxicity[3]	H.I.	-	0.23	2	0.1351	0.1638	0.19
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	4.6	2	9.2	9.4	9.6
Chironomus growth - 10d	mg/organism	-	0.796	2	2.262	2.311	2.36
Hyalella survival - 14d	# surviving	-	8.8	2	8	8.9	9.8
Hyalella growth - 14d	mg/organism	-	0.304	2	0.326	0.332	0.338

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 mm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of Kow (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.2-33 Concentrations of selected sediment quality measurement endpoints in Kearl Lake (KEL-1), fall 2009.

Variables	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay[4]	%	-	4	4	<1	16	58
Silt[4]	%	-	8	4	9	22	36
Sand[4]	%	-	88	4	9	61	92
Total organic carbon	%	-	34.4	5	33.5	34.6	36.6
Total hydrocarbons							
BTEX	mg/kg	-	<220	4	<5	<5	<80
Fraction 1 (C6-C10)	mg/kg	30[1]	<220	4	<5	<5	<80
Fraction 2 (C10-C16)	mg/kg	150[1]	30	4	<5	9	**530**
Fraction 3 (C16-C34)	mg/kg	300[1]	**334**	4	230	**1660**	**3600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	258	4	81	1065	2500
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	ns	3	0.012	0.020	0.036
Retene	mg/kg	-	0.050	5	0.030	0.058	0.113
Total dibenzothiophenes	mg/kg	-	0.044	5	0.028	0.033	0.084
Total PAHs	mg/kg	-	0.917	5	0.793	1.050	1.432
Total Parent PAHs	mg/kg	-	0.078	5	0.125	0.140	0.345
Total Alkylated PAHs	mg/kg	-	0.839	5	0.668	0.724	1.291
Predicted PAH toxicity[3]	H.I.	-	0.402	5	0.031	0.449	0.924
Metals that exceed CCME guidelines in 2009							
Copper (Cu)	mg/kg	35.7	71.3	-	-	-	-

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

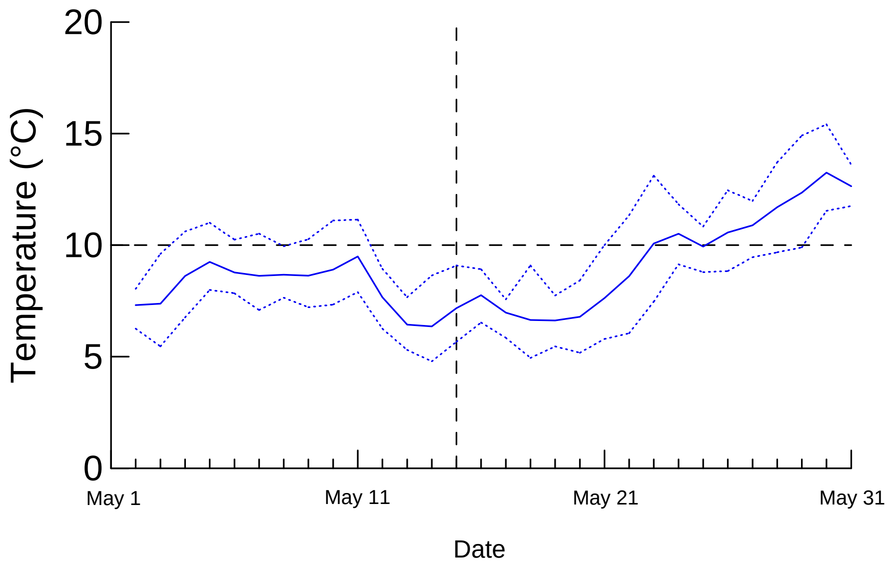
3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

4 Sediment size measured at replicate 2 in 2009, as particle size analysis was not possible at replicate 1.

Table 5.2-34 Sediment quality index (fall 2009) for Muskeg River watershed stations.

Station Identifier	Location	2009 Designation	Sediment Quality Index	Classification
KEL-1	Kearl Lake	*test*	88.3	Negligible-Low
JAC-D1	Mouth of Jackpine Creek	*test*	95.1	Negligible-Low
JAC-D2	Upper Jackpine Creek	*baseline*	94.5	Negligible-Low
MUR-D2	Muskeg River at Canterra Road	*test*	94.4	Negligible-Low
MUR-D3	Upper Muskeg River	*test*	97.7	Negligible-Low

Figure 5.2-20 Mean (solid line), minimum and maximum (dotted line) daily temperature (°C) of the Muskeg River measured during the period of fish fence monitoring, May 2009.



Note: Dashed lines indicate the 10°C historical thermal cue and the initiation of white sucker movement on May 15, 2009.

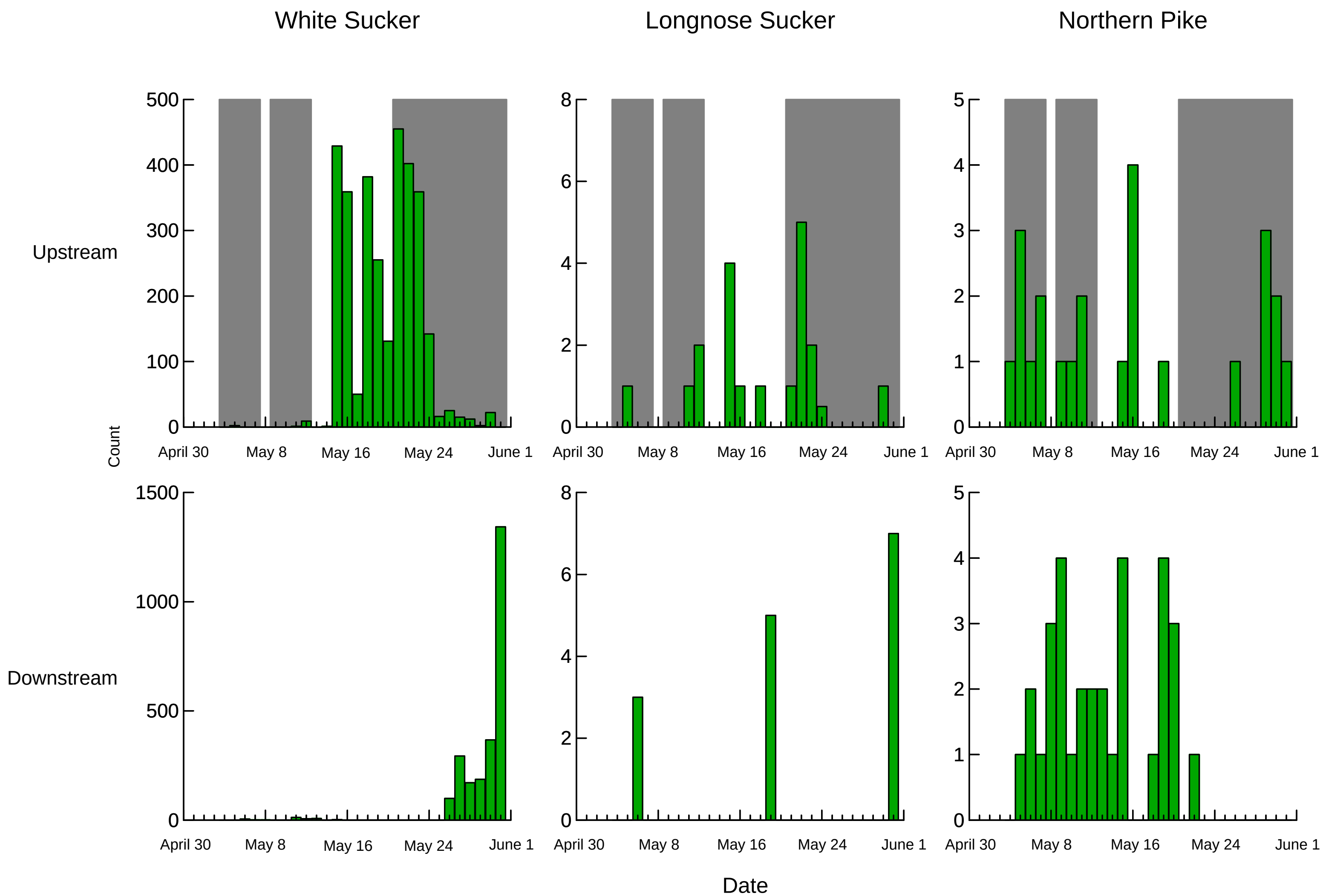
Table 5.2-35 Number of fish captured at the Muskeg River fish fence by species and direction, May 2009.

Species	Migration Direction		Total
	Upstream	Downstream	
white sucker	3,069	2,491	5,560
longnose sucker	20	15	35
northern pike	24	32	56
Arctic grayling	0	2	2
walleye	2	0	2
lake whitefish	1	1	2
Total	**3,116**	**2,541**	**5,657**

Table 5.2-36 Number of fish measured at the Muskeg River fish fence by species and direction, May 2009.

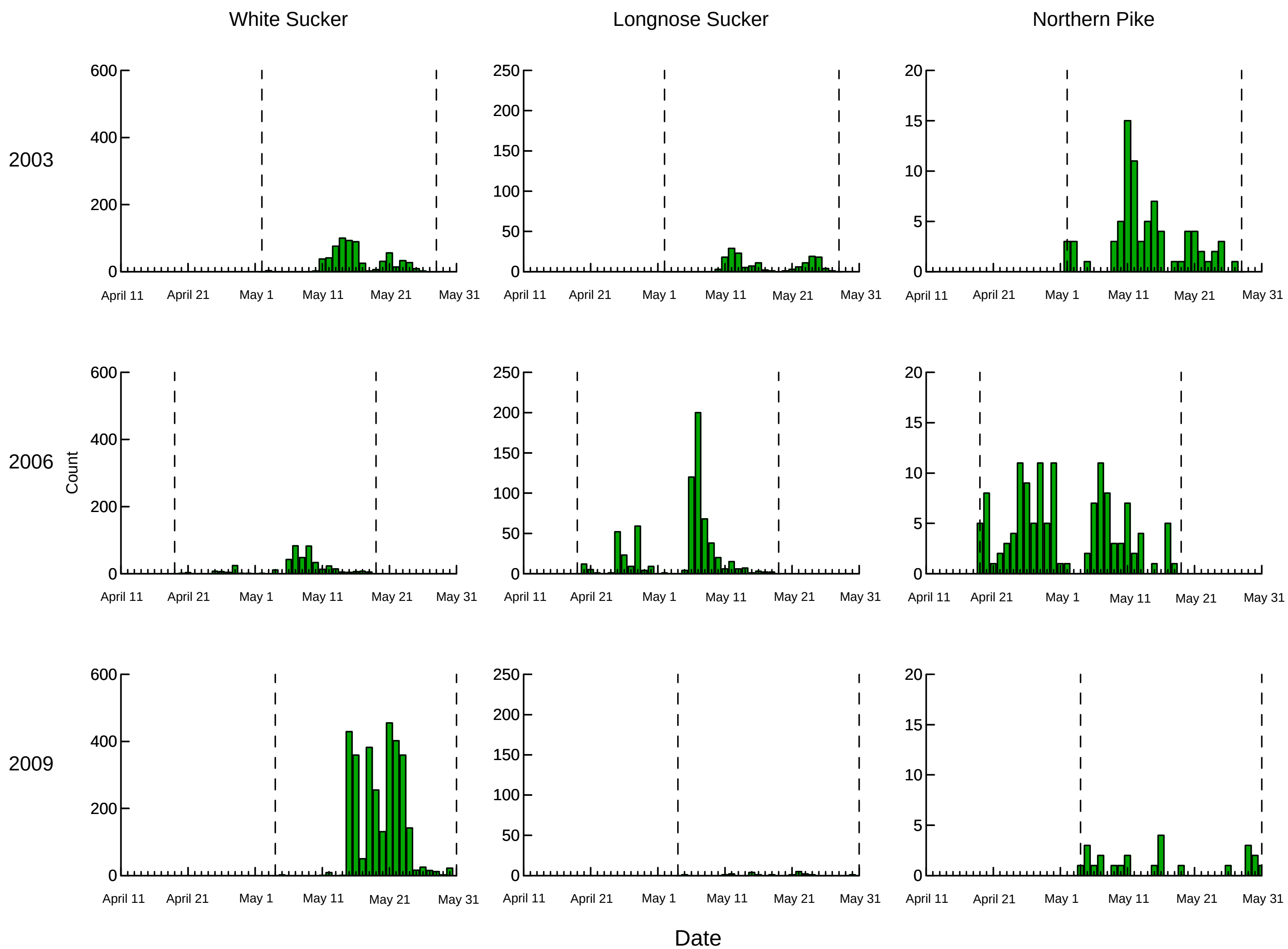
Fish Species	Migration Direction	
	Upstream	Downstream
white sucker	3,069	744
longnose sucker	20	9
northern pike	24	32
Arctic grayling	0	2
walleye	2	0
lake whitefish	1	1
Total	**3,116**	**788**

Figure 5.2-21 Daily fish counts of sucker species and northern pike at the Muskeg River Fish fence, May 2009.



Note: shaded areas indicate dates when maximum daily temperature was greater than 10ºC (temperature cue for white sucker spawning run [RAMP 2004, RAMP 2007]).

Figure 5.2-22 Daily fish counts of white sucker, longnose sucker, and northern pike at the Muskeg River fish fence moving upstream, 2003, 2006, 2009.



Note: dashed line indicates period of fish fence operation.

Figure 5.2-23 Number of white sucker captured at the Muskeg River fish fence, per day by sex and direction of movement, May 2009.

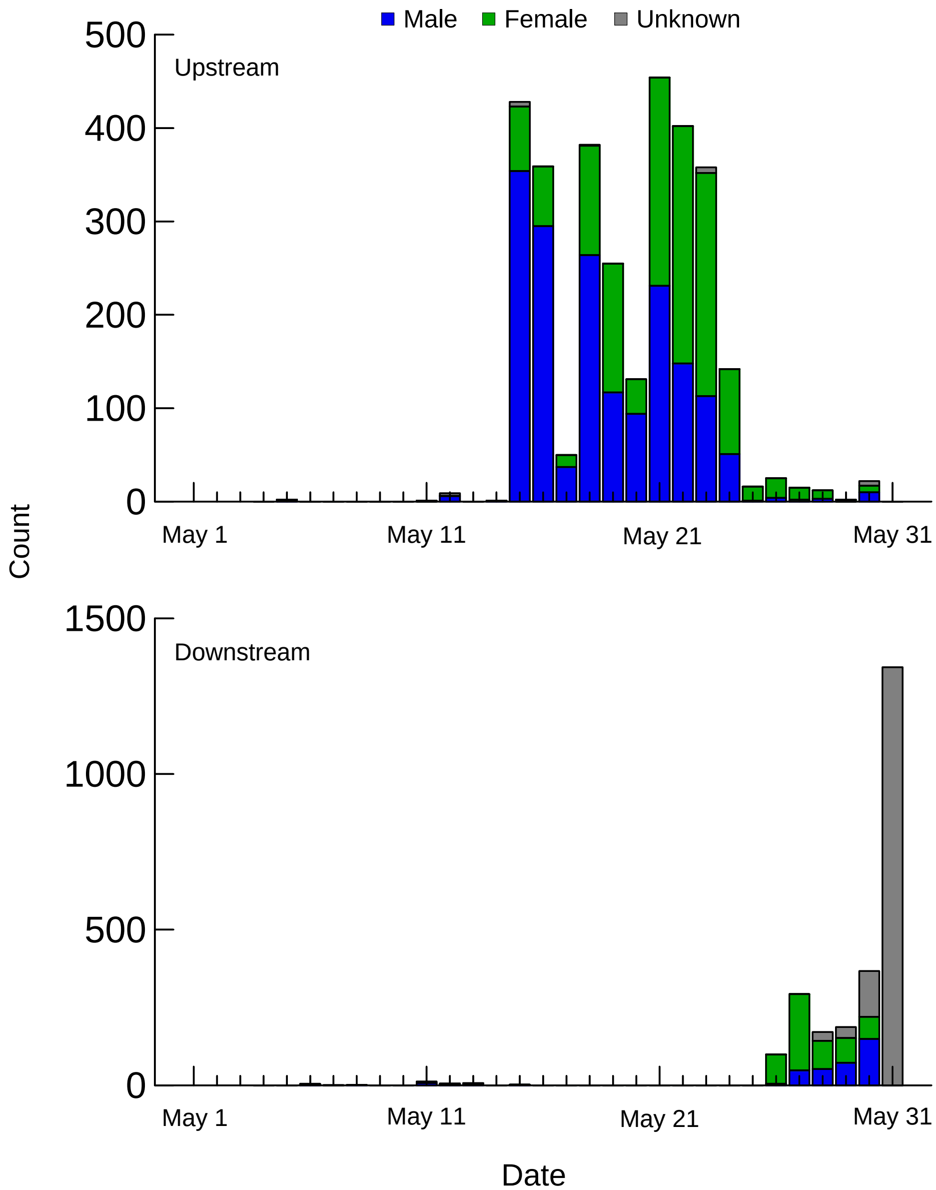


Figure 5.2-24 Reproductive status of all fish with identifiable sex captured at the Muskeg River fish fence and direction of migration.

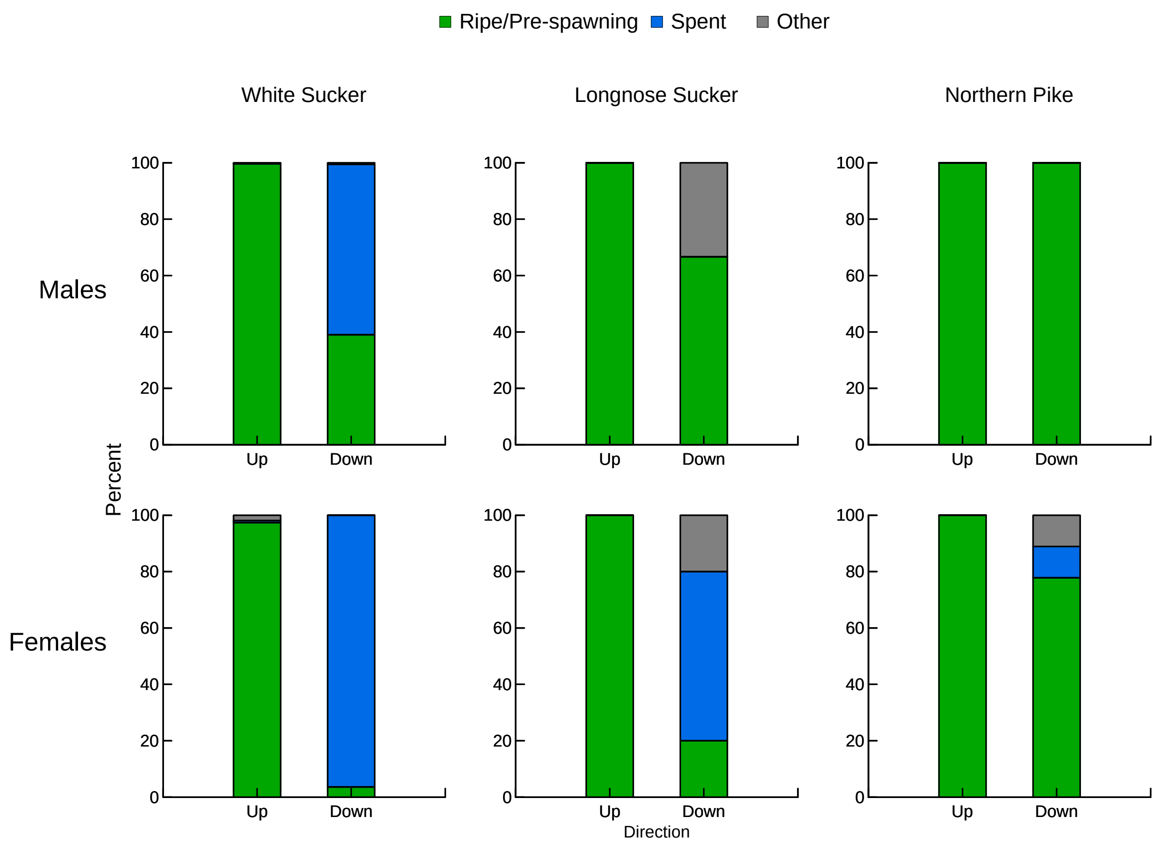


Figure 5.2-25 Relative length-frequency distributions of male, female and unknown white sucker captured at the Muskeg River fish fence moving upstream and downstream, May 2009.

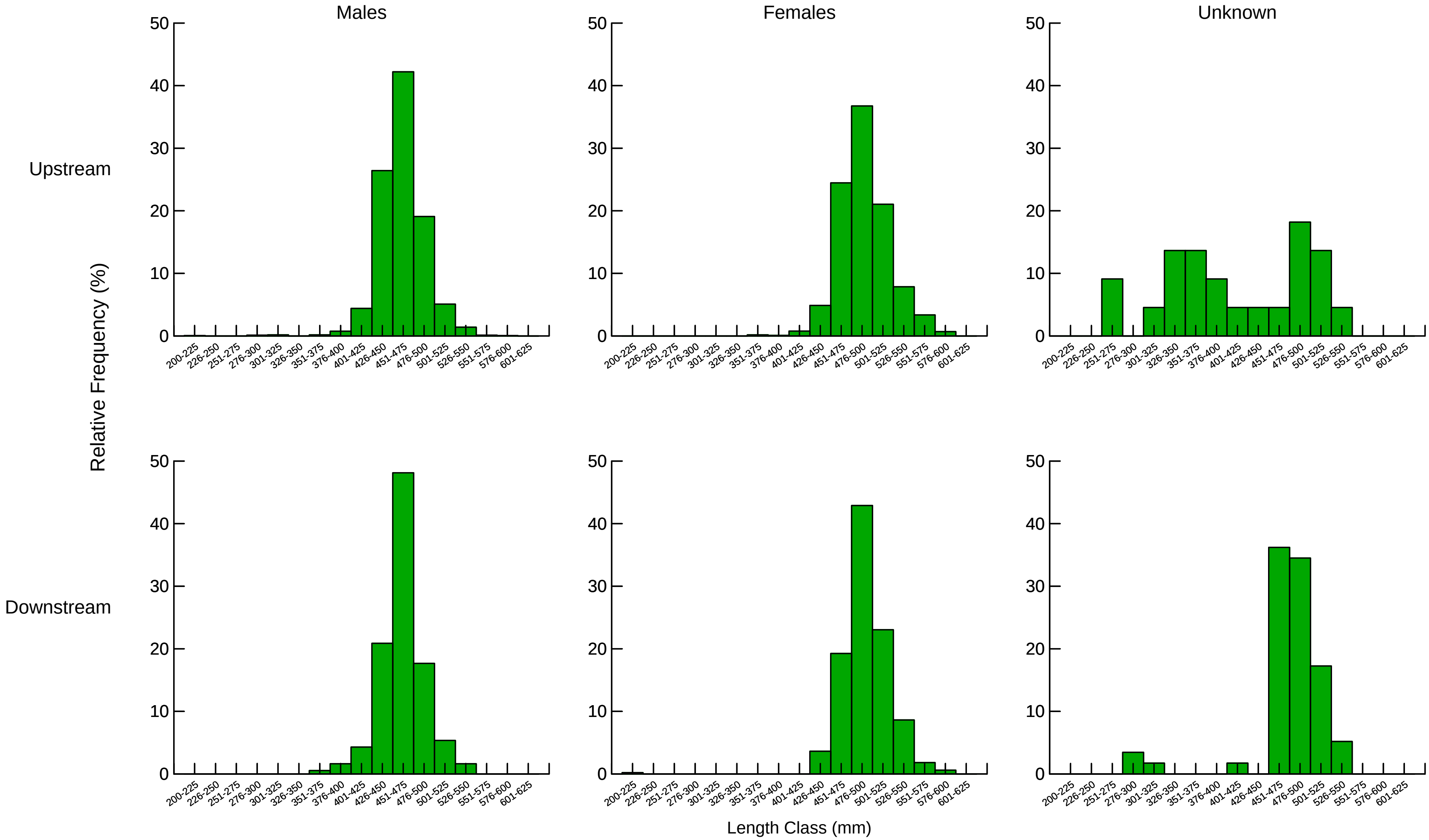


Figure 5.2-26 Mean age (±1SE) of male white sucker, longnose sucker, and northern pike captured in the Muskeg River fish fence, 2003, 2006, 2009 (letters denote significant differences at α=0.05).

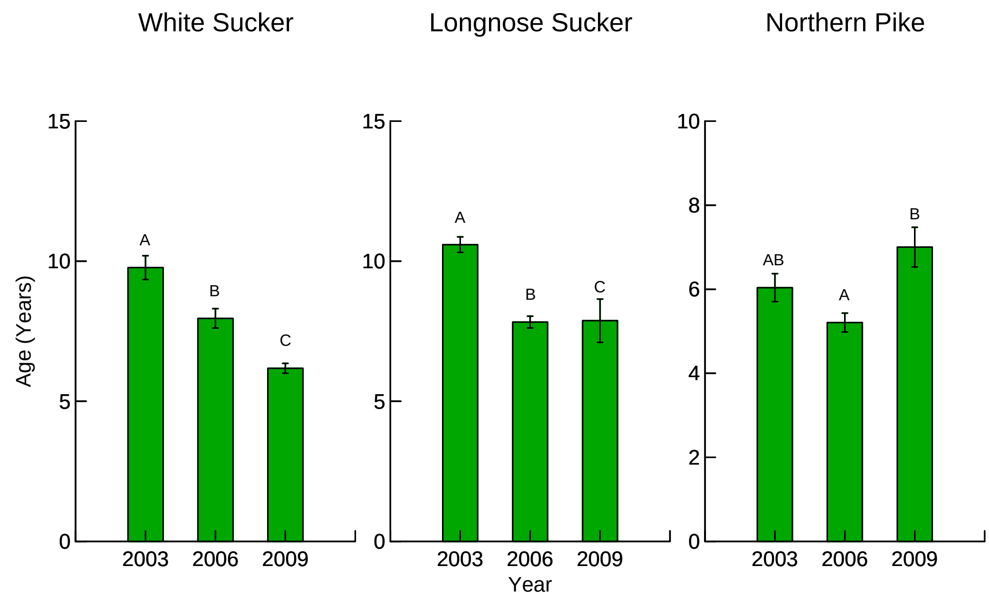


Figure 5.2-27 Mean age (±1SE) of female white sucker, longnose sucker, and northern pike captured in Muskeg River fish fence, 2003, 2006, 2009 (letters denote significant differences at α=0.05).

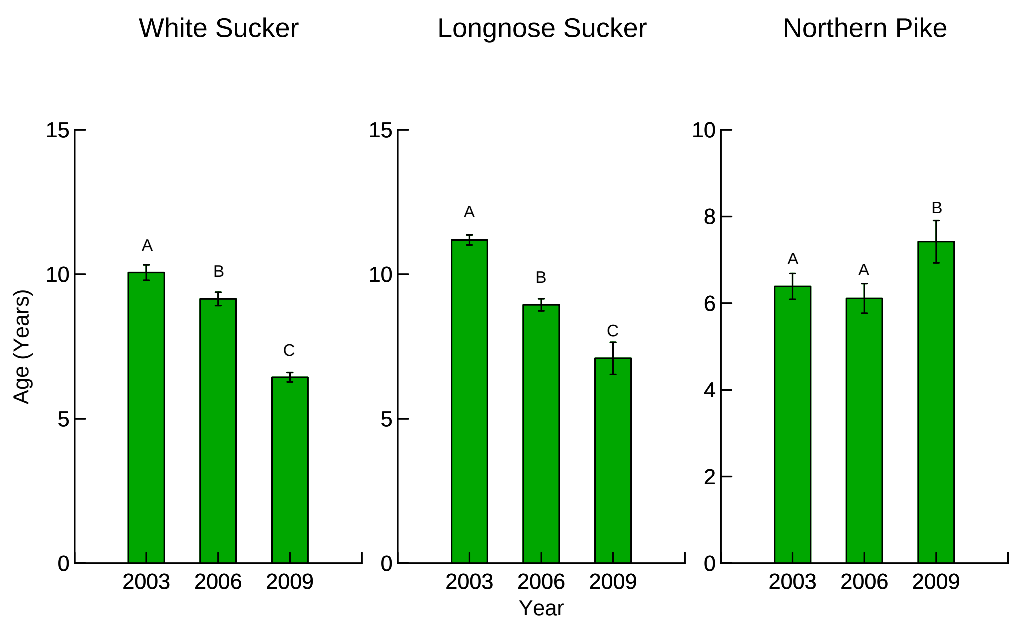


Figure 5.2-28 Length-at-age relationship for male (■) and female (●) white sucker (WHSC), longnose sucker (LNSC), and northern pike (NRPK) sampled at the Muskeg River fish fence, spring 2009.

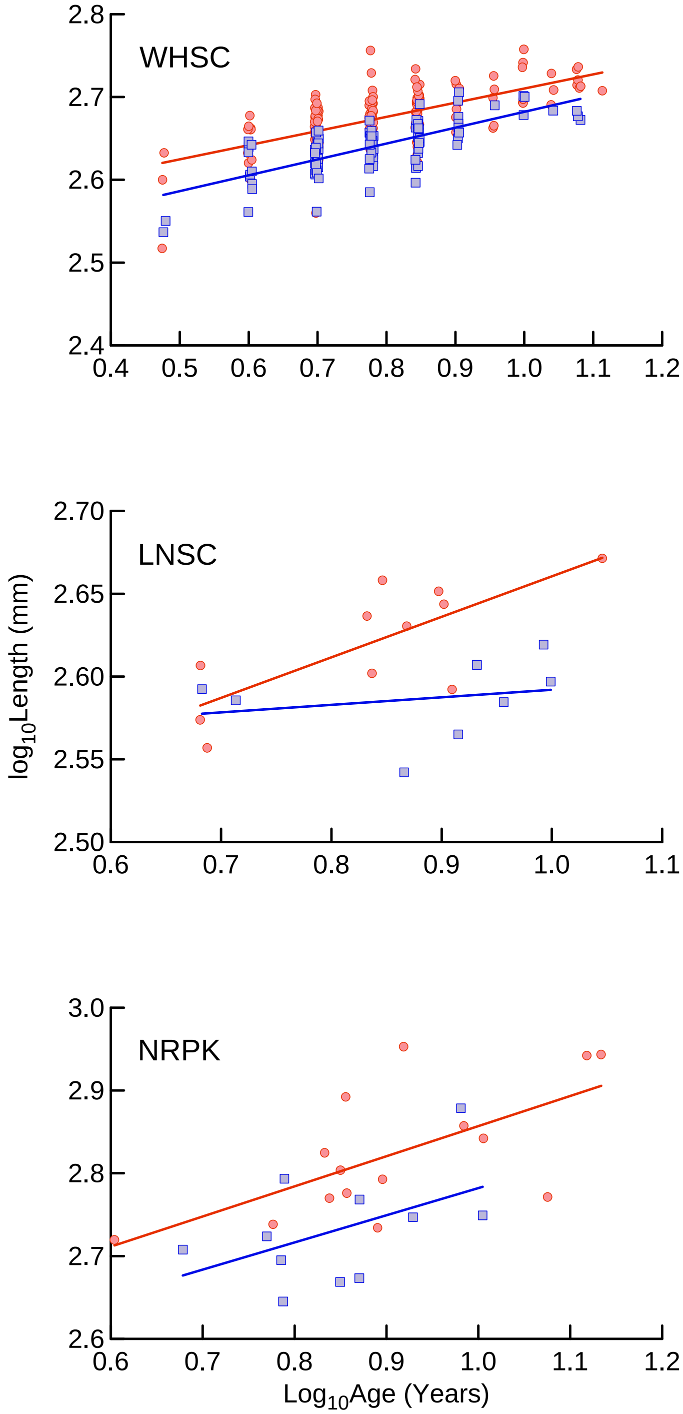


Figure 5.2-29 Length-weight relationship for male (■) and female (●) white sucker (WHSC), longnose sucker (LNSC), and northern pike (NRPK) sampled at the Muskeg River fish fence, spring 2009.

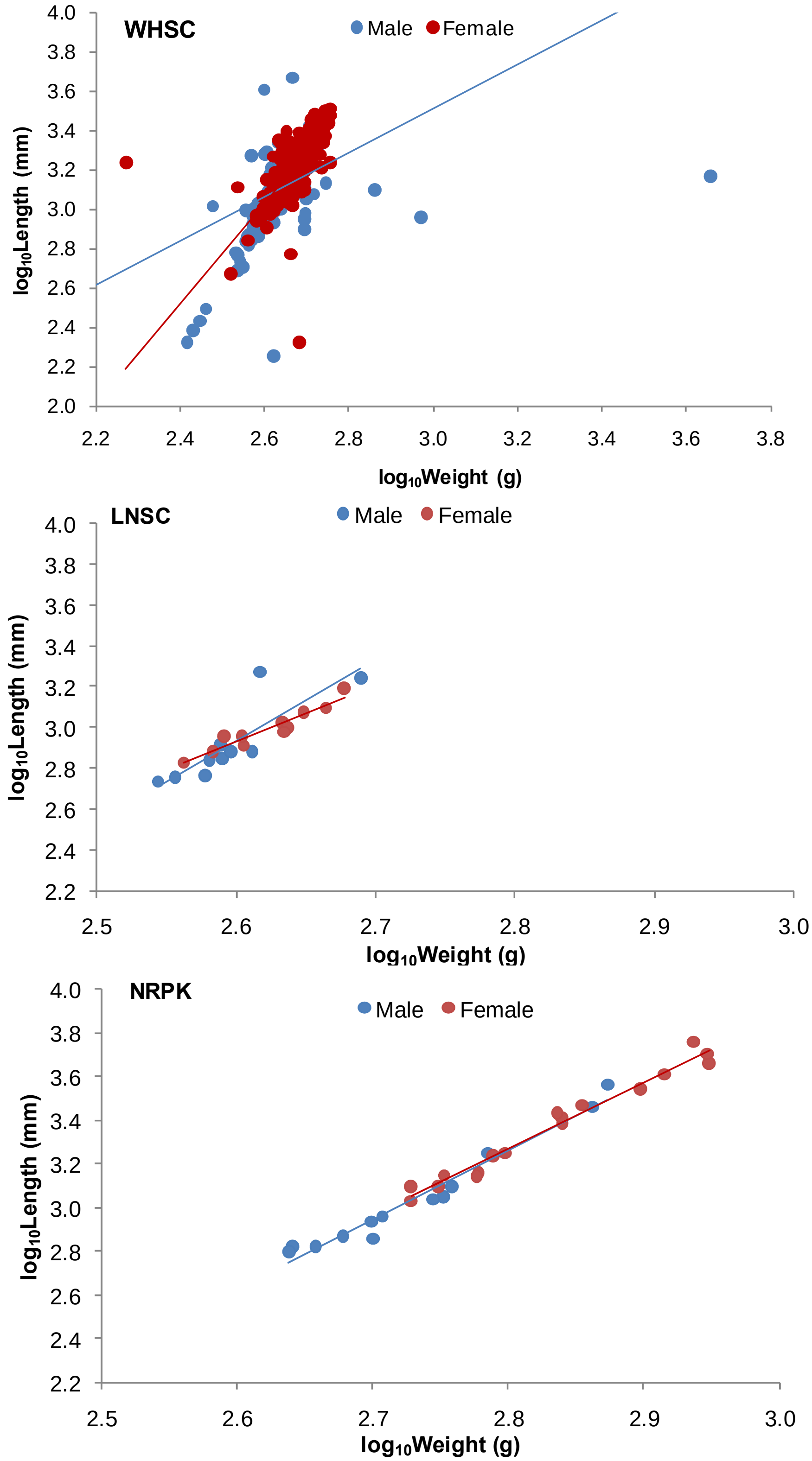


Figure 5.2-30 Mean condition (±1SE) in female and male white sucker captured moving upstream and downstream of the Muskeg River fish fence, May 2009.

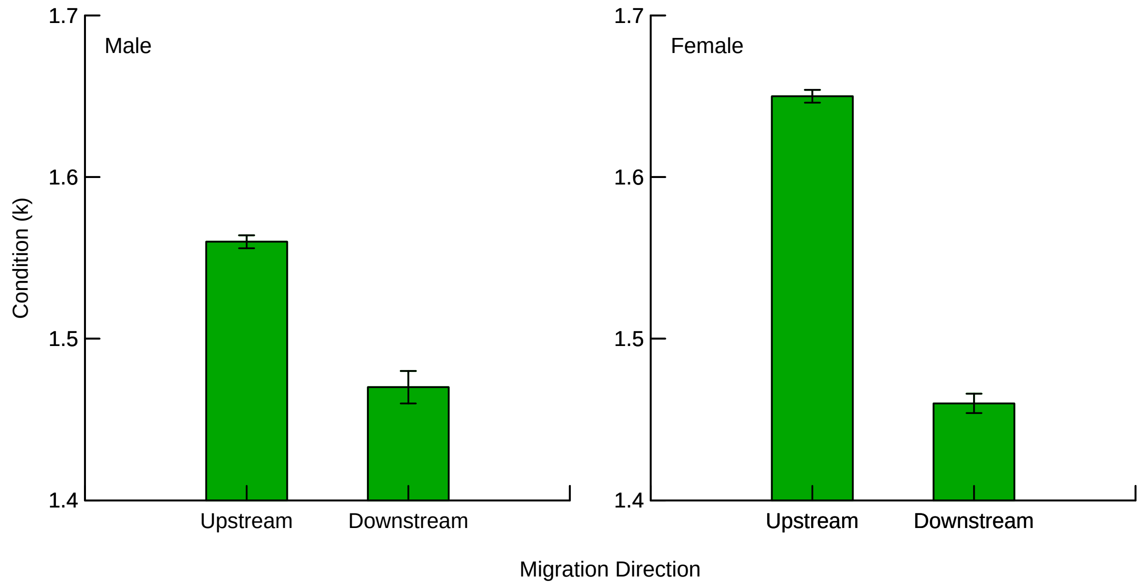


Table 5.2-37 Summary of incidence and severity of external pathology observed in white sucker (WHSC), longnose sucker (LNSC), and northern pike (NRPK) captured in the Muskeg River fish fence, 2009.

Feature	Severity[1]	Total	%	Upstream			Downstream		
				WHSC	LNSC	NRPK	WHSC	LNSC	NRPK
Fin Erosion	1	3,462	88.81	2,714	19	23	668	9	29
	2	326	8.36	270	0	0	54	0	2
	3	89	2.28	67	1	0	20	0	1
	4	21	0.54	18	0	1	2	0	0
Eye damage or swelling	1	3,896	99.95	3,067	20	24	744	9	32
	2	1	0.03	1	0	0	0	0	0
	3	1	0.03	1	0	0	0	0	0
	4	0	0.00	0	0	0	0	0	0
Gill damage	1	3,894	99.90	3,068	20	23	742	9	32
	2	1	0.03	0	0	1	0	0	0
	3	3	0.08	1	0	0	2	0	0
	4	0	0.00	0	0	0	0	0	0
Operculum erosion	1	3,890	99.79	3,064	20	24	741	9	32
	2	3	0.08	2	0	0	1	0	0
	3	4	0.10	2	0	0	2	0	0
	4	1	0.03	1	0	0	0	0	0
Pseudobranch damage	1	3,898	100.00	3,069	20	24	744	9	32
	2	0	0.00	0	0	0	0	0	0
	3	0	0.00	0	0	0	0	0	0
	4	0	0.00	0	0	0	0	0	0
Skin aberration	1	3,420	87.74	2,664	20	23	677	8	28
	2	384	9.85	325	0	1	53	1	4
	3	68	1.74	56	0	0	12	0	0
	4	26	0.67	24	0	0	2	0	0

* Fish that were counted but not measured were not evaluated for external pathology (WHSC-1,805, LNSC-7, NRPK-14 moving downstream).

[1] Severity scale: 1=normal, 2=light, 3=moderate, 4=severe.

Table 5.2-38 Other fish species captured during the operation of the 2009 Muskeg River fish fence.

Species	Date Captured	Direction of Migration	Sex	Stage	Fork Length (mm)	Total Weight (g)	Condition Factor	Age (years)
Lake whitefish	May 6	Upstream	U	U	364	800	1.66	n/a
Arctic grayling	May 7	Downstream	M	R	264	170	0.92	n/a
Walleye	May 9	Upstream	M	R	481	940	0.84	10
Lake whitefish	May 14	Downstream	U	U	386	790	1.37	n/a
Arctic grayling	May 28	Downstream	U	U	255	200	1.21	3
Walleye	May 30	Upstream	U	Sp	437	650	0.78	7

U = Unknown; R – ripe; Sp – spent; n/a = not available

Table 5.2-39 Summary of spring migration fish counts for large-bodies fish species at fish fences in the Muskeg River, 1976-2009.

Species	1976[1]		1977[2]		1995[3]		2003[4]		2006[5]		2009	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
Arctic grayling	305	78	161	11	14	49	1	1	2	0	0	2
Bull trout	0	0	3	0	0	0	0	0	0	0	0	0
Burbot	1	2	1	0	0	0	0	0	0	0	0	0
Cisco	0	0	1	0	0	0	0	0	0	0	0	0
Lake whitefish	3	14	7	6	0	0	0	2	7	1	1	1
Longnose sucker	2,837	2,191	1,641	1,004	308	36	162	47	668	6	20	15
Mountain whitefish	33	101	50	17	0	0	4	0	2	1	0	0
Northern pike	131	155	433	59	126	3	79	27	127	8	24	32
Walleye	4	3	8	5	1	0	0	2	2	1	1	0
White sucker	2,839	1,669	2,970	1,385	299	1	647	234	422	9	3,069	2,491
Total	**6,153**	**4,213**	**5,275**	**2,487**	**748**	**89**	**893**	**313**	**1,230**	**26**	**3,115**	**2,541**

[1] Fish fence operated near the mouth of the river from April 28 to July 30, 1976 (Bond and Machniak 1977).

[2] Fish fence operated near the mouth of the river from April 28 to June 15, 1977 (Bond and Machniak 1979).

[3] Fish fence operated 16.5 km upstream of the mouth of the river from May 6 to 31, 1995 (Golder 1996).

[4] Results from 2003 RAMP fish fence (RAMP 2004).

[5] Results from 2006 RAMP fish fence (RAMP 2007).

This page intentionally left blank for printing purposes.

5.3 STEEPBANK RIVER WATERSHED

Table 5.3-1 Summary of results for Steepbank River watershed.

Steepbank River Watershed	Summary of 2009 Conditions			
	Steepbank River			*North Steepbank River*
Climate and Hydrology				
Criteria	**S38** near Fort McMurray			
Mean open-water season discharge	○			
Mean winter discharge	○			
Annual maximum daily discharge	○			
Minimum open-water season discharge	○			
Water Quality				
Criteria	**STR-1** at the mouth	**STR-2** upstream of Project Millennium	**STR-3** upstream of North Steepbank River	**NSR-1** North Steepbank River
Water Quality Index	○	○	○	○
Benthic Invertebrate Communities and Sediment Quality				
Criteria	**STR-E-1** lower reach	no reach sampled	**STR-E-2** upper reach	no reach sampled
Benthic Invertebrate Communities	○		n/a	
No Sediment Quality component activities conducted in 2009				
Fish Populations				
Criteria	**STR-E** vicinity of Steepbank Mine	**STR-R** upstream of Project Millennium	no reach sampled	no site sampled
± 10% change between condition of fish from *test* and *baseline* sites	not enough data to compare against the criteria	○		

Legend and Notes

○ Negligible - Low

○ Moderate

○ High

baseline

test

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

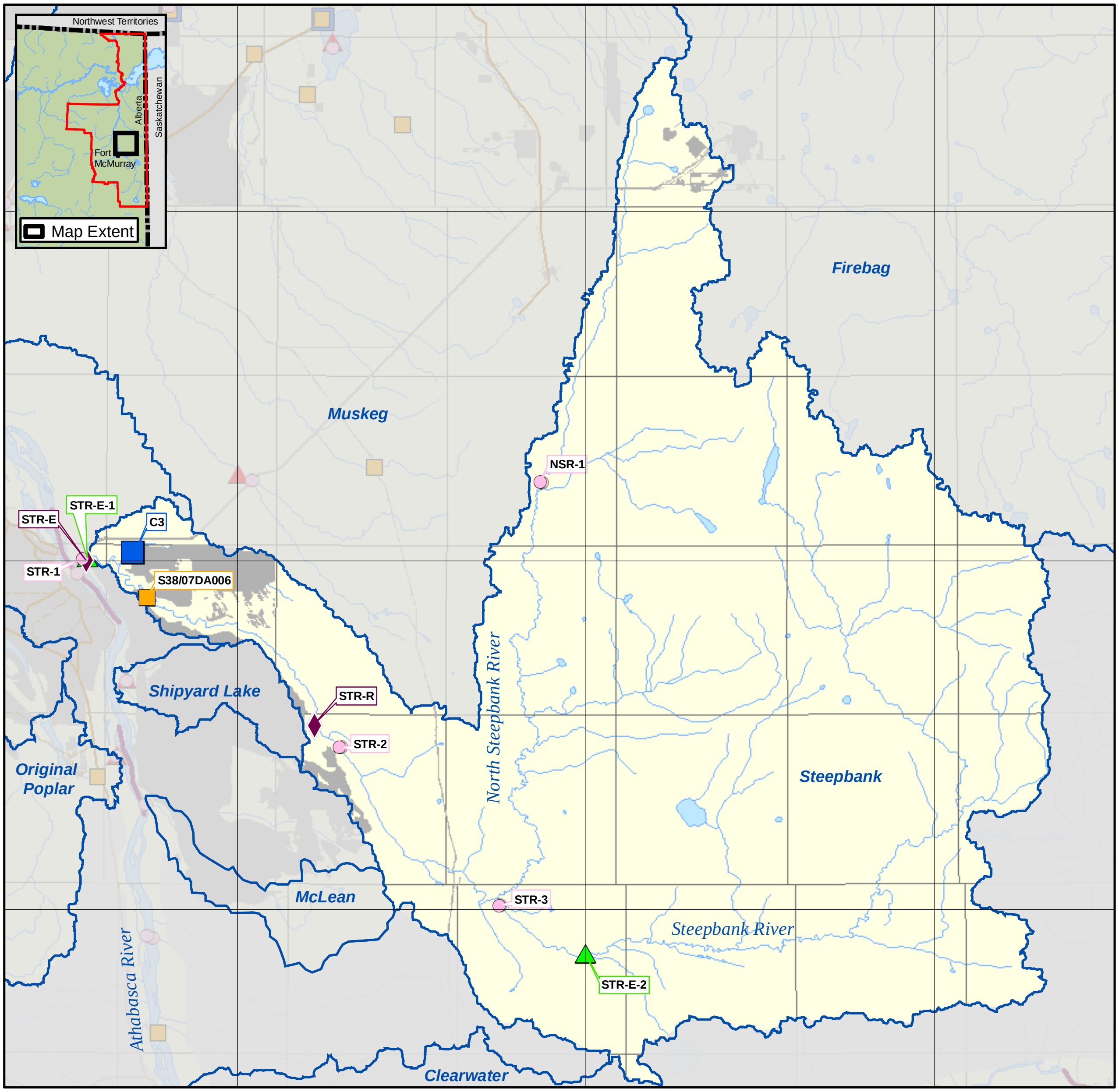
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Fish Populations: Uses Environmental Effects Monitoring Criteria developed by Environment Canada (2005) and concentrations of various substances, see Section 3.4.7.3 for a detailed description of the classification methodology.

Figure 5.3-1 Steepbank River watershed.



LEGEND

Lake/Pond	Climate Station
River/Stream	Hydrometric Station
Watershed Boundary	Water Quality Sampling Station
Major Road	Benthic Invertebrate Community Sampling Reach
Secondary Road	Benthic Invertebrate Community Sampling Reach and Sediment Quality Sampling Station
Railway	Sediment Quality Sampling Station
First Nations Reserve	Fish Sampling Site
RAMP Regional Study Area	Fish Sampling Reach
RAMP Focus Study Area	
Land Change Area	

Regional Aquatics Monitoring Program

0 2.5 5 10 Km

Scale 1:380,000

Projection: UTM Zone 12 NAD83

Land Change Areas Delineated from 10m SPOT-5 (June, July and August 2009) Multispectral Imagery.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K03_Steepbank_20100415.mxd

Figure 5.3-2 Representative monitoring stations of the Steepbank River, fall 2009.

Water Quality Station STR-1: Right Downstream Bank

Water Quality Station STR-1: Left Downstream Bank

Water Quality Station STR-2: Right Downstream Bank

Water Quality Station STR-3: Right Downstream Bank

5.3.1 Summary of 2009 Conditions

Approximately 2.6% (3,500 ha) of the Steepbank River watershed had undergone land change as of 2009 from focal projects (Table 2.4-2), and much of this land change is concentrated in the lower portion of the watershed. The designations of specific areas of the watershed for 2009 are as follows:

1. The Steepbank River watershed downstream of the Suncor oil sands developments (Figure 5.3-1) is designated as *test*.

2. The remainder of the watershed is designated as *baseline*.

Table 5.3-1 is a summary of the 2009 assessment for the Steepbank River watershed, while Figure 5.3-1 is a detailed map of the Steepbank River watershed, indicating the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.3-2 contains fall 2009 photos of water quality monitoring stations in the watershed.

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.14% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low**.

Water Quality Concentrations of a number of water quality measurement endpoints in the Steepbank River watershed in fall 2009 were outside the range of previously-measured values, and a smaller number had concentrations outside the range of regional *baseline* concentrations. The ionic composition at all water quality monitoring stations in the watershed in fall 2009 was consistent with previous years and continued to exhibit little temporal variation. Differences in water quality in fall 2009 at all four stations monitored in the Steepbank River watershed compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**.

Benthic Invertebrate Communities The benthic invertebrate community of *test* reach STR-E-1 in the Steepbank River differs in composition from *baseline* reach STR-E-2. However, all statistical reach-year differences in measurement endpoints between *test* reach STR-E-1 and *baseline* reach STR-E-2 were either insignificant or weaker than the background "noise". In addition, values of all benthic measurement endpoints in 2009 were within regional *baseline* values for erosional reaches. These results indicated **Negligible-Low** differences in benthic invertebrate community conditions in the Steepbank River watershed from regional *baseline* conditions.

Fish Populations Previous monitoring studies and results from the 2009 sentinel species monitoring study suggested that the abundance and recruitment of young individuals in the slimy sculpin population at *test* site STR-E is lower compared to *baseline* sites. Although other fish species were captured at this site, the 2009 results and historical sentinel species studies suggests that this site does not provide optimal conditions for slimy sculpin. The absence of slimy sculpin in summer and low sample size in fall at *test* site STR-E prevented an accurate classification of results based on the impact criterion established by Environment Canada (2005). Differences in condition of slimy sculpin at *test* site MR-E relative to *baseline* sites were assessed as **Moderate**, due to an exceedance greater than 10% in the average condition of slimy sculpin from the average condition of slimy sculpin at *baseline* sites but exceedances were not observed across sampling years. In addition, the abundance of young of year slimy sculpin was highest at *test* site MR-E indicating the presence of suitable habitat for young slimy sculpin and good recruitment of young individuals to the population. Differences in condition of adult slimy sculpin at *test* site STR-R relative to *baseline* sites was assessed as **Negligible-Low** given the difference in average condition of fish between this site and the *baseline* sites was less than ±10%. Comparisons across years for this site was not included in the classification of results because this site was only designated as *test* in 2008, and previous sentinel species monitoring was conducted prior to 2008.

5.3.2 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 070A006 (RAMP Station S38), Steepbank River near Fort McMurray 2009 was the first year since the 1974 to 1986 monitoring period with continuous annual data collection for WSC Station 07DA006 (RAMP Station S38). In 2009, the open-water runoff volume (166 million m^3), open-water maximum daily flow (50.3 m^3/s), and open-water minimum daily flow (2.9 m^3/s) were 19%, 44% and 71% higher, respectively, than their historical mean values. Flows at WSC Station 07DA006 (RAMP Station S38) were near historical median values for most of 2009 (Figure 5.3-3). The exceptions were late April following snowmelt (in upper quartile range), late June in response to the rainfall event in late June described in Section 4 (above historical maximum values), following a smaller rain event on August 24 (in the upper quartile range), and throughout November and December (above historical upper quartile or historical maximum values).

Differences Between Observed *Test* Hydrograph and Estimated B*aseline* Hydrograph
The estimated water balance at WSC Station 07DA006 (RAMP Station S38) is provided in Table 5.3-2 and described below:

1. The closed-circuited land area from focal projects as of 2009 was estimated at 4.3 km^2 (Table 2.4-1). The loss of flow to the Steepbank River that would have otherwise occurred from this land area is estimated at 0.67 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 30.8 km^2 (Table 2.4-1). The increase in flow to the Steepbank River that would not have otherwise occurred from this land area is estimated at 0.96 million m^3.

The estimated cumulative effect of land change is an increase in flow of 0.29 million m^3 in 2009 for WSC Station 07DA006 (RAMP Station S38). The estimated *baseline* hydrograph at WSC Station 07DA006 (RAMP Station S38) is presented in Figure 5.3-3. The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.14% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.3-3). These differences are classified as **Negligible-Low** (Table 5.3-1).

5.3.3 Water Quality

In fall 2009, water quality samples were taken from:

- the mouth of the Steepbank River (*test* station STR-1, sampled from 1997 to 2009);
- Steepbank River upstream of Suncor's oil sands developments (*test* station STR-2, designated as *test* in 2008, sampled from 2002 to 2009);
- Steepbank River upstream of the confluence with the North Steepbank River (*baseline* station STR-3, sampled from 2004 to 2009); and
- North Steepbank River (*test* station NSR-1, designated as *test* in 2008, sampled from 2002 to 2009).

All stations were sampled in fall 2009. Winter water quality sampling was conducted only at *test* station STR-1 in 2009.

2009 Results Relative to Historical and Regional *Baseline* Concentrations
Concentrations of all water quality measurement endpoints in fall 2009 at *test* stations STR-1, STR-2, and NSR-1 were within historical ranges and regional *baseline* concentrations (Table 5.3-4, Table 5.3-5,Table 5.3-7, Figure 5.3-4) with the exception of:

- ultra-trace mercury with a concentration that exceeded the previously-measured maximum value at *test* station STR-1 and the 95th percentile of regional *baseline* concentrations;

- total nitrogen with a concentration that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-1 but was within the range of previously-measured values;

- dissolved organic carbon with a concentration that exceeded previously-measured maximum concentrations at *test* stations STR-2 and NSR-1;
- total nitrogen and calcium with concentrations that exceeded previously-measured maximum concentrations at *test* station NSR-1 but within regional *baseline* concentrations;
- total arsenic and sulphate with concentrations above and below their regional *baseline* concentrations, respectively, at *test* station NSR-1;
- total nitrogen with a concentration that exceeded the previously-measured maximum concentration at *test* station STR-2; and
- naphthenic acids with concentrations below regional *baseline* concentrations at all stations due to greatly improved detection limits for this analysis in 2009.

The concentration of dissolved organic carbon exceeded the previously-measured maximum concentration and concentrations of sodium, calcium, magnesium, chloride and sulphate were below previously-measured minimum concentrations but within regional *baseline* concentrations in fall 2009 at *baseline* station STR-3 (Table 5.3-6, Figure 5.3-4).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of all water quality measurement endpoints in fall 2009 measured in the Steepbank River were below water quality guidelines (Table 5.3-4 to Table 5.3-6) with the exception of total nitrogen at *test* stations STR-1 and STR-2 and *baseline* station STR-3 and total aluminum at *test* stations STR-1 and STR-2. The concentration of (bioavailable) dissolved aluminum at these two stations was below the water quality guideline for aluminum (Table 5.3-4, Table 5.3-5).

Other Water Quality Guideline Exceedances The following additional water quality guideline exceedances were observed in the Steepbank River watershed in 2009 (Table 5.3-8):

- total iron at *test* station STR-1 in winter;
- dissolved iron, total iron, and sulphide at all four stations in fall; and
- total phenols and total Kjeldahl nitrogen at *test* stations STR-1 and STR-2 and *baseline* station STR-3 in fall.

Ion Balance In fall 2009, the ionic composition of all stations in the Steepbank River watershed was dominated by calcium and bicarbonate ions (Figure 5.3-5). The ionic composition at all stations in the Steepbank River watershed has remained consistent since 1997.

Trend Analysis Sufficient data existed as of 2009 for statistical trend analysis of fall water quality data for *test* stations STR-1 (n=12) and STR-2 (n=8) and *test* station NSR-1 (n=8). The only significant trends were decreases in sulphate concentration at *test* stations STR-1 (α=0.05) and STR-2 (α=0.05).

Water Quality Index The WQI values for all stations in the Steepbank River watershed indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.3-9).

Summary Concentrations of a number of water quality measurement endpoints in the Steepbank River watershed in fall 2009 were outside the range of previously-measured values, and a smaller number had concentrations outside the range of regional *baseline* concentrations. The ionic composition at all water quality monitoring stations in the watershed in fall 2009 was consistent with previous years and continued to exhibit little temporal variation. Differences in water quality in fall 2009 at all four stations monitored in the Steepbank River watershed compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**.

5.3.4 Benthic Invertebrate Communities and Sediment Quality

5.3.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in the upper and lower reaches of the Steepbank River. The lower *test* reach (STR-E-1, erosional) has been sampled since 1998, while the upper *baseline* reach (STR-E-2, erosional) has been sampled since 2004.

2009 Habitat Conditions *Test* reach STR-E-1 in fall 2009 was deep (1 m), fast-flowing (0.7 m/s), had a substrate dominated by small cobble with smaller amounts of large gravel large cobble, and sand/silt/clay, and no macrophytes (Table 5.3-10). The concentration of dissolved oxygen in *test* reach STR-E-1 was greater than both the acute and chronic guideline for protection of aquatic life (AENV 1999b). Periphyton biomass in *test* reach STR-E-1 averaged 132 mg/m^2 in fall 2009, which is within the range of regional *baseline* levels of periphyton (Figure 5.3-6).

Baseline reach STR-E-2 was shallow (0.2 m), fast-flowing (0.85 m/s), had a substrate dominated by small cobble with smaller amounts of large cobble large gravel, and sand/silt/clay, and a small amount of macrophyte cover (Table 5.3-10). The concentration of dissolved oxygen in *baseline* reach STR-E-2 was also greater than both the acute and chronic guideline for protection of aquatic life (AENV 1999b). Periphyton biomass in *baseline* reach STR-E-2 averaged 527 mg/m^2, which is greater than the range of regional *baseline* levels of periphyton (Figure 5.3-6). Periphyton biomass has increased over the last three years at *baseline* reach STR-E-2.

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach STR-E-1 was dominated by chironomids (41%) and mayflies (Ephemeroptera, 30%, Table 5.3-11). The chironomid taxa were diverse, consisting of common forms such as *Tanytarsus*, *Rheotanytarsus*, and *Polypedilum*, as well as other forms that are more restricted to clean and cold water such as *Tvetenia*, *Synorthocladius* and *Eukiefferiella*. The mayfly taxa were also diverse and included the widely-distributed *Baetis*, as well as forms restricted to fast-flowing waters such as *Heptagenia* and *Ephemerella*. Other sensitive taxa present included the Plecopteran stonefly *Nemoura* and the Trichopteran caddisfly *Lepidostoma*.

The benthic invertebrate community of *baseline* reach STR-E-2 was dominated by chironomids (41%) and mayflies (30%, Table 5.3-11). Similar to *test* reach STR-E-1, the chironomids of *baseline* reach STR-E-2 contained both widely-distributed forms such as *Polypedilum*, *Cricotopus*/*Orthocladius* and *Rheotanytarsus*, as well as those more typically associated with clean and cold water such as *Tvetenia* and *Lopesocladius*. Other sensitive taxa present included mayflies such as *Baetis* and *Drunella grandis*, stoneflies *Zapada*, and caddisflies *Brachycentrus*, *Lepidostoma* and *Micrasema*.

Abundance, taxa richness, Simpson's diversity, evenness, and %EPT in fall 2009 in both reaches were within their range of natural variation for *baseline* erosional reaches in the RAMP FSA (Figure 5.3-7). *Test* reach STR-E-1 had lower total abundance, lower number of taxa, and lower %EPT taxa than *baseline* reach STR-E-2 in fall 2009.

The Correspondence Analysis results (Figure 5.3-8) indicated a difference in benthic invertebrate community composition between *test* reach STR-E-1 and *baseline* reach STR-E-2, with *baseline* reach STR-E-2 having higher relative abundances of tipulids, Trichoptera and Plecoptera and *test* reach STR-E-1 generally having more naidid and tubificid worms, and fewer tipulids. Relative taxa abundance (Table 5.3-11) suggests these differences are subtle.

Linear contrasts were used to test for a difference in time trends of measurement endpoints for benthic invertebrate communities between *baseline* reach STR-E-2 and *test* reach STR-E-1 (i.e., TT x BT in Table 5.3-12). With the exception of CA Axis 2, there is no significant difference in time trends of benthic invertebrate community measurement endpoints between *test* reach STR-E-1 and *baseline* reach STR-E-2 (Table 5.3-12). The "remainder (noise)" term is larger than the TT x BT term for CA Axis 2, indicating that the difference in time trends for this measurement endpoint was not strong.

In 2008, the benthic invertebrate communities in the upper and lower reaches of the Steepbank River were significantly different with respect to total abundance, number of taxa and %EPT (RAMP 2009a). In 2009, the differences between *baseline* reach STR-E-2 and *test* reach STR-E-1 were evident, but not significant as well as differences from regional *baseline* conditions indicating a **Negligible-Low** difference from regional *baseline* conditions.

Summary

The benthic invertebrate community of *test* reach STR-E-1 in the Steepbank River differed in composition from *baseline* reach STR-E-2. However, all statistical reach-year differences in measurement endpoints between *test* reach STR-E-1 and *baseline* reach STR-E-2 were either insignificant or weaker than the background "noise" component of these differences. In addition, values of all benthic measurement endpoints in 2009 were within regional *baseline* values for erosional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Steepbank River watershed from regional *baseline* conditions.

5.3.4.2 Sediment Quality

No sediment quality sampling was conducted in the Steepbank River in 2009 because both reaches of the Steepbank River where benthic invertebrate communities were sampled are erosional and sediment quality is only sampled in depositional reaches in which benthic invertebrate communities are sampled.

5.3.5 Fish Populations

Fish Population component studies in the Steepbank River in 2009 consisted of sentinel species monitoring using slimy sculpin (*Cottus cognatus*). The Steepbank River watershed was one of four watersheds used in the 2009 sentinel species monitoring, and the results of the entire 2009 sentinel species monitoring activity are presented and discussed below.

The sentinel species monitoring sites designated as *test* for 2009 were:

- the lower Muskeg River, approximately 0.2 to 0.6 km upstream of the confluence with the Athabasca River (MR-E);
- the lower Steepbank River (STR-E) adjacent to the Steepbank Mine (Millenium Project) operations; and
- the upper Steepbank River (STR-R) upstream of Suncor's oil sands developments.

The upper Steepbank River site (STR-R) was designated as *test* for the first time in 2008 because of focal projects upstream of the site location. Therefore, the analyses for the 2009 sentinel species monitoring program will be conducted with three *test* sites and two *baseline* sites, compared to previous programs where the upper Steepbank River site was designated as *baseline*. Comparisons between the 2006 and 2009 sentinel species programs will be conducted at the upper Steepbank River site (STR-R) to assess for changes between before and after oil sands development.

The monitoring sites designated as *baseline* for 2009 were:

- the Horse River (HR-R) approximately 100 km upstream of the confluence with the Athabasca River; and
- the Dunkirk River (DR-R) approximately 25 km upstream of the confluence with the Athabasca River, located in the MacKay River watershed.

These sites were also sampled during the 2004 and 2006 non-lethal sentinel species monitoring activity (RAMP 2005, RAMP 2007). Lethal programs were conducted in 1999 at three of the five sites: *test* sites MR-E and STR-E; and *baseline* site STR-R (Golder 2000) and at all five sites in 2001 (Golder 2002).

5.3.5.1 Field Sampling Results

Aquatic Habitat

An aquatic habitat survey was conducted during the summer sampling event; detailed habitat results are provided in Appendix G and a summary is provided in Table 5.3-13 and below:

1. The channel morphology at *baseline* sites DR-R and HR-R was dominated by run habitat while the channel morphology at *test* sites STR-R, MR-E, and STR-E was dominated by riffle habitat.
2. Percent instream cover available for fish was high at *baseline* sites HR-R and *test* site STR-R, and lower at *baseline* site DR-R and *test* sites MR-E and STR-E. The highest proportion of instream cover was substrate (cobble and boulders) with little instream vegetation, woody debris or undercut banks at all sites.
3. Dissolved oxygen ranged from 9.56 mg/L (*baseline* site HR-R) to 12.28 mg/L (*test* site STR-R); water temperature ranged from 13.1°C (*test* site STR-R) to 18.2°C (*baseline* site DR-R); and conductivity ranged from 144.1 µs/cm (*baseline* site HR-R) to 336.0 µS/cm (*test* site MR-E).

Water temperature recorded continuously by data loggers deployed for the time period between the sampling events exhibited the same general pattern among sites (Figure 5.3-9). Higher temperatures were recorded at *test* site MR-E and *baseline* site DR-R compared to the Steepbank River *test* sites (STR-E and STR-R). Water temperature at *baseline* site HR-R was consistent with *test* site MR-R and *baseline* site DR-R until a sharp decrease at the beginning of September, after which the water temperature was consistent with both Steepbank River sites.

Fish Population

In 2009, the number of slimy sculpin collected at each site ranged from zero (*test* site STR-E) to 123 (*test* site MR-E) during the summer study and from six (*test* site STR-E) to 104 (*baseline* site HR-R) during the fall study (Table 5.3-14). The relative abundance of slimy sculpin was higher in summer than in fall for all sites with the exception of *test* site STR-E (Figure 5.3-10) where no slimy sculpin were captured in summer and only six were captured in fall. The relative abundance of slimy sculpin was highest at *test* site MR-E in both seasons.

5.3.5.2 Survival

A pairwise statistical analysis was used to compare slimy sculpin length-frequency distribution between all pairwise combinations of sampling sites (*test* and *baseline*). In 2009, all comparisons were significantly different in both summer and fall between sites ($p \leq 0.001$), indicating that slimy sculpin at each site had different ranges of abundance in each size class (Figure 5.3-11). *Test* site STR-E was excluded from these analyses given no slimy sculpin were captured at this site in summer and very few were captured in fall. Comparisons within each site between summer and fall were significantly different ($p \leq 0.01$), with the exception of *test* site STR-R ($p=0.04$)[1]. Slimy sculpin captured from *test* site STR-R had a similar length-frequency distribution in both seasons (Figure 5.3-11) while length-frequency distributions at all other sites exhibited a significant increasing shift from summer to fall (i.e., fish were longer in fall relative to summer). The absence of an increasing shift in length-frequency distribution at *test* site STR-R suggests little short-term survival and growth of slimy sculpin.

Reproductive performance and short-term survival can also be evaluated by comparing the proportion of YOY slimy sculpin relative to the total number of fish captured between summer and fall. The length-frequency distributions can be used to discriminate the YOY length class from other length classes (Gray *et al.* 2002) by identifying the first peak in the bimodal distribution (Figure 5.3-11). A length of 50 mm was used to discriminate YOYs from other year classes for all sites in summer. A length of 50 mm for YOYs was determined for *baseline* site HR-R and *test* site STR-R and a length of 60 mm was used for *baseline* site DR-R and *test* site MR-E in fall (Figure 5.3-11); there were no YOY slimy sculpin captured at *test* site STR-E in summer or fall. In contrast to results from 2006 where the proportion of YOY individuals decreased between sampling events, the proportion of YOY individuals was similar in both sampling seasons at all sites in 2009 (Figure 5.3-12), indicating good short-term survival. In both seasons, *test* site MR-E had a higher proportion of YOY slimy sculpin, compared to the *baseline* sites DR-R and HR-R. The *test* site STR-R had the lowest number of YOYs and there were no YOYs captured at *test* site STR-E suggesting poor recruitment to the population of young individuals at these two sites of the Steepbank River or limited habitat available for YOY individuals. A

[1] An adjusted significance level (α) was used to account for the increased likelihood of Type I errors (*i.e.*, false positives) when several statistical analyses are conducted; the adjusted α was 0.008 for spatial comparisons and 0.0125 for temporal comparisons.

low proportion of YOY slimy sculpin at *test* site STR-E in 2006 was also observed (RAMP 2007). Comparisons between before and after oil sands development at *test* site STR-R indicate that the proportion of YOY individuals decreased from 2006 (5.6% in summer, 34.9% in fall) to 2009 (2.9% in summer and 9.1% in fall).

5.3.5.3 Growth

Growth was evaluated by measuring the magnitude of change in mean length of the YOY size class between the summer and fall sampling events. The growth rate in YOY slimy sculpin ranged from 0.08 mm/day at *test* site STR-R to 0.25 mm/day at *test* site MR-E (Figure 5.3-12). Growth rates of slimy sculpin were similar at *baseline* site DR-R and *test* site MR-E and between *baseline* site HR-R and *test* site STR-R. Growth rates in slimy sculpin were not calculated for *test* site STR-E given no YOY sculpin were captured in either season. A summary of mean length and weight by season for each sampling site is provided in Table 5.3-16.

The growth rate of slimy sculpin was correlated with mean water temperature between the first and second sampling period (Figure 5.3-13). Sites where growth rates were higher (*baseline* site DR-R and *test* site MR-E) had higher mean water temperature between the two sampling periods. Lower water temperatures were recorded between sampling events at *test* site STR-R, where growth was the lowest.

Results from spatial comparisons of length and weight indicated that adult slimy sculpin captured during the summer sampling event were significantly longer and heavier at *baseline* site DR-R compared to the *test* sites STR-R, STR-E and MR-E ($p<0.05$) (Figure 5.3-14). In fall, slimy sculpin from *test* site MR-E were significantly heavier and longer than at *baseline* site HR-R and *test* site STR-E ($p<0.05$) (Figure 5.3-14). Results from temporal comparisons of length indicated that adult slimy sculpin captured in fall at *test* site STR-R were longer and heavier than adult slimy sculpin captured in summer at the same site ($p<0.05$) (Figure 5.3-14).

Results from spatial comparisons of length and weight indicated that YOY slimy sculpin were significantly longer at *baseline* site DR-R compared to the *test* site MR-E and slimy sculpin were heavier at *test* site MR-E than at *baseline* site HR-R and *test* site STR-R in summer ($p<0.05$) (Figure 5.3-15). In fall, the average length of YOY slimy sculpin was longest at *baseline* site DR-R and *test* site MR-E; a similar pattern was found in weight of slimy sculpin between sites. Results from temporal comparisons of length and weight indicated that YOY slimy sculpin were longer and heavier in fall than summer at all sites ($p<0.05$) with the exception of test site STR-R where there were no significant differences in length of slimy sculpin between sampling events ($p>0.05$) suggesting limited growth in the population (Figure 5.3-15).

5.3.5.4 Energy Storage

Condition factor is a standard measurement endpoint that is calculated for each fish as a ratio of fish length and weight (i.e., the “fatness” of a fish), and provides a measure of energy storage. An ANCOVA was conducted to statistically compare condition between sites and seasonal condition within a site for both adult and YOY individuals separately. There were no significant differences in slimy sculpin condition within any site across seasons.

The significant differences in condition of adult sculpin at *test* sites compared to *baseline* sites were[2] (Table 5.3-16, Figure 5.3-14):

1. In summer, condition of adult slimy sculpin at *test* site MR-E was 4.3% higher than adult slimy sculpin at *baseline* site HR-R, but similar to *baseline* site DR-R.
2. In fall, condition of adult slimy sculpin at *test* site MR-E was significantly lower than adult slimy sculpin at *baseline* site DR-R.
3. In summer, condition of adult slimy sculpin was significantly lower at test site STR-R than adult slimy sculpin at *baseline* site DR-R.
4. Condition of adult slimy sculpin at *test* site STR-R was significantly different between the summer and fall sampling events where individuals were longer and heavier (i.e., "fatter") in fall relative to summer.

In fall, there were no significant differences in condition of adult slimy sculpin at *test* site STR-E compared to *baseline* sites; however, this may be an artifact of low sample size (n=6). There were no slimy sculpin captured at this site in summer to perform any comparisons in condition factor.

The significant differences in condition of YOY sculpin at *test* sites compared to *baseline* sites were[3] (Table 5.3-16, Figure 5.3-15):

1. In summer and fall, condition in YOY sculpin was significantly higher at *test* site MR-E compared to *baseline* site HR-R.

There were no significant differences in condition of YOY slimy sculpin across seasons within each site ($p>0.01$). There were no YOY slimy sculpin captured at *test* site STR-E in either season to allow for statistical comparison with *baseline* sites.

Given *test* site STR-R was designated as *baseline* prior to 2008, comparisons between the 2006 and 2009 sentinel species programs indicate that condition of adult slimy sculpin was significantly lower in 2009 (summer K=1.15 and fall K=1.19) compared to summer (K=1.20) and fall (K=1.28) 2006 ($p<0.001$).

5.3.5.5 Discussion

Similarly to 2006, slimy sculpin captured at the *test* site MR-E were generally smaller in length and weight compared to individuals captured at the *baseline* sites in both summer and fall 2009. In addition, the *test* site MR-E also had the highest proportion of YOY individuals captured, suggesting increased recruitment to the population, and/or possible reduction in the number of older individuals. These results are in contrast to the 2001 and 2004 sentinel species studies (RAMP 2002, 2005) where there was a larger proportion of adult slimy sculpin at the *test* site MR-E compared to the *baseline* sites.

The difficulty in capturing slimy sculpin at *test* site STR-E has been evident in previous sentinel species studies (RAMP 2005, 2007) although the 2009 survey was the first year that no slimy sculpin were captured during the summer survey. Low reproductive

---

[2] Adjusted α values were used in the condition ANCOVAs and heterogenous slopes were evaluated following guidance in Barrett *et al.* (2009). The ANCOVA adjusted α values for adult condition were 0.008 for the August site comparisons and 0.005 for the October site comparisons.

[3] For the YOY size class, the adjusted significance level was 0.008 for both seasons for the site comparisons. Seasonal comparisons in fish condition at a given site used an adjusted α of 0.0125 for both adult and YOY size classes.

investment has been found in slimy sculpin at *test* site STR-E in the 2001 lethal sentinel survey where condition in slimy sculpin was elevated but gonad size was lower in both sexes (Golder 2001), potentially leading to population decline (Gibbons and Munkittrick 1994). Low reproductive success and survival of younger individuals was also observed at *test* site STR-R indicated by a small number of YOY individuals in the population relative to sites in other watersheds suggesting that the low catch numbers of YOY individuals occur throughout the watershed. The low abundance of young individuals was also observed in previous sampling years at *test* site STR-R, even when the site was designated as *baseline* (RAMP 2005, 2007).

In addition, the 2009 benthic invertebrate community results indicated that the abundance of benthic invertebrates was similar between the *baseline* sites HR-R and DR-R and *test* site STR-E but much lower compared to *test* site MR-E (note: *test* site STR-R used for the slimy sculpin survey was not the location of benthic invertebrate sampling in 2009, which took place further upstream to coincide with water quality sampling station STR-3). The highest abundance (~27,000) and species richness (n=43) of benthic invertebrates was observed at *test* site MR-E (see Section 5.2.4) with the lowest abundance (~4,500) and taxa richness (n=28) observed at *test* site STR-E. Food availability could be a limiting factor given the higher abundance of slimy sculpin and benthic invertebrates at *test* site MR-E compared to *test* site STR-E.

In contrast, water quality results from 2009 showed no significant differences in selected measurement endpoints between the sentinel species monitoring sites. The *test* sites STR-R, STR-E, and MR-E exhibited increases in concentrations of total nitrogen compared to regional *baseline* conditions, but all other measurement endpoints were within regional *baseline* concentrations (Figure 5.3-4 and Section 5.2.2). Higher levels of nutrients (i.e., total nitrogen) have not been related to poor population performance of slimy sculpin but likely provide an enrichment effect on fish populations (Galloway *et al.* 2003). The *baseline* sites HR-R and DR-R exhibited water quality conditions similar to regional *baseline* conditions for all selected water quality measurement endpoints. Variations in water quality conditions between sentinel species monitoring sites are likely not contributing factors to the poor capture success of slimy sculpin at *test* site STR-E.

Sampling efficiency may also be a factor contributing to the poor capture success of slimy sculpin at *test* site STR-E. This site is characterized by a deep, narrow channel dominated by large cobble and boulders along the margins of the river. This type of habitat is typically difficult to sample by backpack electrofishing, particularly for demersal species such as slimy sculpin. It is important to note that other species (e.g., lake chub, brook stickleback, trout-perch, sucker sp., etc.) were captured at this location during the fish assemblage inventory suggesting that habitat conditions were not optimal for slimy sculpin.

5.3.5.6 Classification of Results

Of the measurement endpoints established for lethal sentinel species monitoring approach (Environment Canada 2005), only condition factor can be applied as a measurement endpoint when using a non-lethal approach. The effects criterion defined by Environment Canada (2005) is a ± 10% difference in slimy sculpin condition between the *test* and *baseline* sites. A difference that is greater than ±10% indicates a population may be affected by some factor or factors.

Table 5.3-17 and Table 5.3-18 provide a summary of the difference in condition of slimy sculpin in 2009 at *test* sites STR-E, STR-R, and MR-E, compared to the two *baseline* sites (DR-R, HR-R) for both adult and YOY size classes (site MR-E only). Differences in condition of slimy sculpin exceeded the Environment Canada 10% effects criterion for the following two comparisons:

- Condition of adult slimy sculpin in fall at *test* site MR-E was 10.1% lower compared to the *baseline* site DR-R;

- Condition of YOY slimy sculpin in fall at *test* site MR-E was 26% higher than the *baseline* site HR-R; and

- Condition of YOY slimy sculpin in summer at *test* site STR-R was 34.3% and 14.7% higher than the *baseline* sites HR-R and DR-R, respectively and 30.9% and 28.5% higher in fall at this site than the *baseline* sites HR-R and DR-R, respectively.

The sample size of YOY slimy sculpin at *test* site STR-R was very low in both seasons (n=5 in summer and n=3 in fall) which does not provide adequate statistical power for comparisons with *baseline* sites. The classification of results using YOY individuals from this site should be taken with caution. All other comparisons of YOY and adult condition between *test* and *baseline* sites were below the 10% effects criterion (Table 5.3-17, Table 5.3-18). There were no YOY slimy sculpin captured at the *test* site STR-E, to evaluate whether there is an effect on condition of slimy sculpin. As well, the low number of adult sculpin captured at this site in the fall made it difficult to confidently compare condition with *baseline* sites.

Based on the differences in condition of slimy sculpin at the *test* sites compared to the *baseline* sites, the following assessments were made:

1. The adult and YOY slimy sculpin population at *test* site MR-E indicated a **Moderate** difference from *baseline* sites on the basis that the effects criterion for condition of adult slimy sculpin was exceeded in fall and for YOY slimy sculpin in summer (Table 5.3-17); this exceedance was not observed over three consecutive years of sampling (i.e., 2004, 2006, and 2009) (Table 5.3-19).

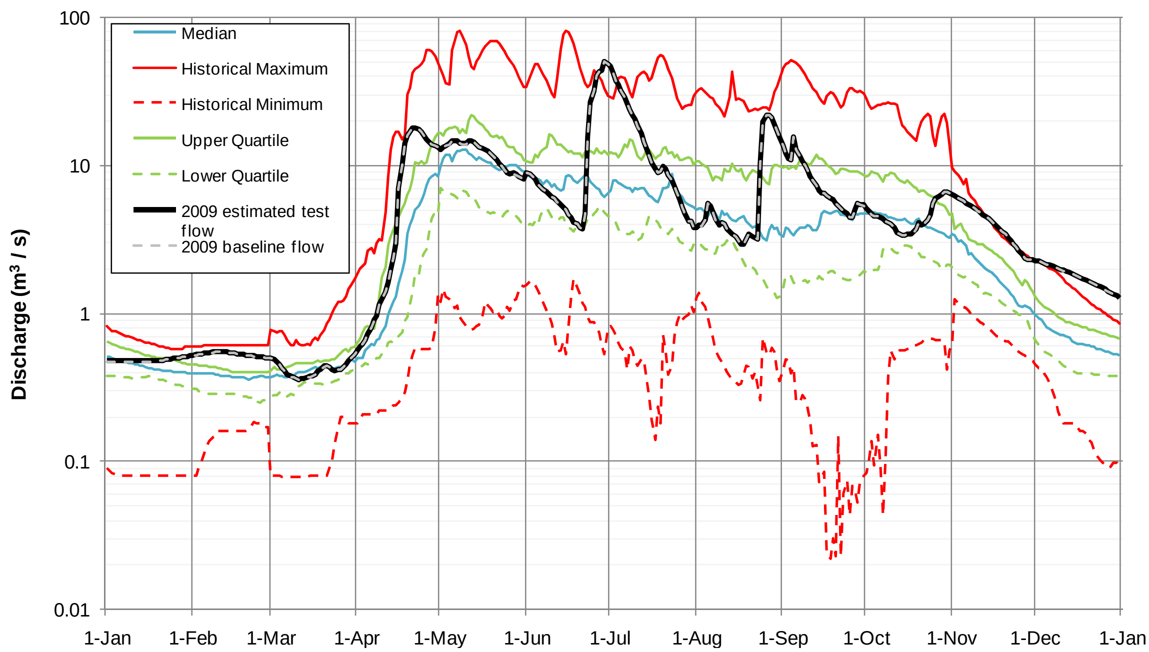
2. The sample size of slimy sculpin captured at the *test* site STR-E was too low to provide statistical power for comparisons with *baseline* sites; therefore, a classification of the results from this site could not be made. Further investigation of the slimy sculpin population at this site is merited. There may be opportunity to monitor the lower Steepbank River *test* site (STR-E) again in 2010 during the Fish Assemblage Monitoring study.

3. The adult slimy sculpin population at *test* site STR-R indicated a **Negligible-Low** difference from *baseline* sites on the basis that the effects criterion for condition of slimy sculpin was not exceeded in 2009 in either season. A temporal assessment was not conducted for this site because it only switched from *baseline* to *test* in 2008, and all previous sentinel species monitoring was conducted prior to 2008.

5.3.5.7 Summary

Previous monitoring studies and results from the 2009 sentinel species monitoring study suggested that the abundance and recruitment of young individuals in the slimy sculpin population at *test* site STR-E is lower compared to *baseline* sites. Although other fish species were captured at this site, the 2009 results and historical sentinel species studies suggests that this site does not provide optimal conditions for slimy sculpin. The absence of slimy sculpin in summer and low sample size in fall at *test* site STR-E prevented an accurate classification of results based on the impact criterion established by Environment Canada (2005). Differences in condition of slimy sculpin at *test* site MR-E relative to *baseline* sites were assessed as **Moderate**, due to an exceedance greater than 10% in the average condition of slimy sculpin from the average condition of slimy sculpin at *baseline* sites but exceedances were not observed across sampling years. In addition, the abundance of young of year slimy sculpin was highest at *test* site MR-E indicating the presence of suitable habitat for young slimy sculpin and good recruitment of young individuals to the population. Differences in condition of adult slimy sculpin at *test* site STR-R relative to *baseline* sites was assessed as **Negligible-Low** given the difference in average condition of fish between this site and the *baseline* sites was less than ±10%. Comparisons across years for this site was not included in the classification of results because this site was only designated as *test* in 2008, and previous sentinel species monitoring was conducted prior to 2008.

Figure 5.3-3 The observed (*test*) hydrograph for the Steepbank River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on WSC Station 07DA006, Steepbank River near Fort McMurray, 2009 provisional data for March 1 to October 31, 2009, and RAMP Station S38 for other months in 2009. The upstream drainage area is 1,320 km^2. Historical values from March 1 to October 31 calculated from data collected from 1972 to 2008, and values in other months calculated from data collected from 1972 to 2008.

Table 5.3-2 Estimated water balance at WSC Station 07DA006 (RAMP Station S38), Steepbank River near Fort McMurray, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**206.1**	**Observed discharge from WSC Station 07DA006, Steepbank River near Fort McMurray**
Closed-circuited area water loss from the observed *test* hydrograph	-0.670	Estimated 4.3 km^2 of the Steepbank River watershed is closed-circuited as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.960	Estimated 30.8 km^2 of the Steepbank River watershed with land change as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the Steepbank River watershed from focal projects	0	None reported
Water releases into the Steepbank River watershed from focal projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Steepbank River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**205.8**	**Estimated *baseline* discharge at WSC Station 07DA006, Steepbank River near Fort McMurray**
Incremental flow (change in total discharge)	+0.290	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+0.14%**	**Incremental flow as a percentage of total annual discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on WSC Station 07DA006, Steepbank River near Fort McMurray, 2009 provisional data for March 1 to October 31, 2009, and RAMP Station S38 for other months in 2009.

Table 5.3-3 Calculated change in hydrologic measurement endpoints for the Steepbank River watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	10.44	10.45	0.14%
Mean winter discharge	1.47	1.48	0.14%
Annual maximum daily discharge	50.2	50.3	0.14%
Open-water period minimum daily discharge	2.906	2.910	0.14%

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on WSC Station 07DA006, Steepbank River near Fort McMurray, 2009 provisional data for March 1 to October 31, 2009, and RAMP Station S38 for other months in 2009.

Table 5.3-4 Concentrations of water quality measurement endpoints in the Steepbank River (*test* station STR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.07	11	7.7	8.2	8.5
Total Suspended Solids	mg/L	-[1]	9	11	<3	5	60
Conductivity	µS/cm	-	190	11	141	234	516
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0182	11	0.006	0.021	0.032
Total nitrogen*	mg/L	1.0	**1.671**	11	0.25	0.7	**2.40**
Nitrate+Nitrite	mg/L	1.0	0.071	11	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	25.7	11	10	19	30
Ions							
Sodium	mg/L	-	8.4	11	6	11	38
Calcium	mg/L	-	26.6	11	17.2	30	50.3
Magnesium	mg/L	-	8.08	11	5.4	8.6	16.2
Chloride	mg/L	230, 860[3]	0.91	11	<1	2	8.4
Sulphate	mg/L	100[4]	3.29	11	2.8	4.7	12.3
Total Dissolved Solids	mg/L	-	161	11	120	182	320
Total Alkalinity	mg/L		93.9	11	63	120	263
Organic compounds							
Naphthenic acids	mg/L	-	0.131	11	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	**0.354**	11	0.040	**0.120**	**2.73**
Dissolved aluminum	mg/L	0.1[2]	0.0198	11	<0.01	0.014	0.099
Total arsenic	mg/L	0.005	0.0007	11	0.00050	0.0008	<0.001
Total boron	mg/L	1.2[5]	0.0483	11	0.025	0.057	0.200
Total molybdenum	mg/L	0.073	0.0002	11	0.0002	0.0002	0.0005
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.6	6	<1.2	<1.2	1.6
Total strontium	mg/L	-	0.0898	11	0.064	0.114	0.252
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0052**	11	**<0.003**	**0.006**	**0.041**
Dissolved iron	mg/L	0.3[2]	**0.453**	11	0.187	**0.373**	**0.599**
Total iron	mg/L	0.3	**0.84**	11	**0.47**	**0.81**	**2.28**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.6**	11	<0.2	0.6	**2.3**
Total phenols	mg/L	0.004	**0.0075**	11	<0.001	0.002	**0.013**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Table 5.3-5 Concentrations of water quality measurement endpoints in the Steepbank River (*test* station STR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.12	7	7.8	8.1	8.3
Total Suspended Solids	mg/L	-[1]	3	7	<3	4	28
Conductivity	µS/cm	-	191	7	121	200	274
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0246	7	0.014	0.022	0.038
Total nitrogen*	mg/L	1.0	**1.081**	7	0.6	0.8	**1.5**
Nitrate+Nitrite	mg/L	1.0	0.071	7	<0.1	<0.1	0.1
Dissolved organic carbon	mg/L	-	29.7	7	14	23	29
Ions							
Sodium	mg/L	-	8.1	7	5	9	16
Calcium	mg/L	-	25.5	7	16.8	26.4	35.9
Magnesium	mg/L	-	7.44	7	5.3	8.1	10.8
Chloride	mg/L	230, 860[3]	0.5	7	1	2	3
Sulphate	mg/L	100[4]	1.79	7	<0.5	3.2	5.5
Total Dissolved Solids	mg/L	-	174	7	140	160	200
Total Alkalinity	mg/L		97.7	7	61	104	155
Organic compounds							
Naphthenic acids	mg/L	-	0.06	7	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	**0.16**	7	0.018	0.086	**0.536**
Dissolved aluminum	mg/L	0.1[2]	0.0212	7	0.0023	0.0127	0.0294
Total arsenic	mg/L	0.005	0.0007	7	0.0005	0.0007	0.00075
Total boron	mg/L	1.2[5]	0.0481	7	0.0227	0.0542	0.0969
Total molybdenum	mg/L	0.073	0.0002	7	0.0001	0.0002	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	1.35	2.3
Total strontium	mg/L	-	0.0971	7	0.053	0.099	0.167
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0057**	7	**<0.003**	**0.007**	**0.012**
Dissolved iron	mg/L	0.3[2]	**0.45**	7	**0.347**	**0.459**	**0.597**
Total iron	mg/L	0.3	**0.733**	7	**0.749**	**0.837**	**1.07**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.01**	7	<0.001	0.01	0.011
Total phenols	mg/L	0.004	**0.0054**	7	<0.001	**0.007**	**0.011**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Table 5.3-6 Concentrations of water quality measurement endpoints in the Steepbank River (*baseline* station STR-3), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.12	5	8.0	8.2	8.3
Total Suspended Solids	mg/L	-[1]	3	5	<3	<3	4
Conductivity	µS/cm	-	195	5	196	276	317
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.034	5	0.027	0.041	0.042
Total nitrogen*	mg/L	1.0	**1.501**	5	0.6	0.7	0.8
Nitrate+Nitrite	mg/L	1.0	0.071	5	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	29.3	5	14	20	28
Ions							
Sodium	mg/L	-	7.6	5	9	15	17
Calcium	mg/L	-	23.1	5	25.5	37.9	40.7
Magnesium	mg/L	-	6.54	5	7.7	11.1	12.4
Chloride	mg/L	230, 860[3]	0.5	5	1	2	2
Sulphate	mg/L	100[4]	0.83	5	2.1	3.15	3.4
Total Dissolved Solids	mg/L	-	173	5	140	199	220
Total Alkalinity	mg/L		101	5	100	165	170
Organic compounds							
Naphthenic acids	mg/L	-	0.07	5	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0593	5	0.021	0.039	0.089
Dissolved aluminum	mg/L	0.1[2]	0.0152	5	0.0040	0.0062	0.0175
Total arsenic	mg/L	0.005	0.0007	5	0.0005	0.0006	0.0007
Total boron	mg/L	1.2[5]	0.052	5	0.049	0.0715	0.114
Total molybdenum	mg/L	0.073	0.0002	5	0.0002	0.0002	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.3	5	<1.2	<1.2	1.3
Total strontium	mg/L	-	0.0975	5	0.0945	0.109	0.150
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.006**	5	**0.004**	**0.006**	**0.011**
Total phenols	mg/L	0.004	**0.0061**	5	<0.001	0.004	**0.019**
Dissolved iron	mg/L	0.3[2]	**0.589**	5	**0.405**	**0.687**	**0.751**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.43**	5	0.5	0.60	0.7
Total iron	mg/L	0.3	**0.932**	5	**0.698**	**0.935**	**1.04**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Table 5.3-7 Concentrations of water quality measurement endpoints in the North Steepbank River (*test* station NSR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.07	7	7.5	8	8.1
Total Suspended Solids	mg/L	-[1]	3	7	<3	4	8
Conductivity	µS/cm	-	179	7	110	143	191
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0347	7	0.015	0.020	0.042
Total nitrogen*	mg/L	1.0[8]	0.991	7	0.4	0.7	0.80
Nitrate+Nitrite	mg/L	1.0	0.0701	7	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	23.1	7	13	18	23
Ions							
Sodium	mg/L	-	3.7	7	2	3	4
Calcium	mg/L	-	37.6	7	16.5	23.1	31
Magnesium	mg/L	-	7.28	7	4.9	6.5	8.8
Chloride	mg/L	230, 860[3]	0.5	7	<1	1	2
Sulphate	mg/L	100[4]	0.5	7	<0.5	1.8	5.2
Total Dissolved Solids	mg/L	-	160	7	109	139	160
Total Alkalinity	mg/L		94.2	7	55	73	106
Organic compounds							
Naphthenic acids	mg/L	-	0.054	7	<1	<1	<1
Selected metals							
Total aluminum	mg/L	0.1	0.0919	7	0.028	0.050	**0.13**
Dissolved aluminum	mg/L	0.1[2]	0.00806	7	0.005	0.011	0.015
Total arsenic	mg/L	0.005	0.00116	7	0.0005	0.0008	0.0013
Total boron	mg/L	1.2[5]	0.016	7	0.010	0.013	0.020
Total molybdenum	mg/L	0.073	0.000301	7	0.0001	0.0002	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.103	7	0.049	0.071	0.111
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0028**	7	**0.004**	**0.006**	**0.008**
Dissolved iron	mg/L	0.3[2]	**0.772**	7	0.275	**0.495**	**0.77**
Total iron	mg/L	0.3	**1.29**	7	**0.507**	**0.791**	**1.17**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.3-8 Water quality guideline exceedances, Steepbank River watershed, 2009.

Variable	Units	Guideline	STR-1	STR-2	STR-3	NSR-1
Winter						
Total iron	mg/L	0.3	**0.732**	-	-	-
Fall						
Sulphide	mg/L	0.002[1]	**0.0052**	**0.0057**	**0.006**	**0.0028**
Dissolved iron	mg/L	0.3[2]	**0.453**	**0.45**	**0.589**	**0.772**
Total iron	mg/L	0.3	**0.84**	**0.733**	**0.932**	**1.29**
Total phenols	mg/L	0.004	**0.0075**	**0.0054**	**0.0061**	-
Total nitrogen	mg/L	1.0	**1.671**	**1.081**	**1.501**	-
Total Kjeldahl Nitrogen	mg/L	1.0[3]	**1.6**	**1.01**	**1.43**	-
Total aluminum	mg/L	0.1	**0.354**	**0.16**	-	-

STR-1 was sampled during winter and fall only.

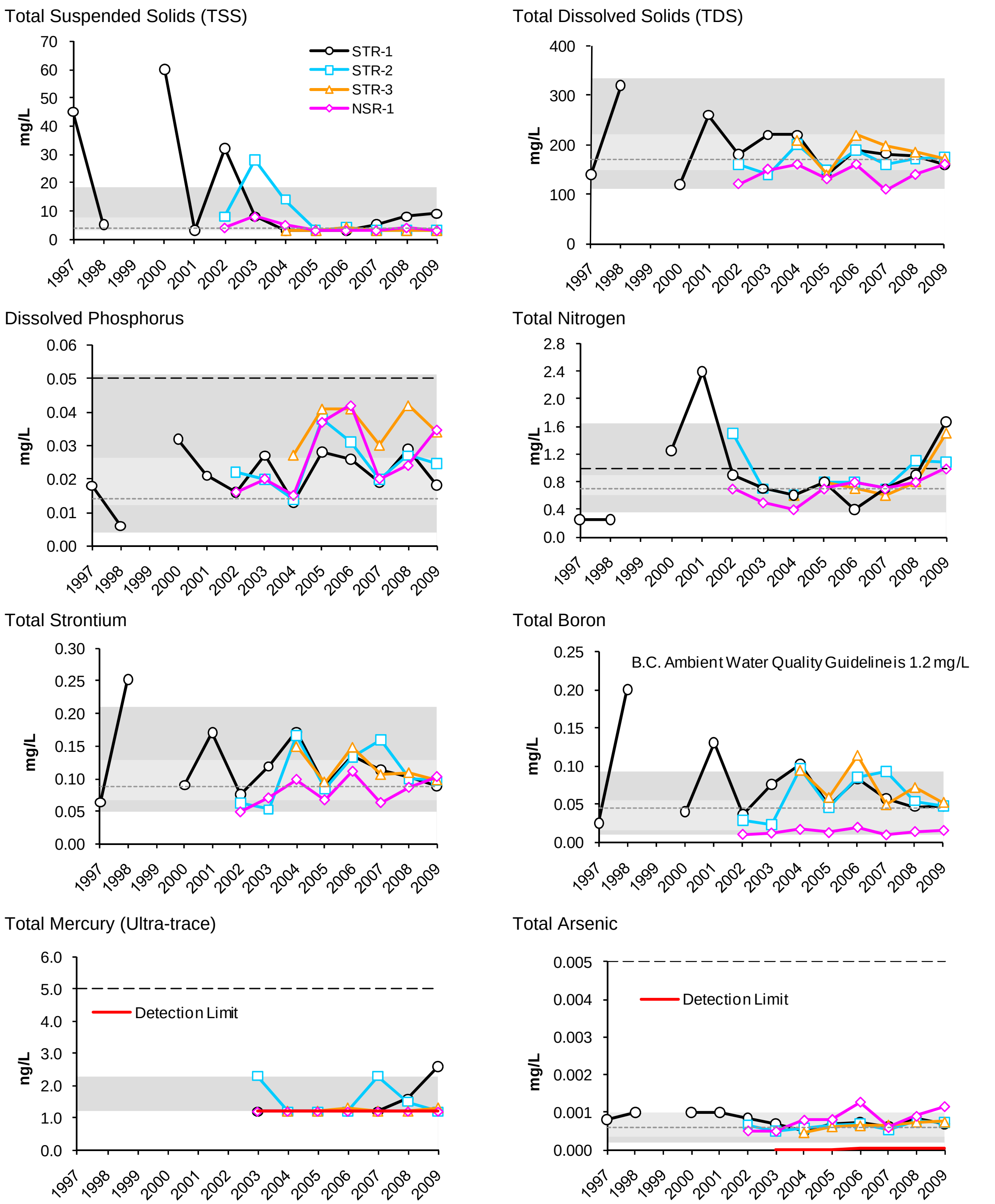
Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] Guideline is for total metal (no guideline for dissolved species).

[3] Guideline is for total nitrogen.

Figure 5.3-4 Concentrations of selected water quality measurement endpoints in the Steepbank River (fall data) relative to regional *baseline* fall concentrations.



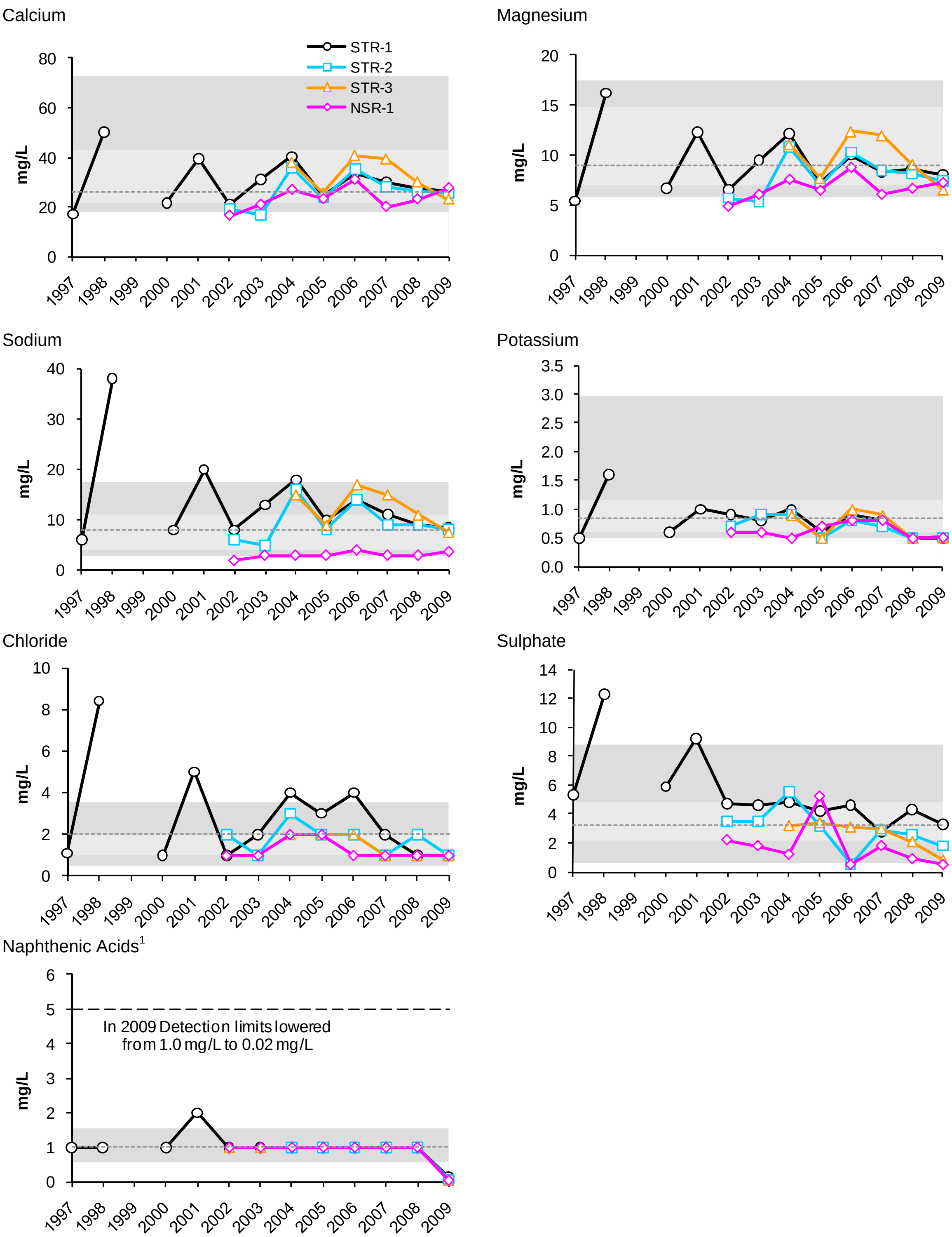
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.3-4 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.3-5 Piper diagram of fall ion concentrations in the Steepbank River, fall 2009.

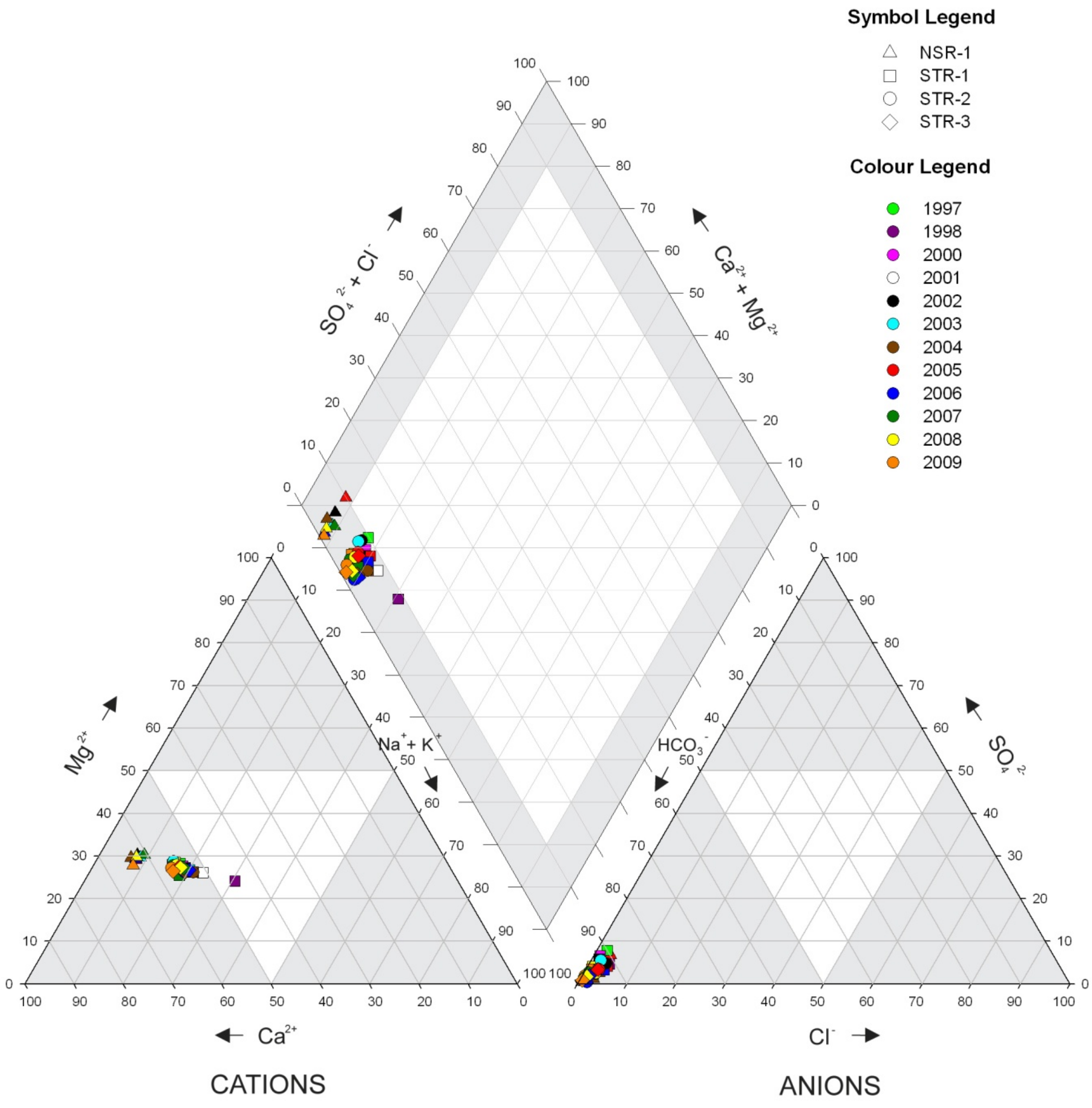


Table 5.3-9 Water quality index (fall 2009) for Steepbank River watershed stations.

Station Identifier	Location	2009 Designation	Water Quality Index	Classification
STR-1	Lower Steepbank River	*test*	94.5	Negligible-Low
STR-2	Upstream of Project Millennium	*test*	89.1	Negligible-Low
STR-3	Upstream of North Steepbank River	*baseline*	89.1	Negligible-Low
NSR-1	North Steepbank River	*baseline*	100.0	Negligible-Low

Note: see Figure 5.3-1 for the locations of these water quality stations.
Note: see Section 3.2.7.4 for a description of the Water Quality Index.

Table 5.3-10 Average habitat characteristics of benthic invertebrate sampling locations in the Steepbank River.

Variable	Units	*Test* Reach STR-E-1	*Baseline* Reach STR-E-2
Sample Date	-	Sept 14, 2009	Sept 10, 2009
Habitat	-	Erosional	Erosional
Water Depth	m	1	0.2
Current Velocity	m/s	0.68	0.85
Macrophyte Cover	%	0	4
Field Water Quality			
Dissolved Oxygen	mg/L	11.8	9.6
Conductivity	µS/cm	200	167
pH	pH units	8.5	7.9
Water Temperature	°C	12.2	11.7
Sediment Composition			
Sand/Silt/Clay	%	10	15
Small Gravel	%	3	1
Large Gravel	%	26	18
Small Cobble	%	39	36
Large Cobble	%	15	28
Boulder	%	0	2
Bedrock	%	7	0

Table 5.3-11 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the Steepbank River.

Taxon	Percent Major Taxa Enumerated in Each Year															
	Test Reach STR-E-1										*Baseline* Reach STR-E-2					
	1998	2000	2001	2002	2004	2005	2006	2007	2008	2009	2004	2005	2006	2007	2008	2009
Anisoptera	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	0.3	<1	<1	
Athericidae		<1	<1	<1	<1	<1	<1	1	1	<1	<1	3	1	1	2	<1
Bivalvia				<1				<1	<1			<1		1	4	2
Ceratopogonidae	<1		<1	<1	<1		<1	3	1	<1				7	<1	
Chironomidae	31	15	25	43	38	25	29	36	17	41	46	32	24	52	24	41
Cladocera	1	<1								<1	4		<1	1		<1
Collembola	<1	<1						1	<1		<1				<1	
Copepoda	<1	<1	<1	<1		<1		1	<1	<1	4	<1	1		<1	<1
Empididae	2	1	2	6	4	9	7	<1	1	2	2	6	2	<1	3	3
Enchytraeidae	1	11	1	9	6	9	15	6	9	3	<1	1			1	1
Ephemeroptera	51	42	51	19	23	38	15	1	11	30	18	23	17	6	35	30
Gastropoda	<1	<1	<1	<1	<1		1	6	2				<1	<1	<1	<1
Heteroptera		<1	<1	<1												
Hydracarina	6	3	6	4	4	9	15	14	20	11	7	3	5	8	12	6
Lepidoptera		<1		<1												
Lumbriculidae		<1			<1											
Naididae	2	21	2	2	21	5	13	4	17	7	2	2	24	16	2	1
Nematoda	1	2	2	2	1	<1	1	1	1	2	3	1	1	1	3	2
Ostracoda	1	<1	<1	<1			<1	5			1			18	<1	<1
Plecoptera	<1	1	<1	1	1	<1	<1	1	<1	<1	2	4	2	1	2	2
Psychodidae		<1													<1	
Simuliidae	3	<1	<1	1	<1	3	1	<1	<1	1	<1	1	1	<1		1
Tabanidae	<1	<1			<1			<1			<1	<1	0	<1	<1	
Tipulidae	<1	<1						<1			1	1	1	<1	1	<1
Trichoptera	1	<1	<1	1	1	1	<1	2	1	2	9	24	22	6	10	9
Tubificidae	2	1	<1	1	<1	1	1	10	19	1	<1		1	1	<1	<1
Benthic Invertebrate Community Measurement Endpoints																
Total Abundance (No./m^2)	29,87	2,321	3,156	1,725	5,259	3,105	1,691	9,497	4,418	4,519	41,844	17,317	26,123	63,294	14,725	19,878
Richness	41	23	21	17	20	17	23	31	21	28	34	29	36	36	46	42
Simpson's Diversity	0.76	0.83	0.79	0.84	0.85	0.81	0.88	0.88	0.75	0.87	0.89	0.81	0.83	0.70	0.86	0.84
Evenness	0.78	0.87	0.83	0.9	0.9	0.87	0.89	0.91	0.80	0.9	0.92	0.83	0.83	0.72	0.88	0.87
% EPT	47	39	47	23	24	34	15	13	10	33	29	54	40	56	31	40

Figure 5.3-6 Periphyton chlorophyll *a* biomass in the Steepbank River.

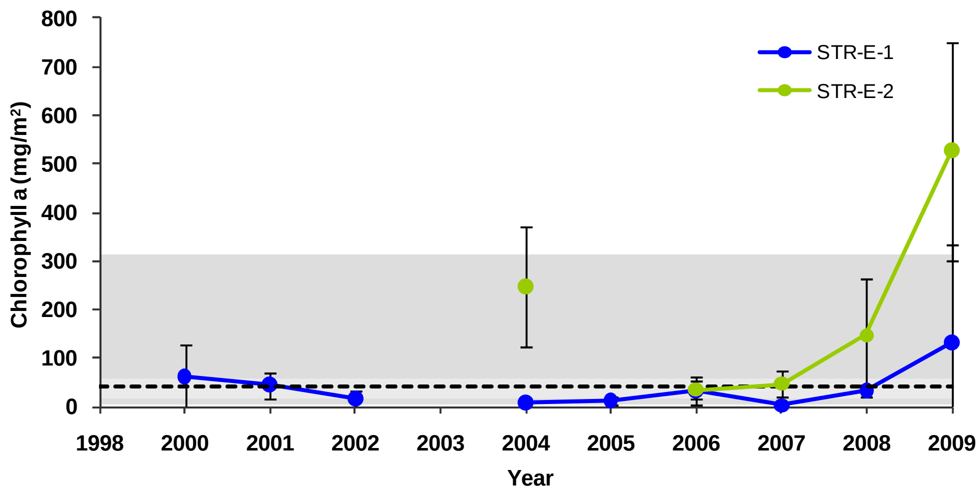
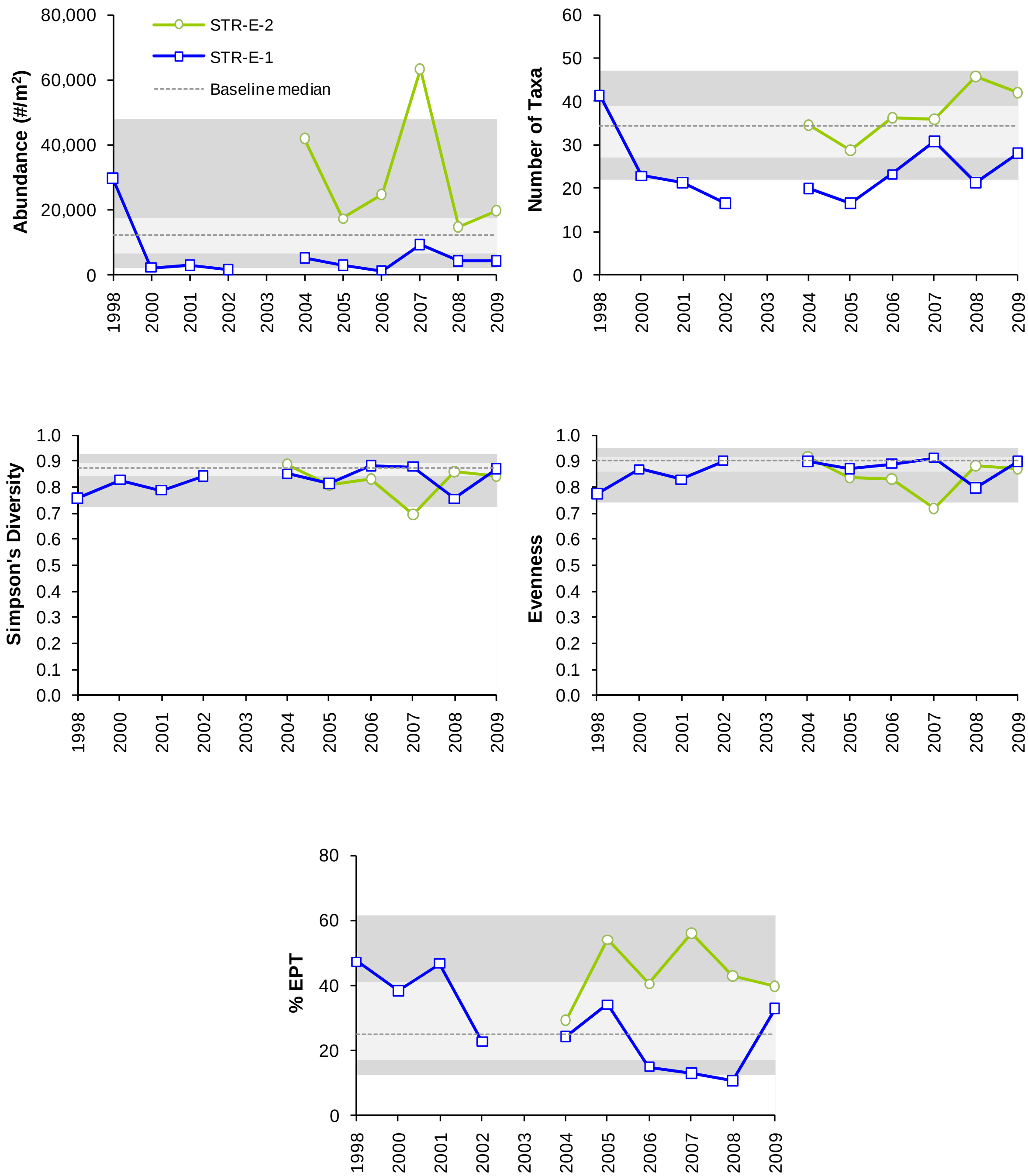
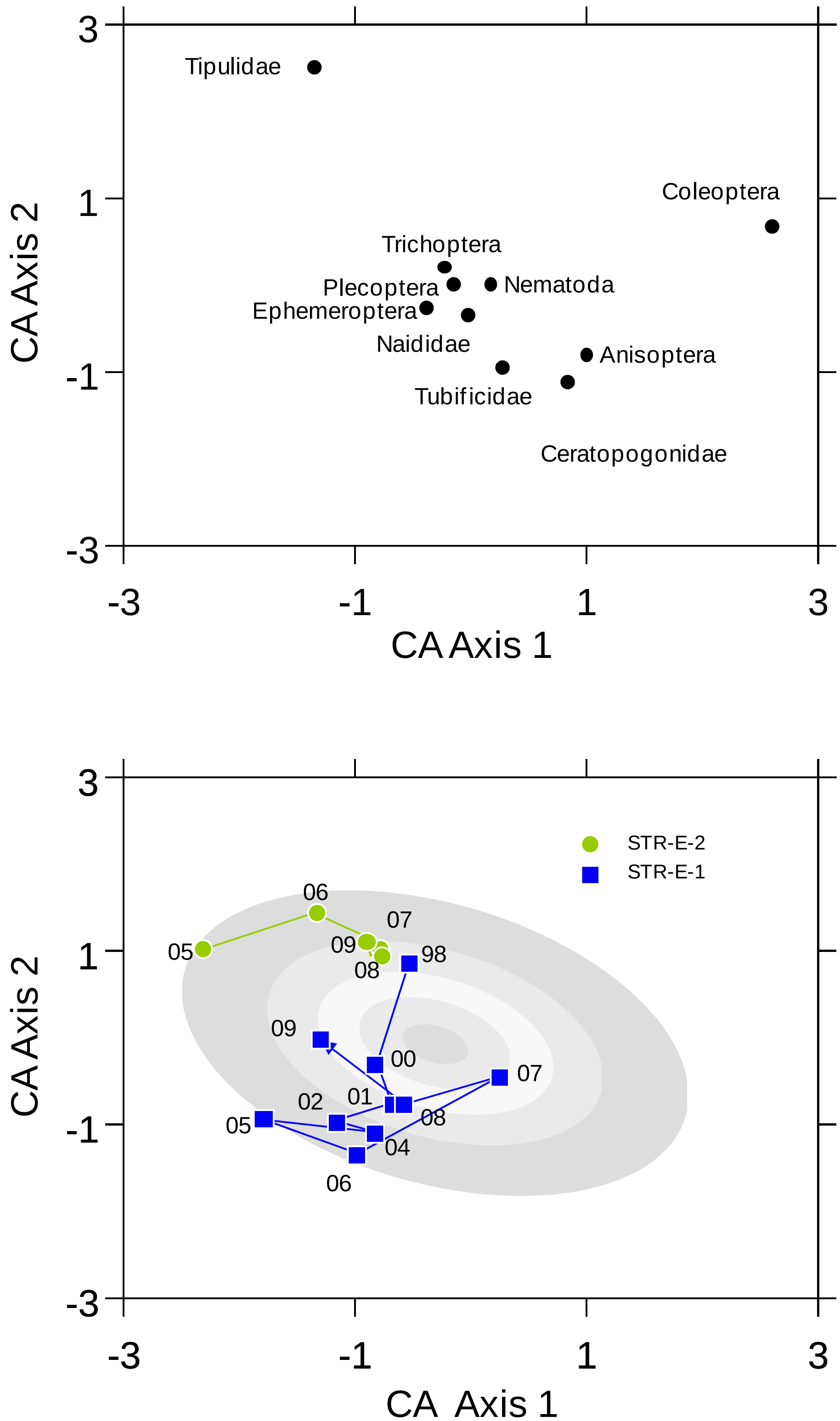


Figure 5.3-7 Variation in benthic invertebrate community measurement endpoints in the Steepbank River.



Note: Regional *baseline* values for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.3-8 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Steepbank River.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for *baseline* data for erosional reaches in the RAMP FSA.

Table 5.3-12 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Steepbank River.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	30.259	11	2.751	38.34	0.000
	TT x BT	0.189	1	0.189	2.63	0.107
	Remainder (noise)	30.070	10	3.007	41.92	0.000
	Error	8.466	118	0.072		
Log Richness	Reach - Year	2.174	11	0.198	21.84	0.000
	TT x BT	0.001	1	0.001	0.07	0.789
	Remainder (noise)	2.173	10	0.217	24.01	0.000
	Error	1.068	118	0.009		
Diversity	Reach - Year	0.381	11	0.035	5.50	0.000
	TT x BT	0.001	1	0.001	0.15	0.704
	Remainder (noise)	0.380	10	0.038	6.04	0.015
	Error	0.742	118	0.006		
Evenness	Reach - Year	0.391	11	0.036	5.30	0.000
	TT x BT	0.00	1	0.00	0.05	0.826
	Remainder (noise)	0.391	10	0.039	5.82	0.017
	Error	0.791	118	0.007		
Log %EPT	Reach - Year	7.39	11	0.67	14.81	0.000
	TT x BT	0.12	1	0.12	2.74	0.101
	Remainder (noise)	7.27	10	0.73	16.02	0.000
	Error	5.35	118	0.05		
CA Axis 1	Reach - Year	44.25	11	4.02	9.82	0.000
	TT x BT	0.68	1	0.68	1.66	0.200
	Remainder (noise)	43.6	10	4.357	10.63	0.001
	Error	48.36	118	0.41		
CA Axis 2	Reach - Year	234.77	11	21.34	62.11	0.000
	TT x BT	23.65	1	23.65	68.84	0.000
	Remainder (noise)	211.11	10	21.11	61.44	0.000
	Error	40.54	118	0.34		

Note: TT x BT = Time Trend x *Baseline* vs. *Test*

Table 5.3-13 Summary of aquatic habitat characteristics collected during the sentinel species monitoring program, August 2009.

Habitat Variable	Site				
	DR-R[1] *Baseline*	HR-R *Baseline*	STR-R *Test*	MR-E *Test*	STR-E *Test*
General Morphology	60% Run; 40% Riffle	60% Run; 40% Riffle	20% Run; 80 % Riffle	20% Run; 80% Riffle	20% Run; 80 % Riffle
Channel Width (m)	33.6	13.7	29.9	61.1	17.5
Wetted Width (m)	31.9	12.3	27.8	21.6	17.5
Mean Depth (m)	0.35	0.13	0.22	0.28	0.28
Width / Depth Ratio	92.0	93.5	125.2	77.0	62.1
Mean Velocity (m/s)	0.8	0.2	0.5	0.4	0.7
Total Instream Cover (%)	48.0	92.7	100.0	26.3	51.5
% Total Instream Cover as Substrate Cover	40.0	87.5	90.0	20.0	50.0
Riparian Area Habitat Type	Deciduous Forest	Mixed Forest, Grasses, Shrubs	Mixed Forest	Mixed Forest	Mixed Forest; Grasses; Shrubs
Dissolved Oxygen (mg/L)	10.5	9.6	12.3	10.3	10.7
pH	8.0	7.6	8.3	7.0	8.7
Specific Conductivity (µS/cm)	218	144	251	336	275
Temperature (°C)	18.2	17.6	13.1	17.2	13.4

[1] Habitat measurements from October sampling period; measurements in August were not recorded.

Figure 5.3-9 Mean daily water temperature (ºC) at sentinel species monitoring sites, 2009.

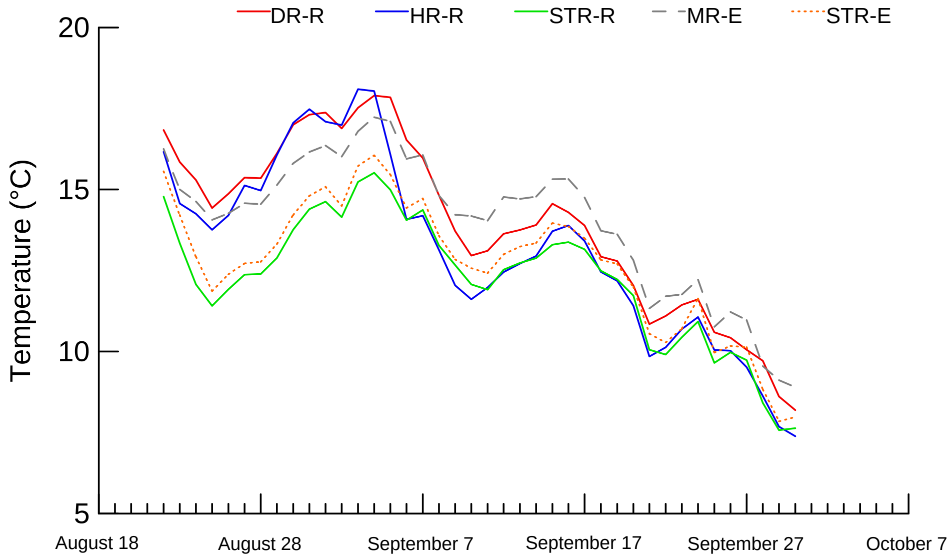


Table 5.3-14 Number of adult and YOY slimy sculpin captured during August and October 2009 sentinel species monitoring programs.

Site	August			October		
	YOY	Adult	Total	YOY	Adult	Total
DR-R	80	22	102	48	25	73
HR-R	60	49	109	69	43	104
STR-R	3	100	103	5	50	55
MR-E	116	7	123	95	8	103
STR-E	0	0	0	0	6	6

Figure 5.3-10 Catch per unit effort (CPUE) of slimy sculpin captured during the 2009 sentinel species monitoring program.

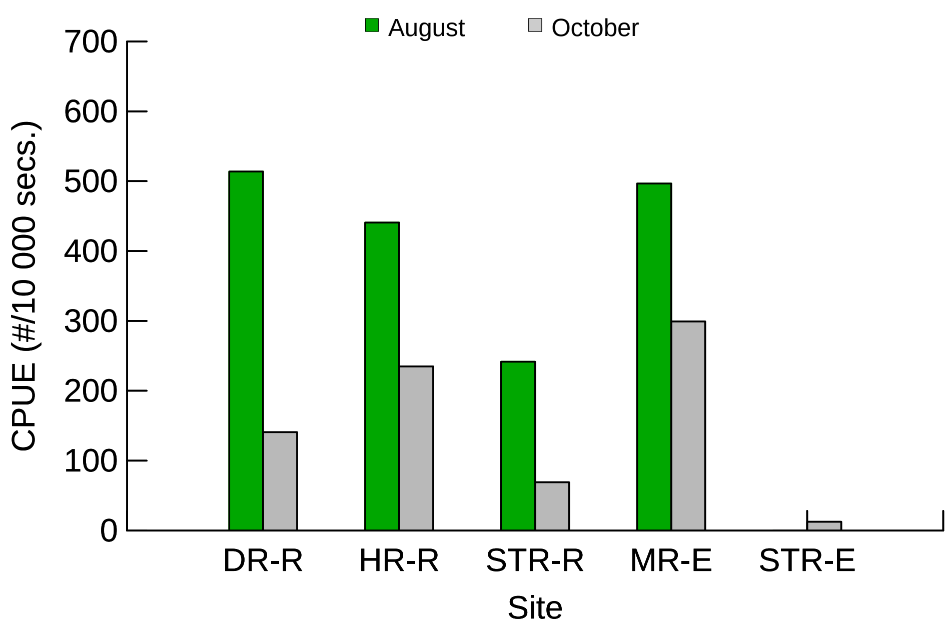


Figure 5.3-11 Length-frequency distributions of slimy sculpin captured for all site and season combinations, 2009.

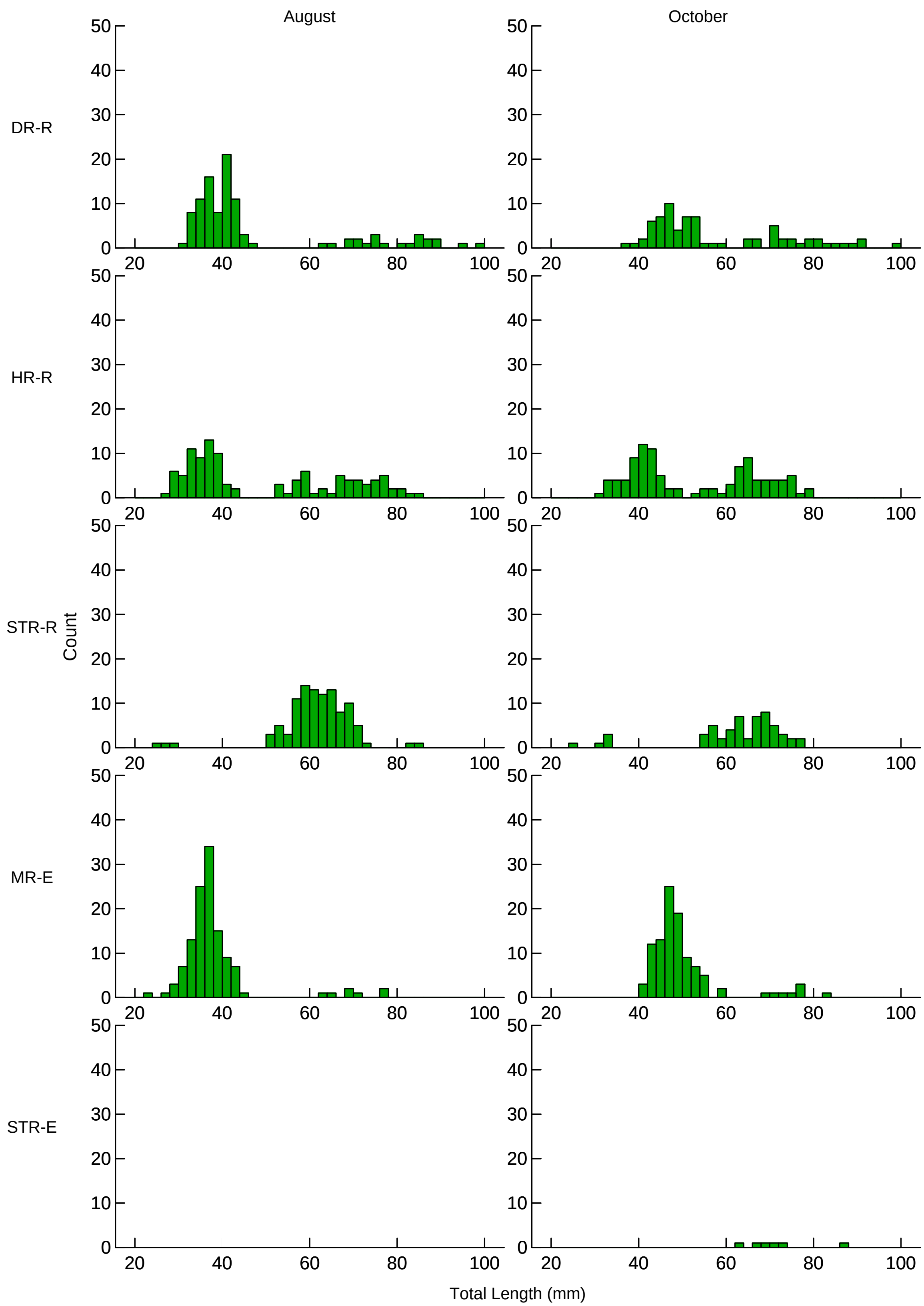


Figure 5.3-12 Proportion of YOY and adult slimy sculpin captured in August and October, 2009.

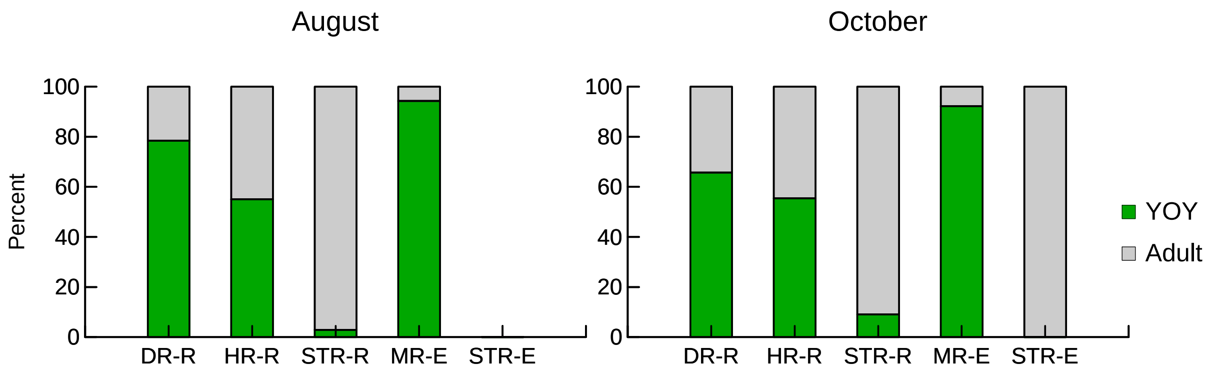


Table 5.3-15 Estimates of growth rates (mm/day) in young-of-year slimy sculpin, 2009.

Site	Designation	Number of Days Between Sampling Events	Mean Length of YOY (mm)		Difference in Mean Length (mm)	Growth Rate (mm/day)
			August	October		
DR-R	*baseline*	44	38.20	47.27	9.07	0.21
HR-R	*baseline*	42	34.75	40.07	5.32	0.13
STR-R	*test*	44	27.00	30.40	3.40	0.08
MR-E	*test*	46	35.82	47.52	11.70	0.25
STR-E[1]	*test*	-	-	-	-	-

[1] There were no YOY sculpin captured at *test* site STR-E.

Table 5.3-16 Summary of mean length, weight, and condition of slimy sculpin captured at each sampling site, summer and fall 2009.

Season	Site	Sample Size	Mean Length (mm)	Mean Weight (g)	Mean Condition (K)
Summer	DR-R	102	47.01	1.79	1.16
	HR-R	109	49.51	1.8	1.05
	STR-R	103	61.03	2.71	1.15
	STR-E	0	-	-	-
	MR-E	123	37.73	0.78	1.26
Fall	DR-R	73	57.48	2.74	1.13
	HR-R	103	52.56	1.95	1.09
	STR-R	55	62.05	3.08	1.21
	STR-E	6	70.83	4.2	1.14
	MR-E	103	49.63	1.47	1.12

Figure 5.3-13 Relationship of growth rate of YOY slimy sculpin to mean water temperature between sampling events, 2009 (r^2=0.93).

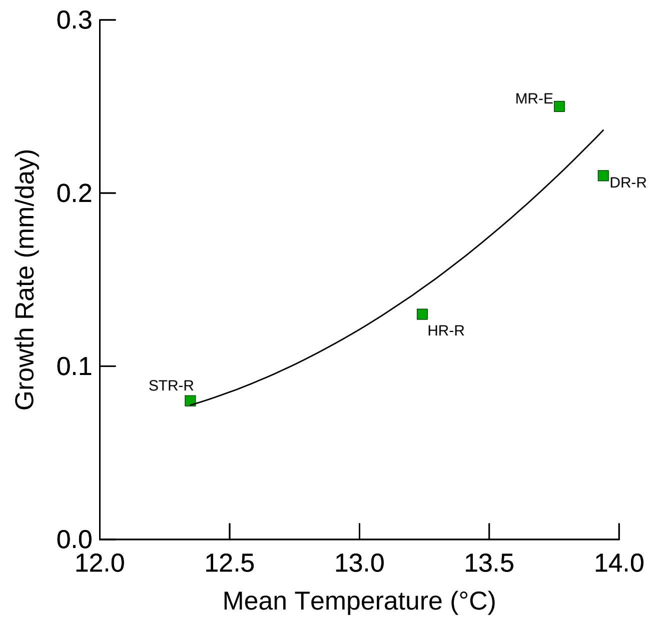
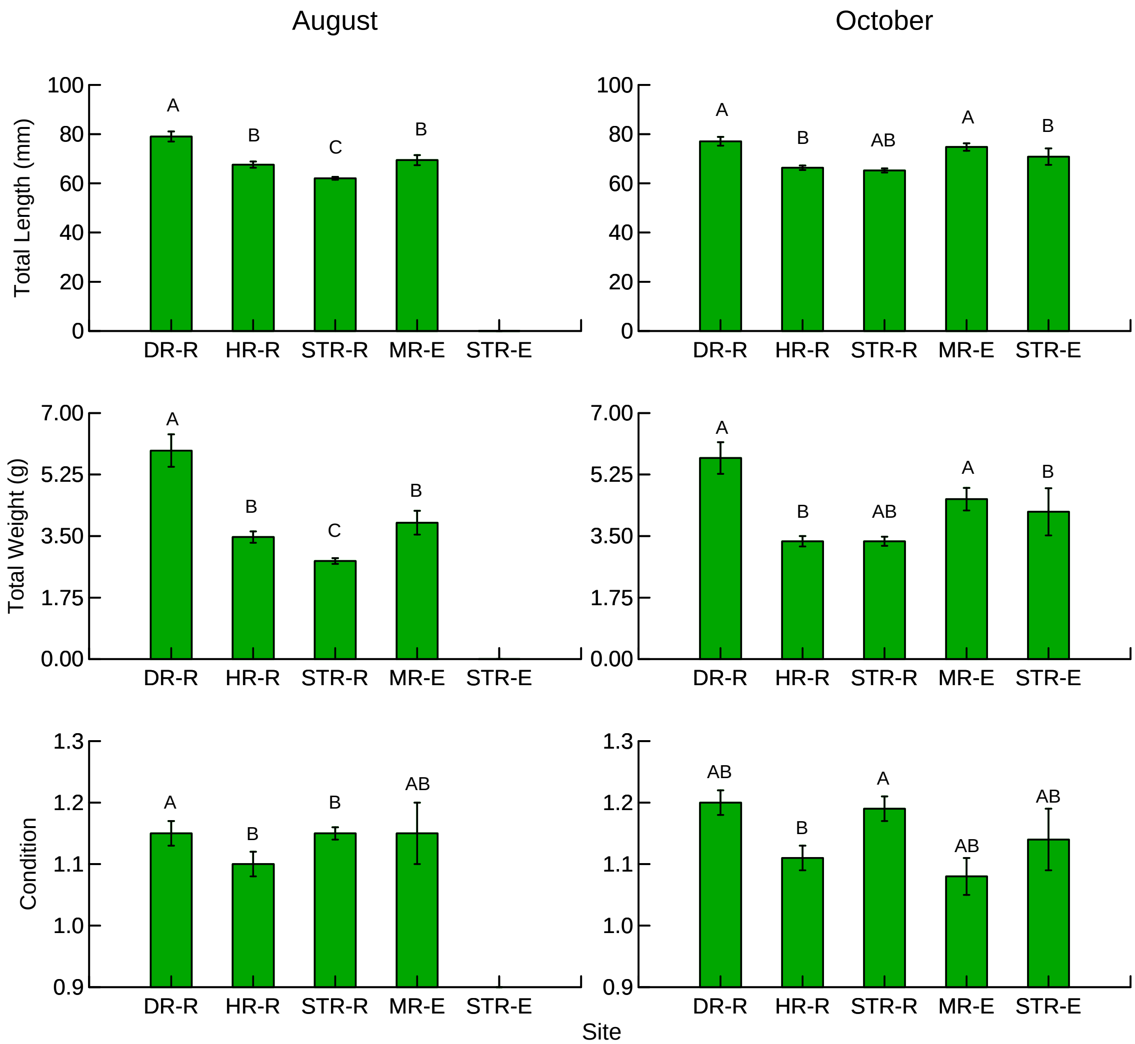
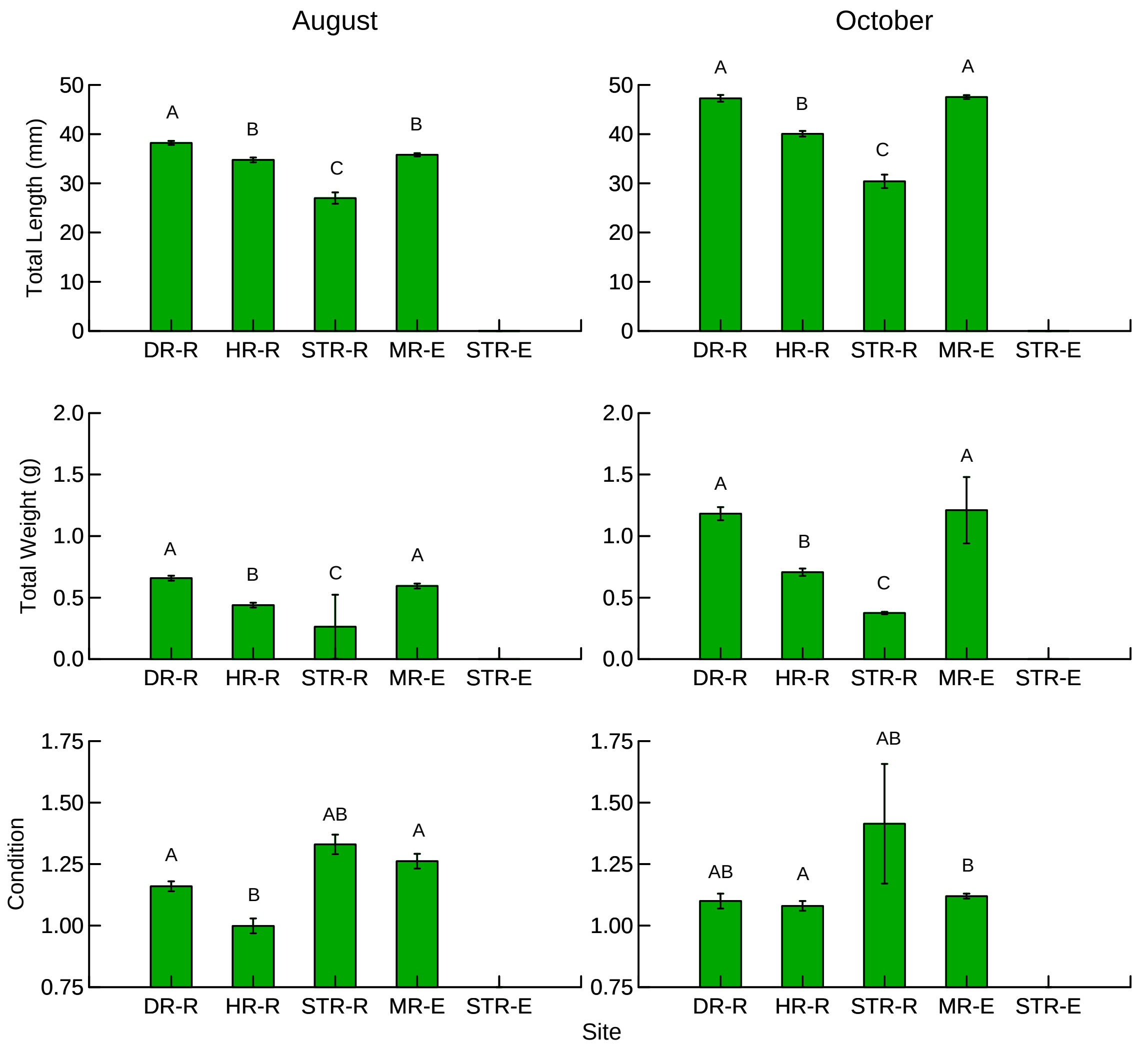


Figure 5.3-14 Mean length, weight, and condition (± 1SE) for adult slimy sculpin, August and October 2009.



Note: Different letters above each bar denote significant differences (i.e., if two sites have different letters, there are significant differences in that variable, if letters are the same, there were no significant differences observed).

Figure 5.3-15 Mean length, weight, and condition (± 1SE) for YOY slimy sculpin, August and October 2009.



Note: Different letters above each bar denote significant differences (i.e., if two sites have different letters, there are significant differences in that variable, if letters are the same, there were no significant differences observed).

Note: Significant differences were not observed between *test* site STR-R and the *baseline* sites given the sample size at STR-R was not large enough to provide adequate statistical power.

Table 5.3-17 Percent difference in condition of adult slimy sculpin between *test* sites (MR-E, STR-E, and STR-R) and *baseline* sites; ±10% effects criterion (Environment Canada 2005).

Month	*Baseline* Site	% Change at MR-E	% Change at STR-E	% Change at STR-R
August	HR-R	+4.3	-	+4.5
	DR-R	0.0	-	0.0
October	HR-R	-2.7	+2.6	7.2
	DR-R	**-10.1**	-5.3	<1.0

Table 5.3-18 Percent difference in condition of YOY slimy sculpin between *test* sites (MR-E, STR-E, and STR-R) and *baseline* sites; ±10% effects criterion (Environment Canada 2005).

Month	*Baseline* Site	% Change at MR-E	% Change at STR-R
August	DR-R	+8.8	**+34.3**
	HR-R	**+26.0**	**+14.7**
October	DR-R	+1.8	**+30.9**
	HR-R	+3.7	**+28.5**

Note: The sample size of YOY individuals at test site STR-R was small in both seasons (n=5 in summer and n=3 in fall), and does not provide enough power for statistical comparisons or accurate classification of results.

Table 5.3-19 Summary of effects criterion for condition factor of adult slimy sculpin from the *test* sites of the lower Muskeg River and Steepbank River compared to *baseline* sites in summer 1999*, and fall 2004, 2006, and 2009.

***Baseline* Site**	**% Change at *Test* Site MR-E[1]**					**% Change at *Test* Site STR-E[1]**					**% Change at *Test* Site STR-R[2]**
	1999*	**2001***	**2004**	**2006**	**2009**	**1999***	**2001***	**2004**	**2006**	**2009**	**2009**
HR-R	-	**+15.5**	-5.3	-4.4	-2.7	-	+12.4	+3.0	-8.6	+2.6	+7.2
DR-R	-	+4.7	+1.5	-3.4	**-10.1**	-	+1.87	**+10.4**	-7.7	-5.3	<1.0
STR-R[3]	+1.0	-1.8	**-15.3**	-7.0	-	-3.1	-4.4	-7.8	**-11.2**	-	-

* Results from 1999 and 2001 are from a summer lethal sampling program, there was no fall program conducted in this year; the *baseline* sites on the Horse and Dunkirk rivers were not used in the 1999 sentinel species program.

1 A change greater than ±10% indicates an effect on the slimy sculpin population at the *test* site.

2 Site STR-R was designated as *test* in 2008, therefore no comparisons were made to *baseline* sites prior to the 2009 sentinel species monitoring program.

3 Site STR-R was designated as *baseline* until 2008 and used for comparisons with *test* sites for the sentinel species program for all sampling years prior to 2008.

5.4 TAR RIVER WATERSHED

Table 5.4-1 Summary of results for Tar River watershed.

Tar River Watershed	Summary of 2009 Conditions	
Climate and Hydrology		
Criteria	**S15A** near the mouth	no station sampled
Mean open-water season discharge	High	
Mean winter discharge	not measured	
Annual maximum daily discharge	High	
Minimum open-water season discharge	Moderate	
Water Quality		
Criteria	**TAR-1** at the mouth	**TAR-2** upstream of Canadian Natural Horizon
Water Quality	Negligible-Low	Negligible-Low
Benthic Invertebrate Communities and Sediment Quality		
Criteria	**TAR-D-1** lower reach	**TAR-E-2** upper reach
Benthic Invertebrate Communities	Negligible-Low	n/a
Sediment Quality	Negligible-Low	n/a
Fish Populations		
Fish Population component activities are included in the Fish Assemblage Monitoring Pilot Study (Section 6)		

Legend and Notes

- Negligible-Low
- Moderate
- High
- *baseline*
- *test*

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

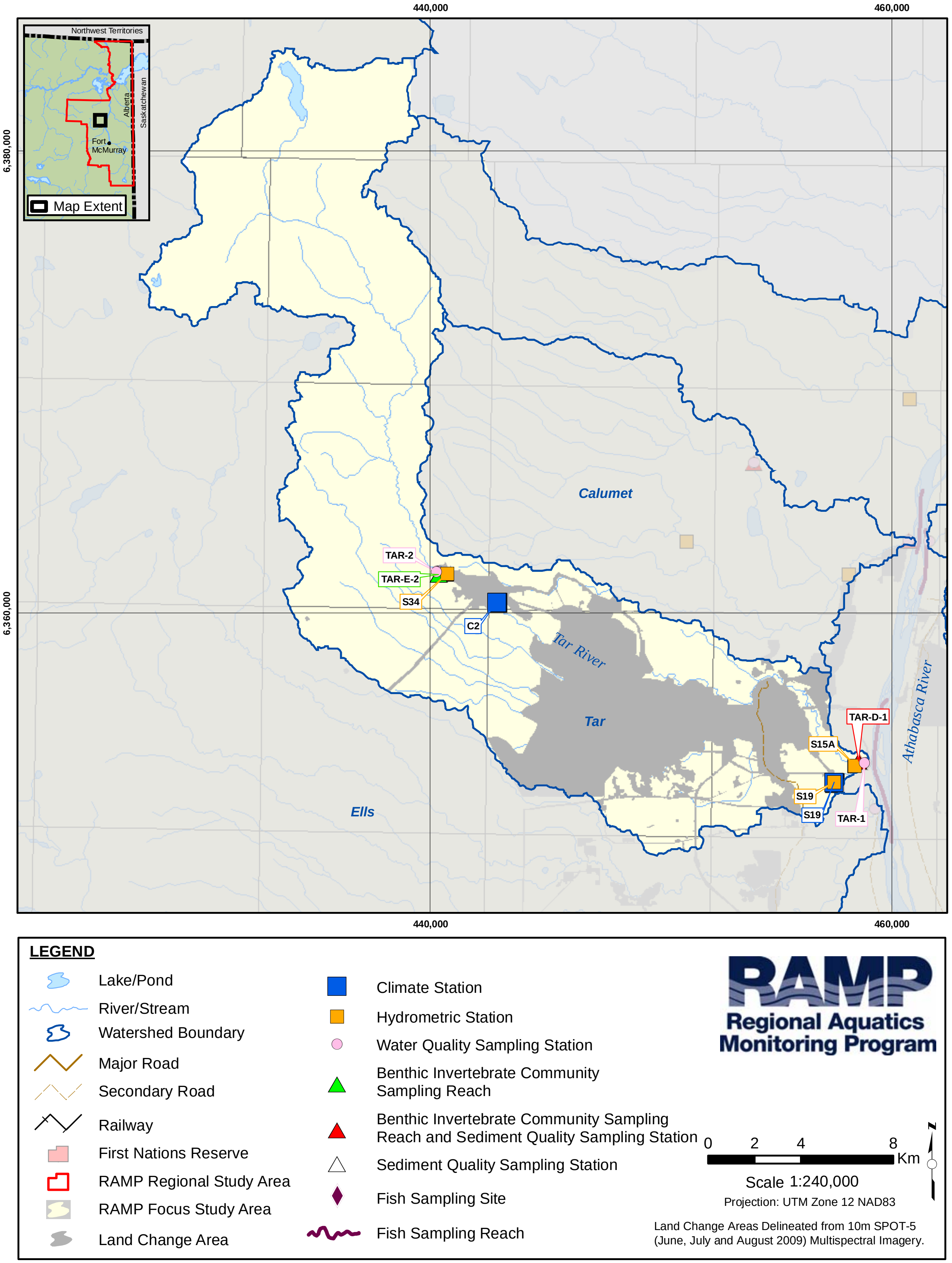
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Figure 5.4-1 Tar River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K04_Tar_20100415.mxd

Figure 5.4-2 Representative monitoring stations of the Tar River, fall 2009.

**Water Quality Station TAR-1:
Centre of Channel, facing downstream**

**Water Quality Station TAR-1:
Centre of Channel, facing upstream**

**Water Quality Station TAR-2:
Left Downstream Bank**

**Water Quality Station TAR-2:
Right Downstream Bank**

5.4.1 Summary of 2009 Conditions

As of 2009, approximately 22% (7,200 ha) of the Tar River watershed had undergone land change from focal projects (Table 2.4-2). The designations of specific areas of the watershed are as follows (Figure 5.4-1):

1. The Tar River watershed downstream of the Canadian Natural Horizon Project operations is designated as *test*.

2. The remainder of the watershed is designated as *baseline*.

The Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality components of RAMP conducted monitoring activities in the Tar River watershed in 2009. The Fish Population component did not conduct regular monitoring activities in the Tar River watershed in 2009, however, a pilot study of fish assemblage monitoring included a reach on the lower Tar River; Section 6 contains the results of this study. Table 5.4-1 is a summary of the 2009 assessment for the Tar River watershed, while

Figure 5.4-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.4-2 contains fall 2009 photos of water quality monitoring stations in the watershed.

Hydrology The mean open-water discharge and the annual maximum daily discharge calculated from the observed *test* hydrograph are 18.5% and 18.8% lower, respectively, than from the estimated *baseline* hydrograph; these differences are classified as **High**. The open-water minimum daily discharge calculated from the observed *test* hydrograph is 12.8% lower than from the estimated *baseline* hydrograph; this difference is classified as **Moderate**.

Water Quality Differences in water quality in fall 2009 in the lower Tar River as compared to regional *baseline* conditions are assessed as **Negligible-Low**. This is in contrast to water quality conditions in the lower Tar River in 2007 and 2008, when water quality was assessed as being measurably different from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality The data from the *test* reach of the Tar River support a conclusion that the benthic invertebrate community had been influenced by focal projects in 2005 and 2006, but have recovered to conditions within the historical *baseline* range in 2009. The variation in benthic invertebrate community composition in the *test* reach of the Tar River are classified as **Negligible-Low** on the basis that changes were modest relative to the remainder (noise) component, and because all measurement endpoints were within regional *baseline* conditions. The reach had previously exhibited changes classified as **High**, but recovered to an approximate *baseline* condition in 2009. Differences in sediment quality observed in fall 2009 between the lower Tar River and regional *baseline* conditions were **Negligible-Low**.

5.4.2 Hydrologic Conditions

2009 Hydrologic Conditions: Station S15A, Tar River near the Mouth The open-water (May to October) runoff volume recorded in 2009 at Station S15A was 16.9 million m^3, 41% higher than the historical mean open-water runoff volume of 11.9 million m^3. Flow was in the upper quartile of historical flows when 2009 flow measurements began in early May (Figure 5.4-3). Flow declined through May and June, reaching the lower quartile of historical flows by the middle of June. Flow increased following the rainfall event on June 22, exceeding the historical maximum flows from June 24 to July 9, decreased to approximately historical minimum flows by the middle of August, and remained below historical median flows until measurements ended on October 21 2009 (Figure 5.4-3). The open-water maximum daily flow in 2009 of 10.4 m^3/s recorded on June 30 was 56% higher than the historical mean maximum daily flow, while the open-water minimum daily flow in 2009 of 0.08 m^3/s recorded on October 21, 2009 was 62% lower than the historical mean minimum daily flow.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at Station S15A over the May 5 to October 21, 2009 measurement period for this station is presented in Table 5.4-2 and described below:

1. The closed-circuited land area from focal projects as of 2009 was estimated at 64.4 km^2 (Table 2.4-1). The loss of flow to the Tar River that would have otherwise occurred from this land area is estimated at 4.01 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 8.1 km^2 (Table 2.4-1). The increase in flow to the Tar River that would not have otherwise occurred from this land area is estimated at 0.10 million m^3.

3. Canadian Natural reported 0.17 million m^3 of water released from the wastewater treatment plant to the Tar River in 2009 (Section 2.4.4). Assuming a constant discharge rate, the increase in flow to the Tar River from the wastewater treatment plant between May 5 and October 21, 2009 is estimated at 0.08 million m^3. It was assumed for the water balance analysis that the water released did not originate from the Tar River system and was flow that would not have occurred in the absence of focal projects.

The estimated cumulative effect of land change and wastewater discharge is a loss of flow of 3.83 million m^3 over the May 5 to October 21, 2009 measurement period for Station S15A. The estimated *baseline* hydrograph is presented in Figure 5.4-3.

The mean open-water discharge and the annual maximum daily discharge calculated from the observed *test* hydrograph are 18.5% and 18.8% lower, respectively, than from the estimated *baseline* hydrograph (Table 5.4-3); these differences are classified as **High** (Table 5.4-1). The open-water minimum daily discharge calculated from the observed *test* hydrograph is 12.8% lower than from the estimated *baseline* hydrograph (Table 5.4-3); this difference is classified as **Moderate** (Table 5.4-1).

5.4.3 Water Quality

In 2009, water quality samples were taken in spring, summer and fall from:

- the Tar River near its mouth (*test* station TAR-1, designated as *test* in summer 2004, sampled from 1998 to 2009); and
- the upper Tar River (*baseline* station TAR-2, sampled since 2004).

2009 Results Relative to Historical and Regional *Baseline* Concentrations At *test* station TAR-1, concentrations of all water quality measurement endpoints were within historical ranges in fall 2009 with the exception of DOC and alkalinity, which exceeded historical maximum concentrations, and total dissolved phosphorus, total aluminum, total arsenic and total suspended solids, which were below historical minimum concentrations (Table 5.4-4). From 2006 to 2008, concentrations of several water quality measurement endpoints were above previous historical maxima and regional *baseline* fall concentrations at *test* station TAR-1; however, all water-quality measurement endpoints at *test* station TAR-1 were within regional *baseline* concentrations in fall 2009 with the exception of calcium (Figure 5.4-4). At *baseline* station TAR-2, concentrations of several water quality measurement endpoints in fall 2009 were outside the range of historical concentrations at this station (Table 5.4-5):

- total boron, total aluminum, indicators of dissolved ions such as conductivity, calcium and sulphate, and dissolved aluminum exceeded historical maximum concentrations; and
- total suspended solids, total dissolved phosphorus and chloride were below historical minimum concentrations.

No water quality measurement endpoint at *baseline* station TAR-2 had concentrations in fall 2009 that exceeded their 95th percentile of regional *baseline* concentrations (Figure 5.4-4).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of total nitrogen, and total aluminum exceeded water quality guidelines in fall 2009 at *test* station TAR-1 (Table 5.4-4), while the concentration of total aluminum exceeded its water quality guideline in fall 2009 at *baseline* station TAR-2 (Table 5.4-5).

Other Water Quality Guideline Exceedances The following are other water quality guideline exceedances observed in the Tar River in 2009 (Table 5.4-6):

- Spring and summer. Sulphide, total aluminum, total phosphorus, total iron, dissolved iron, total phenols, total Kjeldahl nitrogen, and total nitrogen at *test* station TAR-1;
- Spring. Sulphide, total aluminum, total phosphorus, total iron, dissolved iron, total phenols, total Kjeldahl nitrogen, and total nitrogen at *baseline* station TAR-2;
- Summer. Sulphide, total aluminum, total phosphorus, total iron, dissolved iron, and total phenols at *baseline* station TAR-2;
- Fall. Sulphide, total iron, and total phenols at *test* station TAR-1; and
- Fall. Total iron at *baseline* station TAR-2.

Ion Balance In 2009, the anion composition at *test* station TAR-1 shifted towards a carbonate/bicarbonate composition similar to pre-2006 water quality conditions at this station and away from a sulphate and chloride composition observed from 2006 to 2008 (Figure 5.4-5). The ionic characteristics of water at *baseline* station TAR-2 have changed little since 2004 (Figure 5.4-5).

Trend Analysis Significant (α=0.05) upward trends in total nitrogen, sulphate, chloride, and calcium, and a downward trend in total suspended solids were observed in fall over time at *test* station TAR-1 despite decreased in several of these variables in 2009. No trend data was available for *baseline* station TAR-2, given the short period of record.

Water Quality Index The WQI values for both stations in the Tar River watershed (i.e., *test* station TAR-1: 89.1, *baseline* station TAR-2: 100) indicated **Negligible-Low** differences from regional *baseline* fall conditions. The calculated 2009 WQI value for *test* station TAR-1 was substantially higher than the calculated 2008 WQI value of 59.8.

Summary Differences in water quality observed in fall 2009 between the lower Tar River and regional *baseline* fall conditions were **Negligible-Low**. This is in contrast to water quality conditions in the lower Tar River in 2007 and 2008 when water quality was assessed as being measurably different from regional *baseline* conditions.

5.4.4 Benthic Invertebrate Communities and Sediment Quality

5.4.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in the Tar River watershed at:

- depositional *test* reach TAR-D-1 near the mouth of the river, first sampled in 2002; and
- erosional *baseline* reach TAR-E-2, established and first sampled in fall 2009, as the previous erosional *baseline* reach (TAR-E-1) was further downstream in an area of the river that was designated as *test* in 2008.

2009 Habitat Conditions The depositional *test* reach of the Tar River (TAR-D-1) in fall 2009 was shallow (0.3 m), with a substrate dominated by sand (90%), and no macrophyte cover. Water had high conductivity (863 µS/cm), and alkaline pH. The *baseline* erosional reach of the Tar River (TAR-E-2) in fall 2009 was also shallow (0.2 m) with substrate consisting of a mixture of gravel, cobble, boulder and bedrock, and no evident macrophyte cover (Table 5.4-7). Conductivity of the *baseline* reach was about half of that in the lower reach, while pH was similar to the *test* reach. Periphyton biomass in the *baseline* reach TAR-E-2 averaged 220 mg/m^2, near the maximum regional *baseline* periphyton biomass (Figure 5.4-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of the *test* reach TAR-D-1 was dominated by chironomids (43%), tubificid worms (28%), and copepods (11%), with ceratopogonids, naidids, ostracods and bivalves sub-dominant (Table 5.4-8). Mayflies (*Caenis*) and caddisflies (early instar Limnephilidae) were present, but in low relative abundance. The dominant chironomids included *Heterotrissocladius* and *Pseudosmittia*, two forms that are generally associated with good habitat quality. Other dominant chironomids were the ubiquitous *Micropsectra* and *Polypedilum*.

The benthic invertebrate community of *baseline* reach TAR-E-2 was dominated by chironomids (28%), mayflies (Ephemeroptera, 26%), stoneflies (Plecoptera, 15%) and caddisflies (Trichoptera, 16%), with water mites (Hydracarina) and empidid fly larvae sub-dominant (Table 5.4-8). A variety of worms (naidids, nematodes, tubificids) were present, but in low relative abundance (≤ 1%). *Cricotopus* was the most dominant chironomid, while the dominant caddisflies included the *Hydropsyche*, and *Glossosoma*. Mayflies included members of Heptageneiidae and Baetidae, while stoneflies included Capniidae, *Skwala*, *Pteronarcella* and *Zapada*.

Linear contrasts were used to test for the following in *test* reach TAR-D-1:

- a difference from before to after (a significant contrast would imply a "negative" change); and
- a difference from before to 2009, i.e. to test for "recovery" (a non-significant contrast would imply no difference between index values in 2009 and those in the *baseline* condition of depositional reaches).

These contrasts were implemented on abundance, richness, Simpson's diversity, evenness, %EPT, and scores from CA Axes 1 and 2. Abundance, richness, diversity and evenness all decreased significantly since the time when *test* reach TAR-D-1 was designated as *test*. However, there was no significant difference in measurement endpoints when comparing values in 2009 to values in the *baseline* period (prior to 2004), suggesting that although changes had occurred in previous years when the reach was designated as *test* (i.e., 2004, 2005 and 2006), a recovery in the benthic invertebrate community had occurred by 2009.

5.4.4.2 Sediment Quality

Sediment quality was sampled in fall 2009 at *test* station TAR-D-1, in the Tar River near its mouth, in the same location as the benthic invertebrate sampling reach.

2009 Results and Historical Ranges of Concentration 2009 sediment quality data from *test* reach TAR-D-1 may be compared directly with data obtained from this reach in 2006. Prior to integration of the sediment quality and benthic invertebrate communities components of RAMP in 2006, *test* reach TAR-D-1 corresponds to pre-2006 sediment quality station TAR-1.

Sediments at *test* station TAR-D-1 were dominated by sand, with a small proportion of both clay and silt and low total organic carbon content (Table 5.4-10). In fall 2009, concentrations of all sediment quality measurement endpoints were within historical ranges. As in previous years, Fraction-1 hydrocarbons and BTEX (benzene, toluene, ethylene and xylene) were not detectable at *test* station TAR-D-1, with the sediment hydrocarbons dominated by Fraction 3 and Fraction 4 groups. Predicted PAH toxicity was within the historical range of toxicity (Table 5.4-10).

Direct tests of sediment toxicity to invertebrates at *test* station TAR-D-1 showed 100% survival in test organisms of the amphipod *Hyalella*, and 56% survival of test organisms of the midge *Chironomus*. Ten-day growth of *Chironomus* was below the historical minimum, while 14-day growth of *Hyalella* exceeded the historical maximum (Table 5.4-10).

Comparison of Sediment Quality Guidelines There were no sediment quality measurement endpoints with concentrations above sediment or soil quality guidelines in fall 2009.

Sediment Quality Index An SQI of 95.6 was calculated for *test* station TAR-D-1 for fall 2009. Since 1998, this station has maintained a SQI value above 94.3 with the exception of the value calculated in 2004 (SQI: 69.4), indicating consistent sediment quality over time and **Negligible-Low** differences from regional *baseline* conditions.

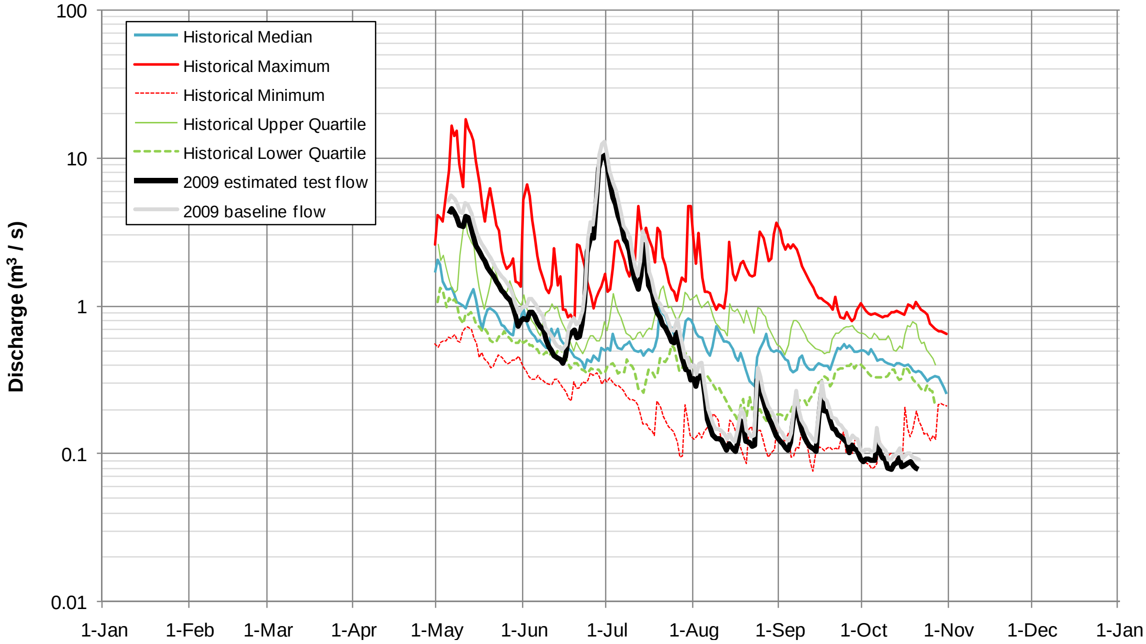
5.4.4.3 Summary

The data from the *test* reach of the Tar River support a conclusion that the benthic invertebrate community had been influenced by focal projects in 2005 and 2006, but have recovered to conditions within the historical *baseline* range in 2009. The variation in benthic invertebrate community composition in the *test* reach of the Tar River are classified as **Negligible-Low** on the basis that changes were modest relative to the remainder (noise) component, and because all measurement endpoints were within regional *baseline* conditions. The reach had previously exhibited changes classified as **High**, but recovered to an approximate *baseline* condition in 2009. Differences in sediment quality observed in fall 2009 between the lower Tar River and regional *baseline* conditions were **Negligible-Low**.

5.4.5 Fish Populations

The Fish Population component did not conduct regular monitoring activities in the Tar River watershed in 2009; however, a pilot study of fish assemblage monitoring included a reach on the lower Tar River; Section 6 contains the results of this study.

Figure 5.4-3 The observed (*test*) hydrograph for the Tar River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on Station S15A, Tar River near the mouth, provisional data for May 5 to October 21, 2009. The upstream drainage area is 333 km^2. Historical values from May 1 to October 31 are calculated from data collected from 1975 to 1977 and 2001 to 2008.

Table 5.4-2 Estimated water balance at RAMP Station S15A, Tar River near the mouth, May 5 to October 21, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**16.89**	**Observed discharge, obtained from Station S15A, Tar River near the mouth**
Closed-circuited area water loss from the observed *test* hydrograph	-4.01	Estimated 64.4 km^2 of the Tar River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.10	Estimated 8.1 km^2 of the Tar River watershed with land change from focal projects as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the Tar River watershed from focal projects	0	None reported
Water releases into the Tar River watershed from focal projects	+0.08	Release from the wastewater treatment plant
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Tar River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**20.72**	**Estimated *baseline* discharge at RAMP Station S15A, Tar River near the mouth**
Incremental flow (change in total discharge)	-3.83	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**-18.5%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on Station S15A, Tar River near the mouth, provisional data for May 5 to October 21, 2009.

Note: In 2009, Canadian Natural reported an annual release of 174,000 m^3 (0.17 million m^3) from the wastewater treatment plant to the Tar River. A constant daily release was calculated from this value, resulting in an estimated 0.08 million m^3 that was released from May 5 to October 21, 2009 when flow measurements were obtained.

Table 5.4-3 Calculated change in hydrologic measurement endpoints for the Tar River watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	1.41	1.15	-18.5%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	12.80	10.39	-18.8%
Open-water period minimum daily discharge	0.09	0.08	-12.8%

Note: Based on Station S15A, Tar River near the mouth, provisional data for May 5 to October 21, 2009.

Table 5.4-4 Concentrations of water quality measurement endpoints, mouth of the Tar River (station TAR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.29	8	8.1	8.2	8.5
Total Suspended Solids	mg/L	-[1]	6	8	7	25.5	214
Conductivity	µS/cm	-	535	8	302	460	875
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.012	8	0.013	0.034	**0.125**
Total nitrogen*	mg/L	1.0	**1.011**	8	0.5	**1.15**	**4.30**
Nitrate+Nitrite	mg/L	1.0	0.071	8	<0.1	0.15	**3.5**
Dissolved organic carbon	mg/L	-	22.6	8	12	16.5	21
Ions							
Sodium	mg/L	-	32	8	15	29.5	50
Calcium	mg/L	-	69.3	8	38	50.75	88.5
Magnesium	mg/L	-	17.8	8	11.3	16.0	24.3
Chloride	mg/L	230, 860[3]	13.8	8	1.7	4.5	50
Sulphate	mg/L	100[4]	45.6	8	20.4	40.1	173.0
Total Dissolved Solids	mg/L	-	380	8	170	315	590
Total Alkalinity	mg/L		221	8	121	175	210
Organic compounds							
Naphthenic acids	mg/L	-	0.308	8	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	**0.167**	8	**0.36**	**0.52**	**3.95**
Dissolved aluminum	mg/L	0.1[2]	0.0054	8	0.005	0.009	0.026
Total arsenic	mg/L	0.005	0.0009	8	0.0011	0.0016	0.0022
Total boron	mg/L	1.2[5]	0.0755	8	0.054	0.101	0.145
Total molybdenum	mg/L	0.073	0.0004	8	0.0004	0.0011	0.0020
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	**5.6**
Total strontium	mg/L	-	0.227	8	0.143	0.215	0.442
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0088**	8	**<0.003**	**0.007**	**0.023**
Total iron	mg/L	0.3	**1.4**	8	**1.4**	**2.1**	**7.0**
Total phenols	mg/L	0.004	**0.0048**	8	<0.001	**0.0055**	**0.008**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.4-5 Concentrations of water quality measurement endpoints, upper Tar River (station TAR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008(fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.29	5	8.0	8.3	8.4
Total Suspended Solids	mg/L	-[1]	<3	5	5	5	7
Conductivity	µS/cm	-	393	5	233	331	383
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.022	5	0.024	**0.051**	**0.058**
Total nitrogen*	mg/L	1.0	0.491	5	0.4	0.5	0.60
Nitrate+Nitrite	mg/L	1.0	0.071	5	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	11	5	8	13	14
Ions							
Sodium	mg/L	-	14.4	4	6	12	16
Calcium	mg/L	-	53	5	31.4	45.6	49
Magnesium	mg/L	-	13.9	5	8.8	13.5	14.3
Chloride	mg/L	230, 860[3]	0.5	5	1.0	2.0	2.0
Sulphate	mg/L	100[4]	49	5	20	37.2	38
Total Dissolved Solids	mg/L	-	262	5	160	234	280
Total Alkalinity	mg/L		157	5	100	159	162
Organic compounds							
Naphthenic acids	mg/L	-	0.074	5	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	**0.121**	5	0.073	**0.17**	**0.708**
Dissolved aluminum	mg/L	0.1[2]	0.0515	5	0.008	0.0163	0.026
Total arsenic	mg/L	0.005	0.00102	5	0.0008	0.0012	0.0014
Total boron	mg/L	1.2[5]	0.074	5	0.035	0.0556	0.067
Total molybdenum	mg/L	0.073	0.0014	5	0.0008	0.0013	0.0015
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	5	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.178	5	0.101	0.161	0.185
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total iron	mg/L	0.3	**0.72**	5	**0.856**	**1.031**	**1.59**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN); non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

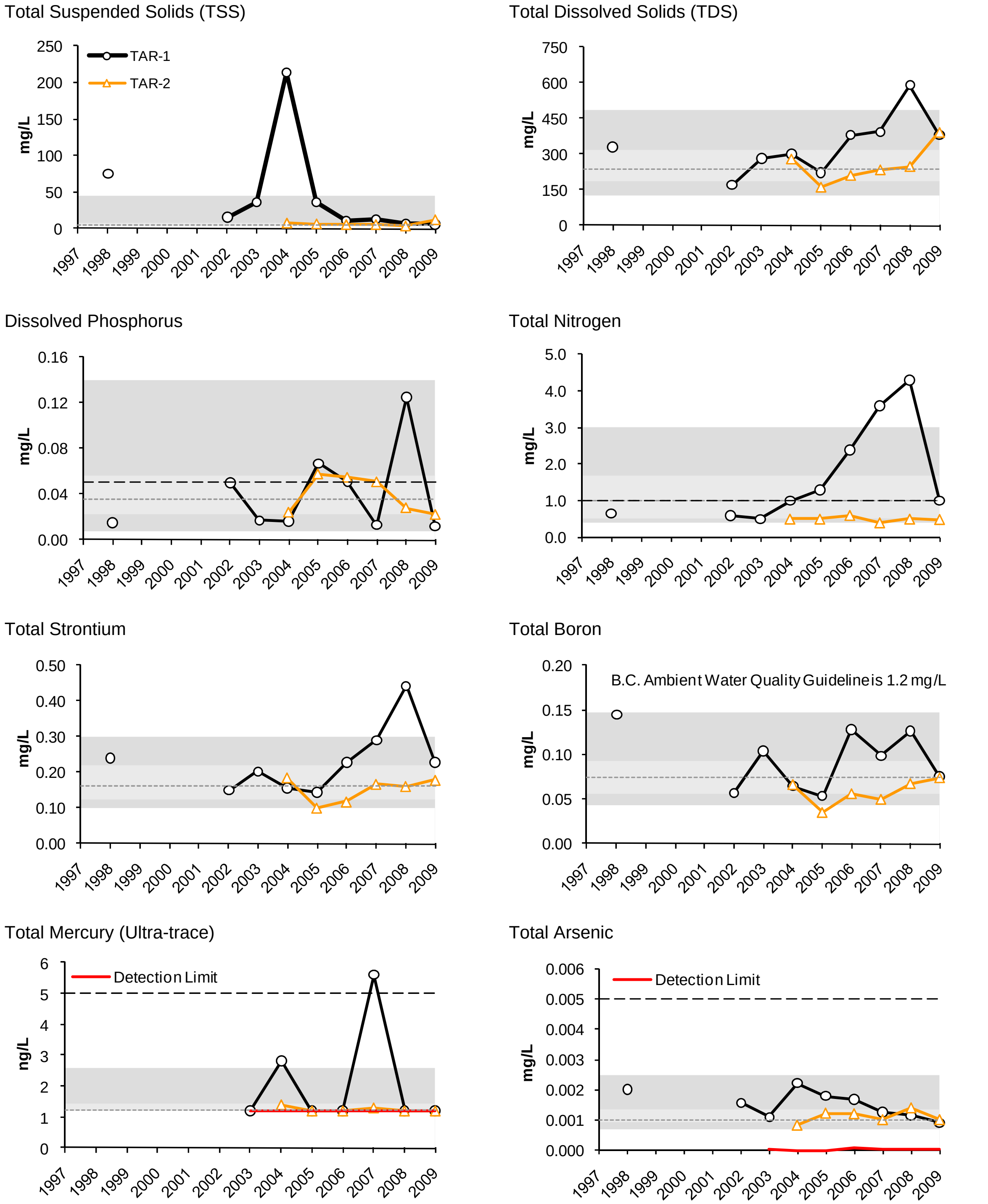
3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

Figure 5.4-4 Concentrations of selected water quality measurement endpoints in the Tar River (fall data) relative to regional *baseline* fall concentrations.



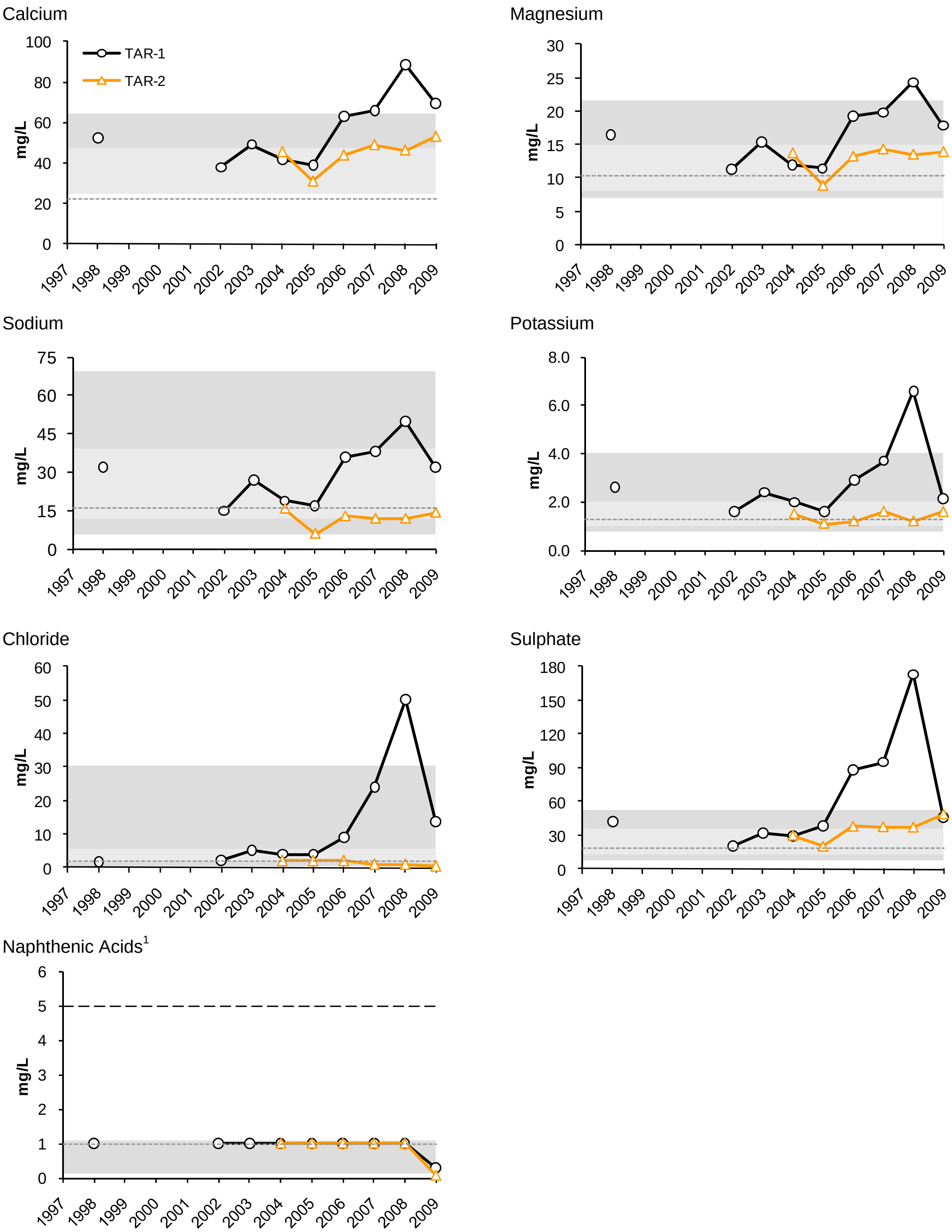
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.4-4 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.4-6 Water quality guideline exceedances, Tar River, 2009.

Variable	Units	Guideline	Station TAR-1	Station TAR-2
Spring				
Dissolved iron	mg/L	0.3[2]	**0.48**	**0.399**
Total phenols	mg/L	0.004	**0.0084**	**0.0081**
Sulphide	mg/L	0.002[1]	**0.0082**	**0.0068**
Total phosphorus	mg/L	0.05	**0.145**	**0.0903**
Total Kjeldahl nitrogen	mg/L	1.0[4]	**1.54**	**1.02**
Total nitrogen	mg/L	1.0	**1.611**	**1.091**
Total aluminum	mg/L	0.1	**2.43**	**1.76**
Total iron	mg/L	0.3	**3.18**	**1.94**
Summer				
Dissolved iron	mg/L	0.3[2]	**0.486**	**0.448**
Total phenols	mg/L	0.004	**0.0063**	**0.0054**
Sulphide	mg/L	0.002[1]	**0.0042**	**0.0031**
Total phosphorus	mg/L	0.05	**0.815**	**0.0653**
Total Kjeldahl nitrogen	mg/L	1.0[4]	**1.21**	**-**
Total nitrogen	mg/L	1.0	**1.281**	**-**
Total aluminum	mg/L	0.1	**1.74**	**0.918**
Total iron	mg/L	0.3	**2.14**	**1.19**
Fall				
Sulphide	mg/L	0.002[1]	**0.0088**	**-**
Total aluminum	mg/L	0.1	**0.167**	**0.121**
Total iron	mg/L	0.3	**-**	**0.72**
Total phenols	mg/L	0.004	**0.0048**	-
Total nitrogen	mg/L	1.0	**1.011**	-

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] Guideline is for total species (no guideline for dissolved species).

[3] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[4] Guideline is for total nitrogen.

Figure 5.4-5 Piper diagram of fall ion concentrations, Tar River.

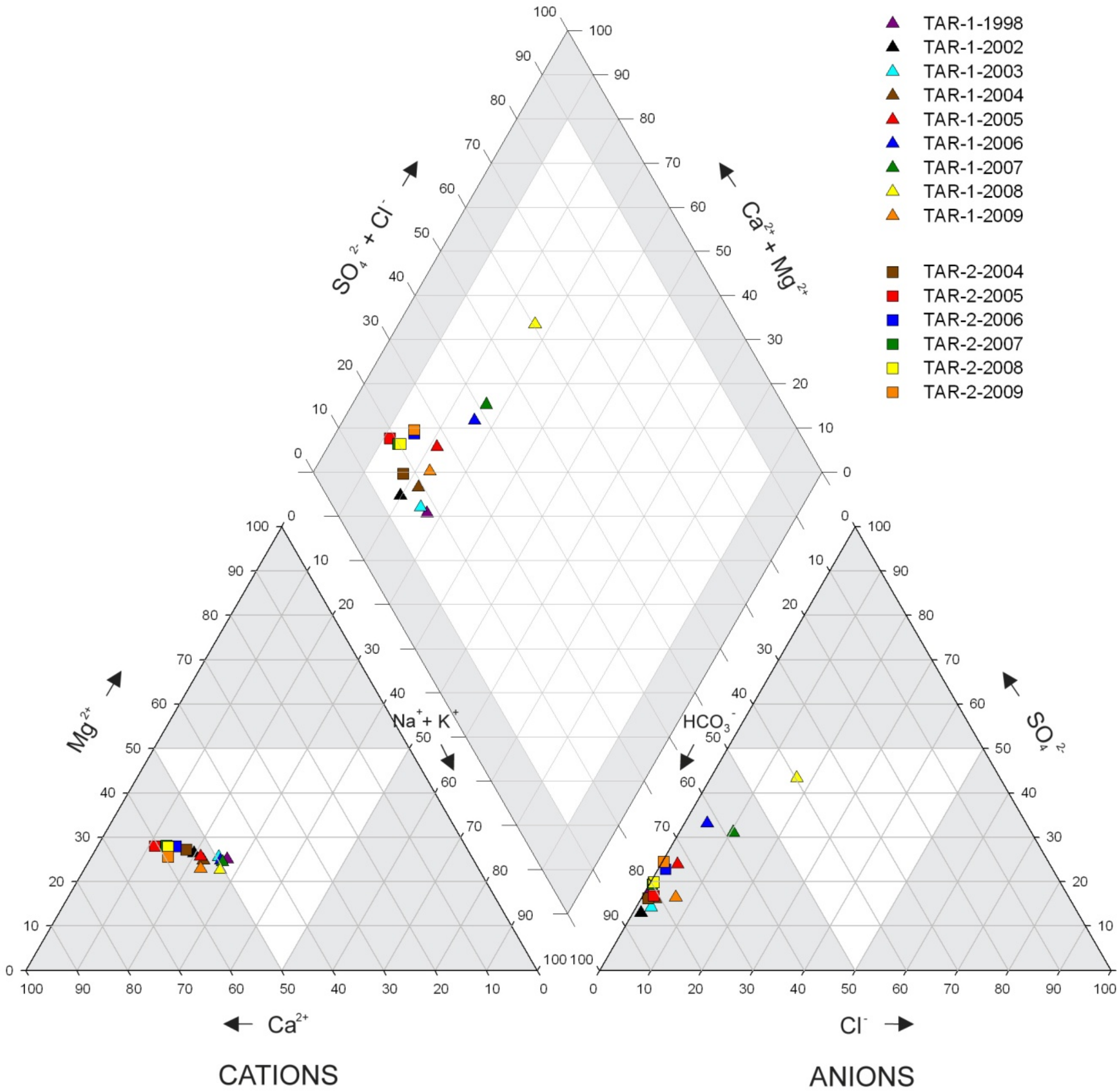


Table 5.4-7 Average habitat characteristics of benthic invertebrate sampling locations in the Tar River (TAR-D-1, TAR-E-2), fall 2009.

Variable	Units	*Test* Reach (TAR-D-1)	*Baseline* Reach (TAR-E-2)
Sample Date	-	Sept 15, 2009	Sept 13, 2009
Habitat	-	Depositional	Erosional
Water Depth	m	0.3	0.2
Velocity	m/s	0.2	0.6
Macrophyte Cover	%	0	0
Field Water Quality			
Dissolved Oxygen	mg/L	8.1	10.0
Conductivity	µS/cm	863	437
pH	pH units	8.2	8.4
Water Temperature	°C	14.2	11.3
Sediment Composition			
Sand	%	90	
Silt	%	6	
Clay	%	4	
Total Organic Carbon	%	1.01	
Sand/Silt/Clay			0
Small Gravel			14
Large Gravel			6
Small Cobble			11
Large Cobble			26
Boulder			37
Bedrock			8

Figure 5.4-6 Periphyton chlorophyll a biomass in the *baseline* reaches of the Tar River.

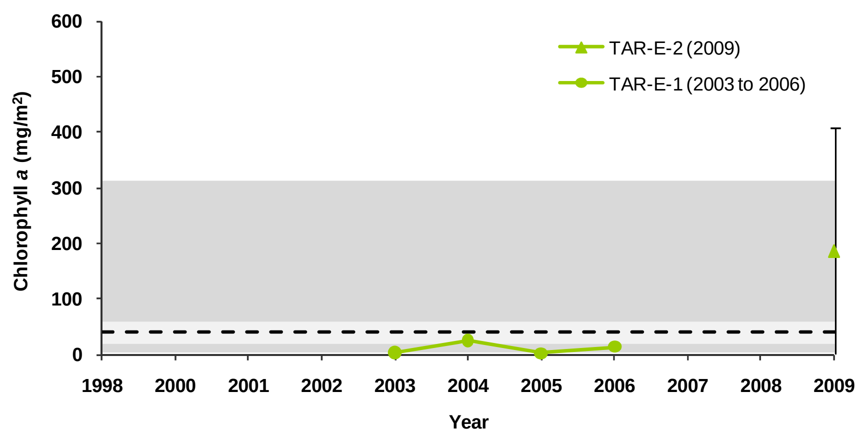
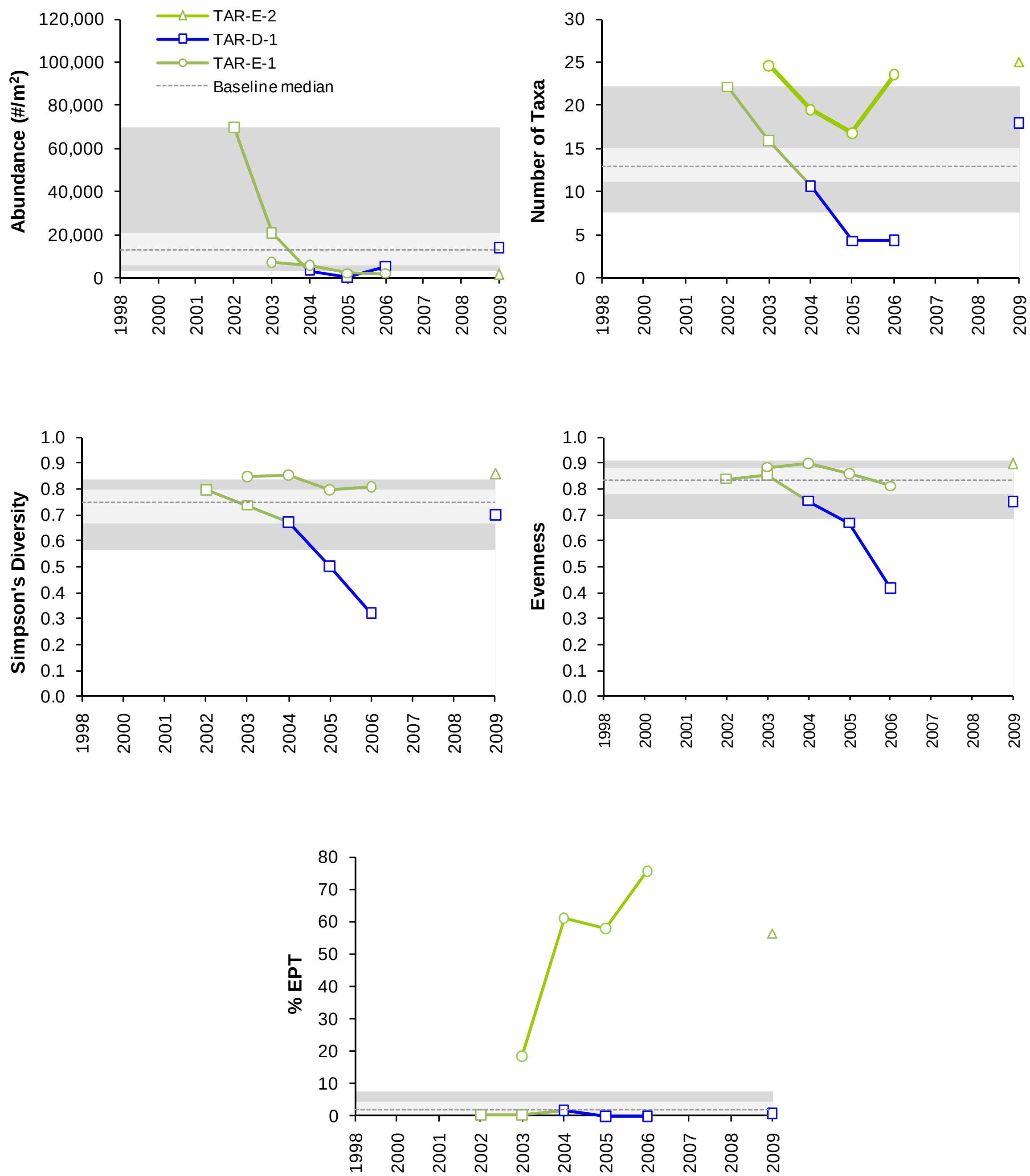


Table 5.4-8 Summary of major taxa abundances and benthic invertebrate community measurement endpoints in the Tar River.

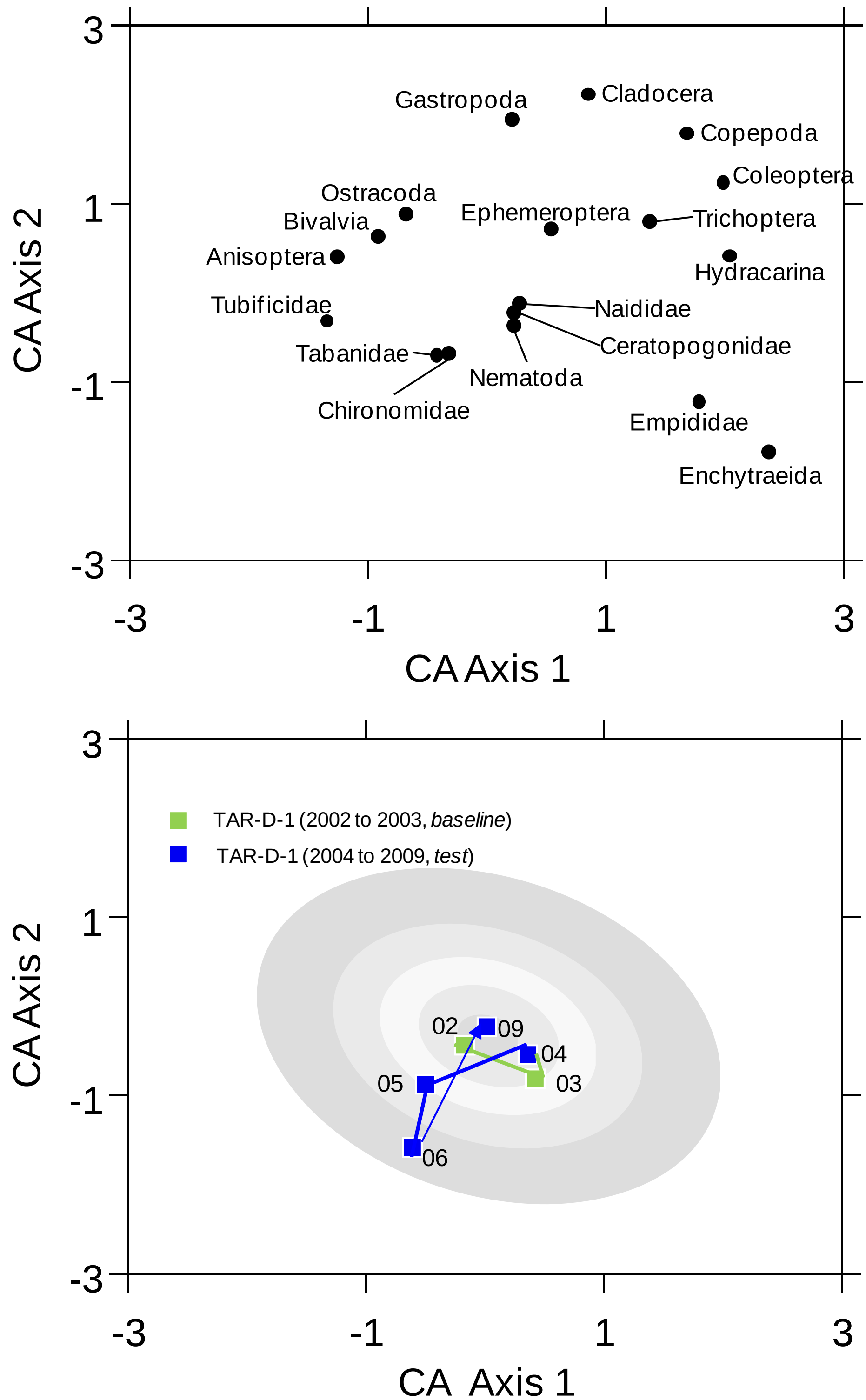
Taxon	Percent Major Taxa Enumerated in Each Year										
	Test Reach TAR-D-1						*Baseline* Reach TAR-E-1				***Baseline* Reach TAR-E-2**
	2002	**2003**	**2004**	**2005**	**2006**	**2009**	**2003**	**2004**	**2005**	**2006**	**2009**
Amphipoda	<1										
Anisoptera	<1										
Bivalvia	1	<1	<1	1		<1					
Ceratopogonidae	1	1	16	8		5	<1	<1			
Chironomidae	86	90	33	20	<1	43	67	21	33	8	28
Chydoridae	<1	<1	<1								
Coleoptera	<1		<1			<1		<1		<1	
Collembola		<1									
Copepoda	<1	<1	2			11	1		<1		<1
Dolichopodidae			1					<1			
Empididae	1	1	1		<1	<1	2	1	2	8	
Enchytraeidae			5	2			2	<1	<1	2	6
Ephemeroptera	<1	<1	1			1	5	38	45	48	1
Ephydridae							<1				26
Erpobdellidae	<1	<1	<1					<1			
Gastropoda	<1		1								
Heteroptera							<1				
Hydracarina	<1	1	1			<1	1	2	<1	2	4
Naididae	<1	4	2			2	6	<1	<1	1	<1
Nematoda	2	<1	4	1	<1	1	2	<1	<1	<1	<1
Ostracoda	2	<1	25	37		5					<1
Plecoptera	<1	<1	<1				8	13	12	8	15
Simuliidae								13	2	1	<1
Tabanidae	<1	<1	<1	1		<1					
Tipulidae	<1	<1	<1	3	<1	<1	1	<1	<1	1	1
Trichoptera	<1	<1	<1			<1	2	10	3	19	16
Tubificidae	7	1	6	28	1	28	1	1	1	0.3	<1
Benthic Invertebrate Community Measurement Endpoints											
Total Abundance (No./m^2)	69,759	20,805	3,489	657	5,534	14,218	7,166	5,781	2,263	21,548	2,037
Richness	22	16	11	4	4	18	25	20	17	24	25
Simpson's Diversity	0.80	0.74	0.67	0.50	0.33	0.70	0.85	0.85	0.80	0.80	0.86
Evenness	0.84	0.85	0.75	0.87	0.33	0.75	0.88	0.90	0.86	0.80	0.90
% EPT	<1	<1	2	0	0	1	18	61	58	7	56

Figure 5.4-7 Variation in benthic invertebrate community measurement endpoints in Tar River.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.4-8 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Tar River (*test* reach TAR-D-1).



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.4-9 Results of analysis of variance (ANOVA) of benthic invertebrate community measurement endpoints between *test* (TAR-D-1) and *baseline* depositional reaches sampled in the RAMP FSA.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	37.644	10	3.764	17.96	0.000
	BA x BT	0.058	1	0.058	0.28	0.601
	TT x BT	4.090	1	4.090	19.52	0.000
	Remainder (noise)	33.496	8	4.187	19.98	0.000
	Error	25.987	124	0.210		
Log Richness	Reach - Year	7.543	10	0.754	26.35	0.000
	BA x BT	0.182	1	0.182	6.36	0.013
	TT x BT	0.007	1	0.007	0.24	0.628
	Remainder (noise)	7.354	8	0.919	32.11	0.000
	Error	3.550	124	0.029		
Diversity	Reach - Year	3.014	10	0.301	11.45	0.000
	BA x BT	0.161	1	0.161	6.10	0.015
	TT x BT	0.006	1	0.006	0.24	0.622
	Remainder (noise)	2.847	8	0.356	13.51	0.000
	Error	3.266	124	0.026		
Evenness	Reach - Year	2.161	10	0.216	7.76	0.000
	BA x BT	0.21	1	0.21	7.45	0.007
	TT x BT	0.02	1	0.02	0.59	0.443
	Remainder (noise)	1.937	8	0.242	8.69	0.004
	Error	3.454	124	0.028		
Log %EPT	Reach - Year	82.63	10	8.26	218.77	0.000
	BA x BT	1.51	1	1.51	39.98	0.000
	TT x BT	0.00	1	0.00	0.13	0.718
	Remainder (noise)	81.11	8	10.14	268.43	0.000
	Error	4.68	124	0.04		

Table 5.4-10 Concentrations of selected sediment measurement endpoints, Tar River (TAR-D-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	7	6	3	13.5	26
Silt	%	-	10	6	3	16.5	50
Sand	%	-	83	6	24	70	94
Total organic carbon	%	-	1.01	6	0.3	0.99	6.3
Total hydrocarbons							
BTEX	mg/kg	-	<10	3	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	3	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	21	3	13	59	100
Fraction 3 (C16-C34)	mg/kg	300[1]	267	3	220	**810**	**860**
Fraction 4 (C34-C50)	mg/kg	2800[1]	215	3	170	360	460
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0013	6	0.0013	0.004	0.015
Retene	mg/kg	-	0.031	5	0.012	0.043	0.379
Total dibenzothiophenes	mg/kg	-	0.723	6	0.152	0.773	6.256
Total PAHs	mg/kg	-	2.142	6	0.490	2.207	17.014
Total Parent PAHs	mg/kg	-	0.057	6	0.047	0.084	0.449
Total Alkylated PAHs	mg/kg	-	2.085	6	0.398	2.145	16.566
Predicted PAH toxicity[3]	H.I.	-	1.238	6	0.206	1.711	5.308
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	5.6	3	5.0	7.0	8.6
Chironomus growth - 10d	mg/organism	-	0.9	3	1.9	2.0	4.0
Hyalella survival - 14d[4]	# surviving	-	10.0	2	6.6	8.8	9.0
Hyalella growth - 14d[4]	mg/organism	-	0.3	2	0.1	0.1	0.2

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[4] 2002 *Hyalella* test based on 10-day test period.

5.5 MACKAY RIVER WATERSHED

Table 5.5-1 Summary of results for MacKay River watershed.

MacKay River Watershed	Summary of 2009 Conditions			
Climate and Hydrology				
Criteria	**S26** near Fort McKay	no stations sampled		no station sampled
Mean open-water season discharge	○			
Mean winter discharge	○			
Annual maximum daily discharge	○			
Minimum open-water season discharge	○			
Water Quality				
Criteria	**MAR-1** at the mouth	**MAR-2** upstream of Suncor MacKay	**MAR-2a** upstream of Suncor Dover MacKay	**DUR-1** Dunkirk River
Water Quality Index	○	○	○	○
Benthic Invertebrate Communities and Sediment Quality				
Criteria	**MAR-E-1** at the mouth	no station sampled	**MAR-E-2** upstream of Suncor MacKay	**DUR-E-1** Dunkirk River
Benthic Invertebrate Communities	○		n/a	n/a
No Sediment Quality component activities conducted in 2009				
Fish Populations				
Fish Population Component activities included a sentinel species study (Section 5.3) and a Fish Assemblage Monitoring Pilot Study (Section 6)				

Legend and Notes

○ Negligible-Low
○ Moderate
○ High
baseline
test

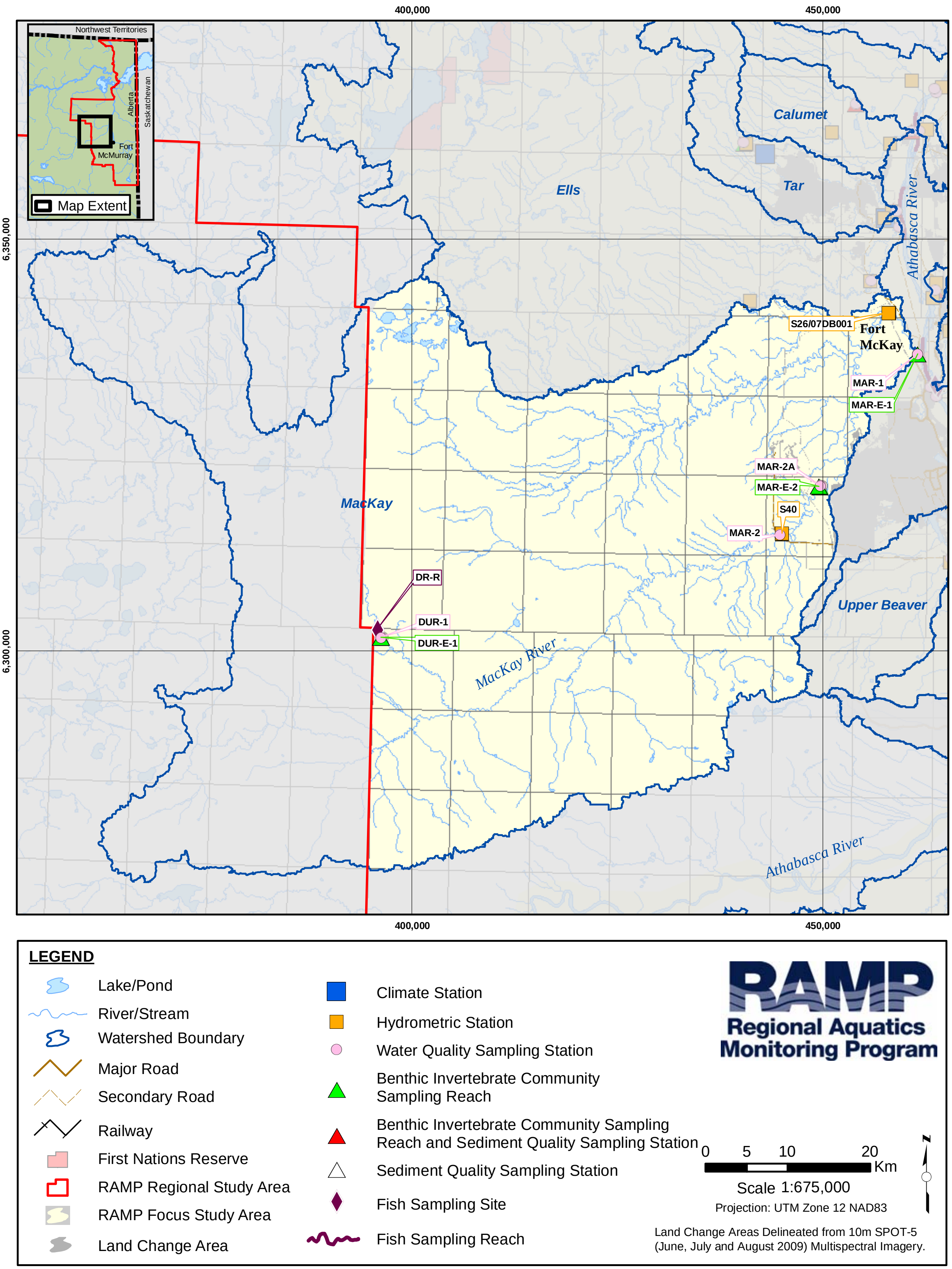
n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Figure 5.5-1 MacKay River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K05_MacKay_20100415.mxd

Figure 5.5-2 Representative monitoring stations of the MacKay River watershed, fall 2009.

Water Quality Station MAR-1: Right Downstream Bank

Water Quality Station MAR-1: Right Downstream Bank

Water Quality Station MAR-2: Right Downstream Bank

Water Quality Station MAR-2a: Right Downstream Bank

Benthic Invertebrate Reach DUR-E-1: Centre of Channel facing downstream

Sentinel Fish Species Site DR-R: Right Downstream Bank

5.5.1 Summary of 2009 Conditions

As of 2009, less than 1% (1,600 ha) of the MacKay River watershed had undergone land change as a result of focal projects (Table 2.4-2). The designations of specific areas of the watershed are therefore as follows:

1. The MacKay River watershed downstream of the Suncor MacKay River *in situ* operations and the part of Syncrude's Mildred Lake operations in the MacKay River watershed (Figure 5.5-1) are designated as *test*.

2. The remainder of the watershed is designated as *baseline*.

The Climate and Hydrology, Water Quality, Benthic Invertebrate Communities, and Fish Population components of RAMP conducted monitoring activities in the MacKay River watershed in 2009. The Fish Population component conducted a non-lethal sentinel species study on a number of tributaries including the Dunkirk River; results are presented in Section 5.3. In addition, a pilot study of fish Assemblage monitoring included a reach on the lower MacKay River; Section 6 contains the results of this study. Table 5.5-1 is a summary of the 2009 assessment of the MacKay River watershed, while Figure 5.5-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.5-2 contains fall 2009 photos of water quality monitoring stations in the watershed.

Hydrology The observed 2009 total discharge for the MacKay River watershed is estimated to be 0.01% less than the total discharge would have been in the absence of oil sands developments in the watershed. Watershed-level differences in the hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality Differences in water quality in fall 2009 in the MacKay River as compared to regional *baseline* conditions are assessed as **Negligible-Low**:

1. Any exceedances of water quality guidelines in 2009 occurred at multiple stations (both *test* and *baseline*) throughout the watershed.

2. Concentrations of almost all water quality measurement endpoints in fall 2009, were within the range of natural variability as they have consistently been since the beginning of the RAMP water quality data record for the MacKay River watershed.

The ionic composition at all water quality monitoring stations in the watershed in 2009 was consistent with previous years and continues to show little year-to-year variation.

Benthic Invertebrate Communities The differences in the benthic invertebrate community in the lower MacKay River as compared to the upper MacKay River were assessed as **Negligible-Low**. Differences in benthic invertebrate community measurement endpoints between the *test* and *baseline* reaches of the Mackay River were statistically weak and values of all benthic invertebrate community measurement endpoints in the lower MacKay River (MAR-E-1) in fall 2009 were within the range of variation for *baseline* erosional reaches in the RAMP FSA. The benthic invertebrate community of the *baseline* reach of the Dunkirk River provides additional data describing the *baseline* condition of erosional reaches in the RAMP FSA.

5.5.2 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay The 2009 annual runoff volume measured at WSC Station 07DB001 (RAMP Station S26) was 523 million m^3, 32% above the historical mean value calculated from the 21 years of annual flow record. Flows in 2009 at this station were similar to historical upper quartile flows from January until the beginning of June, including the snowmelt-driven freshet flows in late April (Figure 5.5-3). The open-water maximum daily flow of 120 m^3/s occurred on June 30 following the June 22 rainfall event. Flows thereafter dropped below median flows in late July and generally remained at this level for the rest of the year. In 2009, the open-water maximum and minimum daily flows of 120 m^3/s and 2.15 m^3/s were 15% higher and 43% lower, respectively, than the corresponding historical mean values.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance for 2009 at WSC Station 07DB001 is presented in Table 5.5-2 and described below:

1. The closed-circuited land area from focal projects as of 2009 was estimated at 2.9 km^2 (Table 2.4-1). The loss of flow to the MacKay River that would have otherwise occurred from this land area is estimated at 0.27 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 13.3 km^2 (Table 2.4-1). The increase in flow to the MacKay River that would not have otherwise occurred from this land area is estimated at 0.25 million m^3.

The estimated cumulative effect of land change is a loss of flow of 0.037 million m^3 at WSC Station 07DB001. The estimated *baseline* hydrograph is presented in Figure 5.5-3.

The 2009 mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are from 0% to 0.04% lower than from the estimated *baseline* hydrograph (Table 5.5-3); these differences are classified as **Negligible-Low** (Table 5.5-1).

5.5.3 Water Quality

In fall 2009, water quality samples were collected from the:

- mouth of the MacKay River (*test* station MAR-1, first sampled in 1998, fall sampling every year from 2000 to 2009);
- MacKay River upstream of the Suncor MacKay River Devon *in situ* developments (*baseline* station MAR-2, sampled from 2002 to 2009);
- MacKay River upstream of the Suncor Dover developments (*baseline* station MAR-2a, initiated as a new RAMP station in 2009); and
- Dunkirk River (*baseline* station DUR-1, initiated as a new RAMP station in fall 2009 to support the Fish Population Component).

All of the MacKay River stations were sampled in all seasons in 2009 with the exception of the Dunkirk River, which was only sampled in fall 2009.

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of all water quality measurement endpoints at *test* station MAR-1 were within the historical range of concentrations and regional *baseline* fall concentrations (Table 5.5-4 and Figure 5.5-4) with the exception of:

- dissolved aluminum, which was below its historical minimum concentration for this station; and
- total mercury, which was measured above analytical detection limits for the first time and was above both regional *baseline* fall concentrations and the historical range for this station. Further discussion of mercury concentrations in the RAMP FSA will be provided in Section 7.2.

Concentrations of all water quality measurement endpoints at *baseline* station MAR-2 in fall 2009 were: (i) within regional *baseline* fall concentrations; and (ii) within historical ranges of concentration for this station, with the exception of calcium, magnesium, pH and conductivity which were higher than historical maximum concentrations (Table 5.5-5 and Figure 5.5-4). Because *baseline* stations MAR-2a and DUR-1 were first sampled in 2009, no historical data were available for comparison with 2009 results (Table 5.5-6 and Table 5.5-7); however, concentrations of all measurement endpoints at these two new stations were within the range of regional *baseline* fall concentrations, with the exception of chloride at *baseline* station DUR-1, which was below the 5th percentile of regional *baseline* fall concentrations (Figure 5.5-4).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines The concentration of total nitrogen exceeded its water quality guideline in fall 2009 at all stations (Table 5.5-4 to Table 5.5-7), while the concentration of total aluminum exceeded the water quality guideline at *baseline* station DUR-1 (Table 5.5-7).

Other Water Quality Guideline Exceedances The other exceedances of water quality guidelines in 2009 in the Mackay River watershed were (Table 5.5-8):

- Winter. Sulphide, dissolved iron, total iron, total nitrogen, total phosphorus and total phenols at *test* station MAR-1, *baseline* stations MAR-2 and MAR-2a and total Kjeldahl nitrogen concentrations at *test* station MAR-1 and *baseline* station MAR-2a;
- Spring. Sulphide, total aluminum, total phenols, total phosphorus, total nitrogen, total Kjeldahl nitrogen, dissolved iron and total iron at *test* station MAR-1, *baseline* stations MAR-2 and MAR-2a;
- Summer. Sulphide, total nitrogen, total Kjeldahl nitrogen, total aluminum, total iron, dissolved iron, and total phenols at *test* station MAR-1, *baseline* stations MAR-2 and MAR-2a; and
- Fall. Sulphide, total nitrogen, total Kjeldahl nitrogen, total iron, dissolved iron and total phenols at *test* station MAR-1, *baseline* stations MAR-2 and MAR-2a; total aluminum and lithium at baseline station MAR-2a; and sulphide, total aluminum, total phenols, total phosphorus, total Kjeldahl nitrogen, total nitrogen, dissolved iron and total iron at *baseline* station DUR-1.

Ion Balance In fall 2009, the ionic composition of water at all stations was dominated by bicarbonate and calcium and was similar to the previously measured ionic composition at all stations since sampling by RAMP began in this watershed in 1999 (Figure 5.5-5).

Trend Analysis There have been no significant trends in water quality measurement endpoints at either *test* station MAR-1 (n=11) or *baseline* station MAR-2 (n=8) (α=0.05) as of 2009. No trend analysis could be conducted for *baseline* stations MAR-2a or DUR-1 as both of these stations were first sampled in 2009.

Water Quality Index The WQI for fall 2009 was 100 for *test* station MAR-1 and *baseline* stations MAR-2a and DUR-1 and 94.6 for *baseline* station MAR-2, indicating **Negligible-Low** differences from regional water quality *baseline* conditions for all water quality stations in the MacKay River watershed in fall 2009.

Summary Differences in water quality in fall 2009 in the MacKay River as compared to regional *baseline* conditions are assessed as **Negligible-Low** (Table 5.5-1):

1. Any exceedances of water quality guidelines in 2009 occurred at multiple stations (both *test* and *baseline*) throughout the watershed.

2. Concentrations of almost all water quality measurement endpoints in fall 2009, were within the range of natural variability as they have consistently been since the beginning of the RAMP water quality data record for the MacKay River watershed.

3. Ionic composition at all water quality monitoring stations in the watershed in 2009 was consistent with previous years and continues to show little year-to-year variation.

5.5.4 Benthic Invertebrate Communities and Sediment Quality

5.5.4.1 Benthic Invertebrate Communities

MacKay River

Benthic invertebrate communities were sampled in fall 2009 at:

- erosional *test* reach MAR-E-1 near the mouth of the river, sampled since 1998, became *test* in 2002); and

- erosional *baseline* reach MAR-E-2 located upstream of Suncor Dover developments, sampled since 2002.

2009 Habitat Conditions *Test* reach MAR-E-1 in fall 2009 was shallow (0.4 m), alkaline, had a substrate dominated by gravel and sand, macrophyte coverage of approximately 33%, and conductivity of 349 µS/cm (Table 5.5-9). Water at *baseline* reach MAR-E-2 in fall 2009 was also alkaline and shallow (water depth averaging 0.3 m), with macrophytes generally absent and conductivity somewhat lower relative to *test* reach MAR-E-1 (279 µS/cm). Water velocity in both the upper and lower reaches were similar, varying between about 0.3 and 0.6 m/s. Periphyton biomass averaged 7.8 g/m^2, below the historical median value for regional *baseline* reaches in the RAMP FSA (Figure 5.5-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach MAR-E-1 in fall 2009 was dominated by chironomids (69%; Table 5.5-10) including those typically associated with lotic environments such as *Rheotanytaarsus* and *Synorthocladius*. Mayflies (Ephemeroptera) comprised 16% of the fauna, and included *Acerpenna*, *Baetis*, and *Heptagenia*. Stoneflies (Plecoptera) were present, reflecting that the *test* reach of the MacKay River was a cool/cold water environment. Common stoneflies included *Isoperla* and *Taeniopteryx*.

The benthic invertebrate community of the *baseline* reach MAR-E-2 in fall 2009 was dominated by chironomids (51%), including those typically associated with cool, running-water environments (e.g., *Tvetenia*, *Lopesocladius*, *Eukiefferiella*, *Subletta*). Mayflies (Ephemeroptera, including *Ephemerella*, *Baetis*, *Acerpenna*) were sub-dominant, as were caddisflies (Trichoptera, including *Chimarra*, *Psychomyia*, Hydropsychidae). Stoneflies were present, including Isoperla, in low relative abundances (Table 5.5-10).

Linear contrasts were used to test for differences in the trend in communities over time between *baseline* reach MAR-E-2 and *test* reach MAR-E-1. This is a test of the interaction between the time trend (TT) and *baseline* vs. *test* (BT) (i.e., TT x BT in Table 5.5-11). This test was done for abundance, richness, Simpson's diversity, evenness, percent EPT, and scores on the first two axes from a CA ordination. The analysis described above assumed that natural time trends in *baseline* reach MAR-E-2 (erosional) would be similar to the *test* reach MAR-E-1 (erosional), under undisturbed conditions.

The %EPT produced the strongest TT x BT interaction reflecting a difference in the time trends for this measurement endpoint (Table 5.5-11). %EPT has been lower in the *test* reach MAR-E-1 than in the *baseline* reach MAR-E-2 across years (Figure 5.5-7). Other time trends were less obvious considering noise-related variation (Table 5.5-11, Figure 5.5-7). Benthic invertebrate community measurement endpoints in fall 2009 for *test* reach MAR-E-1 and *baseline* reach MAR-E-2 were within regional *baseline* conditions (Figure 5.5-7), indicating the subtlety of the observed variations. In addition, the biplot of the multivariate CA axis scores for both reaches (Figure 5.5-8) indicate the lack of variation in benthic invertebrate community composition from year to year compared to the expected range of variation for *baseline* erosional reaches.

Dunkirk River

Benthic invertebrate communities were sampled in fall 2009 in the Dunkirk River at *baseline* reach DUR-E-1 to support the Fish Population component. Fall 2009 was the first time that benthic invertebrate communities have been sampled at this reach.

2009 Habitat Conditions Water in *baseline* reach DUR-E-1 in fall 2009 was 0.3 m deep, slightly alkaline (pH = 8.2), with fast currents (0.75 m/s), some macrophyte cover (12%), conductivity of 227 µS/cm, dissolved oxygen concentration of 9 mg/L (Table 5.5-9). Periphyton biomass averaged 171.1 mg/m^2, above the maximum historical value for regional *baseline* reaches in the RAMP FSA (Figure 5.5-9).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *baseline* reach DUR-E-1 in fall 2009 was dominated by chironomids (26%), caddisflies (Trichoptera, 26%), mayflies (Ephemeroptera, 35%). Stoneflies (Plecoptera) were sub-dominant (4%). Chironomids were dominated by a number of taxa typically found in running waters, including *Tvetenia*, *Lopesocladius*, and *Rheotanytarsus*. Caddisflies were dominated by the *Hydropsyche*, but also included *Psychomyia*, and *Lepidostoma*. Mayflies were dominated by *Acerpenna* and *Acentrella*. Stoneflies included *Isoperla*, *Skwala* and *Taeniopteryx*.

Benthic invertebrate community measurement endpoints were all within regional *baseline* conditions, with the exception of %EPT, which was above the regional *baseline* range (Figure 5.5-10), indicating the high quality of the benthic invertebrate community of this reach. There were an average of 35 taxa per sample, and slightly more than 62% of the fauna in each sample were comprised of EPT taxa. In addition, the biplot of the multivariate CA axis scores for *baseline* reach DUR-E-1 (Figure 5.5-11) support the assessment that the benthic invertebrate community at this reach is similar to *baseline* erosional reaches throughout the RAMP FSA.

5.5.4.2 Sediment Quality

No sediment quality sampling was conducted in the Dunkirk River in 2009 because sediment quality is only sampled in the depositional reaches in which benthic invertebrate communities were sampled and the reach of the Dunkirk River where benthic invertebrate communities were sampled is erosional.

5.5.4.3 Summary

The differences in the benthic invertebrate community in the *test* reach MAR-E-1 of the MacKay River compared to the benthic invertebrate community in the *baseline* reach MAR-E-2 of MacKay River are assessed as **Negligible-Low** (Table 5.5-1) because:

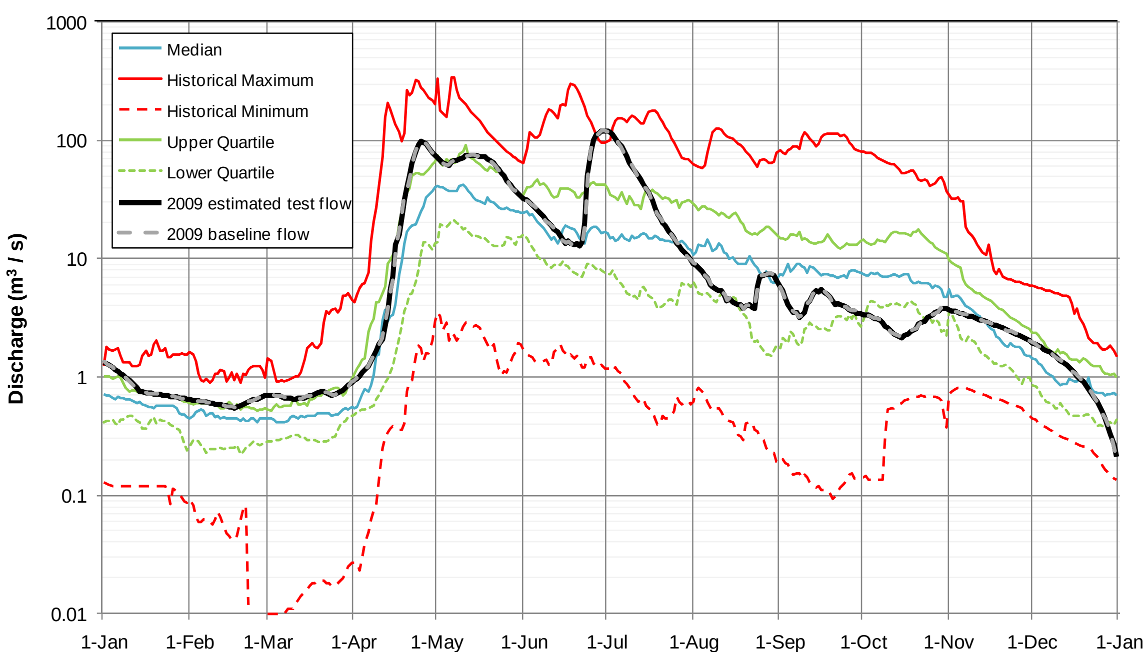
- Differences in benthic invertebrate community measurement endpoints between the *test* reach MAR-E-1 and *baseline* reach MAR-E-2 were statistically weak; and
- Values of all benthic invertebrate community measurement endpoints in *test* reach MAR-E-1 were within the range of variation for *baseline* erosional reaches in the RAMP FSA.

The benthic invertebrate community of the *baseline* reach of the Dunkirk River provides additional data to the *baseline* condition of erosional reaches in the RAMP FSA.

5.5.5 Fish Populations

The 2009 non-lethal sentinel species study included a *baseline* site (DR-R) on the Dunkirk River (Figure 5.5-1). Results of this study are presented in Section 5.3. In addition, the 2009 Fish Assemblage Monitoring pilot study included reaches on the MacKay and Dunkirk rivers; Section 6 contains the results of this study.

Figure 5.5-3 The observed (*test*) hydrograph for the MacKay River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph are based on provisional data for WSC Station 07DB001, MacKay River near Fort McKay, from March 1 to October 31, 2009, and RAMP Station S26 for other months in 2009. The upstream drainage area is 5,569 km^2. Historical values from March 1 to October 31 calculated for the period from 1973 to 2008, and historical values for other months calculated for the period from 1973 to 1987 and from 2002 onwards.

Table 5.5-2 Estimated water balance at WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**523.26**	**Observed discharge, obtained from WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay**
Closed-circuited area water loss from the observed *test* hydrograph	-0.272	Estimated 2.9 km^2 of the MacKay River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.250	Estimated 13.3 km^2 of the MacKay River watershed with land change from focal projects as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the MacKay River watershed from focal projects	-0.015	Water withdrawals from roadside ditches for dust abatement purposes. This withdrawal was assumed to evaporate and therefore not return as runoff to the MacKay River system.
Water releases into the MacKay River watershed from focal projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of MacKay River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**523.30**	**Estimated *baseline* discharge at WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay**
Incremental flow (change in total annual discharge)	-0.037	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-0.01%**	**Incremental flow as a percentage of total annual discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07DB001 and for other all other months for RAMP Station S26.

Table 5.5-3 Calculated change in hydrologic measurement endpoints for the MacKay River watershed, 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	26.65	26.65	-0.01%
Mean winter discharge	1.22	1.22	-0.04%
Annual maximum daily discharge	120	120	0.00%
Open-water period minimum daily discharge	2.15	2.15	-0.03%

Note: Definitions and assumptions are discussed in Section 3.1.7.3

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07DB001 and for other all other months for RAMP Station S26.

Table 5.5-4 Concentrations of water quality measurement endpoints, mouth of MacKay River (station MAR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.26	10	7.6	8.2	8.6
Total Suspended Solids	mg/L	-[1]	3	10	<3	6.5	26
Conductivity	µS/cm	-	336	10	196	260	576
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0183	10	0.004	0.023	0.047
Total nitrogen*	mg/L	1.0	**1.571**	10	0.4	**1.1**	**3.2**
Nitrate+Nitrite	mg/L	1.0	0.071	10	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	28	10	20	26	40
Ions							
Sodium	mg/L	-	27.1	10	15	20	60
Calcium	mg/L	-	37.8	10	24.7	27.9	44.7
Magnesium	mg/L	-	11.5	10	8.1	9.2	15.9
Chloride	mg/L	230, 860[3]	5.96	10	3.0	5.0	41.2
Sulphate	mg/L	100[4]	19.8	10	9.3	18.0	35.5
Total Dissolved Solids	mg/L	-	264	10	170	225.5	342
Total Alkalinity	mg/L		146	10	96	120	202
Organic compounds							
Naphthenic acids	mg/L	-	0.192	10	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0796	10	0.050	**0.219**	**0.501**
Dissolved aluminum	mg/L	0.1[2]	0.00709	10	0.010	0.022	0.030
Total arsenic	mg/L	0.005	0.000798	10	0.00071	0.00095	0.001
Total boron	mg/L	1.2[5]	0.103	10	0.057	0.082	0.140
Total molybdenum	mg/L	0.073	0.0004	10	0.0001	0.0004	0.0006
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.9	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.188	10	0.133	0.0154	0.287
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.012**	10	**0.003**	**0.01**	**0.032**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.5**	10	0.3	**1.1**	**3.1**
Total iron	mg/L	0.3	**0.706**	10	**0.31**	**0.9165**	**23.3**
Dissolved iron	mg/L	0.3[2]	**0.412**	10	0.23	**0.4745**	**0.787**
Total phenols	mg/L	0.004	**0.0076**	10	<0.001	0.003	**0.011**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.5-5 Concentrations of water quality measurement endpoints, upper MacKay River (station MAR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.33	7	7.8	8.2	8.3
Total Suspended Solids	mg/L	-[1]	3	7	<3	<3	10
Conductivity	µS/cm	-	264	7	180	220	249
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0218	7	0.008	0.035	0.043
Total nitrogen*	mg/L	1.0	**2.151**	7	0.8	**1.2**	**3.1**
Nitrate+Nitrite	mg/L	1.0	0.071	7	<0.1	<0.1	0.1
Dissolved organic carbon	mg/L	-	27.8	7	22	32	41
Ions							
Sodium	mg/L	-	18.4	7	11	16.5	19
Calcium	mg/L	-	34.5	7	21.3	23.8	31.5
Magnesium	mg/L	-	11	7	6.9	8.4	10.1
Chloride	mg/L	230, 860[3]	0.8	7	1	2	3
Sulphate	mg/L	100[4]	18.4	7	7.0	11.0	23.7
Total Dissolved Solids	mg/L	-	209	7	160	190	240
Total Alkalinity	mg/L	-	118	7	81	104	128
Organic compounds							
Naphthenic acids	mg/L	-	0.184	7	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0721	7	0.020	**0.159**	**0.468**
Dissolved aluminum	mg/L	0.1[2]	0.0108	7	<0.001	0.0248	0.0268
Total arsenic	mg/L	0.005	0.0010	7	0.0006	0.0008	0.001
Total boron	mg/L	1.2[5]	0.0548	7	0.043	0.059	0.105
Total molybdenum	mg/L	0.073	0.0005	7	0.0001	0.0003	0.0005
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	6	<1.2	<1.2	1.8
Total strontium	mg/L	-	0.175	7	0.114	0.127	0.197
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0167**	7	**0.008**	**0.021**	**0.03**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.08**	7	0.7	**1.1**	**3.0**
Total iron	mg/L	0.3	**0.913**	7	**0.386**	**0.924**	**1.277**
Dissolved iron	mg/L	0.3[2]	**0.598**	7	0.289	**0.54**	**0.76**
Total phenols	mg/L	0.004	**0.0064**	7	<0.001	**0.011**	**0.02**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN); Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.5-6 Concentrations of water quality measurement endpoints, upper MacKay River (station MAR-2a), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009 Value
Physical variables			
pH	pH units	6.5-9.0	8.25
Total Suspended Solids	mg/L	-[1]	3
Conductivity	µS/cm	-	268
Nutrients			
Total dissolved phosphorus	mg/L	0.05[2]	0.0342
Total nitrogen*	mg/L	1.0	**1.751**
Nitrate+Nitrite	mg/L	1.0	0.071
Dissolved organic carbon	mg/L	-	24.7
Ions			
Sodium	mg/L	-	15.1
Calcium	mg/L	-	31.3
Magnesium	mg/L	-	9.13
Chloride	mg/L	230, 860[3]	0.58
Sulphate	mg/L	100[4]	18.4
Total Dissolved Solids	mg/L	-	244
Total Alkalinity	mg/L	-	122
Organic compounds			
Naphthenic acids	mg/L	-	0.178
Selected metals			
Total aluminum	mg/L	0.1	**0.116**
Dissolved aluminum	mg/L	0.1[2]	0.0166
Total arsenic	mg/L	0.005	0.0011
Total boron	mg/L	1.2[5]	0.0719
Total molybdenum	mg/L	0.073	0.0006
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.6
Total strontium	mg/L	-	0.168
Other variables that exceeded CCME/AENV guidelines in fall 2009			
Sulphide	mg/L	0.002[7]	**0.0125**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.68**
Total iron	mg/L	0.3	**1.26**
Dissolved iron	mg/L	0.3[2]	**0.847**
Total phenols	mg/L	0.004	**0.0091**
Lithium	mg/L	5	**18.2**

MAR-2a is a new station for 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.5-7 Concentrations of water quality measurement endpoints, Dunkirk River (station DUR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009
			Value
Physical variables			
pH	pH units	6.5-9.0	8.09
Total suspended solids	mg/L	-[1]	4
Conductivity	µS/cm	-	226
Nutrients			
Total dissolved phosphorus	mg/L	0.05[2]	0.0429
Total nitrogen*	mg/L	1.0	**1.871**
Nitrate+nitrite	mg/L	1.0	0.071
Dissolved organic carbon	mg/L	-	26
Ions			
Sodium	mg/L	-	9.5
Calcium	mg/L	-	31.2
Magnesium	mg/L	-	8.93
Chloride	mg/L	230, 860[3]	0.5
Sulphate	mg/L	100[4]	13.3
Total dissolved solids	mg/L	-	190
Total alkalinity	mg/L		102
Organic compounds			
Naphthenic acids	mg/L	-	0.185
Selected metals			
Total aluminum	mg/L	0.1	**0.245**
Dissolved aluminum	mg/L	0.1[2]	0.0225
Total arsenic	mg/L	0.005	0.0013
Total boron	mg/L	1.2[5]	0.0461
Total molybdenum	mg/L	0.073	0.0006
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.6
Total strontium	mg/L	-	0.143
Other variables that exceeded CCME/AENV guidelines in fall 2009			
Total phosphorus	mg/L	0.05	**0.0639**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.8**
Total iron	mg/L	0.3	**1.3**
Dissolved Iron	mg/L	0.3[2]	**0.772**
Sulphide	mg/L	0.002[7]	**0.0179**
Total phenolics	mg/L	0.004	**0.0101**

DUR-1 is a new station for 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Table 5.5-8 Water quality guideline exceedances, MacKay River watershed, 2009.

Variable	Units	Guideline	MAR-1	MAR-2	MAR-2a	DUR-1
Winter						
Dissolved iron	mg/L	0.3[2]	**0.578**	**0.852**	**1.00**	-
Total phenols	mg/L	0.004	**0.006**	**0.008**	**0.006**	-
Sulphate	mg/L	50, 100	**54.5**	**64.4**	**60.9**	-
Sulphide	mg/L	0.002[1]	**0.007**	**0.008**	**0.009**	-
Total Phosphorus	mg/L	0.05	**0.068**	**0.099**	**0.09**	-
Total Kjeldahl nitrogen	mg/L	1.0	**1.1**	-	**1.1**	-
Total nitrogen	mg/L	1.0	**1.5**	**1.5**	**1.6**	-
Total iron	mg/L	0.3	**1.41**	**1.97**	**2.04**	-
Spring						
Dissolved iron	mg/L	0.3[2]	**0.521**	**0.492**	**0.428**	-
Total phenols	mg/L	0.004	**0.0117**	**0.0137**	**0.0101**	-
Sulphide	mg/L	0.002[1]	**0.0135**	**0.0087**	**0.0205**	-
Total Phosphorus	mg/L	0.05	**0.232**	**0.176**	**0.141**	-
Total Kjeldahl nitrogen	mg/L	1.0	**2.11**	**1.9**	**1.47**	-
Total nitrogen	mg/L	1.0	**2.181**	**1.971**	**1.541**	-
Total Aluminum	mg/L	0.1	**4.32**	**2.52**	**2.59**	-
Total iron	mg/L	0.3	**5.08**	**3.66**	**3.44**	-
Summer						
Dissolved iron	mg/L	0.3[2]	**0.435**	**0.381**	**0.392**	-
Total phenols	mg/L	0.004	**0.0089**	**0.0076**	**0.0084**	-
Sulphide	mg/L	0.002[1]	**0.0093**	**0.0094**	**0.0081**	-
Total Kjeldahl nitrogen	mg/L	1.0	**1.34**	**1.47**	**1.5**	-
Total nitrogen	mg/L	1.0	**1.411**	**1.541**	**1.571**	-
Total Aluminum	mg/L	0.1	**0.266**	**0.286**	**0.302**	-
Total iron	mg/L	0.3	**0.775**	**0.776**	**0.817**	-
Fall						
Sulphide	mg/L	0.002[1]	**0.012**	**0.0167**	**0.0125**	**0.0179**
Total Phosphorus	mg/L	0.05	-	-	-	**0.0639**
Total Kjeldahl nitrogen	mg/L	1.0	**1.5**	**2.08**	**1.68**	**1.8**
Total nitrogen	mg/L	1.0	**1.571**	**2.151**	**1.751**	**1.871**
Total iron	mg/L	0.3	**0.706**	**0.913**	**1.26**	**1.3**
Total Aluminum	mg/L	0.1	-	-	**0.116**	**0.245**
Lithium	mg/L	5	-	-	**18.2**	-
Dissolved iron	mg/L	0.3[2]	**0.412**	**0.598**	**0.847**	**0.772**
Total phenols	mg/L	0.004	**0.0076**	**0.0064**	**0.0091**	**0.0101**

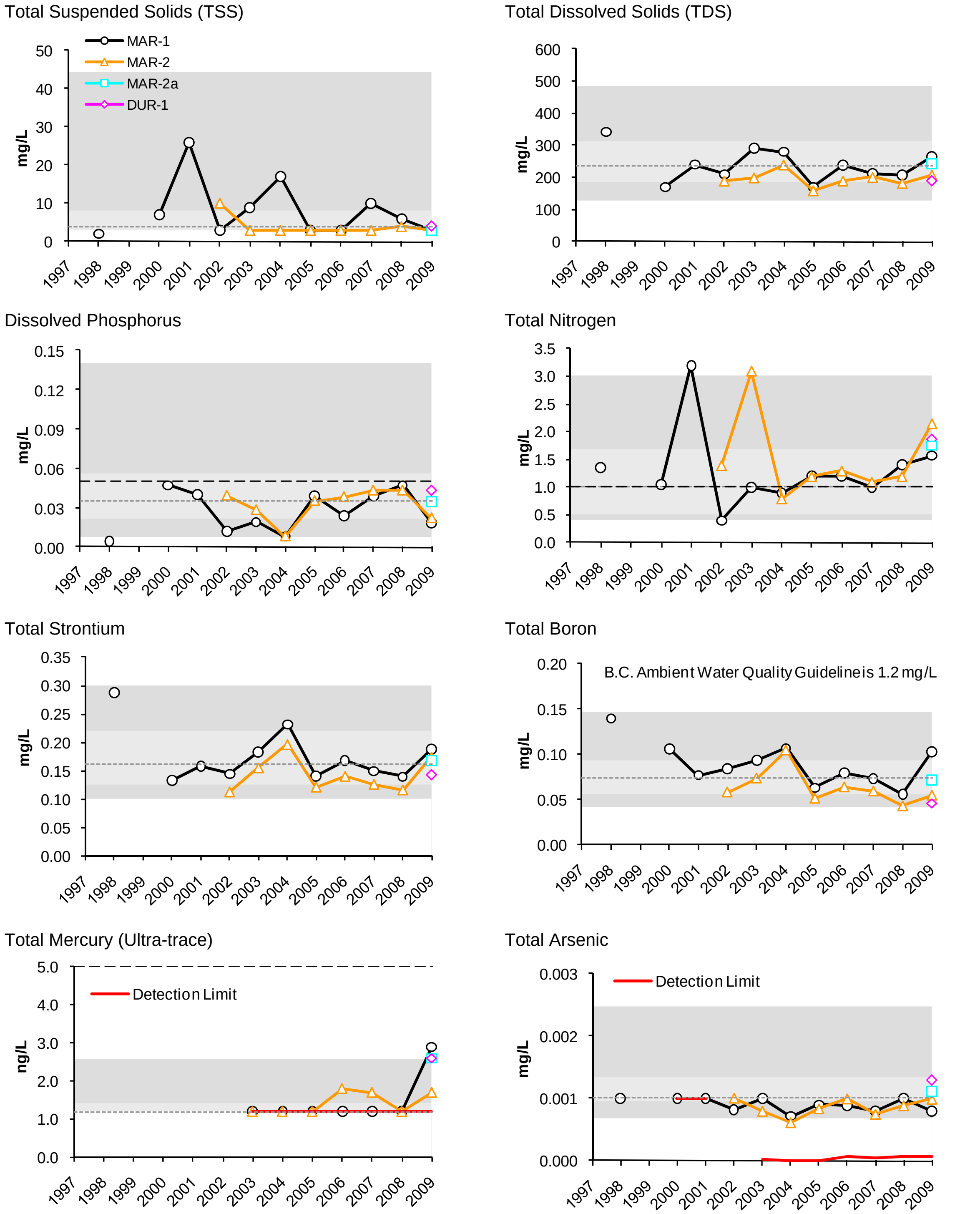
MAR-2a and DUR-1 are new stations for 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (2006).

[2] Guideline is for total species (no guideline for dissolved species).

Figure 5.5-4 Concentrations of selected water quality measurement endpoints in the MacKay River and Dunkirk River (fall data) relative to regional *baseline* fall concentrations.



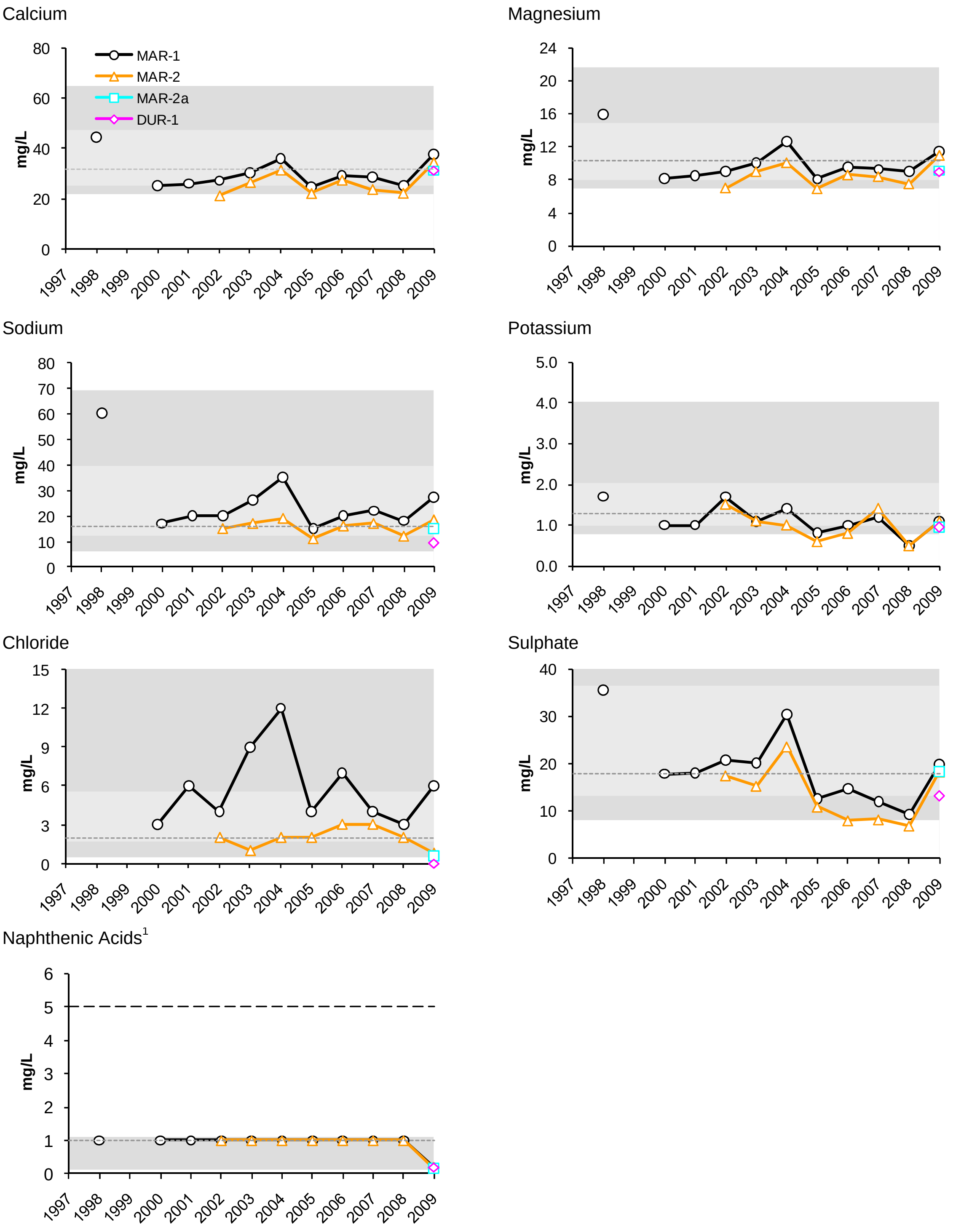
Non-detectable values are shown at the detection limit.

– – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.5-4 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.5-5 Piper diagram of fall ion concentrations in the MacKay River watershed.

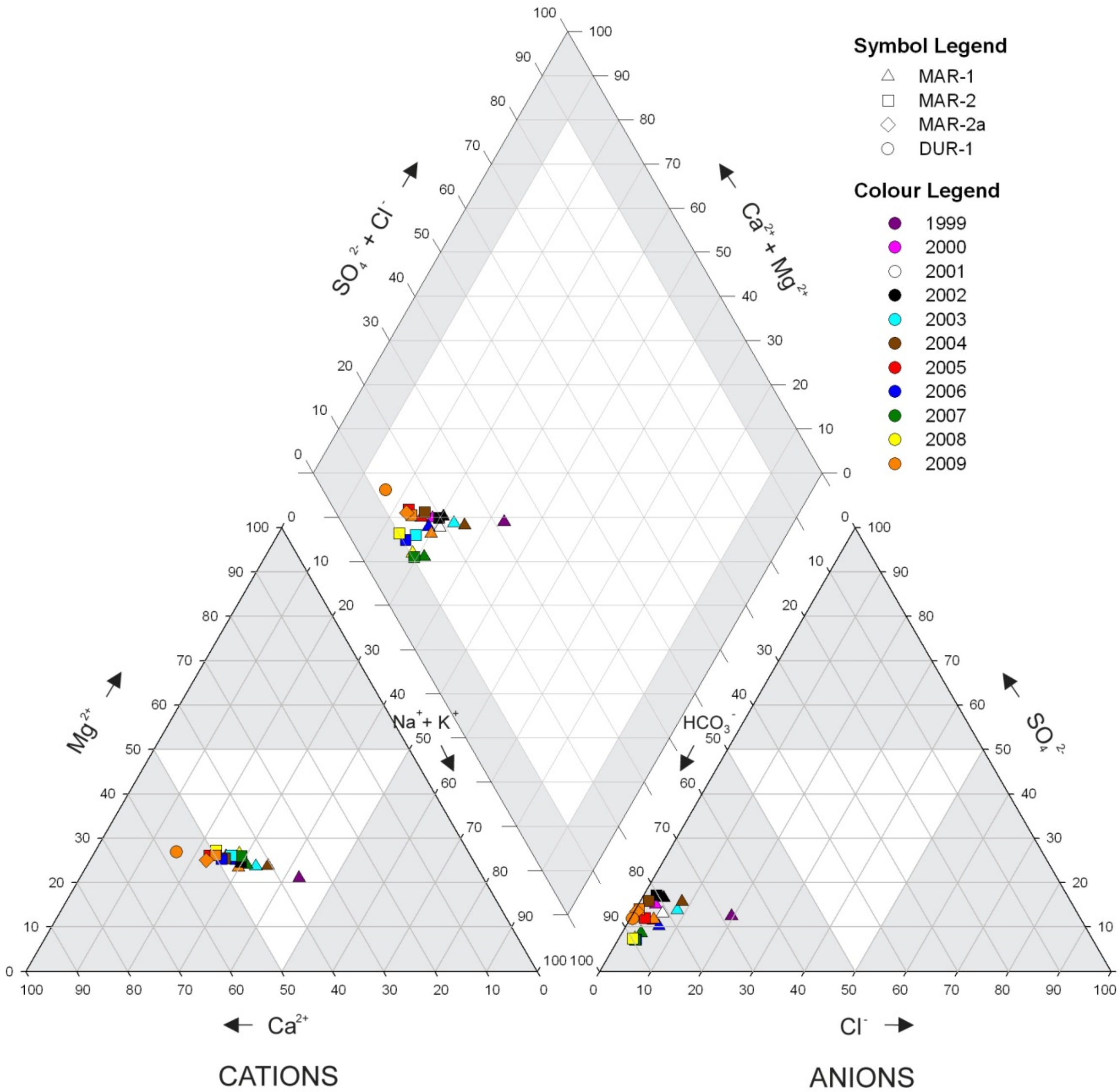


Table 5.5-9 Average habitat characteristics of benthic invertebrate sampling locations in the MacKay River.

Variable	Units	*Test* Reach MAR-E-1	*Baseline* Reach MAR-E-2
Sample Date	-	Sept 12, 2009	Sept 16, 2009
Habitat	-	Erosional	Erosional
Water Depth	m	0.4	0.3
Current Velocity	m/s	0.34	0.57
Macrophyte Cover	%	33	0
Field Water Quality			
Dissolved Oxygen	mg/L	10.2	10.6
Conductivity	µS/cm	349	279
pH	pH units	8.7	8.38
Water Temperature	°C	15.4	16.6
Sediment Composition			
Sand/Silt/Clay	%	22	0
Small Gravel	%	46	4
Large Gravel	%	25	6
Small Cobble	%	7	21
Large Cobble	%	0	50
Boulder	%	0	19
Bedrock	%	0	0

Figure 5.5-6 Periphyton chlorophyll *a* biomass in the *test* (MAR-E-1) and *baseline* (MAR-E-2) reaches of the MacKay River.

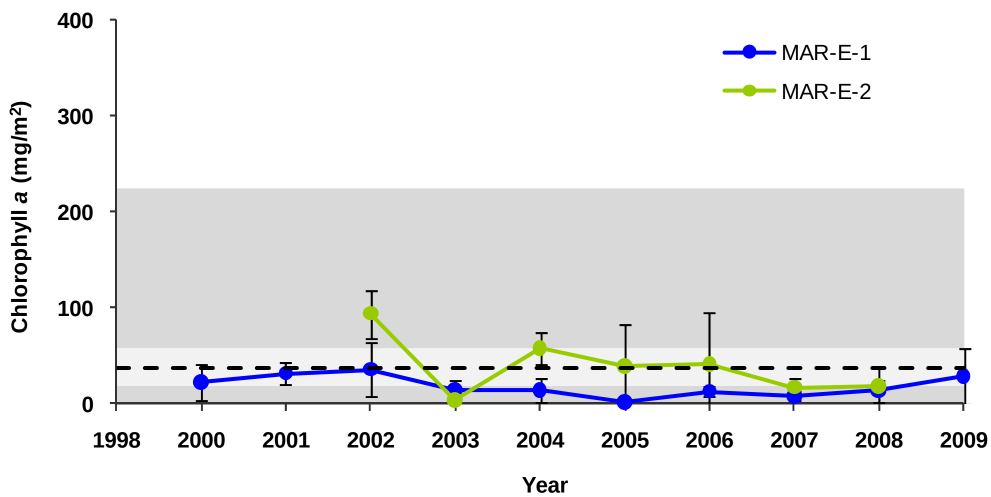
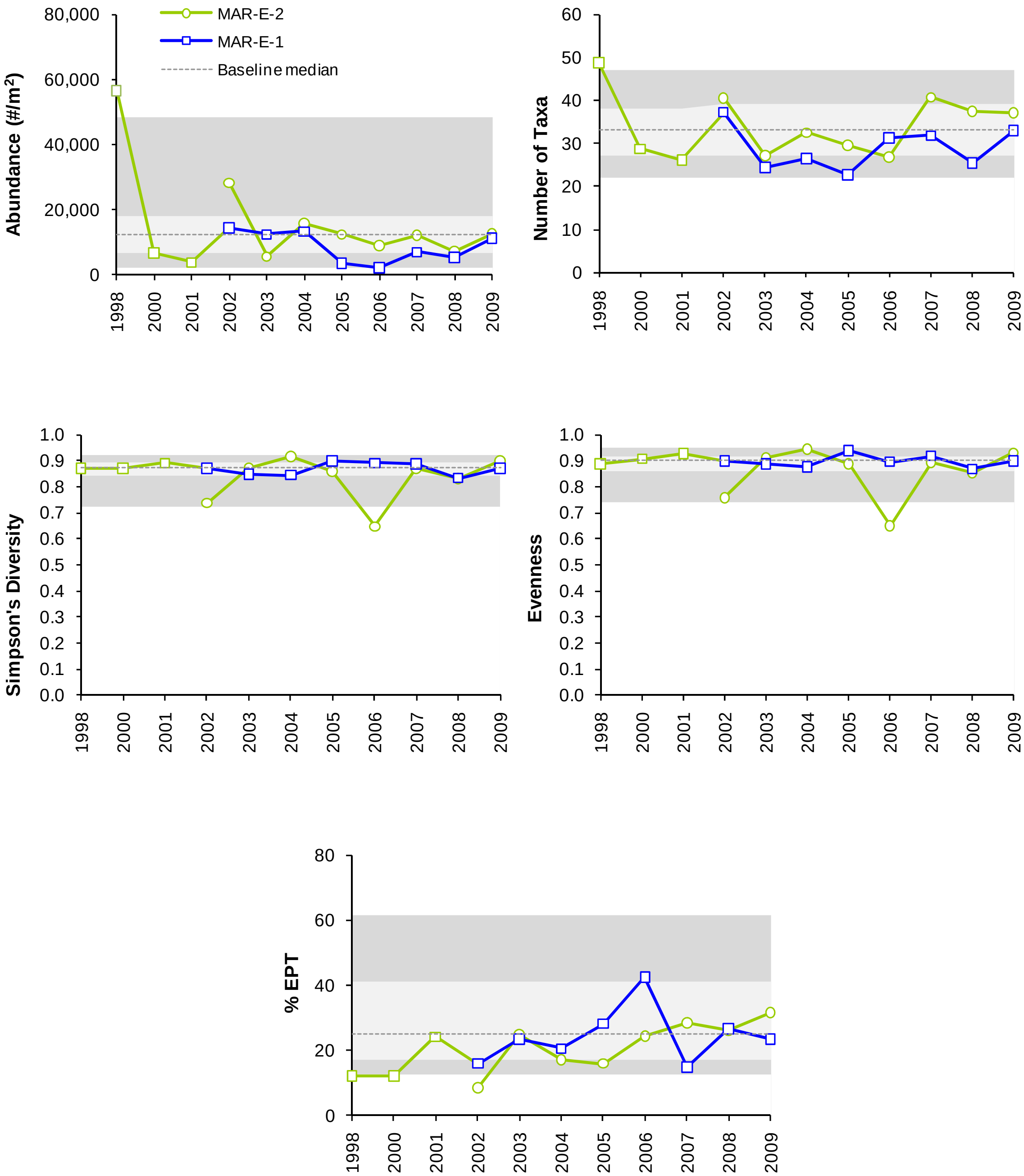


Table 5.5-10 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the MacKay River.

Taxon	Percent Major Taxa Enumerated in Each Year																		
	Test Reach MAR-E-1											*Baseline* Reach MAR-E-2							
	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2002	2003	2004	2005	2006	2007	2008	2009
Anisoptera	1	1	2	1	1	3	2	2	1	5	1	<1	1	<1	<1	<1	<1	<1	<1
Bivalvia		<1	<1	1	2	2	1		<1	1	<1	<1	4	1	<1		<1	1	
Ceratopogonidae	1	1	<1	1	<1	1	5	3	1	1	2	<1	<1	1	1	1	1	2	1
Chironomidae	57	34	4	31	4	57	2	3	40	34	69	31	3	59	49	63	39	43	51
Coleoptera	<1	<1			<1	<1		<1		<1			<1	<1	<1		<1	<1	
Copepoda	<1	<1	<1	<1				<1	1	<1	<1	<1		<1				<1	
Empididae	1	1	4	3	2	2	12	6	1	1	1	1	2	1	5	<1	<1	<1	1
Enchytraeidae	4	12	1	5	5	1	1	1	1	3	1	1	4	3	3	1	1	2	<1
Ephemeroptera	26	21	18	12	19	13	25	29	13	21	16	2	14	11	1	12	16	8	20
Erpobdellidae						<1							<1						
Gastropoda	<1	<1	1	2	<1	1		1	1	3		<1	<1	<1	<1		1	1	<1
Heteroptera	<1		<1																
Hydra	<1			1	<1					<1		<1							
Hydracarina	1	4	6	3	18	6	1	2	15	14	<1	7	21	4	9	5	17	10	5
Lumbriculidae					<1								<1		<1		1		
Macrothricidae		<1		1															
Naididae	2	17	2	24	8	3	11	8	9	6	3	48	15	4	15	2	9	11	5
Nematoda	2	2	8	6	1	3	1	1	3	2	2	3	1	3	1	3	3	3	3
Ostracoda	<1	1	1	6		<1		<1	1	1	<1	<1	<1	<1			1	<1	1
Plecoptera	2	5	5	<1	1	3	3	8	2	3	1	<1	3	3	1	2	3	2	1
Simuliidae	1	<1	<1	<1	<1		2	<1	1	<1	<1		<1		<1	<1	1		<1
Tabanidae					<1		1		1				<1						
Tipulidae	<1	<1			<1				1			<1	<1	<1		1	<1	<1	<1
Trichoptera	<1	<1	3	3	2	5	<1	5	1	<1	<1	6	4	3	5	1	10	12	12
Tubificidae	2	<1	1	2	<1	1	6	2	1	3	2	<1	<1	8	1	1	2	4	2
Benthic Invertebrate Community Measurement Endpoints																			
Total Abundance (No./m^2)	56,434	6,680	3,745	14,425	12,347	13,290	3,592	2,055	6,916	6,970	11,302	28,222	5,568	15,733	12,332	9,409	12,130	5,257	12,415
Richness	49	29	26	37	24	27	23	30	32	38	33	40	27	32	30	27	41	39	37
Simpson's Diversity	0.87	0.87	0.89	0.87	0.85	0.84	0.9	0.89	0.89	0.83	0.87	0.74	0.87	0.91	0.86	0.65	0.87	0.83	0.9
Evenness	0.89	0.91	0.93	0.90	0.89	0.88	0.94	0.89	0.92	0.85	0.9	0.76	0.91	0.94	0.89	0.65	0.89	0.87	0.93
% EPT	26	25	24	16	23	20	28	42	15	26	23	8	25	17	16	24	28	26	32

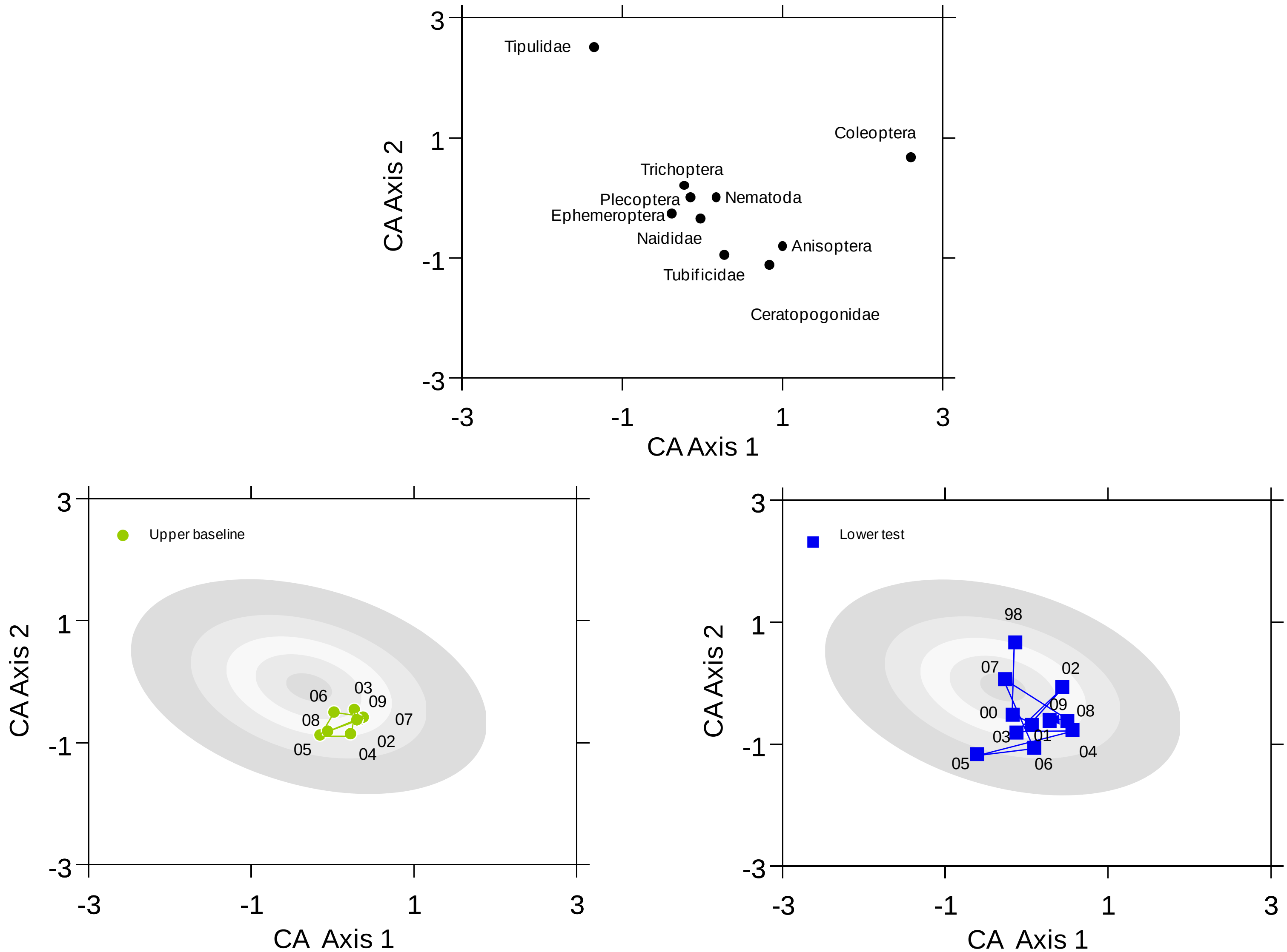
Figure 5.5-7 Variation in benthic invertebrate community measurement endpoints in the MacKay River.



Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.3.1.8

Note: The lower *test* reach was designated as *baseline* prior to 2002.

Figure 5.5-8 Ordination (Correspondence Analysis) of benthic invertebrate communities in the MacKay River.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* erosional reaches in the RAMP FSA.

Table 5.5-11 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints between the *test* (MAR-E-1) and *baseline* (MAR-E-2) reaches of the MacKay River.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	19.202	18	1.067	16.52	0.000
	Time Trend After x BT	0.298	1	0.298	4.61	0.033
	Remainder (noise)	18.905	17	1.112	17.22	0.000
	Error	12.982	201	0.065		
Log Richness	Reach - Year	1.278	18	0.071	13.37	0.000
	Time Trend After x BT	0.017	1	0.017	3.13	0.078
	Remainder (noise)	1.262	17	0.074	13.98	0.000
	Error	1.067	201	0.005		
Diversity	Reach - Year	0.810	18	0.045	6.64	0.000
	Time Trend After x BT	0.009	1	0.009	1.34	0.249
	Remainder (noise)	0.800	17	0.047	6.95	0.009
	Error	1.361	201	0.007		
Evenness	Reach - Year	0.980	18	0.054	7.76	0.000
	Time Trend After x BT	0.01	1	0.01	1.11	0.294
	Remainder (noise)	0.972	17	0.057	8.16	0.005
	Error	1.410	201	0.007		
Log %EPT	Reach - Year	4.75	18	0.26	4.96	0.000
	Time Trend After x BT	0.70	1	0.70	13.21	0.000
	Remainder (noise)	4.05	17	0.24	4.48	0.036
	Error	10.69	201	0.05		
CA Axis 1	Reach - Year	18.53	18	1.03	3.93	0.000
	Time Trend After x BT	0.10	1	0.10	0.39	0.534
	Remainder (noise)	18.4	17	1.084	4.13	0.043
	Error	52.71	201	0.26		
CA Axis 2	Reach - Year	23.35	18	1.30	4.99	0.000
	Time Trend After x BT	0.30	1	0.30	1.15	0.285
	Remainder (noise)	23.05	17	1.36	5.21	0.023
	Error	52.29	201	0.26		

Table 5.5-12 Average habitat characteristics of the benthic invertebrate sampling locations in the Dunkirk River.

Variable	Units	*Baseline* Reach DUR-E-1
Sample Date	-	Sept 14, 2009
Habitat	-	Erosional
Water Depth	m	0.3
Current Velocity	m/s	0.75
Macrophyte Cover	%	12
Field Water Quality		
Dissolved Oxygen	mg/L	9
Conductivity	µS/cm	227
pH	pH units	13.8
Water Temperature	°C	n/a
Sediment Composition		
Sand/Silt/Clay	%	0
Small Gravel	%	0
Large Gravel	%	2
Small Cobble	%	15
Large Cobble	%	50
Boulder	%	33
Bedrock	%	0

Figure 5.5-9 Periphyton chlorophyll *a* biomass in the Dunkirk River (DUR-E-1).

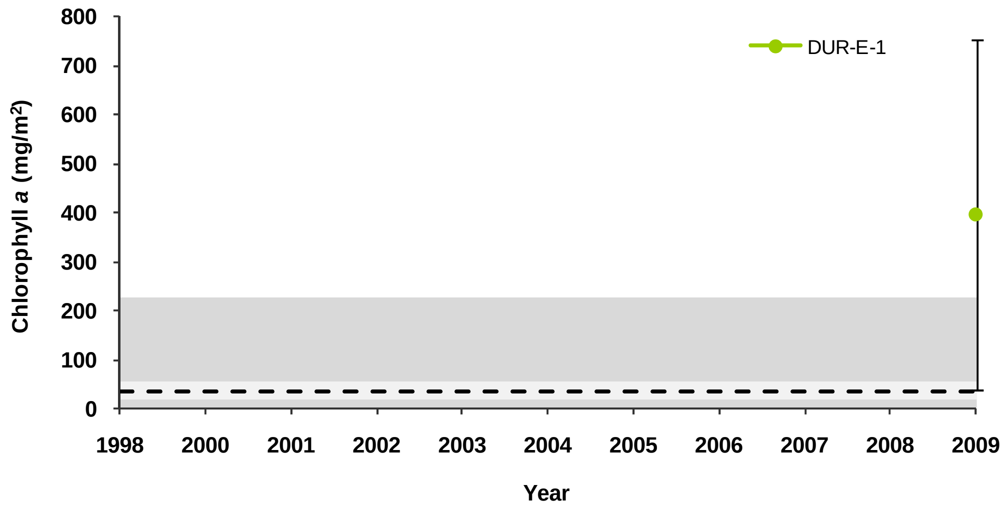
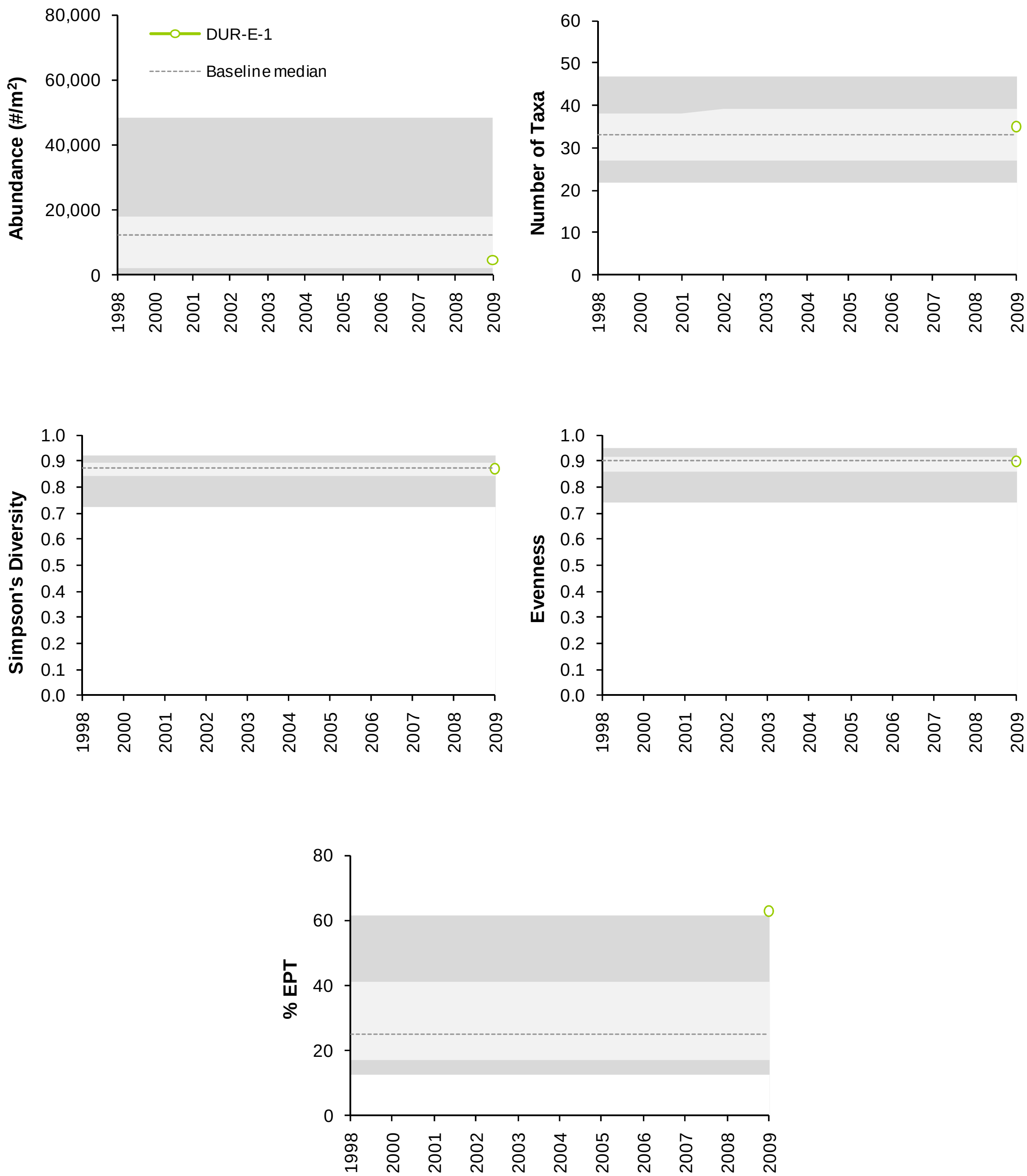


Table 5.5-13 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the Dunkirk River.

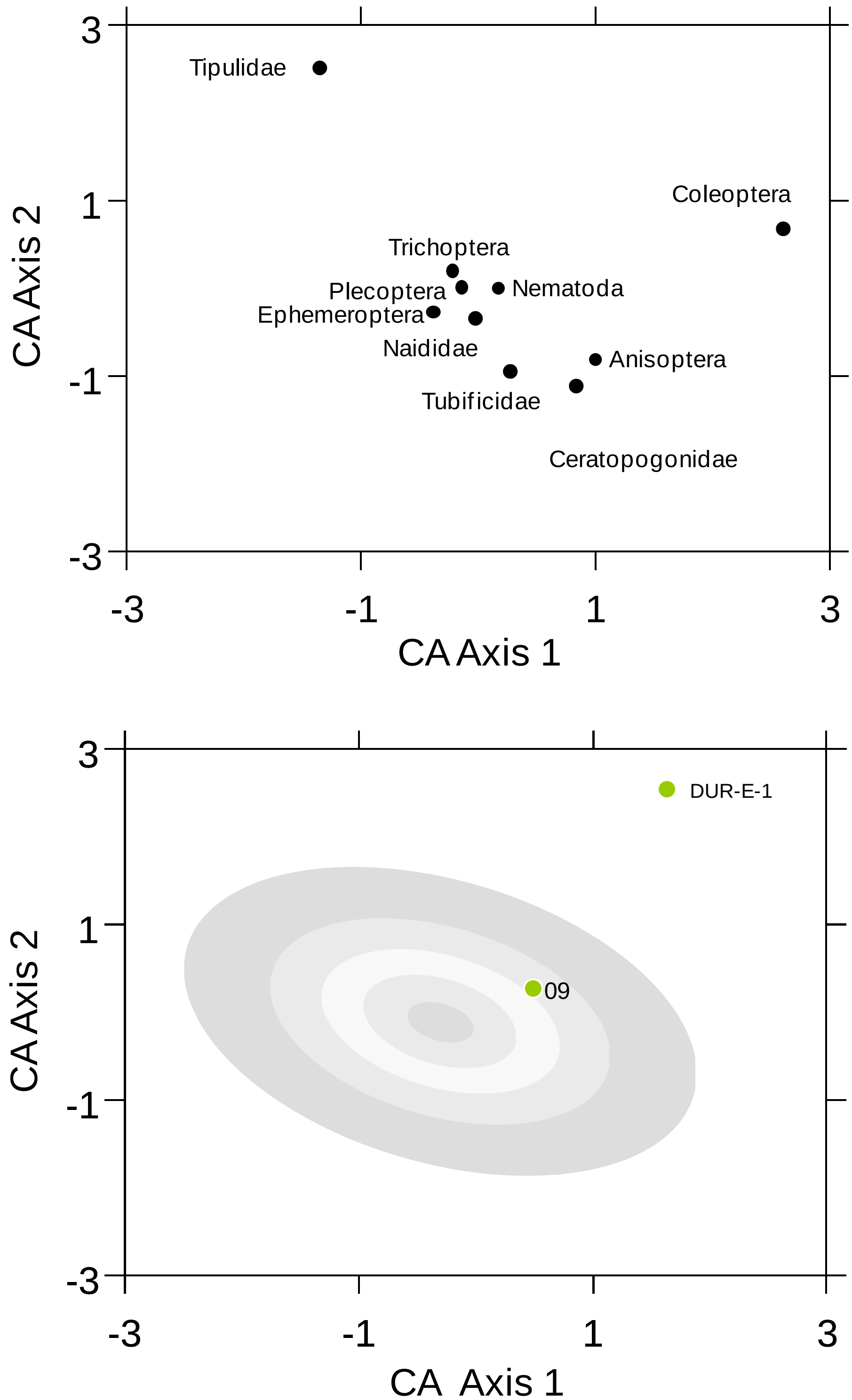
Taxon	Percent Major Taxa Enumerated in Each Year
	Baseline Reach DUR-E-1
	2009
Anisoptera	<1
Bivalvia	1
Ceratopogonidae	<1
Chironomidae	26
Copepoda	<1
Coleoptera	2
Empididae	<1
Ephemeroptera	35
Gastropoda	1
Hydracarina	1
Naididae	<1
Nematoda	1
Plecoptera	4
Tipulidae	2
Trichoptera	26
Tubificidae	<1
Benthic Invertebrate Community Measurement Endpoints	
Total Abundance (No./m^2)	4,554
Richness	35
Simpson's Diversity	0.87
Evenness	0.90
% EPT	63

Figure 5.5-10 Variation in benthic invertebrate community measurement endpoints in the Dunkirk River.



Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.3.1.8.

Figure 5.5-11 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Dunkirk River.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* erosional reaches in the RAMP FSA.

5.6 CALUMET RIVER WATERSHED

Table 5.6-1 Summary of results for Calumet River watershed.

Calumet River Watershed	Summary of 2009 Conditions	
Climate and Hydrology		
Criteria	**Station S16 (Station CR-1)** at the mouth	no station sampled
Mean open-water season discharge	🟡	
Mean winter discharge	not measured	
Annual maximum daily discharge	not measured	
Minimum open-water season discharge	not measured	
Water Quality		
Criteria	**CAR-1** at the mouth	**CAR-2** upstream of Canadian Natural Horizon
Water Quality Index	🟡	🟠
Benthic Invertebrate Communities and Sediment Quality		
Criteria	**CAR-D-1** reach at mouth	**CAR-D-2** upper reach
Benthic Invertebrate Communities	🟡	n/a
Sediment Quality Index	🟡	🟡
Fish Populations		
No Fish Population component activities conducted in 2009		

Legend and Notes

- 🟡 Negligible-Low
- 🟠 Moderate
- 🟤 High
- *baseline*
- *test*

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

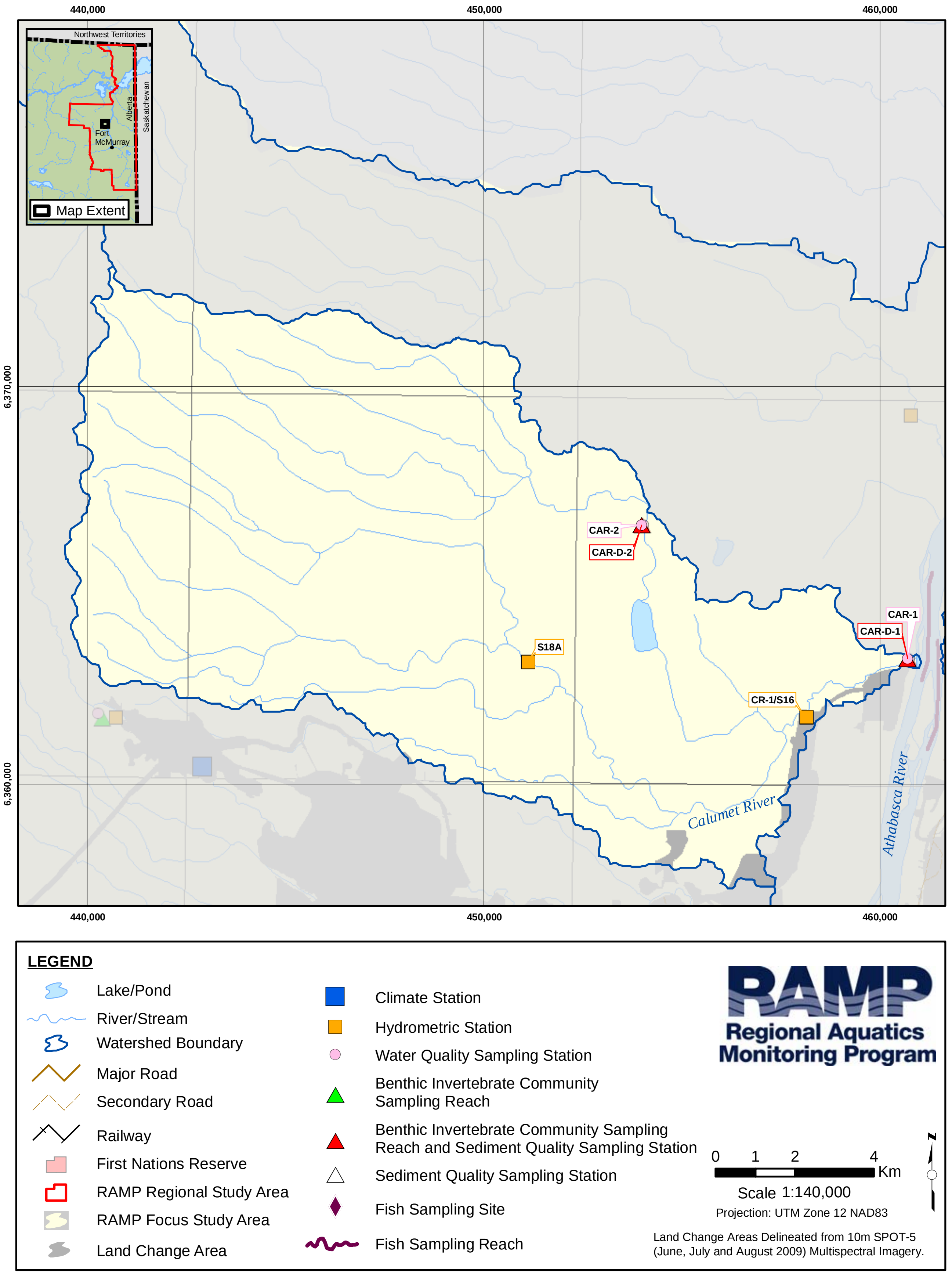
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Figure 5.6-1 Calumet River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K06_Calumet_20100415.mxd

Figure 5.6-2 Representative monitoring stations of the Calumet River, fall 2009.

Water Quality Station CAR-1:
Right Downstream Bank

Water Quality Station CAR-1:
Right Downstream Bank

Water Quality Station CAR-2:
Centre of Channel, facing downstream

Water Quality Station CAR-2:
Right Downstream Bank

5.6.1 Summary of 2009 Conditions

As of 2009, 1.3% (223 ha) of the Calumet River watershed had undergone land change from focal projects (Table 2.4-2). The designations of specific areas of the watershed are as follows:

1. The Calumet River watershed downstream of Canadian Natural Horizon Project operations is designated as *test*.

2. The remainder of the watershed is designated as *baseline* (Figure 5.6-1).

Table 5.6-1 is a summary of the 2009 assessment for the Calumet River watershed, while Figure 5.6-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.6-2 contains fall 2009 photos of water quality monitoring stations in the watershed.

Hydrology The short measurement record for 2009 prevented the calculation of changes to most open-water season measurement endpoints from being reliably determined. The calculated mean open-water period discharge (from 97-days of available data) is 1.0%

lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low**.

Water Quality In fall 2009, water quality at the *test* station CAR-1 showed **Negligible-Low** differences from regional *baseline* conditions. However, water quality at the *baseline* station CAR-2 showed deviations from regional *baseline* conditions, in concentrations of suspended solids, total arsenic and total dissolved phosphorus in fall 2009, indicating a **Moderate** difference from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Reach-year differences in abundance, richness, and %EPT of the benthic invertebrate community between *test* reach CAR-D-1 and *baseline* reach CAR-D-2 were significant but not reflective of an impaired benthic invertebrate community in *test* reach CAR-D-1 because richness and %EPT was higher in *test* reach CAR-D-1 than *baseline* reach CAR-D-2. All other reach-year differences in values of benthic invertebrate community measurement endpoints were not significant between *test* reach CAR-D-1 and *baseline* reach CAR-D-2. In addition, all benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Calumet River watershed from regional *baseline* conditions. Sediment quality at *test* station CAR-D-1 and *baseline* station CAR-D-2 indicated a **Negligible-Low** difference from regional *baseline* sediment quality conditions.

5.6.2 Hydrologic Conditions

2009 Hydrologic Conditions: Station S16 (Canadian Natural Station CR-1), Calumet River near the Mouth The runoff volume observed in 2009 at Station S16 was 2.35 million m^3 measured from April 21 to May 27 and from August 20 to October 18. Flows increased from the start of seasonal flow monitoring on April 21, to a peak of 1.6 m^3/s on April 24, and then remained at about historical median levels until monitoring ceased on May 27, due to a malfunction of the datalogger (Figure 5.6-3). Flows were at approximately median levels when measurements resumed on August 20, but decreased below the historical minimum values recorded from September 17 to October 1, before increasing to near historical median flows in early October prior to the termination of measurement prior to freeze-up.

Differences Between Observed *Test* Hydrograph and Estimated B*aseline* Hydrograph The estimated water balance for 2009 at Station S16 for the 97-day period of measured flows in 2009 is presented in Table 5.6-2 and described below:

1. The closed-circuited land area in the Calumet River watershed as of 2009 was estimated at 1.8 km^2 (Table 2.4-1). The loss of flow to the Calumet River that would have otherwise occurred from this land area is estimated at approximately 25,000 m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 0.4 km^2. The increase in flow to the Calumet River that would have otherwise not occurred from this land area is estimated at 1,000 m^3.

The estimated cumulative effect of land change in 2009 is a loss of flow 24,000 m^3 at Station S16. The estimated *baseline* hydrograph is presented in Figure 5.6-3.

The short measurement record for 2009 prevented the calculation of changes to most measurement endpoints from being reliably determined for Station S16. The calculated mean open-water period discharge (from 97-days of available data) is 1.0% lower in the *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.6-3); these differences are classified as **Negligible-Low** (Table 5.6-1).

5.6.3 Water Quality

In 2009, water quality samples were taken in fall from:

- the Calumet River near its mouth (*test* station CAR-1, established in 2002, designated as *baseline* until 2005); and
- the upper Calumet River (*baseline* station CAR-2, sampled since 2005).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of the following water quality measurement endpoints were outside historical ranges:

- total nitrogen and total Kjeldahl nitrogen at *test* station CAR-1, which were above previously-measured maximum concentrations (Table 5.6-4);
- total suspended solids, total Kjeldahl nitrogen, dissolved organic carbon, total nitrogen, total and dissolved iron, sulphide, total arsenic and total mercury at *baseline* station CAR-2 which were above previously-measured maximum concentrations (Table 5.6-5); and
- pH, chloride and total boron at *baseline* station CAR-2, which were below previously-measured minimum concentrations (Table 5.6-5).

Concentrations of all measurement endpoints at *test* station CAR-1 were within the 5th to 95th percentiles of regional *baseline* concentrations (Figure 5.6-4). At *baseline* station CAR-2, concentrations of total suspended solids, dissolved phosphorus, total nitrogen, total mercury, total arsenic, and potassium exceeded the 95th percentile of regional *baseline* concentrations (Figure 5.6-4). All of these measurement endpoints with the exception of potassium had concentrations in fall 2009 that exceeded their previously-measured maximum concentrations.

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines The concentration of total nitrogen and total dissolved phosphorus at *test* station CAR-1 and *baseline* station CAR-2, and total aluminum at *baseline* station CAR-2 exceeded water quality guidelines in fall 2009 (Table 5.6-4, Table 5.6-5).

Other Water Quality Guidelines Exceedances The following other water quality guideline exceedences were observed in the Calumet River in fall 2009:

- sulphide, total phosphorus, total Kjeldahl nitrogen, total and dissolved iron, and total phenols at *test* station CAR-1 (Table 5.6-4); and
- sulphide, total phosphorus, total Kjeldahl nitrogen, total and dissolved iron, total arsenic and total phenols at *baseline* station CAR-2 (Table 5.6-5).

Concentrations of water quality measurement endpoints that exceeded water quality guidelines were often higher at *baseline* station CAR-2 (Table 5.6-5) than at *test* station CAR-1 (Table 5.6-4).

Ion Balance The ionic composition of water at both *test* station CAR-1 and *baseline* station CAR-2 in fall 2009 were similar to previous years for this station (Figure 5.6-5). The ionic composition of water at *test* station CAR-1 has remained consistent since water quality monitoring first begin in 2002 with the exception of 2007 when cation composition was more calcium-dominated than in other years (Figure 5.6-5). The ionic composition of water at *baseline* station CAR-2 has also been relatively consistent over the sampling period, but with a slightly lower bicarbonate composition than at *test* station CAR-1 (Figure 5.6-5).

Trend Analysis There were no significant trends in water quality measurement endpoints at *test* station CAR-1 or *baseline* station CAR-2 over the sampling period ($\alpha = 0.05$).

Water Quality Index The WQI value calculated for *test* station CAR-1 for fall 2009 was 100 indicating a **Negligible-Low** difference from regional *baseline* water quality conditions. The WQI value for *baseline* station CAR-2 for fall 2009 was 70 indicating a **Moderate** difference from regional *baseline* water quality conditions. The lower WQ value for *baseline* station CAR-2 is a result of high concentrations of total suspended solids, dissolved phosphorus, and total arsenic at this station (Table 5.6-5), particularly in relation to regional *baseline* concentrations (Figure 5.6-4).

Summary In fall 2009, water quality at the *test* station CAR-1 showed **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.6-1). However, water quality at the *baseline* station CAR-2 exhibited deviations from regional *baseline* water quality conditions in fall 2009 due to high concentrations of suspended solids, total arsenic and total dissolved phosphorus, indicating a **Moderate** difference from regional *baseline* water quality conditions (Table 5.6-1).

5.6.4 Benthic Invertebrate Communities and Sediment Quality

5.6.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in the upper and lower reaches of the Calumet River. The lower depositional *test* reach CAR-D-1 has been sampled since 2002, while the upper depositional *baseline* reach CAR-D-2 has been sampled since 2003.

2009 Habitat Conditions *Test* reach CAR-D-1 in fall 2009 was shallow (0.2 m), with a substrate dominated by sand (87%), and no macrophyte cover (Table 5.6-6). The concentration of dissolved oxygen in *test* reach CAR-D-1 was greater than both the acute and chronic guideline for protection of aquatic life (AENV 1999b). *Baseline* reach CAR-D-2 was ponded as a result of beaver dam activity. Water was 0.5 m deep, with no flow, heavily vegetated with plants including duckweed (*Lemna*), bullrush (*Scirpus*) and sedges (*Carex*), and a substrate with high silt/clay fractions and a high percentage of organic material (5.6%) (Table 5.6-6). The concentration of dissolved oxygen in *baseline* reach CAR-D-2 was less than the chronic guideline for protection of aquatic life (AENV 1999b). The lower dissolved oxygen concentrations, higher conductivity, and lower pH of *baseline* reach CAR-D-2 as compared to *test* reach CAR-D-1 potentially reflect higher organic content of the water at *baseline* reach CAR-D-2.

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach CAR-D-1 was dominated by chironomids (84%), with copeopods, mayflies (Ephemeroptera) and tubificid worms sub-dominant (Table 5.6-7). The most dominant chironomids included the common *Ablabesmyia*, *Polypedilum*, *Paratanytarsus* and *Tanytarsus*, as well as the more sensitive *Heterotrissocladius*. The mayflies were represented by *Caenis* and *Leptophlebia*.

The benthic invertebrate community of *baseline* reach CAR-D-2 was dominated by chironomids (54%), copepods (22%) and ostracods (14%), with fingernail clams (Bivalvia), and tubificid worms sub-dominant (Table 5.6-7). Mayflies, including *Caenis* and *Callibaetis* were present, but in low (1%) relative abundance.

Abundance, taxa richness, Simpson's diversity, evenness, and %EPT in fall 2009 in both reaches were within their range of variation for *baseline* depositional reaches in the RAMP FSA (Figure 5.6-6). *Test* reach CAR-D-1 had a higher number of taxa, Simpson's diversity, evenness, and %EPT taxa than *baseline* reach CAR-D-2 in fall 2009.

The Correspondence Analysis results (Figure 5.6-7) indicated that both reaches in all sampled years were within the 95th percentile of the range of variation for *baseline* depositional reaches in the RAMP FSA.

Linear contrasts were used to test for a difference in time trends of measurement endpoints for benthic invertebrate communities between *baseline* reach CAR-D-2 and *test* reach CAR-D-1 (i.e., BA x BT in Table 5.6-8). With the exception of evenness, there was no significant difference in time trends of benthic invertebrate community measurement endpoints between *baseline* reach CAR-D-2 and *test* reach CAR-D-1 (Table 5.6-8). The difference in time trends in evenness between *baseline* reach CAR-D-2 and *test* reach CAR-D-1 does not reflect a negative change because evenness was higher at *test* reach CAR-D-1 than at *baseline* reach CAR-D-2 and evenness at reach CAR-D-1 has been higher since the reach was designated as *test* in 2005 (Figure 5.6-6).

5.6.4.2 Sediment Quality

Sediment quality was sampled in fall 2009 in depositional reaches of the Calumet River where benthic invertebrate communities were sampled, at the:

- Calumet River near its mouth (*test* station CAR-D-1, designated as *baseline* until 2005); and
- upper Calumet River (*baseline* station CAR-D-2, first sampled in 2005).

2009 Results and Historical Ranges of Concentration Sediment at *test* station CAR-D-1 was comprised of mostly sand in fall 2009 and the sand fraction was greater in fall 2009 than previously-measured (Table 5.6-9). Total organic carbon content was within the range of previously-measured concentrations. As in previous years, fraction-1 hydrocarbons including BTEX were not detectable at CAR-D-1, the concentration of fraction-2 hydrocarbons was within the range of previously-measured values, while concentrations of fraction-3 and fraction-4 hydrocarbon concentrations were below previously-measured minimum values for this station. The midge *Chironomus* had lower survival but higher growth in sediment toxicity tests than previously-measured at this station, while survival and growth of the amphipod *Hyalella* were within historical ranges for this station (Table 5.6-9).

Sediments at *baseline* station CAR-D-2 in fall 2009 were finer than at *test* station CAR-D-1, with approximately equal proportions of sand, silt, and clay (Table 5.6-10). Total organic carbon content was below the previously-measured minimum value. Volatile, low-molecular-weight hydrocarbons (i.e., CCME fraction 1 and BTEX) were not detected at *baseline* station CAR-D-2 in fall 2009. Concentrations of heavier hydrocarbon fractions were lower than previously-measured values with the exception of fraction-2 hydrocarbon which had a concentration in fall 2009 that was within the range of previously-measured values. All polycyclic aromatic hydrocarbons (PAHs) measured in fall 2009 were lower than previously-measured minimum values, although predicted PAH toxicity was slightly higher than previously-measured maximum values. Direct tests of toxicity of sediments from *baseline* station CAR-D-2 found:

- for the midge *Chironomus*, survival was consistent with and growth was lower than previously-measured values; and
- for the amphipod *Hyalella*, survival was higher and growth was lower than previously-measured values.

Comparison of Sediment Quality Guidelines No hydrocarbon, PAH or metal concentrations measured at either station exceeded relevant sediment or soil quality guidelines in fall 2009 with the exception of CCME fraction-2 and fraction-3 hydrocarbons at *test* station CAR-D-1 (Table 5.6-9).

Sediment Quality Index The SQI values for *test* station CAR-D-1 and *baseline* station CAR-D-2 were 90.0 and 93.1, respectively, indicating **Negligible-Low** differences from regional *baseline* sediment quality conditions.

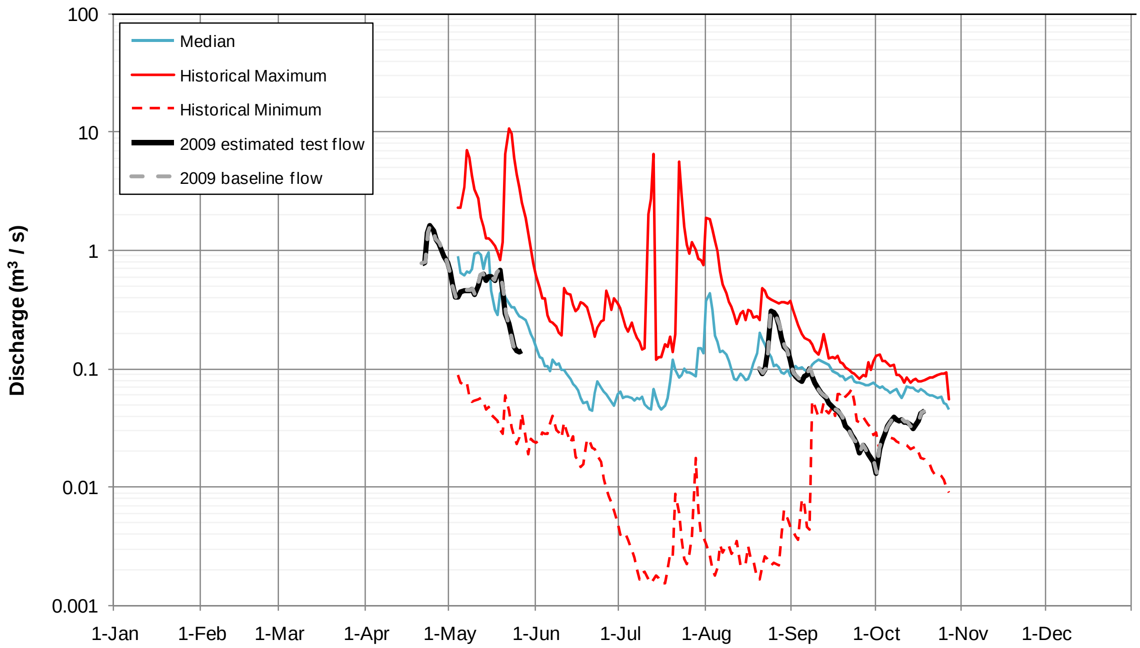
5.6.4.3 Summary

Reach-year differences in abundance, richness, and %EPT of the benthic invertebrate community between *test* reach CAR-D-1 and *baseline* reach CAR-D-2 were significant but not reflective of an impaired benthic invertebrate community in *test* reach CAR-D-1 because richness and %EPT was higher in *test* reach CAR-D-1 than *baseline* reach CAR-D-2. All other reach-year differences in values of benthic invertebrate community measurement endpoints were not significant between *test* reach CAR-D-1 and *baseline* reach CAR-D-2. In addition, all benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Calumet River watershed from regional *baseline* conditions. Sediment quality at *test* station CAR-D-1 and *baseline* station CAR-D-2 indicated a **Negligible-Low** difference from regional *baseline* sediment quality conditions.

5.6.5 Fish Populations

There were no Fish Population component activities conducted in the Calumet River watershed in 2009.

Figure 5.6-3 The observed (*test*) hydrograph for the Calumet River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on RAMP Station S16 (Canadian Natural Station CR-1), Calumet River near the mouth, provisional data. The upstream drainage area is 173.5 km^2. Historical values from 2001 to 2008 for the open-water period. There are insufficient data to present upper and lower quartile values.

Table 5.6-2 Estimated water balance at Station S16 (CR-1), Calumet River near the mouth, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**2.35**	**Observed discharge obtained from Station S16 (Canadian Natural Station CR-1), Calumet River near the mouth**
Closed-circuited area water loss from the observed *test* hydrograph	-0.025	Estimated 1.8 km^2 of the Calumet River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.001	Estimated 0.4 km^2 of the Calumet River watershed with land change from focal projects as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the Calumet River watershed from focal projects	0	None reported
Water releases into the Calumet River watershed from focal projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Calumet River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**2.38**	**Estimated *baseline* discharge at Station S16 (Canadian Natural Station CR-1), Calumet River near the mouth**
Incremental flow (change in total discharge)	-0.024	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**-1.0%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on Station S16 (Canadian Natural Station CR-1), Calumet River near the mouth, 2009 provisional data for April 21 to May 27, 2009 and August 20 to October 18, 2009.

Table 5.6-3 Calculated change in hydrologic measurement endpoints the Calumet River watershed, 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.187	0.185	-1.0%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	Insufficient data	Insufficient data	Insufficient data
Open-water season minimum daily discharge	Insufficient data	Insufficient data	Insufficient data

Note: Based on Station S16 (Canadian Natural Station CR-1), Calumet River near the mouth, 2009 provisional data for April 21 to May 27, 2009 and August 20 to October 18, 2009.

Table 5.6-4 Concentrations of water quality measurement endpoints, mouth of Calumet River (station CAR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.21	7	8.1	8.2	8.4
Total suspended solids	mg/L	-[1]	8	7	<3	10.5	41
Conductivity	µS/cm	-	554	7	188	611	702
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.0686**	7	0.025	0.044	**0.076**
Total nitrogen*	mg/L	1.0	**1.541**	7	0.8	**1.2**	**1.5**
Nitrate+nitrite	mg/L	1.0	<0.071	7	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	34.8	7	22	30	38
Ions							
Sodium	mg/L	-	47.3	7	7	55	71
Calcium	mg/L	-	55.3	7	25.3	55.7	67.3
Magnesium	mg/L	-	17.9	7	7.8	19.4	22.5
Chloride	mg/L	230, 860[3]	12.8	7	2	18	34
Sulphate	mg/L	100[4]	13.3	7	3.6	11.9	14.5
Total dissolved solids	mg/L	-	394	7	151	400	480
Total alkalinity	mg/L		275	7	96	295	337
Organic compounds							
Naphthenic acids	mg/L	-	0.446	7	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	0.067	7	0.040	**0.158**	**0.337**
Dissolved aluminum	mg/L	0.1[2]	0.0031	7	0.0013	0.0036	0.0058
Total arsenic	mg/L	0.005	0.0011	7	0.0009	0.001	0.0012
Total boron	mg/L	1.2[5]	0.0776	7	0.074	0.090	0.122
Total molybdenum	mg/L	0.073	0.0001	7	0.0001	0.0002	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.224	7	0.195	0.263	0.297
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total phosphorus	mg/L	0.05	**0.0967**	7	**0.066**	**0.089**	**0.099**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.47**	7	0.7	**1.1**	**1.4**
Total iron	mg/L	0.3	**1.03**	7	**0.6**	**1.48**	**3.14**
Dissolved iron	mg/L	0.3[2]	**0.635**	7	**0.339**	**0.492**	**0.911**
Sulphide	mg/L	0.002[7]	**0.005**	7	**0.007**	**0.014**	**0.028**
Total phenols	mg/L	0.004	**0.0094**	6	<0.001	**0.0065**	**0.013**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.6-5 Concentrations of water quality measurement endpoints, upper Calumet River (station CAR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.71	4	7.8	8	8.21
Total suspended solids	mg/L	-[1]	208	4	<3	3	5
Conductivity	µS/cm	-	583	4	526	658.5	772
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.242**	4	**0.086**	**0.124**	**0.305**
Total nitrogen*	mg/L	1.0	**5.541**	4	**1.8**	**1.9**	**2.4**
Nitrate+nitrite	mg/L	1.0	0.071	4	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	54.4	4	40	47.5	48
Ions							
Sodium	mg/L	-	61.2	4	53	67	76
Calcium	mg/L	-	52.8	4	44	54.4	68.2
Magnesium	mg/L	-	18.4	4	18	21.6	26.6
Chloride	mg/L	230, 860[3]	12.3	4	14	16	17
Sulphate	mg/L	100[4]	47.7	4	45.3	62.15	78.4
Total dissolved solids	mg/L	-	467	4	370	499	547
Total alkalinity	mg/L		238	4	213	265.5	315
Organic compounds							
Naphthenic acids	mg/L	-	0.686	3	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	**4.1**	4	0.0203	0.037	0.0621
Dissolved aluminum	mg/L	0.1[2]	0.0241	4	0.0036	0.0089	0.0172
Total arsenic	mg/L	0.005	**0.00501**	4	0.0021	0.0023	0.00276
Total boron	mg/L	1.2[5]	0.0808	4	0.0817	0.09205	0.128
Total molybdenum	mg/L	0.073	0.0003	4	0.0001	0.0005	0.0008
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.8	4	<1.2	<1.2	1.3
Total strontium	mg/L	-	0.287	4	0.242	0.3005	0.356
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total phosphorus	mg/L	0.05	**1.48**	4	**0.101**	**0.251**	**0.349**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**5.47**	4	**1.7**	**1.8**	**2.3**
Total iron	mg/L	0.3	**6.68**	4	**0.551**	**0.6425**	**1.45**
Dissolved Iron	mg/L	0.3[2]	**1.5**	4	**0.239**	**0.3455**	**0.404**
Sulphide	mg/L	0.002[7]	**0.588**	4	**0.024**	**0.0026**	**0.095**
Total phenols	mg/L	0.004	**0.0189**	4	**0.008**	**0.012**	**0.041**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

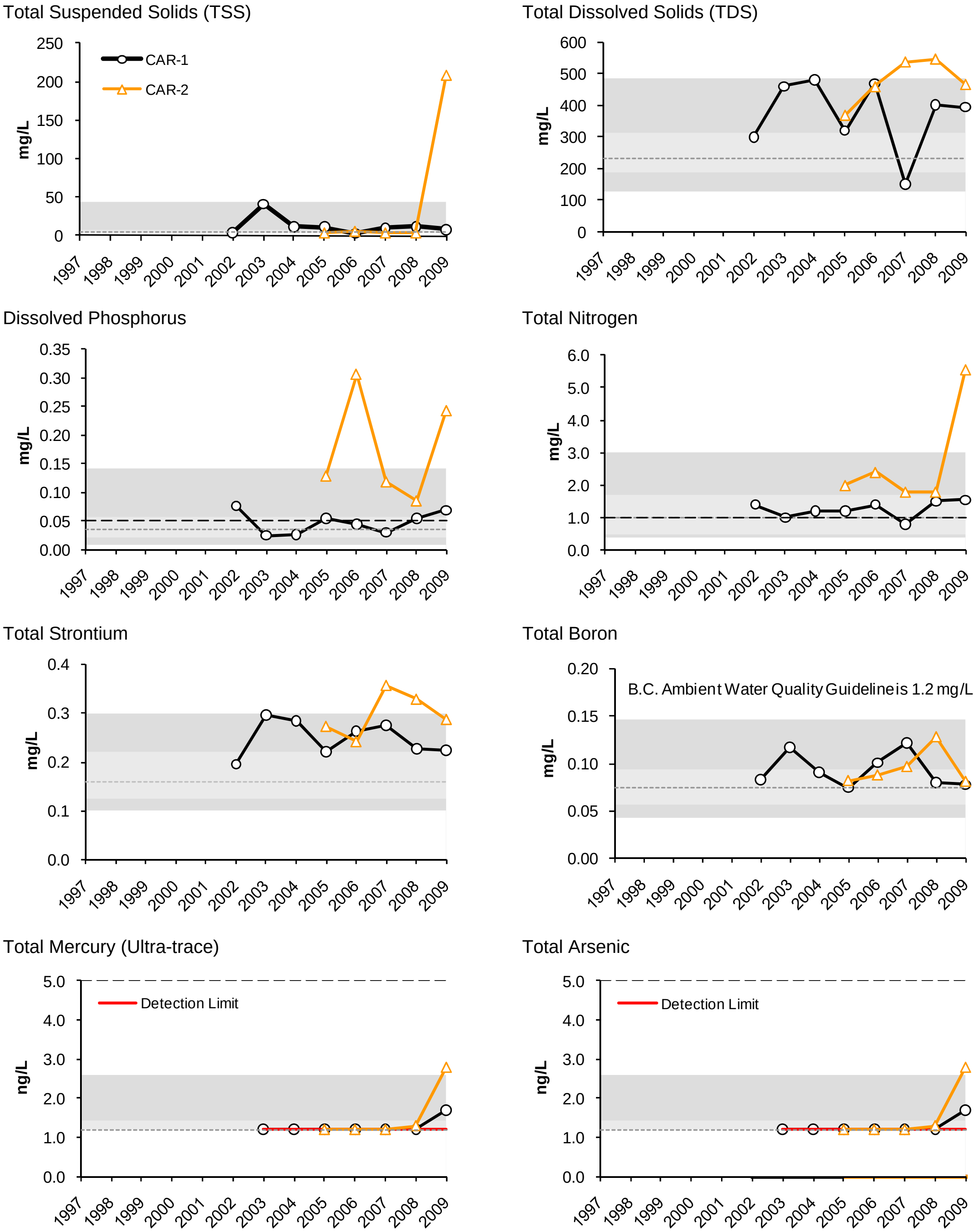
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Figure 5.6-4 Concentrations of selected water quality measurement endpoints in the Calumet River (fall data) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

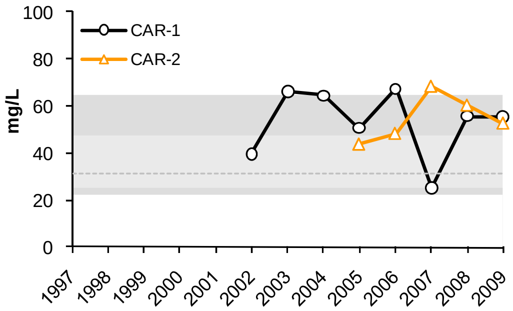
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

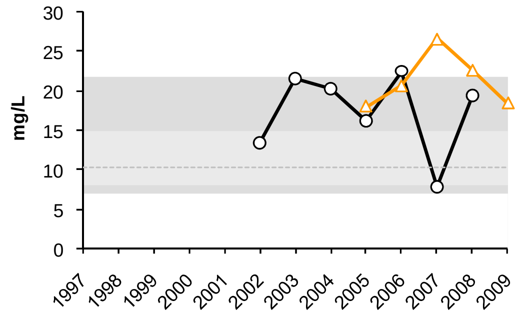
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.6-4 (Cont'd.)

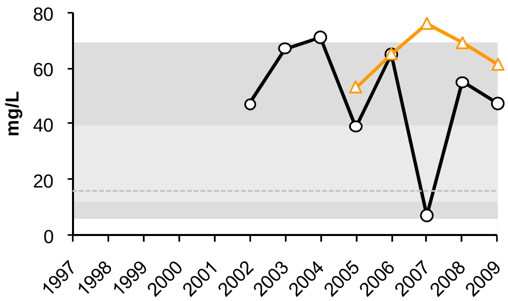
Calcium



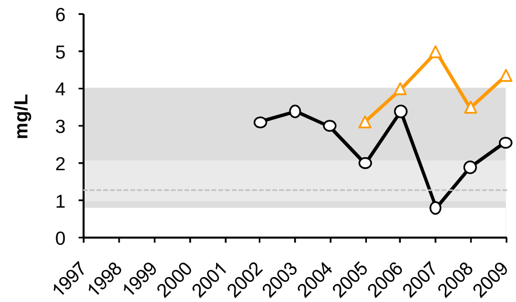
Magnesium



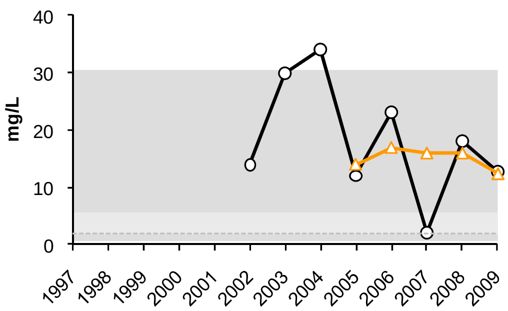
Sodium



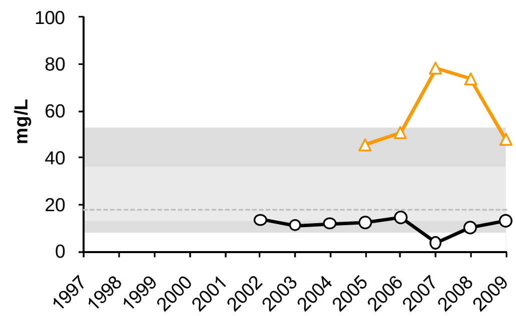
Potassium



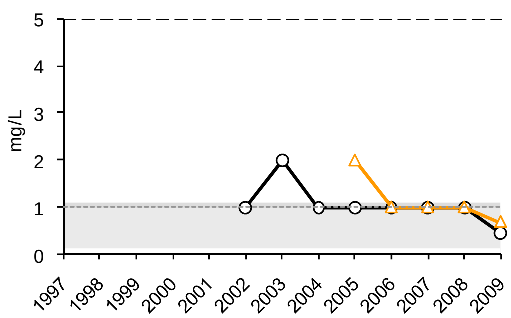
Chloride



Sulphate



Naphthenic Acids[1]



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.6-5   Piper diagram of fall ion concentrations in Calumet River watershed.

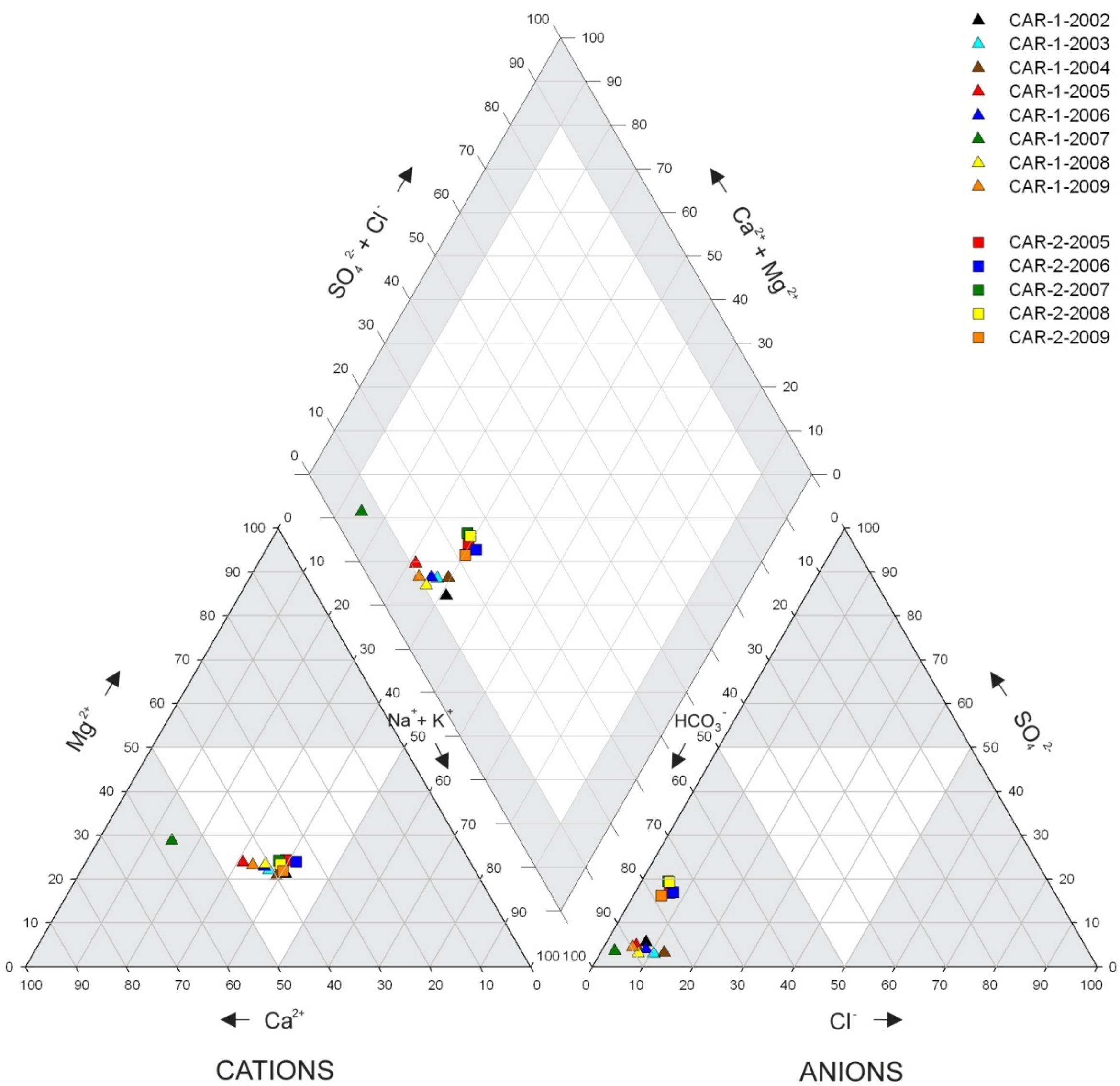


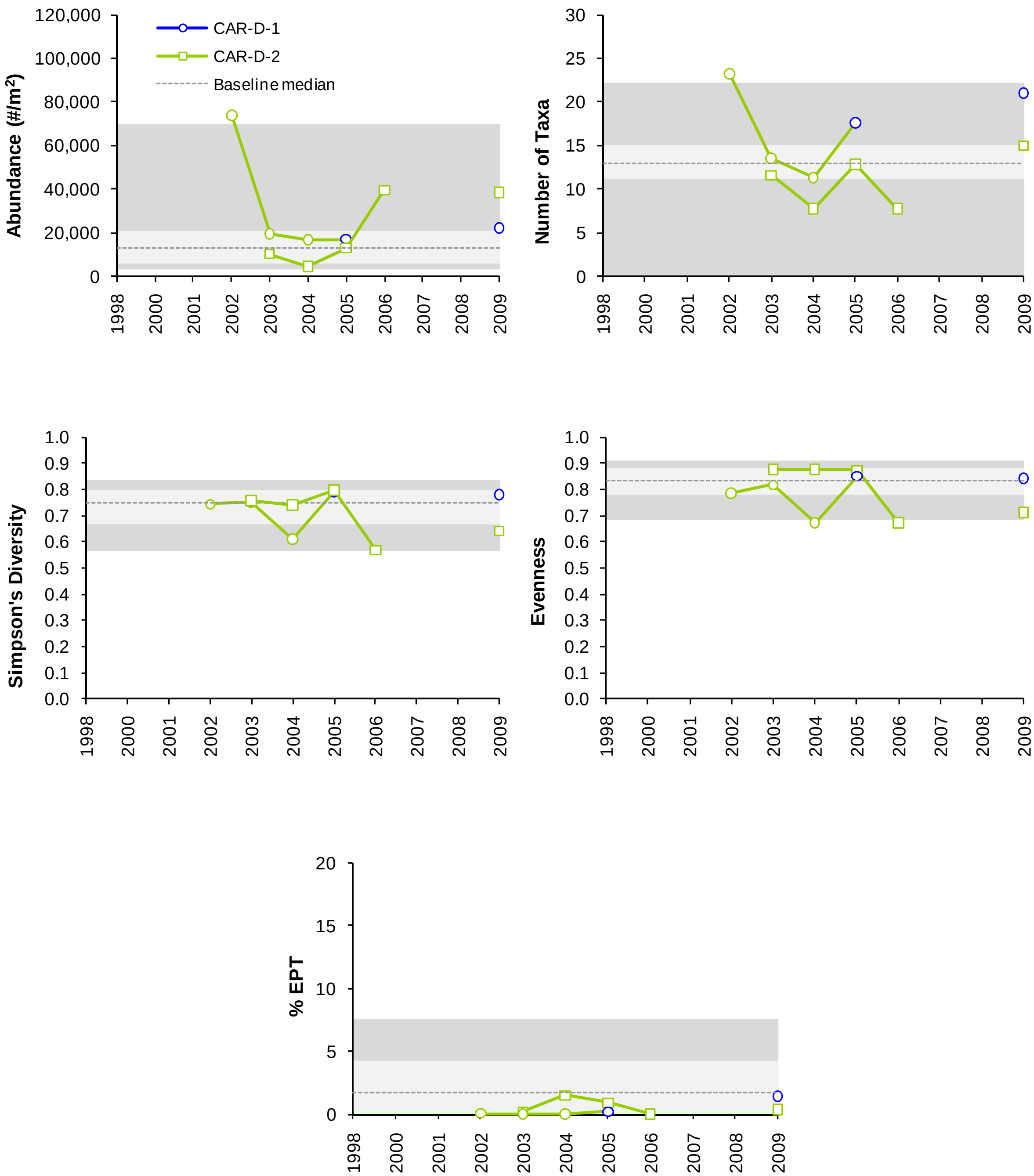
Table 5.6-6 Average habitat characteristics of benthic invertebrate sampling locations in the Calumet River (CAR-D-1 and CAR-D-2).

Variable	Units	*Test* Reach CAR-D-1	*Baseline* Reach CAR-D-2
Sample Date	-	Sept 15, 2009	Sept 11, 2009
Habitat	-	Depositional	Depositional
Water Depth	m	0.2	0.5
Current Velocity	m/s	0.2	0.0
Macrophyte Cover	%	0	0
Field Water Quality			
Dissolved Oxygen	mg/L	9.0	7.8
Conductivity	µS/cm	530	628
pH	pH units	8.3	7.5
Water Temperature	°C	14.0	17.3
Sediment Composition			
Sand	%	87	35
Silt	%	6	39
Clay	%	7	27
Total Organic Carbon	%	2.9	5.6

Table 5.6-7 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the Calumet River.

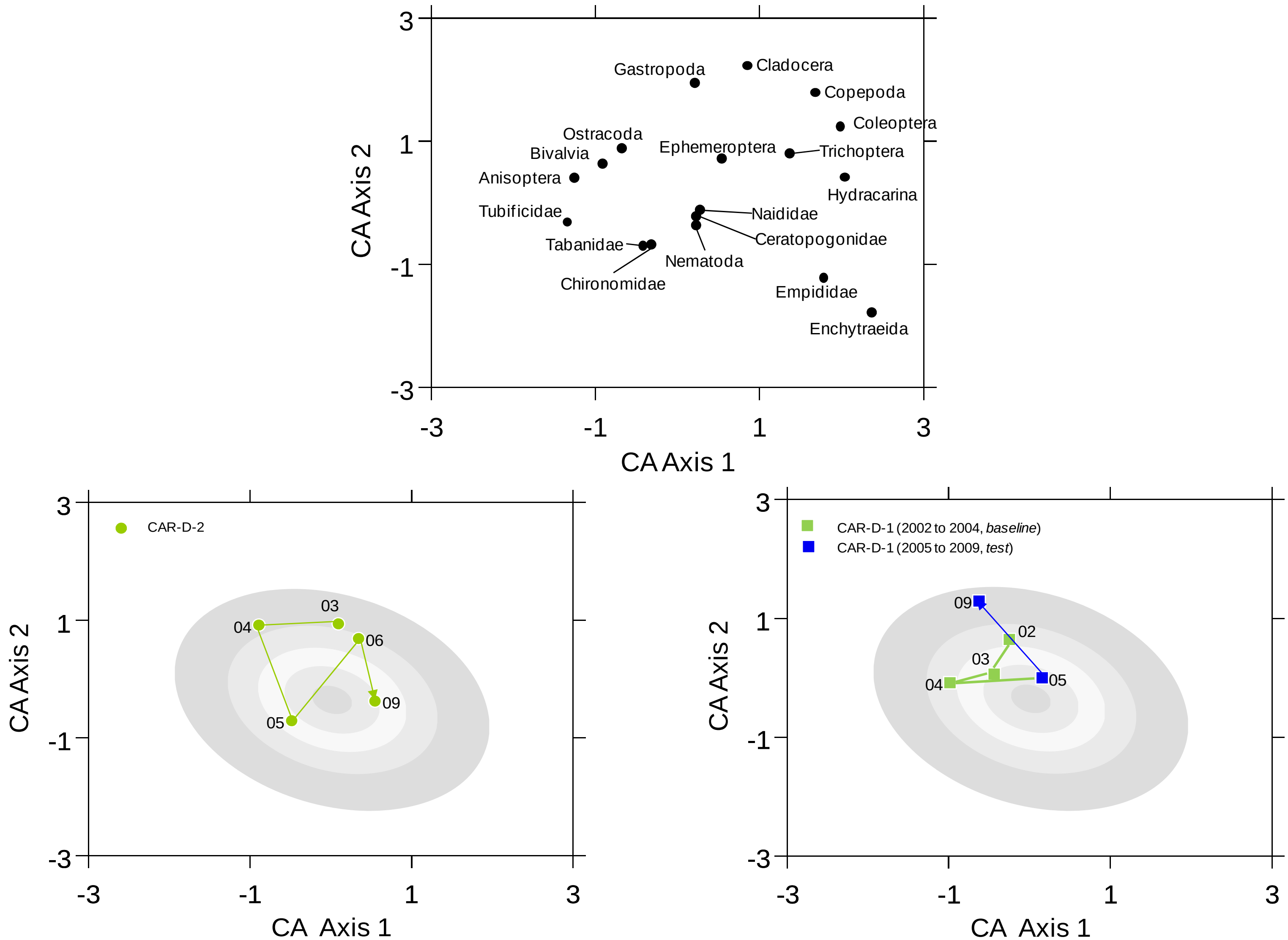
Taxon	Percent Major Taxa Enumerated in Each Year								
	Test Reach CAR-D-1					*Baseline* Reach CAR-D-2			
	2002	2003	2004	2005	2009	2003	2004	2005	2009
Amphipoda	<1		<1			3	2		<1
Anisoptera	<1	<1	<1		<1	<1	<1	1	
Bivalvia	1	2	1	1	<1	1	10	<1	3
Ceratopogonidae	1	2	2	<1	1	3		4	1
Chaoboridae						3	1	2	54
Chironomidae	91	85	48	86	84	54	42	67	
Chydoridae	<1								
Coleoptera	<1	<1	1	<1					22
Copepoda	1	2	<1	1	4	4	3	4	
Daphniidae	<1	<1	<1			3			
Daphniidae		<1	<1						
Enchytraeidae	<1	<1	<1	<1	1				
Ephemeroptera	<1	<1	<1	<1	2	<1	1	1	1
Erpobdellidae	<1	<1	<1			0	<1	<1	
Gastropoda	<1	<1	<1			13	5	1	<1
Heteroptera	<1	<1	<1						
Hydracarina	<1	<1	<1	<1		3		2	1
Macrothricidae	<1	<1	<1						
Naididae	<1	4	2	<1	1	9	6	6	1
Nematoda	1	<1	3	1	1	4	16	5	2
Ostracoda	3	2	4	3	1		12	7	14
Plecoptera	<1		<1	1					
Trichoptera	<1	<1			<1	<1	<1	<1	
Tubificidae	1	1	37	6	2		1		2
Benthic Invertebrate Community Measurement Endpoints									
Total Abundance	73,983	19,664	16,954	17,096	22,301	10,302	4,612	12,957	38,358
Richness	23	14	11	18	21	12	8	13	15
Simpson's Diversity	0.74	0.75	0.61	0.79	0.78	0.76	0.74	0.8	0.64
Evenness	0.78	0.82	0.67	0.85	0.84	0.87	0.88	0.87	0.71
Percent EPT	<1	<1	<1	<1	1	<1	2	1	<1

Figure 5.6-6 Variation in benthic invertebrate community measurement endpoints in the Calumet River.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.6-7 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Calumet River.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the two lower panels is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.6-8 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Calumet River.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	7.918	9	0.880	3.34	0.002
	BA x BT	0.875	1	0.875	3.32	0.072
	Remainder (noise)	7.043	8	0.880	3.34	0.071
	Error	21.102	80	0.264		
Log Richness	Reach - Year	1.596	9	0.177	4.62	0.000
	BA x BT	0.000	1	0.000	0.01	0.928
	Remainder (noise)	1.596	8	0.199	5.19	0.025
	Error	3.074	80	0.038		
Diversity	Reach - Year	0.484	9	0.054	1.92	0.060
	BA x BT	0.067	1	0.067	2.41	0.125
	Remainder (noise)	0.417	8	0.052	5.32	0.022
	Error	1.746	178	0.010		
Evenness	Reach - Year	0.495	9	0.055	1.93	0.059
	BA x BT	0.120	1	0.120	4.20	0.044
	Remainder (noise)	0.376	8	0.047	1.64	0.203
	Error	2.284	80	0.029		
Log %EPT	Reach - Year	0.70	9	0.08	2.52	0.014
	BA x BT	0.05	1	0.05	1.77	0.187
	Remainder (noise)	0.65	8	0.08	2.61	0.110
	Error	2.48	80	0.03		
CA Axis 1	Lake - Year	21.01	9	2.33	3.37	0.002
	BA x BT	1.23	1	1.23	1.77	0.188
	Remainder (noise)	19.79	8	2.47	3.57	0.063
	Error	55.50	80	0.69		
CA Axis 2	Reach - Year	28.76	9	3.20	3.65	0.001
	BA x BT	0.18	1	0.18	0.21	0.649
	Remainder (noise)	28.58	8	3.57	4.08	0.047
	Error	70.05	80	0.88		

Table 5.6-9 Concentrations of sediment quality measurement endpoints, mouth of Calumet River (station CAR-D-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	6	3	10	18	21
Silt	%	-	7	3	9	23	30
Sand	%	-	87	3	52	67	70
Total organic carbon	%	-	2.8	3	0.6	3.8	4.1
Total hydrocarbons							
BTEX	mg/kg	-	<10	2	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	2	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	**215**	2	**200**	**420**	**640**
Fraction 3 (C16-C34)	mg/kg	300[1]	**2850**	2	**3400**	**5300**	**7200**
Fraction 4 (C34-C50)	mg/kg	2800[1]	2260	2	**3000**	**4150**	**5300**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0014	3	0.0036	0.0048	0.011
Retene	mg/kg	-	0.094	3	0.05	0.172	0.181
Total dibenzothiophenes	mg/kg	-	5.52	3	0.31	5.39	9.68
Total PAHs	mg/kg	-	14.60	3	1.39	16.70	24.92
Total Parent PAHs	mg/kg	-	0.36	3	0.09	0.57	0.63
Total Alkylated PAHs	mg/kg	-	14.24	3	1.30	16.12	24.29
Predicted PAH toxicity[3]	H.I.	-	0.79	3	0.60	0.77	1.95
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.8	2	8.0	8.5	9.0
Chironomus growth - 10d	mg/organism	-	1.9	2	1.3	1.5	1.8
Hyalella survival - 14d[4]	# surviving	-	9.0	2	9.0	9.0	9.0
Hyalella growth - 14d[4]	mg/organism	-	0.3	2	0.1	0.2	0.3

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

4 2002 *Hyalella* test based on 10-day test period.

Table 5.6-10 Concentrations of sediment quality measurement endpoints, upper Calumet River (station CAR-D-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay[4]	%	-	27.0	1	13	13	13
Silt[4]	%	-	31	1	31	31	31
Sand[4]	%	-	42	1	56	56	56
Total organic carbon	%	-	12.0	2	16.5	18.5	20.5
Total hydrocarbons							
BTEX	mg/kg	-	<30	2	<5	<43	<80
Fraction 1 (C6-C10)	mg/kg	30[1]	<30	2	<5	**<43**	**<80**
Fraction 2 (C10-C16)	mg/kg	150[1]	50	2	<5	112.5	**230**
Fraction 3 (C16-C34)	mg/kg	300[1]	245	2	**4100**	**5100**	**6100**
Fraction 4 (C34-C50)	mg/kg	2800[1]	154	2	**3000**	**3650**	**4300**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0020	2	0.0147	**0.1740**	**0.201**
Retene	mg/kg	-	0.107	2	0.353	0.549	0.745
Total dibenzothiophenes	mg/kg	-	0.016	1	0.41	0.41	0.41
Total PAHs	mg/kg	-	0.253	2	1.90	2.28	2.66
Total Parent PAHs	mg/kg	-	0.018	2	0.07	0.08	0.10
Total Alkylated PAHs	mg/kg	-	0.235	2	1.81	2.20	2.60
Predicted PAH toxicity[3]	H.I.	-	0.17	2	0.06	0.80	0.10
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.0	2	4.6	6.3	8.0
Chironomus growth - 10d	mg/organism	-	1.3	2	2.2	2.4	2.5
Hyalella survival - 14d	# surviving	-	6.6	2	5.8	5.9	6.0
Hyalella growth - 14d	mg/organism	-	0.2	2	0.4	0.4	0.4

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

4 Sediment size measured at replicate 2 in 2009, as particle size analysis was not possible at replicate 1.

5.7 FIREBAG RIVER WATERSHED

Table 5.7-1 Summary of results for Firebag River watershed.

Firebag River Watershed	Summary of 2009 Conditions		
	Firebag River		*Lakes*
Climate and Hydrology			
Criteria	**S27** at the mouth		no lakes sampled
Mean open-water season discharge	○		
Mean winter discharge	○		
Annual maximum daily discharge	○		
Minimum open-water season discharge	○		
Water Quality			
Criteria	**FIR-1** at the mouth	**FIR-2** upstream of Suncor Firebag	**MCL-1** McClelland Lake
Water Quality Index	○	○	○
Benthic Invertebrate Communities and Sediment Quality			
Criteria	no station sampled	no station sampled	**MCL-1** McClelland Lake
Benthic Invertebrate Communities			n/a
Sediment Quality Index			○
Fish Populations			
No Fish Population component activities conducted in 2009			

Legend and Notes

○ Negligible-Low

● Moderate

● High

baseline

test

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches or *baseline* lakes.

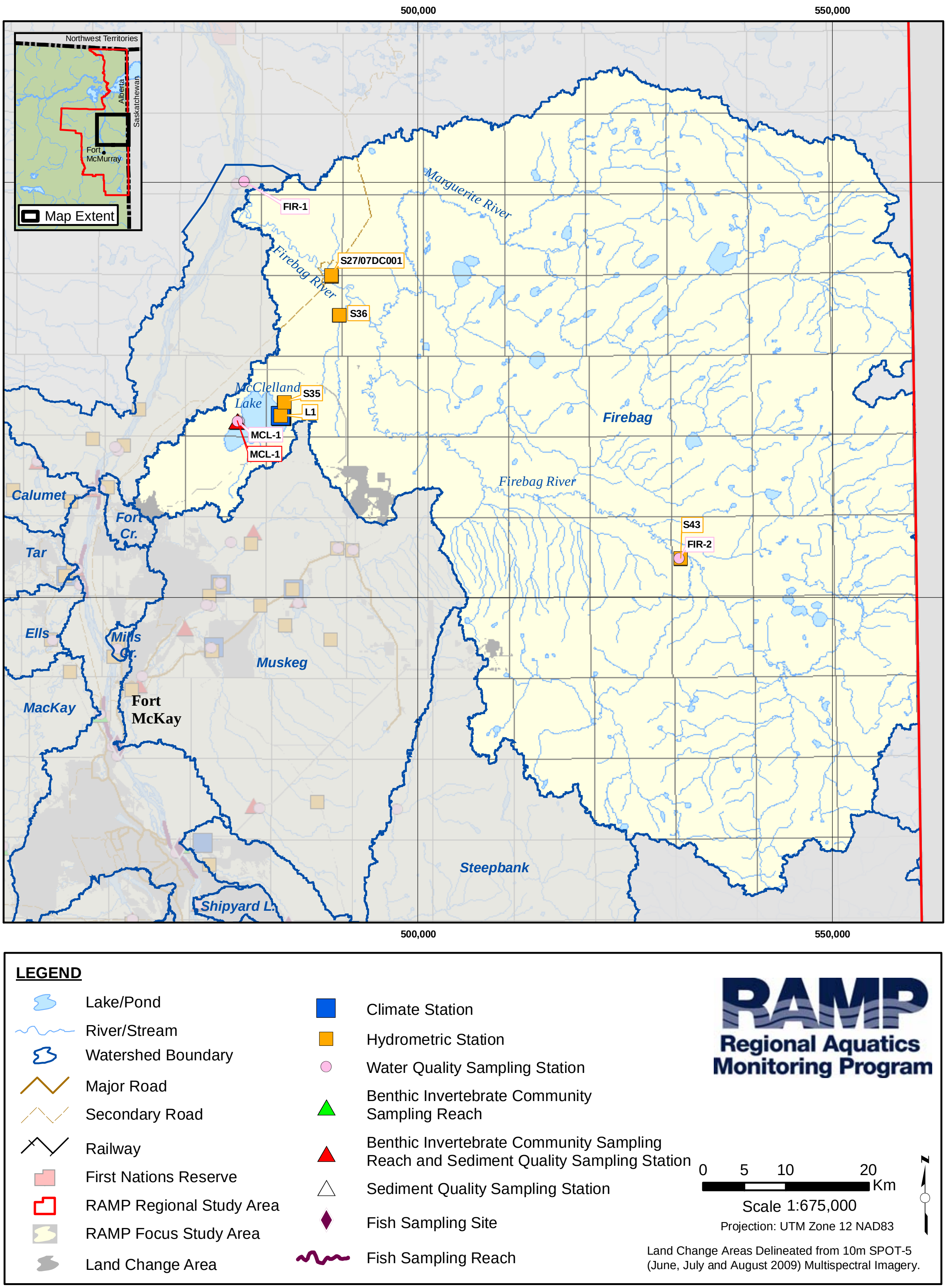
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Figure 5.7-1 Firebag River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K07_Firebag_20100415.mxd

Figure 5.7-2 Representative monitoring stations of the Firebag River watershed, fall 2009.

Water Quality Station FIR-1: Right Downstream Bank

Water Quality Station FIR-1: Right Downstream Bank

Water Quality Station FIR-2: Right Downstream Bank

Water Quality Station FIR-2: Left Downstream Bank

Climate and Hydrology Station S43: Firebag River, Right Downstream Bank

Quality Station MCL-1: McClelland Lake

5.7.1 Summary of 2009 Conditions

Approximately 0.65% (3,700 ha) of the Firebag River watershed had undergone land change as of 2009 from focal projects (Table 2.4-2). The part of the watershed downstream of those portions of the Suncor Firebag and Fort Hills, Imperial Kearl, and Husky Sunrise projects that are in the Firebag River watershed (Figure 5.7-1) is designated as *test*; the remainder of the watershed is designated as *baseline*.

Table 5.7-1 is a summary of the 2009 assessment of the Firebag River watershed, while Figure 5.7-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.7-2 contains 2009 fall photos of a number of monitoring stations in the watershed.

Hydrology The mean open-water period discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to be 0.07% greater than the estimated *baseline* hydrograph. Watershed-level differences in hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality With few exceptions, concentrations of water quality measurement endpoints in fall 2009 were within the range of regional *baseline* concentrations, and consistent with historical observations at these stations over the period of record. There was no change in ionic composition in fall 2009 from previous years, and the water quality index for fall 2009 indicated **Negligible-Low** differences in water quality conditions from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Measurement endpoints for the benthic invertebrate community in McClelland Lake were within or above the range of variation for *baseline* lakes in the RAMP FSA. Differences in sediment quality in McClelland Lake compared to regional *baseline* conditions were assessed as **Negligible-Low**.

5.7.2 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth The annual runoff volume observed at WSC Station 07DC001 was 1,115 million m^3 in 2009. The 2009 open-water period (May to October) runoff volume was 813 million m^3, 37% higher than the historical mean open-water runoff volume calculated from measurements obtained since 1972. The 2009 open-water maximum daily flow of 190 m^3/s recorded on June 29 was 72% higher than the historical mean open-water maximum daily flow. The minimum open-water daily flow of 23.7 m^3/s was recorded on October 14, and was 54% higher than the historical open-water mean minimum daily flow. Flows closely followed historical median values from January until the middle of June (Figure 5.7-1), and from the middle of September for a period of one month. Flows were generally in the upper quartile for remaining periods of the year, and exceeded historical maximum values recorded at the end of June, soon after the large rainfall event that occurred on June 22.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance for 2009 at WSC Station 07DC001 is provided in Table 5.7-2 and described as follows:

1. The closed-circuited land area in the Firebag River watershed as of 2009 was estimated at 2.6 km^2 (Table 2.4-1). The loss of flow to the Firebag River that would have otherwise occurred from this land area is 0.475 million m^3.

2. The land area not closed-circuited as of 2009 was estimated at 34.5 km^2 (Table 2.4-1). The increase in flow to the Firebag River that would have otherwise not occurred from this land area is estimated at 1.3 million m^3.

The estimated cumulative effect of land change is an increase in flow of 0.81 million m^3 to the Firebag River. The resulting *baseline* hydrograph is presented in Figure 5.7-1.

The mean open-water period discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to be 0.07% greater than the estimated *baseline* hydrograph (Table 5.7-3). Watershed-level differences in hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low** (Table 5.7-1).

2009 Hydrologic Conditions: Station L1, McClelland Lake From January to mid-June 2009, water levels recorded at Station L1 fluctuated around the historical upper quartile value (Figure 5.7-4). Water levels only went below the historical median during this period in February 2009. In response to the late June rainfall event, lake water level rose to values approximately 0.1 m higher than the historical upper quartile and also exceeded historical maximum values that were previously measured in early July. Water levels remained approximately 0.1 m above the historical upper quartile value for the remainder of the year.

5.7.3 Water Quality

In fall 2009, water quality samples were taken from:

- the Firebag River near its mouth (*test* station FIR-1, first sampled in 2002 and designated as *test* since 2002);
- the Firebag River upstream of all focal project developments (*baseline* station FIR-2, first sampled in 2003); and
- McClelland Lake (*baseline* station MCL-1, sampled from 2000 to 2009).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of most water quality measurement endpoints were within the range of historical measurements at both *test* station FIR-1 and *baseline* station FIR-2, with the exception of total strontium at *test* station FIR-1, which slightly exceeded previously-recorded maximum concentration, and sulphate at *baseline* station FIR-2, which fell below its previously-recorded minimum concentrations at this station (Table 5.7-4 to Table 5.7-5). Concentrations of all measurement endpoints were within the range of regional *baseline* concentrations with the exception of dissolved phosphorus at *baseline* station FIR-2 and potassium at *baseline* station MCL-1, which both were greater than the 95th percentile of *baseline* regional concentrations in fall 2009. Total strontium at *baseline* station FIR-2, and dissolved phosphorus, total arsenic, and sulphate at *baseline* station MCL-1 were below the 5th percentile of regional *baseline* concentrations (Figure 5.7-6).

Concentrations of naphthenic acids at all stations were below the 5th percentile of regional *baseline* concentrations due to greatly improved detection limits for this analysis 2009.

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of all water quality measurement endpoints in fall 2009 were below water quality guidelines with the exception of total dissolved phosphorus at *baseline* station FIR-2 (Table 5.7-5) and total nitrogen at *baseline* station MCL-1 (Table 5.7-6).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in fall 2009 (Table 5.7-7):

- Total and dissolved iron and sulphide at *test* station FIR-1 and *baseline* station FIR-2;
- Total phosphorus and total phenols at *baseline* station FIR-2; and
- Total Kjeldahl nitrogen at *baseline* station MCL-1.

Ion Balance The ionic composition of water sampled in the fall 2009 at *test* station FIR-1 and *baseline* station FIR-2 has remained consistent since 2000, dominated by calcium and bicarbonate (Figure 5.7-7). The ionic composition of McClelland Lake (measured at *baseline* station MCL-1) in fall 2009 was consistent with that of previous years, and dominated by magnesium and bicarbonate (Figure 5.7-7).

Trend Analysis There were no significant trends in water quality measurement endpoints at *test* station FIR-1 over the period of record (α=0.05). Significant trends in the following water quality measurement endpoints were observed at *baseline* station FIR-2 and *baseline* station MCL-1 (α = 0.05): upward trend in arsenic at *baseline* station FIR-2; and downward trend in arsenic at *baseline* station MCL-1, occurring only as an artifact of a lower detection limit in total arsenic after the 2002 sampling year.

Water Quality Index The WQI values were 100, 100, and 89.1 for *test* station FIR-1, *baseline* station FIR-2, and *baseline* station MCL-1, respectively, indicating **Negligible-Low** differences from regional water quality *baseline* conditions.

Summary With few exceptions, concentrations of water quality measurement endpoints in fall 2009 were within the range of regional *baseline* concentrations, and consistent with historical observations at these stations over the period of record. There was no change in the ionic composition in fall 2009 from previous years, and the water quality index for fall 2009 indicated **Negligible-Low** differences in water quality conditions from regional *baseline* conditions.

5.7.4 Benthic Invertebrate Communities and Sediment Quality

5.7.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in 2009 in the Firebag River watershed in McClelland Lake (MCL-1), a depositional waterbody designated as *baseline* for its entire data record (2002 to 2009).

2009 Habitat Conditions Samples were taken at a depth of 2 m in McClelland Lake. The lake in fall 2009 was dominated by sand substrate with high organic content (30% TOC) (Table 5.7-8), comprised of dead and decaying vegetative material, primarily of the plant species, *Chara*.

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of McClelland Lake in fall 2009 was dominated by chironomids (75%), with water mites (Hydracarina, 5%), and naidid worms (3%) sub-dominant (Table 5.7-9). Bivalve clams, gastropod snails, caddisflies (Trichoptera), mayflies (Ephemeroptera), and amphipods, were also present, but in low (1% or less) relative abundances. The dominant chironomids included *Dicrotendipes*, *Paratanytarsus*, *Einfeldia*, *Tanytarsus*, and *Ablabesmyia*. Mayflies were represented by the common form *Caenis*, while caddisflies were represented by *Oxyethira*, *Agraylea*, and *Oecetis*.

The fall 2009 values and temporal trends in the benthic invertebrate community measurement endpoints for McClelland Lake (Figure 5.7-8) have the following characteristics:

1. Total abundance (~107,000) was well above any previous abundance estimates. High total numbers did not reflect any observed changes in lake water quality or sediment quality. Benthic samples tended to consist of clumps of *Chara*, which were retained, and may have been the cause of the high numbers of chironomids. The types of organisms found were not typical of disturbed environments, but were representative of fairly typical lake environments;

2. Taxa richness (23 taxa per sample) was near the historically highest value;

3. Both Simpson's diversity and evenness were within the range of *baseline* lake conditions; and

4. The percent of the fauna as EPT taxa in 2009 was lower than previously-measured values, perhaps a result of the high abundance of chironomids, but still within the normal range of regional *baseline* lake conditions.

Results for the Correspondence Analysis (Figure 5.7-9) indicated that, based on relative abundance (%), the composition of the benthic invertebrate community of McClelland Lake has been consistent over time.

5.7.4.2 Sediment Quality

Sediment quality in fall 2009 was sampled in McClelland Lake (MCL-1, designated as *baseline*, with sampling conducted in 2002, 2003, and 2006 to 2009).

2009 Results and Historical Ranges of Concentration Sediments collected at *baseline* station MCL-1 in fall 2009 were comprised of a greater percentage of sand than in previous years; organic carbon content was just above the historical maximum value (Table 5.7-10). As in previous years, fraction 1 hydrocarbons including BTEX were not detectable in fall 2009. Fraction 3 and fraction 4 hydrocarbons were similar to or lower than median historical observations at *baseline* station MCL-1; fraction 2 hydrocarbons in fall 2009 were higher than previously-observed (Table 5.7-10). All polycyclic aromatic hydrocarbon values including predicted PAH toxicity were within the range of historical concentrations (Table 5.7-10).

Comparison with Sediment Quality Guidelines No hydrocarbon, PAH, or metal concentrations measured at *baseline* station MCL-1 exceeded relevant sediment or soil quality guidelines in fall 2009 with the exception of CCME fraction-3 hydrocarbons, which exceeded the CCME soil-quality guideline, but was within the range of historical concentrations (Table 5.7-10).

Sediment Quality Index A SQI value of 93.0 was calculated for *baseline* station MCL-1. This slight decrease from previously-calculated values was the result of hydrocarbon, copper, and strontium concentrations being above regional *baseline* sediment concentrations in fall 2009. SQI values have been greater than 92.3 as this station, indicating consistent sediment quality over time and **Negligible-Low** differences from regional *baseline* sediment quality conditions.

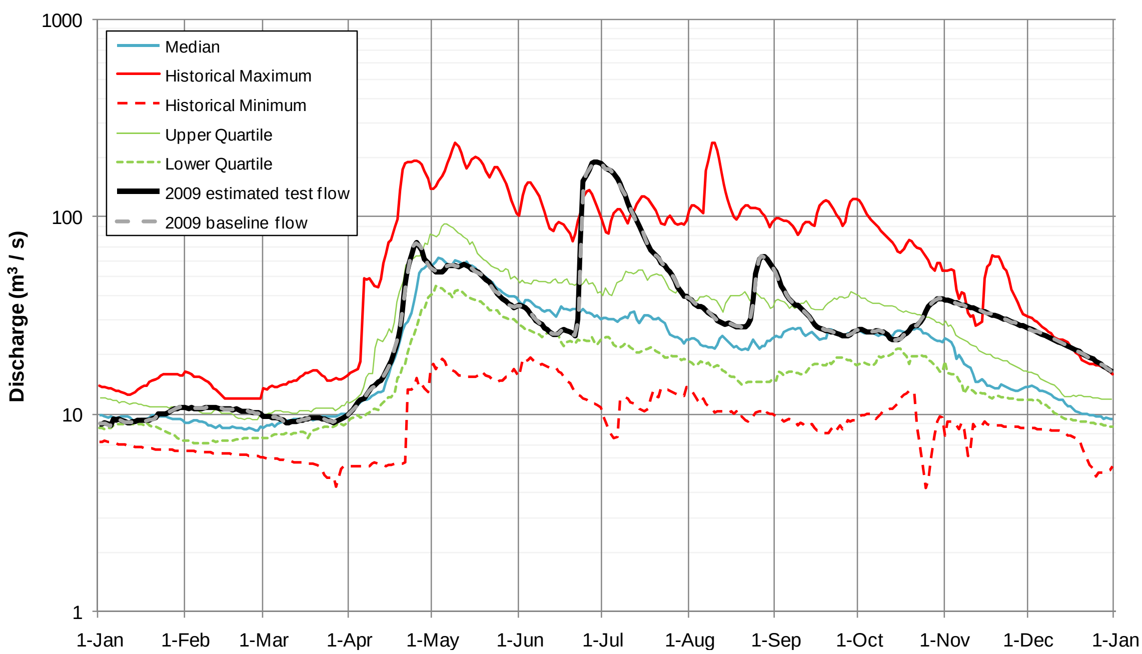
5.7.4.3 Summary

Measurement endpoints for the benthic invertebrate community in McClelland Lake were within or above the range of variation for *baseline* lakes in the RAMP FSA. Differences in sediment quality in McClelland Lake compared to regional *baseline* conditions are assessed as **Negligible-Low.**

5.7.5 Fish Populations

There were no Fish Population component activities conducted in the Firebag River watershed in 2009.

Figure 5.7-3 The observed (*test*) hydrograph for the Firebag River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on provisional data for WSC Station 07DC001, Firebag River near the mouth, (March 1 to October 31, 2009) and on data for RAMP Station S27 for other months in 2009. The upstream drainage area is 5,988 km^2. Historical values calculated for the period from 1972 to 2008.

Table 5.7-2 Estimated water balance at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**1115.3**	**Observed discharge, obtained from WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth**
Closed-circuited area water loss from the observed hydrograph	-0.475	Estimated 2.6 km^2 of the Firebag River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+1.286	Estimated 34.5 km^2 of the Firebag River watershed with land change from focal projects as of 2009 (Table 2.4-1), that is not closed-circuited
Water withdrawals from the Firebag River watershed from focal projects	0	None reported
Water releases into the Firebag River watershed from focal projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between observed and estimated hydrographs on tributary streams	0	No focal projects on tributaries of Firebag River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**1114.5**	**Estimated *baseline* discharge at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth**
Incremental flow (change in total discharge)	+0.811	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.07%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07DC001, Firebag River near the mouth and on RAMP Station S27 for other months in 2009.

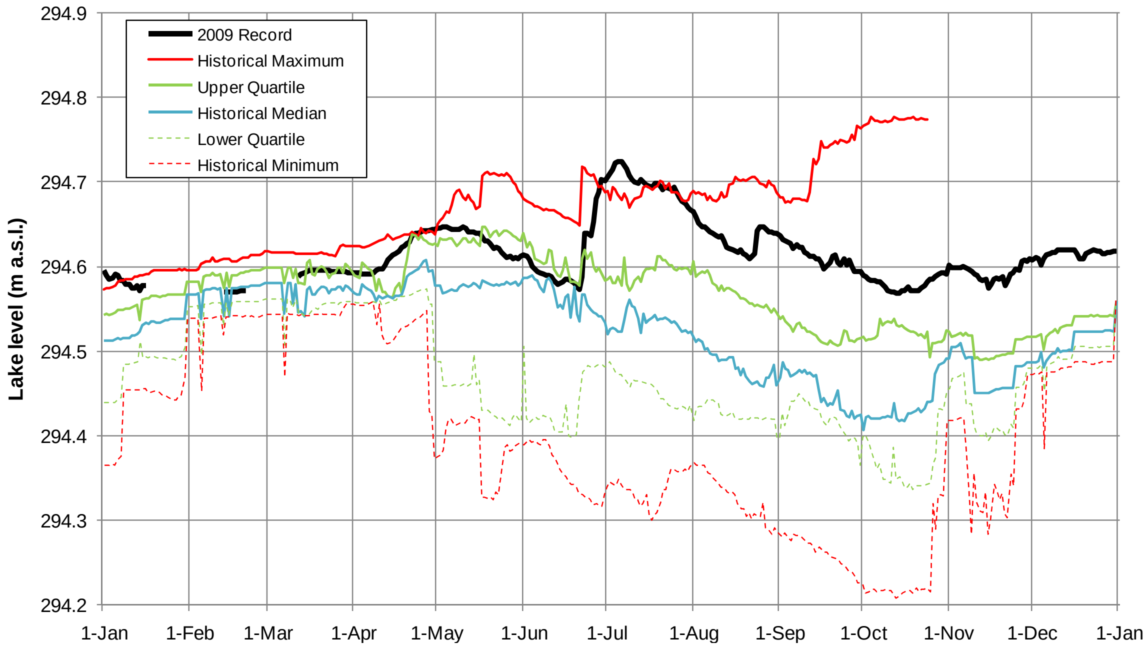
Table 5.7-3 Calculated change in hydrologic measurement endpoints for 2009 at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	51.12	51.16	+0.07%
Mean winter discharge	16.86	16.88	+0.07%
Annual maximum daily discharge	189.9	190.0	+0.07%
Open-water period minimum daily discharge	23.68	23.70	+0.07%

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07DC001, Firebag River near the mouth and on RAMP Station S27 for other months in 2009.

Figure 5.7-4 McClelland Lake level data for 2009, compared to historical values.



Note: Observed 2009 record based on RAMP Station L1, McClelland Lake, 2009 provisional data. Periods of missing data occur from January to March. Historical values calculated for the period from 1997 to 2008 with numerous periods of missing data over the data record.

Note: There are no reliable maximum data available after October 24, and these data are therefore not presented.

Table 5.7-4 Concentrations of water quality measurement endpoints, mouth of Firebag River (station FIR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.16	7	7.9	8.2	8.2
Total suspended solids	mg/L	-[1]	4	7	<3	5	17
Conductivity	µS/cm	-	214	7	178	199	227
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0345	7	0.016	0.032	**0.057**
Total nitrogen*	mg/L	1.0	0.691	7	0.4	0.6	**1.7**
Nitrate+nitrite	mg/L	1.0	0.071	7	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.7	7	8	13	16
Ions							
Sodium	mg/L	-	3.9	7	2	4	4
Calcium	mg/L	-	30.2	7	25.2	30.2	33.2
Magnesium	mg/L	-	8.5	7	6.8	9.4	9.7
Chloride	mg/L	230, 860[3]	1.79	7	2	2	3
Sulphate	mg/L	100[4]	1.99	7	1.7	3.2	10.3
Total dissolved solids	mg/L	-	164	7	60	137	170
Total alkalinity	mg/L		108	7	87	110	114
Organic compounds							
Naphthenic acids	mg/L	-	0.061	6	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0599	7	0.033	0.069	**0.292**
Dissolved aluminum	mg/L	0.1[2]	0.00679	7	0.0028	0.0049	0.0089
Total arsenic	mg/L	0.005	0.0005	7	0.0003	0.0004	0.0006
Total boron	mg/L	1.2[5]	0.0196	7	0.0136	0.0162	0.0200
Total molybdenum	mg/L	0.073	0.0001	6	0.0001	0.0001	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0767	6	0.053	0.067	0.076
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0034**	7	**<0.003**	**0.003**	**0.006**
Dissolved iron	mg/L	0.3[2]	**0.501**	7	0.235	**0.395**	**0.54**
Total iron	mg/L	0.3	**0.758**	7	**0.394**	**0.785**	**1.06**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.7-5 Concentrations of water quality measurement endpoints, Firebag River above the Suncor Firebag project (station FIR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.05	6	7.9	8.1	8.3
Total suspended solids	mg/L	-[1]	8	6	<3	3	8
Conductivity	µS/cm	-	171	6	160	171.5	261
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.0822**	6	0.009	**0.061**	**0.096**
Total nitrogen*	mg/L	1.0	0.631	6	0.5	0.7	0.8
Nitrate+nitrite	mg/L	1.0	0.071	6	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.1	6	8	12.5	16
Ions							
Sodium	mg/L	-	3.6	6	3	4	16
Calcium	mg/L	-	24.3	6	22.9	25.6	28.4
Magnesium	mg/L	-	6.43	6	6.4	7.3	8.7
Chloride	mg/L	230, 860[3]	0.5	6	<1	2	2
Sulphate	mg/L	100[4]	0.81	6	0.9	2.85	22.6
Total dissolved solids	mg/L	-	140	6	110	130	158
Total alkalinity	mg/L		89.3	6	81	92	114
Organic compounds							
Naphthenic acids	mg/L	-	0.059	6	<1	<1	<1
Selected metals							
Total aluminum	mg/L	0.1	0.0339	6	0.0154	0.0324	0.0369
Dissolved aluminum	mg/L	0.1[2]	0.00428	6	0.0031	0.0042	0.0066
Total arsenic	mg/L	0.005	0.0005	6	0.0001	0.0006	0.0006
Total boron	mg/L	1.2[5]	0.0122	6	0.0107	0.0132	0.0153
Total molybdenum	mg/L	0.073	0.0002	6	0.0002	0.0002	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0477	6	0.046	0.049	0.068
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0029**	6	**0.0029**	**0.004**	**0.009**
Total phosphorus	mg/L	0.05	**0.103**	6	**0.068**	**0.112**	**0.134**
Dissolved iron	mg/L	0.3[2]	**0.66**	6	0.281	**0.4305**	**0.886**
Total iron	mg/L	0.3	**0.99**	6	**0.525**	**0.751**	**1.39**
Total phenols	mg/L	0.004	**0.0042**	6	<0.001	0.004	**0.012**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.7-6 Concentrations of water quality measurement endpoints, McClelland Lake (station MCL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.46	7	8.1	8.5	8.7
Total suspended solids	mg/L	-[1]	5	7	<3	<3	5
Conductivity	µS/cm	-	238	7	224	240	253
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0033	7	0.002	0.004	0.013
Total nitrogen*	mg/L	1.0	**1.121**	7	0.6	1.0	**2.0**
Nitrate+nitrite	mg/L	1.0	0.071	7	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13	7	11	13	17
Ions							
Sodium	mg/L	-	4.5	7	4	4	6
Calcium	mg/L	-	23.8	7	19.3	21.3	25.8
Magnesium	mg/L	-	16.3	7	14.6	16.6	17.3
Chloride	mg/L	230, 860[3]	0.5	7	<1	<1	1
Sulphate	mg/L	100[4]	0.5	7	<0.5	1.3	4.3
Total dissolved solids	mg/L	-	155	7	80	155	167
Total alkalinity	mg/L		128	7	122	129	145
Organic compounds							
Naphthenic acids	mg/L	-	0.152	7	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	0.0162	7	0.003	0.017	0.026
Dissolved aluminum	mg/L	0.1[2]	0.00035	7	<0.001	0.0012	0.010
Total arsenic	mg/L	0.005	0.0002	7	0.00019	0.0002	0.0010
Total boron	mg/L	1.2[5]	0.0635	7	0.0513	0.0649	0.0670
Total molybdenum	mg/L	0.073	0.0000058	7	<0.000008	0.000030	0.0001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	4	<1.2	<1.2	2.4
Total strontium	mg/L	-	0.135	7	0.112	0.132	0.145
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total Kjeldahl Nitrogen	mg/L	0.2	**1.05**	7	**0.5**	**0.9**	**1.9**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

Table 5.7-7 Water quality guideline exceedances, Firebag River watershed, 2009.

Variable	Units	Guideline	FIR-1	FIR-2	MCL-1
Fall					
Sulphide	mg/L	0.002[1]	**0.0034**	**0.0029**	-
Total phosphorus	mg/L	0.05	-	**0.103**	-
Total dissolved phosphorus	mg/L	0.05[2]	-	**0.0822**	-
Dissolved iron	mg/L	0.3[2]	**0.501**	**0.66**	-
Total iron	mg/L	0.3	**0.758**	**0.99**	-
Total phenols	mg/L	0.004	-	**0.0042**	-
Total nitrogen	mg/L	1.0	-	-	**1.121**
Total Kjeldahl Nitrogen	mg/L	1.0[3]	-	-	**1.05**

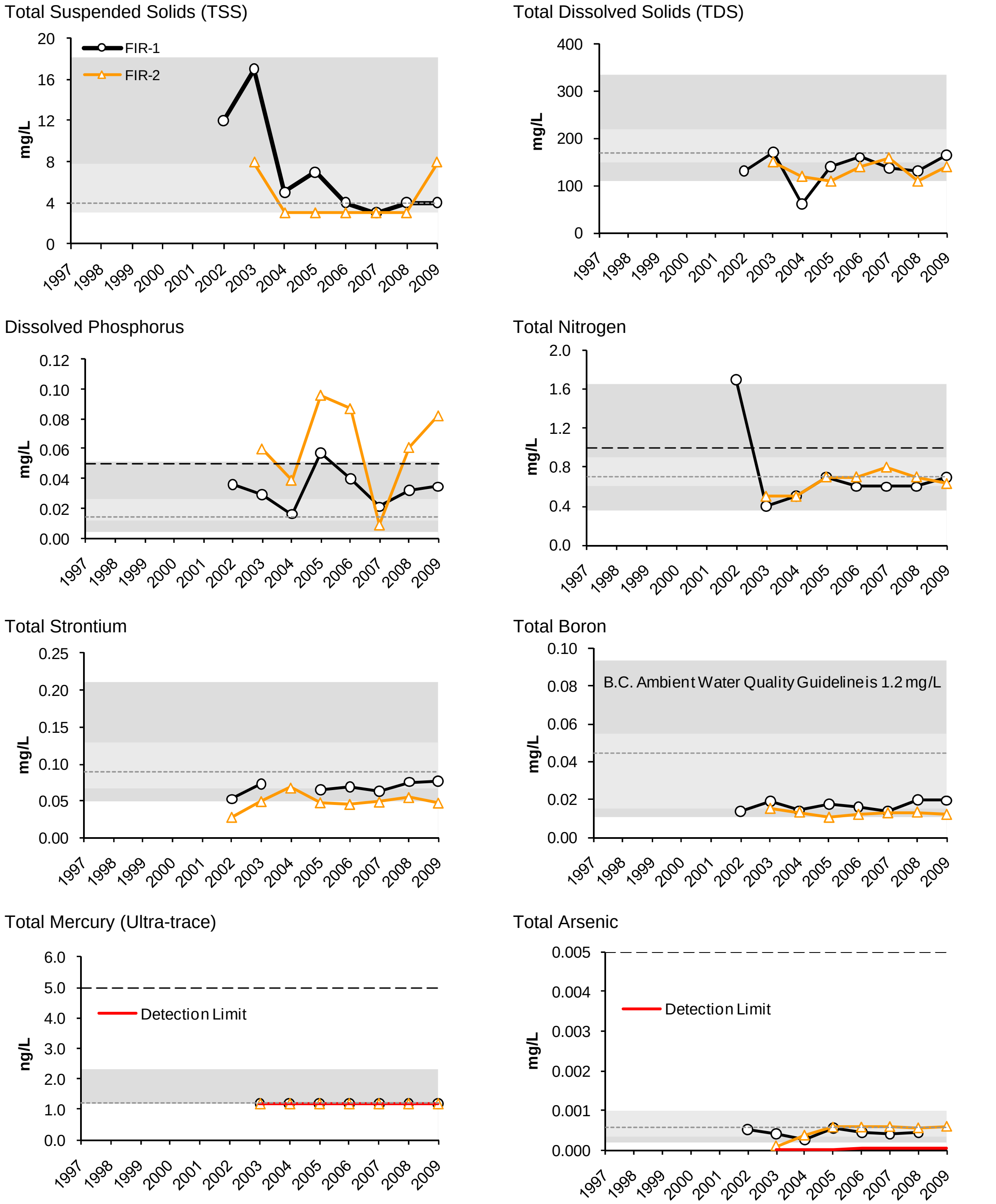
Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] Guideline is for total species (no guideline for dissolved species).

[3] Guideline is for total nitrogen.

Figure 5.7-5 Concentrations of selected water quality measurement endpoints in the Firebag River watershed (fall 2009) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

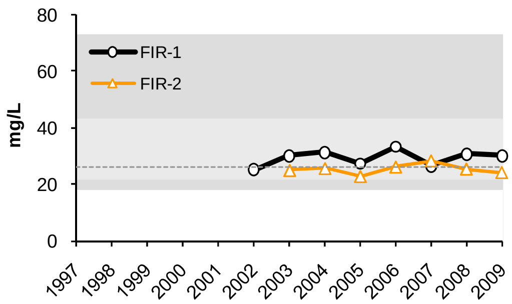
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

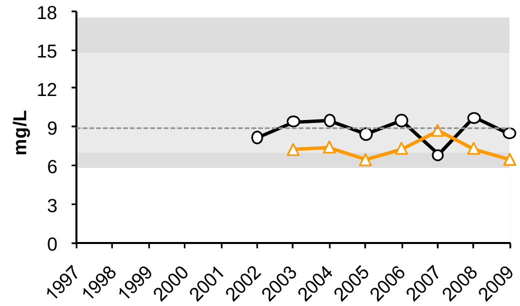
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-5 (Cont'd.)

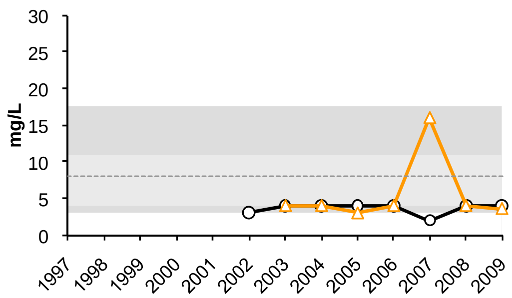
Calcium



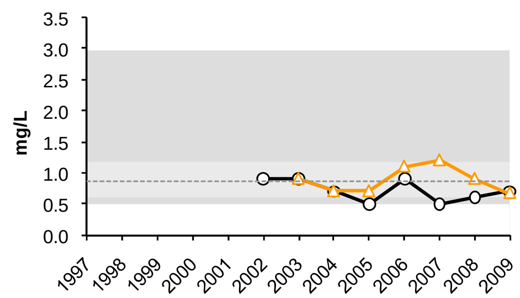
Magnesium



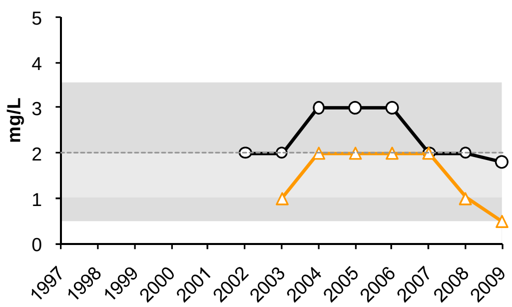
Sodium



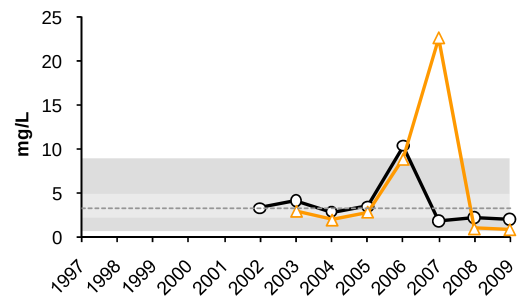
Potassium



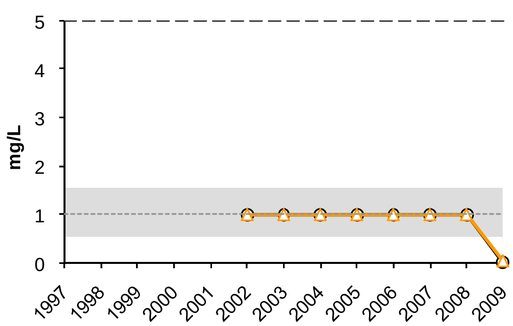
Chloride



Sulphate



Naphthenic Acids[1]



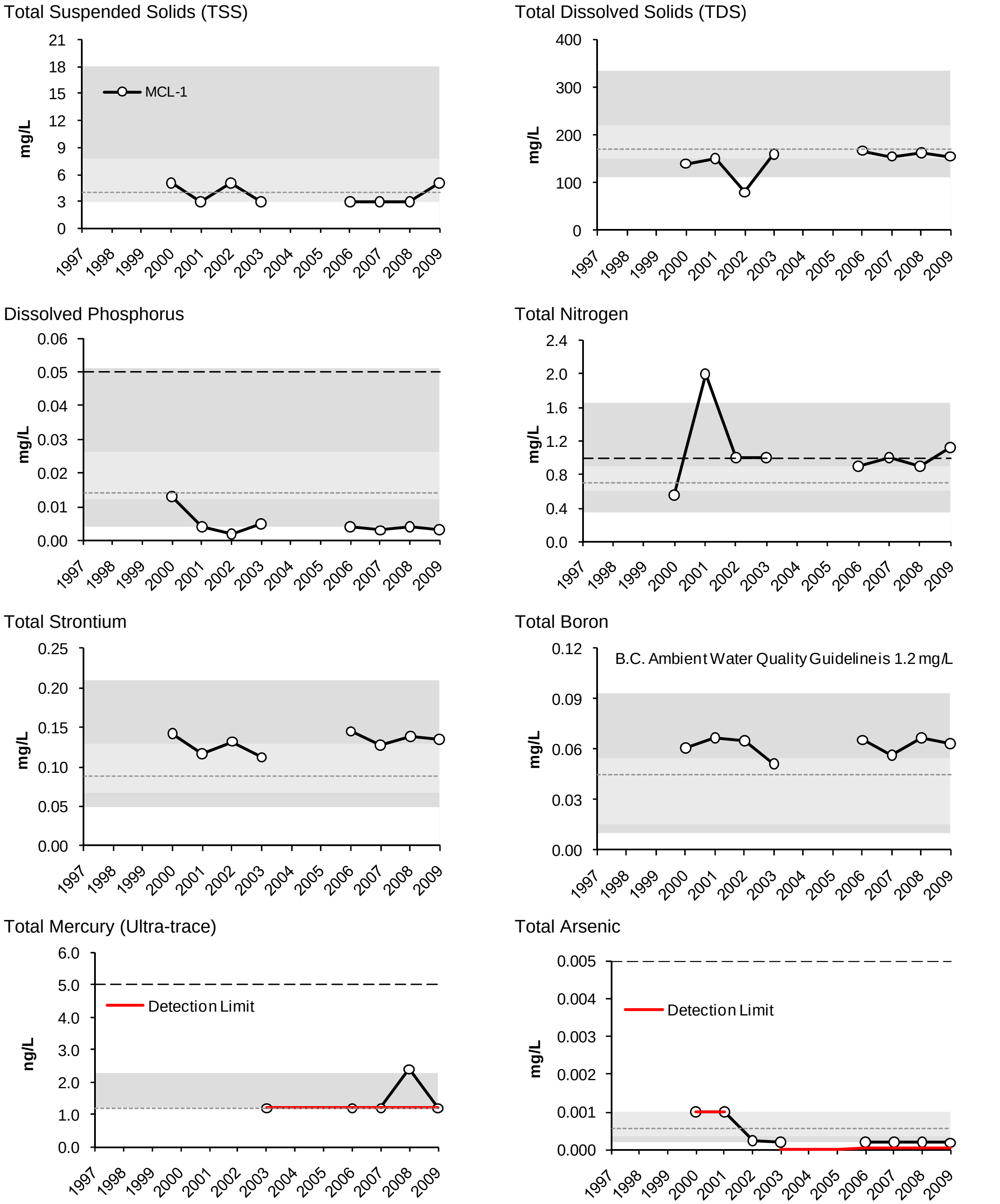
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-6 Concentrations of selected water quality measurement endpoints in McClelland Lake (fall 2009) relative to regional *baseline* fall concentrations.



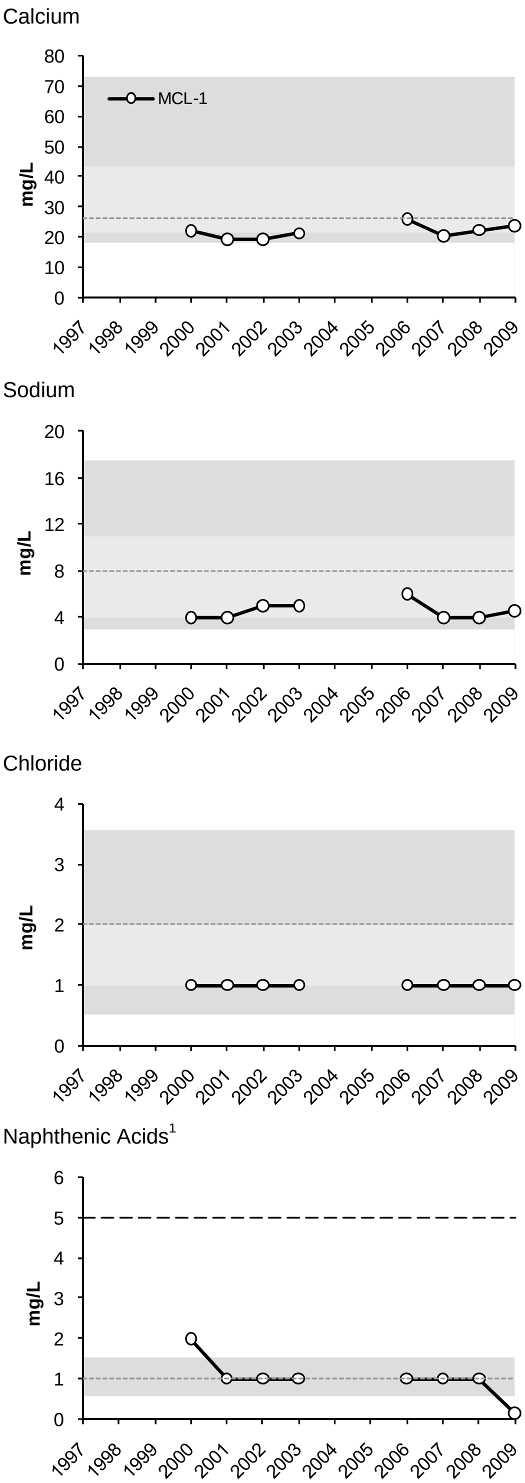
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-6 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-7 Piper diagram of fall ion concentrations in the Firebag River watershed, fall 2009.

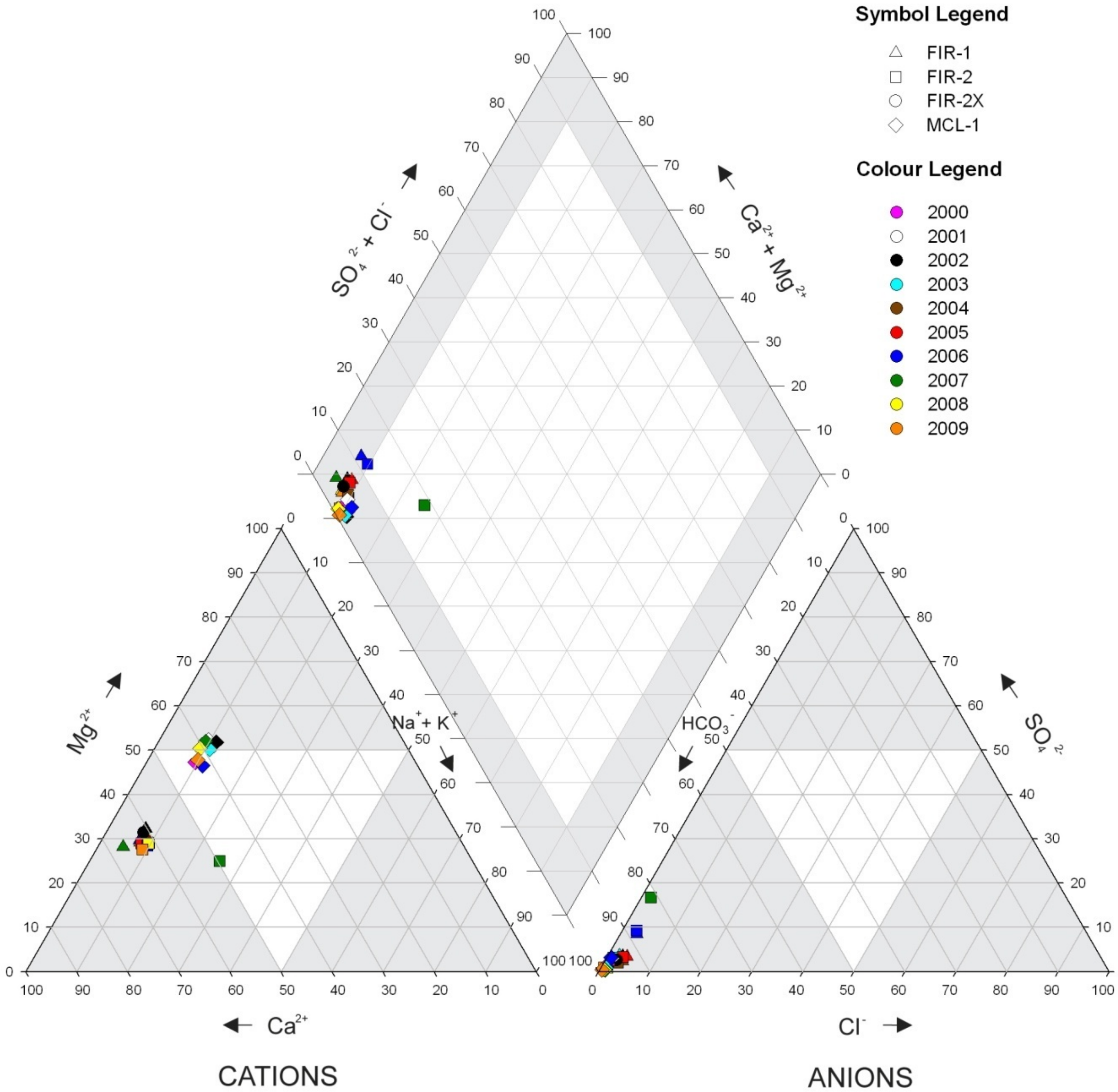


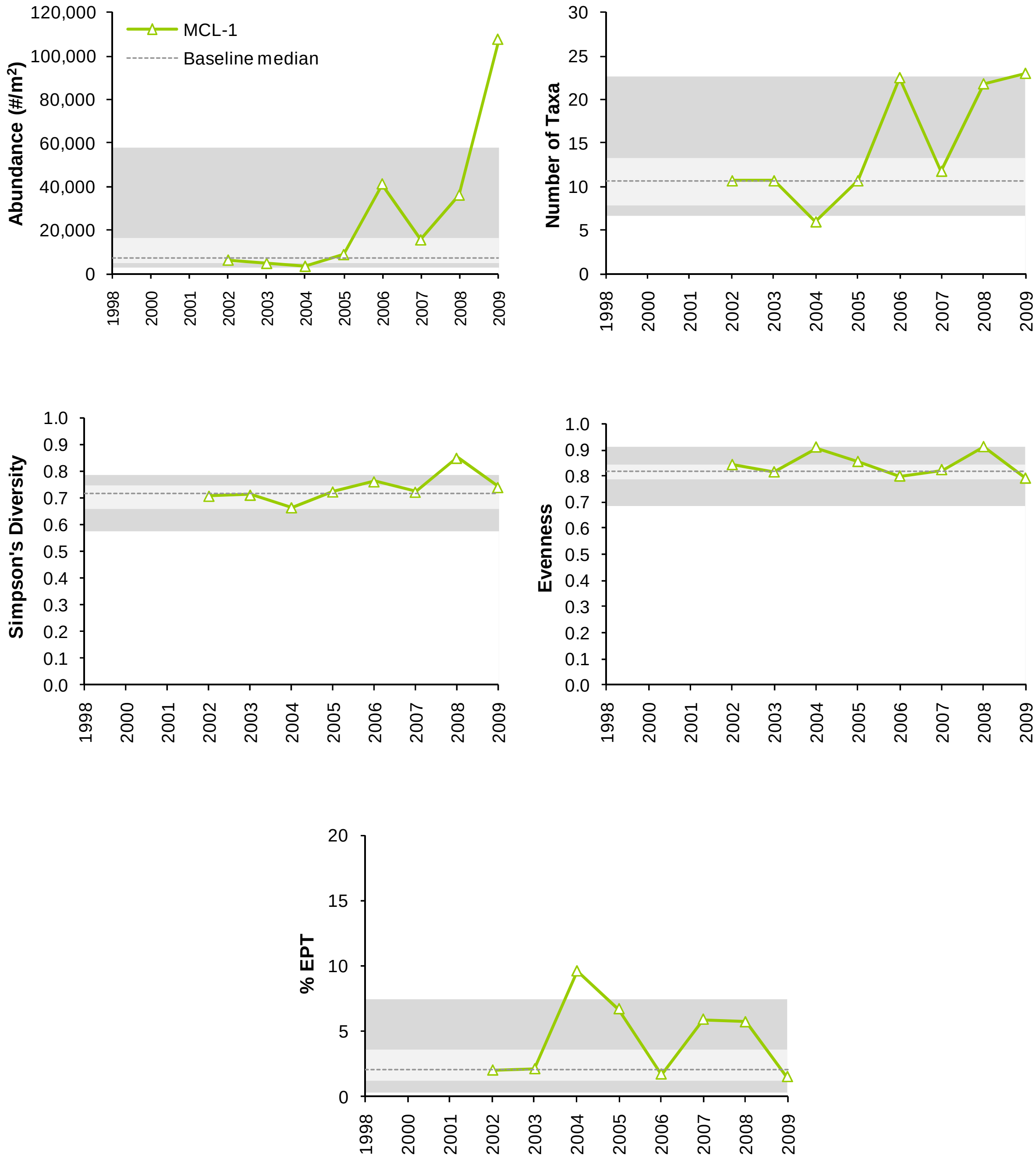
Table 5.7-8 Average habitat characteristics of benthic invertebrate sampling locations in McClelland Lake, fall 2009.

Variable	Units	McClelland Lake
Sample Date	-	Sept 13, 2009
Habitat	-	Depositional
Water Depth	m	2
Macrophyte Cover	%	55
Field Water Quality		
Dissolved Oxygen	mg/L	11
Conductivity	µS/cm	250
pH	-	9.1
Water Temperature	°C	17.1
Sediment Composition		
Sand	%	73
Silt	%	20
Clay	%	8
Total Organic Carbon	%	30

Table 5.7-9 Summary of major taxon abundances of benthic invertebrate community measurement endpoints in McClelland Lake.

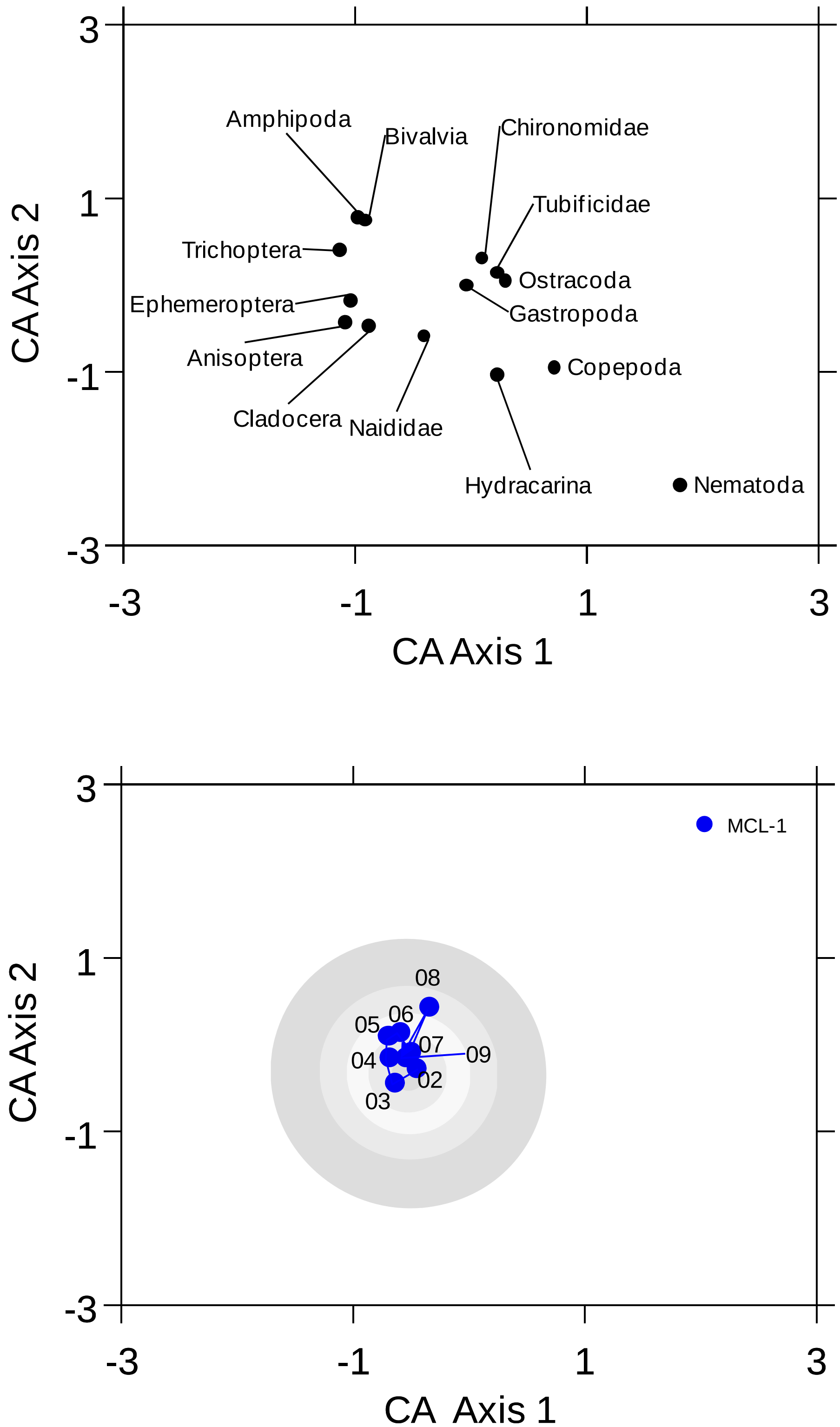
Taxon	Percent Major Taxa Enumerated in Each Year							
	McClelland Lake							
	2002	2003	2004	2005	2006	2007	2008	2009
Amphipoda	11	22	21	7	<1	4	3	4
Anisoptera			<1	1	<1		<1	<1
Bivalvia	2	8	6	9	<1	1	1	3
Ceratopogonidae				1	<1			
Chaoboridae								
Chironomidae	58	39	24	27	91	41	33	75
Cladocera	<1		2	2	1	7	14	<1
Copepoda			2	1	1	10	13	<1
Ephemeroptera	1	2	8	7	1	12	5	<1
Erpobdellidae	1	<1	<1				<1	
Gastropoda	<1	1		2	<1		<1	1
Glossiphoniidae							<1	
Hydracarina	1	<1		1			6	5
Lumbriculidae		<1	<1	<1		8	<1	<1
Naididae	14	13	7	12	2	12	17	3
Nematoda	1	<1	4	<1	1		1	<1
Ostracoda	10	8	15	29	1	3	3	5
Trichoptera	1		3	1	<1	2	1	<1
Tubificidae		6	<1		1		<1	1
Zygoptera		<1			1			
Benthic Invertebrate Community Measurement Endpoints								
Total Abundance (No./m^2)	6,352	4,823	3,504	8,874	40,526	15,591	36,071	107,273
Richness	11	11	6	11	23	12	22	23
Simpson's Diversity	0.71	0.71	0.66	0.72	0.76	0.72	0.85	0.74
Evenness	0.84	0.81	0.91	0.85	0.76	0.82	0.91	0.79
% EPT	2	2	10	7	2	6	5	2

Figure 5.7-8 Variation in benthic invertebrate community measurement endpoints in McClelland Lake.



Note: Regional *baseline* values reflect pooled results for all *baseline* lakes sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.7-9 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in McClelland Lake (MCL-1).



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* data for lakes in the RAMP FSA.

Table 5.7-10 Concentrations of sediment quality measurement endpoints, McClelland Lake (station MCL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	2	5	5.0	39.0	49
Silt	%	-	15	5	14.0	23.0	37
Sand	%	-	83	5	14	32	81
Total organic carbon	%	-	30.5	5	25.0	27.6	30.0
Total hydrocarbons							
BTEX	mg/kg	-	<150	3	<5	<5	<100
Fraction 1 (C6-C10)	mg/kg	30[1]	<150	3	<5	<5	<100
Fraction 2 (C10-C16)	mg/kg	150[1]	240	3	<5	<5	65
Fraction 3 (C16-C34)	mg/kg	300[1]	**794**	3	**360**	**1200**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	586	3	38	580	2400
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.011	2	0.011	0.018	0.024
Retene	mg/kg	-	0.071	5	0.019	0.119	0.161
Total dibenzothiophenes	mg/kg	-	0.055	5	0.025	0.029	0.083
Total PAHs	mg/kg	-	0.567	5	0.363	0.564	0.751
Total Parent PAHs	mg/kg	-	0.060	5	0.053	0.068	0.107
Total Alkylated PAHs	mg/kg	-	0.506	5	0.310	0.499	0.674
Predicted PAH toxicity[3]	H.I.	-	0.097	5	0.039	0.151	0.368
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

5.8 ELLS RIVER WATERSHED

Table 5.8-1 Summary of results for Ells River watershed.

Ells River Watershed	Summary of 2009 Conditions	
Climate and Hydrology		
Criteria	**S14A** at Canadian Natural bridge	
Mean open-water season discharge	○	
Mean winter discharge	○	
Annual maximum daily discharge	○	
Minimum open-water season discharge	○	
Water Quality		
Criteria	**ELR-1** at the mouth	**ELR-2** upstream of Canadian Natural Lease 7
Water Quality Index	○	○
Benthic Invertebrate Communities and Sediment Quality		
No Benthic Invertebrate Communities and Sediment Quality component activities conducted in 2009		
Fish Populations		
No Fish Population component activities conducted in 2009		

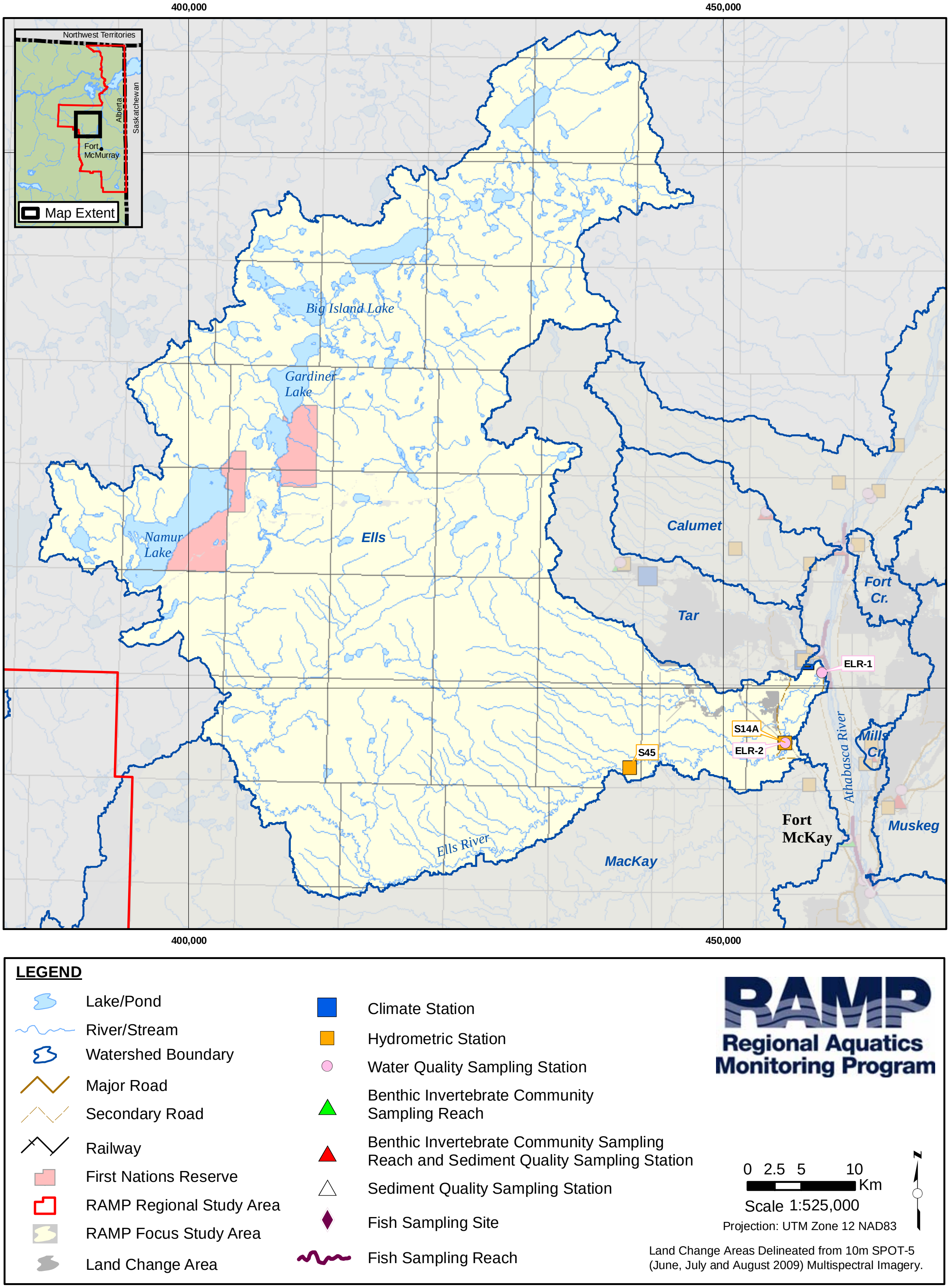
Legend and Notes

○ Negligible-Low
○ Moderate
○ High
baseline
test

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Figure 5.8-1 Ells River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K08_Ells_20100415.mxd

Figure 5.8-2 Representative monitoring stations of the Ells River, fall 2009.

Water Quality Station ELR-1: Right Downstream Bank

Water Quality Station ELR-1: Right Downstream Bank

Water Quality Station ELR-2: Left Downstream Bank

Water Quality Station ELR-2: Left Downstream Bank

5.8.1 Summary of 2009 Conditions

Approximately 0.4% (927 ha) of the Ells River watershed had undergone land change as of 2009 from focal projects (Table 2.4-2); much of this land change is located in the Joslyn Creek drainage. The designations of specific areas of the watershed are as follows:

1. The Ells River watershed downstream of the confluence of Joslyn Creek with the Ells River (Figure 5.8-1) is designated as *test*.

2. The remainder of the watershed is designated as *baseline*.

Table 5.8-1 is a summary of the 2009 assessment for the Ells River watershed, while Figure 5.8-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.8-2 contains fall 2009 photos of a number of monitoring stations in the watershed.

Hydrology The mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to change by less than 0.003% from the estimated *baseline* hydrograph. Watershed-level differences in the values of hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low**.

Water Quality Water quality in fall 2009 in the Ells River was consistent with previous years and had **Negligible-Low** differences from regional water quality *baseline* conditions.

5.8.2 Hydrologic Conditions

2009 Hydrologic Conditions: Station S14A, Ells River above Joslyn Creek 2009 was the first year data was collected for the entire year at Station S14A. In the past, flows have been measured for various times of the year at this station for a relatively short period of time (since 2001), and comparison of 2009 hydrologic conditions to historical values is therefore less robust than for a number of the other hydrology stations in the RAMP FSA. The annual runoff volume measured at Station S14A was 257.3 million m^3 in 2009. Flows were approximately 1 m^3/s from January until mid-March (Figure 5.8-3), and did not increase until snowmelt in April. The freshet peak of 32 m^3/s occurred on May 12 and the annual maximum daily flow of 51 m^3/s occurred on July 10 following a rainfall event in late-June. This is the highest open-water daily flow (May to October) and the second-highest flow (after the freshet flow of 62 m^3/s in April 2005) recorded at this station. Flows after July 10 generally decreased until October and then remained at 2 to 3 m^3/s until mid-December. By the end of December, flows had dropped to the lowest-ever recorded daily value at this station (0.28 m^3/s).

Differences between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance for 2009 is based on the recorded flows at Station S14A while focal projects located within the Ells River watershed are located downstream of this station. The hydrology station could not be placed downstream of focal projects because of the influence of the Athabasca River given the shallow gradient of the Ells River at the mouth to the Athabasca River. The analysis is therefore conservative with relative impacts expected to be lower than estimated when considered in relation to the Ells River watershed upstream of the mouth. The estimated water balance is provided in Table 5.8-2 and described below:

1. The closed-circuited land area in the Ells watershed was estimated at 1.61 km^2 (Table 5.8-2). The loss of flow to the Ells River that would have otherwise occurred from this land area is 0.17 million m^3.

2. The land area not closed-circuited as of 2009 was estimated at 7.7 km^2 (Table 5.8-2). The increase in flow to the Ells River that would have otherwise not occurred from this land area is estimated at 0.16 million m^3.

3. Total E&P reported 2,233 m^3 of water released from the Joslyn SAGD runoff pond into the bog area downstream.

The estimated cumulative effect of land change and water releases is a loss of flow of 7,000 m^3 at Station S14 in 2009. The estimated *baseline* hydrograph is presented in Figure 5.8-3.

The mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are estimated to change by less than 0.003% from the estimated *baseline* hydrograph

(Table 5.8-3). Watershed-level differences in the values of hydrologic measurement endpoints between the observed *test* hydrologic conditions and the estimated *baseline* hydrologic conditions are assessed as **Negligible-Low** (Table 5.8-1).

5.8.3 Water Quality

Water quality samples were taken in fall 2009 from:

- the Ells River near its mouth (*test* station ELR-1, established in 1998, sampled annually since 2002); and
- the Ells River upstream of Joslyn Creek (*baseline* station ELR-2, established in 2000, sampled annually since 2004).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of all water quality measurement endpoints at *test* station ELR-1 (Table 5.8-4) and *baseline* station ELR-2 (Table 5.8-5) were within historical ranges with the exception of chloride (below its historical minimum concentration) and calcium (just above its historical maximum) at *baseline* station ELR-2. Concentrations of all selected water quality measurement endpoints were within the 5^{th} to 95^{th} percentile of regional water quality *baseline* concentrations at both stations (Figure 5.8-4).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines The Concentration of total aluminum at both *test* station ELR-1 and *baseline* station ELR-2 exceeded the water quality guideline in fall 2009 (Table 5.8-4, Table 5.8-5).

Other Water Quality Guideline Exceedances The concentrations of total iron, total phenols, and sulphide at both *test* station ELR-1 and *baseline* station ELR-2 and dissolved iron at *test* station ELR-1 exceeded relevant water quality guidelines in fall 2009 (Table 5.8-4, Table 5.8-5).

Ion Balance The ionic composition of water sampled in fall 2009 at both *test* station ELR-1 and *baseline* station ELR-2 was dominated by calcium and bicarbonate (Figure 5.8-5), similar to the ionic composition of both stations for all previously-sampled years with the exception of *baseline* station ELR-2 in fall 2007 (Figure 5.8-5).

Trend Analysis There have been no significant trends in water quality measurement endpoints in the Ells River watershed over the RAMP sampling period ($\alpha = 0.05$).

Water Quality Index The WQI value was 100 for both *test* station ELR-1 and *baseline* station ELR-2, indicating **Negligible-Low** differences in water quality from regional water quality *baseline* conditions at both stations.

Summary Water quality in fall 2009 at both *test* station ELR-1 and *baseline* station ELR-2 was consistent with previous years and had **Negligible-Low** differences from regional water quality *baseline* conditions.

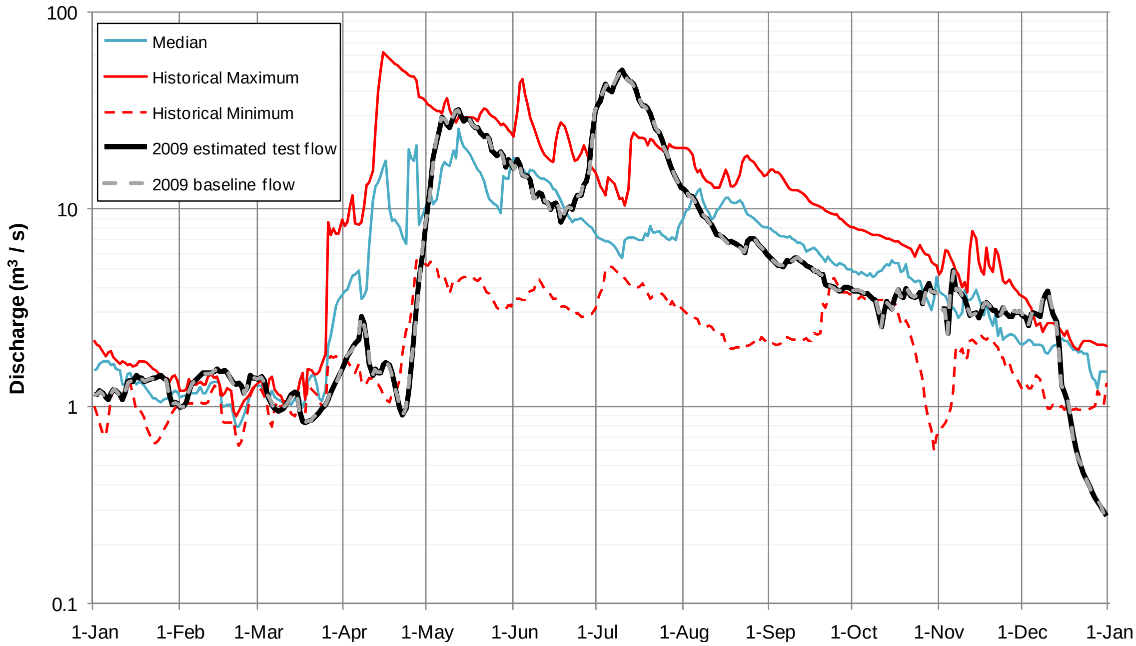
5.8.4 Benthic Invertebrate Communities and Sediment Quality

There were no Benthic Invertebrate Communities and Sediment Quality component activities conducted in the Ells River watershed in 2009.

5.8.5 Fish Populations

There were no Fish Population component activities conducted in the Ells River watershed in 2009.

Figure 5.8-3 The observed (*test*) hydrograph for the Ells River in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: The observed 2009 hydrograph is based on Station S14A, Ells River above Joslyn Creek, 2009 provisional data. The upstream drainage area is 2,450 km^2. Historical values are calculated for the period from 2001 to 2008 during the open-water period, and from 2004 to 2008 for the remaining (winter) period, although many short periods of missing data exist. There are generally insufficient data to calculate upper and lower quartile values for this station.

Table 5.8-2 Estimated water balance at Station S14A, Ells River above Joslyn Creek, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**257.33**	**Observed discharge at Station S14A, Ells River above Joslyn Creek**
Closed-circuited area water loss from the observed *test* hydrograph	-0.17	Estimated 1.6 km^2 of the Ells River watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.16	Estimated 7.7 km^2 of the Ells River watershed with land change from focal projects as of 2009 that is not closed-circuited (Table 2.4-1)
Water withdrawals from the Ells River watershed from focal projects	0	0.03 million m^3 water withdrawn from a surficial groundwater aquifer; zero withdrawal assumed from surface water sources.
Water releases into the Ells River watershed from focal projects	+0.002	Amount pumped from Joslyn SAGD industrial runoff pond into the area downstream of pond
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Ells River not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**257.33**	**Estimated *baseline* discharge at Station S14A, Ells River above Joslyn Creek**
Incremental flow (change in total discharge)	-0.01	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**0.00%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on Station S14A, Ells River above Joslyn Creek, 2009 provisional data.

Table 5.8-3 Calculated change in hydrologic measurement endpoints for the Ells River watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	14.44	14.44	0.00%
Mean winter discharge	1.70	1.70	0.00%
Annual maximum daily discharge	50.98	50.98	0.00%
Open-water period minimum daily discharge	2.52	2.52	0.00%

Note: Based on Station S14A, Ells River above Joslyn Creek, 2009 provisional data.

Table 5.8-4 Concentrations of water quality measurement endpoints, mouth of Ells River (station ELR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	8	7.8	8.2	8.4
Total suspended solids	mg/L	-[1]	3	8	3	6	16
Conductivity	µS/cm	-	223	8	175	232.5	272
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0198	8	0.003	0.008	0.02
Total nitrogen*	mg/L	1.0	0.971	8	0.3	0.6	**1.1**
Nitrate+nitrite	mg/L	1.0	0.071	8	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	15.8	8	11	13.5	20
Ions							
Sodium	mg/L	-	11.2	8	8	11	18
Calcium	mg/L	-	24.9	8	21.6	24.55	30.4
Magnesium	mg/L	-	7.66	8	6.5	7.55	9.1
Chloride	mg/L	230, 860[3]	1.46	8	<1	2	4
Sulphate	mg/L	100[4]	14.8	8	10.5	16.55	27.9
Total dissolved solids	mg/L	-	176	9	110	163	220
Total alkalinity	mg/L		95.9	8	76	98	117
Organic compounds							
Naphthenic acids	mg/L	-	0.204	8	<1	<1	3
Selected metals							
Total aluminum	mg/L	0.1	**0.194**	8	0.06	**0.294**	**0.673**
Dissolved aluminum	mg/L	0.1[2]	0.0059	8	0.0077	0.01885	0.078
Total arsenic	mg/L	0.005	0.0011	8	<0.001	0.0008	0.0012
Total boron	mg/L	1.2[5]	0.0607	8	0.0410	0.6355	0.0834
Total molybdenum	mg/L	0.073	0.0007	8	0.0006	0.0007	0.0008
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.125	8	0.095	0.129	0.14
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0057**	8	**<0.003**	**0.006**	**0.135**
Total iron	mg/L	0.3	**0.728**	8	**0.45**	**0.606**	**1.14**
Dissolved iron	mg/L	0.3[2]	**0.389**	8	0.162	0.231	**0.404**
Total phenols	mg/L	0.004	**0.0045**	8	<0.001	0.004	**0.011**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN); Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.8-5 Concentrations of water quality measurement endpoints, upper Ells River (station ELR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.15	5	7.7	8.1	8.3
Total suspended solids	mg/L	-[1]	3	5	<3	4	8
Conductivity	µS/cm	-	206	5	164	185	219
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0116	5	0.004	0.017	0.061
Total nitrogen*	mg/L	1.0	0.711	5	0.6	0.7	1.0
Nitrate+nitrite	mg/L	1.0	0.071	5	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	14.5	5	10	14	20
Ions							
Sodium	mg/L	-	10.3	5	3	8	13
Calcium	mg/L	-	25.6	5	20.5	24.5	24.9
Magnesium	mg/L	-	7.53	5	6.2	7	7.8
Chloride	mg/L	230, 860[3]	0.87	5	2	2	3
Sulphate	mg/L	100[4]	13.6	5	2.2	10.8	18.9
Total dissolved solids	mg/L	-	164	5	110	130	190
Total alkalinity	mg/L		90.5	5	73	91	110
Organic compounds							
Naphthenic acids	mg/L	-	0.119	5	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	**0.104**	5	0.0515	**0.271**	**0.735**
Dissolved aluminum	mg/L	0.1[2]	0.00424	5	<0.001	0.0153	0.0255
Total arsenic	mg/L	0.005	0.00082	5	0.0006	0.0009	0.0011
Total boron	mg/L	1.2[5]	0.0527	5	0.0405	0.0591	0.0836
Total molybdenum	mg/L	0.073	0.0006	5	0.0006	0.0007	0.0008
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	5	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.106	5	0.094	0.11	0.137
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Total iron	mg/L	0.3	**0.413**	5	0.26	**0.48**	**0.922**
Sulphide	mg/L	0.002[7]	**0.0034**	5	**0.003**	**0.006**	**0.014**
Total phenols	mg/L	0.004	**0.0042**	5	<0.001	0.004	**0.007**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

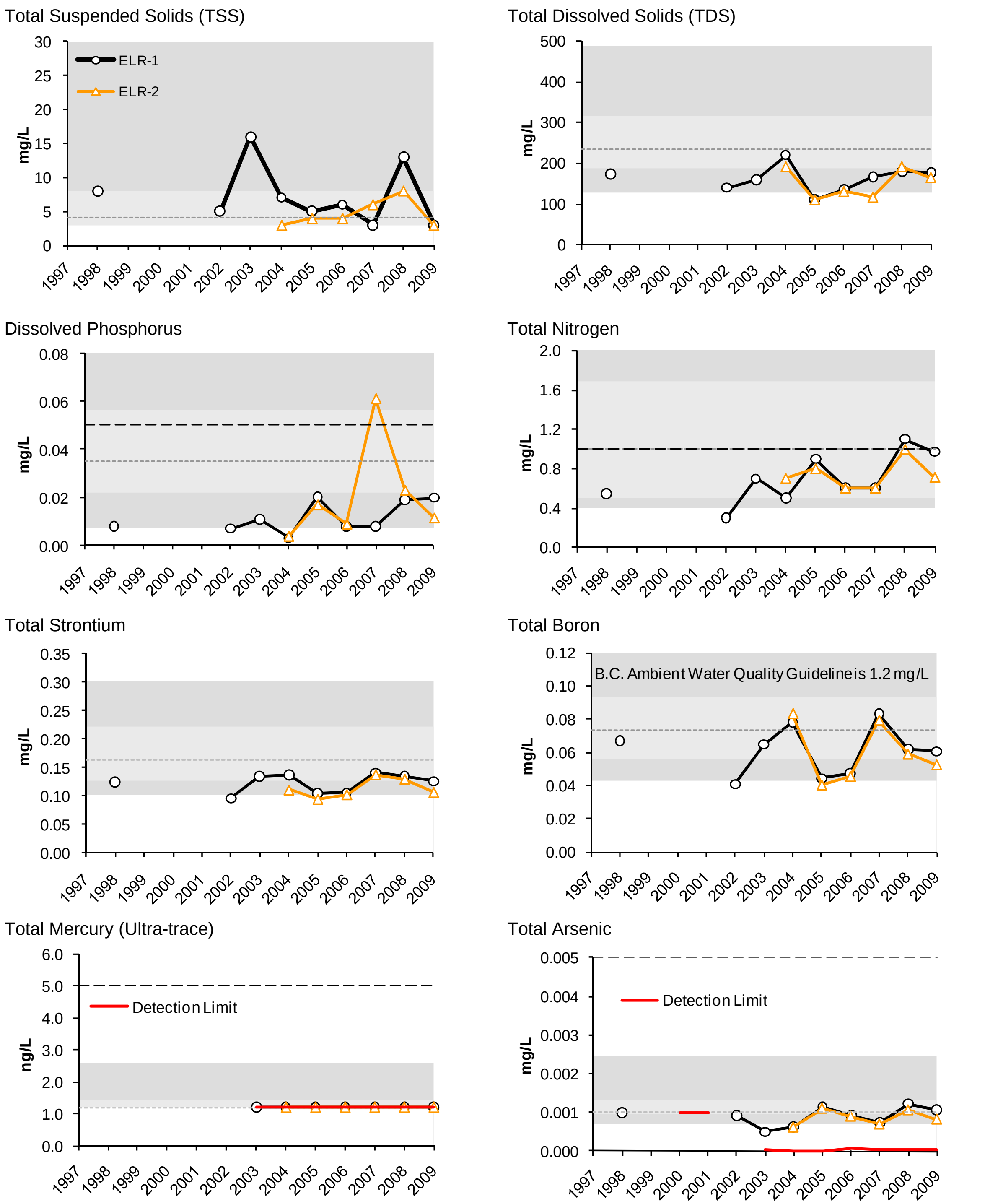
4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Figure 5.8-4 Selected water quality measurement endpoints in the Ells River (fall data) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

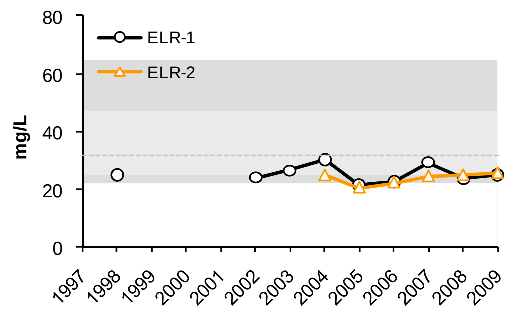
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

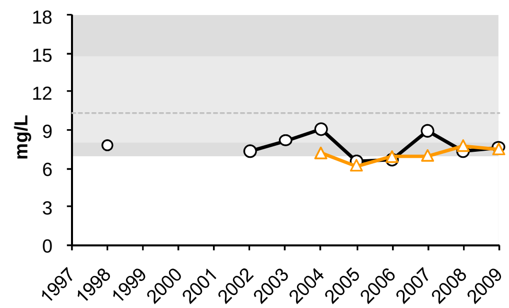
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.8-4 (Cont'd.)

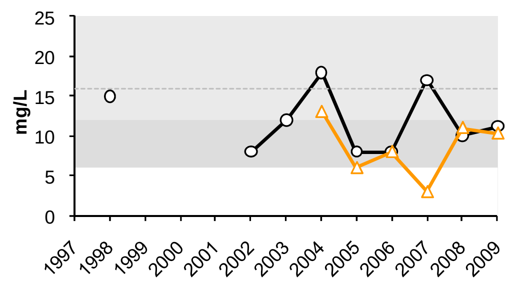
Calcium



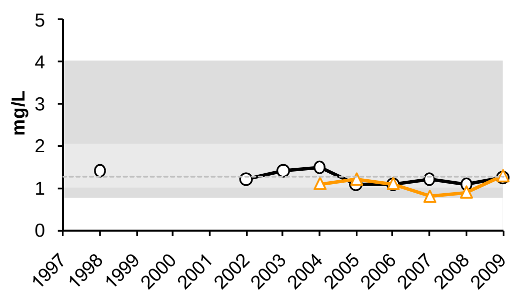
Magnesium



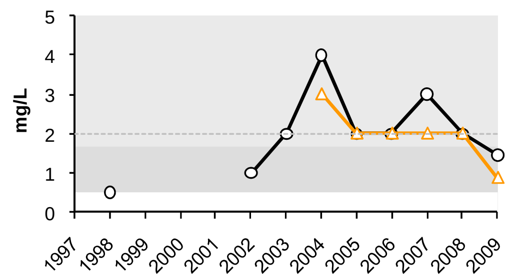
Sodium



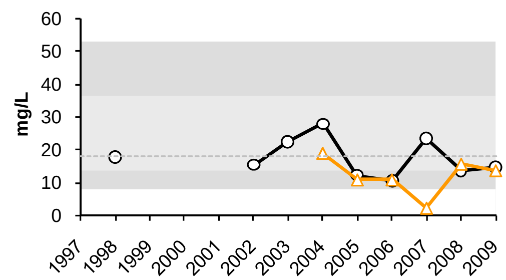
Potassium



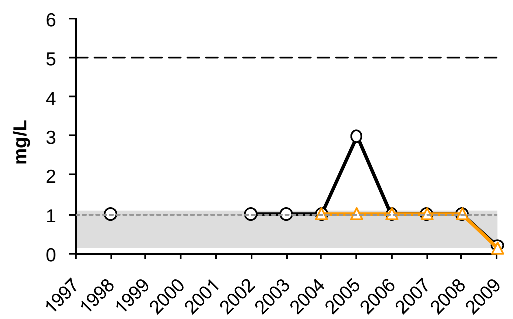
Chloride



Sulphate



Naphthenic Acids[1]



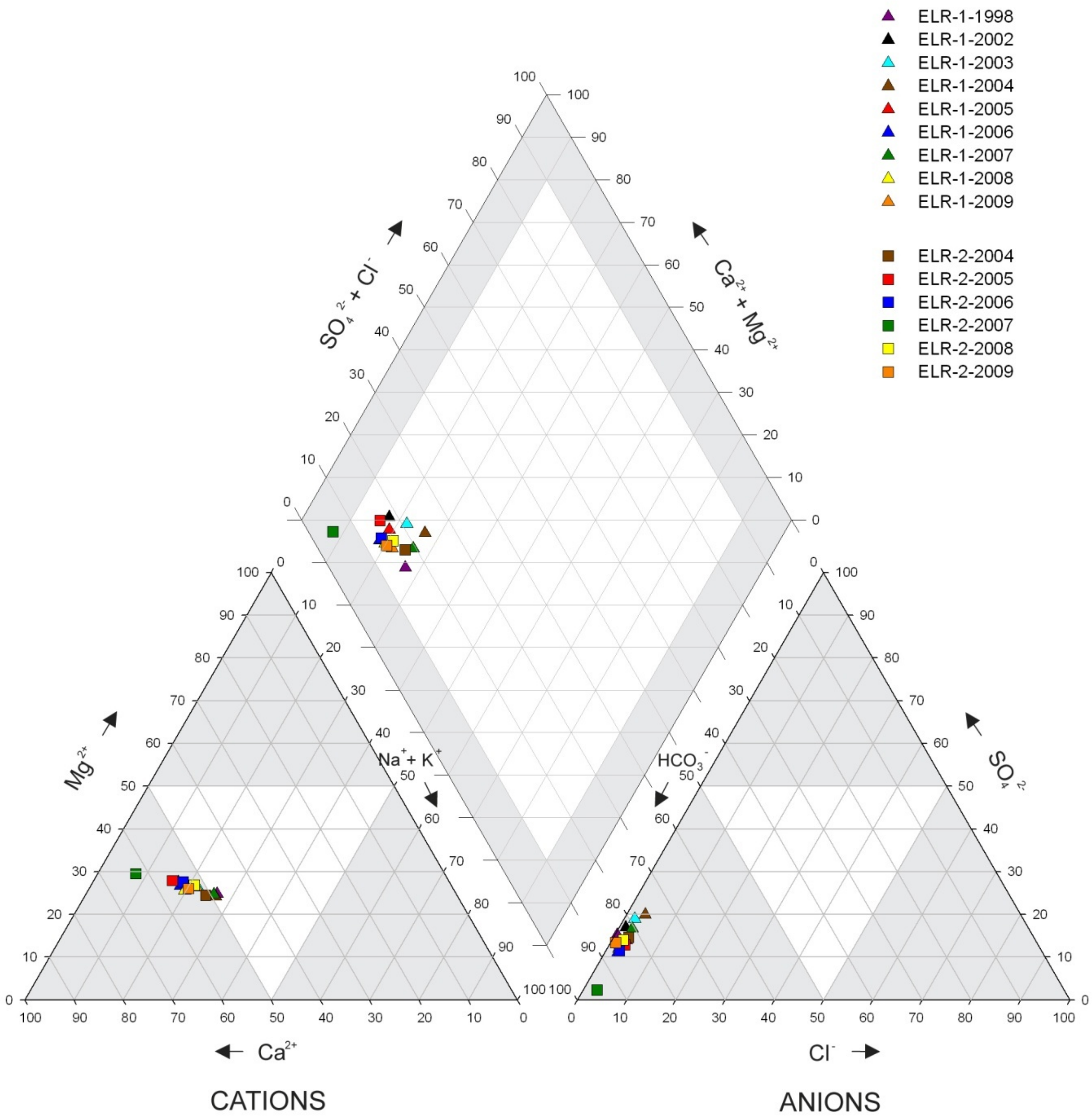
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.8-5 Piper diagram of fall ion concentrations in the Ells River watershed.



5.9 CLEARWATER-CHRISTINA RIVER WATERSHEDS

Table 5.9-1 Summary of results for Clearwater-Christina River watersheds.

<table>
<tr><th rowspan="2">Clearwater-Christina River Watershed</th><th colspan="6">Summary of 2009 Conditions</th></tr>
<tr><th colspan="4">Clearwater River</th><th colspan="2">Christina River</th></tr>
<tr><th colspan="7">Climate and Hydrology</th></tr>
<tr><td>Criteria</td><td colspan="2">S42/07CD005
Clearwater River above Christina River</td><td colspan="2">07CD001
Clearwater River at Draper</td><td></td><td>Christina River at the mouth (estimated)</td></tr>
<tr><td>Mean open-water season discharge</td><td colspan="2">not measured</td><td colspan="2">not measured</td><td></td><td>🟡</td></tr>
<tr><td>Mean winter discharge</td><td colspan="2">not measured</td><td colspan="2">not measured</td><td></td><td>not measured</td></tr>
<tr><td>Annual maximum daily discharge</td><td colspan="2">not measured</td><td colspan="2">not measured</td><td></td><td>🟡</td></tr>
<tr><td>Minimum open-water season discharge</td><td colspan="2">not measured</td><td colspan="2">not measured</td><td></td><td>🟡</td></tr>
<tr><th colspan="7">Water Quality</th></tr>
<tr><td>Criteria</td><td colspan="2">CLR-1
upstream of Fort McMurray</td><td colspan="2">CLR-2
upstream of Christina River</td><td>CHR-1
at the mouth</td><td>CHR-2
upstream of Janvier</td></tr>
<tr><td>Water Quality</td><td colspan="2">🟡</td><td colspan="2">🟡</td><td>🟠</td><td>🟡</td></tr>
<tr><th colspan="7">Benthic Invertebrate Communities and Sediment Quality</th></tr>
<tr><td>Criteria</td><td colspan="4">no reaches sampled</td><td>CHR-D-1
lower reach</td><td>CHR-D-2
upper reach</td></tr>
<tr><td>Benthic Invertebrate Communities</td><td colspan="2"></td><td colspan="2"></td><td>🟡</td><td>n/a</td></tr>
<tr><td>Sediment Quality</td><td colspan="2"></td><td colspan="2"></td><td>🟡</td><td>🟡</td></tr>
<tr><th colspan="7">Fish Populations</th></tr>
<tr><td>Criteria</td><td colspan="2">CR-3
upstream of Fort McMurray</td><td colspan="2">CR1 and CR2
upstream of Christina River</td><td colspan="2">no reaches sampled</td></tr>
<tr><td rowspan="2">Human Health</td><td>Sp.[1]</td><td>Size[2]</td><td>Sub.[3]</td><td>Gen.[3]</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>NRPK</td><td>all sizes</td><td>🟡</td><td>🟡</td></tr>
<tr><td>Fish Palatability</td><td colspan="4">NRPK 🟡</td><td colspan="2"></td></tr>
<tr><td>Fish Health</td><td colspan="4">NRPK 🟡</td><td colspan="2"></td></tr>
</table>

Legend and Notes

🟡 Negligible-Low	*baseline*
🟠 Moderate	*test*
🟤 High	

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

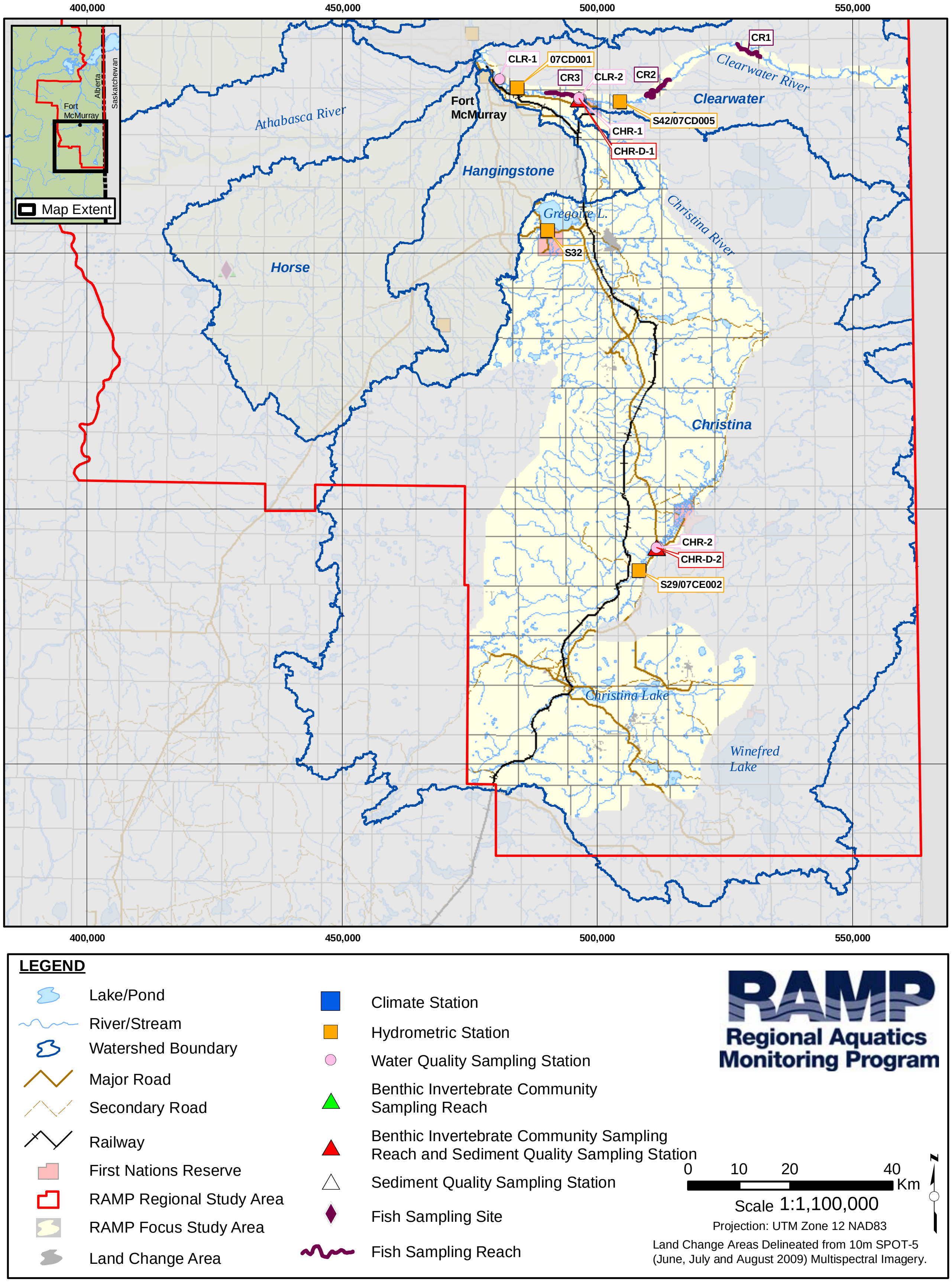
Fish Populations: Uses various USEPA and Health Canada criteria for risks to human health, fish health, and tainting from fish tissue concentrations of various substances, see Section 3.4.7.3 for a detailed description of the classification methodology.

[1] Species (Sp.): NRPK=northern pike

[2] The classification of risk to human health was Negligible-Low below the size class specified

[3] Sub. Refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada (see Section 3.4.7.3)

Figure 5.9-1 Clearwater-Christina River watersheds.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K09_ChrisClear_20100415.mxd

Figure 5.9-2 Representative monitoring stations of the Clearwater-Christina River watersheds, fall 2009.

Water Quality Station CHR-1 (Christina River): Right Downstream Bank

Water Quality Station CLR-1 (Clearwater River): Right Downstream Bank, cross-channel

Water Quality Station CHR-2 (Christina River): Centre of Channel, facing downstream

Water Quality Station CLR-2 (Clearwater River): Left Downstream Bank

5.9.1 Summary of 2009 Conditions

As of 2009, approximately 0.3% (4,327 ha) of the Christina River watershed had undergone land change from focal projects and other oil sands developments (Table 2.4-2). None of the area of the Clearwater River watershed within the RAMP FSA contains any focal projects or other oil sands developments. The designations of specific areas of the Clearwater-Christina River watersheds are as follows:

1. The Christina River watershed downstream of the Nexen Long Lake Project is designated as *test*.

2. The remainder of the Christina River watershed is designated as *baseline* but monitoring data from this part of the Christina River watershed were not used in the calculation of regional *baseline* ranges for water quality, benthic invertebrate communities, or sediment quality because of the existence of a number of other oil sands developments in the watershed upstream of the Nexen Long Lake Project.

3. The Clearwater River downstream of the confluence with the Christina River is designated as *test*.

4. The remainder of the Clearwater River upstream of the confluence with the Christina River is designated as *baseline*.

Table 5.9-1 is a summary of the 2009 assessment for the Clearwater-Christina River system, while Figure 5.9-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.9-2 contains fall 2009 photos of a number of monitoring stations in the watersheds.

Hydrology Based on the estimated flow for the Christina River at the mouth, the effects of both focal projects and other oil sands developments were estimated to increase the discharge by 0.01% from *baseline* values that would have occurred in the absence of these activities. The differences in the Christina River watershed between the observed *test* hydrograph and the estimated *baseline* hydrograph are assessed as **Negligible-Low** for all hydrologic measurement endpoints.

Water Quality As of 2009, water quality at stations in the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2) showed **Negligible-Low** differences from regional *baseline* conditions. Water quality at the *test* station (CHR-1) in the Christina River showed a **Moderate** difference from regional *baseline* conditions, resulting from higher concentrations of total nitrogen, total boron, and several ions exceeding historical values and regional *baseline* ranges and **Negligible-Low** differences at the *baseline* station (CHR-2) from regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Differences in time trends of measurement endpoints for benthic invertebrate communities between *baseline* reach CHR-D-2 and *test* reach CHR-D-1 were either insignificant, significant but weaker than the background “noise” component of these differences, or significant but not consistent with a negative impact at *test* reach CHR-D-1. In addition, values of most benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Christina River watershed from regional *baseline* conditions of benthic invertebrate communities in depositional habitats. Sediment quality conditions in fall 2009 at both Christina River stations indicated **Negligible-Low** differences from regional *baseline* conditions. Sediment quality at *test* station CHR-D-1 and *baseline* station CHR-D-2 was generally consistent with that of previous years, with concentrations of sediment quality measurement endpoints largely within previously measured and regional *baseline* ranges.

Fish Populations The 2009 Clearwater River inventory results suggested that the relative abundance of fish species is within the natural variability established during historical fish sampling years (2003 to 2008). Species richness in the spring of 2009 was lower than in 2008, but within the range of natural variability. Statistically significant differences were observed between years for length-frequency distributions and condition of KIR species with no significant increasing or decreasing trends over time.

Mean mercury concentrations across all size classes in northern pike were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. A **Negligible-Low** risk to the health of northern pike was identified given all metals in composite samples were below sublethal effects and no-effects criteria. All tainting compounds in northern pike muscle tissue from the Clearwater River were below guideline concentrations indicating a **Negligible-Low** influence on fish palatability.

5.9.2 Hydrologic Conditions

2009 Hydrologic Conditions: Mouth of Christina River In previous years, the change in flow was estimated for the Christina River watershed; however, measurement endpoints were not calculated due to the absence of a monitoring station at the mouth of the Christina River. In 2009, the assumption was made that the flow at the mouth of the Christina River is calculated from the difference between the measured flow at WSC Station 07CD005, Clearwater River above Christina River, and WSC Station 07CD001, Clearwater River above Draper. The 2009 open-water (May to October) runoff volume estimated for Christina River at the mouth was 1,250 million m^3, 33% higher than the historical mean open-water runoff volume calculated from the 39 years of available record. The 2009 seasonal (March to October) maximum daily flow was estimated at 202 m^3/s for April 27 and was 15% higher than the historical mean maximum daily flow. The 2009 open-water maximum daily flow of 173 m^3/s occurred on May 1 and was 1% lower than the historical mean open-water maximum value. The minimum daily flow of 22 m^3/s on October 14 was 32% higher than the calculated historical mean minimum daily flow.

Flows in 2009, at the mouth of the Christina River, were approximately 10 m^3/s throughout March, similar to historical upper quartile values (Figure 5.9-1). Flows were estimated to increase during April due to snowmelt, reaching a peak of 202 m^3/s on April 27, close to the historical maximum values for late April. Flows were similar to the historical upper quartile values from May to August and to the historical median values from September to October.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance from March 1 to October 31, 2009 for the mouth of the Christina River is presented for two different cases in Table 5.9-2. The first case considered only focal projects in the Christina River watershed:

1. The closed-circuited land area from focal projects as of 2009 was estimated at 1.1 km^2 (Table 2.4-1). The loss of flow to the Christina River that would have otherwise occurred from this land area is estimated at 0.13 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 12.4 km^2 (Table 2.4-1). The increase in flow to the Christina River that would have otherwise not occurred from this land area is estimated at 0.28 million m^3.

3. Nexen withdrew 7,600 m^3 of water from surface water courses during the winter months for various purposes, of which 2,600 m^3 is assumed to have occurred in March (uniform allocation of total withdrawal across the winter months).

The estimated cumulative effect was an increase of flow of 0.15 million m^3 to the Christina River. The estimated *baseline* hydrograph for this case is presented in Figure 5.9-3.

The mean open-water period (May to October) discharge, annual maximum daily discharge and open-water minimum discharge calculated from the observed *test* hydrograph are 0.01% higher than from the estimated *baseline* hydrograph (Table 5.9-3); these differences are classified as **Negligible-Low** (Table 5.9-1).

The second case considered focal projects plus other oil sands developments in the Christina River watershed:

1. The closed-circuited land area from focal projects plus other oil sands developments as of 2009 was estimated at 6.5 km^2 (Table 2.4-1). The loss of flow to the Christina River that would have otherwise occurred from this land area is estimated at 0.74 million m^3;

2. The land area not closed-circuited from focal projects plus other oil sands developments as of 2009 was estimated at 36.8 km^2 (Table 2.4-1). The increase in flow to the Christina River that would have otherwise not occurred from this land area is estimated at 0.83 million m^3; and

3. The water withdrawal by Nexen of 2,600 m^3 in March is applied to this case as well.

The estimated cumulative effect for this case is an increase in flow of 0.09 million m^3 to the Christina River. The mean open-water period (May-October) discharge, annual maximum daily discharge and open-water minimum discharge at the mouth of the Christina River calculated from the observed *test* hydrograph are 0.01% higher than from the estimated *baseline* hydrograph (Figure 5.9-3). The differences from focal projects plus other oil sands developments are classified as **Negligible-Low**, and similar to the differences calculated for the first case (to two decimal places) (Table 5.9-1).

5.9.3 Water Quality

In 2009, water quality samples were taken from:

- the Clearwater River upstream of Fort McMurray (*test* station CLR-1, data available from 2001);
- the Clearwater River upstream of the Christina River confluence (*baseline* station CLR-2, data available from 2001);
- the Christina River near its mouth (*test* station CHR-1, data available from 2002); and
- the Christina River upstream of Janvier (*baseline* station CHR-2, data available from 2002). Data from station CHR-2 were excluded from the calculation of regional *baseline* water quality conditions because the presence of other oil sands developments upstream of this station.

2009 Results Relative to Historical and Regional *Baseline* Concentrations
Concentrations of water quality measurement endpoints in fall 2009 were within the range of previously-measured concentrations at all four stations with the following exceptions:

1. At *test* station CLR-1, concentrations of total nitrogen and total mercury were above previously-measured maximum concentrations, while concentrations of magnesium and total alkalinity were below previously-measured minimum concentrations (Table 5.9-4).

2. At *baseline* station CLR-2, concentrations of dissolved organic carbon and total mercury were above previously-measured maximum concentrations, while the concentration of magnesium was below its previously-measured minimum concentration (Table 5.9-5).

3. At *test* station CHR-1, concentrations of total nitrogen, calcium, magnesium, sulphate, total alkalinity, total aluminum, total boron, total strontium and total Kjeldahl nitrogen were above the previously measured maximum concentrations, while the concentration of total dissolved phosphorus was below its previously measured minimum concentration (Table 5.9-6).

4. At *baseline* station CHR-2, concentrations of conductivity, total molybdenum and total strontium were above the previously-measured maximum concentrations (Table 5.9-7).

Water quality measurement endpoints with concentrations in fall 2009 exceeding the 95th percentile of regional *baseline* concentrations were:

- total nitrogen at *test* station CLR-1 and *baseline* station CLR-2;
- total dissolved solids, total nitrogen, total boron, sodium and chloride at *test* station CHR-1; and
- dissolved phosphorus and total boron at *baseline* station CHR-2.

Water quality measurement endpoint with concentrations in fall 2009 below the 5th percentile of regional *baseline* concentrations were:

- total suspended solids and chloride at *baseline* station CHR-2;
- potassium and sulphate at *test* station CLR-1; and
- total strontium, total arsenic, total boron, calcium, magnesium, potassium and sulphate at *baseline* station CLR-2.

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines The concentration of total aluminum at both *test* stations CLR-1 and CHR-1 and *baseline* station CLR-2, and total nitrogen at *test* station CHR-1 exceeded water quality guidelines in fall 2009 (Table 5.9-4 to Table 5.9-7).

Other Water Quality Guideline Exceedances The following are other water quality guideline exceedances observed in the Clearwater-Christina River watersheds in 2009 (Table 5.9-8):

- sulphide, dissolved iron, total iron and total phenols at *test* station CLR-1;
- sulphide, dissolved iron and total iron at *baseline* station CLR-2;
- sulphide, total phosphorus, dissolved iron, total iron, and total Kjeldahl nitrogen at *test* station CHR-1; and
- sulphide, total phosphorus, dissolved iron and total iron at *baseline* station CHR-2.

Ion Balance The ionic composition of water at all stations in the Clearwater-Christina watersheds in fall 2009 was consistent with historical observations since 2001, with the exception of 2008 at *baseline* station CLR-2, where a greater proportion of calcium and magnesium were observed (Figure 5.9-5).

Trend Analysis Significant temporal trends in concentrations of water quality measurement endpoints were an increase in total nitrogen at *test* station CLR-1 and a decrease in total arsenic at *baseline* station CLR-2. This significant trend in total arsenic is likely related only to a lower detection limit after 2002 (Table 5.9-5).

Water Quality Index The WQI values for both stations on the Clearwater River for fall 2009 (i.e., CLR-1: 100; CLR-2: 94.2) indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.9-9). The WQI value for the *test* station CHR-1 (61.8) indicated a **Moderate** difference from regional *baseline* water quality conditions (Table 5.9-9), related to relatively higher levels of total nitrogen, total boron, and certain ions, which were higher in the Christina River than in previous years (Table 5.9-6). The WQI value for the *baseline* station in the Christina River (i.e., CHR-2: 89.1) indicated a **Negligible-Low** difference from regional *baseline* conditions (Table 5.9-9).

Summary As of 2009, water quality at stations in the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2) showed **Negligible-Low** differences from regional *baseline* conditions. Water quality at *test* station CHR-1 showed a **Moderate** difference from regional *baseline* conditions, due to concentrations of total nitrogen, total boron, and a number of ions exceeding previously-measured values and **Negligible-Low** differences at *baseline* station CHR-2 from regional *baseline* conditions.

5.9.4 Benthic Invertebrate Communities and Sediment Quality

5.9.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in the upper and lower reaches of the Christina River. Both the lower depositional *test* reach (CHR-D-1) and the upper depositional *baseline* reach (CHR-D-2) have been sampled since 2002.

2009 Habitat Conditions *Test* reach CHR-D-1 in fall 2009 had a depth of 0.5 m, a substrate dominated by sand, and no macrophyte cover (Table 5.9-10). *Baseline* reach CHR-D-2 was shallow (0.2 m) with a substrate also dominated by sand, and no macrophyte cover (Table 5.9-10).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community in *test* reach CHR-D-1 in fall 2009 was dominated by tubificid worms (71%) and chironomids (16%), with fingernail clams (bivalves), nematodes, ostracods and ceratopogonids sub-dominant (Table 5.9-11). The dominant chironomids included the common *Polypdelim*, and *Paralauterbourniella*. Mayflies (Ephemeroptera) including Ephemerella and *Tricorythodes* were present, as were stoneflies (Plecoptera, *Taeniopteryx*) and caddisflies (Trichoptera, *Hydropsyche*), in lower abundances.

The benthic invertebrate community in *baseline* reach CHR-D-2 in fall 2009 was dominated by chironomids (96%) (Table 5.9-11). Taxa that were less abundant included fingernail clams, ceratopogonids, various worms, mayflies (*Hexagenia*, *Ametropus neavei*), caddisflies (*Brachycentrus*) and stoneflies (*Isoperla*, Capniidae).

The values of all benthic invertebrate community measurement endpoints in fall 2009 were within the range of values for *baseline* depositional reaches in the RAMP FSA with the exception of Simpson's diversity and evenness in *baseline* reach CHR-D-2, which were less than the range of *baseline* values (Figure 5.9-6).

Linear contrasts were used to test for differences in the trend over time between *baseline* reach CHR-D-2 and *test* reach CHR-D-1. This is a test of the interaction between the time trend (TT) and b*aseline* vs. *test* (BT) (i.e., TT x BT in Table 5.9-12).

There were significant differences in time trends of total abundance, %EPT, and CA Axis 1 scores between *test* reach CHR-D-1 and *baseline* reach CHR-D-2 (Table 5.9-12), however:

1. The "remainder" component for both total abundance and CA Axis 1 score is insignificant indicating there is considerable "noise" in the data which can

put these significant differences into question (DFO and Environment Canada 1995).

2. The significant differences in %EPT are not consistent with a negative impact (Figure 5.9-6).

The Correspondance Analysis results (Figure 5.9-7) indicated that both reaches in all sampling years have been within the 95th percentile of the range of variability for *baseline* depositional reaches in the RAMP FSA.

5.9.4.2 Sediment Quality

Sediment quality was sampled in fall 2009 at two stations of the Clearwater River watershed where benthic invertebrate communities were sampled:

- station CHR-D-1 at the mouth of Christina River designated as *test* (previously sampled 2006–2007 and corresponds to pre-2006 sediment station CHR-1 sampled 2002 to 2004); and

- station CHR-D-2 in the upper Christina River designated as *baseline* (previously sampled in 2006 and corresponds to pre-2006 sediment station CHR-2 sampled in 2002 to 2004).

2009 Results and Historical Ranges of Concentration Historical sample sizes for both reaches were low (n=2 to 5) with only two measurements of CCME hydrocarbon fractions and PAH toxicity at *baseline* station CHR-D-2, and only two previous studies for chronic toxicity of invertebrates at *test* station CHR-D-1.

In 2009, sediments at *test* station CHR-D-1 were dominated by sand and silt, while sediments from CHR-D-2 were dominated by sand (Table 5.9-13 and Table 5.9-14). Total organic carbon was low at both stations. Hydrocarbon concentrations in sediments from both stations were either undetectable or within previously-measured ranges (Table 5.9-13 and Table 5.9-14).

Concentrations of all sediment quality measurement endpoints at both reaches in fall 2009 were within historical ranges with the exception of naphthalene and predicted PAH toxicity at CHR-D-2 with concentrations that were below historical minimum values (Table 5.9-13 and Table 5.9-14). In both reaches, survival and growth of both *Chrionomus* and *Hyalella* generally were within historical ranges with the exception of *Hyalella* survival *test* station CHR-D-1, which exceeded the previously-measured maximum value, *Chironomus* survival at *test* station CHR-D-1, which was below the previously-measured minimum value, and *Chironomus* growth at *baseline* station CHR-D-2, which was below the previously-measured minimum value.

Comparison to Sediment Quality Guidelines The only sediment or soil quality guideline exceedance measured in fall 2009 was the CCME hydrocarbon fraction 3 for *test* reach CHR-D-1 (Table 5.9-14).

Sediment Quality Index The SQI values for *baseline* station CHR-D-2 and *test* station CHR-D-1 in fall 2009 were 95.5 and 94.6, respectively indicating **Negligible-Low** differences from regional *baseline* sediment quality conditions.

5.9.4.3 Summary

Differences in time trends of measurement endpoints for benthic invertebrate communities between *baseline* reach CHR-D-2 and *test* reach CHR-D-1 were either insignificant, significant but weaker than the background "noise" component of these differences, or significant but not consistent with a negative impact at *test* reach CHR-D-1. In addition, values of most benthic invertebrate community measurement endpoints in 2009 were within regional *baseline* values for depositional reaches. These results indicated a **Negligible-Low** difference in benthic invertebrate community conditions in the Christina River watershed from regional *baseline* conditions of benthic invertebrate communities in depositional habitats. Sediment quality conditions in fall 2009 at both Christina River stations indicated **Negligible-Low** differences from regional *baseline* conditions. Sediment quality at *test* station CHR-D-1 and *baseline* station CHR-D-2 was generally consistent with that of previous years, with concentrations of sediment quality measurement endpoints largely within previously measured and regional *baseline* ranges.

5.9.5 Fish Populations

Fish population monitoring for 2009 in the Clearwater-Christina River watersheds consisted of a spring, summer, and fall fish inventory on the Clearwater River, as well as fish tissue analysis of northern pike captured during the fall inventory. 2009 was the first year of a summer inventory on the Clearwater River.

5.9.5.1 Clearwater River Fish Inventory

Species Composition

A total of 1,493 fish were captured in the spring, summer and fall at the three sampling reaches of the Clearwater River in 2009 (Table 5.9-15), of which:

- 621 fish comprised of 12 species were captured in the spring;
- 540 fish comprised of 15 species were captured in the summer; and
- 332 fish comprised of 16 species were captured in the fall.

A total of 17 species were captured in the 2009 Clearwater River Fish Inventory across all three seasons. The species richness in 2009 was lower than 2008 (22 species [RAMP 2009a]) when species not normally captured in the Clearwater River inventory such as brook stickleback, fathead minnow and finescale dace were recorded. Seasonal richness has ranged from five to 15 species in the Clearwater River over time (Figure 5.9-8). In previous sampling years, higher species richness was observed in the spring and it was thought that this was related to higher numbers of spring spawning fish species in the oil sands region. However, in 2009, species richness was highest in fall (Figure 5.9-8).

White sucker was the dominant species captured in the Clearwater River in 2009, comprising 33.7%, 29.7% and 46.4% of the total catch in spring, summer, and fall, respectively (Table 5.9-15). Northern pike was the second most dominant species in spring (12.7%) and fall (21.1%), while longnose sucker was the second dominant species in the summer, comprising 26.2% of the total catch. Spottail shiner was the dominant small-bodied species in spring (21.1% of the total catch) and trout-perch was the dominant small-bodied species in summer and fall, comprising 11.6% and 7.8% of the total catch, respectively (Table 5.9-15).

Fish that were observed but not captured are summarized in Table 5.9-16.

Catch per Unit Effort

The total catch per unit effort (CPUE) for all species combined and for KIR species was lower in 2009 than 2007 and 2008, but similar to what was observed between 2003 and 2006 (Figure 5.9-9, Figure 5.9-10). CPUE was similar in spring and summer, but lower in fall. A summary of spring and fall CPUE for KIR species in 2009 and comparisons to previous inventory results are as follows (Figure 5.9-10):

1. CPUE for goldeye in spring 2009 was higher than 2007 and 2008, but within the historical range. As in most years of the Clearwater River inventory (with the exception of 2003) there were no goldeye caught in the fall.
2. CPUE for longnose sucker in spring 2009 was within the historical range with no clear trend across years. CPUE in fall 2009 was lower than fall 2008, but within the historical range.
3. CPUE for northern pike in spring 2009 was higher than spring 2008, but within the historical range. CPUE in fall 2009 was lower than the three previous sampling years (2006 to 2008) but within the historical range (2003 to 2005).
4. CPUE for walleye in spring 2009 was lower than spring 2008, but higher than all other sampling years (2003 to 2007). CPUE in fall 2009 was also lower than fall 2008, but within the historical range.
5. CPUE for white sucker in spring and fall 2009 was lower than in fall 2007 and 2008 but higher than all other sampling years (2003 to 2006).

Temporal comparisons were not possible for the summer fish inventory given 2009 was the first year a summer inventory was conducted in the Clearwater River.

Results for the Correspondence Analysis (CA) (Figure 5.9-11) are as follows:

1. In spring 2009, species relative abundance was similar to results in 2003 and 2004. Spring 2009 was close to the origin of the CA plot indicating an average year for relative abundance relative to historical inventory results.
2. In fall 2009, species relative abundance was similar to 2004 and 2007. Fall 2009 was close to the origin of the CA plot indicating an average year for relative abundance relative to historical inventory results.

Length-Frequency Analysis

Length-frequency distributions (2003 to 2009) for the five KIR species for all seasons combined (including the summer for 2009 data) are presented in Figure 5.9-12 to Figure 5.9-16. Comparisons in length-frequency distributions across years were conducted using a two-sample Kolmogonov-Smirnov (K-S) test (two-sided, α=0.05) for each species.

The length-frequency distribution of goldeye in 2009 was significantly different from 2003, 2004, 2005, and 2006 ($p \leq 0.04$) (Figure 5.9-12). There were a higher number of longer individuals captured in 2009 compared to these years. Consistent with 2004 to 2006 and 2008, the dominant length class of goldeye captured in 2009 was 351 to 375 mm, comprising 60% of the total catch.

The length-frequency distribution of longnose sucker in 2009 was significantly different from all previous years ($p \leq 0.001$) with the exception of 2003 (Figure 5.9-13). The dominant length class of longnose sucker captured in 2009 was 101 to 150 mm, comprising 40% of the total catch. The summer catch of longnose sucker comprised the largest proportion of the dominant length class, likely representing juvenile fish. The addition of the summer data is likely a large factor in the observed significant difference between the length-frequency distributions in 2009 relative to historical sampling years. Although a summer inventory was not conducted in previous sampling years, a peak in this juvenile size class has been observed historically (RAMP 2009a). The second dominant size class was between 301 and 350 mm, likely representing adult longnose sucker.

The length-frequency distribution of northern pike is wider and flatter than all other species, with no defined peaks (Figure 5.9-14). The distribution of northern pike captured in 2009 was only significantly different from 2007 ($p=0.014$). There were two co-dominant length classes (451 to 500 mm and 501 to 550 mm) in 2009, each comprising approximately 12% of the total catch. The co-dominant length classes in 2009 were smaller than observed in 2007 and 2008 (> 551 mm).

The length-frequency distribution of walleye in 2009 was statistically different from 2003, 2005, and 2008 ($p \leq 0.01$) (Figure 5.9-15). The co-dominant length classes in 2009 were 351 to 400 mm and 401 to 450 mm comprising approximately 20% of walleye captured in each season. The length-frequency distribution in 2009 is flatter compared to previous years, with fewer individuals captured from the 401 to 450 mm length class compared to 2008 and 2006, suggesting a higher proportion of younger fish captured in 2009, likely a result of juvenile fish being captured during the summer inventory.

The length-frequency distribution of white sucker in 2009 was significantly different from all previous sampling years ($p \leq 0.01$) (Figure 5.9-16). The dominant size class in 2009 was 401 to 450 mm with a second dominant size class between 151 and 200 mm, comprising 17% and 21% of the total catch. Similar to longnose sucker, the smaller length class (151 to 200 mm) likely represents juvenile fish and the longer length class (300 to 450 mm) likely represents adult fish. The dominant size class of white sucker captured during the Athabasca River fish inventory and at the Muskeg River fish fence in 2009 was similar, ranging between 400 and 500 mm (Section 5.1.5 and Section 5.2.5).

Given the decrease in total catch numbers and relative abundance in 2009 compared to 2008, the length-frequency distributions likely do not represent the entire Clearwater River populations for the KIR species.

Condition Factor

Mean condition factors for KIR fish species captured during the Clearwater River inventory from 2003 to 2009 are presented in Figure 5.9-17. Separate analysis of covariance (ANCOVA) was performed on fish captured in spring and fall. The species-specific results are as follows:

1. Condition of spring-captured goldeye was significantly lower in 2009 compared to 2008 ($p=0.03$).

2. There were no significant differences among years in the condition of longnose sucker captured in spring or fall ($p \geq 0.06$).

3. Condition of northern pike captured in spring and fall was variable among years, but higher in fall 2009 compared to fall 2006 ($p=0.01$) and fall 2007

(p=0.01), and higher in spring 2009 compared to spring 2003 (p=0.02), 2004 (p<0.001), 2005 (p=0.03), and 2007 (p=0.01). Northern pike condition was lower in fall 2009 compared to fall 2008 (p<0.001).

4. Walleye condition was significantly lower in fall 2009 compared to fall 2006 (p=0.048) and lower in spring 2009 compared to spring 2006 and 2008 (p<0.01).

5. Condition of white sucker was significantly higher in fall 2009 compared to fall 2008 (p<0.001). There were no significant differences among years in the condition of spring-captured white sucker.

Currently, only condition can be applied as a measurement endpoint for large-bodied fish species for the Clearwater River fish inventory. Environment Canada (2005) has defined a critical effect size for fish condition as ± 10% relative to fish captured from *baseline* reaches. From this perspective, a change greater than 10% in condition is considered important. The two upper reaches (CR1 and CR2) of the Clearwater fish inventory are designated as *baseline* and the lower reach (CR3) is designated as *test*. The criterion was exceeded for the following:

1. Condition of northern pike captured in summer in *test* reach CR3 was 26% lower than the average condition in northern pike captured from the *baseline* reaches. However, in 2008, condition in spring-captured northern pike in *test* reach CR3 was more than 10% greater than condition in fish from the *baseline* reaches, indicating no consistent increasing or decreasing trend in condition of northern pike captured from the *test* reach.

2. Condition of walleye captured in summer from *test* reach CR3 was 23% lower than the average condition of walleye from the *baseline* reaches.

Condition of fish in spring was not used to establish an impact criterion because changes in condition may be related to physiological behaviour during spawning season rather than changes in somatic tissue of fish.

In addition, given the large migratory routes of large-bodied fish species throughout the RAMP FSA, the fish populations between reaches are not necessarily distinct and therefore, any differences in condition between fish from *baseline* and *test* reaches may not be related to oil sands developments.

External Health Assessment

Observed abnormalities were primarily associated with minor skin aberrations or wounds, scars and fin erosion. In 2009, approximately 13.7%, 7.8%, and 6.3% of fish captured in spring, summer, and fall, respectively, were found to have some type of external abnormality. The 2009 incidence of external abnormalities was slightly higher than observed in 2008 (10.8% and 2.6% in spring and fall, respectively [RAMP 2009a]). The mean health assessment index (HAI) for all KIR species across seasons and years (Table 5.9-17) was within the historical range for all species with the exception of northern pike and walleye in the spring. The high HAI score for northern pike in the spring, the highest on record for the Clearwater Inventory, is attributed to severe fraying of the fins across most individuals of this species, which was not observed in the other seasons.

27 of 1,493 fish (i.e, 1.8%; three in the spring, 19 in the summer, and five in the fall) exhibited some form of external pathology such as parasites, growths, lesions or body

deformities. A summary of the percentage of fish by year, season and species exhibiting some form of pathology is presented in Table 5.9-18; the percentage of captured fish with evidence of external pathology is less than 1% in all years and seasons.

Summary Assessment for Fish Inventory

The Clearwater River fish inventory is a community-driven activity primarily suited for assessing general trends in abundance and population variables (i.e., condition, length-frequency) for large-bodied species, rather than assessing detailed fish community structure.

The 2009 Clearwater River inventory results suggests that the current species relative abundance of fish species is within the natural variability established during historical fish sampling years (2003 to 2008). Species richness in the spring of 2009 was lower than in 2008 but within the range of natural variability. Annual variability in relative fish abundance is expected given the changes in hydrologic conditions and subsequent access to spawning grounds across years in tributaries of the Clearwater River, both of which can strongly influence fish abundance (Danehy *et al.* 1998).

Statistically-significant differences were observed between years for length-frequency distributions and condition of KIR species with no significant increasing or decreasing trends over time. The increase in fish from smaller size classes captured in 2009 is attributed to the summer inventory when the abundance of juvenile fish in the Clearwater River was high.

The addition of the summer fish inventory in the Clearwater River increases the understanding of the presence of juvenile fish of some KIR species, such as longnose sucker and goldeye, which may help to provide information on recruitment trends in these populations.

5.9.5.2 Fish Tissue Analysis Results

Whole-Organism Metrics

A total of 30 northern pike (four males, eight females, 18 unknown sex) from the Clearwater River were sampled for tissue analyses in conjunction with the fall 2009 fish inventory.

The fork length of fish sampled ranged from 234 to 708 mm (average = 467 mm) (Table 5.9-19). The average weight of northern pike was 801 g, ranging from 75 to 2,474 g and the average age ranged from two to seven years (average = four years).

External and internal health assessments were conducted on the nine northern pike that were sacrificed for metal and organics tissue analyses. Northern pike from the Clearwater River were generally healthy both internally and externally in fall 2009. No abnormalities were observed externally on any captured northern pike. A single northern pike had a fatty liver; no other internal abnormalities were observed.

Mercury

Mercury was analyzed in both non-lethally and lethally sampled northern pike (Table 5.9-19). Concentrations of mercury ranged from 0.065 mg/kg to 0.249 mg/kg. The Health Canada subsistence guideline (0.2 mg/kg) for northern pike was exceeded in three fish and the USEPA guideline for subsistence fishers (0.049 mg/kg) was exceeded in all fish. There were no fish that exceeded the Health Canada general consumer guideline (0.5 mg/kg). Mean mercury concentration by length class were below the Health Canada guideline for subsistence fishers (Figure 5.9-18).

Temporal comparisons of mercury concentrations adjusted to length in northern pike from the Clearwater River are presented in Figure 5.9-19. Mercury concentrations were pooled across sex by size class for temporal comparisons because sex is a weak predictor of mercury concentration. There were no significant differences across sampling years in the relationship between length and mercury concentration ($p \geq 0.02$). The relationships between length ($p<0.01$, $r^2=0.37$), age ($p<0.01$, $r^2=0.31$) and weight ($p<0.01$, $r^2=0.36$) and mercury concentration were significant but weakly predictive.

Mean 2009 mercury concentrations in northern pike from the Clearwater River were compared to mean mercury concentrations in northern pike sampled from other rivers within the region (AOSERP 1977, Grey *et al.* 1995, NRBS 1996, Golder 2004, RAMP 2004, RAMP 2007, RAMP 2008) (Figure 5.9-20). The relationships between mercury concentrations and fish weight for northern pike in regional rivers in the RAMP FSA is presented in Figure 5.9-21. The relationship between weight and mercury concentration was significant but weakly predictive ($p=0.002$, $r^2=0.143$). The mean mercury concentration in northern pike from the Clearwater River in 2009 was below the mean mercury concentration in other sampled rivers and within the 95% confidence interval of all rivers sampled (Figure 5.9-20).

Relatively low concentrations of mercury observed in Clearwater River northern pike is contrary to data presented in Evans *et al.* (2005), which shows that mercury concentrations exceeding the Health Canada guideline for subsistence fishers was observed in at least 50% of all pike captured in northern areas of Canada (North West Territories, Nunavut, and Québec). Exceedances of the Health Canada guideline for subsistence fisher guideline were observed in only three (10%) northern pike from the Clearwater River. A regional assessment of mercury concentrations in fish tissue is further discussed in Section 7.4.

Other Chemicals

Two composite tissue samples from northern pike were collected from the Clearwater River in fall 2009: five females from a target size class between 500 and 550 mm and four males from a target size class between 450 and 500 mm (Table 5.9-20). Fifteen of the 30 metals analyzed in pike tissue were below the detection limit in males and sixteen metals were below the detection limit in females. All selected tainting compounds were below analytical detection limits for all composite tissue samples (Table 5.9-20).

Potential Risk to Human Health

Mercury Northern pike captured in the Clearwater River in 2009 were screened against several criteria of fish consumption (Table 5.9-20). The mean level of mercury concentration was 0.133 mg/kg, below the Health Canada guideline for subsistence fishers. Individually, three northern pike, two greater than 600 mm and one greater than 400 mm, exceeded the subsistence fisher guideline. All northern pike exceeded the National USEPA guideline for subsistence fishers; no fish exceeded the Health Canada guideline for general consumers.

The Government of Alberta (GOA 2009b) established fish consumption guidelines for watercourses within the RAMP FSA (Table 3.4-10). For northern pike captured from the Clearwater River, consumption guidelines were established for fish greater than 908 g. Nine of the twenty-eight northern pike captured from the Clearwater River in 2009 exceeded 908 g in weight and fall within the new consumption guideline (i.e., child-bearing women – eight servings per week, children between one and four years of age – two servings per week and children between five and eleven years of age – four servings per week).

Other Chemicals Arsenic concentrations exceeded the US EPA guideline for recreational fishers in male and female northern pike (Table 5.9-20). There is no Health Canada guideline for arsenic, and no other metals exceeded Health Canada or National US EPA guidelines.

Potential Risks to Fish and Fish Health

Based on criteria for evaluating potential lethal (survival) or sublethal (growth) effects on northern pike from chemicals presented in Table 3.4-11, there were no risks to fish health in northern pike captured from the Clearwater River (Table 5.9-20).

Potential Influence on Fish Palatability

All tainting compounds in Clearwater River northern pike tissue were present at concentrations well below the 1 mg/kg threshold for effects on palatability as outlined in Jardine and Hrudey (1988) (Table 5.9-20).

Summary Assessment for Fish Tissue

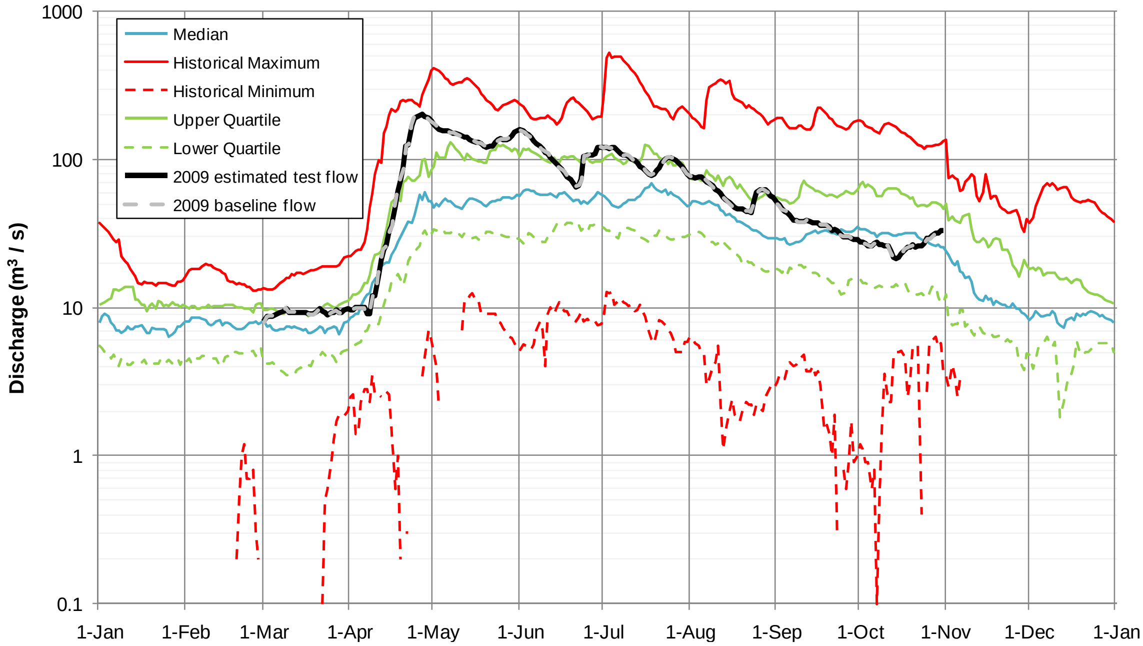
Measurement endpoints used in the assessment of the results of the Clearwater River fish tissue program are the concentrations of metals and tainting compounds in relation to human and fish health guidelines. The potential risk to human health was predicted from the individual and composite fish tissue analyses. Average mercury concentrations across all size classes were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health.

A **Negligible-Low** risk to northern pike was identified given all metals in composite samples were below sublethal effects and no-effects criteria.

All tainting compounds in northern pike muscle tissue from the Clearwater River were below guideline concentrations indicating a **Negligible-Low** influence on fish palatability.

To provide a regional context to the mercury results in pike from the Clearwater River, concentrations of mercury in relation to fish weight from the Clearwater River were compared to mercury concentrations in northern pike from watercourses in the region. Mercury levels in Clearwater River northern pike were within the 95% confidence interval of mercury levels in fish from rivers within the region (Figure 5.9-21).

Figure 5.9-3 The estimated (*test*) hydrograph for the mouth of the Christina River in 2009 and estimated *baseline* hydrograph, compared to historical values.



Note: The 2009 estimated test hydrograph is calculated as the difference between provisional 2009 data from WSC Station 07CD005, Clearwater River above Christina River, and WSC Station 07CD001, Clearwater at Draper. Historical data are calculated using the same method based on 42-years of record (1967-2008) from March to October, and 21-years of record for other months (1976-1996).

Note: For clarity, the estimated *baseline* hydrograph from focal projects in the Christina River watershed is shown here; differences between this and the estimated *baseline* hydrograph from focal project plus other oil sands developments in the Christina River watershed is negligible.

Table 5.9-2 Estimated water balance at the mouth of the Christina River, March 1 to October 31, 2009.

Component	Volume (million m^3)		Basis and Data Source
	Focal Projects	Focal Projects Plus Other Oil Sands Developments	
Observed *test* hydrograph (total discharge)	**1,473.5**	**1,473.5**	**Calculated as the difference between provisional 2009 data from WSC Station 07CD005, Clearwater River above Christina River, and WSC Station 07CD001, Clearwater at Draper.**
Closed-circuited area water loss from the observed *test* hydrograph	-0.126	-0.737	Estimated 1.1 km^2 and 6.5 km^2 of the Christina River watershed is closed-circuited from focal projects and from focal projects plus other oil sands developments, respectively, as of 2009 (Table 2.4-1).
Incremental runoff from land clearing (not closed-circuited area)	+0.281	+0.831	Estimated 12.4 km^2 and 36.8 km^2 of the Christina River watershed with land change from focal projects and from focal projects plus other oil sands developments as of 2009, respectively that is not closed-circuited (Table 2.4-1).
Water withdrawals from the Christina River watershed from projects	-0.003	-0.003	Water withdrawn by Nexen (see note).
Water releases into the Christina River watershed from projects	0	0	None reported
Diversions into or out of the watershed	0	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	0	No focal projects or other oil sands developments on tributaries of Christina River not accounted for in figures contained in this table.
Estimated *baseline* hydrograph (total discharge)	**1,473.4**	**1,473.4**	**Estimated *baseline* discharge for the mouth of the Christina River**
Incremental flow (change in total annual discharge)	+0.152	+0.091	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.01%**	**+0.01%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Based on flows estimated for the mouth of the Christina River, calculated as the difference of 2009 provisional values collected on the Clearwater River, just upstream of where the Christina River joins the Clearwater River (WSC Station 07CD005, Clearwater River above Christina River), and immediately downstream of this confluence (WSC Station 07CD001, Clearwater at Draper).

Note: In 2009, Nexen reported a withdrawal from various surface waterbodies of 7,600 m^3 for winter activities such as core hole drilling and freezing of winter access roads/bridges. A constant daily withdrawal from January 1 to March 31 was assumed, resulting in an estimated 2,600 m^3 withdrawn from March 1 to March 31.

Table 5.9-3 Calculated change in hydrologic measurement endpoints for the mouth of the Christina River in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	78.63	78.64	+0.01%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	201.98	202.00	+0.01%
Open-water season minimum daily discharge	21.498	21.50	+0.01%

Note: Based on flows estimated for the mouth of the Christina River, calculated as the difference of 2009 provisional values collected on the Clearwater River, just upstream of where the Christina River joins the Clearwater River (WSC Station 07CD005, Clearwater River above Christina River), and immediately downstream of this confluence (WSC Station 07CD001, Clearwater at Draper).

Note: The calculated change in hydrologic measurement endpoints from focal projects in the Christina River watershed is shown in this table. Additional changes in measurement endpoints from focal projects plus other oil sands developments in the Christina River watershed is negligible and does not affect the measurement endpoint values or relative change (to two decimal places).

Table 5.9-4 Concentrations of water quality measurement endpoints, mouth of Clearwater River (CLR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.91	8	7.5	8.05	8.2
Total Suspended Solids	mg/L	-[1]	24	8	<3	13.5	38
Conductivity	µS/cm	-	193	8	177	231.5	291
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0175	8	0.012	0.023	0.044
Total nitrogen*	mg/L	1.0	0.991	8	0.3	0.6	0.7
Nitrate+Nitrite	mg/L	1.0	0.071	8	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	10.4	8	8	10.5	16
Ions							
Sodium	mg/L	-	17.8	8	16	21.5	31
Calcium	mg/L	-	15	8	14.7	17.5	20.1
Magnesium	mg/L	-	4.98	8	5.1	5.75	6.5
Chloride	mg/L	230, 860[3]	22.1	8	17	25.5	43
Sulphate	mg/L	100[4]	4.29	8	1.4	5.85	7.7
Total Dissolved Solids	mg/L	-	132	8	60	150	200
Total Alkalinity	mg/L	-	55.5	8	59	67.5	74
Organic compounds							
Naphthenic acids	mg/L	-	0.205	8	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	**0.72**	8	**0.14**	**0.56**	**1.46**
Dissolved aluminum	mg/L	0.1[2]	0.011	8	0.0059	0.009	0.015
Total arsenic	mg/L	0.005	0.0006	8	0.0005	0.0008	0.0014
Total boron	mg/L	1.2[5]	0.0301	8	0.0275	0.0333	0.0548
Total molybdenum	mg/L	0.073	0.0002	8	0.0002	0.0002	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.5	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0801	8	0.079	0.09995	0.118
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0032**	8	**<0.003**	**0.0045**	**0.009**
Dissolved iron	mg/L	0.3[2]	**0.517**	8	0.161	**0.312**	**0.756**
Total iron	mg/L	0.3	**1.44**	8	**0.51**	**1.14**	**2.43**
Total phenols	mg/L	0.004	**0.0053**	8	0.001	0.0025	**0.009**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.9-5 Concentrations of water quality measurement endpoints, upper Clearwater River (CLR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.74	8	7.2	7.9	8.0
Total Suspended Solids	mg/L	-[1]	21	8	7	13	36
Conductivity	µS/cm	-	151	8	138	203.5	249
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.021	8	0.010	0.019	0.026
Total nitrogen*	mg/L	1.0	0.931	8	0.30	0.45	**1.2**
Nitrate+Nitrite	mg/L	1.0	0.071	8	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	24.2	8	6	7.5	9
Ions							
Sodium	mg/L	-	13.7	8	11	18	29
Calcium	mg/L	-	10.3	8	10.0	11.9	21.6
Magnesium	mg/L	-	3.35	8	3.7	4.2	7
Chloride	mg/L	230, 860[3]	18.7	8	16	28.5	43
Sulphate	mg/L	100[4]	3.51	8	<0.5	5.95	7.7
Total Dissolved Solids	mg/L	-	130	8	40	119	160
Total Alkalinity	mg/L	-	40.4	8	39	46	51
Organic compounds							
Naphthenic acids	mg/L	-	0.119	8	<1	<1	<1
Selected metals							
Total aluminum	mg/L	0.1	**0.568**	8	**0.102**	**0.23**	**0.70**
Dissolved aluminum	mg/L	0.1[2]	0.0117	8	0.00479	0.0068	0.0400
Total arsenic	mg/L	0.005	0.0156	8	0.00042	0.00052	0.001
Total boron	mg/L	1.2[5]	0.0005	8	0.0142	0.02385	0.03
Total molybdenum	mg/L	0.073	0.0001	8	0.000094	0.000119	0.00020
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.1	6	<1.2	<1.2	1.2
Total strontium	mg/L	-	0.0637	8	0.061	0.085	0.094
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0022**	8	**<0.003**	**0.005**	**0.013**
Total iron	mg/L	0.3	**1.37**	8	**0.55**	**0.704**	**2.07**
Dissolved iron	mg/L	0.3	**0.549**	8	0.17	0.221	**0.672**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.9-6 Concentrations of water quality measurement endpoints, mouth of Christina River (CHR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.14	7	8.1	8.3	8.4
Total Suspended Solids	mg/L	-[1]	18	7	<3	26	49
Conductivity	µS/cm	-	366	7	244	291	375
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0179	7	0.021	0.025	**0.054**
Total nitrogen*	mg/L	1.0	**1.801**	7	0.6	1.0	**1.6**
Nitrate+Nitrite	mg/L	1.0	0.071	7	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	19.8	7	14	20	25
Ions							
Sodium	mg/L	-	33.2	7	16	25	34
Calcium	mg/L	-	30.2	7	25.4	27.3	29.7
Magnesium	mg/L	-	9.42	7	7.8	8.4	9.1
Chloride	mg/L	230, 860[3]	36.5	7	17	24	41
Sulphate	mg/L	100[4]	8.49	7	2.2	6.8	7.9
Total Dissolved Solids	mg/L	-	231	7	140	189	250
Total Alkalinity	mg/L	-	120	7	101	104	118
Organic compounds							
Naphthenic acids	mg/L	-	0.176	7	<1	<1	<1
Selected metals							
Total aluminum	mg/L	0.1	**0.84**	7	**0.24**	**0.59**	**0.77**
Dissolved aluminum	mg/L	0.1[2]	0.0072	7	0.0066	0.0099	0.0182
Total arsenic	mg/L	0.005	0.0011	7	0.0007	0.0010	0.0017
Total boron	mg/L	1.2[5]	0.074	7	0.027	0.049	0.066
Total molybdenum	mg/L	0.073	0.0004	7	0.0002	0.0004	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	6	<1.2	<1.2	2.4
Total strontium	mg/L	-	0.15	7	0.078	0.124	0.145
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0071**	7	**<0.003**	**0.005**	**0.011**
Total phosphorus	mg/L	0.05	**0.0516**	7	0.049	**0.064**	**0.131**
Total Kjeldahl nitrogen	mg/L	1.0	**1.73**	7	0.5	0.9	**1.5**
Total iron	mg/L	0.3	**1.2**	7	**0.778**	**1.49**	**2.51**
Dissolved iron	mg/L	0.3[2]	**0.314**	7	0.255	**0.493**	**0.957**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 5.9-7 Concentrations of water quality measurement endpoints, upper Christina River (CHR-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.27	7	8	8.2	8.3
Total Suspended Solids	mg/L	-[1]	3	7	<3	8	22
Conductivity	µS/cm	-	268	7	164	205	266
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0308	7	0.026	0.038	**0.053**
Total nitrogen*	mg/L	1.0	0.901	7	0.6	0.8	**1.4**
Nitrate+Nitrite	mg/L	1.0	<0.071	7	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	15.8	7	13	18	26
Ions							
Sodium	mg/L	-	9.4	7	5	6	10
Calcium	mg/L	-	34.9	7	22.6	27.4	35.1
Magnesium	mg/L	-	9.27	7	7	8	10.6
Chloride	mg/L	230, 860[3]	0.5	7	<1	2	2
Sulphate	mg/L	100[4]	6.46	7	3.2	4.4	9.6
Total Dissolved Solids	mg/L	-	180	7	130	140	240
Total Alkalinity	mg/L	-	135	7	82	102	138
Organic compounds							
Naphthenic acids	mg/L	-	0.19	7	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.080	6	0.049	**0.212**	**0.304**
Dissolved aluminum	mg/L	0.1[2]	0.00464	6	0.0041	0.0096	0.0193
Total arsenic	mg/L	0.005	0.0010	6	0.0007	0.0010	0.0016
Total boron	mg/L	1.2[5]	0.0453	6	0.0253	0.0313	0.0459
Total molybdenum	mg/L	0.073	0.0007	6	0.0004	0.0004	0.0006
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	1.8
Total strontium	mg/L	-	0.156	6	0.087	0.098	0.147
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0023**	7	**<0.003**	**0.007**	**0.04**
Total phosphorus	mg/L	0.05	**0.0528**	7	0.048	**0.068**	**0.108**
Total iron	mg/L	0.3	**1.19**	6	**0.999**	**1.385**	**2.62**
Dissolved iron	mg/L	0.3[2]	**0.657**	6	**0.406**	**0.726**	**1.41**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

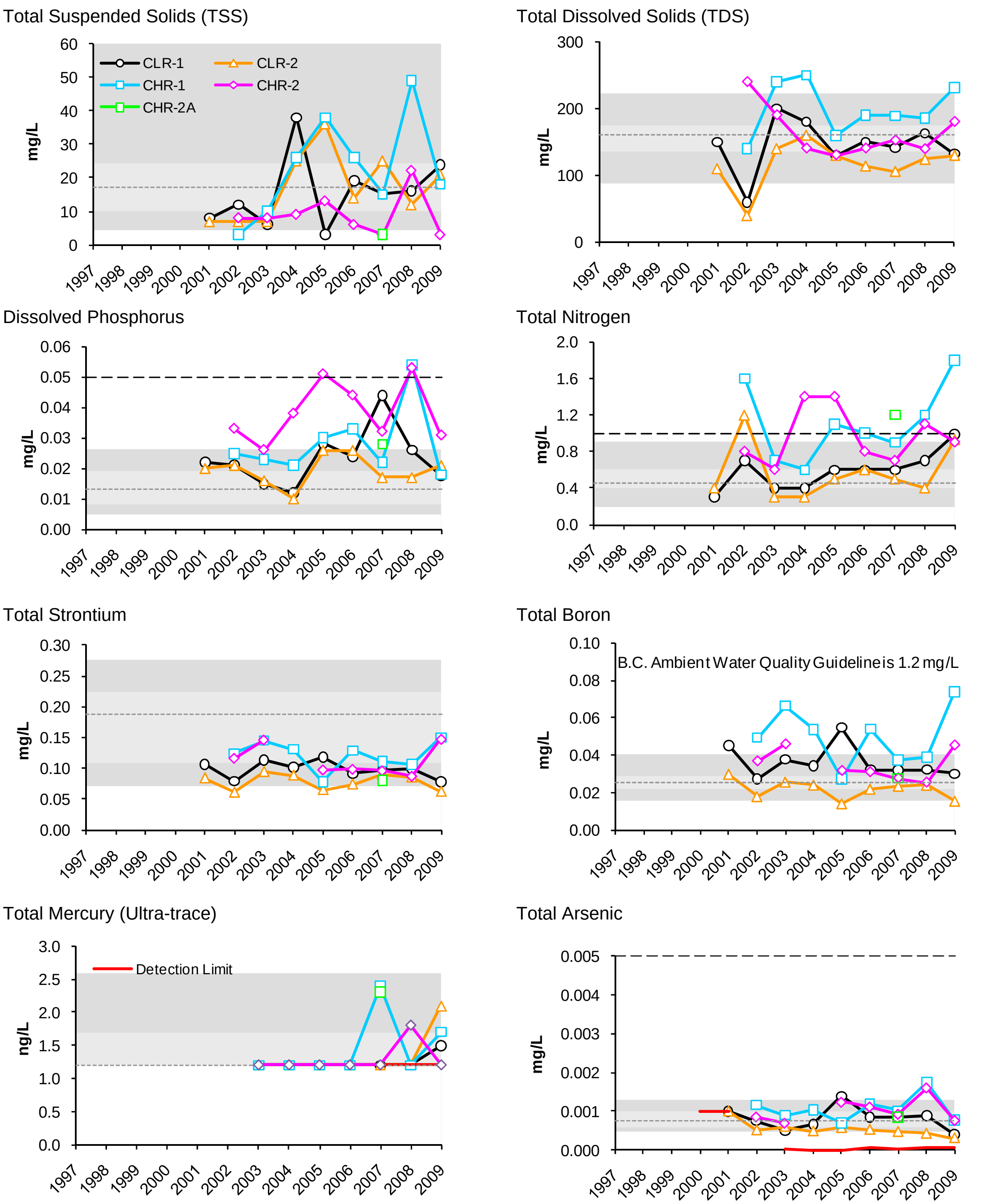
4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Figure 5.9-4 Concentrations of selected water quality measurement endpoints in the Clearwater and Christina watersheds (fall data) relative to regional *baseline* fall concentrations.



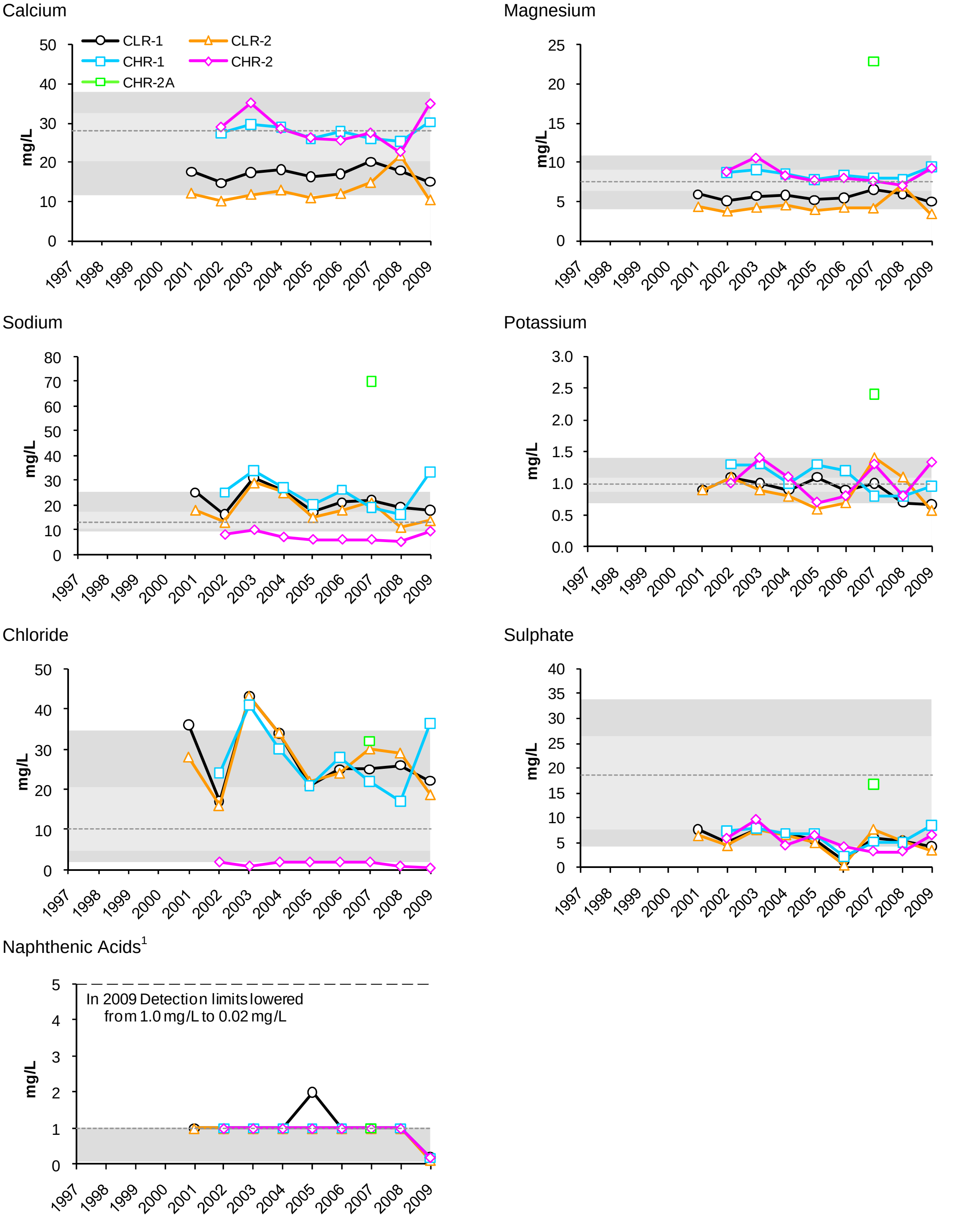
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.9-4 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling.

See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.9-8 Water quality guideline exceedances, Clearwater-Christina River watersheds, 2009.

Variable	Units	Guideline	CHR-1	CHR-2	CLR-1	CLR-2
Fall						
Sulphide	mg/L	0.002[2]	**0.0071**	**0.0023**	**0.0032**	**0.0022**
Total phosphorus	mg/L	0.05	**0.0516**	**0.0528**	**-**	**-**
Total aluminum	mg/L	0.1	**0.84**	**-**	**0.72**	**0.568**
Dissolved iron	mg/L	0.3[1]	**0.314**	**0.657**	**0.517**	**0.549**
Total iron	mg/L	0.3	**1.2**	**1.19**	**1.44**	**1.37**
Total Kjeldahl Nitrogen	mg/L	1.0	**1.73**	**-**	**-**	**-**
Total nitrogen	mg/L	1.0	**1.801**	**-**	**-**	**-**
Total phenols	mg/L	0.004	**-**	**-**	**0.0053**	**-**

CHR-1, CHR-2, CLR-1 and CLR-2 were sampled only in fall 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] Guideline is for total species (no guideline for dissolved species).

[2] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Figure 5.9-5 Piper diagram of fall ion concentrations in the Clearwater-Christina River watersheds.

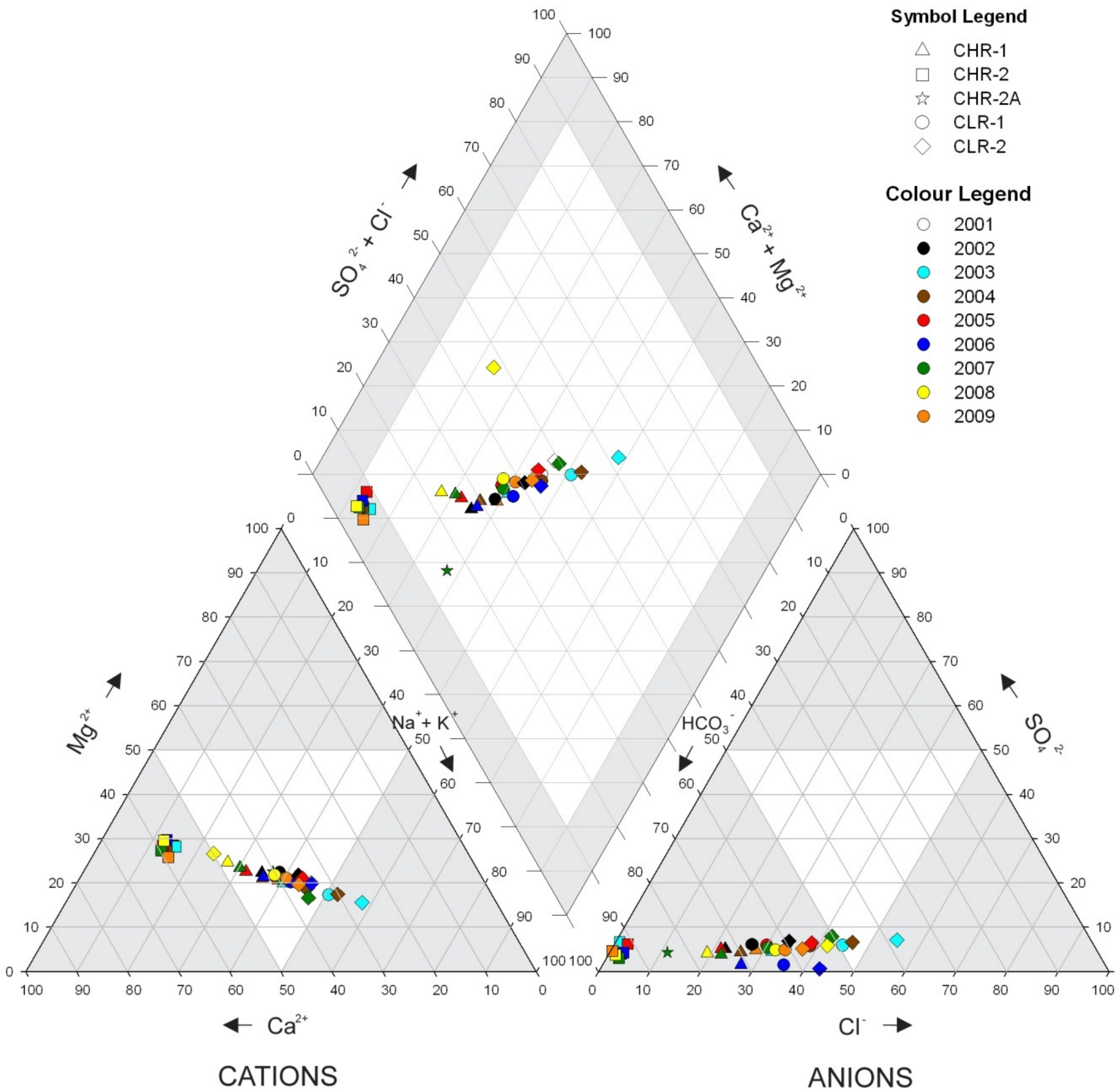


Table 5.9-9 Water quality index (fall 2009) for Clearwater-Christina River watersheds stations.

Station Identifier	Location	2009 Designation	Water Quality Index	Classification
CLR-1	Upstream of Fort McMurray	*test*	100.0	Negligible-Low
CLR-2	Upstream of Christina River	*baseline*	94.2	Negligible-Low
CHR-1	Near the mouth of the Christina River	*test*	61.8	Moderate
CHR-2	Upstream of Janvier	*baseline*	89.1	Negligible-Low

Note: see Figure 5.9-1 for the locations of these water quality stations.

Note: see Section 3.2.7.4 for a description of the Water Quality Index.

Table 5.9-10 Average habitat characteristics of benthic invertebrate sampling locations in the Christina River.

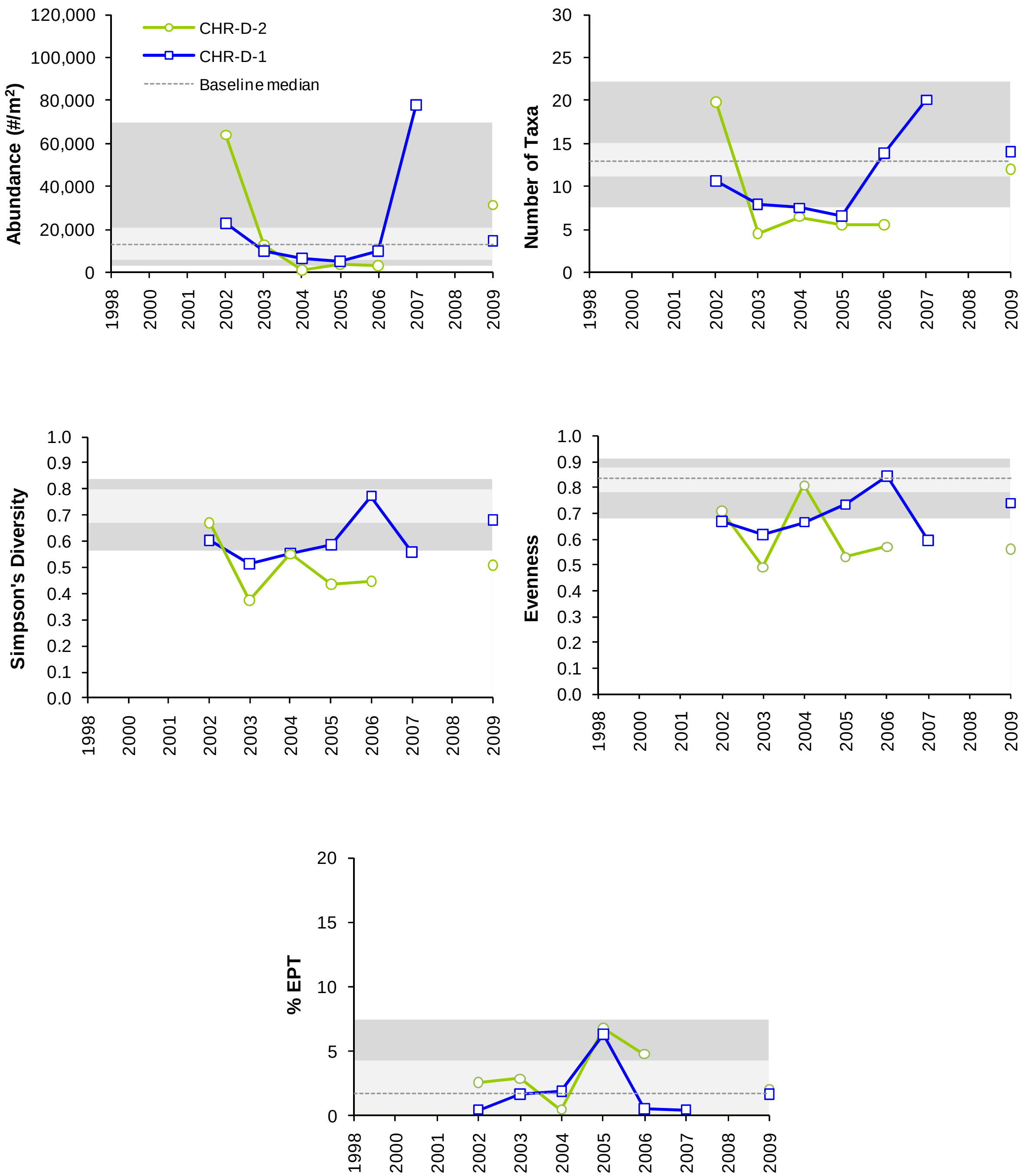
Variable	Units	*Test* Reach CHR-D-1	*Baseline* Reach CHR-D-2
Sample Date	-	Sept 10, 2009	Sept 17, 2009
Habitat	-	Depositional	Depositional
Water Depth	m	0.5	0.2
Current Velocity	m/s	0.25	0.2
Macrophyte Cover	%	0	0
Field Water Quality			
Dissolved Oxygen	mg/L	12.69	nm
Conductivity	µS/cm	380	284
pH	pH units	8.62	8.45
Water Temperature	°C	16.5	17.1
Sediment Composition			
Sand	%	59	95
Silt	%	29	4
Clay	%	12	1
Total Organic Carbon	%	1.0	0.2

nm: not measured

Table 5.9-11 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the Christina River.

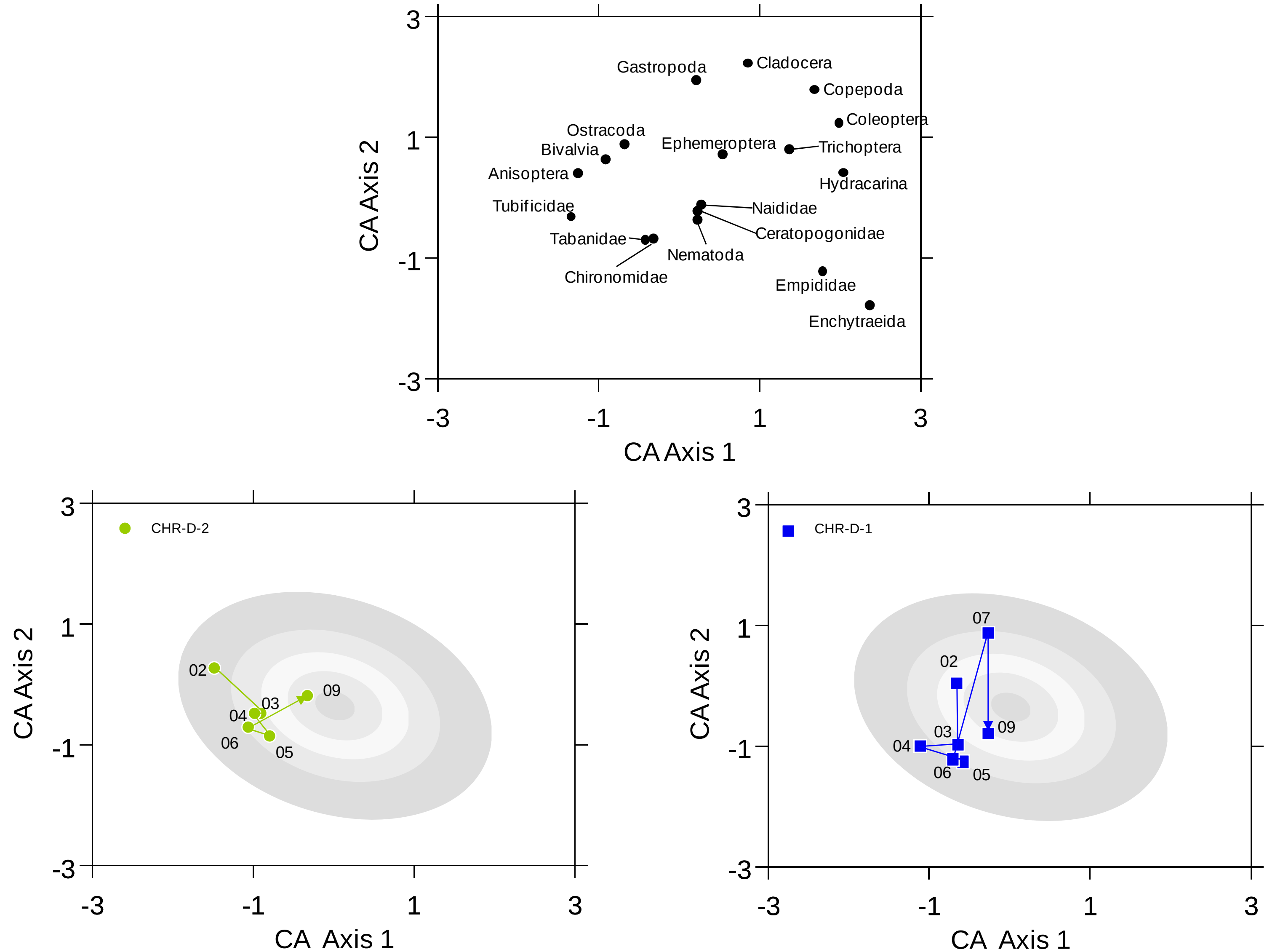
Taxon	Percent Major Taxa Enumerated in Each Year												
	Test Reach CHR-D-1							*Baseline* Reach CHR-D-2					
	2002	2003	2004	2005	2006	2007	2009	2002	2003	2004	2005	2006	2009
Anisoptera	<1	<1	<1	<1	<1	1		<1	<1		<1	<1	
Bivalvia	11	1	1	<1		<1	2	3	<1	7			<1
Ceratopogonidae	<1	1	7	3	8	1	4	2		2	1	<1	1
Chironomidae	39	23	29	46	70	15	16	44	99	28	89	91	96
Cladocera						3	<1	<1					
Coleoptera						<1				<1		<1	
Copepoda	<1	<1				<1	<1	<1		<1			
Dolichopodidae			<1							4			
Empididae		<1	1	1	3		1	<1			1	<1	
Enchytraeidae				<1			<1			3	<1		<1
Ephemeroptera		1	1	1	<1	1	<1	2	<1	<1	<1	<1	<1
Ephydridae			<1							4			
Erpobdellidae		<1	<1										
Gastropoda	2	<1			0.5	2	1	<1					
Glossiphoniidae	<1							<1					
Heteroptera		<1						<1					
Hydracarina						<1	<1		<1				
Lumbriculidae		<1	<1										
Macrothricidae								<1					
Naididae	<1	5	1	2	<1	1	<1		<1	4			1
Nematoda	1	1	2	1	1	1	2	1	<1	11	<1		1
Ostracoda	2	<1	9		1	43	2	24	<1	2			
Plecoptera	<1	<1	<1	<1	<1	<1	1				<1		<1
Tabanidae	<1	<1		<1	0.2	<1	<1	<1		<1	1		
Tipulidae			<1			1		<1		2			<1
Trichoptera	<1	<1		<1	<1	<1		<1	<1		4	4	
Tubificidae	44	66	5	45	16	33	71	23	<1	33	4	3	1
Benthic Invertebrate Community Measurement Endpoints													
Total Abundance (No./m^2)	22,928	10,178	6,405	5,052	9,935	77,955	14,561	63,968	12,963	1,305	3,848	3,122	31,462
Richness	11	8	8	7	14	20	14	20	5	6	6	6	12
Simpson's Diversity	0.60	0.51	0.56	0.59	0.77	0.56	0.68	0.67	0.37	0.55	0.44	0.45	0.51
Evenness	0.67	0.62	0.67	0.73	0.85	0.60	0.74	0.71	0.49	0.81	0.53	0.57	0.56
% EPT	1	2	2	6	1	1	2	3	3	1	7	5	2

Figure 5.9-6 Variation in benthic invertebrate community measurement endpoints in the Christina River.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.9-7 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Christina River.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panels is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.9-12 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the *test* (CHR-D-1) and *baseline* (CHR-D-2) reaches of the Christina River.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Lake - Year	44.923	13	3.456	12.04	0.000
	TT x BT	1.685	1	1.685	5.87	0.017
	Remainder (noise)	43.238	12	3.603	12.55	0.001
	Error	44.781	156	0.287		
Log Richness	Lake - Year	9.293	13	0.715	19.08	0.000
	TT x BT	0.058	1	0.058	1.56	0.214
	Remainder (noise)	9.235	12	0.770	20.54	0.000
	Error	5.844	156	0.037		
Diversity	Lake - Year	2.250	13	0.173	3.46	0.000
	TT x BT	0.025	1	0.025	0.50	0.478
	Remainder (noise)	2.225	12	0.185	3.70	0.056
	Error	7.810	156	0.050		
Evenness	Lake - Year	2.068	13	0.159	2.81	0.001
	TT x BT	0.002	1	0.002	0.03	0.861
	Remainder (noise)	2.067	12	0.172	3.04	0.083
	Error	8.831	156	0.057		
Log %EPT	Lake - Year	12.27	13	0.94	6.65	0.000
	TT x BT	1.39	1	1.39	9.80	0.002
	Remainder (noise)	10.88	12	0.91	6.39	0.012
	Error	22.13	156	0.14		
CA Axis 1	Lake - Year	55.19	13	4.25	7.09	0.000
	TT x BT	4.47	1	4.47	7.46	0.007
	Remainder (noise)	50.72	12	4.23	7.06	0.009
	Error	93.36	156	0.60		
CA Axis 2	Lake - Year	65.49	13	5.04	12.71	0.000
	TT x BT	0.80	1	0.80	2.02	0.157
	Remainder (noise)	64.69	12	5.39	13.60	0.000
	Error	61.83	156	0.40		

Note: TT x BT = Time Trend x *Baseline* vs *Test*

Table 5.9-13 Sediment quality measurement endpoints, Christina River (CHR-D-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	12	5	8	10	17
Silt	%	-	34	5	16	21	38
Sand	%	-	54	5	54	69	74
Total organic carbon	%	-	1.16	5	0.7	1.6	2
Total hydrocarbons							
BTEX	mg/kg	-	<10	3	<5	<5	13
Fraction 1 (C6-C10)	mg/kg	30[2]	<10	3	<5	<5	13
Fraction 2 (C10-C16)	mg/kg	150[2]	40	3	66	81	100
Fraction 3 (C16-C34)	mg/kg	300[2]	**374**	3	200	**830**	**970**
Fraction 4 (C34-C50)	mg/kg	2800[2]	228	3	130	480	600
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.0017	5	0.0012	0.0019	0.008
Retene	mg/kg	-	0.046	5	0.020	0.042	0.149
Total dibenzothiophenes	mg/kg	-	0.815	5	0.252	1.005	3.321
Total PAHs	mg/kg	-	2.679	5	0.975	3.283	11.187
Total Parent PAHs	mg/kg	-	0.089	5	0.045	0.127	0.277
Total Alkylated PAHs	mg/kg	-	2.590	5	0.930	3.190	10.927
Predicted PAH toxicity[1]	H.I.	-	1.220	5	0.647	1.263	2.743
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.6	2	9.0	9.1	9.2
Chironomus growth - 10d	mg/organism	-	2.2	2	2.1	2.4	2.7
Hyalella survival - 14d	# surviving	-	9.0	2	6.0	7.2	8.4
Hyalella growth - 14d	mg/organism	-	0.2	2	0.1	0.2	0.3

Values in **bold** indicate concentrations exceeding guidelines.

[1] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[2] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[3] Interim sediment quality guideline (ISQG) (CCME 2002).

Table 5.9-14 Sediment quality measurement endpoints, Christina River (reach CLR-D-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	3.0	4	2.0	6	13
Silt	%	-	2	4	1	19.5	30
Sand	%	-	95	4	57	74	97
Total organic carbon	%	-	0.12	4	0.1	0.85	1.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	2	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	2	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	2	<5	9	13
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	2	<5	21	47
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	2	<5	13.5	32
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0007	4	0.0014	0.0019	0.003
Retene	mg/kg	-	0.005	4	0.0012	0.044	0.092
Total dibenzothiophenes	mg/kg	-	0.007	4	0.001	0.016	0.021
Total PAHs	mg/kg	-	0.070	4	0.024	0.199	0.296
Total Parent PAHs	mg/kg	-	0.008	4	0.006	0.023	0.029
Total Alkylated PAHs	mg/kg	-	0.062	4	0.018	0.176	0.267
Predicted PAH toxicity[3]	H.I.	-	0.320	4	0.457	0.540	0.882
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.8	3	5.0	7.2	9.0
Chironomus growth - 10d	mg/organism	-	1.4	3	1.8	2.5	4.3
Hyalella survival - 14d	# surviving	-	9.0	3	8.0	9.8	10.0
Hyalella growth - 14d	mg/organism	-	0.3	3	0.1	0.2	0.4

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.9-15 Species composition of the Clearwater River during spring, summer, and fall, 2009.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
arctic grayling	0	0.0	6	1.3	7	2.1
burbot	0	0.0	2	0.4	1	0.3
emerald shiner	0	0.0	2	0.4	0	0.0
flathead chub	1	0.2	0	0.0	0	0.0
goldeye	41	6.6	2	0.4	1	0.3
lake chub	16	2.6	37	8.1	2	0.6
lake whitefish	3	0.5	1	0.2	3	0.9
longnose sucker	39	6.3	120	26.2	14	4.2
mountain whitefish	6	1.0	2	0.4	7	2.1
northern pike	79	12.7	55	12.0	70	21.1
slimy sculpin	1	0.2	15	3.3	3	0.9
spoonhead sculpin	0	0.0	1	0.2	2	0.6
spottail shiner	131	21.1	52	11.4	19	5.7
trout-perch	33	5.3	53	11.6	26	7.8
walleye	62	10.0	37	8.1	19	5.7
white sucker	209	33.7	136	29.7	154	46.4
yellow perch	0	0.0	19	4.2	4	1.2
Total	**621**	**100**	**540**	**100**	**332**	**100**

Figure 5.9-8 Seasonal species richness in the Clearwater River, 2003 to 2009.

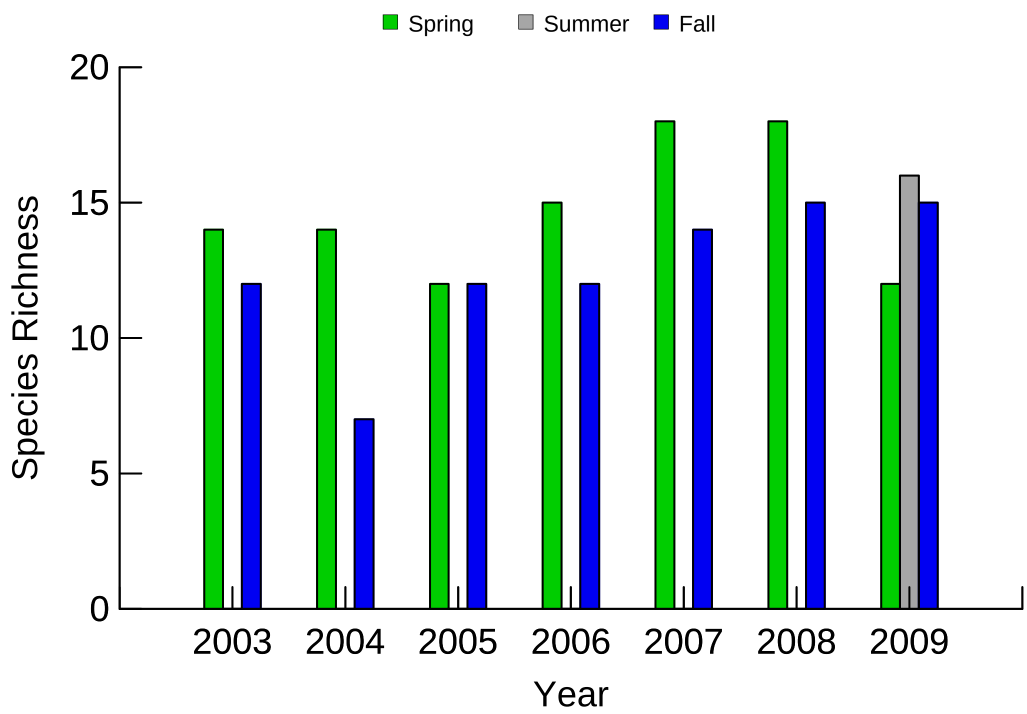


Table 5.9-16 Species composition of fish observed but not captured during the Clearwater River fish inventory in spring, summer, and fall, 2009.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
goldeye	22	2.1	5	2.0	0	0.0
lake chub	0	0.0	20	7.8	0	0.0
longnose sucker	0	0.0	7	2.7	2	0.9
mountain whitefish	3	0.3	0	0.0	0	0.0
northern pike	81	7.8	62	24.2	56	25.9
sculpin spp.	0	0.0	7	2.7	0	0.0
spottail shiner	783	75.4	6	2.3	55	25.5
trout-perch	46	4.4	54	21.1	56	25.9
walleye	22	2.1	26	10.2	4	1.6
white sucker	82	7.9	65	25.4	43	19.9
yellow perch	0	0.0	4	1.6	0	0.0
Total	1,039	100	256	100	216	100

Note: Counts are approximate based on field observations.

Figure 5.9-9 Seasonal catch per unit effort (CPUE) for all species combined and for all KIR species combined in the Clearwater River, 2003 to 2009.

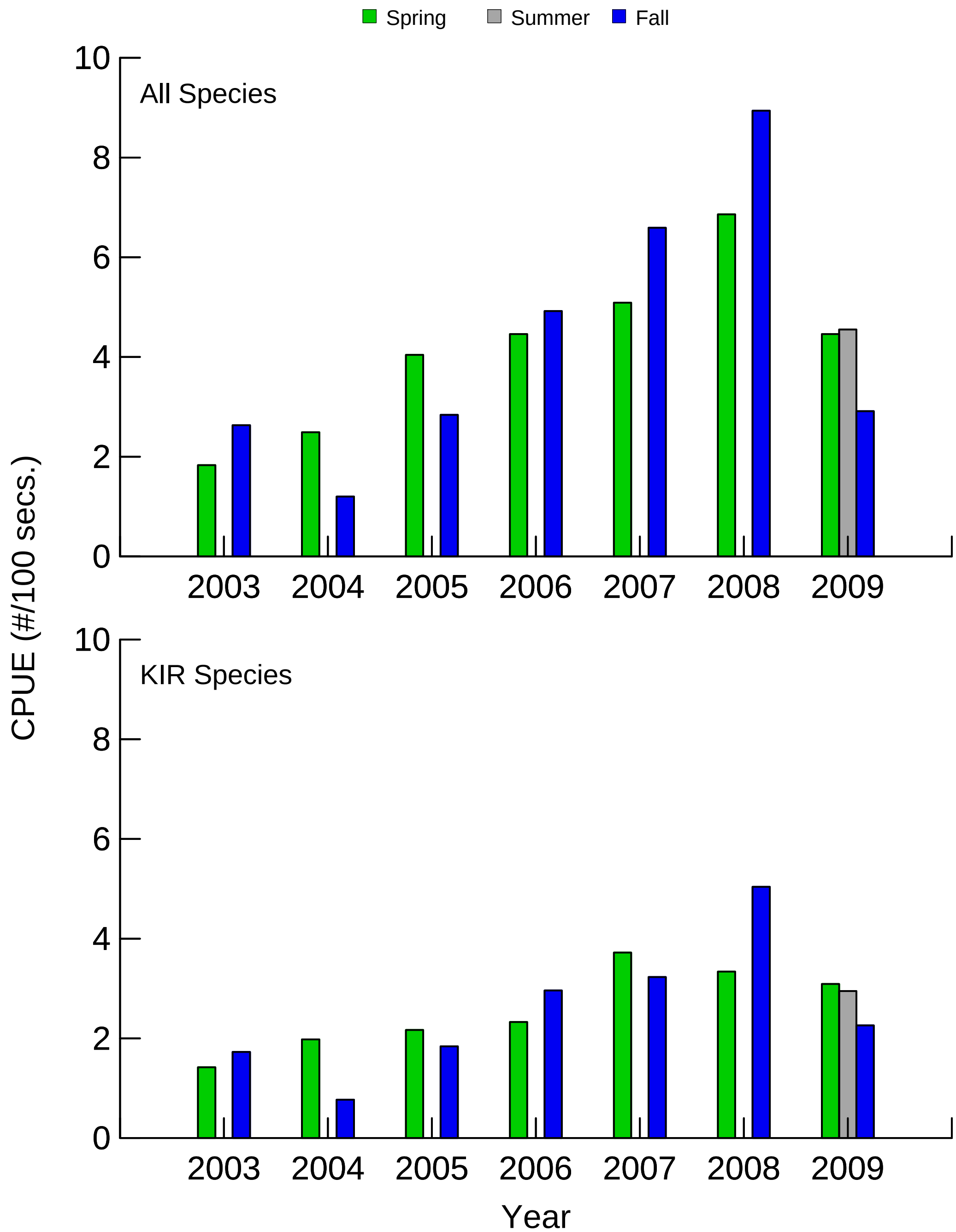


Figure 5.9-10 Seasonal catch per unit effort for captured KIR species, Clearwater Inventory, 2003-2009.

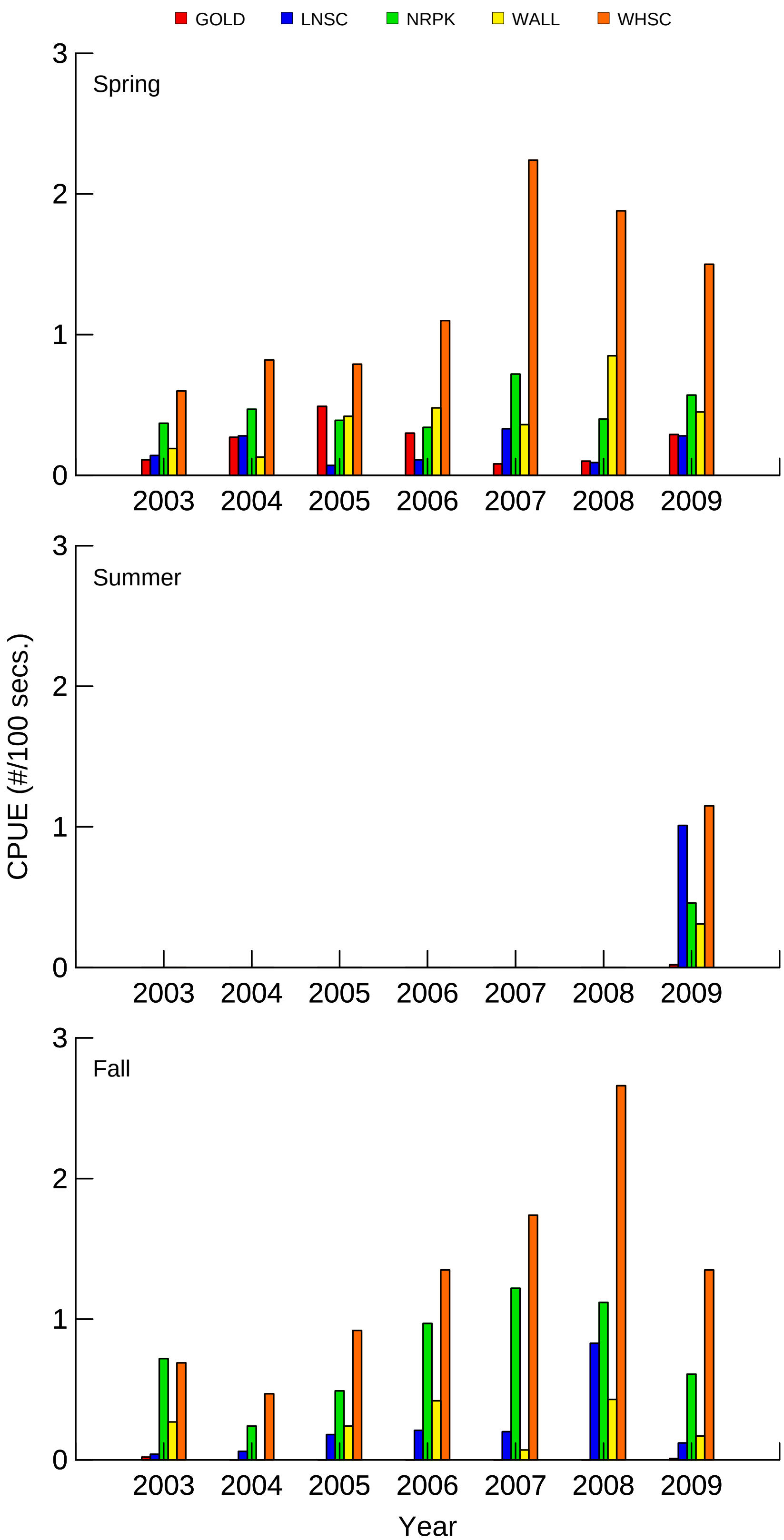
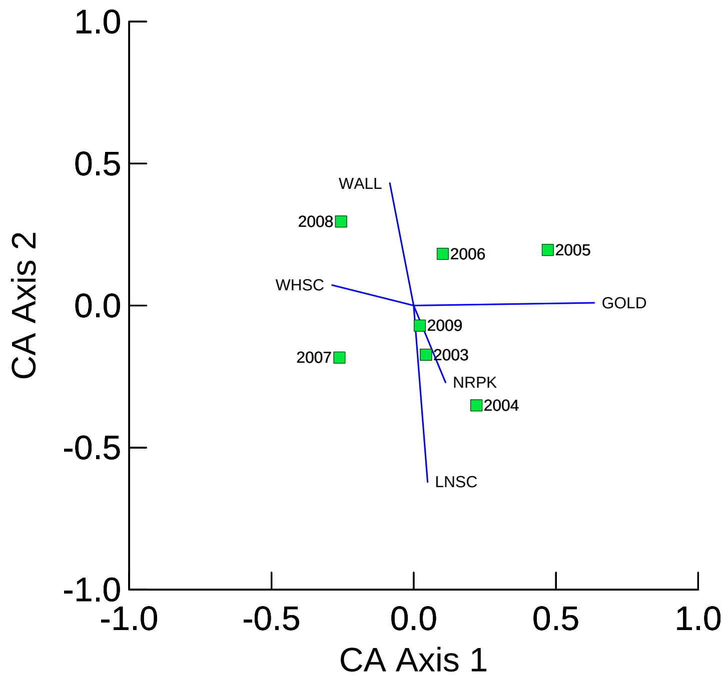


Figure 5.9-11 Correspondence analysis for KIR species captured in the spring and fall Clearwater River inventory, 2003 to 2009.



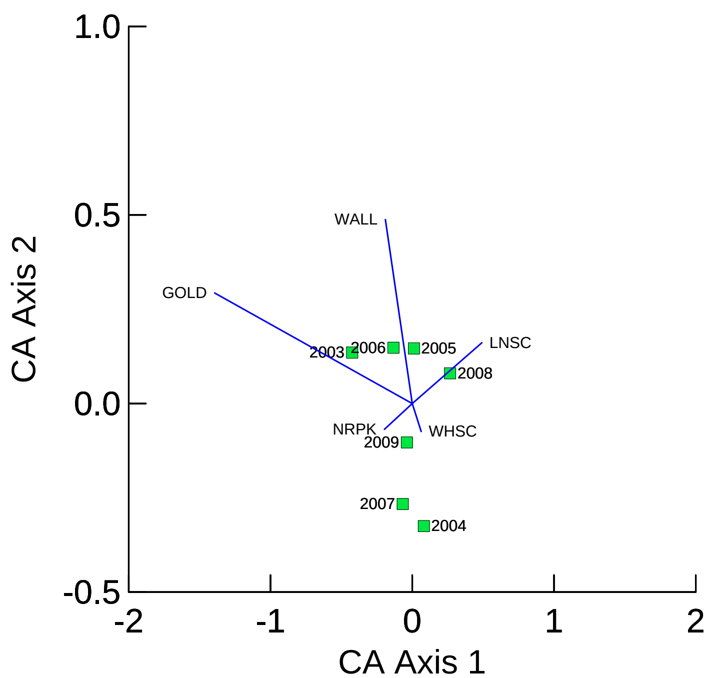


Figure 5.9-12 Relative length-frequency distribution for goldeye captured in the Clearwater River, spring and fall 2003-2009 (upper pane) and spring and fall 2009 (lower pane); 50 mm length classes; n=44.

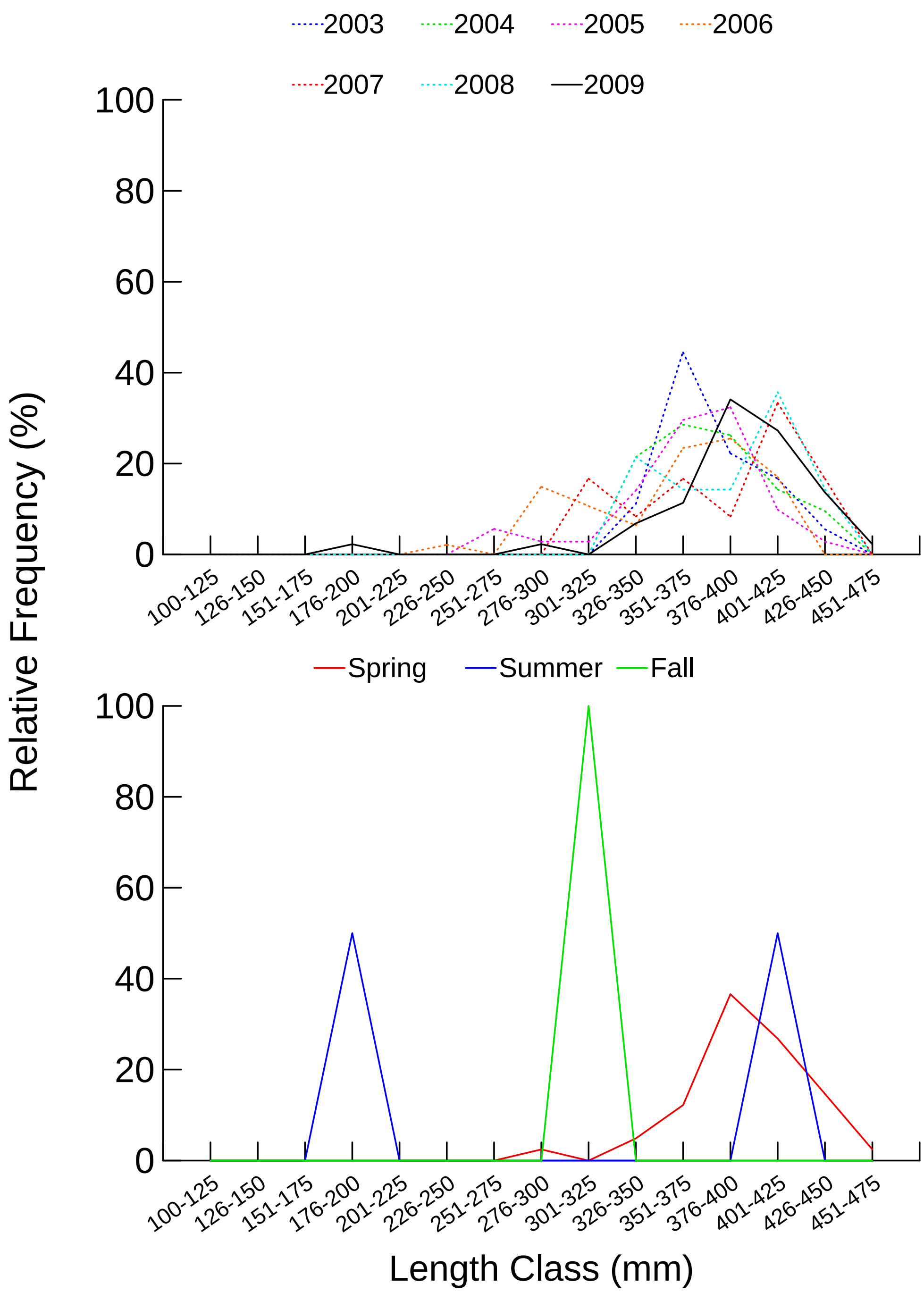


Figure 5.9-13 Relative length-frequency distributions for longnose sucker captured in the Clearwater River, spring and fall 2003-2009 (upper pane) and spring and fall 2009 (lower pane); 50 mm length classes; n=173.

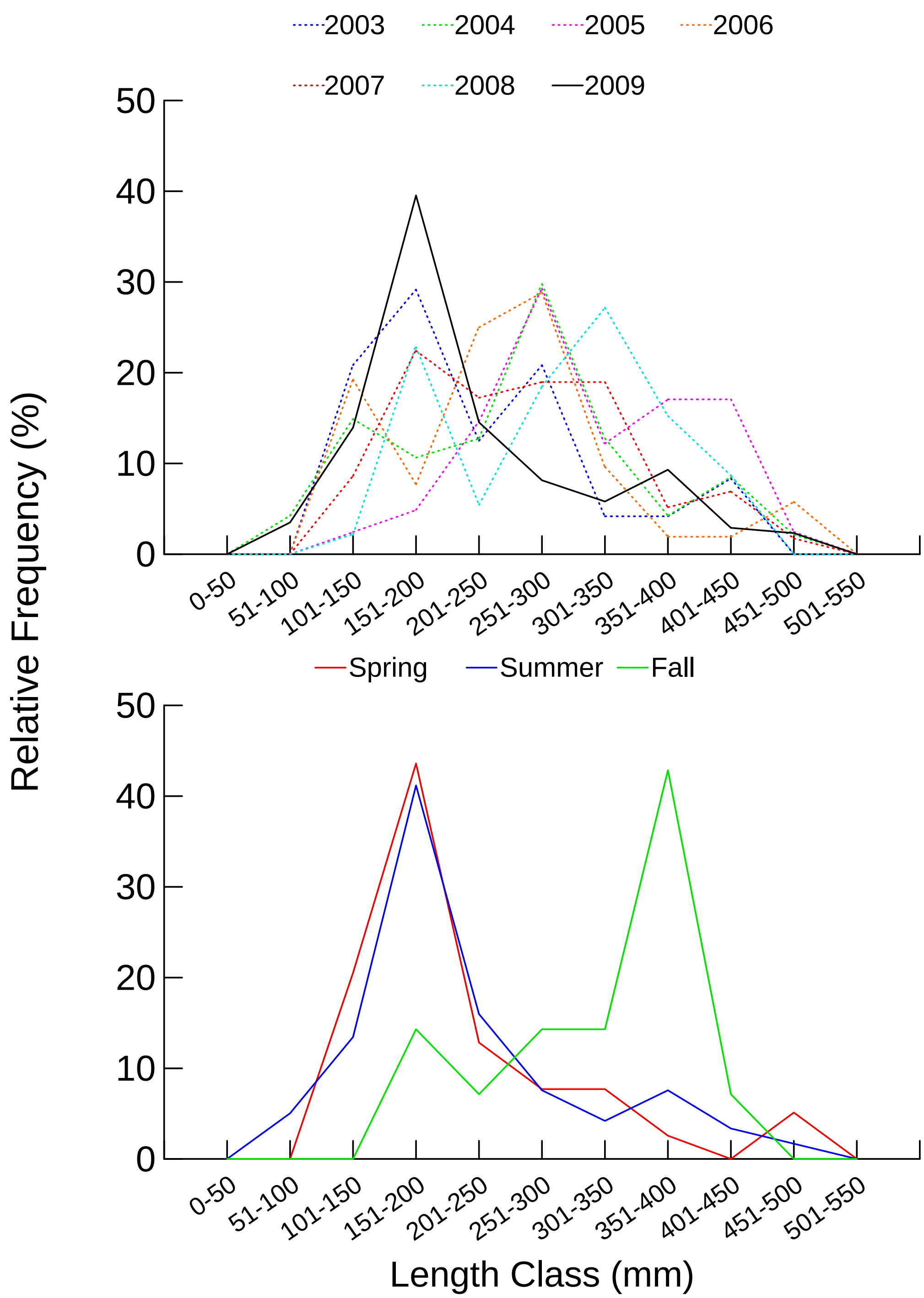


Figure 5.9-14 Relative length-frequency distributions for northern pike captured in the Clearwater River, spring and fall 2003-2009 (upper pane) and spring and fall 2009 (lower pane); 50 mm length classes; n=204.

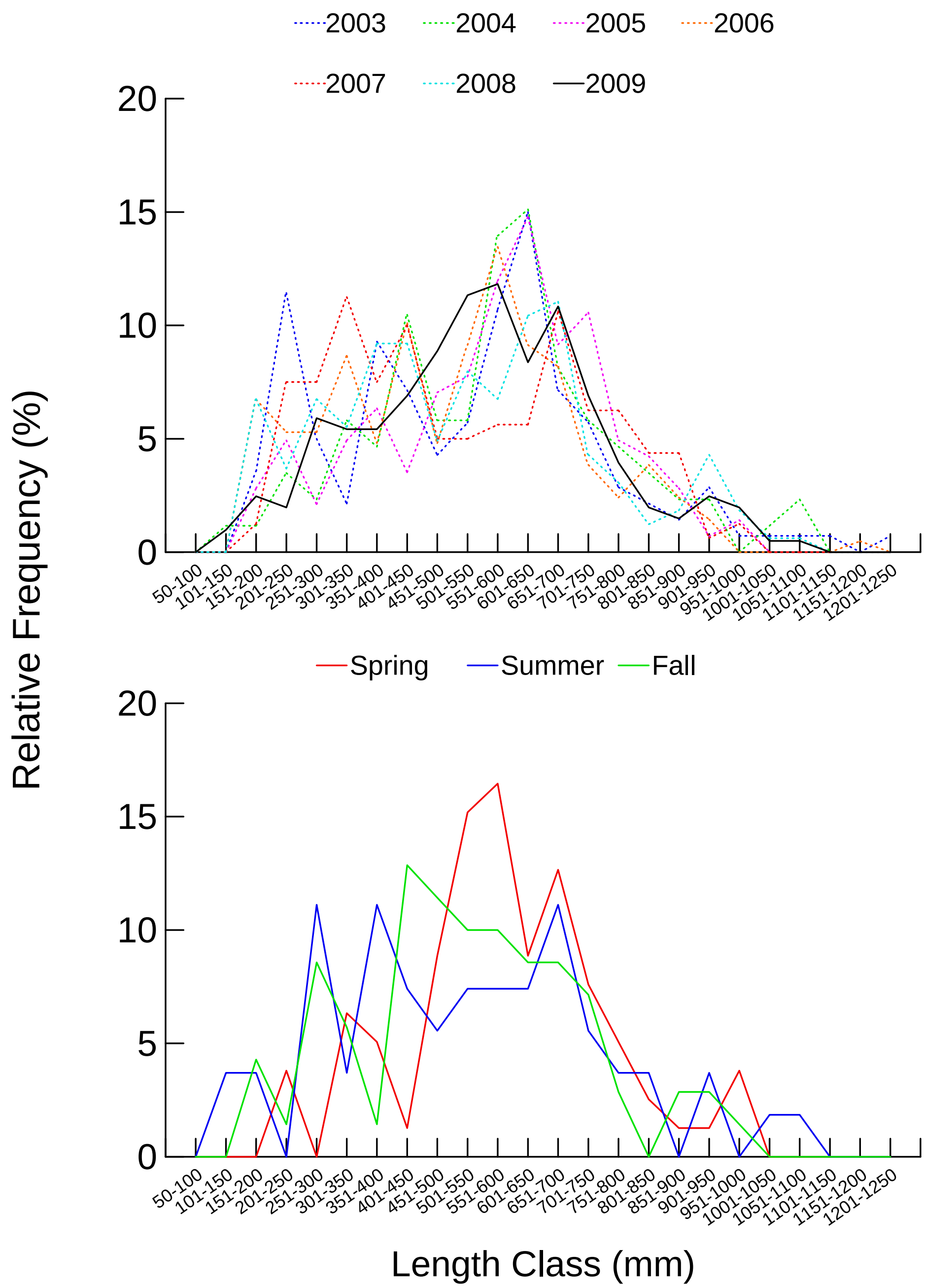


Figure 5.9-15 Relative length-frequency distributions for walleye captured in the Clearwater River, spring and fall 2003-2009 (upper pane) and spring and fall 2009 (lower pane); 50 mm length classes; n=118.

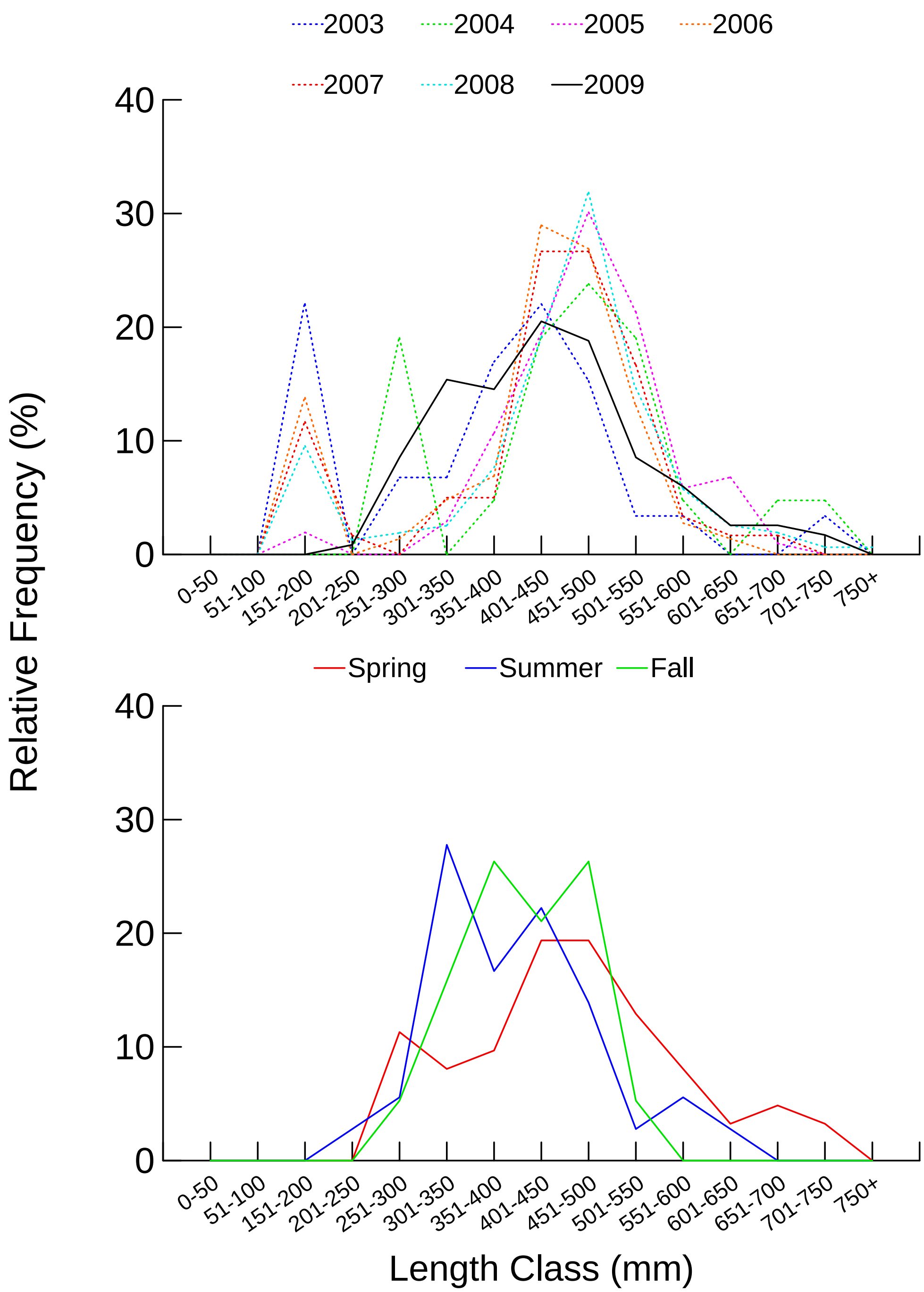


Figure 5.9-16 Relative length-frequency distributions for white sucker captured in the Clearwater River, spring and fall 2003-2009 (upper pane) and spring and fall 2009 (lower pane); 50 mm length classes; n=499.

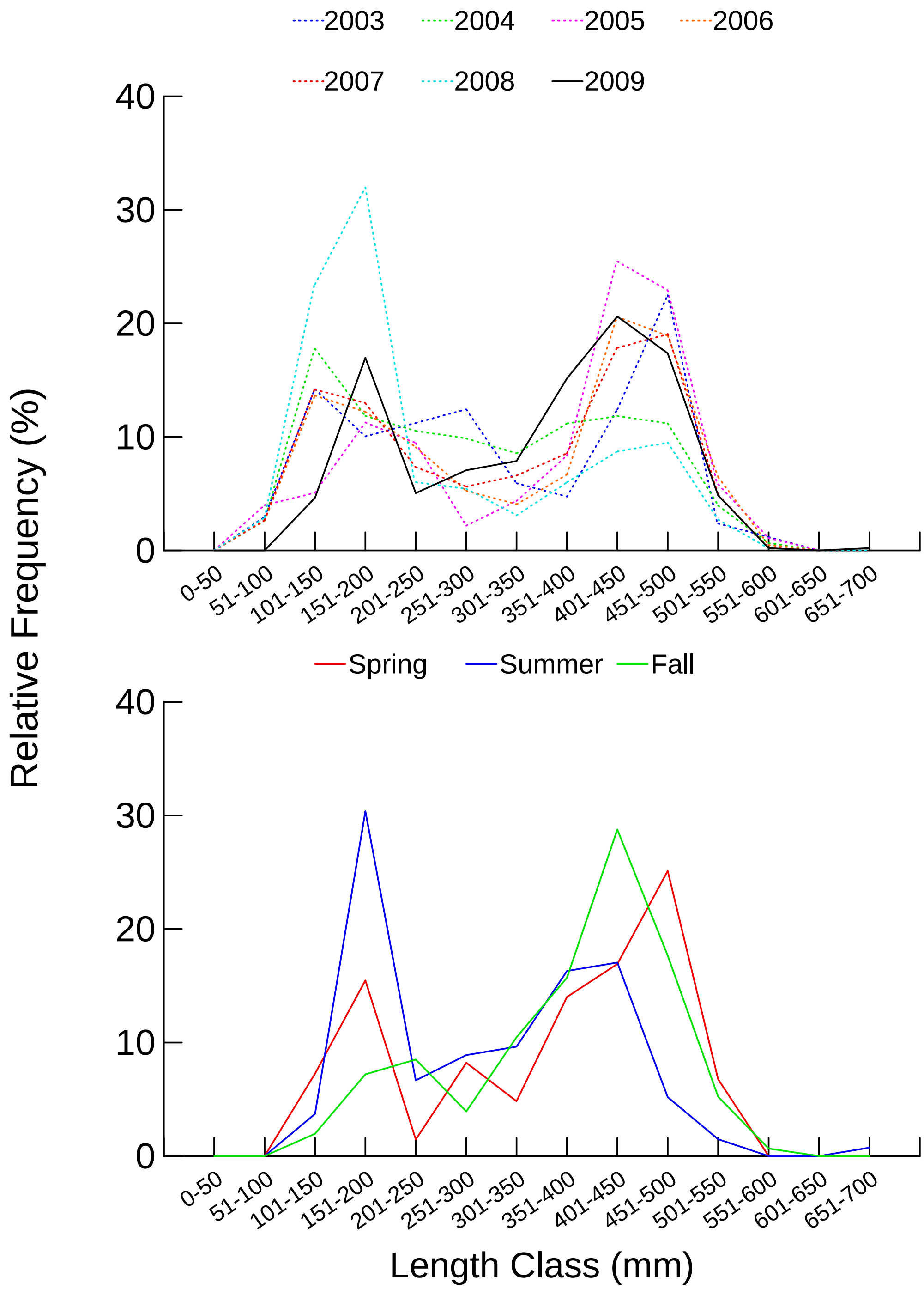
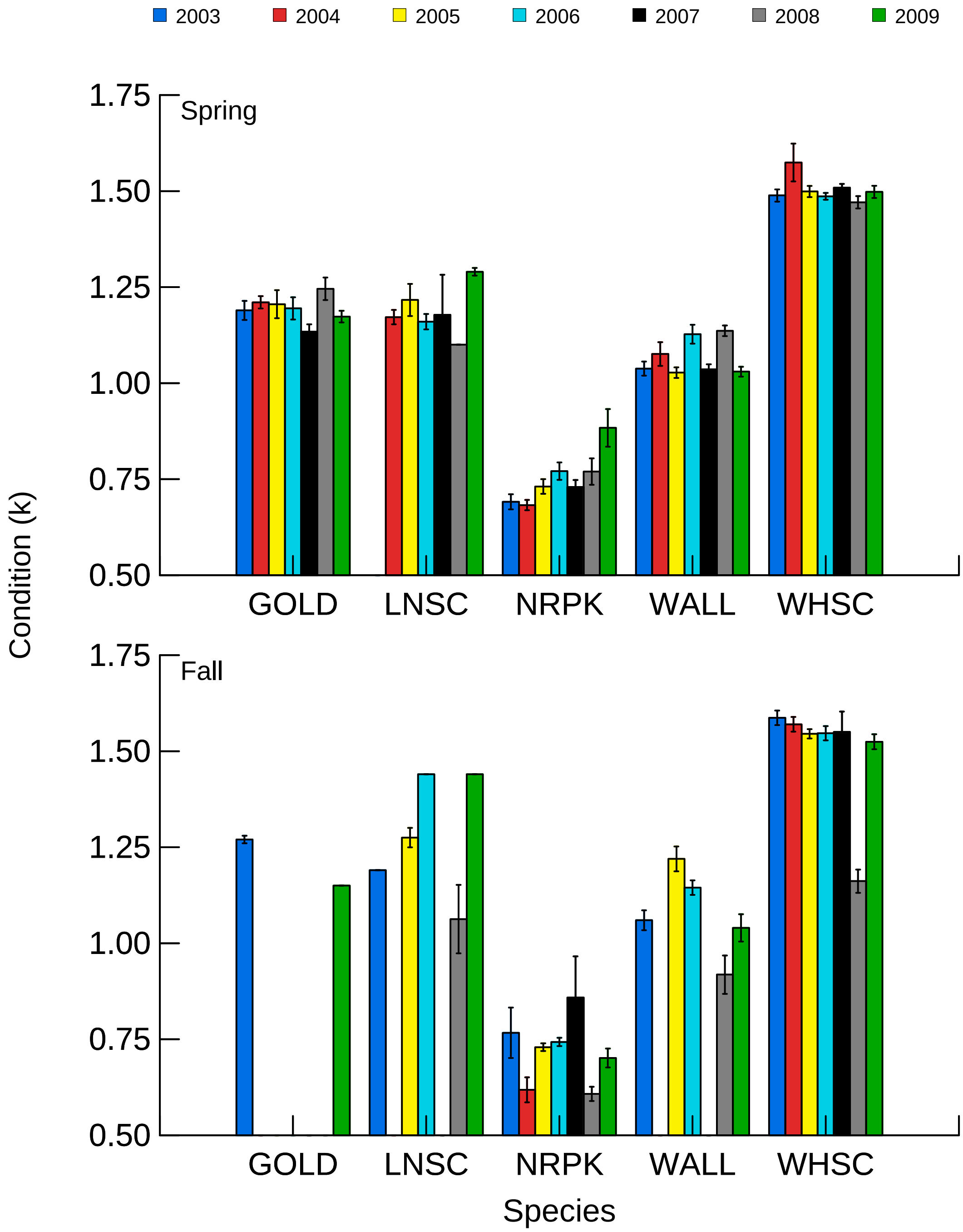


Figure 5.9-17 Condition factor (mean ± 1SE) for KIR fish species captured in the Clearwater River, 2003 to 2009.



Note: Condition factor = (weight/length^3)*10^5

Table 5.9-17 Summary of mean health assessment index (HAI) scores for five key indicator fish species, Clearwater River, 2003 to 2009.

Year	Goldeye			Longnose Sucker			Northern Pike			Walleye			White Sucker		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
2003	1.9	-	-	0.5	-	0.04	1.9	-	1.4	0.7	-	1.2	2.0	-	0.5
2004	0.5	-	-	0.2	-	3.3	2.8	-	1.7	0.5	-	-	0.7	-	2.1
2005	0.3	-	-	1.0	-	1.3	1.4	-	0.2	0.0	-	0.5	0.9	-	0.2
2006	1.9	-	-	0.0	-	0.9	3.1	-	1.4	0.9	-	0.3	1.8	-	0.9
2007	1.7	-	-	1.2	-	0.0	4.4	-	3.4	0.6	-	0.0	3.5	-	0.8
2008	3.6	-	-	3.8	-	0.4	6.1	-	2.2	2.8	-	0.5	2.6	-	0.3
2009	0.7	0.0	0.0	0.0		1.4	8.6	2.9	1.6	2.1	0.5	1.6	2.3	2.1	0.7

Note: 2009 was the first year of sampling in the summer for the RAMP Clearwater Inventory.

Table 5.9-18 Percent of KIR fish species captured with some form of external pathology, Clearwater River, 2003 to 2009.

Year	Goldeye			Longnose Sucker			Northern Pike			Walleye			White Sucker		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
2003	0.0	-	-	0.0	-	0.0	0.0	-	0.03	0.0	-	0.03	0.0	-	0.0
2004	0.0	-	-	0.0	-	0.0	0.01	-	0.0	0.0	-	-	0.0	-	0.0
2005	0.01	-	-	0.0	-	0.0	0.0	-	0.0	0.0	-	0.02	0.0	-	0.0
2006	0.0	-	-	0.0	-	0.0	0.0	-	0.03	0.0	-	0.0	0.0	-	0.01
2007	0.0	-	-	0.0	-	0.0	0.01	-	0.1	0.0	-	0.0	0.01	-	0.0
2008	0.0	-	-	0.0	-	0.03	0.02	-	0.02	0.03	-	0.0	0.02	-	0.004
2009	0.0	0.0	0.0	0.0	0.02	0.1	0.0	0.0	0.03	0.02	0.1	0.1	0.01	0.1	0.01

Note: 2009 was the first year of sampling in the summer for the RAMP Clearwater Inventory.

Table 5.9-19 Mercury concentration and whole-organism metrics of northern pike collected from the Clearwater River, fall 2009, and screened of concentrations against criteria for fish consumption criteria for the protection of human health.

Date	Fish ID	Type of Sample	Sex	Length (mm)	Weight (g)	Age (yrs)	Hg (mg/kg)
Oct 6/09	NRPK-1-3B	dissected	M	463	644	5	0.201
Oct 5/09	NRPK-1-1A	dissected	M	450	567	3	0.115
Oct 5/09	NRPK-2-1A	dissected	M	532	969	5	**0.183**
Oct 6/09	NRPK-2-2C	dissected	F	508	772	4	0.085
Oct 6/09	NRPK-1-2B	dissected	F	545	1,055	4	**0.180**
Oct 5/09	NRPK-6-1A	dissected	M	481	702	4	0.100
Oct 5/09	NRPK-3-1A	dissected	F	538	934	4	0.132
Oct 6/09	NRPK-1-2C	dissected	F	504	789	5	**0.186**
Oct 6/09	NRPK-1-3A	dissected	F	500	840	4	0.115
Oct 6/09	NRPK-4-2B	non-lethal plug	U	592	-	4	**0.149**
Oct 5/09	NRPK-17-1B	non-lethal plug	U	244	95	2	0.065
Oct 5/09	NRPK-30-2A	non-lethal plug	U	585	1,314	6	**0.155**
Oct 5/09	NRPK-17-1A	non-lethal plug	F	466	712	4	0.091
Oct 5/09	NRPK-18-1A	non-lethal plug	F	359	320	3	0.080
Oct 5/09	NRPK-21-1A	non-lethal plug	U	360	301	3	0.108
Oct 5/09	NRPK-22-1A	non-lethal plug	U	234	75	3	0.077
Oct 5/09	NRPK-9-1A	non-lethal plug	U	240	89	2	0.071
Oct 5/09	NRPK-10-1A	non-lethal plug	U	553	-	5	0.151
Oct 5/09	NRPK-9-1B	non-lethal plug	U	635	1,666	-	0.208
Oct 5/09	NRPK-8-1B	non-lethal plug	U	378	337	5	**0.145**
Oct 5/09	NRPK-7-1A	non-lethal plug	F	635	1,475	7	**0.175**
Oct 5/09	NRPK-8-1A	non-lethal plug	U	435	557	5	0.100
Oct 5/09	NRPK-4-1A	non-lethal plug	U	466	646	5	0.133
Oct 5/09	NRPK-5-1A	non-lethal plug	U	708	2,474	6	0.086
Oct 5/09	NRPK-15-1B	non-lethal plug	U	295	164	2	**0.155**
Oct 5/09	NRPK-16-1B	non-lethal plug	U	239	92	3	0.081
Oct 5/09	NRPK-10-1B	non-lethal plug	U	360	395	3	0.097
Oct 5/09	NRPK-11-1B	non-lethal plug	U	359	285	4	**0.165**
Oct 5/09	NRPK-11-1A	non-lethal plug	U	656	2,332	6	**0.167**
Oct 5/09	NRPK-12-1A	non-lethal plug	U	680	1,832	-	0.249

M = Male; F= Female; U= Unknown

exceeds National USEPA Criterion for subsistence fishers (0.049 mg/kg)

exceeds Region III USEPA Risk-Based Criterion (0.14 mg/kg)

exceeds Health Canada Criterion for subsistence fishers (0.20 mg/kg)

exceeds USEPA National Criterion for recreational fishers (0.40 mg/kg)

exceeds Health Canada Criterion for general consumers (0.50 mg/kg)

Figure 5.9-18 Mean mercury concentrations (± 95% CI) by length class for northern pike captured in the Clearwater River, fall 2009.

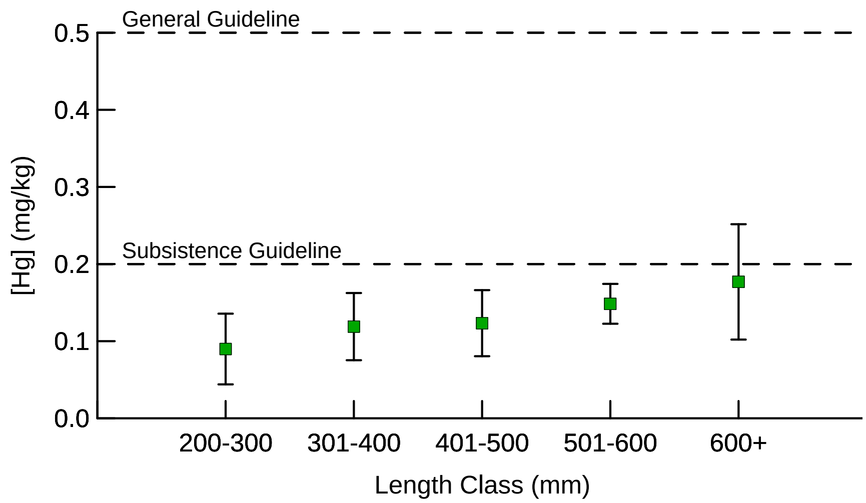
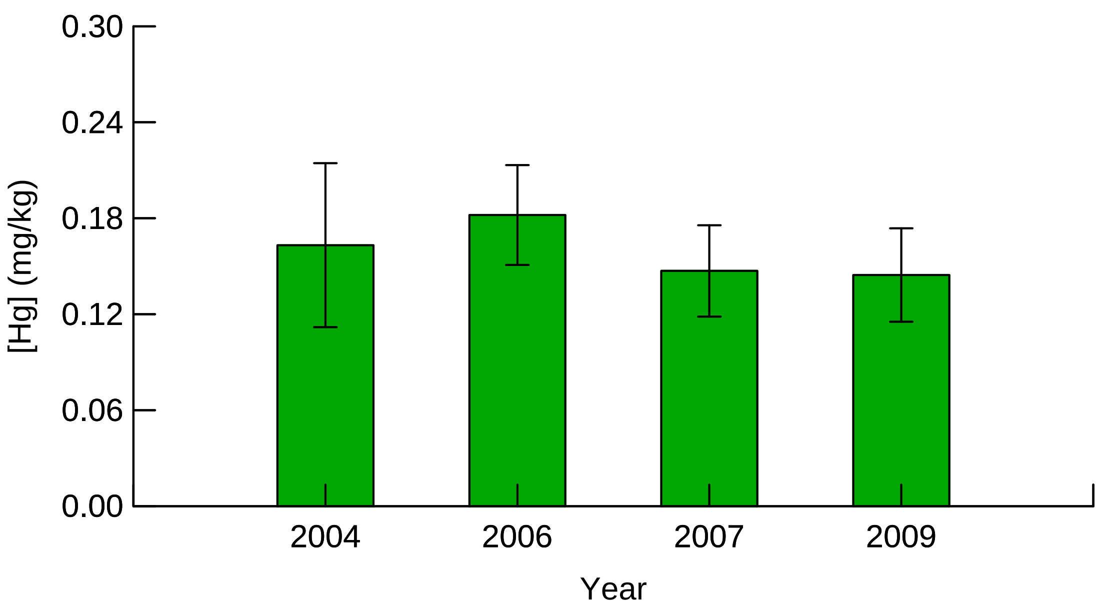
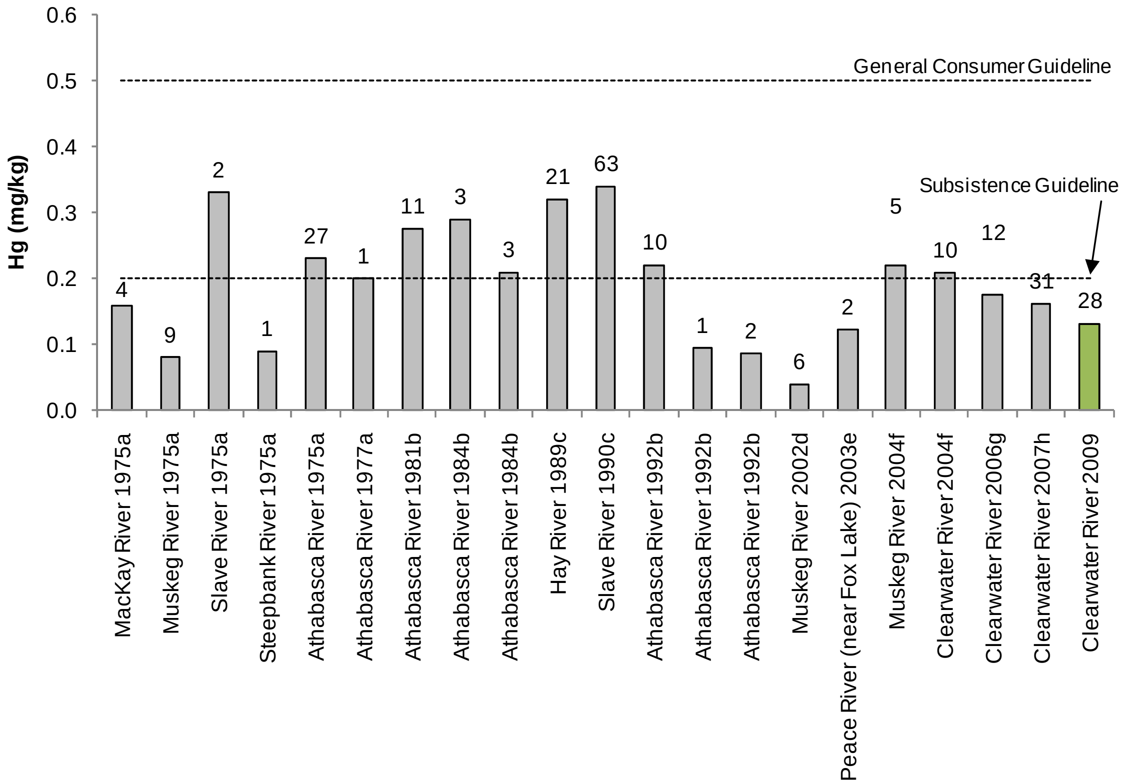


Figure 5.9-19 Temporal comparison of mercury concentration (± 1SE) in northern pike muscle from the Clearwater River, fall 2004, 2006, 2007, and 2009.



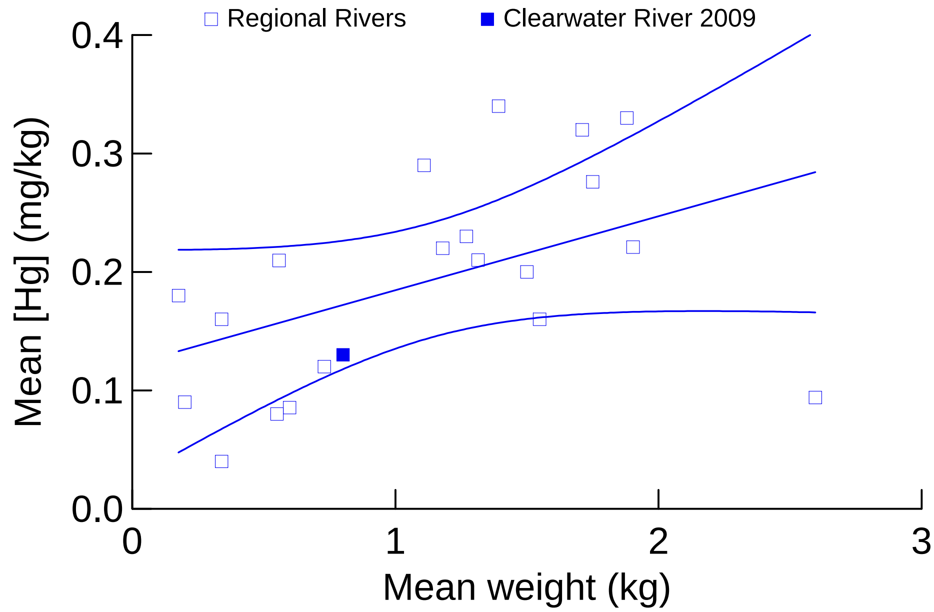
Note: Length-adjusted mercury concentrations were used for temporal comparisons.

Figure 5.9-20 Mean mercury concentrations in northern pike from regional watercourses, 1975 to 2009 (sample size represented by number on each bar).



Note: Green bars indicate mercury concentrations from fish collected for the 2009 RAMP Fisheries Program. Years denoted with “a” - data from NRBS (1996); years denoted with “b” – data from AOSERP (1977); years denoted with “c” – data from Grey *et al*. (1995); years denoted with “d” – data from RAMP (2003); years denoted with “e” – data from Golder (2004); years denoted with “f” – data from RAMP (2004); years denoted with “g” – data from RAMP (2007); years denoted with “h” – data from RAMP (2008).

Figure 5.9-21 Relationship between mercury and fish weight (mean ±95% CI) for northern pike in regional rivers within the RAMP FSA, 1976 to 2009.



Note: Regression of mercury concentration and mean weight was statistically significant ($p=0.002$, $r^2=0.143$).

Table 5.9-20 Screening of metals and tainting compounds in northern pike composite samples collected in 2009 from the Clearwater River against fish consumption criteria for the protection of human health.

	Units	Detection Limit	Composite NRPK Male[1] (n=4)	Composite NRPK Female[2] (n=5)	Guidelines: Health Canada Subsistence[3]	Health Canada General[4]	National USEPA[5] Subsistence	National USEPA[5] Recreational	Region III USEPA[6] Risk-based Criteria
Total Metals									
Aluminum (Al)	mg/kg	2	<2.0	<2.0	nc	nc	nc	nc	nc
Antimony (Sb)	mg/kg	0.01	<0.010	<0.010	nc	nc	nc	nc	0.54
Arsenic (As)	mg/kg	0.002	**<u>0.036</u>**	**<u>0.036</u>**	nc	nc	0.00327	0.026	0.0021
Barium (Ba)	mg/kg	0.02	0.067	0.082	nc	nc	nc	nc	270
Beryllium (Be)	mg/kg	0.05	<0.050	<0.050	nc	nc	nc	nc	2.7
Bismuth (Bi)	mg/kg	0.06	<0.060	<0.060	nc	nc	nc	nc	nc
Cadmium (Cd)	mg/kg	0.006	<0.0060	<0.0060	nc	nc	nc	nc	1.4
Calcium (Ca)	mg/kg	2	579	630	nc	nc	nc	nc	nc
Chromium (Cr)	mg/kg	0.1	0.2	0.17	nc	nc	nc	nc	4.1
Cobalt (Co)	mg/kg	0.1	<0.10	<0.10	nc	nc	nc	nc	nc
Copper (Cu)	mg/kg	0.1	0.26	0.17	nc	nc	nc	nc	54
Iron (Fe)	mg/kg	1	2.7	2.1	nc	nc	nc	nc	410
Lead (Pb)	mg/kg	0.02	<0.020	<0.020	nc	nc	nc	nc	nc
Lithium (Li)	mg/kg	0.1	<0.10	<0.10	nc	nc	nc	nc	nc
Magnesium (Mg)	mg/kg	1	289	291	nc	nc	nc	nc	nc
Manganese (Mn)	mg/kg	0.05	0.567	0.397	nc	nc	nc	nc	190
Molybdenum (Mo)	mg/kg	0.01	0.018	<0.010	nc	nc	nc	nc	6.8
Nickel (Ni)	mg/kg	0.1	<0.10	<0.10	nc	nc	nc	nc	27
Phosphorus (P)	mg/kg	5	2540	2480	nc	nc	nc	nc	nc
Potassium (K)	mg/kg	20	4100	4020	nc	nc	nc	nc	nc
Selenium (Se)	mg/kg	0.004	0.157	0.111	nc	nc	2.457	20	6.8
Silver (Ag)	mg/kg	0.02	<0.020	<0.020	nc	nc	nc	nc	6.8
Sodium (Na)	mg/kg	20	252	279	nc	nc	nc	nc	nc
Strontium (Sr)	mg/kg	0.05	0.744	0.805	nc	nc	nc	nc	810
Thallium (Tl)	mg/kg	0.01	<0.010	<0.010	nc	nc	nc	nc	0.095
Tin (Sn)	mg/kg	0.05	<0.050	<0.050	nc	nc	nc	nc	810
Titanium (Ti)	mg/kg	0.1	<0.10	<0.10	nc	nc	nc	nc	nc
Uranium (U)	mg/kg	0.002	<0.0020	<0.0020	nc	nc	nc	nc	nc
Vanadium (V)	mg/kg	0.06	<0.060	<0.060	nc	nc	nc	nc	1.4
Zinc (Zn)	mg/kg	0.1	3.85	3.68	nc	nc	nc	nc	410
Tainting Compounds									
1,3,5-Trimethylbenzene	mg/kg	0.004	<0.0040	<0.0040	nc	nc	nc	nc	13.5
Naphthalene[7]	mg/kg	0.05	<0.050	<0.050	nc	nc	nc	nc	94.6
m+p-Xylenes	mg/kg	0.008	<0.0080	<0.0080	nc	nc	nc	nc	270
Thiophene	mg/kg	0.0004	<0.00040	<0.00040	nc	nc	nc	nc	nc
Toluene	mg/kg	0.004	<0.0040	<0.0040	nc	nc	nc	nc	110

value exceeds Region III USEPA Risk-based Criteria

value exceeds National USEPA subsistence guideline

<u>value exceeds National USEPA Recreation fisher guideline</u>

1 Composite sample of 4 males between 450-500 mm.

2 Composite sample of 5 females between 500-550 mm.

3 http://www.hc-sc.gc.ca/fn-an/pubs/mercur/merc_fish_poisson-eng.php; updated July 2007.

4 http://www.ainc-inac.gc.ca/ncp/pub/hig/hig15_e.html; updated June 2006.

5 http://www.epa.gov/waterscience/fish/advice/volume1/index.html; updated November 2000.

6 http://www.epa.gov/reg3hwmd/risk/human/index.htm; updated December 2009.

7 Naphthalene was tested for three target analytes: 1-Methylnaphthalene; 2,6-Dimethylnaphthalene; and 2,3,5-Trimethylnaphthalene all with a detection limit of 0.05 mg/kg.

nc=no criteria

This page intentionally left blank for printing purposes.

5.10 HANGINGSTONE RIVER WATERSHED

Table 5.10-1 Summary of results for Hangingstone River watershed.

Hangingstone River	Summary of 2009 Conditions
Climate and Hydrology	
Criteria	**WSC 07CD004** Hangingstone River at Fort McMurray
Mean open-water season discharge	○
Mean winter discharge	not measured
Annual maximum daily discharge	○
Minimum open-water season discharge	○
Water Quality	
No Water Quality component activities conducted in 2009	
Benthic Invertebrate Communities and Sediment Quality	
No Benthic Invertebrate Communities component or Sediment Quality component activities conducted in 2009	
Fish Populations	
No Fish Population component activities conducted in 2009	

Legend and Notes

○ Negligible-Low

● Moderate

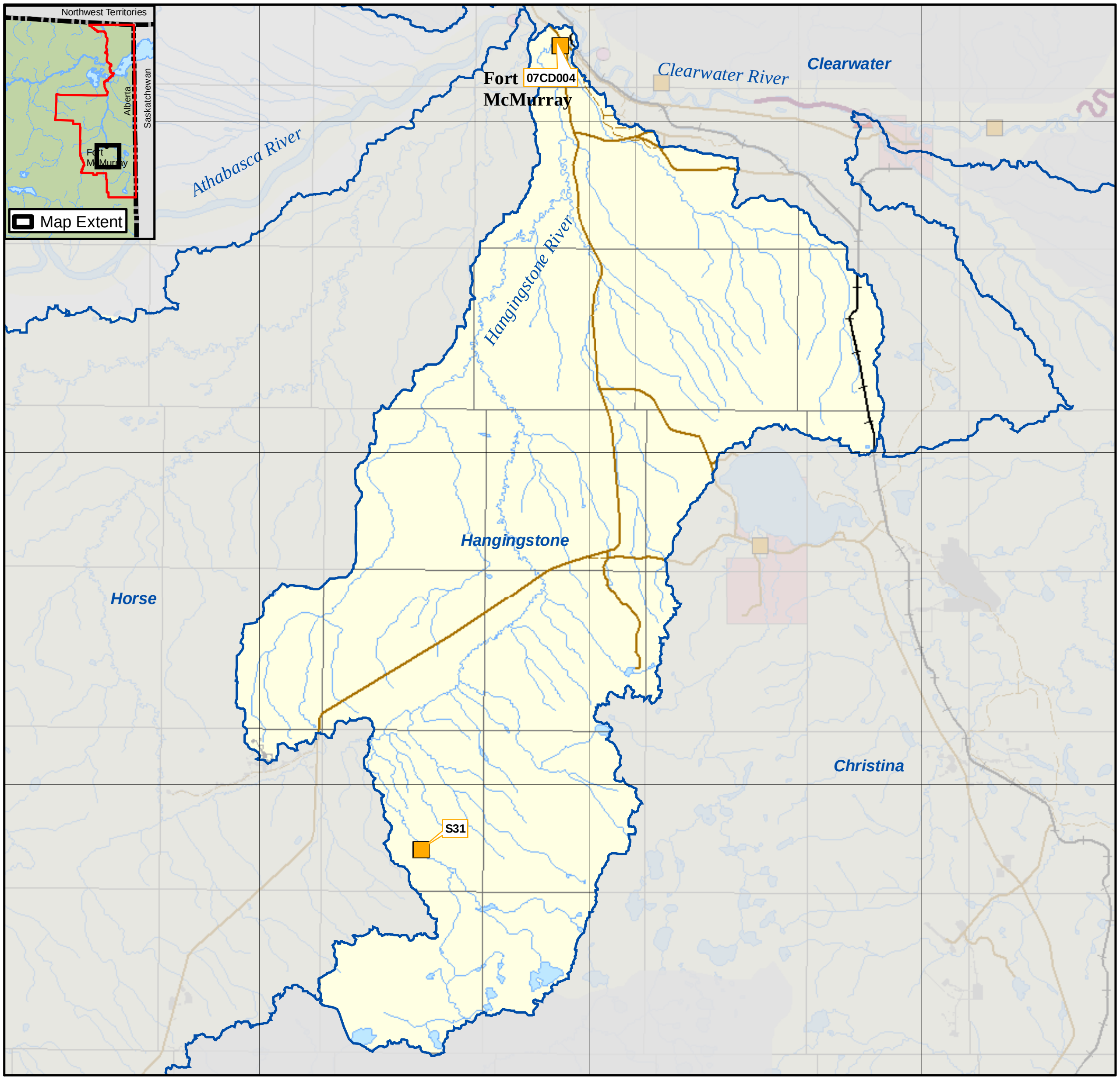
● High

baseline

test

Hydrology: Measurement endpoints calculated on differences between observed hydrograph and estimated hydrographs that would have been observed in the absence of oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Figure 5.10-1 Hangingstone River watershed.



LEGEND

Lake/Pond	Climate Station
River/Stream	Hydrometric Station
Watershed Boundary	Water Quality Sampling Station
Major Road	Benthic Invertebrate Community Sampling Reach
Secondary Road	Benthic Invertebrate Community Sampling Reach and Sediment Quality Sampling Station
Railway	Sediment Quality Sampling Station
First Nations Reserve	Fish Sampling Site
RAMP Regional Study Area	Fish Sampling Reach
RAMP Focus Study Area	
Land Change Area	

RAMP Regional Aquatics Monitoring Program

0 2.5 5 10 km

Scale 1:400,000

Projection: UTM Zone 12 NAD83

Land Change Areas Delineated from 10m SPOT-5 (June, July and August 2009) Multispectral Imagery.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K10_HangingStone_20100415.mxd

5.10.1 Summary of 2009 Conditions

Approximately 0.05% (56 ha) of the Hangingstone River watershed had undergone land change as of 2009 from oil sands developments (Table 2.4-2); none of this land change has been due to focal projects as there have been no focal projects in the Hangingstone River watershed to date.

Only the Climate and Hydrology component of RAMP conducted monitoring activities in the Hangingstone River watershed in 2009. Table 5.10-1 is a summary of the 2009 assessment of the Hangingstone River watershed, while Figure 5.10-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009 in the Hangingstone River watershed. This land change is due to oil sands developments from companies that were not members of RAMP as of 2009.

Hydrology The observed total discharge for the Hangingstone River watershed from March 1 to October 31, 2009 is estimated to be 0.05% less than the total discharge in this period would have been in the absence of oil sands developments in the watershed. The watershed-level hydrologic effects of these oil sands developments are assessed as **Negligible-Low** for mean open-water season discharge, annual maximum daily discharge, and minimum open-water season discharge.

5.10.2 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 07CD004, Hangingstone River at Fort McMurray The open-water (May to October) runoff volume recorded at WSC Station 07CD004 was 103.6 million m^3. This value was the highest recorded since 2005, and exceeded the historical average value by 9%. Flows in 2009 were between historical lower and upper quartile values from March until late June, including a snowmelt-driven increase in flow which peaked at 13.3 m^3/s on May 6, 2009 and equivalent to the historical upper quartile flow for this date (Figure 5.10-2). Flows generally remained within the inter-quartile range from early May until the end of October with the exception of late June, the middle of July, and early September in which flows exceeded 10 m^3/s and historical upper quartile values. The annual maximum daily flow of 22.6 m^3/s recorded on June 30 was 44% lower than the historical mean maximum daily flow, while the minimum daily flow of 1.37 m^3/s recorded on October 21 was 44% higher than the historical mean minimum daily flow (Figure 5.10-2).

Hydrologic Effects of Oil Sands Developments The estimated water balance for March 1 to October 31, 2009 at WSC Station 07CD004 is provided in Table 5.10-3 and described below:

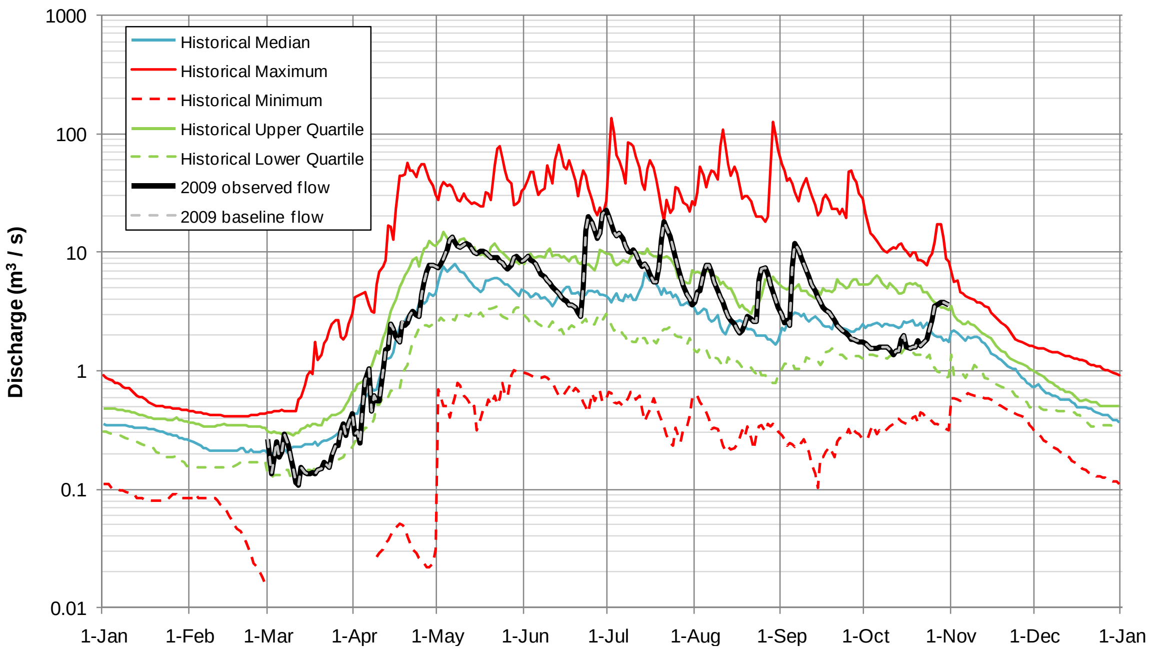
1. The closed-circuited land area as of 2009 was estimated at 0.47 km^2 (Table 2.4-1), representing an estimated loss of flow to the Hangingstone River of 0.54 million m^3 that would have otherwise occurred.

2. The land area not closed-circuited as of 2009 was estimated at 0.09 km^2, representing an estimated increase in flow to the Hangingstone River of 0.002 million m^3 that would not have otherwise occurred.

The estimated cumulative effect is a decrease in flow of 0.052 million m^3 to the Hangingstone River. The estimated hydrograph that would have been observed at WSC Station 07CD004 in the absence of oil sands developments is provided in Figure 5.10-2.

The 2009 open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for WSC Station 07CD004 are estimated to be 0.05% less than they would have been in the absence of oil sands developments (Table 5.10-3). These estimated watershed-level effects of oil sands developments are classified as **Negligible-Low** (Table 5.10-1).

Figure 5.10-2 The observed hydrograph for the Hangingstone River in 2009 and estimated hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on WSC Station 07CD004, Hangingstone River at Fort McMurray, provisional data for March 1 to October 31, 2009. The drainage area upstream of WSC Station 07CD004 is 962 km^2, which is slightly smaller than the size of the entire Hangingstone River watershed (1,066 km^2, Table 2.4-1). Historical values from March 1 to October 31 calculated for the period from 1965 to 2008, and historical values for other months calculated for the period from 1970 to 1987.

Note: Historical minimum daily flows are zero from March 1 to April 9, and are not plotted here due to the logarithmic axis used in the graph.

Table 5.10-2 Estimated water balance at WSC Station 07CD004, Hangingstone River at Fort McMurray, March 1 to October 31 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed hydrograph (total discharge)	**110.85**	**Observed discharge, obtained from WSC Station 07CD004, Hangingstone River at Fort McMurray**
Closed-circuited area water loss from the observed hydrograph	-0.054	Estimated 0.47 km^2 of Hangingstone River watershed closed-circuited by other oil sands developments as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.002	Estimated 0.09 km^2 of Hangingstone River watershed with land change from other oil sands developments as of 2009 that is not closed-circuited (Table 2.4-1)
Water withdrawals from the Hangingstone River watershed from oil sands development projects	0	Assumed
Water releases into the Hangingstone River watershed from oil sands development projects	0	Assumed
Diversions into or out of the watershed	0	Assumed
The difference between observed and estimated hydrographs on tributary streams	0	No other oil sands developments on tributaries of Hangingstone River not accounted for in figures contained in this table
Estimated hydrograph in absence of oil sands development projects (total discharge)	**110.90**	**Estimated discharge at WSC Station 07CD004, Hangingstone River at Fort McMurray that would have been observed in the absence of oil sands developments**
Incremental flow (change in total discharge)	-0.052	Total discharge from observed hydrograph less total discharge of estimated hydrograph
Incremental flow (% of total discharge)	**-0.05%**	**Incremental flow as a percentage of total discharge of estimated hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07CD004, Hangingstone River at Fort McMurray.

Table 5.10-3 Estimated change in hydrologic measurement endpoints for the Hangingstone River watershed, 2009.

Measurement Endpoint	Value from Estimated Hydrograph in Absence of Oil Sands Developments (m^3/s)	Value from Observed Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	6.522	6.519	-0.05%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	22.61	22.60	-0.05%
Open-water period minimum daily discharge	1.371	1.370	-0.05%

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Values are calculated from provisional data for March 1 to October 31, 2009 for WSC Station 07CD004, Hangingstone River at Fort McMurray.

5.11 HORSE RIVER WATERSHED

Table 5.11-1 Summary of results for Horse River watershed.

Horse River	Summary of 2009 Conditions
Climate and Hydrology	
No Climate and Hydrology component activities conducted in 2009	
Water Quality	
Criteria	**HOR-1** Horse River
Water Quality Index	
Benthic Invertebrate Communities and Sediment Quality	
Criteria	**HOR-E-1** Horse River
Benthic Invertebrate Communities	n/a
No Sediment Quality component activities conducted in 2009	
Fish Populations	
Fish Population component activities included a sentinel species study (Section 5.4) and a Fish Assemblage Monitoring Pilot Study (Section 6)	

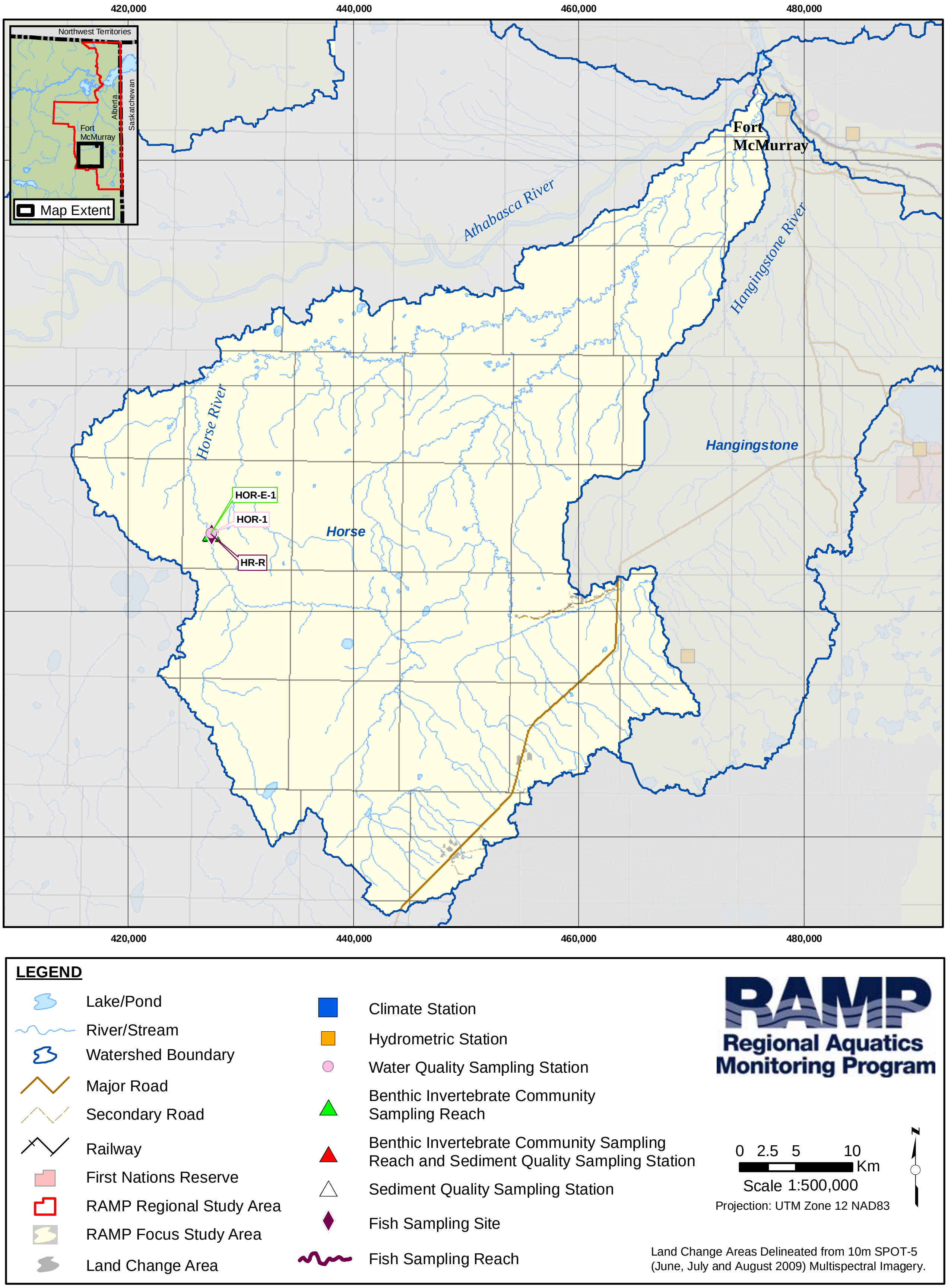
Legend and Notes

- Negligible-Low
- Moderate
- High
- *baseline*
- *test*

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Figure 5.11-1 Horse River watershed.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K11_Horse_20100415.mxd

Figure 5.11-2 Representative monitoring stations of the Horse River, fall 2009.

Sentinel Species Site HR-R: Right Downstream Bank

Water Quality Station HOR-1: Left Downstream Bank

5.11.1 Summary of 2009 Conditions

Approximately 0.18% (388 ha) of the Horse River watershed had undergone land change as of 2009 from oil sands developments (Table 2.4-2); none of this land change has been due to focal projects, as there have been no focal projects located in the Horse River watershed to date. The entire Horse River watershed is designated as *baseline* for 2009, but monitoring data from the Horse River watershed were not used in the calculation of regional *baseline* ranges for water quality or benthic invertebrate communities because of the existence of oil sands developments in the watershed upstream of RAMP monitoring stations (Figure 5.11-1).

Table 5.11-1 is a summary of the 2009 assessment for the Horse River watershed, while Figure 5.11-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.11-2 contains fall 2009 photos of monitoring stations in the watershed.

Water Quality Concentrations of seven out of 15 selected water quality measurement endpoints at the Horse River *baseline* station in fall 2009 were outside the range of regional *baseline* concentrations. The WQI value for the Horse River watershed indicated a **Moderate** difference from regional *baseline* conditions, primarily due to relatively high concentrations of nutrients (nitrogen and phosphorus) and total mercury.

Benthic Invertebrate Communities Benthic invertebrate communities in fall 2009 in the *baseline* reach of the Horse River were similar to regional *baseline* conditions of benthic invertebrate communities in erosional reaches in the RAMP FSA.

5.11.2 Hydrologic Conditions

There was no monitoring conducted for the Climate and Hydrology component in the Horse River watershed in 2009.

5.11.3 Water Quality

In fall 2009, water quality samples were taken from the Horse River (*baseline* station HOR-1, first sampled in fall 2009).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of eight out of 15 selected water quality measurement endpoints were within the range of regional *baseline* concentrations (Figure 5.11-3). Total nitrogen, dissolved phosphorus and total mercury (ultra-trace) were present at concentrations greater than the 95th percentile of regional *baseline* concentrations, while chloride, total strontium, potassium, sulphate, and magnesium occurred at concentrations lower than the 5th percentile of regional *baseline* concentrations.

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of all water quality measurement endpoints were below water quality guidelines in fall 2009, with the exception of total dissolved phosphorus, total nitrogen, and total and dissolved aluminum (Table 5.11-2).

Other Water Quality Guideline Exceedances Concentrations of total phosphorus, total Kjeldahl nitrogen, total and dissolved iron, sulphide and total phenolics exceeded water quality guidelines at *baseline* station HOR-1 in fall 2009 (Table 5.11-2).

Ion Balance In fall 2009, the ionic composition of water at *baseline* station HOR-1 was dominated by calcium and bicarbonate (Figure 5.11-4).

Water Quality Index The WQI value for the *baseline* station HOR-1 was 72.2 indicating a **Moderate** difference from regional *baseline* water quality conditions. This is primarily due to relatively high concentrations of nutrients (nitrogen and phosphorus) and total mercury.

Summary Concentrations of seven out of 15 selected water quality measurement endpoints at the Horse River *baseline* station in fall 2009 were outside the range of regional *baseline* concentrations. The WQI values for the Horse River watershed indicated a **Moderate** difference from regional *baseline* conditions, primarily due to relatively high concentrations of nutrients (nitrogen and phosphorus) and total mercury.

5.11.4 Benthic Invertebrate Communities and Sediment Quality

5.11.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled for the first time in fall 2009 in an erosional reach of the Horse River (*baseline* reach HOR-E-1).

2009 Habitat Conditions The *baseline* reach HOR-E-1 in fall 2009 was 0.3 m deep, slightly alkaline, with fast currents (1.2 m/s), no macrophytes, and relatively low levels of dissolved oxygen and conductivity for the RAMP FSA (Table 5.11-3). The substrate was dominated by small cobble, with lower amounts of large cobble, gravel, and boulder (Table 5.11-3). Periphyton biomass in the *baseline* reach HOR-E-1 averaged about 180 mg/m^2, near the maximum regional *baseline* periphyton biomass (Figure 5.11-5) and consistent with the relatively high concentrations of nutrients in water.

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of the erosional *baseline* reach HOR-E-1 was dominated by chironomids (30%), caddisflies (Trichoptera, 25%), mayflies (Ephemeroptera, 13%), and water mites (Hydracarina, 10%; Table 5.11-4). The chironomid taxa were diverse, consisting of common forms such as *Tanytarsus*, and *Micropsectra,* as well as other forms that are more restricted to clean cold-water such as *Tvetenia*, *Rheosmittia* and *Potthastia longimana*. Mayfly taxa included the common forms *Baetis* and *Heptagenia*, as well *Ephemerella*, which require good water quality. The caddisfly taxa were dominated numerically by the Hydropsychidae. Stoneflies (Plecoptera) included members of Capniidae, and *Zapada*.

Values of benthic invertebrate community measurement endpoints were within the range of regional *baseline* values, with the exception of Simpson's diversity and evenness, which were above regional *baseline* values (Figure 5.11-6). There were on average approximately 40 taxa per sample and more than 40% of the fauna (per sample) were comprised of EPT taxa. Benthic invertebrate community conditions in fall 2009 in the *baseline* reach of the Horse River were similar to regional *baseline* conditions of benthic invertebrate communities in erosional reaches in the RAMP FSA.

The biplot of the multivariate CA axis scores for *baseline* reach HOR-E-1 (Figure 5.11-7) support the assessment that the benthic invertebrate community at this reach is similar to *baseline* erosional reaches throughout the RAMP FSA.

5.11.4.2 Sediment Quality

No sediment quality sampling was conducted in the Horse River in 2009 because sediment quality is only sampled in the depositional reaches in which benthic invertebrate communities were sampled and the reach of the Horse River where benthic invertebrate communities were sampled is erosional.

5.11.4.3 Summary

Benthic invertebrate community conditions in fall 2009 in the *baseline* reach of the Horse River were similar to regional *baseline* conditions of benthic invertebrate communities in erosional reaches in the RAMP FSA.

5.11.5 Fish Populations

The 2009 non-lethal sentinel species study included *baseline* site HR-R (Figure 5.11-1) on the Horse River. Results of this study are presented in Section 5.3. In addition, the 2009 Fish Assemblage Monitoring pilot study included a reach on the Horse River; Section 6 contains the results of this study.

Table 5.11-2 Water quality measurement endpoints, Horse River (station HOR-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009
			Value
Physical variables			
pH	pH units	6.5-9.0	7.27
Total suspended solids	mg/L	-[1]	8
Conductivity	µS/cm	-	79.7
Nutrients			
Total dissolved phosphorus	mg/L	0.05[2]	**0.0727**
Total nitrogen*	mg/L	1.0	**1.661**
Nitrate+nitrite	mg/L	1.0	0.071
Dissolved organic carbon	mg/L	-	44.8
Ions			
Sodium	mg/L	-	9.9
Calcium	mg/L	-	11.6
Magnesium	mg/L	-	2.86
Chloride	mg/L	230, 860[3]	0.5
Sulphate	mg/L	100[4]	4.03
Total dissolved solids	mg/L	-	168
Total alkalinity	mg/L		29.8
Organic compounds			
Naphthenic acids	mg/L	-	0.393
Selected metals			
Total aluminum	mg/L	0.1	**0.589**
Dissolved aluminum	mg/L	0.1[2]	**0.1460**
Total arsenic	mg/L	0.005	0.0011
Total boron	mg/L	1.2[5]	0.0302
Total molybdenum	mg/L	0.073	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	4.2
Total strontium	mg/L	-	0.051
Other variables that exceeded CCME/AENV guidelines in fall 2009			
Total phosphorus	mg/L	0.05	**0.0984**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.59**
Total iron	mg/L	0.3	**1.44**
Dissolved Iron	mg/L	0.3[2]	**0.999**
Sulphide	mg/L	0.002[7]	**0.0167**
Total phenolics	mg/L	0.004	**0.0138**

Baseline station HOR-1 was a new station for 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

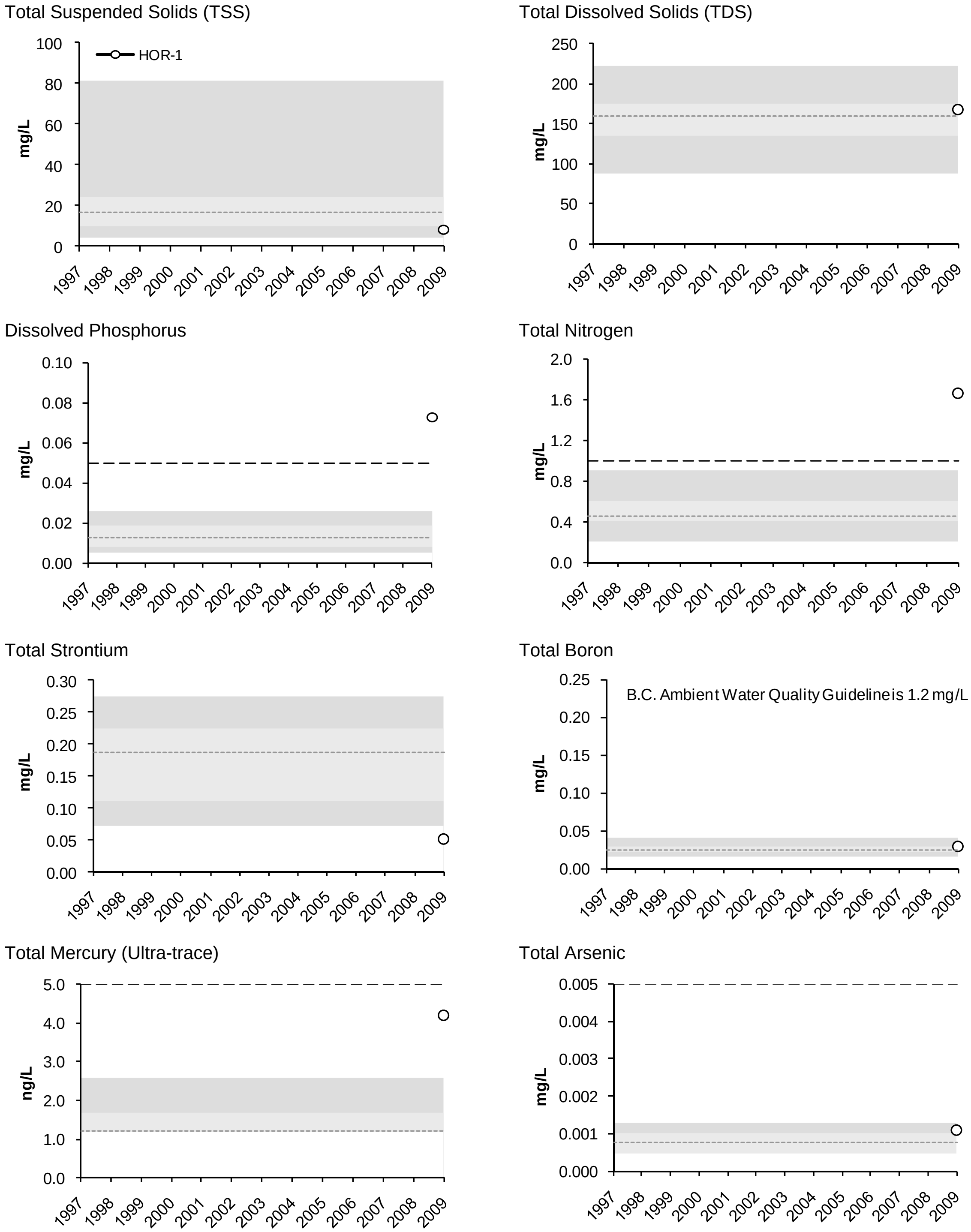
5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Figure 5.11-3 Concentrations of selected water quality measurement endpoints at the mouth of the Horse River (station HOR-1, fall 2009) relative to regional *baseline* fall concentrations.



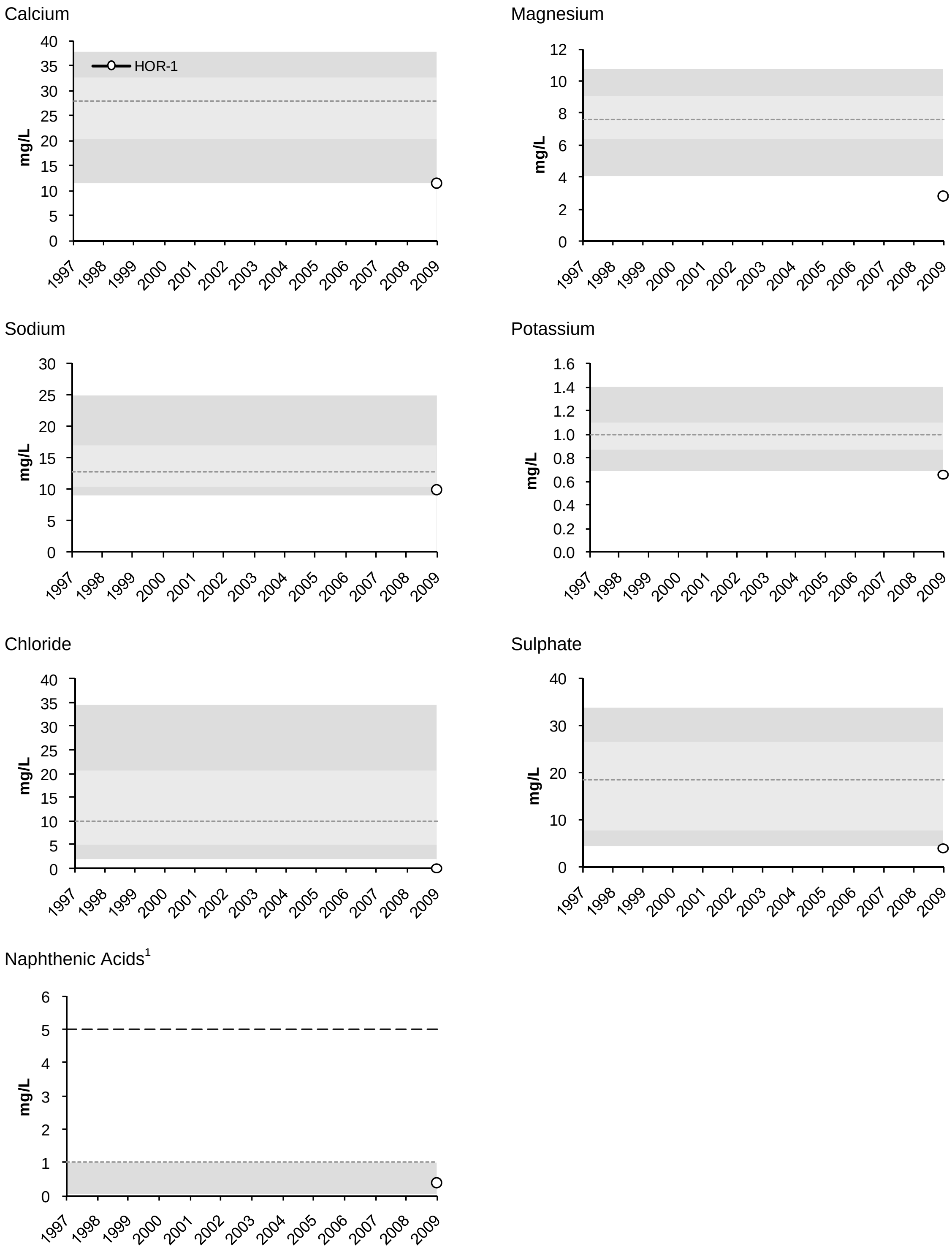
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-3 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-4 Piper diagram of fall ion concentrations, Horse River (station HOR-1), fall 2009.

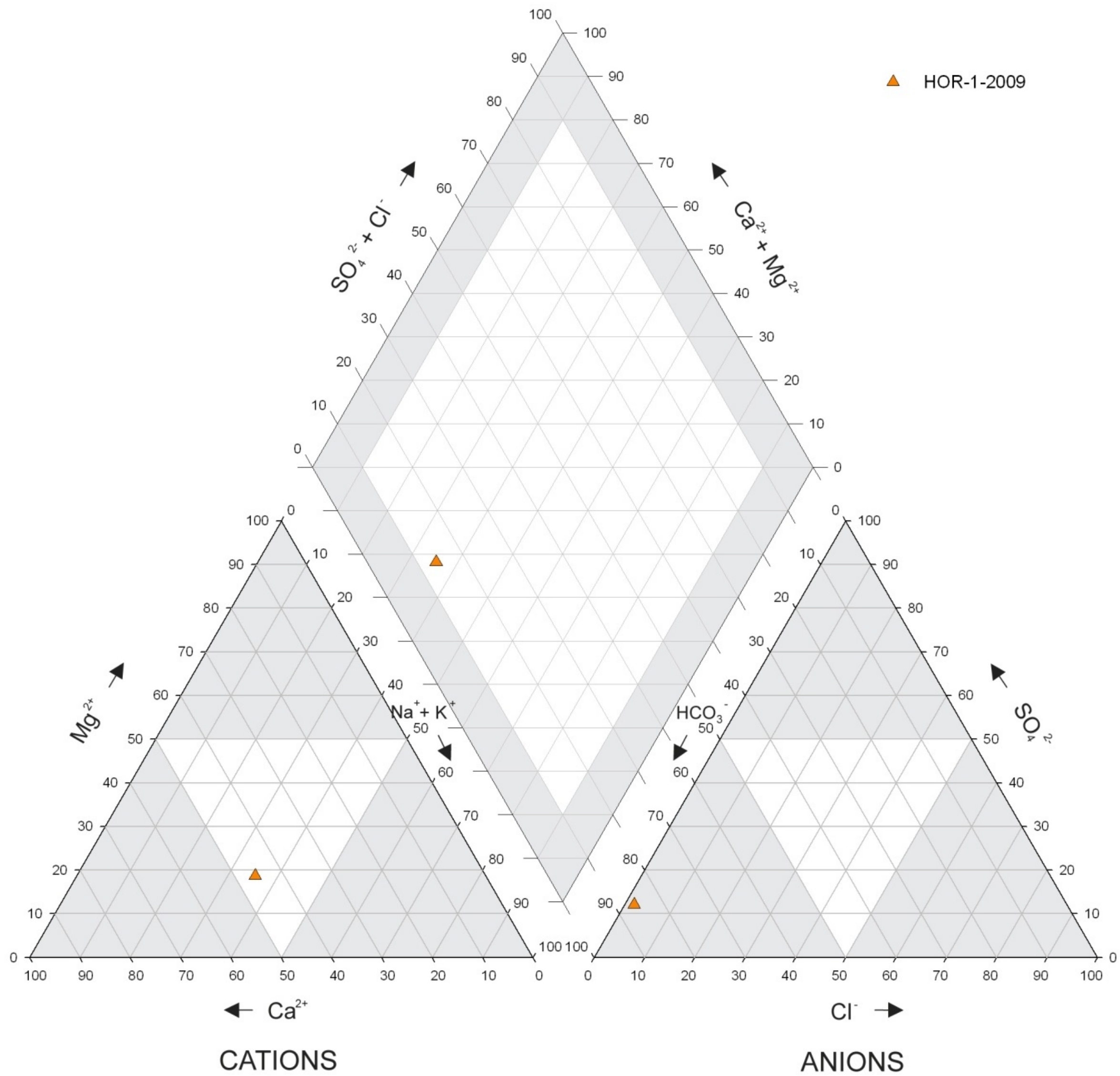


Table 5.11-3 Average habitat characteristics of the benthic invertebrate sampling locations in the Horse River (HOR-E-1), fall 2009.

Variable	Units	*Baseline* Reach HOR-E-1
Sample Date	-	Sept 12, 2009
Habitat	-	Erosional
Water Depth	m	0.3
Current Velocity	m/s	1.2
Macrophyte Cover	%	0
Field Water Quality		
Dissolved Oxygen	mg/L	8.5
Conductivity	µS/cm	72
pH	pH units	7.4
Water Temperature	°C	13.5
Sediment Composition		
Sand/Silt/Clay	%	1
Small Gravel	%	12
Large Gravel	%	18
Small Cobble	%	30
Large Cobble	%	25
Boulder	%	15
Bedrock	%	0

Table 5.11-4 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the Horse River.

Taxon	Percent Major Taxa Enumerated in Each Year *Baseline* Reach HOR-E-1 2009
Ceratopogonidae	<1
Chironomidae	30
Copepoda	<1
Empididae	3
Enchytraeidae	<1
Ephemeroptera	13
Hydracarina	10
Naididae	4
Nematoda	4
Plecoptera	8
Simuliidae	<1
Tipulidae	<1
Trichoptera	25
Tubificidae	1
Benthic Invertebrate Community Measurement Endpoints	
Total Abundance (No./m^2)	5,568
Richness	41
Simpson's Diversity	0.93
Evenness	0.96
% EPT	41

Figure 5.11-5 Periphyton chlorophyll a biomass in the Horse River.

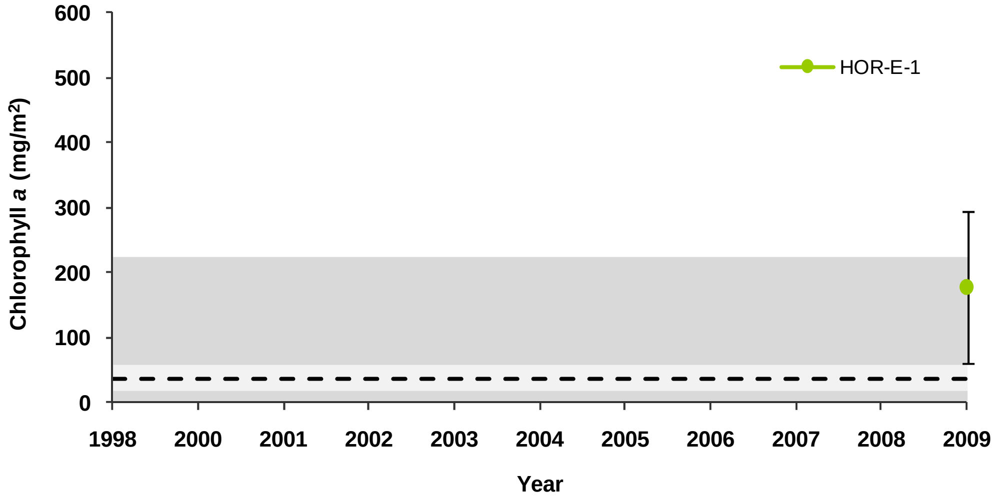
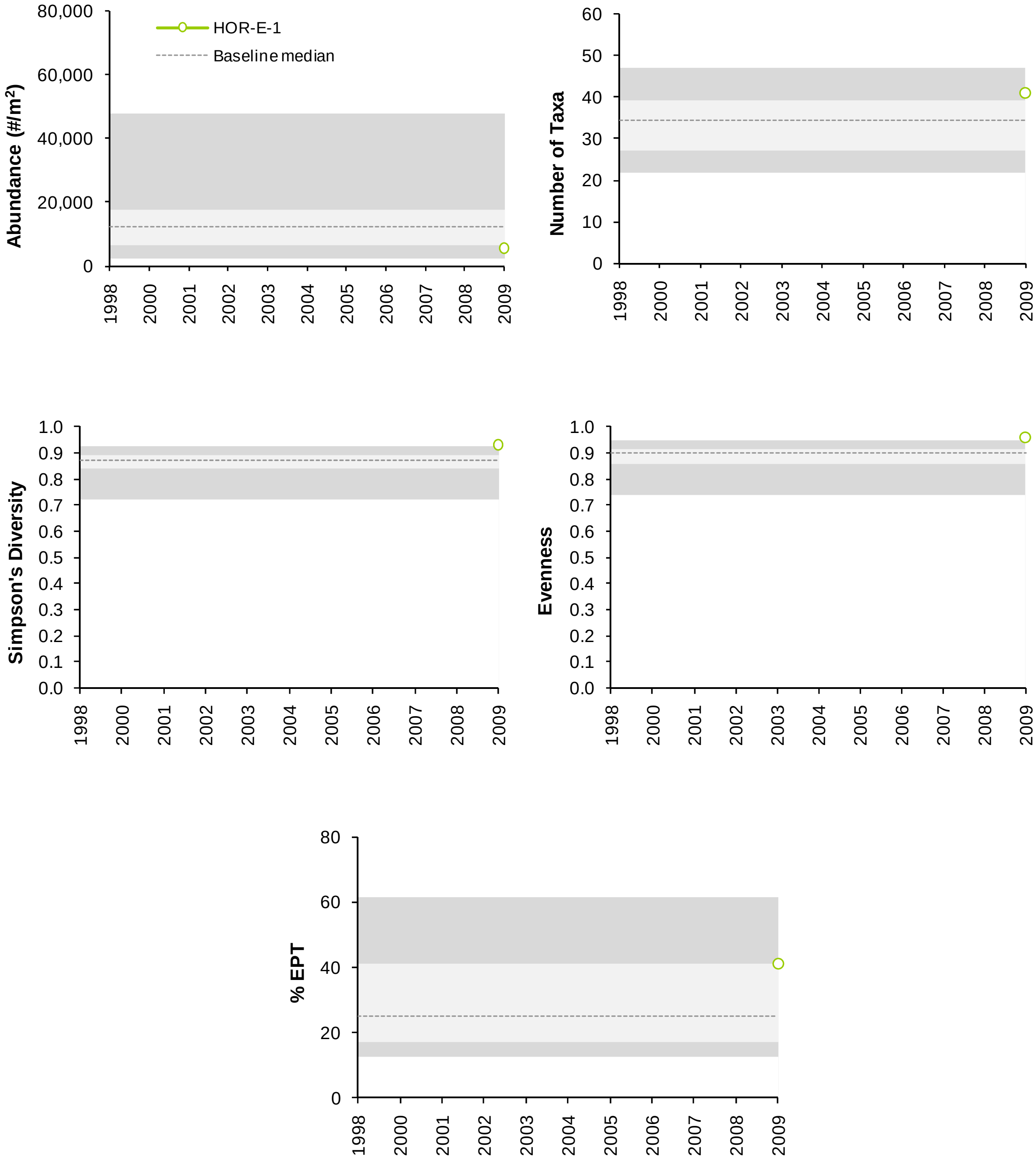
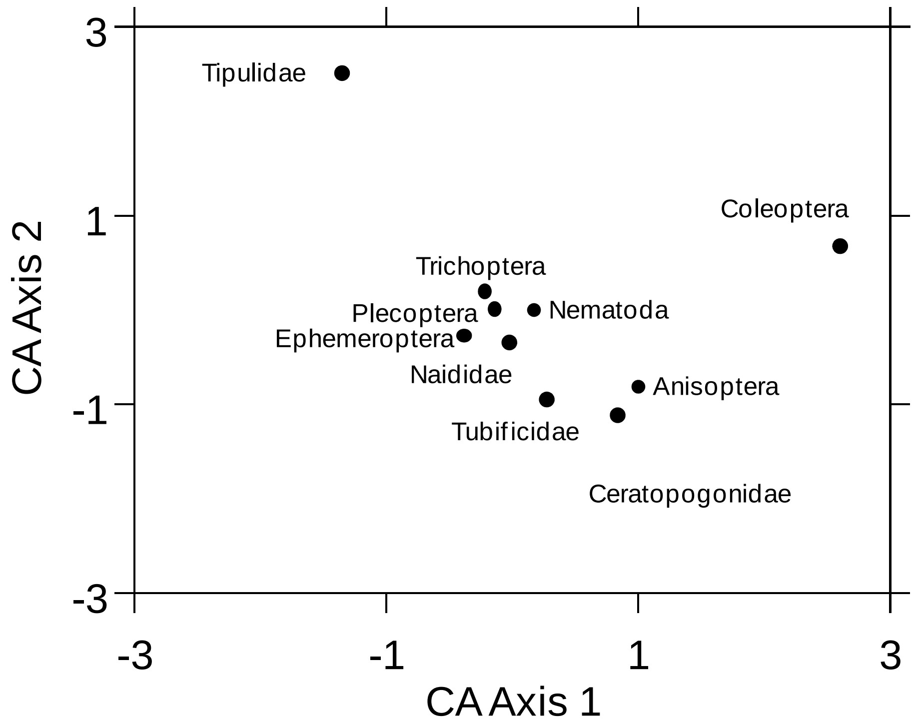


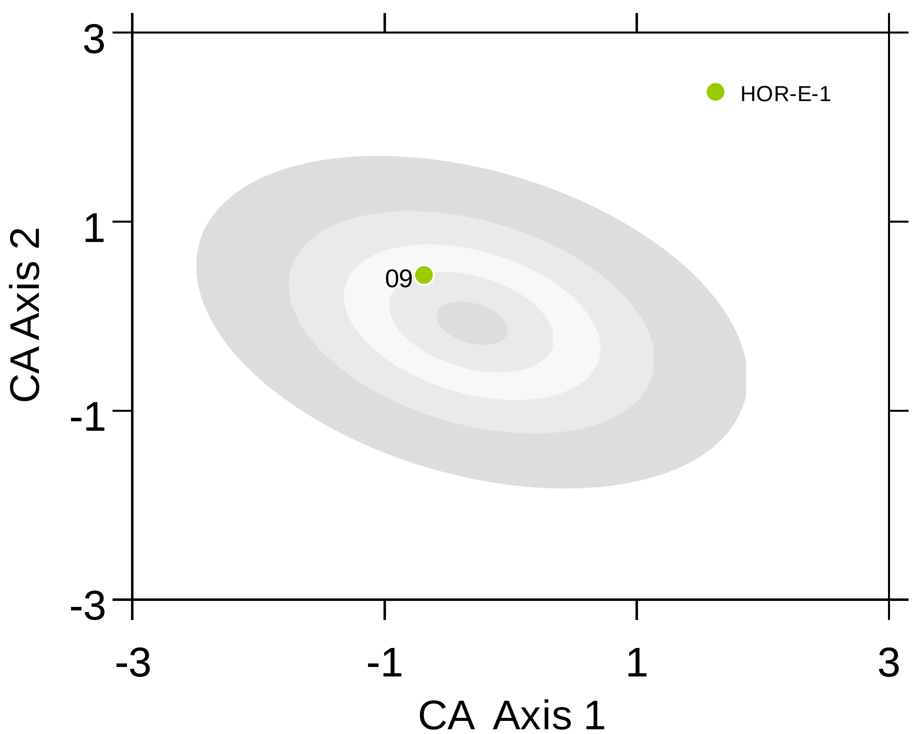
Figure 5.11-6 Variation in benthic invertebrate community measurement endpoints in the Horse River.



Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.11-7 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Horse River.





Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* erosional reaches in the RAMP FSA.

5.12 MISCELLANEOUS AQUATIC SYSTEMS

Table 5.12-1 Summary of results for miscellaneous aquatic systems.

Miscellaneous Aquatic Systems	Summary of 2009 Conditions										
	Lakes					*Tributaries*					
Climate and Hydrology											
Criteria	S25 Susan Lake Outlet	L3 Isadore's Lake				S11 Poplar Creek at Highway 63	S12 Fort Creek at Highway 63				S6 Mills Creek at Highway 63
Mean open-water season discharge	not measured	not measured				🟤	🟠				🟤
Mean winter discharge	not measured	not measured				not measured	not measured				🟤
Annual maximum daily discharge	not measured	not measured				🟡	🟠				🟤
Minimum open-water season discharge	not measured	not measured				🟡	🟠				🟤
Water Quality											
Criteria	no station sampled	ISL-1 Isadore's Lake	SHL-1 Shipyard Lake	no station sampled	no station sampled	POC-1 Poplar Creek at the mouth	FOC-1 Fort Creek at the mouth	BER-1 Beaver River at the mouth	BER-2 upper Beaver River	MCC-1 McLean Creek at the mouth	no station sampled
Water Quality Index		🟠	🟠			🟠	🟠	🟠	🟡	🟡	
Benthic Invertebrate Communities and Sediment Quality											
Criteria	no reach sampled	ISL-1 Isadore's Lake	SHL-1 Shipyard Lake	no reach sampled	no reach sampled	POC-D-1 Poplar Creek lower reach	no reach sampled	no reach sampled	BER-D-2 Beaver River upper reach	no reach sampled	no reach sampled
Benthic Invertebrate Communities		🟤	🟡			🟠			n/a		
Sediment Quality Index		🟡	🟡			🟡			🟡		

Fish Populations

Criteria	Unnamed Jackson Lake				no reaches sampled
	Sp.[1]	Size[2]	Sub.[3]	Gen.[3]	
Human Health	WALL	>400m	🟤	🟠	
	NRPK	all sizes	🟡	🟡	
	LKWH	all sizes	🟡	🟡	
Fish Palatability	not measured				
Fish Health	all species 🟡				

Legend and Notes

🟡 Negligible-Low

🟠 Moderate

🟤 High

baseline

test

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

1 Species (Sp.): WALL=walleye; NRPK=northern pike; LKWH=lake whitefish

2 The classification of risk to human health was Negligible-Low below the size class specified.

3 Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada (see Section 3.4.7.3).

Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

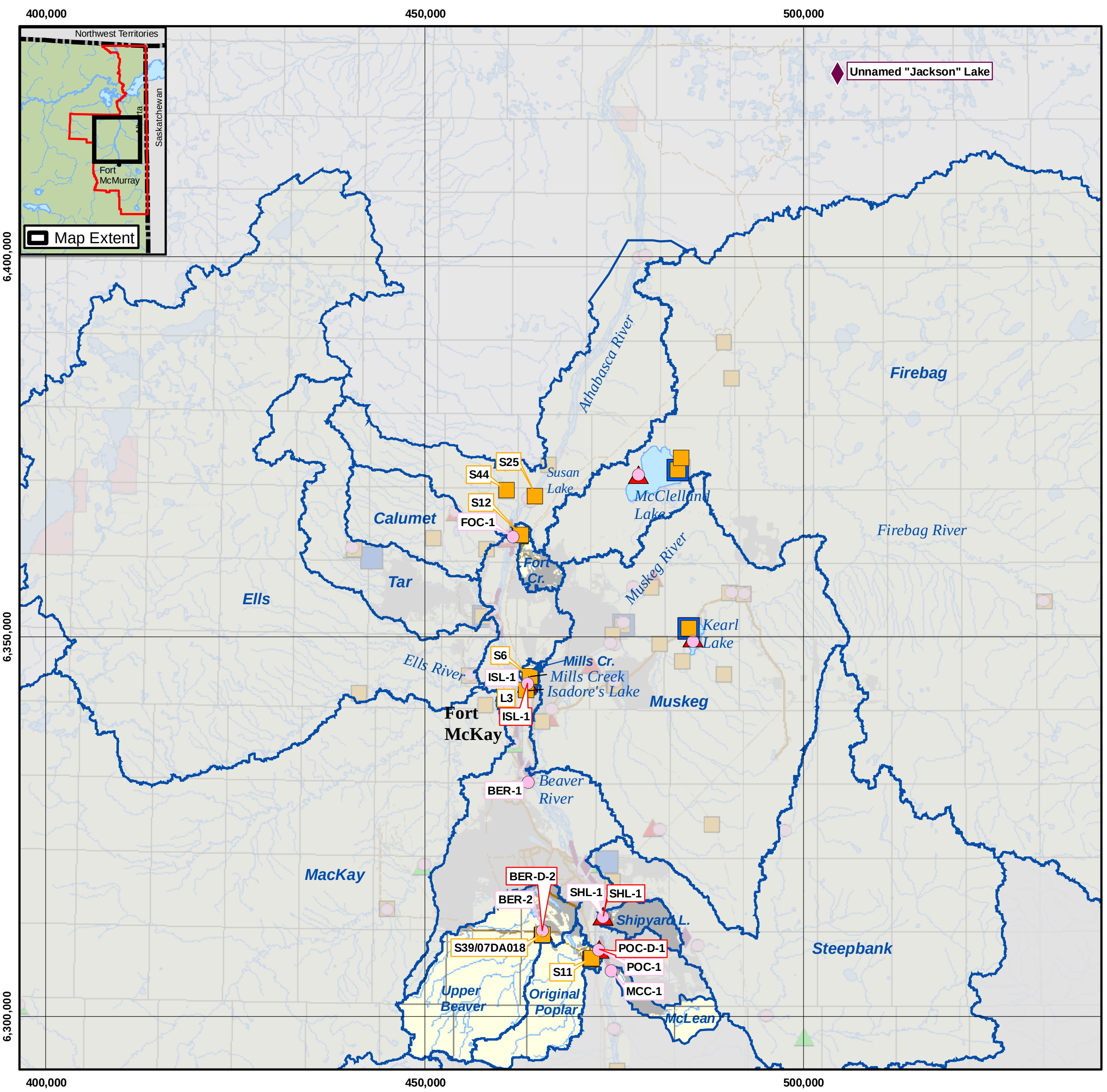
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional *baseline* conditions; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Fish Populations: Uses various USEPA and Health Canada criteria for risks to human health, fish health, and tainting from fish tissue concentrations of various substances, see Section 3.4.7.3 for a detailed description of the classification methodology.

Figure 5.12-1 Miscellaneous aquatic systems.



LEGEND

Lake/Pond	Climate Station
River/Stream	Hydrometric Station
Watershed Boundary	Water Quality Sampling Station
Major Road	Benthic Invertebrate Community Sampling Reach
Secondary Road	Benthic Invertebrate Community Sampling Reach and Sediment Quality Sampling Station
Railway	Sediment Quality Sampling Station
First Nations Reserve	Fish Sampling Site
RAMP Regional Study Area	Fish Sampling Reach
RAMP Focus Study Area	
Land Change Area	

RAMP Regional Aquatics Monitoring Program

0 5 10 20 km

Scale 1:850,000

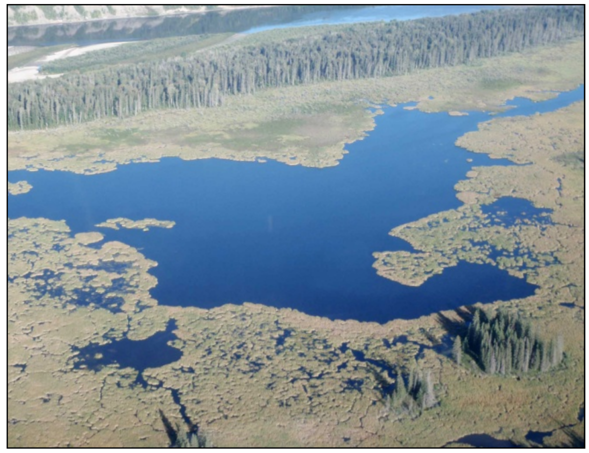
Projection: UTM Zone 12 NAD83

Land Change Areas Delineated from 10m SPOT-5 (June, July and August 2009) Multispectral Imagery.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_K12_Misc_20100415.mxd

Figure 5.12-2 Representative monitoring stations of miscellaneous aquatic systems, fall 2009.

**Water Quality Station ISL-1:
Isadore's Lake, aerial view**



**Water Quality Station SHL-1:
Shipyard Lake, aerial view**

**Water Quality Station BER-2 (Beaver River):
Left Downstream Bank**

**Water Quality Station FOC-1 (Fort Creek):
Right Downstream Bank**

**Water Quality Station MCC-1 McLean Creek):
Centre of Channel, facing upstream**

**Water Quality Station POC-1 (Poplar Creek):
Left Downstream Bank**

5.12.1 Summary of 2009 Conditions

This section includes 2009 results for the following aquatic systems, each with a specific status:

- Mills Creek, Original Poplar Creek, McLean Creek, Fort Creek, Beaver River, Isadore's Lake, and Shipyard Lake are designated as *test*. Land change as of 2009 comprises approximately 3.2% (446 ha) of the original Poplar Creek watershed, 62.5% (1,996 ha) of the Fort Creek watershed, 25.2% (1,187 ha) of the McLean Creek watershed, approximately 28.6% (255 ha) of the Mills Creek watershed, 93% (3,753 ha) of the original watershed draining into Shipyard Lake[1], and approximately 9.5% (2,719 ha) of the Upper Beaver watershed (Table 2.4-2); and
- The Susan Lake outlet is designated as *baseline* for 2009 as is the unnamed regional lake where fish tissue studies were conducted, known locally as Jackson Lake.

Table 5.12-1 is a summary of the 2009 assessment of the miscellaneous aquatic systems in the RAMP FSA, while Figure 5.12-1 denotes the location of the monitoring stations for each RAMP component and the area of land change for 2009. Figure 5.12-2 contains fall 2009 photos of water quality monitoring stations located in the miscellaneous aquatic systems in the RAMP FSA.

Mills Creek The differences in the Mills Creek watershed between the observed *test* hydrograph and the estimated *baseline* hydrograph are assessed as **High** for all calculated hydrology measurement endpoints.

Isadore's Lake The water level of Isadore's Lake was consistently near the historical maximum values until monitoring temporarily ceased in late June due to equipment malfunction. When monitoring resumed in early October, the water level was above the historical upper quartile value, and reduced to the median level by the end of 2009.

Water quality in Isadore's Lake in fall 2009 showed a **Moderate** difference from regional *baseline* lake water quality concentrations. Ionic composition continued recent trends towards a higher proportion of bicarbonate ions, and a number of dissolved ions exceeded the 95th percentile of regional *baseline* concentrations.

The differences in benthic invertebrate communities between Isadore's Lake and benthic invertebrate communities of *baseline* lakes in the RAMP FSA are classified as **High.** Number of taxa, Simpson's diversity and evenness were significantly lower than what is observed in *baseline* lakes, and there have essentially been no EPT (mayflies, stoneflies, caddisflies) in Isadore's Lake during the entire sampling period for this lake. Values of six of seven measurement endpoints for benthic invertebrate communities in 2009 were outside the range of variation observed for *baseline* lakes. Differences in sediment quality observed in fall 2009 in Isadore's Lake compared to conditions in regional *baseline* lakes were **Negligible-Low**.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2009 at *test* station SHL-1 were within historical ranges with the exception of concentrations of sodium and chloride which have shown consistent increases over the period of record. Concentrations of these ions in fall 2009 are now well above regional *baseline* concentrations. Differences in water quality in fall 2009 at *test* station SHL-1 compared to regional *baseline* conditions are assessed as **Moderate**.

---

[1] The boundary of the original Shipyard Lake watershed was estimated on an overlay of watershed boundaries prepared by CEMA with the 1:50,000 NTDB water and contour layers.

The differences in benthic invertebrate communities between Shipyard Lake as measured at *test* station SHL-1 and regional *baseline* lakes in the RAMP FSA are classified as **Negligible-Low** (Table 5.12-1). Differences in values of benthic invertebrate community measurement endpoints between Shipyard Lake and *baseline* lakes in the RAMP FSA were statistically weak, with only one measurement endpoint (CA axis score 1) exceeding its regional *baseline* range. Differences in sediment quality conditions at *test* station SHL-1 were **Negligible-Low** compared to regional *baseline* conditions.

Poplar Creek and Beaver River The mean open-water discharge (May to October) calculated from the observed *test* hydrograph is 49% higher than from the estimated *baseline* hydrograph; this difference is classified as **High**. The annual maximum daily discharge from the observed *test* hydrograph is 1.3% less than from the estimated *baseline* hydrograph; this difference is classified as **Negligible-Low**. The open-water minimum daily discharge from the observed *test* hydrograph is 2.1% less than from the estimated *baseline* hydrograph; this difference is classified as **Negligible-Low**.

In fall 2009, differences in water quality from regional *baseline* conditions were **Moderate** for *test* stations BER-1 and POC-1, largely as a result of relatively high concentrations of a number of ions and total dissolved solids. Differences in water quality in fall 2009 at *baseline* station BER-2 compared to regional *baseline* conditions are assessed as **Negligible-Low**.

The data from *test* reach POC-D-1 support a conclusion that the benthic invertebrate community has exhibited changes over time, potentially related to oil sands developments. The variations in benthic invertebrate community measurement endpoints at *test* reach POC-D-1 are classified as **Moderate** on the basis that there are significant differences in diversity, evenness, and %EPT, while measurement endpoint values were still within the range of regional *baseline* conditions. Differences in sediment quality at *test* station POC-D-1 and *baseline* station BER-D-2 indicated a **Negligible-Low** difference from regional *baseline* conditions.

McLean Creek Water quality in fall 2009 at *test* station MCC-1 showed a **Negligible-Low** difference from regional *baseline* conditions and was generally consistent with previous sampling years.

Fort Creek The mean open-water period (May to October) discharge, minimum daily discharge, and annual maximum daily discharge calculated from the observed *test* hydrograph are approximately 11% higher than from the estimate *baseline* hydrograph; these differences are classified as **Moderate**.

Differences in water quality in fall 2009 in lower Fort Creek as measured at *test* station FOC-1 compared to regional *baseline* water quality conditions are assessed as **Moderate** on the basis of exceedances of total dissolved solids, sulphate, and calcium above and total aluminum, total dissolved phosphorus, and total suspended solids below the range of regional *baseline* conditions.

Unnamed "Jackson" Lake A fish tissue sampling program was conducted in an unnamed lake, known locally as Jackson Lake. The measurement endpoint used in the assessment of results is mercury concentration in fish tissue related to potential effects on human health and fish health. The average mercury concentration in lake whitefish from Jackson Lake across all size classes (200 to 600 mm) was below the subsistence fisher guideline indicating a **Negligible-Low** risk to human health. The average mercury concentration in captured walleye greater than 400 mm (0.9 kg) from Jackson Lake in

2009 was above the Health Canada subsistence fisher guideline indicating a **High** risk to health of subsistence fishers and a **Moderate** risk to health of general consumers for consumption of fish of this size. For fish less than 400 mm in length, the risk to human health is classified as **Negligible-Low** for subsistence fishers and general consumers. The mercury concentration in the single captured northern pike (323 mm) from Jackson Lake in 2009 was below the Health Canada subsistence fisher guideline indicating a **Negligible-Low** risk to human health for subsistence fishers and general consumers. Fish tissue results for Jackson Lake in 2009 indicate a **Negligible-Low** risk to fish health given mercury concentrations did not exceed the lethal (survival) and non-lethal (growth, reproduction) effects thresholds.

5.12.2 Mills Creek and Isadore's Lake

Monitoring was conducted in the Mills Creek watershed in 2009 for the Climate and Hydrology component (Mills Creek and Isadore's Lake), as well as the Water Quality, and Benthic Invertebrate Communities and Sediment Quality components in Isadore's Lake.

5.12.2.1 Hydrologic Conditions

2009 Hydrologic Conditions: Station S6, Mills Creek at Highway 63 The annual runoff volume for Station S6 was 1.02 million m^3 and the open-water runoff volume was 0.78 million m^3, which was 3% higher than the historical mean open-water runoff volume. Flows from January to March were around historical lower quartile values (Figure 5.12-3). Flows increased during April due to snowmelt, reaching a peak value of 0.19 m^3/s on May 16, which was similar to the historical maximum values recorded for this time of the year and 5% higher than the historical mean open-water maximum daily flow. Flows thereafter remained above historical median values until late July, with rainfall-driven increases observed in late June, mid-July and late August. Flows remained at near historical median levels from September to early November and then decreased to below the historical minimum values. The minimum open-water flow of 0.021 m^3/s recorded on October 31 was 20% higher than the historical average.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at Station S6 is presented in Figure 5.12-3 and described below:

1. The closed-circuited land area as of 2009 was estimated at 2.1 km^2 (Table 2.4-1). The loss of flow to Mills Creek that would have occurred from this land area is estimated at 0.52 million m^3.

2. The land area not closed-circuited from focal projects as of 2009 was estimated at 0.5 km^2 (Table 2.4-1). The increase in flow to Mills Creek that would not have otherwise occurred from this land area is estimated at 0.02 million m^3.

The estimated cumulative effect of land change is a loss of flow of 0.50 million m^3 to Mills Creek at Station S6. The estimated *baseline* hydrograph is presented in Figure 5.12-3.

The calculated mean open-water discharge, minimum daily discharge, annual maximum daily discharge, and mean winter discharge from the observed *test* hydrograph are 33% lower than calculated from the estimated *baseline* hydrograph (Table 5.12-2); these differences are classified as **High** (Table 5.12-1).

2009 Hydrologic Conditions: Station L3, Isadore's Lake In 2009, water levels on Isadore's Lake were recorded from January 1 to June 27 and from October 8 to December 31 (Figure 5.12-4). Prior to June 27, water levels were consistently near historical maximum values. When data collection resumed on October 9, water levels were above the historical upper quartile, and decreased to the median level by the end of 2009.

5.12.2.2 Water Quality

In fall 2009, water quality samples were taken from Isadore's Lake (*test* station ISL-1, sampled in 2000, 2001 and annually since 2004).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of all water quality measurement endpoints at *test* station ISL-1 were within the range of previously-measured values with the exception of calcium, sulphate, chloride, conductivity, and total dissolved solids (TDS), which exceeded the previously-measured maximum values (Table 5.12-4). Of these, concentrations of chloride, sulphate and total dissolved solids at *test* station ISL-1 also exceeded the 95th percentile of regional *baseline* concentrations, as did magnesium and total strontium (Figure 5.12-5). The concentration of total dissolved phosphorus was below both its previously-measured minimum value station and its 5th percentile of regional *baseline* concentrations, as was the concentration of naphthenic acids due to greatly improved detection limits for this analysis in 2009 (Table 5.12-10, Figure 5.12-5).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of sulphate and total nitrogen exceeded water quality guidelines at *test* station ISL-1 in fall 2009 (Table 5.12-4).

Other Water Quality Guideline Exceedances Concentrations of sulphide, total phenols and total Kjeldahl nitrogen exceeded water quality guidelines at *test* station ISL-1 in fall 2009 (Table 5.12-5).

Ion Balance Since 2004, the anion composition of water at *test* station ISL-1 has shifted from a dominance of bicarbonate to a greater proportion of sulphate. Calcium and magnesium continue to dominate the cation composition (Figure 5.12-6).

Trend Analysis The following significant trends were detected in water quality at *test* station ISL-1 over the RAMP sampling period ($\alpha = 0.05$):

- increasing concentrations of chloride, magnesium, sodium, sulphate, and total dissolved solids; and
- decreasing concentration of total arsenic, although this is likely due to improved analytical detection limits after 2002 (Figure 5.12-5).

Water Quality Index The WQI value for *test* station ISL-1 for fall 2009 was 63.2 (Table 5.12-6), indicating a **Moderate** difference in water quality conditions at this station compared to regional *baseline* lake water quality conditions. This classification of water quality condition is because of the concentration of a number of dissolved ions exceeding the 95th percentile of regional *baseline* concentrations.

Summary Water quality in Isadore's Lake in fall 2009 showed a **Moderate** difference from regional *baseline* lake water quality concentrations. The ionic composition continued recent trends towards a higher proportion of bicarbonate, and a number of dissolved ions exceeded the 95th percentile of regional *baseline* concentrations.

5.12.2.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in Isadore's lake (*test* station ISL-1, depositional, sampled since 2006).

2009 Habitat Conditions The substrate at *test* station ISL-1 was dominated by silt and clay; with slightly alkaline water and 25% macrophyte cover (Table 5.12-7). The amount of total organic carbon in the lake sediments was moderate at 3% and the concentration of dissolved oxygen was equal to the chronic guideline for protection of aquatic life (AENV 1999b).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* station ISL-1 was dominated by copepods (67%) and nematode worms (25%), with chironomids (7%) subdominant (Table 5.12-8).

The time trends in the benthic invertebrate community measurement endpoints for Isadore's Lake (Figure 5.12-7) have the following characteristics:

1. Total abundance, while decreasing continuously since sampling began in 1998, remained within the range for regional *baseline* lakes.
2. The number of taxa has decreased continuously since sampling began in 1998 and in fall 2009 was lower than the range for regional *baseline* lakes.
3. Diversity and evenness in fall 2009 were below the range of regional *baseline* lakes.
4. There was an absence of EPT taxa in fall 2009, consistent with previous years, and remaining at the minimum of the range of %EPT for regional *baseline* lakes.

The results of the Correspondence Analysis indicated that *test* station ISL-1 in fall 2009 had a benthic invertebrate community composition that was outside the range of regional *baseline* lakes in the RAMP FSA (Figure 5.12-8).

Linear contrasts were used to test for:

- a difference in the average value of the benthic invertebrate community measurement endpoints between *test* station ISL-1, and the *baseline* lake in the RAMP FSA (i.e., McClelland Lake), designated as "BT" in Table 5.12-9; and
- a difference in time trends (designated as "T" in Table 5.12-9) between *test* station ISL-1 and the *baseline* lake in the RAMP FSA (i.e., McClelland Lake), designated as "BT x T" in Table 5.12-9.

The average values of taxa richness, Simpson's diversity, evenness, and %EPT were significantly lower in Isadore's Lake compared to the *baseline* lake in the RAMP FSA (Table 5.12-9). In addition, the benthic invertebrate community of Isadore's Lake generally had higher CA Axis 1 and 2 scores (Table 5.12-9), reflecting a higher proportion of the benthic invertebrate community in Isadore's Lake as copepods, nematodes and Ostracods, and a relative absence of fingernail clams and amphipods (Table 5.12-8), compared to the regional *baseline* lake which was more dominated numerically by amphipods, fingernail clams and tubificid worms.

Sediment Quality

Sediment quality in fall 2009 was sampled in Isadore's Lake (*test* station ISL-1, sampled first 2001 and continuously since 2006) at the same location at which sampling of benthic invertebrate communities was undertaken in fall 2009.

2009 Results and Historical Ranges of Concentration As in previous years, sediments at *test* station ISL-1 were dominated by silt (Table 5.12-10). In fall 2009, concentrations of low-molecular-weight hydrocarbons (CCME fraction-1 [F1], including BTEX) were undetectable and concentrations of heavier hydrocarbon fractions (CCME F2 to F4) were generally below historical median concentrations. All other sediment quality measurement endpoints were within the historical range of concentrations with the exception of retene, which had a concentration that was below its previously-measured minimum value.

Comparison with Sediment Quality Guidelines There were no sediment quality measurement endpoints with concentrations above sediment or soil quality guidelines in fall 2009 (Table 5.12-10).

Sediment Quality Index An SQI value of 94.4 was calculated for *test* station ISL-1 for fall 2009, indicating a **Negligible-Low** difference from regional *baseline* sediment quality conditions for lakes (Table 5.12-11).

Summary

The differences in benthic invertebrate communities between Isadore's Lake and benthic invertebrate communities of *baseline* lakes in the RAMP FSA are classified as **High** (Table 5.12-1). Number of taxa, Simpson's diversity and evenness are significantly lower than what is observed in *baseline* lakes, and there have essentially been no EPT (mayflies, stoneflies, caddisflies) in Isadore's Lake during the entire sampling period for this lake. Values of six of seven measurement endpoints for benthic invertebrate communities 2009 are outside the normal range of variation observed for *baseline* lakes. Differences in sediment quality observed in fall 2009 in Isadore's Lake compared to conditions in regional *baseline* lakes were **Negligible-Low** (Table 5.12-1).

5.12.3 Shipyard Lake

Monitoring was conducted in Shipyard Lake in 2009 for the Water Quality and the Benthic Invertebrate Communities and Sediment Quality component.

5.12.3.1 Water Quality

Water quality samples were taken from Shipyard Lake in fall 2009 at *test* station SHL-1 (sampled annually since 1998).

2009 Results Relative to Historical and Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints at Shipyard Lake in fall 2009 were within the range of previously-measured concentrations at this station with the exception of sodium, chloride and nitrate+nitrite, which exceeded previously-measured maximum concentrations, and total strontium and total dissolved phosphorus, which were below previously-measured minimum concentrations (Table 5.12-12).

Concentrations of all water quality measurement endpoints were within the range of regional *baseline* concentrations with the exception of sodium and chloride which had concentrations that exceeded the 95th percentile of regional *baseline* concentrations, and naphthenic acids which had concentrations below the 5th percentile of regional *baseline* concentrations due to greatly improved detection limits for this analysis in 2009 (Figure 5.12-5).

Comparison of Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of total nitrogen exceeded its water quality guideline in fall 2009 at *test* station SHL-1 (Table 5.12-12).

Other Water Quality Guideline Exceedances Concentrations of sulphide, total phenols and total iron exceeded relevant water quality guidelines in fall 2009 at *test* station SHL-1 (Table 5.12-5).

Ion Balance The ionic composition in Shipyard Lake in fall 2009 continued to shift towards a greater proportion of sodium and chloride ions, concomitant with decreasing proportions of calcium and bicarbonate (Figure 5.12-6).

Trend Analysis The following significant trends were detected in water quality at *test* station SHL-1 over the RAMP sampling period ($\alpha = 0.05$):

- increasing concentrations of sodium, magnesium, potassium, chloride and total boron; and
- decreasing concentrations of sulphate and total arsenic, with the latter trend likely due to improved analytical detection limits after 2002.

Water Quality Index The WQI value for *test* station SHL-1 for fall 2009 was 74.5 (Table 5.12-6), indicating a **Moderate** difference from regional *baseline* water quality conditions. This classification of water quality condition is because of the concentration of a number of dissolved ions exceeding the 95th percentile of regional *baseline* concentrations (Figure 5.12-5).

Summary Concentrations of most water quality measurement endpoints in fall 2009 at *test* station SHL-1 were within historical ranges with the exception of concentrations of sodium and chloride which have shown consistent increases over the period of record. Concentrations of these ions in fall 2009 are now well above regional *baseline* concentrations. Differences in water quality in fall 2009 at *test* station SHL-1 compared to regional *baseline* conditions are assessed as **Moderate** (Table 5.12-1).

5.12.3.2 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in Shipyard Lake (*test* station SHL-1, sampled since 2000).

2009 Habitat Conditions *Test* station SHL-1 in fall 2009 was characterized by moderate macrophyte cover, a substrate comprised of equal amounts of sand and silt with high total organic carbon content and a concentration of dissolved oxygen that was below the chronic guideline for protection of aquatic life (AENV 1999b) (Table 5.12-13).

Relative Abundance of Benthic Invertebrate Community Taxa The composition of the benthic invertebrate community at *test* station SHL-1 in fall 2009 was dominated by ostracods (32%), chironomids (20%), and copepods (16%), with Enchytraeidae worms (7%), snails, (Gastropoda, 7%), and nematodes (5%) sub-dominant (Table 5.12-14).

Abundance, taxa richness, Simpson's diversity, evenness and %EPT at *test* station SHL-1 in fall 2009 were all within the range of values for these benthic invertebrate community measurement endpoints for regional *baseline* lakes (Figure 5.12-9).

The Correspondence Analysis for illustrated the high relative abundances of copepods and ostracods at *test* station SHL-1 in fall 2009, causing the average CA Axis 1 scores to fall outside the range for *baseline* lake conditions (Figure 5.12-10).

Linear contrasts were used to test for:

- a difference in the average value of the benthic invertebrate community measurement endpoints between *test* station SHL-1 and the *baseline* lake in the RAMP FSA (i.e., McClelland Lake), designated as "BT" in Table 5.12-15; and
- differences in time trends (designated as "T" in Table 5.12-15) between *test* station SHL-1 and the *baseline* lake in the RAMP FSA (i.e., McClelland Lake) that would occur if the benthic invertebrate community at *test* station SHL-1 in Shipyard Lake was continuing to degrade (designated as "BT x T" in Table 5.12-15).

Simpson's diversity, evenness and %EPT were significantly lower at *test* station SHL-1 relative to the *baseline* lake (Table 5.12-15). The "remainder (noise)" term, however, is larger than the BT term for any of these differences. In addition, the differences in time trends between *test* station SHL-1 and the *baseline* lake was significant for abundance and tax richness (Table 5.12-15). Again, the "remainder (noise)" term, however, is larger than the BT x T term for either of these differences, indicating that all these differences are not strong and are therefore considered negligible.

Sediment Quality

Sediment quality in fall 2009 was sampled in Shipyard Lake (*test* station SHL-1, sampled since 2001 with the exception of 2005) at the same location at which benthic invertebrate community sampling was undertaken in fall 2009.

2009 Results and Historical Ranges of Concentration Sediments at *test* station SHL-1 were composed of equal amounts of silt and sand, with less clay (41%, 41%, and 18% respectively) (Table 5.12-16). Low-molecular-weight hydrocarbons (CCME fraction-1 [F1], including BTEX) were undetectable at *test* station SHL-1 in fall 2009 while concentrations of heavier hydrocarbon fractions (CCME F2 to F4) in fall 2009 exceeded their previously-measured maximum concentrations (Table 5.12-16). Concentrations of all other sediment quality measurement endpoints at *test* station SHL-1 in fall 2009 were within the range of historical values with the exception of naphthalene which had a concentration that exceeded its previously-measured concentration (Table 5.12-16).

Comparison with Sediment Quality Guidelines Concentrations of F2, F3 and F4 hydrocarbons exceeded CCME soil quality guidelines at *test* station SHL-1 in fall 2009 (Table 5.12-16).

Sediment Quality Index An SQI value of 81.5 was calculated for *test* station SHL-1 for fall 2009, indicating a **Negligible-Low** difference from regional *baseline* sediment quality conditions for lakes (Table 5.12-11).

Summary

The differences in benthic invertebrate communities between Shipyard Lake as measured at *test* station SHL-1 and regional *baseline* lakes in the RAMP FSA are classified as **Negligible-Low** (Table 5.12-1). Differences in values of benthic invertebrate community measurement endpoints between Shipyard Lake and *baseline* lakes in the RAMP FSA were statistically-weak, with only one measurement endpoint (CA axis score 1) exceeding its regional *baseline* range. Differences in sediment quality conditions at *test* station SHL-1 were **Negligible-Low** compared to regional *baseline* conditions for sediment quality (Table 5.12-1).

5.12.4 Poplar Creek and Beaver River

Monitoring was conducted in the Poplar Creek and Beaver River watersheds in 2009 for the Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality components.

5.12.4.1 Hydrologic Conditions

2009 Hydrologic Conditions: WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 Flow data at WSC Station 07DA007 (RAMP Station S11), were recorded in 2009 from May 3 to August 7 and from September 21 to October 20. The open-water runoff volume during the measurement period was 19.8 million m^3. The first daily flow measurement on May 3 (4.8 m^3/s) was the highest discharge recorded in 2009 (Figure 5.12-11). Flows after early May remained within historical upper quartile values, with the exception of an increase in flow following the rainfall event on June 22. When measurements resumed on September 21, flows were below the lower quartile values and remained at this level until measurements ceased on October 20.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DA007 (RAMP Station S11) for the period of measurement in 2009 is presented in Table 5.12-17 and described below:

1. The closed-circuited land area as of 2009 was estimated at 3.1 km^2 (Table 2.4-1). The loss of flow to Poplar Creek that would have otherwise occurred from this land area is estimated at 0.27 million m^3.

2. The land area not closed-circuited as of 2009 was estimated at 1.4 km^2 (Table 2.4-1). The increase in flow to Poplar Creek that would not have otherwise occurred from this land area is estimated 0.02 million m^3.

3. Syncrude reported 11.5 million m^3 of water released to Poplar Creek via the Poplar Creek spillway in 2009 (Section 2.4.4), with 7.6 million m^3 of this volume calculated to be released during the period of measurement.

4. Suncor reported 1,273 m^3 of water withdrawn from the Poplar Creek reservoir, over the period of measurement in 2009.

The estimated cumulative effects of land change and water discharges and withdrawals is an increase in flow of 6.5 million m^3 over the period of measurement. The estimated *baseline* hydrograph is presented in Figure 5.12-11.

The mean open-water discharge (May to October) calculated from the observed *test* hydrograph is 49% higher than from the estimated *baseline* hydrograph (Table 5.12-18); this difference is classified as **High** (Table 5.12-1). The annual maximum daily discharge from the observed *test* hydrograph is 1.3% less than from the estimated *baseline* hydrograph; this difference is classified as **Negligible-Low** (Table 5.12-1). The open-water minimum daily discharge from the observed *test* hydrograph is 2.1% less than from the estimated *baseline* hydrograph; this difference is classified as **Negligible-Low** (Table 5.12-1).

5.12.4.2 Water Quality

In fall 2009, water quality samples were taken from:

- the Beaver River near its mouth (*test* station BER-1, sampled from 2003 to 2009);
- the upper Beaver River, upstream of all focal project developments (*baseline* station BER-2, sampled for the first time in 2008); and
- Poplar Creek near its mouth (*test* station POC-1, sampled from 2000 to 2009).

Sampling was also conducted at *baseline* station BER-2 in winter, spring, and summer in 2009.

2009 Results Relative to Historical and Regional *Baseline* Concentrations Water quality at *test* station BER-1 has historically shown high variability, with high concentrations of many dissolved ions relative to regional *baseline* values (Figure 5.12-12). In 2009, concentrations of several measurement endpoints at BER-1 exceeded the 95^{th} percentile of regional *baseline* concentrations, including sulphate, calcium, chloride, sodium, total dissolved solids, and total mercury. Concentrations of all these water quality measurement endpoints were within historical ranges of concentrations for this station (Table 5.12-19). Total nitrogen was the only water quality measurement endpoint that had a concentration in fall 2009 that was higher than its previously-measured maximum concentration at this station.

Concentrations of all water quality measurement endpoints in 2009 at *baseline* station BER-2 represented either historical minimum or maximum concentrations, as 2009 was only the second year of sampling at this station (Table 5.12-20). Concentrations of all water quality measurement endpoints at *baseline* station BER-2 were within the range of regional *baseline* concentrations with the exception of total boron and total mercury, with concentrations that exceeded the 95^{th} percentile of regional *baseline* concentrations (Figure 5.12-12).

Concentrations of sodium, chloride, total strontium, and total dissolved solids exceeded their 95^{th} percentile of regional *baseline* concentrations at *test* station POC-1 in fall 2009 (Figure 5.12-12). Concentrations of total nitrogen, total dissolved phosphorus, total arsenic, and total mercury were above previously-measured maximum concentrations for this station (Table 5.12-21).

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of the following water quality measurement endpoints exceeded water quality guidelines in the Beaver River and Poplar Creek in fall 2009 (Table 5.12-19 to Table 5.12-21):

- total aluminum and total nitrogen at both *test* station BER-1 and *baseline* station BER-2;
- total dissolved phosphorus at *baseline* station BER-2; and
- total aluminum and total nitrogen at *test* station POC-1.

Other Water Quality Guideline Exceedences The following are other water quality guideline exceedences observed in the Beaver River and Poplar Creek in 2009 (Table 5.12-5):

- Winter. Sulphide, total Kjeldahl nitrogen, total and dissolved iron and total phenols at *test* station POC-1, total dissolved phosphorus and total phosphorus at *baseline* station BER-2, and total aluminum, total phosphorus, total iron, and total phenols at *baseline* station BER-2;
- Spring. Sulphide, total phosphorus, total Kjeldahl nitrogen, total nitrogen, dissolved iron, total aluminum, total phenols, and total iron at *baseline* station BER-2;
- Summer. Sulphide, total phosphorus, total dissolved phosphorus, total Kjeldahl nitrogen, total nitrogen, total and dissolved iron, total aluminum, and total phenols at *baseline* station BER-2; and
- Fall. Sulphide, total Kjeldahl nitrogen, total nitrogen, total aluminum, dissolved iron, total iron, and total phenols at both *test* station BER-1 and *baseline* station BER-2.

Ion Balance The ionic composition of water at *test* stations BER-1 and POC-1 has been variable over the period of record (Figure 5.12-13). In fall 2009, the anion composition of water at these stations was more highly dominated by bicarbonate than sulphate or chloride, which were more dominant in previous years of sampling. Calcium and sodium were the dominant cations in fall 2009 at these stations, consistent with previous years (Figure 5.12-13). The ionic character of water at *baseline* station BER-2 in fall 2009 was dominated by calcium, sodium, and bicarbonate, which is consistent with results from 2008, the only previous year of sampling at this station (Figure 5.12-13).

Trend Analysis There were no statistically significant trends in water quality measurement endpoints at either *test* station BER-1 or *test* station POC-1. Trend analyses could not be completed for *baseline* station BER-2 due to insufficient data.

Water Quality Index The WQI values for fall 2009 for *test* stations BER-1 and POC-1 and *baseline* station BER-2 are presented in Table 5.12-6**:**

1. The WQI value of 67.1 for *test* station BER-1 in fall 2009 indicated a **Moderate** difference in water quality from regional *baseline* water quality conditions, which was consistent with the 2008 WQI value.
2. The WQI value of 76.5 for *test* station POC-1 in fall 2009 indicated a **Moderate** difference in water quality from regional *baseline* water quality conditions.
3. The WQI value for *baseline* station BER-2 was 100 in fall 2009, indicated a **Negligible-Low** difference from regional *baseline* water quality conditions.

The **Moderate** differences at both *test* stations BER-1 and POC-1 is a result of concentrations of several ions and other dissolved constituents of water quality at both stations being greater than their range of regional *baseline* concentrations in fall 2009.

Summary In fall 2009, differences in water quality from regional *baseline* conditions were **Moderate** for *test* stations BER-1 and POC-1, largely as a result of relatively high concentrations of a number of ions and total dissolved solids. Differences in water quality in fall 2009 at *baseline* station BER-2 compared to regional *baseline* conditions are assessed as **Negligible-Low**.

5.12.4.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2009 in the upper Beaver River and lower Poplar Creek. Both the *test* reach POC-D-1 and *baseline* reach BER-D-2 are depositional reaches and sampled for the first time in 2008; 2009 was the second year of sampling.

2009 Habitat Conditions *Test* reach POC-D-1 was shallow, had a substrate dominated by sand (74%), and had no macrophyte cover (Table 5.12-22). *Baseline* reach BER-D-2 was deep, had a substrate dominated by sand, and negligible macrophyte cover (Table 5.12-22). Current velocities were slow in both reaches, being non-measurable at *baseline* reach BER-D-2 and 0.05 m/s at *test* reach POC-D-1. The concentration of dissolved oxygen at both reaches in fall 2009 was between the acute and chronic guidelines for protection of aquatic life (AENV 1999b).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach POC-D-1 in fall 2009 was dominated by chironomids (64%) (Table 5.12-23) consisting primarily of *Tanytarsus*, *Micropsectra*, *Procladius*, *Cryptochironomus* and *Heterotrissocladius*. Tubificid worms were sub-dominant, comprising about 22% of the total fauna. *Test* reach POC-D-1 in fall 2009 also contained ceratopogonids, fingernail clams (bivalves), a variety of worms, mayflies, (Ephemeroptera consisting of *Hexagenia limbata*, Leptophebiidae) and caddisflies (Trichoptera, consisting of *Mystacides*).

The benthic invertebrate community at *baseline* reach BER-D-2 in fall 2009 was dominated by chironomids (71%) consisting principally of *Tanytarsus*, *Micropsectra* and (Table 5.12-14). Beetles (Coleoptera, *Dubiraphia*) comprised 10% of the total fauna. Sub-dominant groups included ceratopogonids, Ephemeroptera (6%, *Leptophlebia*, *Hexagenia limbata*), various worms, and fingernail clams (Table 5.12-23).

Abundance, taxa richness, Simpson's diversity, evenness and %EPT at both *test* reach POC-D-1 and *baseline* reach BER-D-2 in fall 2009 were all within the range of values for regional *baseline* depositional reaches (Figure 5.12-14).

The Correspondance Analysis illustrated that the composition of the benthic invertebrate community in *test* reach POC-D-1 shifted substantially in 2009 from conditions in 2008, becoming more similar to the average *baseline* conditions (Figure 5.12-15).

Linear contrasts were used to test for a difference in the average values of benthic invertebrate community measurement endpoints between *test* reach POC-D-1 and *baseline* reach BER-D-2 (designated as "BT" in Table 5.12-24).

Benthic invertebrate communities at *test* reach POC-D-1 have had lower diversity, evenness, and %EPT compared to benthic invertebrate communities in *baseline* reach BER-D-2 (Figure 5.12-14), producing significant BT contrasts for these measurement endpoints (Table 5.12-24).

Sediment Quality

Sediment quality was sampled in fall 2009 at *baseline* station BER-D-2 (depositional, first sampled in 2008) and *test* station POC-D-1 (depositional, sampled intermittently since 1997).

2009 Results and Historical Ranges of Concentration Sediments at *test* station POC-D-1 were comprised mostly of silt, as observed in previous years (Table 5.12-25). Concentrations of all measurable total-hydrocarbon fractions and total PAHs exceeded previously-measured maximum values for this station.

Only a single year of historical data exists for *baseline* station BER-D-2. As a result, all data presented for *baseline* station BER-D-2 for fall 2009 represent either historical minimum or maximum values. As in fall 2008, sediments at *baseline* station BER-D-2 were dominated by sand in fall 2009, and all sediment quality measurement endpoints were higher in fall 2009 than fall 2008 (Table 5.12-26). CCME fractions were not measured in 2008; therefore no temporal comparisons can be made.

In sediments collected at *test* station POC-D-1 in fall 2009, growth of the amphipod *Hyalella* and the midge *Chironomus* were higher than the previously-measured maximum growth and lower than the previously-measured minimum growth, respectively (Table 5.12-25). In sediments collected at *baseline* station BER-D-2 in fall 2009, growth and survival for both *Hyalella* and *Chironomus* were lower than in fall 2008 (Table 5.12-26).

Comparison with Sediment Quality Guidelines Concentrations of F3 and F4 hydrocarbons exceeded CCME soil quality guidelines at *test* station POC-D-1 (Table 5.12-25). Concentrations of specific metals or PAHs did not exceed relevant sediment or soil quality guidelines at either *test* station POC-D-1 (Table 5.12-25) or *baseline* station BER-D-2 (Table 5.12-26).

Sediment Quality Index The SQI values for fall 2009 *test* station POC-D-1 and *baseline* station BER-D-2 were 85.2 and 95.5, respectively (Table 5.12-11) indicating **Negligible-Low** differences in sediment quality conditions at these stations compared to regional *baseline* conditions of sediment quality (Table 5.12-1).

Summary

The differences in benthic invertebrate communities in the lower Poplar Creek as measured at *test* reach POC-D-1 and regional *baseline* depositional reaches are classified as **Moderate** on the basis that there are significant differences in diversity, evenness, and %EPT in benthic invertebrate communities between *test* reach POC-D-1 and *baseline* station BER-D-2. Values of all benthic invertebrate community measurement endpoints for both reaches were within the range of regional *baseline* conditions. Differences in sediment quality at *test* station POC-D-1 and *baseline* station BER-D-2 indicate **Negligible-Low** in sediment quality conditions at these stations from regional *baseline* conditions of sediment quality.

5.12.5 McLean Creek

Monitoring was conducted in McLean Creek watershed in 2009 for the Water Quality component.

5.12.5.1 Water Quality

In fall 2009, water quality samples were collected near the mouth of McLean Creek (*test* station MCC-1, sampled from 1999 to 2009).

2009 Results Relative to Historical and Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints at *test* station MCC-1 in fall 2009 were within the range of historical values, with the exception of conductivity, sodium, chloride, sulphate and total dissolved solids which had concentrations that were below previously-measured minimum concentrations at this station (Table 5.12-27). Concentrations of all water quality measurement endpoints at *test* station MCC-1 in fall 2009 were within the range of regional *baseline* concentrations with the exception of total arsenic and total suspended solids, which had concentrations that were below the 5th percentile of regional *baseline* concentrations (Figure 5.12-12).

Comparison of Water Quality Measurement Endpoints to Water Quality Guidelines Concentrations of total nitrogen and total aluminum exceeded water quality guidelines at *test* station MCC-1 in fall 2009 (Table 5.12-27).

Other Water Quality Guideline Exceedances Concentrations of sulphide, total Kjeldahl nitrogen, total iron, and total phenols exceeded water quality guidelines at *test* station MCC-1 in fall 2009 (Table 5.12-5).

Ion Balance While the ionic composition of water at *test* station MCC-1 has been variable across the sampling period, relative ion balance in fall 2009 was similar to that observed for most years since monitoring began at this station in 1999 (Figure 5.12-13). The ionic character of *test* station MCC-1 continues to generally be dominated by calcium and bicarbonate, although some years (particularly 1999, 2001, 2002 and 2007) have shown a greater influence of sodium and chloride.

Trend Analysis A decreasing trend in naphthenic acid and total arsenic was observed over the period of record (n=10; α=0.05). These changes are likely related to improvements in analytical detection limits for these measurement endpoints over the sampling period.

Water Quality Index The WQI value of 100 for *test* station MCC-1 in fall 2009 indicated a **Negligible-Low** difference in water quality conditions in McLean Creek from regional water quality *baseline* conditions (Table 5.12-6).

Summary Water quality in fall 2009 at *test* station MCC-1 showed **Negligible-Low** differences from regional *baseline* conditions and was generally consistent with previous years.

5.12.6 Fort Creek

Monitoring was conducted in the Fort Creek watershed in 2009 for the Climate and Hydrology and Water Quality components.

5.12.6.1 Hydrologic Conditions

2009 Hydrologic Conditions: Station S12, Fort Creek at Highway 63 The open-water runoff volume recorded in 2009 at Station S12 was 2.51 million m^3. Flows generally remained around historical median levels from May 1 to mid-June (Figure 5.12-16). Flows increased following the rainfall event of June 22 and reached a peak of 1.4 m^3/s on June 29. This flow exceeded the maximum values recorded at this station during the open-water (May to October) period. Flows decreased through July and August, and briefly rose following a rainfall event in early September above the historical maximum values recorded during this period. Flows decreased to below historical minimum values at the start of October and then increased until measurements ceased on October 21.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at Station S12 is presented in Figure 5.12-16 and described below:

1. The closed-circuited land area as of 2009 was estimated at 0.3 km^2 (Table 2.4-1). The loss of flow to Fort Creek that would have otherwise occurred from this land area is estimated at 0.02 million m^3.
2. The land area not closed-circuited as of 2009 was estimated at 19.7 km^2. The increase in flow to Fort Creek that would not have otherwise occurred from this land area is estimated at 0.28 million m^3.

The estimated cumulative effect of land change is an increase in flow of 0.26 million m^3 over the measurement period. The estimated *baseline* hydrograph is presented in Figure 5.12-16.

The mean open-water period (May to October) discharge, minimum daily discharge, and annual maximum daily discharge calculated from the observed *test* hydrograph are approximately 11% higher than from the estimate *baseline* hydrograph (Table 5.12-29); these differences are classified as **Moderate** (Table 5.12-1).

5.12.6.2 Water Quality

In fall 2009, water quality samples were taken from the mouth of Fort Creek (*test* station FOC-1, first sampled in 2000 and sampled intermittently from 2000 to 2009).

2009 Results Relative to Historical and Regional *Baseline* Concentrations In fall 2009, concentrations of calcium, sulphate, total dissolved solids (TDS), total strontium and conductivity at *test* station FOC-1 were greater than previously-measured maximum concentrations at this station (Table 5.12-30). Concentrations of total dissolved solids, total strontium, sulphate, and calcium in fall 2009 exceeded the 95th percentile of regional *baseline* concentrations at this station (Figure 5.12-17). Concentrations of total aluminum, total dissolved phosphorus and total suspended solids at *test* station FOC-1 in fall 2009 were below previously-measured minimum concentrations (Table 5.12-30). Concentrations of naphthenic acids were also below the 5th percentile of regional *baseline* concentrations due to greatly increased detection limits for this analysis in 2009.

Comparison of Water Quality Measurement Endpoints to Water Quality Guidelines There were no water quality measurement endpoints at *test* station FOC-1 with concentrations in fall 2009 that exceeded water quality guidelines (Table 5.12-30).

Other Water Quality Guideline Exceedances Concentrations of sulphide and total iron exceeded the water quality guidelines at *test* station FOC-1 in fall 2009 (Table 5.12-5).

Ion Balance The ionic composition of water at *test* station FOC-1 in fall 2009 was similar to that observed historically, although there was an increase in the relative proportion of sulphate to other ions (Figure 5.12-18).

Trend Analysis There were no significant trends in water quality measurement endpoints at *test* station FOC-1 across sampling years ($n=8$; $\alpha=0.05$).

Water Quality Index A WQI value of 78.0 was calculated for *test* station FOC-1 for fall 2009 (Table 5.12-6), indicating a **Moderate** difference in water quality conditions in lower Fort Creek from regional *baseline* water quality conditions.

Summary Differences in water quality in fall 2009 in lower Fort Creek as measured at *test* station FOC-1 as compared to regional *baseline* water quality conditions are assessed as **Moderate** on that basis of exceedances of total dissolved solids, sulphate, and calcium above and total aluminum, total dissolved phosphorus, and total suspended solids below the range of regional water quality *baseline* conditions.

5.12.7 Susan Lake Outlet

Monitoring was conducted at the Susan Lake outlet in 2009 for the Climate and Hydrology component.

5.12.7.1 Hydrologic Conditions

2009 Hydrologic Conditions: Station S25, Susan Lake Outlet Flows at Station S25 were measured from June 17 to July 12, and July 23 to October 23, 2009. When monitoring began on June 17, 2009, flow was above the historical maximum flows measured in mid-June (Figure 5.12-19). Flows increased to the maximum value recorded in 2009 at this station of 0.33 m^3/s on June 27, as a result of the late June heavy rainfall event. Flows remained above historical maximum or median values from late July until mid-September, and then decreased to below median levels until flow measurements ceased in late October.

5.12.8 Unnamed "Jackson" Lake

The Fish Population component for miscellaneous aquatic systems consisted of tissue analyses on target fish species captured in fall 2009 from an unnamed lake known locally as Jackson Lake, located north of Fort McMurray in the Richardson backcountry (Figure 5.12-1).

5.12.8.1 Whole-Organism Metrics

A total of 17 lake whitefish (eight female, eight male and one unsexed), one female northern pike, and 22 walleye (12 female, nine male and one unsexed) from "Jackson" Lake were sampled for fish tissue (muscle) analysis. The fork lengths of fish sampled were as follows:

1. Lake whitefish fork lengths ranged from a 256 mm immature female to 523 mm mature male. Males (average fork length: 415 mm) were larger than females (average fork length: 374 mm). The average length of all sampled fish was 387 mm. Lake whitefish were not aged.

2. The single captured northern pike was a 323 mm long two-year old mature female.

3. Walleye fork lengths ranged from a 193 mm one-year old immature female to a 617 mm 20-year old mature female. Females (average fork length: 448 mm, average age: nine years) were larger but younger than males (average fork length: 414 mm, average age: 11 years). The average length of all sampled fish was 425 mm and the average age was nine years.

5.12.8.2 Mercury Concentrations

Total mercury concentrations in muscle of individual walleye, northern pike and lake whitefish collected from Jackson Lake in 2009 are presented in Table 5.12-31:

1. Mercury concentrations in lake whitefish tissue ranged from 0.02 mg/kg in a 313 mm immature female to 0.16 mg/kg in a 450 mm mature male.

2. Mercury concentration in the 323 mm mature female northern pike was 0.05 mg/kg.

3. Walleye tissue mercury concentrations ranged from 0.05 mg/kg in a 193 mm immature female to 0.56 mg/kg in a 445 mm mature male.

Mercury concentrations in lake whitefish and walleye increased with increasing size class, with the exception of a single walleye in the 501-600 mm size class (Figure 5.12-20).

Regressions were performed to determine the relationships between size and age of fish with mercury concentration given mercury bioaccumulates in fish over time (Evans *et al*. 2005). Regressions between mercury concentration and fork length (log_{10}-transformed) were statistically-significant for both lake whitefish (p < 0.01; fork length adjusted r^2 = 0.79) and walleye and (p < 0.01; fork length adjusted r^2 = 0.88). Regressions between mercury concentration and weight (log_{10}-transformed) were also significant for both lake whitefish (p < 0.01; weight-adjusted r^2 = 0.51) and walleye (p < 0.01; weight-adjusted r^2 = 0.89) for lake whitefish and walleye, respectively). A regression of mercury concentration by age for walleye was statistically-significant (p < 0.01; age-adjusted r^2 = 0.93). Regressions were not performed for northern pike as there was only one fish captured of this species.

Figure 5.12-21 presents the relationship between mercury concentration and body weight for lake whitefish, walleye, and northern pike collected from Jackson Lake and other regional waterbodies in northern Alberta as reported in Grey *et al*. (1995), Golder (2003), NRBS (1996), RAMP (2004), Golder (2004), RAMP (2005), RAMP (2008), and RAMP (2009a):

1. The mean mercury concentration in lake whitefish from Jackson Lake in 2009 was within the 95% confidence interval of regional mercury concentrations and less than the mean value from regional waterbodies sampled between 1975 and 2008.

2. The mean mercury concentration in walleye from Jackson Lake in 2009 was within the 95% confidence interval of regional mercury concentrations measured in walleye from other waterbodies in the region sampled between 1975 and 2008.

3. The mean mercury concentration in northern pike from Jackson Lake was within the 95% confidence interval of regional mercury concentrations measured in walleye from other waterbodies in the region sampled between 1975 and 2008.

The relationship of mercury concentrations to fish weight were not significant and weakly predictive for lake whitefish (p=0.32, r^2=0.037) and walleye (p=0.14, r^2=0.046) and significant but weakly predictive for northern pike (p=0.002, r^2=0.143).

Regional comparisons of mercury concentrations in fish in northern Alberta are further discussed in Section 7.4

5.12.8.3 Potential Risks of Mercury in Fish Tissue to Human Health

A summary of 2009 walleye, northern pike and lake whitefish muscle mercury concentrations from Jackson Lake relative to United States Environmental Protection Agency (USEPA) and Health Canada fish consumption guidelines (Table 5.12-31) is as follows:

Lake Whitefish

The mean mercury concentration in lake whitefish in each size class did not exceed any criteria for fish consumption (Figure 5.12-20). Mercury concentration in lake whitefish did not exceed the Health Canada guideline for general consumers and subsistence fishers or the USEPA criteria for recreational fishers.

Northern Pike

The mercury concentration (0.05 mg/kg) in the northern pike exceeded the USEPA criteria for subsistence fishers (0.049 mg/kg), but did not exceed the Health Canada guidelines for either subsistence fishers (0.2 mg/kg) or general consumers (0.5 mg/kg).

Walleye

The mean mercury concentration in walleye greater than 400 mm exceeded the Health Canada guideline for subsistence fishers (0.2 mg/kg) (Figure 5.12-20). One of the 22 walleye captured exceeded the Health Canada guideline for general consumers (0.5 mg/kg).

The Government of Alberta does not have any fish consumption guidelines developed for Jackson Lake given the absence of any historical fish mercury data (GOA 2009b).

5.12.8.4 Potential Risks of Mercury in Fish Tissue to Fish and Fish Health

Mercury concentrations in muscle of captured walleye, northern pike and lake whitefish from Jackson Lake in 2009 did not exceed any of the effects (or no effects) thresholds for fish and fish health based on methylmercury concentration ranges described in Table 3.4-11 (i.e., thresholds inhibiting growth and survival are greater than 191 mg/kg).

5.12.8.5 Summary Assessment

Although mercury concentrations in "Jackson" Lake walleye, northern pike and lake whitefish in 2009 often exceeded the USEPA subsistence fisher guideline, comparisons with historical regional data indicated that mercury concentrations were within the range of mercury concentrations observed in other Alberta lakes in the region in which larger walleye (>400 mm) exceeded the Health Canada subsistence guideline but generally concentrations for lake whitefish and northern pike were below any Health Canada consumption guidelines (Grey *et al*. 1995, RAMP 2004, Golder 2004, RAMP 2005, RAMP 2008, RAMP 2009a). A regional assessment of mercury concentrations in fish is further discussed in Section 7.4.

5.12.8.6 Classification of Results

The classification of fish tissue results relative to human health and fish health is outlined in Section 3.4.7.3.

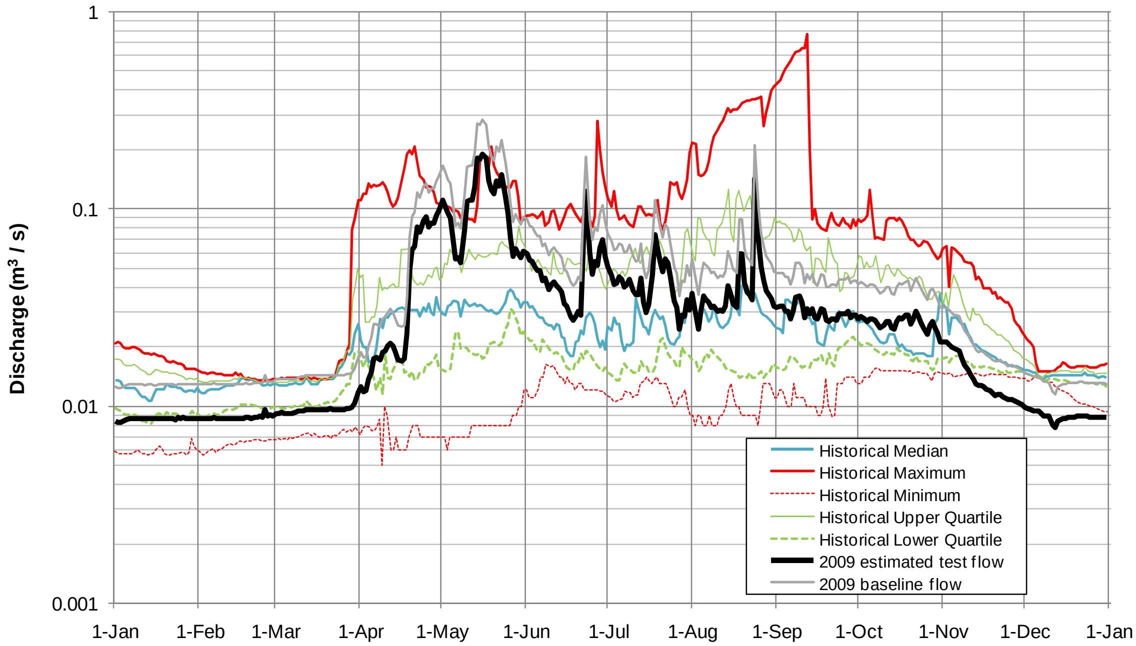
The average mercury concentration in lake whitefish from Jackson Lake across all size classes was below the subsistence fisher guideline (Figure 5.12-20) indicating a **Negligible-Low** risk to human health.

The average mercury concentration in captured walleye greater than 400 mm from Jackson Lake in 2009 was above the Health Canada subsistence fisher guideline indicating a **High** risk to health of subsistence fishers and a **Moderate** risk to health of general consumers for consumption of fish of this size (Figure 5.12-20). For fish less than 400 mm in length, the risk to human health is classified as **Negligible-Low**.

The mercury concentration in the single captured northern pike from Jackson Lake in 2009 was below the Health Canada subsistence fisher guideline indicating a **Negligible-Low** risk to human health for subsistence fishers and general consumers (Figure 5.12-20).

Fish tissue results for Jackson Lake in 2009 suggest **Negligible-Low** risk to fish health given mercury concentrations did not exceed the lethal (survival) and non-lethal (growth, reproduction) effects thresholds (Table 5.12-31).

Figure 5.12-3 The observed (test) hydrograph for Mills Creek in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed hydrograph based on Station S6, Mills Creek at Highway 63, 2009 provisional data. The drainage area for Station S6, Mills Creek at Highway 63 is assumed to be approximately 6 km^2 (two-thirds of the catchment). This was determined by initial DEM analysis from available data. Historical values from May 1 to October 31 calculated from data collected from 1997 to 2008 and from 2006 to 2008 for other months.

Table 5.12-2 Estimated water balance at Station S6, Mills Creek at Highway 63, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	1.02	**Observed discharge, obtained from Station S6, Mills Creek at Highway 63**
Closed-circuited area water loss from the observed *test* hydrograph	-0.52	Estimated 2.1 km^2 of the Mills Creek watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.02	Estimated 0.5 km^2 of the Mills Creek watershed with land change from focal projects as of 2009, that is not closed-circuited (Table 2.4-1)
Water withdrawals from the Mills Creek watershed from focal projects	0	None reported
Water releases into the Mills Creek watershed from focal projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects on tributaries of Mills Creek not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	1.52	**Estimated *baseline* discharge at RAMP Station S6, Mills Creek at Highway 63**
Incremental flow (change in total discharge)	-0.50	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-33%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: The observed discharge volume is calculated from 2009 provisional data for Station S6, Mills Creek at Highway 63.

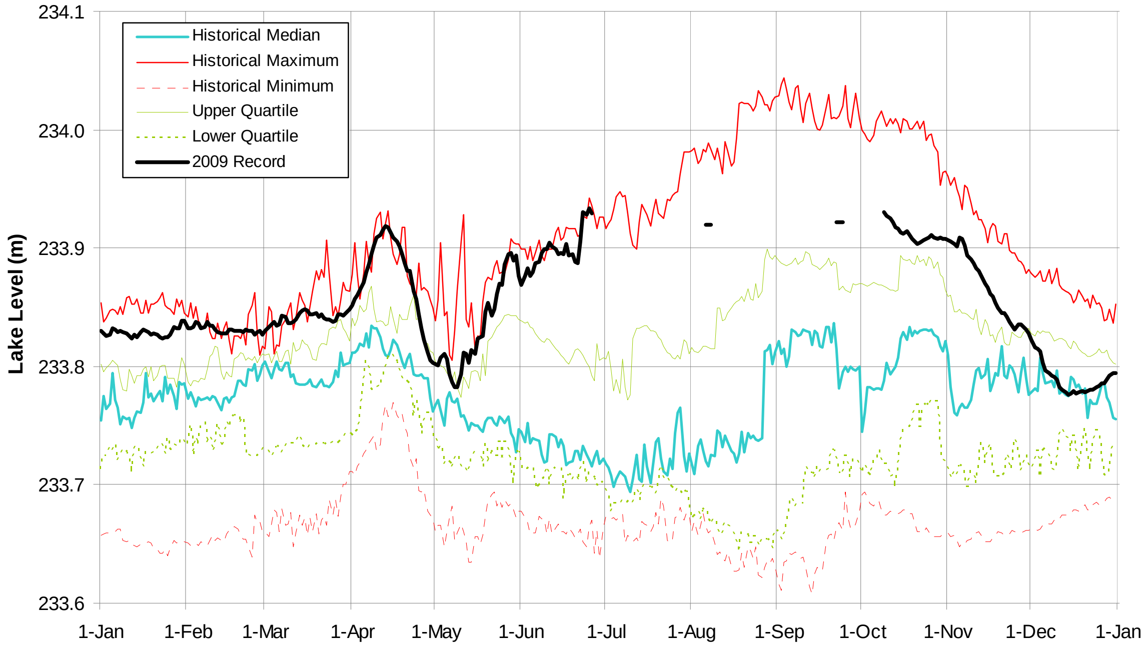
Note: The drainage area for Station S6, Mills Creek at Highway 63 is assumed to be approximately 6 km^2 (two-thirds of the catchment). This was determined by initial DEM analysis from available data, and will be updated in future using ground-truthing and higher-resolution DEM analysis.

Table 5.12-3 Calculated change in hydrologic measurement endpoints for the Mills Creek watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.07	0.05	-33%
Mean winter discharge	0.015	0.010	-33%
Annual maximum daily discharge	0.28	0.19	-33%
Open-water season minimum daily discharge	0.03	0.02	-33%

Note: Values are calculated from 2009 provisional data for Station S6, Mills Creek at Highway 63.

Figure 5.12-4 Isadore's Lake: 2009 hydrograph and historical context.



Note: Observed 2009 hydrograph based on 2009 provisional data for Station L3, Isadore's Lake 2009. Historical values calculated from the 2000-2008 period of record.

Table 5.12-4 Concentrations of water quality measurement endpoints, Isadore's Lake (ISL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.15	7	7.7	8.2	8.3
Total Suspended Solids	mg/L	-[1]	7	7	<3	5	10
Conductivity	µS/cm	-	608	7	353	526	588
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0039	7	0.004	0.009	**0.067**
Total nitrogen*	mg/L	1.0	**1.161**	7	0.3	0.8	**1.25**
Nitrate+Nitrite	mg/L	1.0	0.071	7	<0.1	<0.1	0.3
Dissolved organic carbon	mg/L	-	9.8	7	8	11	12
Ions							
Sodium	mg/L	-	11.4	7	6	10	13
Calcium	mg/L	-	72.8	7	37	60.2	72.2
Magnesium	mg/L	-	30.7	7	25.6	29.2	33.2
Chloride	mg/L	230, 860[3]	20.2	7	4	12	16
Sulphate	mg/L	100[4]	**141**	7	63.9	103	**109**
Total Dissolved Solids	mg/L	-	445	7	250	340	380
Total Alkalinity	mg/L	-	146	7	122	170	227
Organic compounds							
Naphthenic acids	mg/L	-	0.152	7	<1	<1	1
Selected metals							
Total aluminum	mg/L	0.1	0.0169	7	0.00555	0.020	**0.182**
Dissolved aluminum	mg/L	0.1[2]	<0.001	7	<0.001	0.00203	0.020
Total arsenic	mg/L	0.005	0.0005	7	0.00048	0.0085	0.0012
Total boron	mg/L	1.2[5]	0.0429	7	0.0350	0.0407	0.0491
Total molybdenum	mg/L	0.073	0.00002	7	<0.000008	0.00002	0.0001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	5	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.233	7	0.162	0.21	0.244
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.008**	7	**0.003**	**0.008**	**0.015**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.09**	7	<0.2	0.7	**1.2**
Total phenols	mg/L	0.004	**0.0063**	7	<0.001	0.001	**0.007**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

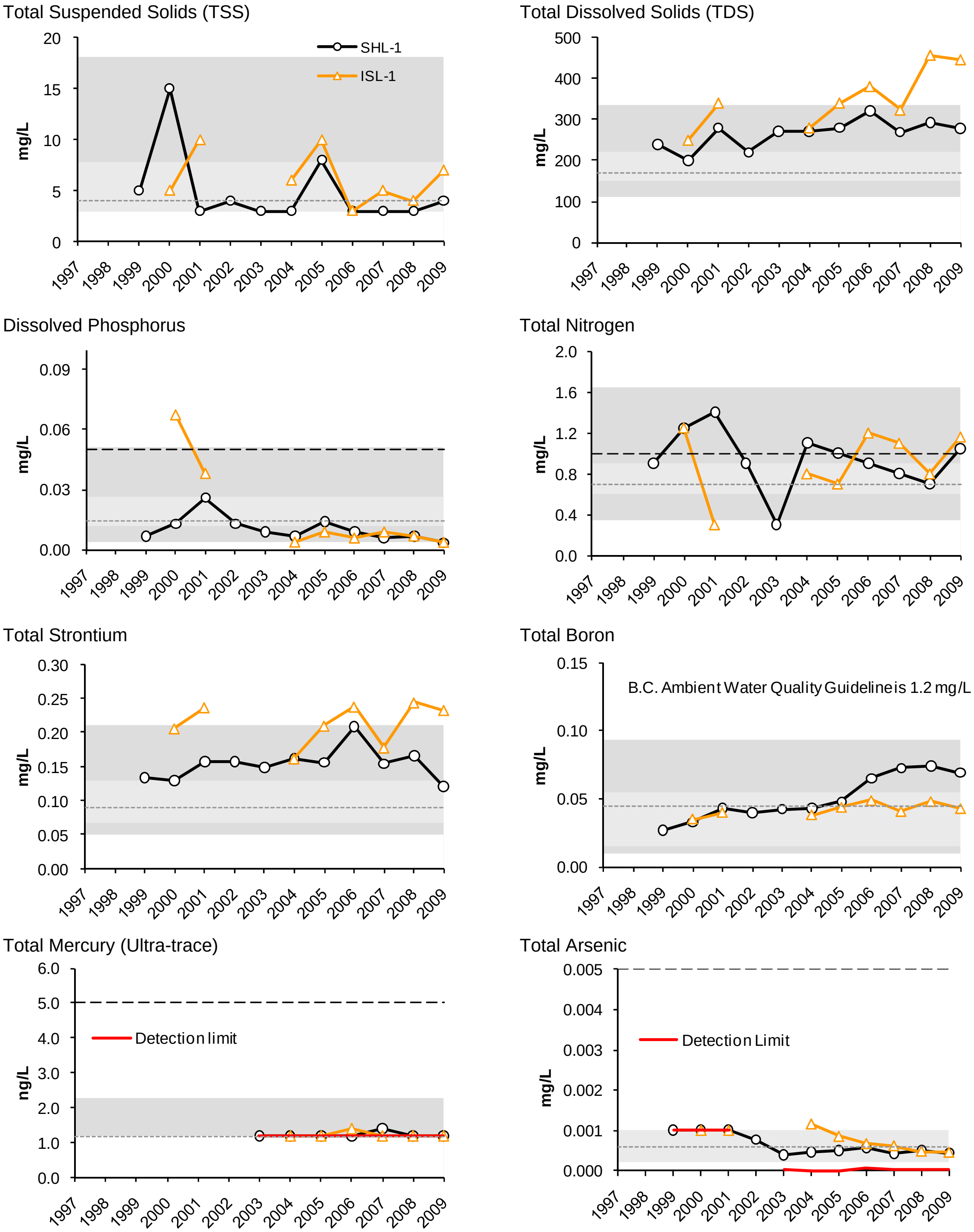
5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Figure 5.12-5 Concentrations of selected fall water quality measurement endpoints, Isadore's Lake (ISL-1) and Shipyard Lake (SHL-1) (fall 2009), relative to regional fall *baseline* concentrations.



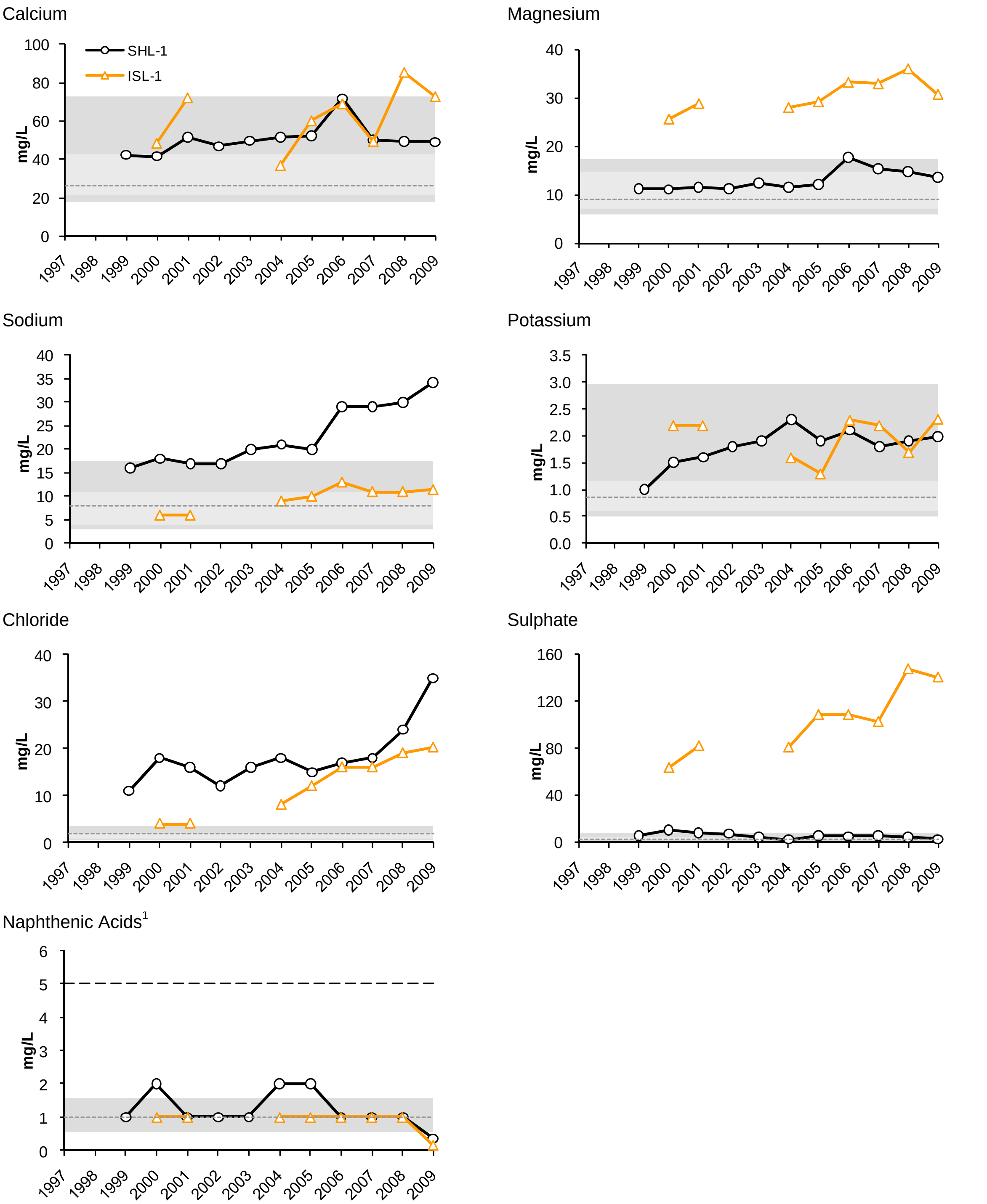
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.12-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.12-5 Water quality guideline exceedances in the Beaver River (station BER-1), Poplar Creek (station POC-1), McLean Creek (station MCC-1), Isadore's Lake (stations ISL-1), Shipyard Lake (stations SHL-1), and Fort Creek (station FOC-1) 2009.

Variable	Units	Guideline	POC-1	BER-1	BER-2	MCC-1	ISL-1	SHL-1	FOC-1
Winter									
Total iron	mg/L	0.3	ns	ns	**1.14**	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	**0.005**	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	**0.091**	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	**0.128**	ns	ns	ns	ns
Spring									
Sulphide	mg/L	0.002[2]	ns	ns	**0.0095**	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	**0.178**	ns	ns	ns	ns
Total Kjeldahl nitrogen	mg/L	1.0[4]	ns	ns	**1.69**	ns	ns	ns	ns
Total nitrogen	mg/L	1.0	ns	ns	**1.761**	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	**2.55**	ns	ns	ns	ns
Dissolved iron	mg/L	0.3[3]	ns	ns	**0.744**	ns	ns	ns	ns
Total iron	mg/L	0.3	ns	ns	**4.09**	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	**0.0109**	ns	ns	ns	ns
Summer									
Sulphide	mg/L	0.002[2]	ns	ns	**0.0083**	ns	ns	ns	ns
Total dissolved phosphorus	mg/L	0.05	ns	ns	**0.0668**	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	**0.0939**	ns	ns	ns	ns
Total nitrogen	mg/L	1.0	ns	ns	**1.681**	ns	ns	ns	ns
Total Kjeldahl nitrogen	mg/L	1.0[4]	ns	ns	**1.61**	ns	ns	ns	ns
Dissolved iron	mg/L	0.3[3]	ns	ns	**1.05**	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	**0.423**	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	**0.0077**	ns	ns	ns	ns
Total iron	mg/L	0.3	ns	ns	**1.7**	ns	ns	ns	ns
Fall									
Sulphate	mg/L	100[1]	-	-	-	-	**141**	-	-
Sulphide	mg/L	0.002[2]	**0.0102**	**0.018**	**0.0112**	**0.0062**	**0.008**	**0.0064**	**0.0021**
Total dissolved phosphorus	mg/L	0.05	-	-	**0.067**	-	-	-	-
Total phosphorus	mg/L	0.05	-	-	**0.108**	-	-	-	-
Total Kjeldahl nitrogen	mg/L	1.0[4]	**1.93**	**1.38**	**2.09**	**1.11**	**1.09**	-	-
Total nitrogen	mg/L	1.0	**2.001**	**1.451**	**2.161**	**1.181**	**1.161**	**1.051**	-
Total aluminum	mg/L	0.1	**0.408**	**0.519**	**0.431**	**0.31**	-	-	-
Dissolved iron	mg/L	0.3[3]	**2.32**	**1.08**	**0.991**	-	-	-	-
Total iron	mg/L	0.3	**3.51**	**2.08**	**2.14**	**0.55**	-	**0.417**	**0.58**
Total phenols	mg/L	0.004	**0.0084**	**0.0104**	**0.0047**	**0.0073**	**0.0063**	**0.0063**	-

BER-1, MCC-1, POC-1, ISL-1, SHL-1 and FOC-1 were sampled only in fall 2009.

BER-2 was sampled in winter, spring, summer, and fall 2009.

ns = not sampled.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

[1] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[2] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[3] Guideline is for total metal (no guideline for dissolved species).

[4] Guideline is for total nitrogen.

Figure 5.12-6 Piper diagram of fall ion balance in Isadore's Lake and Shipyard Lake, 1999-2009.

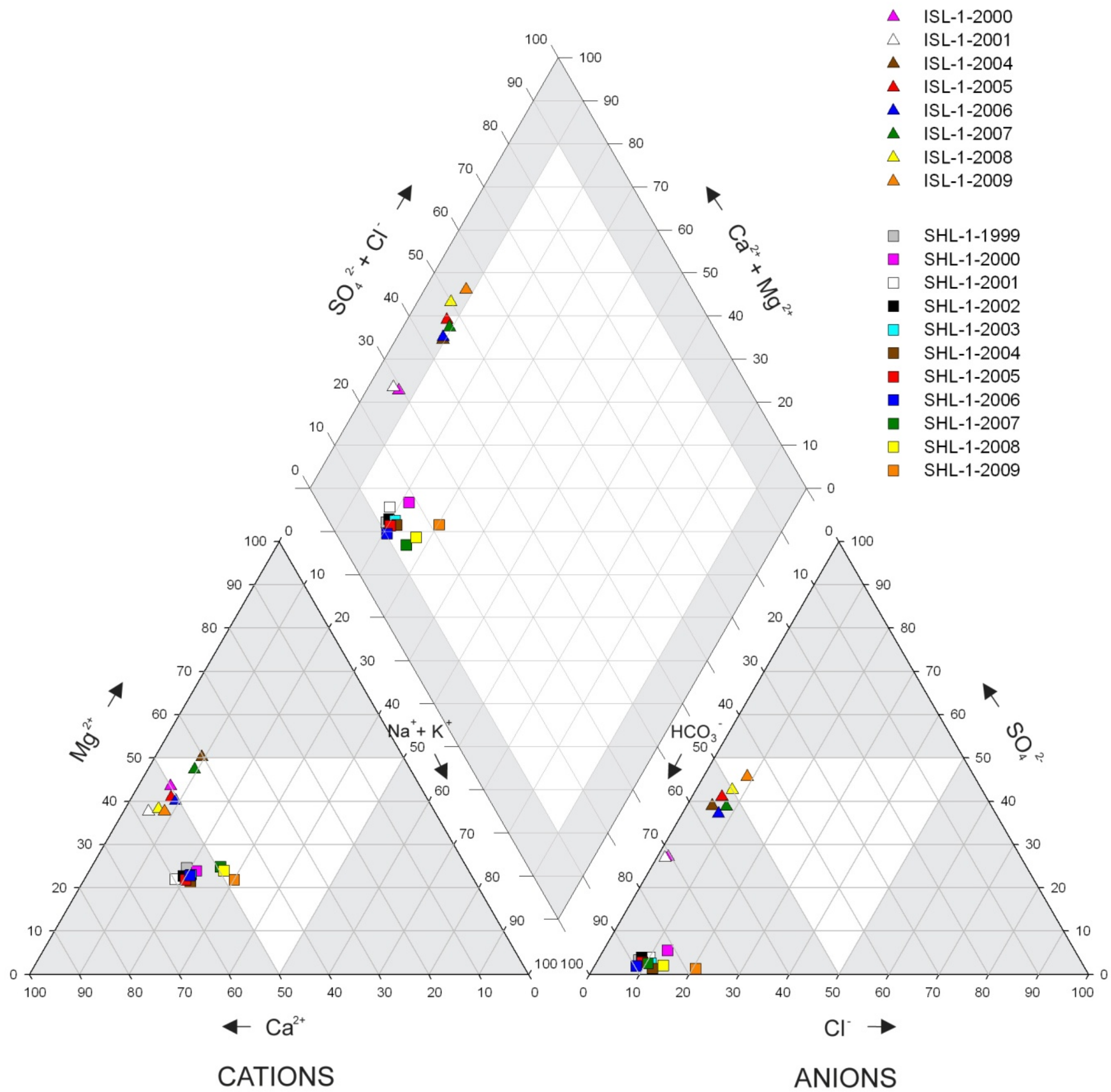


Table 5.12-6 Water quality index (fall 2009) for miscellaneous watershed stations.

Station Identifier	Location	2009 Designation	Water Quality Index	Classification
ISL-1	Isadore's Lake	*test*	63.2	Moderate
SHL-1	Shipyard Lake	*test*	74.5	Moderate
POC-1	near the mouth of Poplar Creek	*test*	76.5	Moderate
FOC-1	near the mouth of Fort Creek	*test*	78.0	Moderate
BER-1	near the mouth of Beaver River	*test*	67.1	Moderate
BER-2	upper Beaver River	*baseline*	100	Negligible-Low
MCC-1	near the mouth of McLean Creek	*test*	100	Negligible-Low

Note: see Figure 5.12-1 for the locations of these water quality stations.

Note: see Section 3.2.7.4 for a description of the Water Quality Index.

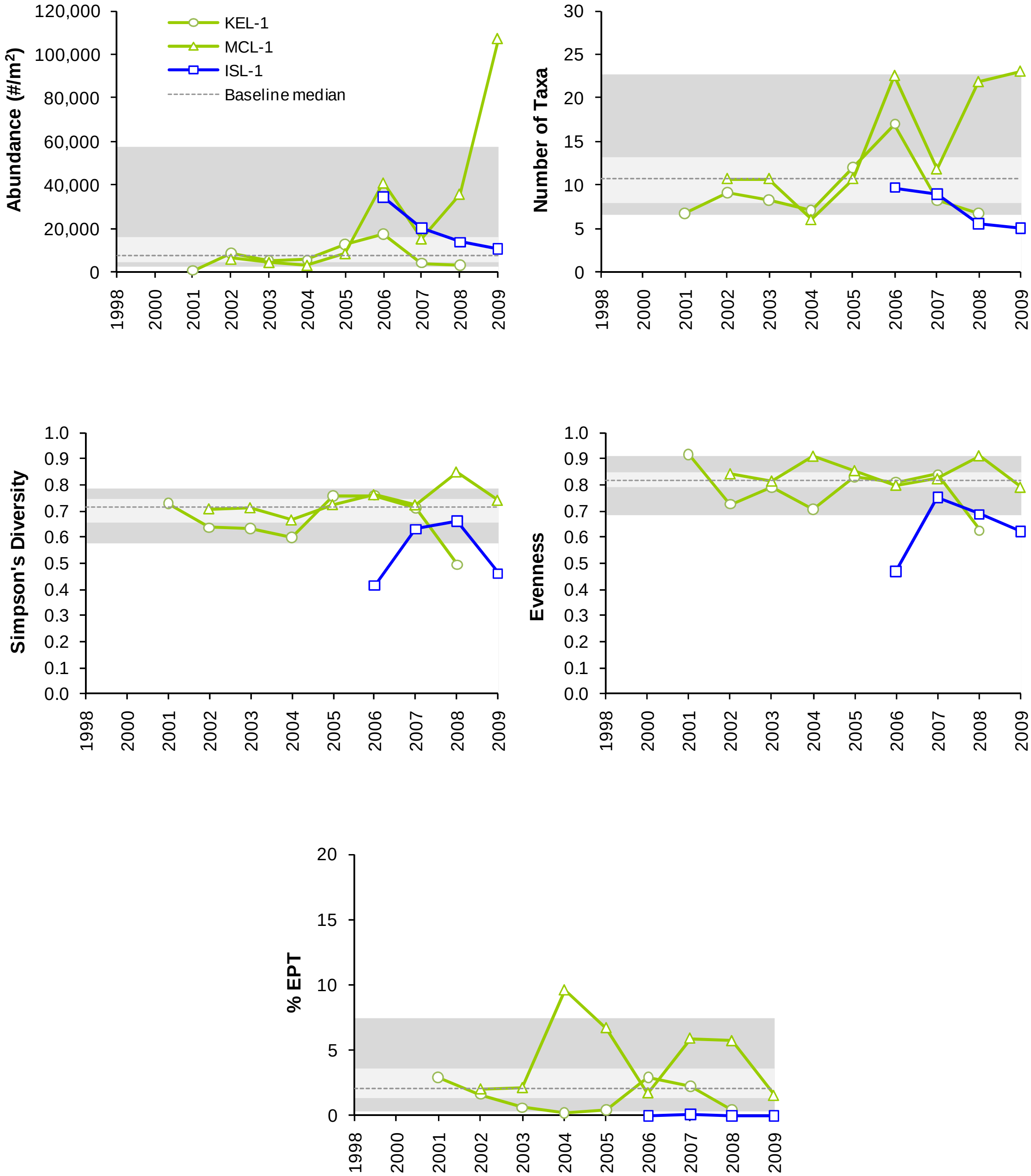
Table 5.12-7 Average habitat characteristics of benthic invertebrate sampling locations in Isadore's Lake.

Variable	Units	Isadore's Lake (*Test* Station ISL-1)
Sample Date	-	Sept 13, 2009
Habitat	-	Depositional
Water Depth	m	8
Macrophyte Cover	%	25
Field Water Quality		
Dissolved Oxygen	mg/L	9
Conductivity	µS/cm	621
pH	pH units	8.0
Water Temperature	°C	16.5
Sediment Composition		
Sand	%	9
Silt	%	64
Clay	%	27
Total Organic Carbon	%	3

Table 5.12-8 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Isadore's Lake.

Taxon	Percent Major Taxa Enumerated in Each Year			
	2006	2007	2008	2009
Amphipoda	<1			
Anisoptera			<1	
Bivalvia				
Ceratopogonidae	<1			
Chaoboridae	<1			<1
Chironomidae	2	57	19	7
Cladocera		4		
Copepoda	3	4	11	67
Ephemeroptera		1		
Erpobdellidae				
Gastropoda				<1
Glossiphoniidae				
Hydracarina			8	
Lumbriculidae				
Naididae	4	1	6	
Nematoda	72	32	49	25
Ostracoda	1	2	7	<1
Trichoptera				
Tubificidae				<1
Zygoptera				
Benthic Invertebrate Community Measurement Endpoints				
Total Abundance (No./m^2)	33,987	20,110	13,870	10,948
Richness	10	9	6	5
Simpson's Diversity	0.41	0.63	0.66	0.46
Evenness	0.42	0.75	0.69	0.62
% EPT	0	1	0	0

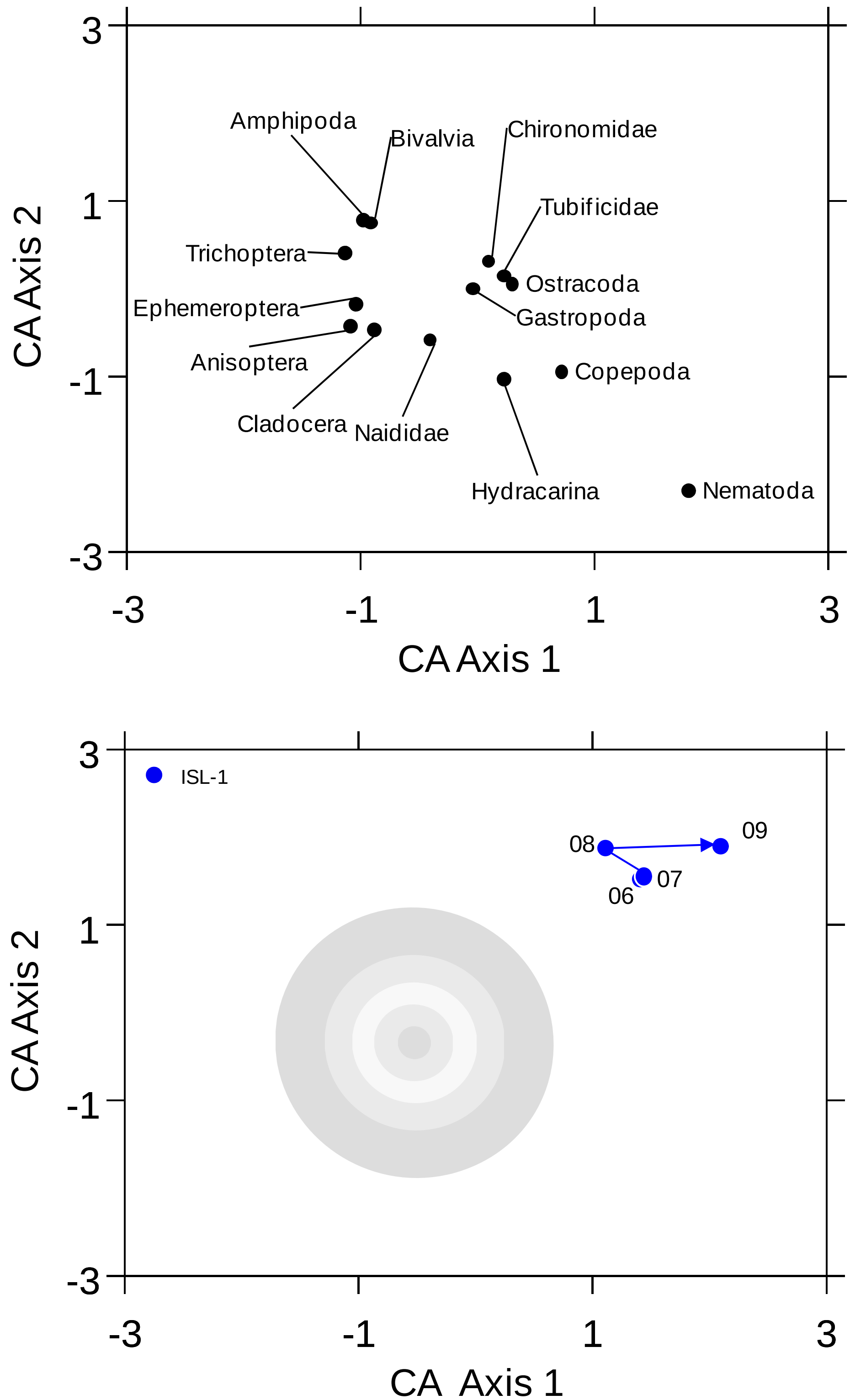
Figure 5.12-7 Variation in benthic invertebrate community measurement endpoints in Isadore's Lake (*test*) relative to *baseline* lakes in the RAMP FSA.



Note: Regional *baseline* values reflect pooled results for all *baseline* lakes sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Note: Kearl Lake (KEL-1) was designated as a *baseline* lake between 2001 and 2008. In 2009, Kearl Lake was designated as a *test* lake.

Figure 5.12-8 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in Isadore's Lake.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* lakes (Kearl [2001 to 2008] and McClelland) in the RAMP FSA.

Table 5.12-9 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Isadore's Lake (ISL-1) relative to McClelland Lake.

Measurement Endpoint	Source	SS	df	MS	F-ratio	P
Log Abundance	Lake - Year	23.056	11	2.096	4.66	0.000
	Baseline vs Test (BT)	3.695	1	3.695	8.22	0.005
	Linear Time Trend (TT)	0.345	1	0.345	0.77	0.383
	BT x TT	1.639	1	1.639	3.65	0.059
	Remainder (noise)	17.377	8	2.172	4.83	0.030
	Error	48.542	108	0.449		
Log Richness	Lake - Year	5.386	11	0.490	8.75	0.000
	Baseline vs Test (BT)	3.459	1	3.459	61.85	0.000
	Linear Time Trend (TT)	0.134	1	0.134	2.39	0.125
	BT x TT	0.384	1	0.384	6.87	0.010
	Remainder (noise)	1.408	8	0.176	3.15	0.079
	Error	6.041	108	0.056		
Diversity	Lake - Year	1.659	11	0.151	5.14	0.000
	Baseline vs Test (BT)	1.042	1	1.042	35.52	0.000
	Linear Time Trend (TT)	0.015	1	0.015	0.52	0.473
	BT x TT	0.002	1	0.002	0.08	0.779
	Remainder (noise)	0.600	8	0.075	2.55	0.113
	Error	3.169	108	0.029		
Evenness	Lake - Year	2.097	11	0.191	6.41	0.000
	Baseline vs Test (BT)	0.808	1	0.808	27.15	0.000
	Linear Time Trend (TT)	0.128	1	0.128	4.31	0.040
	BT x TT	0.042	1	0.042	1.40	0.240
	Remainder (noise)	1.119	8	0.140	4.70	0.032
	Error	3.214	108	0.030		
Log %EPT	Lake - Year	5.79	11	0.53	3.46	0.000
	Baseline vs Test (BT)	3.91	1	3.91	25.72	0.000
	Linear Time Trend (TT)	0.00	1	0.00	0.00	0.963
	BT x TT	0.00	1	0.00	0.01	0.914
	Remainder (noise)	1.88	8	0.23	1.55	0.216
	Error	16.40	108	0.15		
CA Axis 1	Lake - Year	119.45	11	10.86	33.16	0.000
	Baseline vs Test (BT)	82.42	1	82.42	251.69	0.000
	Linear Time Trend (TT)	1.59	1	1.59	4.85	0.030
	BT x TT	0.19	1	0.19	0.57	0.450
	Remainder (noise)	35.3	8	4.407	13.46	0.000
	Error	35.04	107	0.33		
CA Axis 2	Lake - Year	69.79	11	6.34	15.44	0.000
	Baseline vs Test (BT)	34.63	1	34.63	84.28	0.000
	Linear Time Trend (TT)	0.00	1	0.00	0.00	0.977
	BT x TT	0.00	1	0.00	0.00	0.991
	Remainder (noise)	35.16	8	4.39	10.69	0.001
	Error	43.97	107	0.41		

Table 5.12-10 Concentrations of sediment quality measurement endpoints, Isadore's Lake (ISL-1), fall 2009.

Variables	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	27	4	19	26	57
Silt	%	-	61	4	39	50	62
Sand	%	-	12	4	3	16	35
Total organic carbon	%	-	4.5	4	1.3	4.5	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<50	3	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<50	3	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	91	3	<5	16	23
Fraction 3 (C16-C34)	mg/kg	300[1]	286	3	150	**790**	**4600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	252	3	89	540	**3500**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.007	4	0.006	0.007	0.009
Retene	mg/kg	-	0.037	4	0.056	0.068	0.071
Total dibenzothiophenes	mg/kg	-	0.170	4	0.145	0.199	0.261
Total PAHs	mg/kg	-	1.362	4	1.279	1.401	2.056
Total Parent PAHs	mg/kg	-	0.100	4	0.143	0.172	0.375
Total Alkylated PAHs	mg/kg	-	1.262	4	1.115	1.139	1.881
Predicted PAH toxicity[3]	H.I.	-	0.595	4	0.007	0.437	1.288
Metals that exceed CCME guidelines in 2009							
None	mg/kg	-	-	-	-	-	-

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.12-11 Sediment quality index (fall 2009) for miscellaneous watershed stations.

Station Identifier	Location	2009 Designation	Sediment Quality Index	Classification
ISL-1	Isadore's Lake	*test*	94.4	Negligible-Low
SHL-1	Shipyard Lake	*test*	81.5	Negligible-Low
POC-D-1	mouth of Poplar Creek	*test*	85.2	Negligible-Low
BER-D-2	upper Beaver River	*baseline*	95.5	Negligible-Low

Table 5.12-12 Concentrations of water quality measurement endpoints, Shipyard Lake (SHL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.18	10	7.7	8.1	8.2
Total Suspended Solids	mg/L	-[1]	4	10	<3	3	15
Conductivity	µS/cm	-	461	10	358	391.5	509
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0036	10	0.006	0.009	0.026
Total nitrogen*	mg/L	1.0	**1.057**	10	0.3	0.9	**1.4**
Nitrate+Nitrite	mg/L	1.0	0.071	10	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	16.7	10	17	20	24
Ions							
Sodium	mg/L	-	34.1	10	16	20	30
Calcium	mg/L	-	49.1	10	41.7	49.8	71.8
Magnesium	mg/L	-	13.6	10	11.1	11.8	17.7
Chloride	mg/L	230, 860[3]	35	10	11	16.5	24
Sulphate	mg/L	100[4]	2.95	10	2.8	5.95	10.5
Total Dissolved Solids	mg/L	-	279	10	200	270	320
Total Alkalinity	mg/L	-	186	10	159	185.5	251
Organic compounds							
Naphthenic acids	mg/L	-	0.357	10	<1	1	2
Selected metals							
Total aluminum	mg/L	0.1	0.0142	10	<0.002	0.009	**0.140**
Dissolved aluminum	mg/L	0.1[2]	<0.001	10	<0.001	0.00173	<0.01
Total arsenic	mg/L	0.005	0.0004	10	0.0004	0.0005	0.001
Total boron	mg/L	1.2[5]	0.0693	10	0.0270	0.0430	0.0744
Total molybdenum	mg/L	0.073	0.00002	10	0.000029	0.00008	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	6	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.121	10	0.129	0.1565	0.209
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0064**	10	**<0.003**	**0.009**	**0.014**
Total iron	mg/L	0.3	**0.417**	10	0.27	**0.60**	**1.48**
Total phenols	mg/L	0.004	**0.0063**	10	<0.001	**0.005**	**0.012**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

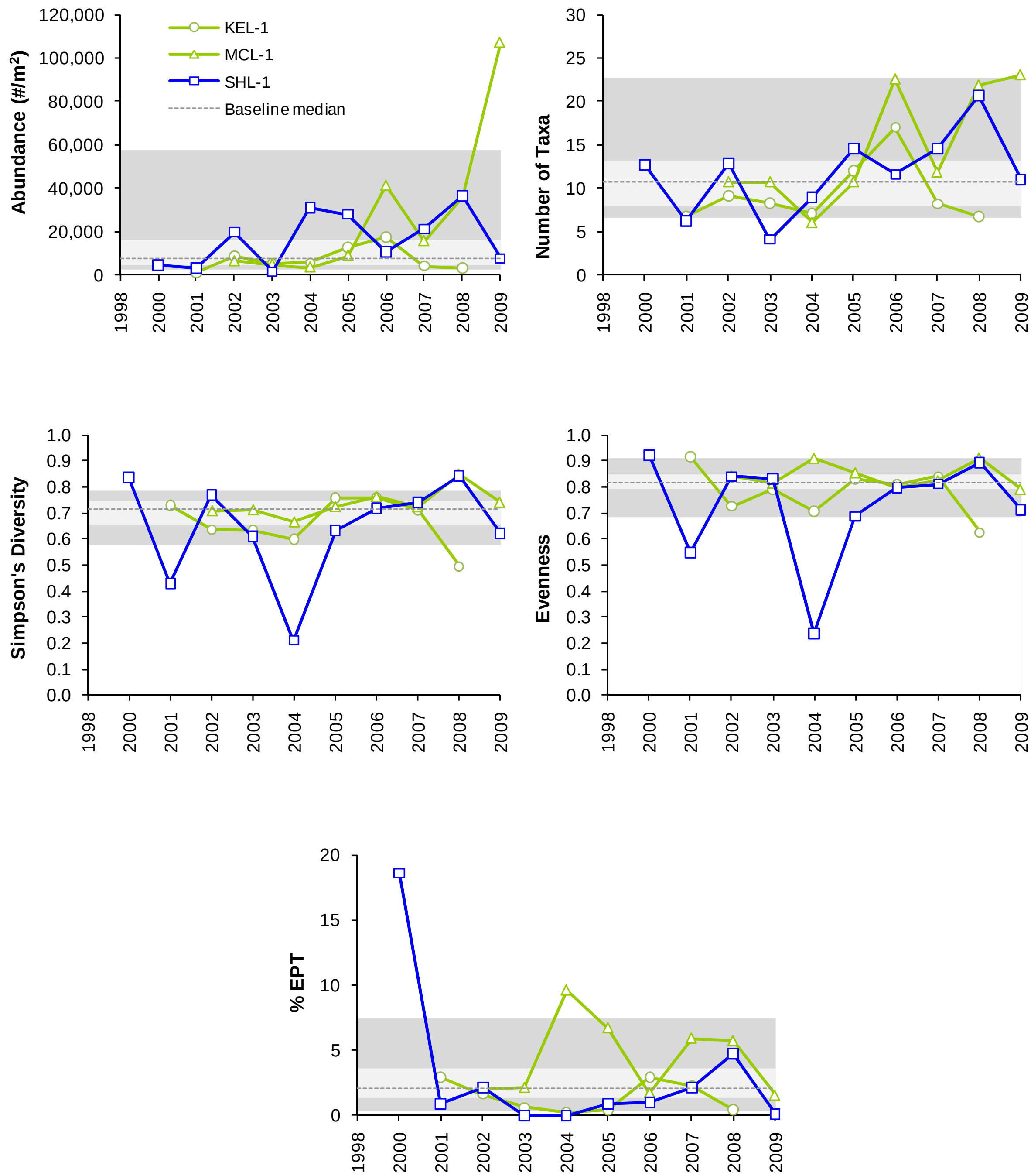
Table 5.12-13 Average habitat characteristics of benthic invertebrate sampling locations in Shipyard Lake.

Variable	Units	Shipyard Lake (*test* station SHL-1)
Sample Date	-	Sept 13, 2009
Habitat	-	Depositional
Water Depth	m	1
Macrophyte Cover	%	25
Field Water Quality		
Dissolved Oxygen	mg/L	7
Conductivity	µS/cm	469
pH	pH units	7.8
Water Temperature	°C	16.5
Sediment Composition		
Sand	%	34
Silt	%	39
Clay	%	26
Total Organic Carbon	%	10

Table 5.12-14 Summary of major taxon abundances and benthic invertebrate community measurement endpoints, Shipyard Lake.

Taxon	Percent Major Taxa Enumerated in Each Year									
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Amphipoda	7		2	3		2	2	2	1	<1
Anisoptera	<1	1	<1			<1			<1	
Bivalvia	7	<1	8	6	1	<1	2	1	1	2
Ceratopogonidae		1	<1	1			6			<1
Chaoboridae	3	53	1	32	1	<1	6			2
Chironomidae	25	40	48	32	3	30	37	27	40	20
Cladocera	3				<1	2		1	3	<1
Copepoda	1	<1		9	1	3	1	11	16	16
Enchytraeidae										7
Ephemeroptera	16	1	2			<1	<1	3	6	<1
Erpobdellidae							1			
Gastropoda	18	1	7	5	1	2	<1	3	2	7
Glossiphoniidae		<1	<1	<1						
Hydracarina		1	<1		<1	1		3	2	2
Lumbriculidae						<1				
Naididae	8	<1	3		4	9	16	6	5	3
Nematoda			3	2	2	1	1	1	1	5
Ostracoda	6	2	25	8	87	5	22	40	22	32
Trichoptera	2	1	<1		<1	1	1	1	<1	<1
Tubificidae	1		1	3	1	7			<1	<1
Zygoptera	3		1		<1				1	
Benthic Invertebrate Community Measurement Endpoints										
Total Abundance (No./m^2)	4,552	3,284	19,780	1,530	30,867	27,930	10,647	21,305	36,328	7,644
Richness	13	6	13	4	9	15	12	15	21	11
Simpson's Diversity	0.84	0.43	0.77	0.61	0.21	0.63	0.72	0.74	0.84	0.62
Evenness	0.92	0.55	0.84	0.83	0.24	0.69	0.72	0.81	0.89	0.71
% EPT	19	1	2	<1	<1	1	<1	2	4	0.1

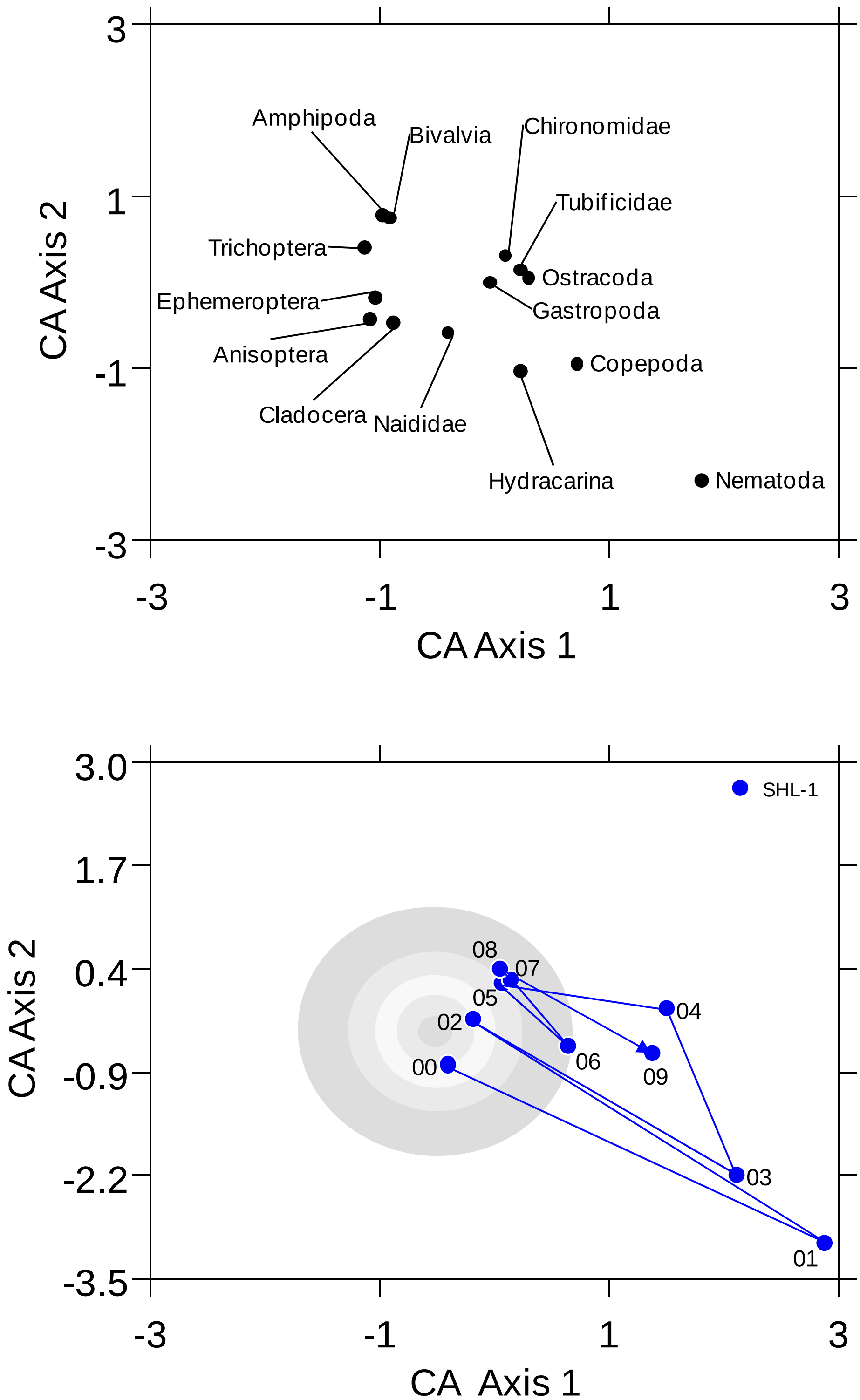
Figure 5.12-9 Variation in benthic invertebrate community measurement endpoints in Shipyard, Kearl, and McClelland lakes.



Note: Regional *baseline* values reflect pooled results for all *baseline* lakes sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Note: Kearl Lake (KEL-1) was designated as a *baseline* lake between 2001 and 2008. In 2009, Kearl Lake was designated as a *test* lake.

Figure 5.12-10 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in Shipyard Lake (*test* station SHL-1).



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* lakes in the RAMP FSA (i.e., Kearl [2001 to 2008] and McClelland lakes).

Table 5.12-15 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Shipyard Lake (SHL-1) relative to McClelland Lake.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Lake - Year	39.672	17	2.334	10.37	0.000
	Baseline vs Test (BT)	0.858	1	0.858	3.81	0.053
	Linear Time Trend (T)	9.313	1	9.313	41.38	0.000
	BT x T	4.316	1	4.316	19.18	0.000
	Remainder (noise)	25.185	14	1.799	7.99	0.005
	Error	36.013	160	0.225		
Log Richness	Lake - Year	6.511	17	0.383	8.37	0.000
	Baseline vs Test (BT)	0.073	1	0.073	1.60	0.207
	Linear Time Trend (T)	1.826	1	1.826	39.89	0.000
	BT x T	0.191	1	0.191	4.16	0.043
	Remainder (noise)	4.422	14	0.316	6.90	0.009
	Error	7.323	160	0.046		
Diversity	Lake - Year	3.578	17	0.210	8.38	0.000
	Baseline vs Test (BT)	0.346	1	0.346	13.77	0.000
	Linear Time Trend (T)	0.258	1	0.258	10.28	0.002
	BT x T	0.012	1	0.012	0.46	0.497
	Residual (noise)	2.963	14	0.212	8.42	0.004
	Error	4.019	160	0.025		
Evenness	Lake - Year	3.909	17	0.230	10.83	0.000
	Baseline vs Test (BT)	0.585	1	0.585	27.53	0.000
	Linear Time Trend (T)	0.022	1	0.022	1.02	0.313
	BT x T	0.057	1	0.057	2.67	0.104
	Remainder (noise)	3.246	14	0.232	10.92	0.001
	Error	3.397	160	0.021		
Log %EPT	Lake - Year	11.48	17	0.68	4.15	0.000
	Baseline vs Test (BT)	1.70	1	1.70	10.48	0.001
	Linear Time Trend (T)	0.54	1	0.54	3.33	0.070
	BT x T	0.01	1	0.01	0.06	0.801
	Remainder (noise)	9.22	14	0.66	4.05	0.046
	Error	26.00	160	0.16		
CA Axis 1	Lake - Year	190.2	17	11.19	19.58	0.000
	Baseline vs Test (BT)	63.7	1	63.68	111.43	0.000
	Linear Time Trend (T)	0.1	1	0.10	0.18	0.673
	BT x T	0.4	1	0.45	0.78	0.378
	Remainder (noise)	126.0	14	9.000	15.75	0.000
	Error	91.4	160	0.57		
CA Axis 2	Lake - Year	165.05	17	9.71	12.73	0.000
	Baseline vs Test (BT)	8.80	1	8.80	11.54	0.001
	Linear Time Trend (T)	9.00	1	9.00	11.80	0.001
	BT x T	0.03	1	0.03	0.04	0.837
	Remainder (noise)	147.22	14	10.52	13.78	0.000
	Error	122.06	160	0.76		

Table 5.12-16 Concentrations of sediment quality measurement endpoints, Shipyard Lake (SHL-1), fall 2009.

Variables	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	18	7	3	53	60
Silt	%	-	41	7	36	42	69
Sand	%	-	41	7	2	4	39
Total organic carbon	%	-	11.6	7	5.5	14.5	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<150	4	<5	<5	<60
Fraction 1 (C6-C10)	mg/kg	30[1]	<150	4	<5	<5	<60
Fraction 2 (C10-C16)	mg/kg	150[1]	**243**	4	<5	<5	69
Fraction 3 (C16-C34)	mg/kg	300[1]	**1440**	4	290	**665**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	919	4	<5	180	280
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.031	5	0.011	0.019	0.025
Retene	mg/kg	-	0.058	7	0.046	0.094	0.199
Total dibenzothiophenes	mg/kg	-	0.991	7	0.265	0.470	2.622
Total PAHs	mg/kg	-	4.378	7	2.276	4.073	13.865
Total Parent PAHs	mg/kg	-	0.341	7	0.231	0.256	5.886
Total Alkylated PAHs	mg/kg	-	4.037	7	2.020	3.822	8.464
Predicted PAH toxicity[3]	H.I.	-	0.467	7	0.097	0.885	3.786
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-

Values in **bold** indicate concentrations exceeding guidelines.

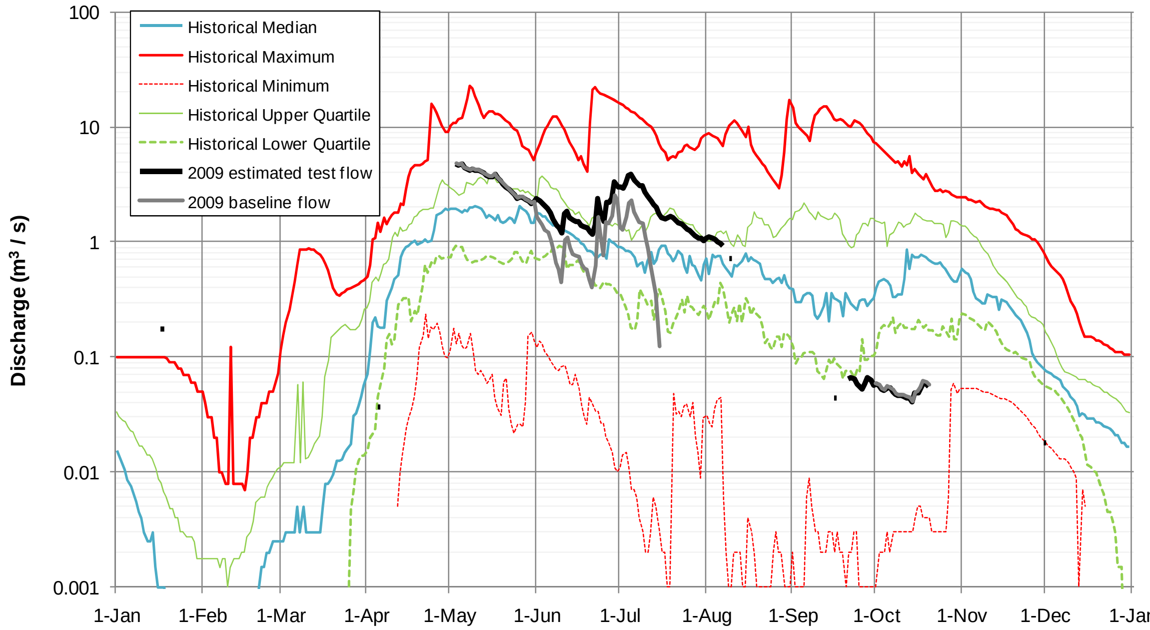
[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[4] 2002 *Hyalella* test based on 10-day test period.

Figure 5.12-11 The observed (*test*) hydrograph for Poplar Creek in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed values are calculated from provisional data for May 3, 2009 to August 7, 2009 and September 21 to October 20, 2009 for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63. The upstream drainage area is 151 km^2. Historical values from May 1 to October 31 calculated from data collected from 1996 onwards and from 1973 to 1986 for other months.

Note: Negative baseline flow values computed to be less than zero when the cumulative flows by focal projects were estimated to be greater than the observed flows at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 were set to zero, in accordance with previous reports (e.g., RAMP 2009a).

Table 5.12-17 Estimated water balance at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63, May 3 to August 7 and September 21 to October 20, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**19.8**	**Observed daily discharges, obtained from WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63.**
Closed-circuited area water loss from the observed *test* hydrograph	-0.27	Estimated 3.1 km^2 of the Poplar Creek watershed is closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.02	Estimated 1.4 km^2 of the Poplar Creek watershed with land change from focal projects as of 2009 that is not closed-circuited (Table 2.4-1)
Water withdrawals from the Poplar Creek watershed from focal projects	-0.001	1,273 m^3 of water assumed to be withdrawn by Suncor for the specified time period from Poplar Creek Reservoir
Water releases into the Poplar Creek watershed from focal projects	0	None reported
Diversions into or out of the watershed	+7.6	Diversion from original upper Beaver River catchment area into Poplar Creek via the spillway.
The difference between *test* and *baseline* hydrographs on tributary streams	0	No focal projects or other oil sands projects on tributaries of Poplar Creek not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**13.3**	**Estimated *baseline* discharge at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63.**
Incremental flow (change in total discharge)	+6.5	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+49%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Values are calculated from provisional data for May 3 2009 to August 7, 2009 and September 21 to October 20, 2009 for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63. Upstream drainage area of 151 km^2 assumed, from WSC data.

Note: Negative baseline flow values computed to be less than zero when the net flows by focal activities were estimated to be greater than the observed flows at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63, were set to zero, in accordance with previous reports (e.g., RAMP 2009a).

Table 5.12-18 Calculated change in hydrologic measurement endpoints for the Poplar Creek watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	1.57	2.35	+49%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	4.88	4.82	-1.3%
Open-water season minimum daily discharge	0.042	0.041	-2.1%

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed values are calculated from provisional data for May 3 to August 7, 2009 and September 21 to October 20, 2009 for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63

Note: Negative baseline flow values computed to be less than zero when the net flows by focal activities were estimated to be greater than the observed flows at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63, were set to zero, in accordance with previous reports (RAMP 2009a).

Table 5.12-19 Concentrations of water quality measurement endpoints, lower Beaver River (*test* station BER-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	6	8.0	8.2	8.3
Total Suspended Solids	mg/L	-[1]	13	6	<3	8	35
Conductivity	µS/cm	-	731	6	566	970.5	1430
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0124	6	0.004	0.0065	0.022
Total nitrogen*	mg/L	1.0	**1.45**	6	0.7	0.9	**1.4**
Nitrate+Nitrite	mg/L	1.0	<0.071	6	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	36.6	6	15	28.5	52
Ions							
Sodium	mg/L	-	70.3	6	53	97.5	181
Calcium	mg/L	-	70.2	6	49.1	71.6	91.4
Magnesium	mg/L	-	19.1	6	15.5	21.85	27.9
Chloride	mg/L	230, 860[3]	55.3	6	55	99.5	221
Sulphate	mg/L	100[4]	54.6	6	54	76	**117**
Total Dissolved Solids	mg/L	-	496	6	450	654.5	830
Total Alkalinity	mg/L	-	239	6	158	243.5	294
Organic compounds							
Naphthenic acids	mg/L	-	0.848	6	<1	1	3
Selected metals							
Total aluminum	mg/L	0.1	**0.519**	6	0.0314	**0.252**	**5.130**
Dissolved aluminum	mg/L	0.1[2]	0.0065	6	0.0017	0.0086	0.0445
Total arsenic	mg/L	0.005	0.0010	6	0.0007	0.0010	0.00208
Total boron	mg/L	1.2[5]	0.098	6	0.088	0.143	0.169
Total molybdenum	mg/L	0.073	0.0003	6	0.0002	0.0003	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.9	6	<1.2	<1.2	8.1
Total strontium	mg/L	-	0.294	6	0.233	0.28	0.425
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.018**	6	**<0.003**	**0.0215**	**0.038**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.38**	6	0.6	0.8	**1.3**
Dissolved iron	mg/L	0.3[2]	**1.08**	6	0.046	**0.382**	**1.87**
Total iron	mg/L	0.3	**2.08**	6	**1.79**	**2.94**	**5.88**
Total phenols	mg/L	0.004	**0.0104**	5	0.002	**0.006**	**0.009**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN); Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.12-20 Concentrations of water quality measurement endpoints, upper Beaver River (*baseline* station BER-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	September 2008
			Value	Value
Physical variables				
pH	pH units	6.5-9.0	8.15	8.3
Total Suspended Solids	mg/L	-[1]	10	6
Conductivity	µS/cm	-	445	315
Nutrients				
Total dissolved phosphorus	mg/L	0.05[2]	**0.067**	**0.074**
Total nitrogen*	mg/L	1.0	**2.161**	**1.3**
Nitrate+Nitrite	mg/L	1.0	0.071	<0.1
Dissolved organic carbon	mg/L	-	24.6	34
Ions				
Sodium	mg/L	-	53.5	31
Calcium	mg/L	-	35.8	29.7
Magnesium	mg/L	-	11.3	10.3
Chloride	mg/L	230, 860[3]	1.67	2
Sulphate	mg/L	100[4]	14.8	15.3
Total Dissolved Solids	mg/L	-	332	238
Total Alkalinity	mg/L	-	225	151
Organic compounds				
Naphthenic acids	mg/L	-	0.12	<1
Selected metals				
Total aluminum	mg/L	0.1	**0.431**	**0.266**
Dissolved aluminum	mg/L	0.1[2]	0.0116	0.0272
Total arsenic	mg/L	0.005	0.0017	0.00137
Total boron	mg/L	1.2[5]	0.218	0.163
Total molybdenum	mg/L	0.073	0.0005	0.0003
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.9	1.5
Total strontium	mg/L	-	0.242	0.175
Other variables that exceeded CCME/AENV guidelines in fall 2009				
Sulphide	mg/L	0.002[7]	**0.0112**	**0.017**
Total phosphorus	mg/L	0.05	**0.108**	**0.102**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.09**	**1.2**
Dissolved iron	mg/L	0.3[2]	**0.991**	**1.16**
Total iron	mg/L	0.3	**2.14**	**1.79**
Total phenols	mg/L	0.004	**0.0047**	**0.008**

BER-2 only sampled during Fall 2008 and 2009.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is for total nitrogen.

Table 5.12-21 Concentrations of water quality measurement endpoints, Poplar Creek (station POC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.29	9	7.9	8.3	8.4
Total Suspended Solids	mg/L	-[1]	10	9	4	10	61
Conductivity	µS/cm	-	789	9	308	442	1590
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0273	9	0.007	0.013	0.022
Total nitrogen*	mg/L	1.0	**2.001**	9	0.3	1.0	**1.9**
Nitrate+Nitrite	mg/L	1.0	0.071	9	<0.1	<0.1	0.1
Dissolved organic carbon	mg/L	-	29.6	9	10	24	32
Ions							
Sodium	mg/L	-	87.8	9	27	46	238
Calcium	mg/L	-	50.9	9	28.2	35.6	72.1
Magnesium	mg/L	-	16.9	9	10	13.3	29.3
Chloride	mg/L	230, 860[3]	99.5	9	7	26	**321**
Sulphate	mg/L	100[4]	20.1	9	10.4	14.7	44.2
Total Dissolved Solids	mg/L	-	516	9	200	270	890
Total Alkalinity	mg/L	-	234	9	135	176	304
Organic compounds							
Naphthenic acids	mg/L	-	0.353	9	<1	1	2
Selected metals							
Total aluminum	mg/L	0.1	**0.408**	9	**0.207**	**0.320**	**1.44**
Dissolved aluminum	mg/L	0.1[2]	0.00605	9	0.0019	0.0083	0.0121
Total arsenic	mg/L	0.005	0.0023	9	0.00075	0.0010	0.002
Total boron	mg/L	1.2[5]	0.124	9	0.039	0.116	0.178
Total molybdenum	mg/L	0.073	0.0004	9	0.0002	0.0003	0.0007
Total mercury (ultra-trace)	ng/L	5, 13[6]	2	6	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.33	9	0.149	0.202	0.513
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0102**	9	**<0.003**	**0.007**	**0.009**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.93**	9	<0.2	0.9	**1.8**
Total iron	mg/L	0.3	**3.51**	9	**0.698**	**1.21**	**3.63**
Dissolved iron	mg/L	0.3	**2.32**	9	0.0495	0.249	0.019
Total phenols	mg/L	0.004	**0.0084**	9	<0.001	**0.007**	**0.019**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

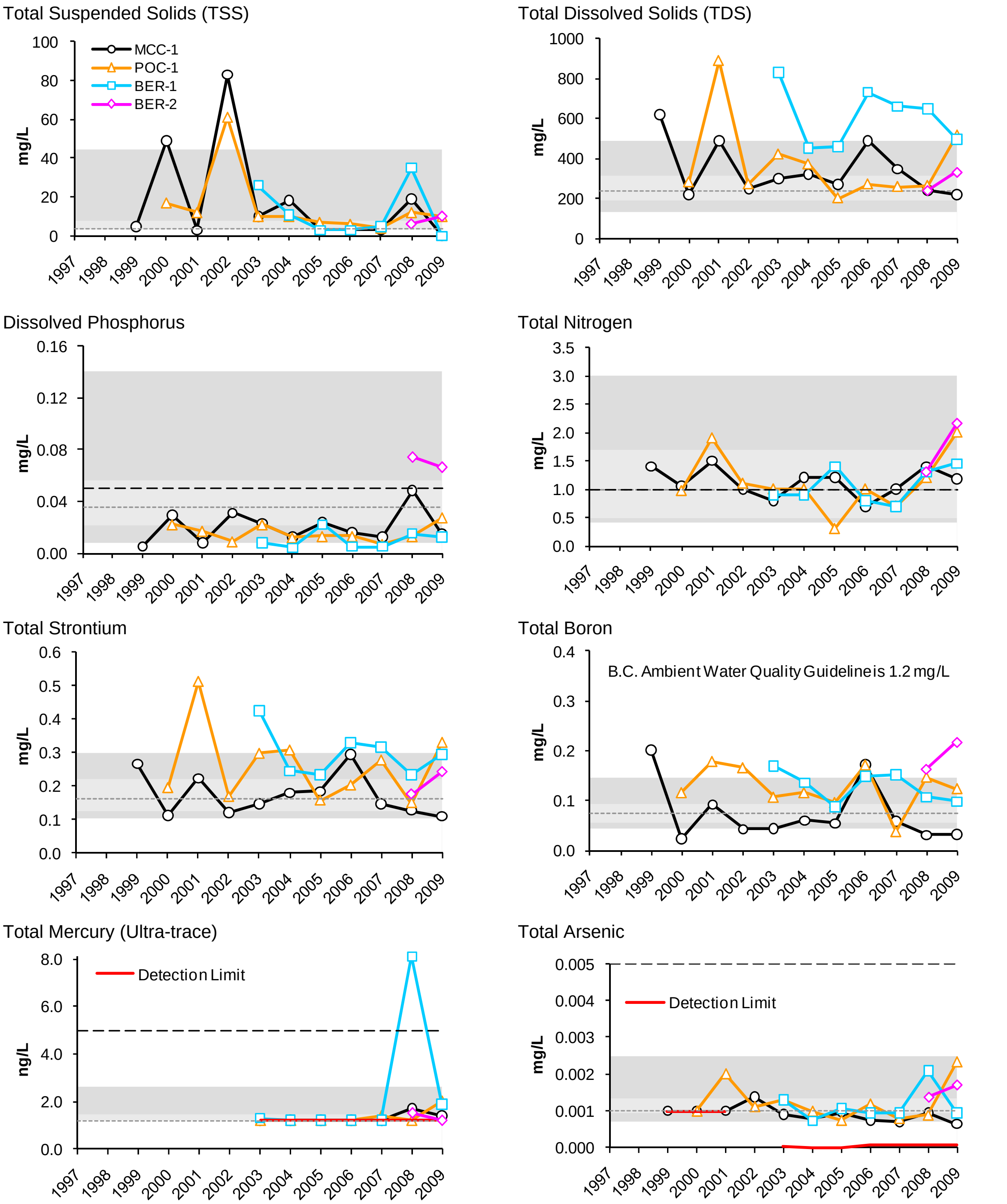
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Figure 5.12-12 Concentrations of selected water quality measurement endpoints in the Beaver River (station BER-1), Poplar Creek (station POC-1), and McLean Creek (station MCC-1) (fall data) relative to regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

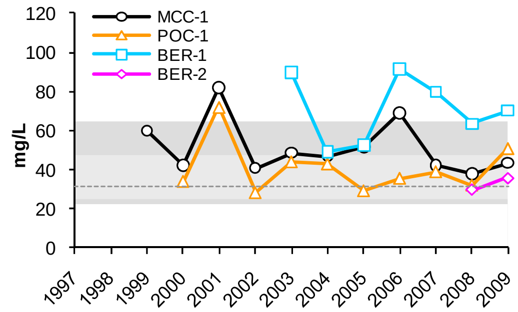
– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

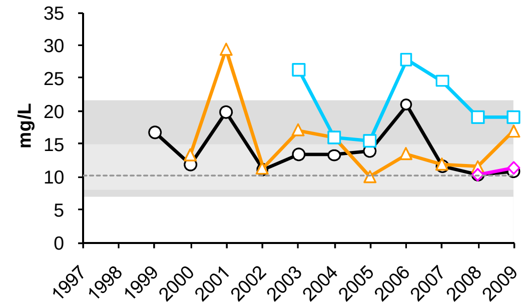
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.12-12 (Cont'd.)

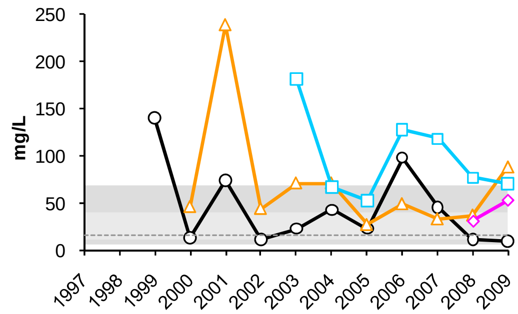
Calcium



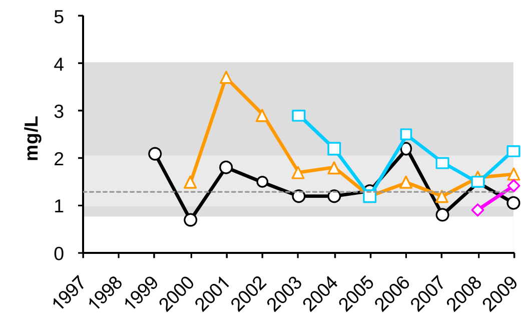
Magnesium



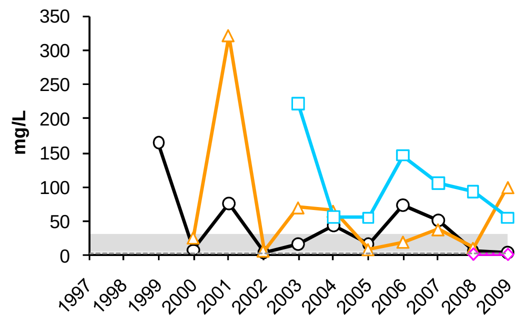
Sodium



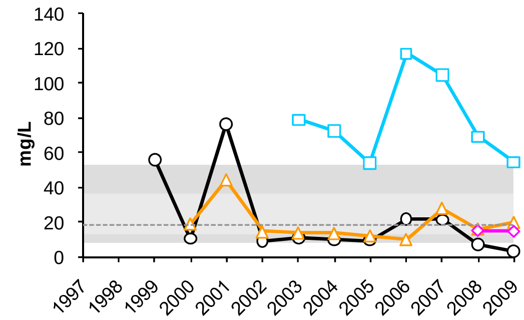
Potassium



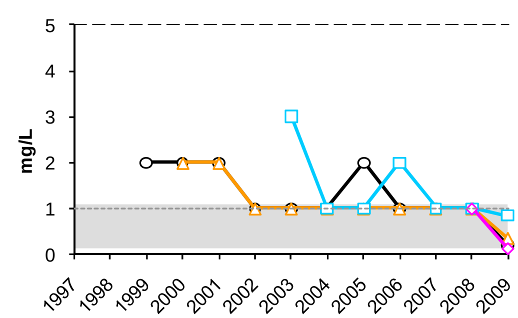
Chloride



Sulphate



Naphthenic Acids[1]



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.12-13 Piper diagram of fall ion balance at *test* station BER-1, *baseline* station BER-2, *test* station POC-1, and *test* station MCC-1, 1999-2009.

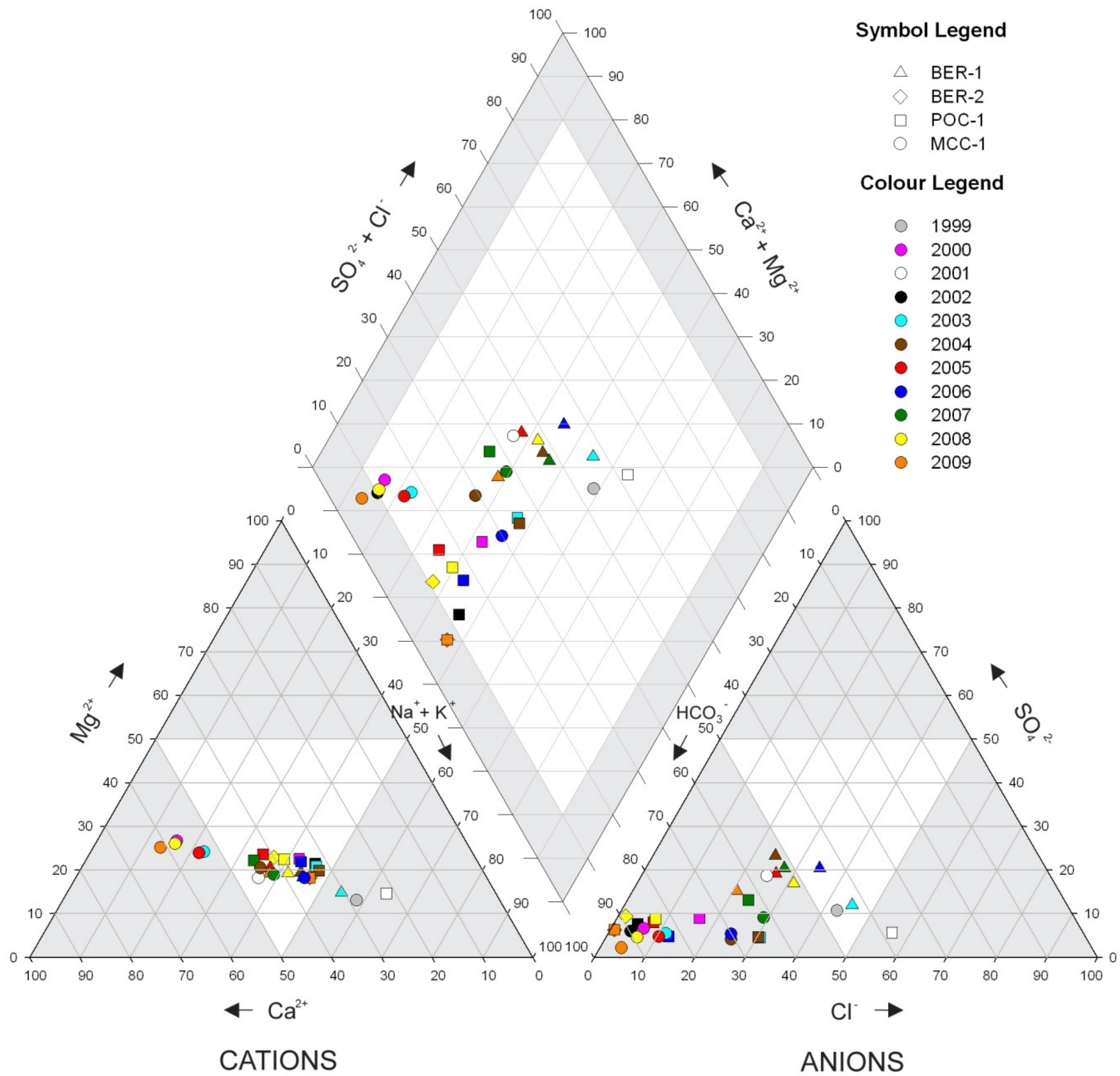


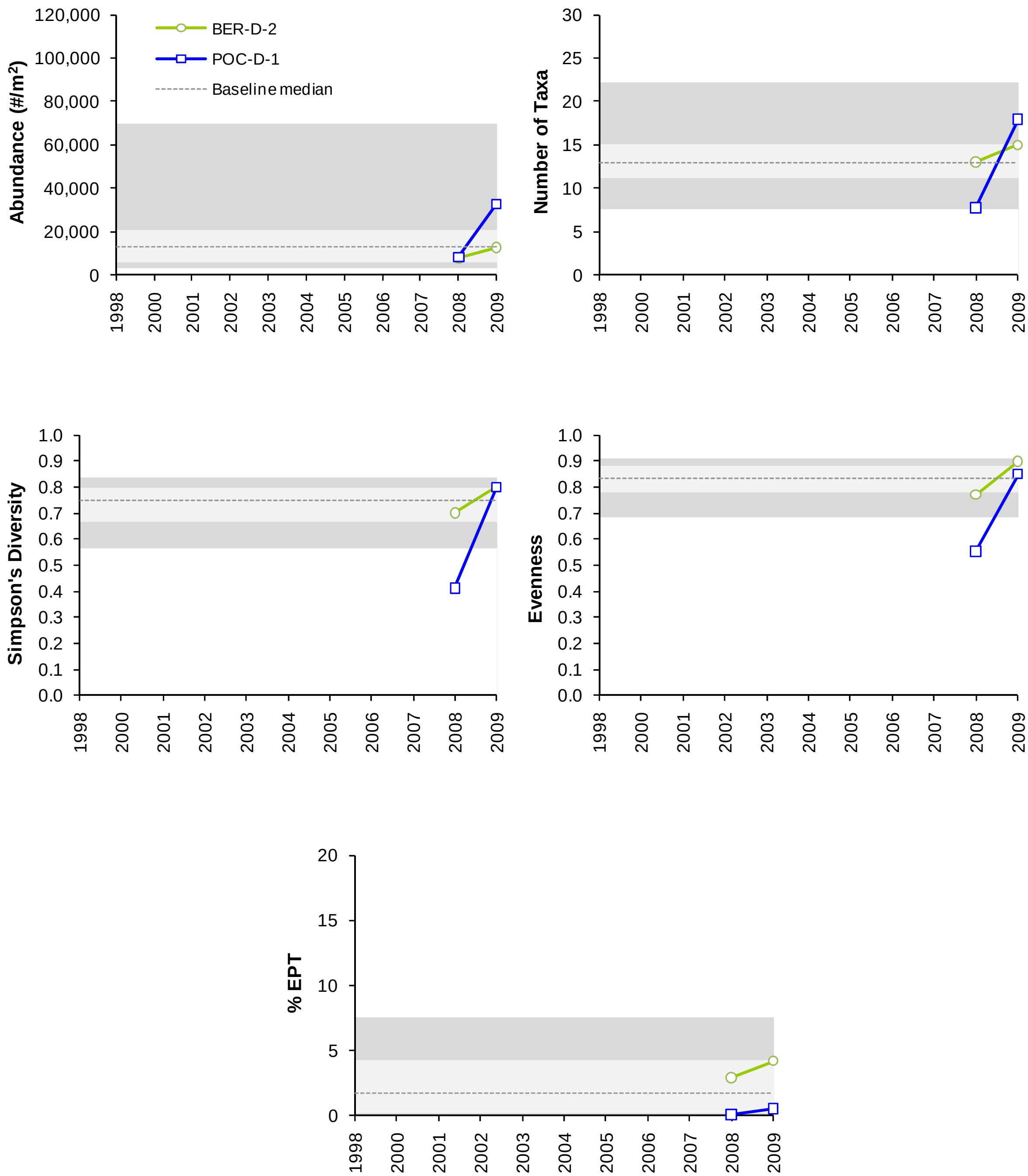
Table 5.12-22 Average habitat characteristics of benthic invertebrate sampling locations in the Beaver River (BER-D-2) and Poplar Creek (POC-D-1).

Variable	Units	*Baseline* Reach BER-D-2	*Test* Reach POC-D-1
Sample Date	-	Sept 9, 2009	Sept 15, 2009
Habitat	-	Depositional	Depositional
Water Depth	m	1	0.3
Current Velocity	m/s	Negligible	0.05
Macrophyte Cover	%	2	0
Field Water Quality			
Dissolved Oxygen	mg/L	8.3	7.75
Conductivity	µS/cm	462	600
pH	pH units	8.08	8.20
Water Temperature	°C	14.4	15.9
Sediment Composition			
Sand	%	69	74
Silt	%	21	14
Clay	%	9	12
Total Organic Carbon	%	1.48	1.76

Table 5.12-23 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Upper Beaver River and Lower Poplar Creek.

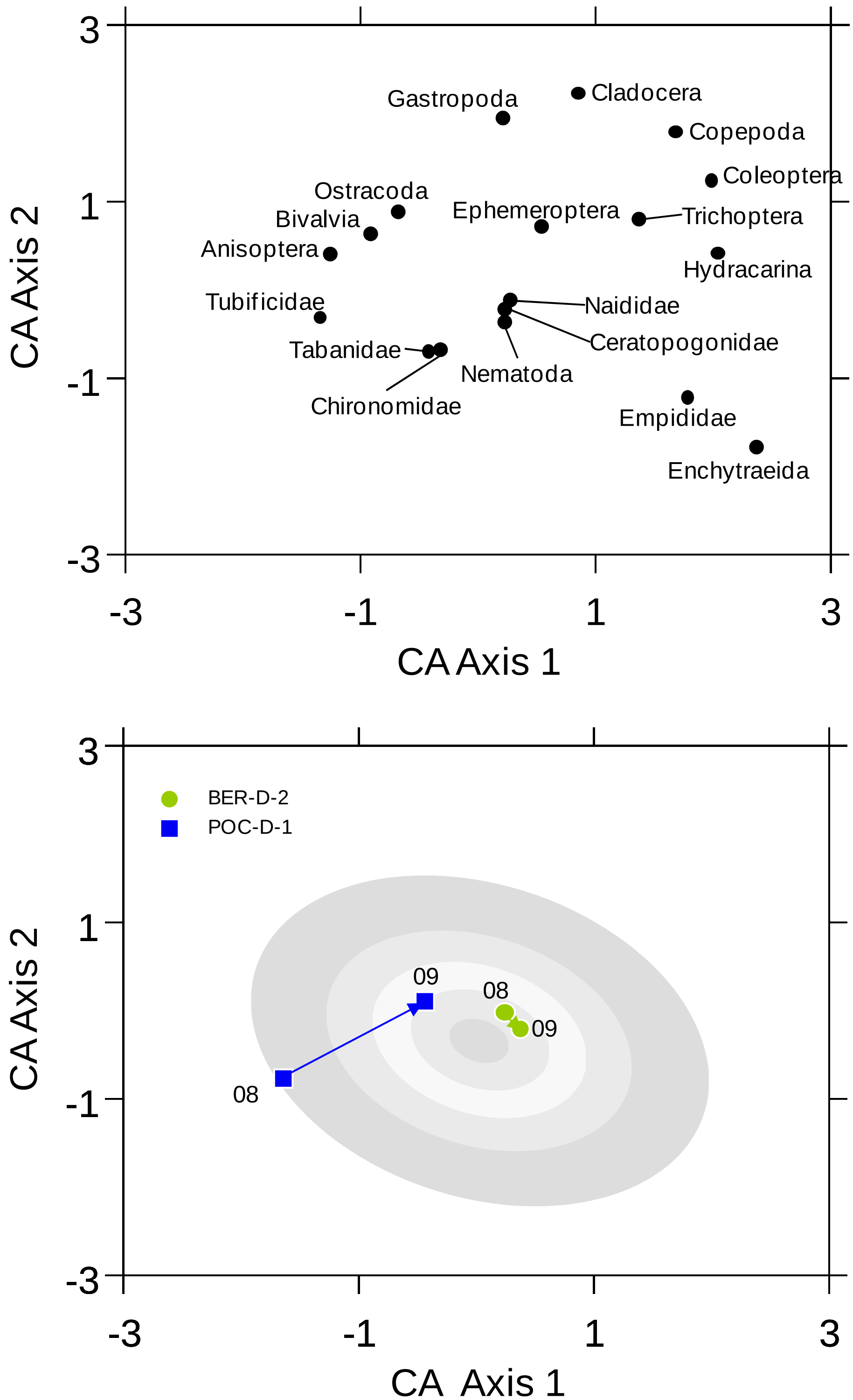
Taxon	Percent Major Taxa Enumerated in Each Year			
	Baseline Reach BER-D-2		*Test* Reach POC-D-1	
	2008	**2009**	**2008**	**2009**
Bivalvia	1	<1	1	4
Ceratopogonidae	6	4	2	
Chironomidae	84	71	21	64
Coleoptera		10	<1	1
Copepoda	<1	<1		
Empididae	1	<1		<1
Enchytraeidae	<1	<1		<1
Ephemeroptera	4	6	<1	<1
Gastropoda	<1	1		<1
Glossiphoniidae	<1			
Hydracarina	1	>1		
Naididae	<1	4	<1	<1
Nematoda	1	<1	2	1
Ostracoda	1		1	4
Tabanidae		<1	<1	<1
Trichoptera	<1		<1	<1
Tubificidae	1	2	72	22
Benthic Invertebrate Community Measurement Endpoints				
Total Abundance (No./m^2)	7,687		8,345	32,810
Richness	13		8	18
Simpson's Diversity	0.7		0.41	0.8
Evenness	0.77		0.55	0.85
% EPT	3		<1	<1

Figure 5.12-14 Variation in benthic invertebrate community measurement endpoints in Beaver River and Poplar Creek.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.3.1.8 for a description of the approach.

Figure 5.12-15 Ordination (Correspondence Analysis) of benthic invertebrate communities in Beaver River and Poplar Creek.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* depositional reaches in the RAMP FSA.

Table 5.12-24 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Upper Beaver River and Lower Poplar Creek.

Variable	Source	SS	df	MS	F-ratio	P
Log Abundance	Reach - Year	2.968	3	0.989	4.29	0.012
	Baseline vs Test (BT)	0.924	1	0.924	4.01	0.054
	Remainder (noise)	2.044	2	1.022	4.43	0.170
	Error	7.611	33	0.231		
Log Richness	Reach - Year	0.812	3	0.271	4.21	0.013
	Baseline vs Test (BT)	0.028	1	0.028	0.43	0.516
	Remainder (noise)	0.784	2	0.392	6.09	0.132
	Error	2.124	33	0.064		
Diversity	Reach - Year	0.774	3	0.258	12.48	0.000
	Baseline vs Test (BT)	0.179	1	0.179	8.66	0.006
	Remainder (noise)	0.595	2	0.297	14.39	0.063
	Error	0.682	33	0.021		
Evenness	Reach - Year	0.564	3	0.188	10.23	0.000
	Baseline vs Test (BT)	0.167	1	0.167	9.08	0.005
	Remainder (noise)	0.397	2	0.199	10.81	0.081
	Error	0.607	33	0.018		
Log %EPT	Reach - Year	0.92	3	0.31	2.36	0.090
	Baseline vs Test (BT)	0.90	1	0.90	6.91	0.013
	Remainder (noise)	0.021	2	0.011	0.08	0.802
	Error	4.31	33	0.13		
CA Axis 1	Reach - Year	20.14	3	6.71	9.87	0.000
	Baseline vs Test (BT)	16.36	1	16.36	24.04	0.000
	Remainder (noise)	3.784	2	1.892	2.78	0.237
	Error	22.45	33	0.68		
CA Axis 2	Reach - Year	3.50	3	1.17	1.47	0.241
	Baseline vs Test (BT)	0.42	1	0.42	0.53	0.471
	Remainder (noise)	3.08	2	1.539	1.94	0.299
	Error	26.24	33	0.80		

Table 5.12-25 Concentrations of sediment quality measurement endpoints, lower Poplar Creek (*test* station POC-D-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	13.0	4	10	20.85	35
Silt	%	-	63.0	4	12	40.5	73
Sand	%	-	24.0	4	13	35	63
Total organic carbon	%	-	1.1	4	1.82	2.15	2.5
Total hydrocarbons							
BTEX	mg/kg	-	<10	2	<5	<5	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	2	<5	<5	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	143	2	<5	57.5	120
Fraction 3 (C16-C34)	mg/kg	300[1]	**2830**	2	170	**785**	**1400**
Fraction 4 (C34-C50)	mg/kg	2800[1]	**2820**	2	54	727	1400
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0028	4	0.002	0.011	0.018
Retene	mg/kg	-	0.114	3	0.048	0.104	0.108
Total dibenzothiophenes	mg/kg	-	3.898	4	0.307	0.790	1.320
Total PAHs	mg/kg	-	13.256	4	1.753	2.789	4.828
Total Parent PAHs	mg/kg	-	0.434	4	0.148	0.195	0.209
Total Alkylated PAHs	mg/kg	-	12.821	4	1.605	2.584	4.640
Predicted PAH toxicity[3]	H.I.	-	0.65	4	0.159	0.540	4.154
Metals that exceed CCME guidelines in 2009							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.4	2	7	8.2	9
Chironomus growth - 10d	mg/organism	-	1.612	2	1.7	2.063	2.426
Hyalella survival - 14d	# surviving	-	8.2	2	8	8.6	9
Hyalella growth - 14d	mg/organism	-	0.264	2	0.1	0.2	0.208

Values in **bold** indicate concentrations exceeding guidelines.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.12-26 Concentrations of sediment quality measurement endpoints, upper Beaver River (*baseline* station BER-D-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	September 2008
			Value	Value
Physical variables				
Clay	%	-	9	5
Silt	%	-	21	1
Sand	%	-	70	94
Total organic carbon	%	-	1.97	0.2
Total hydrocarbons				
BTEX	mg/kg	-	<20	-
Fraction 1 (C6-C10)	mg/kg	30[2]	<20	-
Fraction 2 (C10-C16)	mg/kg	150[2]	40	-
Fraction 3 (C16-C34)	mg/kg	300[2]	119	-
Fraction 4 (C34-C50)	mg/kg	2800[2]	94	-
Polycyclic Aromatic Hydrocarbons (PAHs)				
Naphthalene	mg/kg	0.0346[3]	0.001	0.00096
Retene	mg/kg	-	0.520	0.0052
Total dibenzothiophenes	mg/kg	-	0.015	0.0015
Total PAHs	mg/kg	-	0.704	0.0178
Total Parent PAHs	mg/kg	-	0.017	0.0037
Total Alkylated PAHs	mg/kg	-	0.686	0.0141
Predicted PAH toxicity[4]	H.I.	-	0.881	na[1]
Metals that exceed CCME guidelines in 2009				
none	mg/kg	-	-	-
Chronic toxicity				
Chironomus survival - 10d	# surviving	-	7.4	8.8
Chironomus growth - 10d	mg/organism	-	2.09	2.14
Hyalella survival - 14d	# surviving	-	8.6	9.6
Hyalella growth - 14d	mg/organism	-	0.24	0.44

Values in **bold** indicate concentrations exceeding guidelines.

[1] Hazard Index (H.I.) could not be calculated due to absence of total hydrocarbon data.

[2] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[3] Interim sediment quality guideline (ISQG) (CCME 2002).

[4] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

na= not analyzed

Table 5.12-27 Concentrations of water quality measurement endpoints, McLean Creek (*test* station MCC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.19	10	8.0	8.3	8.6
Total Suspended Solids	mg/L	-[1]	8	10	<3	7.5	83
Conductivity	µS/cm	-	289	10	290	404.5	1000
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0146	10	0.005	0.0195	0.048
Total nitrogen*	mg/L	1.0	**1.181**	10	0.7	**1.125**	**1.5**
Nitrate+Nitrite	mg/L	1.0	<0.071	10	<0.05	<0.1	<1
Dissolved organic carbon	mg/L	-	25.6	10	14	23.5	35
Ions							
Sodium	mg/L	-	10.3	10	11	33	140
Calcium	mg/L	-	43.5	10	37.9	47.8	81.7
Magnesium	mg/L	-	10.8	10	10.3	13.35	21
Chloride	mg/L	230, 860[3]	4.75	10	5	30.5	165
Sulphate	mg/L	100[4]	3.17	10	7	10.75	76.4
Total Dissolved Solids	mg/L	-	218	10	220	310	620
Total Alkalinity	mg/L	-	141	10	141	175	319
Organic compounds							
Naphthenic acids	mg/L	-	0.202	10	<1	1	2
Selected metals							
Total aluminum	mg/L	0.1	**0.31**	10	0.07	**0.34**	**2.58**
Dissolved aluminum	mg/L	0.1[2]	0.0039	10	<0.01	0.0083	0.0157
Total arsenic	mg/L	0.005	0.0006	10	<0.001	0.0008	0.0014
Total boron	mg/L	1.2[5]	0.0315	10	0.024	0.057	0.201
Total molybdenum	mg/L	0.073	0.0001	10	0.0001	0.00018	0.0005
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.4	6	<1.2	<1.2	1.7
Total strontium	mg/L	-	0.11	10	0.111	0.164	0.294
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0062**	10	**<0.003**	**0.0085**	**0.025**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.11**	10	0.4	0.95	**1.4**
Total iron	mg/L	0.3	**0.55**	10	**0.36**	**0.64**	**3.46**
Total phenols	mg/L	0.004	**0.0073**	10	<0.001	0.001	**0.012**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

[4] B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006).

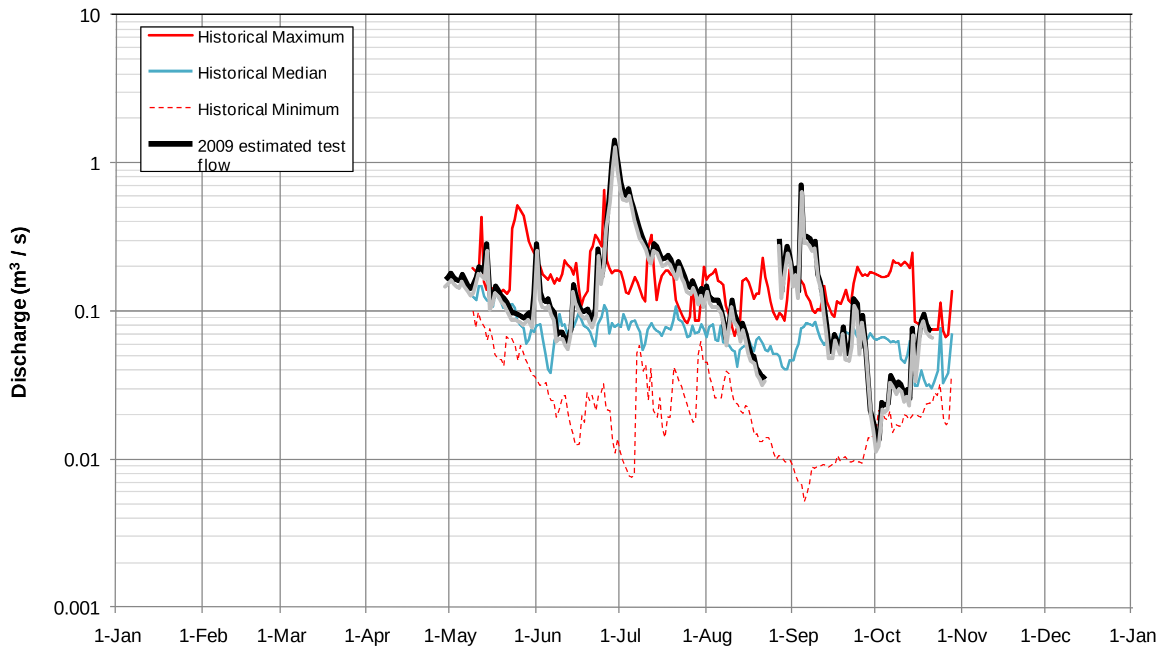
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Figure 5.12-16 The observed (*test*) hydrograph for Fort Creek in 2009, and estimated *baseline* hydrograph, compared to historical values.



Note: Observed 2009 hydrograph based on Station S12, Fort Creek at Highway 63, 2009 provisional data from May 1 to October 21. The upstream drainage area is 31.9 km^2. Historical values from May 1 to October 31 calculated from available data collected from 2000 to 2002 and from 2006 to 2008.

Table 5.12-28 Estimated water balance at Station S12, Fort Creek at Highway 63, May 1 to October 21, 2009.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	2.51	**Observed discharge, obtained from Station S12, Fort Creek at Highway 63**
Closed-circuited area water loss from the observed *test* hydrograph	-0.02	Estimated 0.3 km^2 of Fort Creek watershed closed-circuited by focal projects as of 2009 (Table 2.4-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.28	Estimated 19.7 km^2 of Fort Creek watershed with land change from focal projects as of 2009 that is not closed-circuited (Table 2.4-1)
Water withdrawals from the Fort Creek watershed from oil sands development projects	0.0	None reported
Water releases into the Fort Creek watershed from oil sands development projects	0	Assumed
Diversions into or out of the watershed	0	Assumed
The difference between observed and estimated hydrographs on tributary streams	0	No focal projects on tributaries of Fort Creek not accounted for in figures contained in this table
Estimated *baseline* hydrograph (total discharge)	2.26	**Estimated *baseline* discharge at RAMP Station S12, Fort Creek at Highway 63**
Incremental flow (change in total discharge)	+0.26	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+11.4%**	**Incremental flow as a percentage of total discharge of estimated hydrograph**

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Observed discharge volume is calculated from provisional data from May 1 to October 21, 2009 for Station S12, Fort Creek at Highway 63.

Table 5.12-29 Calculated change in hydrologic measurement endpoints for the Fort Creek watershed in 2009.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.15	0.17	+11.4%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	1.27	1.41	+11.4%
Open-water season minimum daily discharge	0.011	0.013	+11.2%

Note: Definitions and assumptions are discussed in Section 3.1.7.3.

Note: Values are calculated from provisional data for May 1 2009 to October 21, 2009 for Station S12, Fort Creek at Highway 63.

Table 5.12-30 Concentrations of water quality measurement endpoints, lower Fort Creek (*test* station FOC-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	1997-2008 (fall data only)			
			Value	n[8]	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.27	8	8.1	8.3	8.4
Total Suspended Solids	mg/L	-[1]	3	8	5	14.5	61
Conductivity	µS/cm	-	573	8	432	511.5	572
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0088	8	0.009	0.012	0.02
Total nitrogen*	mg/L	1.0	0.631	8	0.4	0.625	1.0
Nitrate+Nitrite	mg/L	1.0	<0.071	8	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.2	8	11	13	14
Ions							
Sodium	mg/L	-	12.3	8	8	10	18
Calcium	mg/L	-	96.8	8	69.4	79.3	89.6
Magnesium	mg/L	-	16.5	8	14.3	17.75	20.1
Chloride	mg/L	230, 860[3]	2.17	8	2	2.5	7
Sulphate	mg/L	100[4]	39.5	8	3.7	7.25	29.3
Total Dissolved Solids	mg/L	-	370	8	260	325	360
Total Alkalinity	mg/L	-	283	8	231	276	304
Organic compounds							
Naphthenic acids	mg/L	-	0.169	8	<1	<1	2
Selected metals							
Total aluminum	mg/L	0.1	0.0309	8	0.04	0.081	**0.85**
Dissolved aluminum	mg/L	0.1[2]	0.0013	8	0.0001	0.0021	0.0900
Total arsenic	mg/L	0.005	0.0003	8	0.00024	0.00059	<0.001
Total boron	mg/L	1.2[5]	0.0724	8	0.026	0.050	0.073
Total molybdenum	mg/L	0.073	0.0001	8	0.00003	0.000099	0.0001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	4	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.235	8	0.142	0.175	0.224
Other variables that exceeded CCME/AENV guidelines in fall 2009							
Sulphide	mg/L	0.002[7]	**0.0021**	8	**<0.003**	**0.004**	**0.006**
Total iron	mg/L	0.3	**0.58**	8	0.07	**0.88**	**1.94**

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (U.S. EPA 2006).

4 B.C. maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, B.C. 2006)

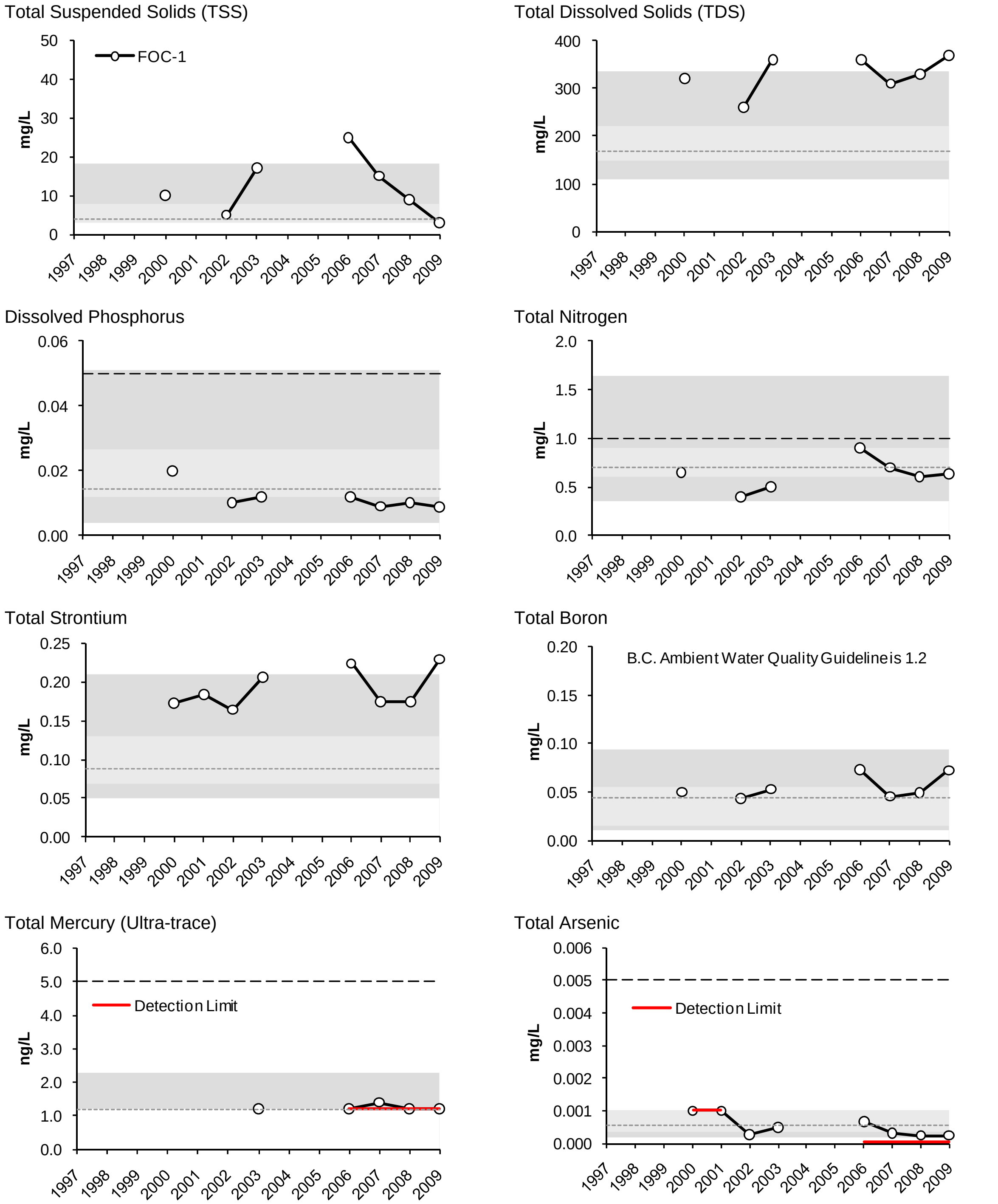
5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 FOC-1 was sampled in both September and October 2000.

Figure 5.12-17 Concentrations of selected water quality measurement endpoints in Fort Creek (fall data) relative to regional *baseline* fall concentrations.



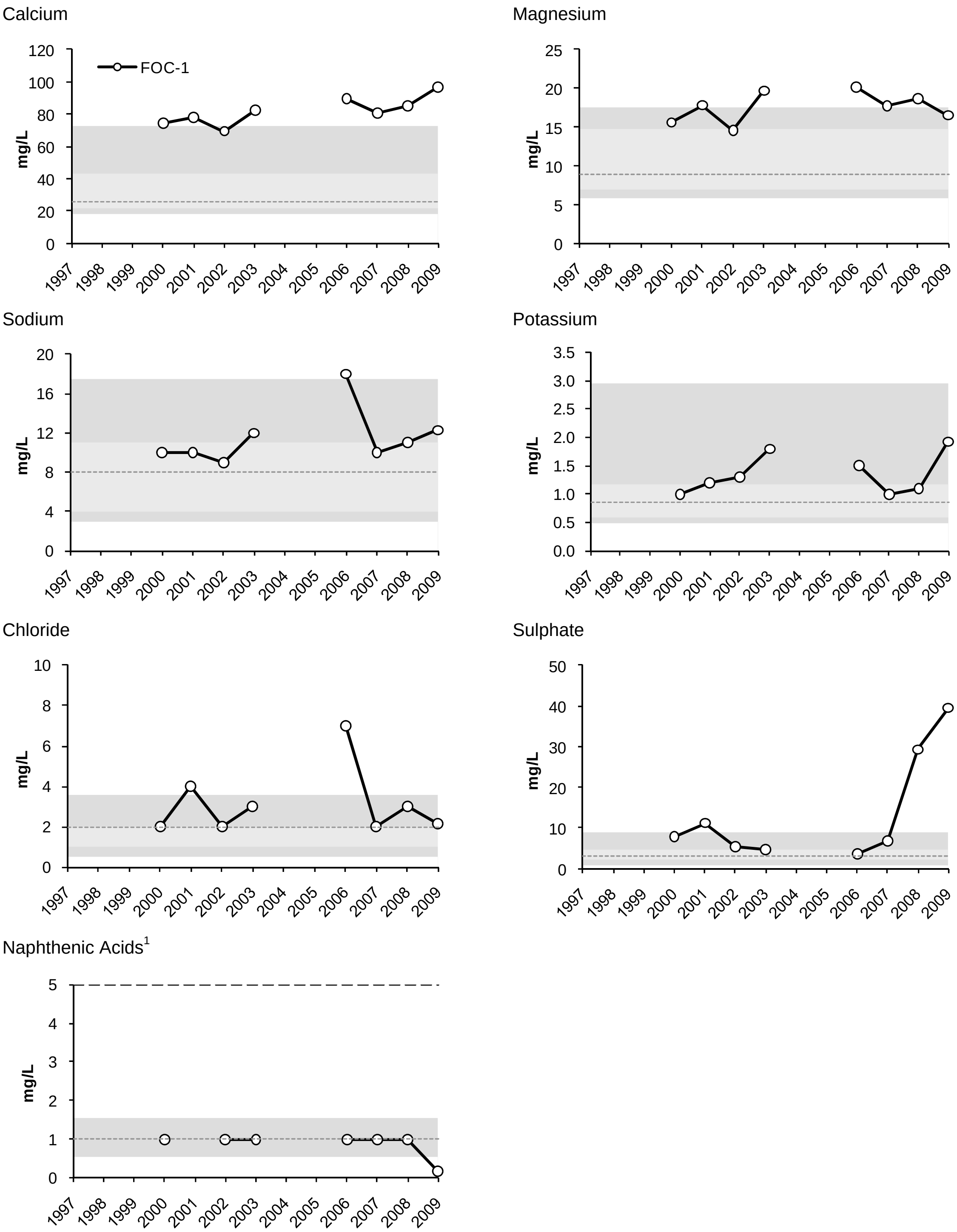
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.12-17 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus, total nitrogen, and naphthenic acids (AENV1999b), total arsenic and total mercury (CCME 2007).

[1] The detection limit for naphthenic acids was lowered from 1.0 mg/L to 0.02 mg/L in 2009.

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.12-18 Piper diagram of ion balance in Fort Creek, 2000-2009.

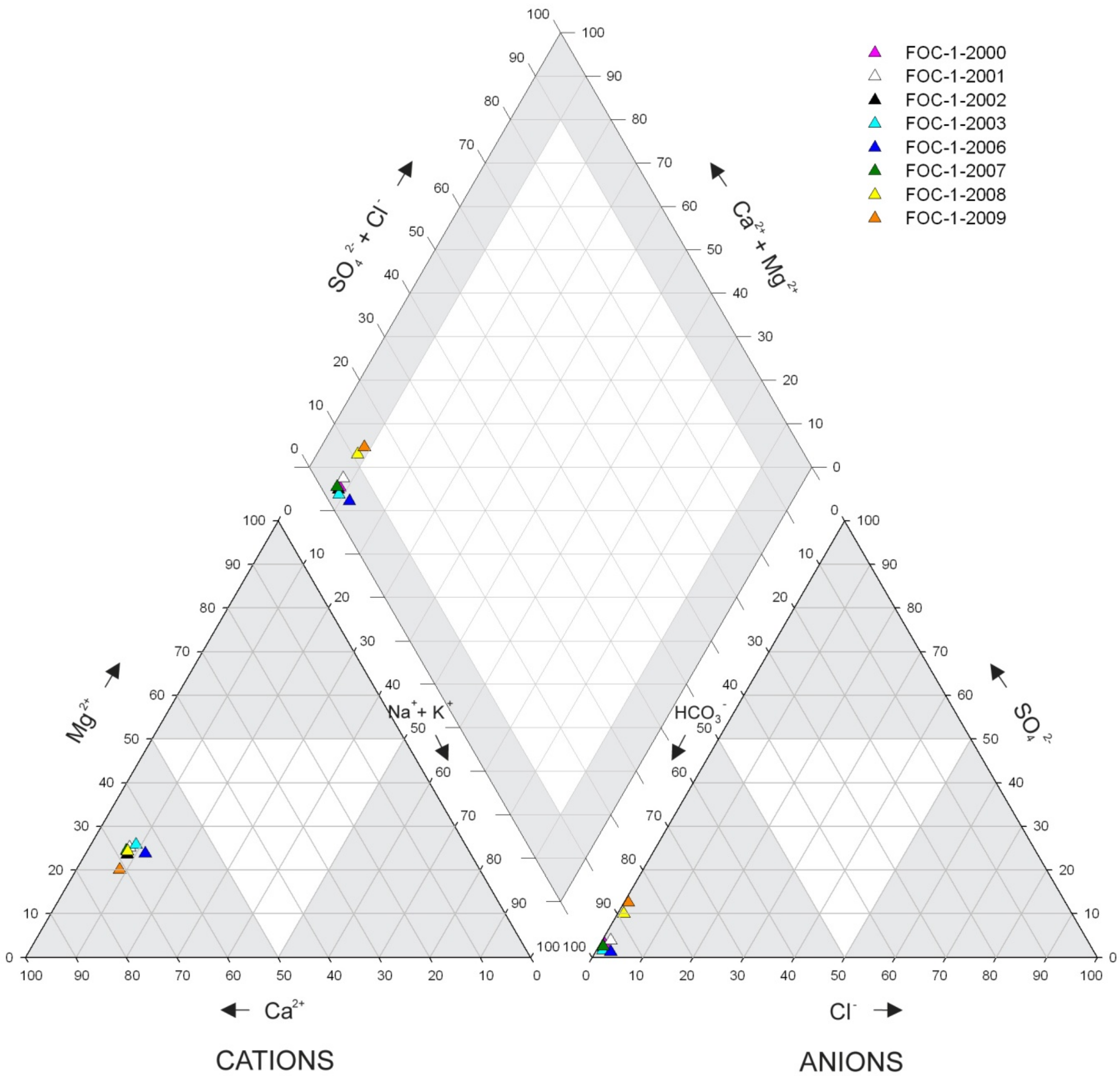
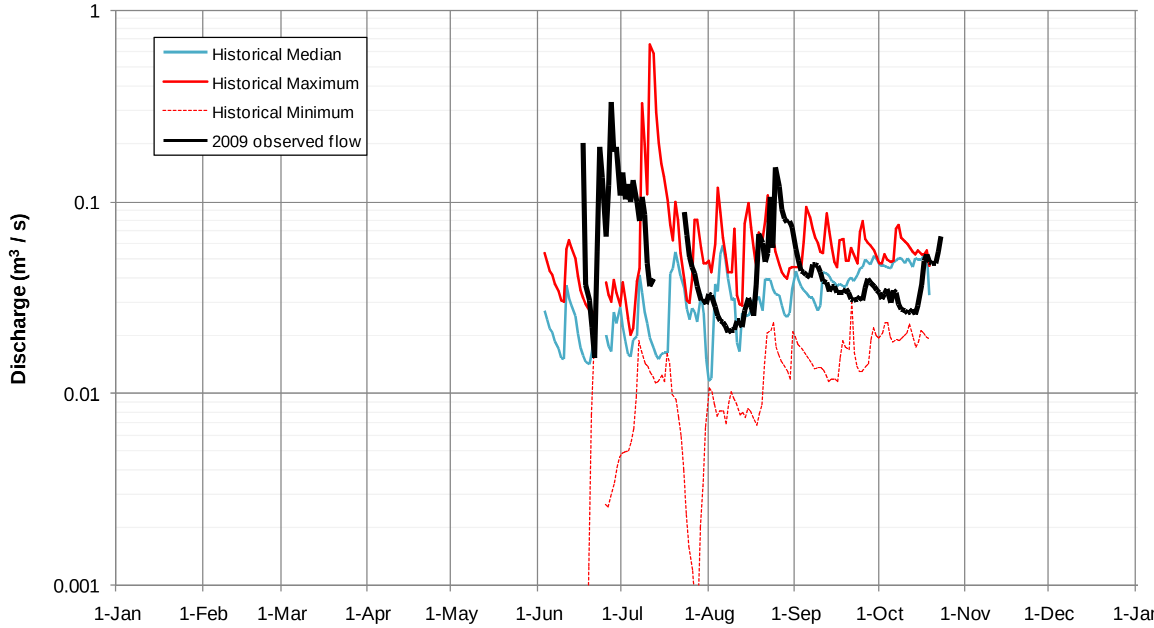


Figure 5.12-19 Susan Lake Outlet: 2009 hydrograph.



Note: Observed 2009 hydrograph based on available provisional data for Station S25, Susan Lake Outlet. Historical values from calculated from data collected in 2002 and from 2006 to 2008.

Table 5.12-31 Metrics and mercury concentrations of walleye, northern pike and lake whitefish from Unnamed "Jackson" Lake, September 2009.

Species	Fish ID	Sex	Age (yrs)	Stage	Length (mm)	Weight (g)	Hg (mg/kg)
Lake whitefish	1.1	F	-	I	256	190	0.026
Lake whitefish	1.2	U	-	I	261	210	0.020
Lake whitefish	2.3	F	-	I	309	375	0.024
Lake whitefish	2.5	F	-	I	313	370	0.019
Lake whitefish	2.4	M	-	M	333	470	0.027
Lake whitefish	3.3	M	-	M	339	1,760	0.037
Lake whitefish	2.1	M	-	M	352	580	0.021
Lake whitefish	2.2	F	-	M	372	710	0.038
Lake whitefish	3.2	F	-	M	413	1,720	0.040
Lake whitefish	3.4	M	-	M	421	2,380	0.040
Lake whitefish	3.5	F	-	M	430	2,240	0.035
Lake whitefish	3.1	F	-	M	445	2,280	0.041
Lake whitefish	4.2	M	-	M	447	1,130	0.031
Lake whitefish	4.5	M	-	M	450	n/a	<u>0.115</u>
Lake whitefish	4.4	F	-	M	456	1,230	<u>0.091</u>
Lake whitefish	4.1	M	-	M	458	2,540	0.026
Lake whitefish	4.3	M	-	M	523	1,990	<u>0.050</u>
Northern pike	2.1	F	2	M	323	220	<u>0.050</u>
Walleye	1.4	F	1	I	193	66	<u>0.054</u>
Walleye	1.3	F	2	I	246	136	<u>0.072</u>
Walleye	1.1	U	2	I	248	136	<u>0.066</u>
Walleye	2.5	F	3	I	302	240	<u>0.100</u>
Walleye	2.3	M	3	I	306	270	<u>0.063</u>
Walleye	2.4	F	4	I	318	270	<u>0.073</u>
Walleye	2.2	M	3	I	319	335	<u>0.081</u>
Walleye	1.2	M	4	I	328	350	<u>0.084</u>
Walleye	2.1	F	4	I	338	333	<u>0.074</u>
Walleye	3.5	M	11	M	439	900	**<u>0.227</u>**
Walleye	3.1	M	26	M	445	950	**<u>0.557</u>**
Walleye	3.2	M	11	M	463	1,040	**<u>0.230</u>**
Walleye	3.4	M	12	M	464	1,070	**<u>0.230</u>**
Walleye	3.3	M	12	M	469	1,110	**<u>0.282</u>**
Walleye	4.2	M	17	M	494	1,330	**<u>0.283</u>**
Walleye	4.4	F	12	M	522	1,640	**<u>0.274</u>**
Walleye	4.1	F	12	M	539	1,940	**<u>0.259</u>**
Walleye	4.5	F	11	M	544	1,850	**<u>0.253</u>**
Walleye	4.3	F	12	M	551	1,940	**<u>0.310</u>**
Walleye	5.3	F	12	M	594	2,570	**<u>0.270</u>**
Walleye	5.2	F	16	M	616	2,970	**<u>0.266</u>**
Walleye	5.1	F	20	M	617	2,880	**<u>0.448</u>**

Sex: F-female; M-male; U-unknown

Stage: M-mature; I-immature

<u>exceeds National USEPA Criterion for subsistence fishers (0.049 mg/kg)</u>

<u>exceeds Health Canada Criterion for subsistence fishers (0.20 mg/kg)</u>

<u>exceeds National USEPA Criterion for recreational fishers (0.40 mg/kg)</u>

<u>exceeds Health Canada Criterion for general consumers (0.50 mg/kg)</u>

Figure 5.12-20 Mean mercury concentration (± 1SE) by size class in lake whitefish, walleye and northern pike captured from "Jackson" Lake, September 2009.

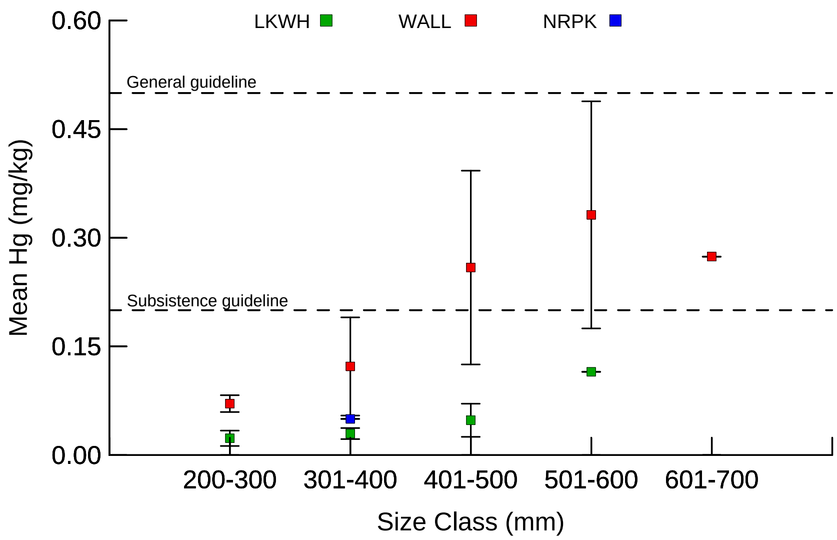
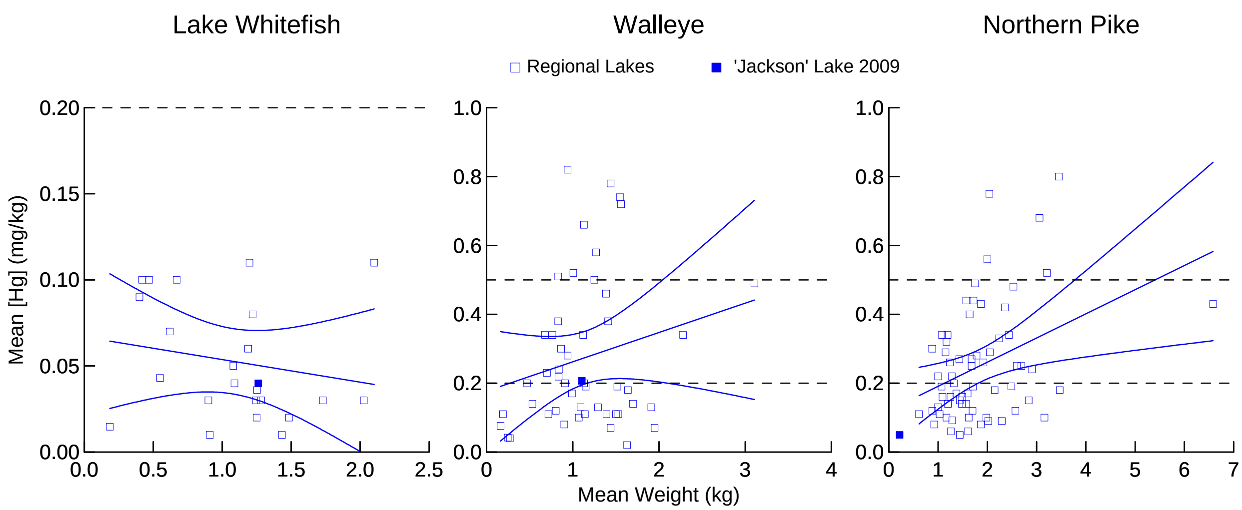


Figure 5.12-21 Relationship between mean weight and mercury concentration (± 95 CI) for lake whitefish, walleye and northern pike from regional waterbodies, 1975 to 2009.



Note: Regression of mercury concentration and mean weight were not statistically significant for lake whitefish (p=0.318, r^2=0.037) and walleye (p=0.136, r^2=0.046) but statistically significant for northern pike (p=0.002, r^2=0.143).

6.0 SPECIAL STUDIES

This part of the RAMP 2009 Technical Report presents results from special studies that were conducted in 2009, but are not part of the core monitoring program that is described in Section 3. These assessments were conducted either as part of specific requirements from focal projects or to add further support or new methods in which to conduct monitoring for particular components of RAMP.

In 2009, there were two studies conducted by RAMP that were not part of the core monitoring program: the reporting of water quality results for a subset of lakes in the Nexen Lakes Wetlands Monitoring Program (Hatfield 2010) and a Fish Assemblage Monitoring Pilot Study conducted as part of the Fish Populations component of RAMP.

6.1 NEXEN LAKES WATER QUALITY MONITORING

Nine lakes south of Fort McMurray were sampled for water quality in spring and fall of 2009, in conjunction with the Nexen Wetlands Monitoring Program (Hatfield 2010). The Nexen Wetlands Monitoring Program includes 17 water quality stations (15 lakes and two river stations) in total, eight of which are sampled annually (six lakes and the two river stations) (Hatfield 2010). The nine lakes included in the RAMP report are scheduled for sampling every two years, as part of Nexen's approval requirements and intended to address community concerns. These lakes were first sampled in 2000, and most recently sampled in 2006; although scheduled for biannual sampling, the 2008 program was rescheduled to 2009.

6.1.1 Summary of Field Methods and Sample Analysis

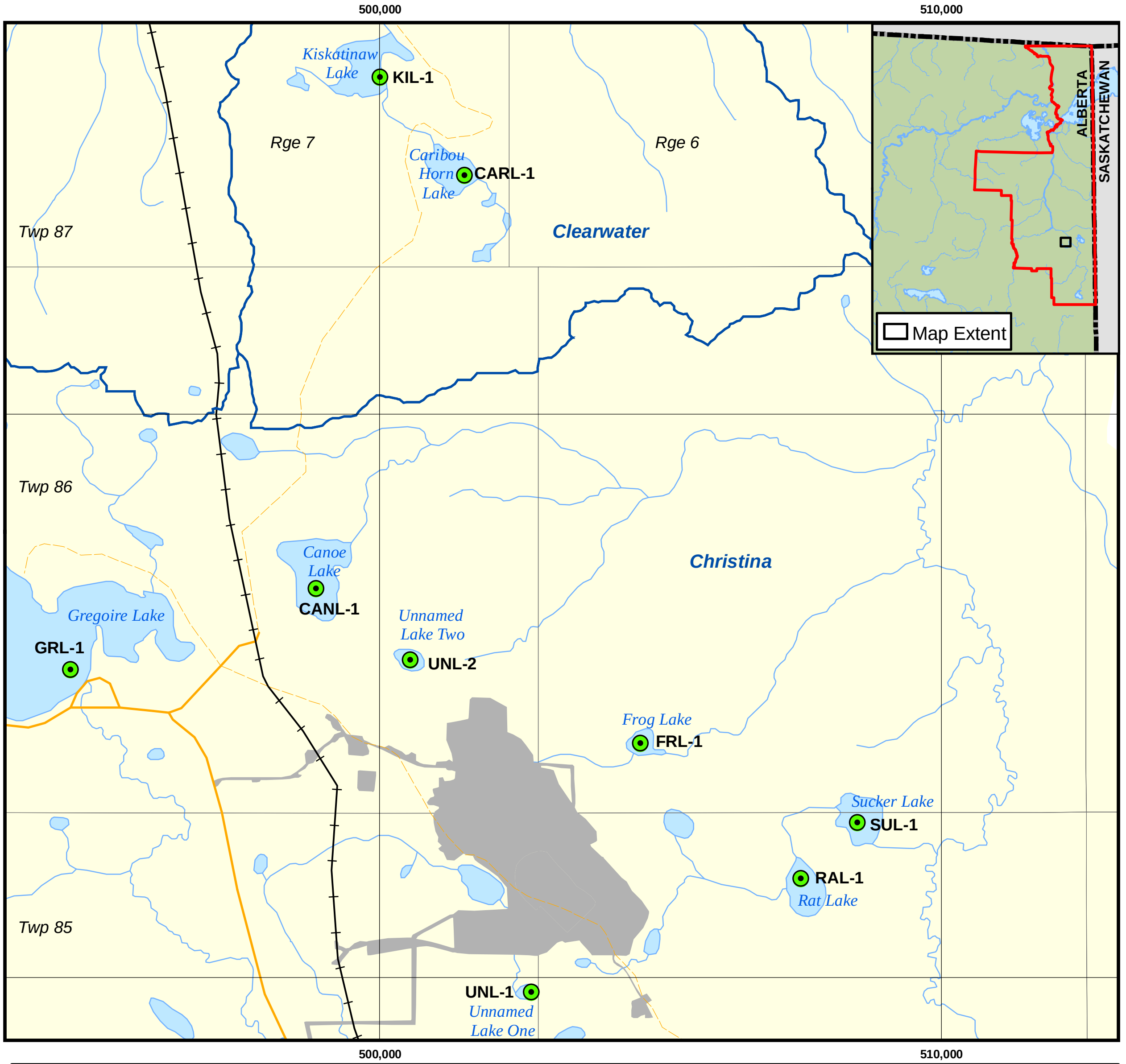
The 2009 Nexen lakes program consisted of spring and fall ambient water sampling surveys at each of nine lakes (Table 6.1-1 and Figure 6.1-1). Each water quality station was accessed via a pontoon equipped helicopter in both the spring and fall monitoring programs. For each lake station, the helicopter landed near the edge of the lake and taxied out to the center of the lake. This approach ensured surface waters at the sample collection point were not disturbed by rotor wash.

Water quality sampling procedures in each lake followed RAMP's, as outlined in Section 3.2.2. All water samples were collected, preserved, and shipped according to protocols specified by consulting laboratories. All water quality samples taken in 2009 were analyzed for the RAMP standard variables (Table 3.2.2). All analyses were conducted by ALS Environmental Ltd. (Fort McMurray and Edmonton, Alberta) except total and dissolved metals (including ultra-trace mercury) and naphthenic acids, which were analyzed by Alberta Research Council (ARC) in Vegreville, Alberta.

Table 6.1-1 Location of water quality sampling stations in Nexen Lakes, spring and fall 2009.

Waterbody	Station Name	UTM Coordinates (NAD83, Zone 12)	
		Easting	Northing
Canoe Lake	CANL-1	498500	6257000
Caribou Horn Lake	CARL-1	501500	6264250
Frog Lake	FRL-1	504500	6254000
Gregoire Lake	GRL-1	494490	6255457
Kiskatinaw Lake	KIL-1	500000	6266000
Rat Lake	RAL-1	507500	6251750
Sucker Lake	SUL-1	508500	6252750
Unnamed Lake One	UNL-1	502250	6249750
Unnamed Lake Two	UNL-2	500000	6255250

Figure 6.1-1 Locations of water quality sampling stations for Nexen Lakes Monitoring Program, spring and fall 2009.



RAMP
Regional Aquatics Monitoring Program

<u>LEGEND</u>

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area as of 2009
- Water Sampling Station

0 1 2 4 km

Scale 1:120,000

Projection: UTM Zone 12 NAD83

<u>Data Sources:</u>
a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, and First Nation Reserve from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries Modified from Cumulative Environmental Management Association (CEMA).
d) Land change areas delineated from 10m SPOT-5 (June, July, and August 2009) multispectral imagery.

Township and Range designations are relative to W4M.

K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_L_WaterNexen_20100415.mxd

6.1.2 Analytical Approach

The analytical approach used in 2009 for the Nexen Lakes Water Quality monitoring program was based on the analytical approach described in Section 3.2.7 for the RAMP Water Quality component.

Development of Regional Water Quality Baseline

Determination of regional *baseline* concentrations for the Nexen lakes was conducted separately from the RAMP water quality dataset. The regional *baseline* range was defined from all observations from fall sampling conducted from 2000 to 2006 for all Nexen lakes. All waterbodies sampled for the Nexen lakes component were considered to be *baseline* from 2000 to 2006 given operations on the Long Lake project did not start until 2008. This approach maximized the number of observations used to define regional *baseline* conditions against which observations from individual Nexen lakes could be compared.

Comparison to Water Quality Guidelines and Historical Data

The fall 2009 concentration of each water quality measurement endpoint was tabulated for each station sampled. Historical variability was presented for each water quality measurement endpoint, represented by minimum, maximum and median values observed, as well as the number of observations, at each station from 1997 to 2009 (fall observations only). All cases where concentrations of water quality variables exceeded relevant guidelines, including water quality measurement endpoints and any other monitored water quality variables, also were reported.

Comparison to Natural Variation in Baseline Conditions

Descriptive statistics describing natural water quality characteristics for *baseline* years (2000 to 2006) for all lakes were calculated; the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined for comparison against station-specific data. The median rather than the mean was used as an indicator of typical conditions.

Data for the fifteen selected water quality measurement endpoints (Table 3.2-8) were presented graphically against regional *baseline* variability by presenting data for each station for all years of sampling to allow assessment of any temporal trends.

6.1.3 Water Quality Sampling Results

2009 Results Relative to Historical and Regional *Baseline* Concentrations Given the small number of observations from each lake, concentrations of many water quality measurement endpoints in fall 2009 exceeded previously-measured minimum or maximum concentrations for each lake (Table 6.1-2 to Table 6.1-10). Concentrations of most selected measurement endpoints in fall 2009 were within their regional *baseline* concentrations for the Nexen lakes (Figure 6.1-2 to Figure 6.1-4). Water quality measurement endpoints with concentrations in fall 2009 that were outside *baseline* concentrations for the Nexen lakes were total nitrogen in Frog Lake, dissolved phosphorus in Sucker Lake and Unnamed lakes 1 and 2, and total mercury in Caribou Horn Lake, Canoe Lake, Rat Lake, and Unnamed lakes 1 and 2 with concentrations above their 95th percentile of *baseline* concentrations for the Nexen lakes.

Generally, concentrations of water quality measurement endpoints in fall 2009 were similar to previously-measured fall concentrations (Figure 6.1-2 to Figure 6.1-4). Concentrations of several water quality measurement endpoints appear to vary similarly across all lakes such as total dissolved solids decreasing between 2006 and 2009 in all lakes sampled in both years), while concentrations of other measurement endpoints (e.g. total suspended solids) vary differently over time among lakes. For example, in fall 2009, concentrations of dissolved phosphorus in Sucker Lake, Unnamed Lake 1 and Unnamed Lake 2 were higher than in any other lake and higher than concentrations in 2006, while concentrations of dissolved phosphorus in most other lakes decreased from 2006 to 2009.

Concentrations of naphthenic acids in all lakes were below the detection limit of 1 mg/L in all years of sampling. In 2009, the detection limit for naphthenic acids was reduced to 0.2 mg/L, resulting in concentrations in all lakes in fall 2009 below the 5th percentile of *baseline* concentrations for the Nexen lakes.

Comparison of Fall Water Quality Measurement Endpoints to Water Quality Guidelines The concentration of total nitrogen exceeded its water quality guideline in all lakes in fall 2009 with the exception of Gregoire Lake (Table 6.1-2 to Table 6.1-10). Additional water quality guideline exceedances in fall 2009 were:

- total phosphorus in Canoe Lake, Frog Lake, Sucker Lake, Unnamed Lake 1 and Unnamed Lake 2;
- dissolved phosphorus in Unnamed Lake 1 and Unnamed Lake 2;
- pH (below 6.5) in Unnamed Lake 1 and Unnamed Lake 2; and
- total and dissolved aluminum in Unnamed Lake 2.

Other Water Quality Guideline Exceedances The other exceedances of water quality guidelines in fall 2009 in the Nexen lakes were (Table 6.1-2 to Table 6.1-10):

- total phenols at all lakes with the exception of Rat Lake and Sucker Lake;
- sulphide concentrations exceeded the British Columbia working guideline at all lakes except Canoe Lake and Gregoire Lake;
- total iron in Birch Lake, Frog Lake, Rat Lake, Sucker Lake, Unnamed Lake 1 and Unnamed Lake 2; and
- total and dissolved cadmium in both Unnamed Lake 1 and Unnamed Lake 2 (it should be noted that this guideline is very low in these lakes due to low hardness).

Table 6.1-11 contains the spring water quality guideline exceedances measured in the Nexen lakes in 2009.

Ion Balance The ionic composition of water in all lakes in fall 2009 was dominated primarily by calcium bicarbonate, similar to previous sampling years (Figure 6.1-5 to Figure 6.1-7). In fall 2009, Canoe Lake had higher relative chloride levels than previously-measured (Figure 6.1-5). In 2006, Unnamed Lake 1 and Unnamed Lake 2 had ionic compositions that were very different to other lakes in the region; the ionic composition of these lakes in 2009 was similar to the other Nexen lakes (Figure 6.1-7).

Summary Water quality in the Nexen lakes in fall 2009 was similar to water quality in these lakes during the period they were designated as *baseline*. Concentrations of most water quality measurement endpoints in fall 2009 were within their regional *baseline* concentrations for the Nexen lakes. In addition, the ionic composition of water in all lakes in fall 2009 was similar to the dominant composition of previous sampling years.

Table 6.1-2 Concentrations of water quality measurement endpoints, Canoe Lake (CANL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.53	4	6.8	7.3	7.4
Total Suspended Solids	mg/L	-[1]	8	4	<3.0	2.5	19
Conductivity	µS/cm	-	140	4	83	89	102
Nutrients							
Total phosphorus	mg/L	0.05	**0.0577**	4	0.035	**0.072**	**0.14**
Total dissolved phosphorus	mg/L	0.05[2]	0.0233	3	0.013	0.020	**0.065**
Total nitrogen*	mg/L	1.0	**1.221**	4	**1.1**	**1.3**	**1.4**
Nitrate+Nitrite	mg/L	-	<0.071	4	0.061	<0.1	<0.1
Dissolved organic carbon	mg/L	-	24	4	20	22	23
Ions							
Sodium	mg/L	-	10.8	4	3	5	7
Calcium	mg/L	-	11.7	4	9.2	9.9	10.8
Magnesium	mg/L	-	4.09	4	3.1	3.2	3.5
Chloride	mg/L	230, 860[3]	15.6	4	<1.0	1.4	5
Sulphate	mg/L	50, 100[4]	0.81	4	0.8	2.2	2.5
Total Dissolved Solids	mg/L	-	130	4	46	105	110
Total Alkalinity	mg/L	-	41	4	36	42	43
Organic compounds							
Naphthenic acids	mg/L	-	0.1374	2	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000576	4	0.00023	0.00072	**<0.01**
Total aluminum	mg/L	0.1	0.0151	4	0.014	0.0499	**0.11**
Dissolved aluminum	mg/L	0.1[2]	0.0034	1	0.00633	0.00633	0.00633
Total boron	mg/L	1.2[5]	0.0219	4	0.015	0.0178	0.0193
Total molybdenum	mg/L	0.073	0.000148	4	<0.00002	<0.00006	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Phenols	mg/L	0.004	**0.008**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0052**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in bold indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-3 Concentrations of water quality measurement endpoints, Caribou Horn Lake (CARL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8	3	7.2	7.7	7.8
Total Suspended Solids	mg/L	-[1]	4	3	5	7	22
Conductivity	µS/cm	-	97.3	3	88	92.4	97.8
Nutrients							
Total phosphorus	mg/L	0.05	0.041	3	0.037	0.039	0.048
Total dissolved phosphorus	mg/L	0.05[2]	0.0131	3	0.004	0.009	0.017
Total nitrogen*	mg/L	1.0	**1.031**	3	0.616	**1.1**	**1.2**
Nitrate+Nitrite	mg/L	-	<0.071	3	<0.006	<0.006	0.2
Dissolved organic carbon	mg/L	-	24.7	3	18	22	26
Ions							
Sodium	mg/L	-	4.3	3	5.2	6	6
Calcium	mg/L	-	19.8	3	21.6	22	23.1
Magnesium	mg/L	-	6.37	3	7	7.4	7.56
Chloride	mg/L	230, 860[3]	<0.5	3	<1.0	1.1	2
Sulphate	mg/L	50, 100[4]	1.86	3	1.3	3.4	16.1
Total Dissolved Solids	mg/L	-	122	3	97	138	180
Total Alkalinity	mg/L	-	78.5	3	74	77	94
Organic compounds							
Naphthenic acids	mg/L	-	0.0573	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000615	3	0.000567	0.00028	**<0.01**
Total aluminum	mg/L	0.1	0.0193	3	0.0343	0.0470	**0.116**
Dissolved aluminum	mg/L	0.1[2]	0.00263	1	0.00803	0.00803	0.00803
Total boron	mg/L	1.2[5]	0.0332	3	0.0113	0.0311	0.032
Total molybdenum	mg/L	0.073	0.0000926	3	0.00002	0.00002	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.4	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Iron	mg/L	0.3	**0.345**	-	-	-	-
Total Phenols	mg/L	0.004	**0.0064**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0059**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-4 Concentrations of water quality measurement endpoints, Frog Lake (FRL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.97	3	7.5	7.6	7.8
Total Suspended Solids	mg/L	-[1]	6	3	3	3	5
Conductivity	µS/cm	-	196	3	178	180	181
Nutrients							
Total phosphorus	mg/L	0.05	**0.0522**	3	0.035	0.042	**0.16**
Total dissolved phosphorus	mg/L	0.05[2]	0.0107	2	0.015	0.015	0.015
Total nitrogen*	mg/L	1.0	**1.591**	3	**1.3**	**1.3**	**1.6**
Nitrate+Nitrite	mg/L	-	<0.0071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	34.1	3	28	30	39
Ions							
Sodium	mg/L	-	11.4	3	7.5	8.0	9
Calcium	mg/L	-	22.4	3	24.2	24.3	24.5
Magnesium	mg/L	-	6.58	3	7.18	7.5	7.6
Chloride	mg/L	230, 860[3]	12	3	<1.0	1	5
Sulphate	mg/L	50, 100[4]	0.67	3	1.9	2.9	3.4
Total Dissolved Solids	mg/L	-	167	3	100	183	200
Total Alkalinity	mg/L	-	78.2	3	83	88	95
Organic compounds							
Naphthenic acids	mg/L	-	<1.0	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000462	3	0.00044	0.000427	**<0.01**
Total aluminum	mg/L	0.1	0.0235	3	0.016	0.035	0.043
Dissolved aluminum	mg/L	0.1[2]	0.00258	1	0.00365	0.00365	0.00365
Total boron	mg/L	1.2[5]	0.0432	3	0.0375	0.0520	0.0696
Total molybdenum	mg/L	0.073	0.0000462	3	0.00006	0.000074	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.2	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Iron	mg/L	0.3	**0.337**	-	-	-	-
Total Phenols	mg/L	0.004	**0.0093**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0056**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-5 Concentrations of water quality measurement endpoints, Gregoire Lake (GRL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2002-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.92	2	7.6	7.6	7.6
Total Suspended Solids	mg/L	-[1]	7	2	<3.0	1.5	6
Conductivity	µS/cm	-	136	2	127	136.5	146
Nutrients							
Total phosphorus	mg/L	0.05	0.0275	2	0.021	0.023	0.025
Total dissolved phosphorus	mg/L	0.05[2]	0.0064	2	0.006	0.007	0.007
Total nitrogen*	mg/L	1.0	0.771	2	0.6	0.8	**0.9**
Nitrate+Nitrite	mg/L	-	<0.071	2	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	11	2	11	11	11
Ions							
Sodium	mg/L	-	3.2	2	4	4	4
Calcium	mg/L	-	17.3	2	16.9	17.6	18.3
Magnesium	mg/L	-	4.44	2	4.5	4.7	4.9
Chloride	mg/L	230, 860[3]	1.7	2	<1.0	1	3
Sulphate	mg/L	50, 100[4]	5.32	2	6.4	6.6	6.7
Total Dissolved Solids	mg/L	-	97	2	96	108	120
Total Alkalinity	mg/L	-	59	2	53	59	64
Organic compounds							
Naphthenic acids	mg/L	-	0.0639	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.00105	2	0.000728	0.000914	<0.0011
Total aluminum	mg/L	0.1	0.0335	2	0.021	0.0379	0.0548
Dissolved aluminum	mg/L	0.1[2]	0.00173	1	0.00279	0.00279	0.00279
Total boron	mg/L	1.2[5]	0.0197	2	0.0174	0.0180	0.0186
Total molybdenum	mg/L	0.073	0.000698	2	0.000563	0.000652	0.00074
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.2	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Phenols	mg/L	0.004	**0.0047**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

[4] Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

Table 6.1-6 Concentrations of water quality measurement endpoints, Kiskatinaw Lake (KIL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8	3	7.7	7.8	7.8
Total Suspended Solids	mg/L	-[1]	3	3	<3.0	1	4
Conductivity	µS/cm	-	158	3	164	183	185
Nutrients							
Total phosphorus	mg/L	0.05	0.0242	3	0.025	0.029	**0.15**
Total dissolved phosphorus	mg/L	0.05[2]	0.0079	2	0.008	0.010	0.011
Total nitrogen*	mg/L	1.0	**1.001**	3	0.776	**1.1**	**1.1**
Nitrate+Nitrite	mg/L	-	<0.071	3	<0.006	<0.1	0.1
Dissolved organic carbon	mg/L	-	24.9	3	20	24	40
Ions							
Sodium	mg/L	-	5.5	3	6.2	7	7
Calcium	mg/L	-	20.9	3	21.2	22.7	24.1
Magnesium	mg/L	-	6.46	3	6.6	6.9	7.31
Chloride	mg/L	230, 860[3]	<0.5	3	<1.0	1.1	2
Sulphate	mg/L	50, 100[4]	2.03	3	1.1	2.8	3.8
Total Dissolved Solids	mg/L	-	140	3	102	146	160
Total Alkalinity	mg/L	-	79.7	3	80	92	99
Organic compounds							
Naphthenic acids	mg/L	-	0.0616	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000542	3	0.00002	0.000442	**<0.01**
Total aluminum	mg/L	0.1	0.0172	3	0.002	0.034	0.047
Dissolved aluminum	mg/L	0.1[2]	0.00224	1	0.00293	0.00293	0.00293
Total boron	mg/L	1.2[5]	0.048	3	<0.00008	0.040	0.0445
Total molybdenum	mg/L	0.073	0.0000912	3	<0.00002	0.000085	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<1.2	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Phenols	mg/L	0.004	**0.007**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.049**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-7 Concentrations of water quality measurement endpoints, Rat Lake (RAL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.15	3	7.7	7.7	7.9
Total Suspended Solids	mg/L	-[1]	3	3	<1.0	4	6
Conductivity	µS/cm	-	209	3	204	206	208
Nutrients							
Total phosphorus	mg/L	0.05	0.0349	3	0.042	0.045	**0.11**
Total dissolved phosphorus	mg/L	0.05[2]	0.0127	2	0.009	0.011	0.012
Total nitrogen*	mg/L	1.0	**1.191**	3	0.826	**1.3**	**1.4**
Nitrate+Nitrite	mg/L	-	<0.071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	22.4	3	18	18	26
Ions							
Sodium	mg/L	-	7.6	3	6.5	8	8
Calcium	mg/L	-	26.8	3	26.6	26.6	27
Magnesium	mg/L	-	7.64	3	7.83	8.0	8.3
Chloride	mg/L	230, 860[3]	2.58	3	0.9	<1.0	2
Sulphate	mg/L	50, 100[4]	2.17	3	2.7	4.4	4.6
Total Dissolved Solids	mg/L	-	160	3	113	167	180
Total Alkalinity	mg/L	-	101	3	100	103	109
Organic compounds							
Naphthenic acids	mg/L	-	0.1154	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000402	3	0.00039	0.00039	**<0.01**
Total aluminum	mg/L	0.1	0.0162	3	0.0157	0.0160	0.033
Dissolved aluminum	mg/L	0.1[2]	0.00107	1	<0.001	<0.001	<0.001
Total boron	mg/L	1.2[5]	0.0311	3	0.023	0.0331	0.03406
Total molybdenum	mg/L	0.073	0.000091	3	0.0000688	0.00007	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.4	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Iron	mg/L	0.3	**0.533**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0069**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-8 Concentrations of water quality measurement endpoints, Sucker Lake (SUL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.06	4	7.7	7.8	7.9
Total Suspended Solids	mg/L	-[1]	5	3	<1.0	4	8
Conductivity	µS/cm	-	187	4	187	215	219
Nutrients							
Total phosphorus	mg/L	0.05	**0.06**	3	**0.054**	**0.084**	**0.11**
Total dissolved phosphorus	mg/L	0.05[2]	0.029	2	0.013	0.016	0.019
Total nitrogen*	mg/L	1.0	**1.381**	3	0.77	**1.5**	**1.9**
Nitrate+Nitrite	mg/L	-	<0.071	4	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	25	3	19	20	25
Ions							
Sodium	mg/L	-	8.8	4	9.8	10	11
Calcium	mg/L	-	21.5	4	23	24.5	26.7
Magnesium	mg/L	-	6.34	4	6.8	7.6	8.3
Chloride	mg/L	230, 860[3]	1.79	4	<1.0	1.4	2
Sulphate	mg/L	50, 100[4]	3.09	4	2.5	3.7	6
Total Dissolved Solids	mg/L	-	152	3	117	157	190
Total Alkalinity	mg/L	-	89.8	4	91	110	115
Organic compounds							
Naphthenic acids	mg/L	-	0.1134	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000513	3	0.000409	0.0005	**<0.01**
Total aluminum	mg/L	0.1	0.0135	3	0.01	0.0164	0.032
Dissolved aluminum	mg/L	0.1[2]	0.000708	1	<0.001	<0.001	<0.001
Total boron	mg/L	1.2[5]	0.0536	3	0.0441	0.0500	0.06852
Total molybdenum	mg/L	0.073	0.000127	3	0.0000393	0.00006	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.2	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Total Iron	mg/L	0.3	**0.405**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0064**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

[4] Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Table 6.1-9 Concentrations of water quality measurement endpoints, Unnamed Lake One (UNL-1), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	**5.32**	4	**5.3**	**5.8**	**6.4**
Total Suspended Solids	mg/L	-[1]	7	4	<1.0	4	22
Conductivity	µS/cm	-	22.3	4	23	25.2	39.2
Nutrients							
Total phosphorus	mg/L	0.05	**0.163**	3	0.032	0.040	**0.12**
Total dissolved phosphorus	mg/L	0.05[2]	**0.14**	2	0.023	0.027	0.03
Total nitrogen*	mg/L	1.0	**1.181**	3	0.656	1.0	**1.3**
Nitrate+Nitrite	mg/L	-	<0.071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	29.4	4	21	22	28
Ions							
Sodium	mg/L	-	<1.0	4	0.6	<1.0	<1.0
Calcium	mg/L	-	2.4	4	2.6	3.1	3.3
Magnesium	mg/L	-	0.72	4	0.7	0.8	0.9
Chloride	mg/L	230, 860[3]	<0.5	4	0.8	1	2
Sulphate	mg/L	50, 100[4]	0.57	4	0.8	2.2	2.7
Total Dissolved Solids	mg/L	-	29.4	4	21	22	28
Total Alkalinity	mg/L	-	<5.0	4	6	9	15
Organic compounds							
Naphthenic acids	mg/L	-	0.1315	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000333	3	0.000292	0.00043	**<0.01**
Total aluminum	mg/L	0.1	0.0951	3	0.058	0.081	0.097
Dissolved aluminum	mg/L	0.1[2]	0.0696	1	0.0749	0.0749	0.0749
Total boron	mg/L	1.2[5]	0.0103	3	<0.002	0.0084	0.0249
Total molybdenum	mg/L	0.073	0.0000435	3	0.0000463	0.00011	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.2	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Dissolved Cadmium	µg/L	0.00417[8]	**0.012**	-	-	-	-
Total Cadmium	µg/L	0.00417[8]	**0.017**	-	-	-	-
Dissolved Iron	mg/L	0.3	**0.481**	-	-	-	-
Total Iron	mg/L	0.3	**0.557**	-	-	-	-
Total Phenols	mg/L	0.004	**0.0125**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0072**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

1 AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

2 Guideline is for total species (no guideline for dissolved species).

3 U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

4 Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

5 B.C. ambient water quality guideline for boron (B.C. 2003).

6 Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

7 B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

8 Guideline is Hardness dependent.

Table 6.1-10 Concentrations of water quality measurement endpoints, Unnamed Lake Two (UNL-2), fall 2009.

Measurement Endpoint	Units	Guideline	September 2009	2000-2008 (Fall Data Only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	**5.69**	4	**5.6**	**5.9**	**6.22**
Total Suspended Solids	mg/L	-[1]	<3.0	3	<1.0	<3.0	<3.0
Conductivity	µS/cm	-	33.7	4	34	35.7	41.5
Nutrients							
Total phosphorus	mg/L	0.05	**0.102**	3	0.026	**0.112**	**0.14**
Total dissolved phosphorus	mg/L	0.05[2]	**0.09**	2	0.014	**0.062**	**0.11**
Total nitrogen*	mg/L	1.0	**1.131**	3	0.716	**1.1**	**1.2**
Nitrate+Nitrite	mg/L	-	<0.071	4	<0.006	<0.1	0.1
Dissolved organic carbon	mg/L	-	36.6	4	25	30	39
Ions							
Sodium	mg/L	-	<1.0	4	1	2	8.5
Calcium	mg/L	-	4.87	4	4.7	5.2	32
Magnesium	mg/L	-	1.27	4	1.4	1.5	8.1
Chloride	mg/L	230, 860[3]	<0.5	4	1	1.8	3
Sulphate	mg/L	50, 100[4]	<0.5	4	1.2	2.9	6.2
Total Dissolved Solids	mg/L	-	109	3	17	100	109
Total Alkalinity	mg/L	-	<5.0	4	7	10	11
Organic compounds							
Naphthenic acids	mg/L	-	0.0477	1	<1.0	<1.0	<1.0
Selected metals							
Total arsenic	mg/L	0.005	0.000405	4	0.00039	0.00077	**<0.01**
Total aluminum	mg/L	0.1	**0.151**	4	0.021	**0.147**	**0.23**
Dissolved aluminum	mg/L	0.1[2]	**0.145**	1	**0.144**	**0.144**	**0.144**
Total boron	mg/L	1.2[5]	0.0104	4	0.0077	0.024	0.0394
Total molybdenum	mg/L	0.073	0.0000798	4	0.0000333	0.000495	<0.001
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.6	1	<1.2	<1.2	<1.2
Parameters that exceeded CCME guidelines in Fall 2009							
Dissolved Cadmium	µg/L	0.00736[8]	**0.0093**	-	-	-	-
Total Cadmium	µg/L	0.00736[8]	**0.0094**	-	-	-	-
Dissolved Iron	mg/L	0.3	**0.567**	-	-	-	-
Total Iron	mg/L	0.3	**0.599**	-	-	-	-
Total Phenols	mg/L	0.004	**0.0089**	-	-	-	-
Sulphide	mg/L	0.002[7]	**0.0067**	-	-	-	-

Guidelines are CCME (2006) or AENV (1999b) unless otherwise noted.

Values in **bold** indicate concentrations exceeding guidelines for the protection of aquatic life.

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN);
Non-detectable results were assumed to be equal to the detection limit for calculating total nitrogen.

[1] AENV guideline: TSS is not to be increased by more than 10 mg/L over background value.

[2] Guideline is for total species (no guideline for dissolved species).

[3] U.S. EPA Guideline for Continuous and Maximum Concentration, respectively (US EPA 2006).

[4] Alert level and maximum concentration, respectively (B.C. Approved Water Quality Guideline, B.C. 2006).

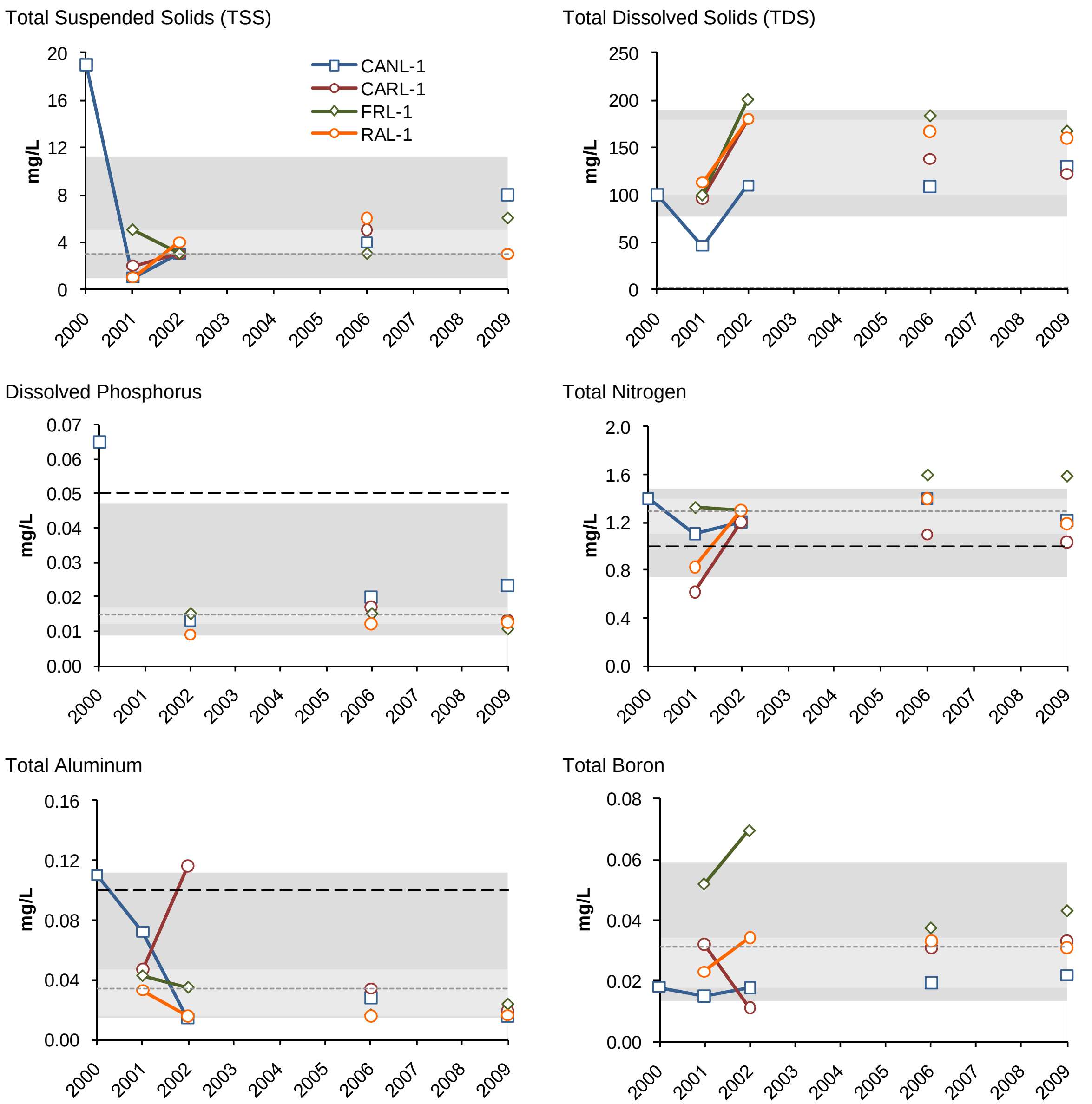
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is Hardness dependent.

Figure 6.1-2 Selected water quality measurement endpoints in CANL-1,CARL-1, FRL-1, and RAL-1 lakes (fall data) relative to regional *baseline* fall concentrations.



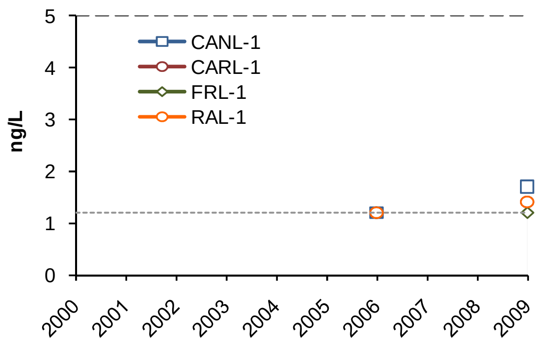
Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

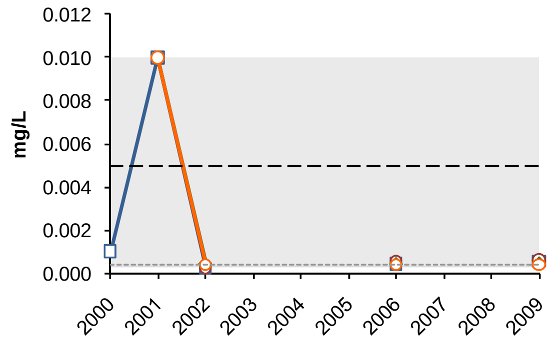
[2] Guideline is for total species, no guideline for dissolved species.

Figure 6.1-2 (Cont'd.)

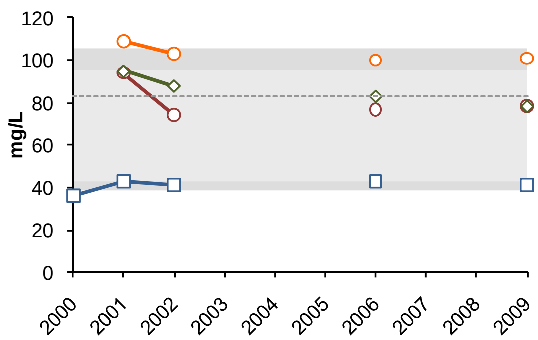
Total Mercury



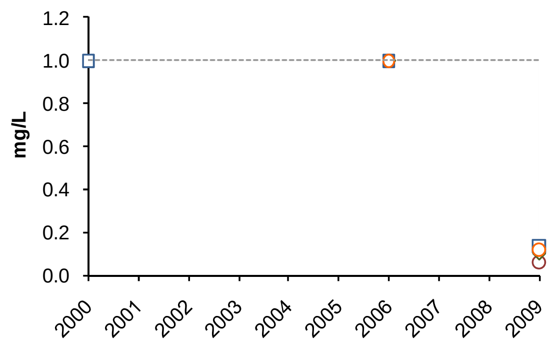
Total Arsenic



Total Alkalinity



Naphthenic Acids

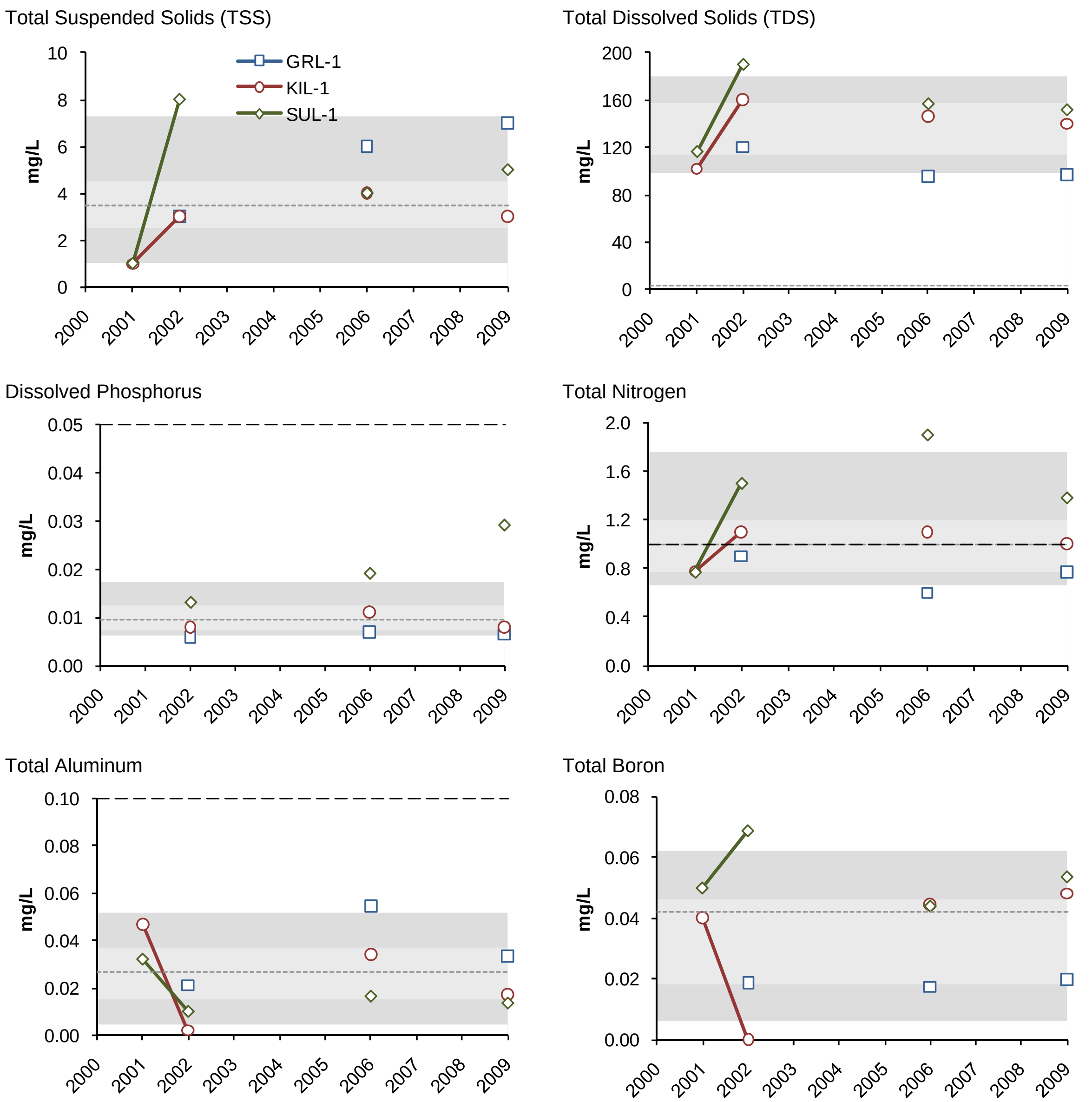


Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

[2] Guideline is for total species, no guideline for dissolved species.

Figure 6.1-3 Selected water quality measurement endpoints in GRL-1, KIL-1, and SUL-1 lakes (fall data) relative to regional *baseline* fall concentrations.



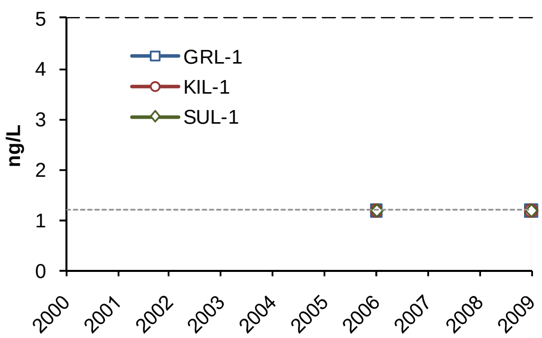
Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

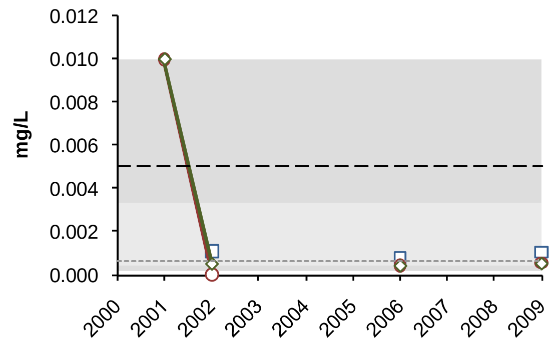
[2] Guideline is for total species, no guideline for dissolved species.

Figure 6.1-3 (Cont'd.)

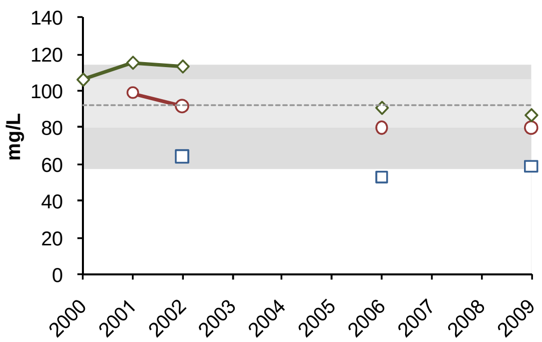
Total Mercury



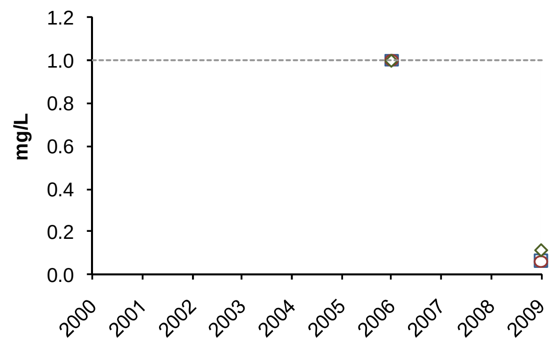
Total Arsenic



Total Alkalinity



Naphthenic Acids

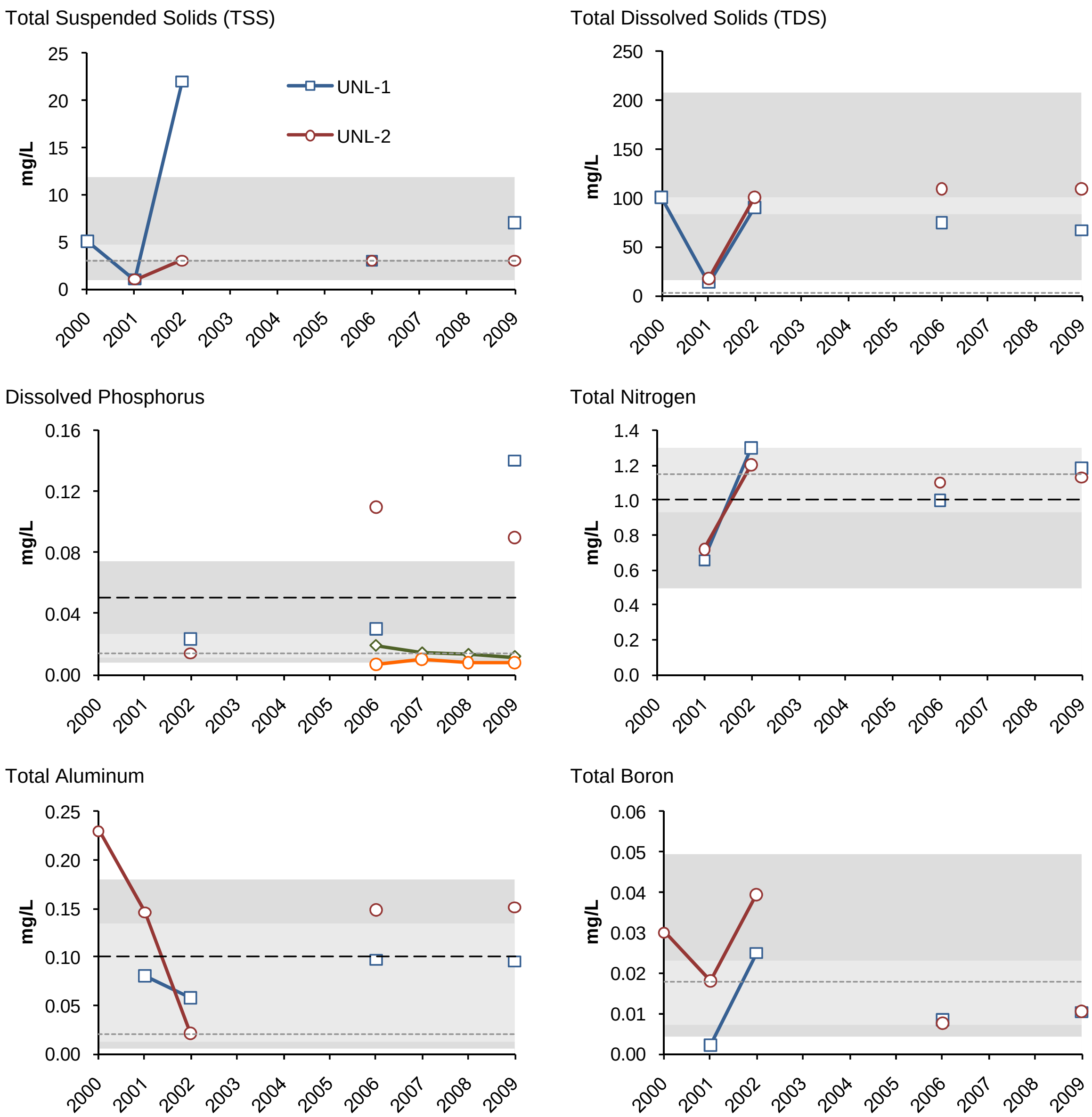


Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

[2] Guideline is for total species, no guideline for dissolved species.

Figure 6.1-4 Selected water quality measurement endpoints in UNL-1 and UNL-2 lakes (fall data) relative to regional *baseline* fall concentrations.

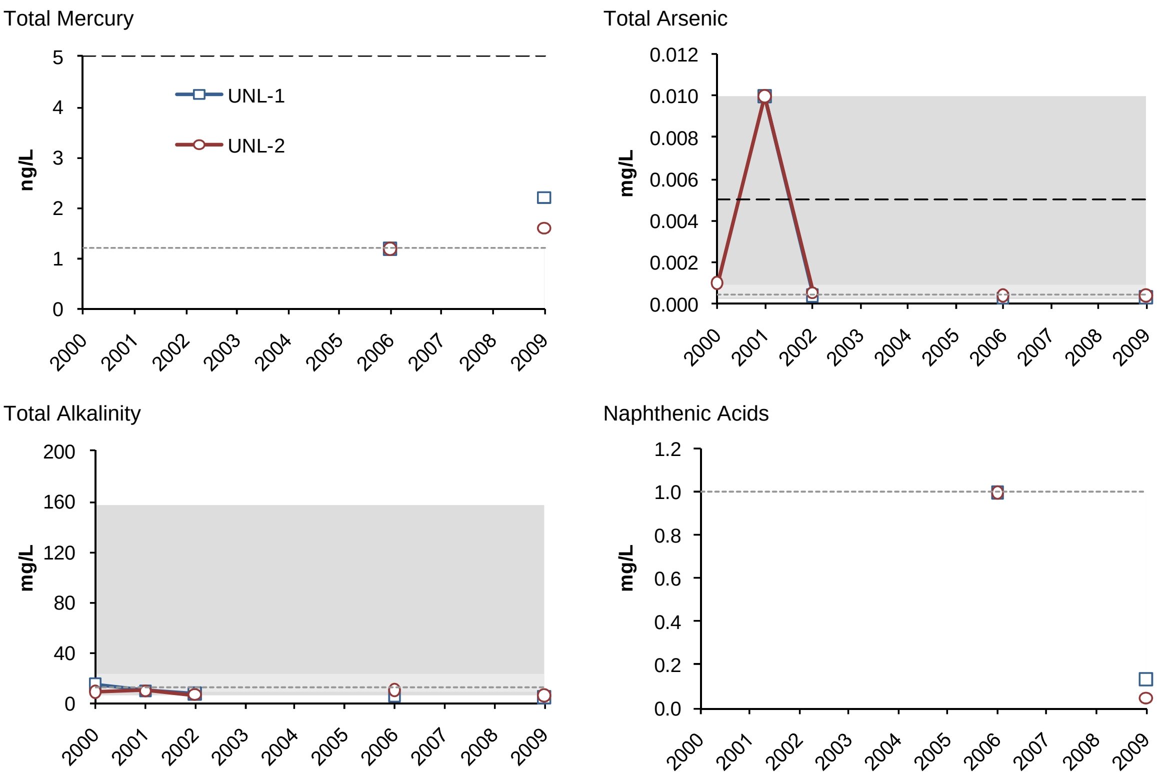


Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

[2] Guideline is for total species, no guideline for dissolved species.

Figure 6.1-4 (Cont'd.)



Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all Nexen *baseline* stations from all years of sampling.

[2] Guideline is for total species, no guideline for dissolved species.

Table 6.1-11 Spring water quality guideline exceedances in the Nexen lakes, 2009.

Variable	Units	Guideline	CANL-1	CARL-1	FRL-1	GRL-1	KIL-1	RAL-1	SUL-1	UNL-1	UNL-2
pH	pH units	6.5-9.0	-	-	-	-	-	-	-	5.62	6.35
Total phosphorus	mg/L	0.05	0.0554	-	-	-	-	0.0519	0.0631	0.127	0.103
Total dissolved phosphorus	mg/L	0.05[1]	-	-	-	-	-	-	-	0.116	0.0631
Total nitrogen*	mg/L	1.0	2.25	1.241	2.031	-	1.761	1.671	2.011	1.751	1.391
Total aluminum	mg/L	0.1	-	-	-	-	-	-	-	-	0.132
Dissolved aluminum	mg/L	0.1[1]	-	-	-	-	-	-	-	-	0.122
Total cadmium	µg/L	0.00721[2]	-	-	-	-	-	-	-	0.0337	0.0112
Dissolved cadmium	µg/L	0.00721[2]	-	-	-	-	-	-	-	0.0336	0.0122
Total Iron	mg/L	0.3	0.302	-	0.426	-	0.303	0.665	0.656	0.503	0.444
Dissolved Iron	mg/L	0.3	-	-	-	-	-	-	0.339	0.471	0.484
Total Phenols	mg/L	0.004	0.0082	0.0071	0.0098	0.0043	0.0061	0.0085	0.0083	0.0104	0.0127
Sulphide	mg/L	0.002[3]	0.0119	-	0.0105	-	0.0048	0.0027	0.0028	0.0055	0.0105

* Total nitrogen = Nitrate+nitrite plus total Kjeldahl nitrogen (TKN).

[1] Guideline is for total species (no guideline for dissolved species).

[2] Guideline is hardness-dependent.

[3] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

Figure 6.1-5 Piper diagram of fall ion concentrations in CANL-1, CARL-1, FRL-1, and RAL-1 lakes.

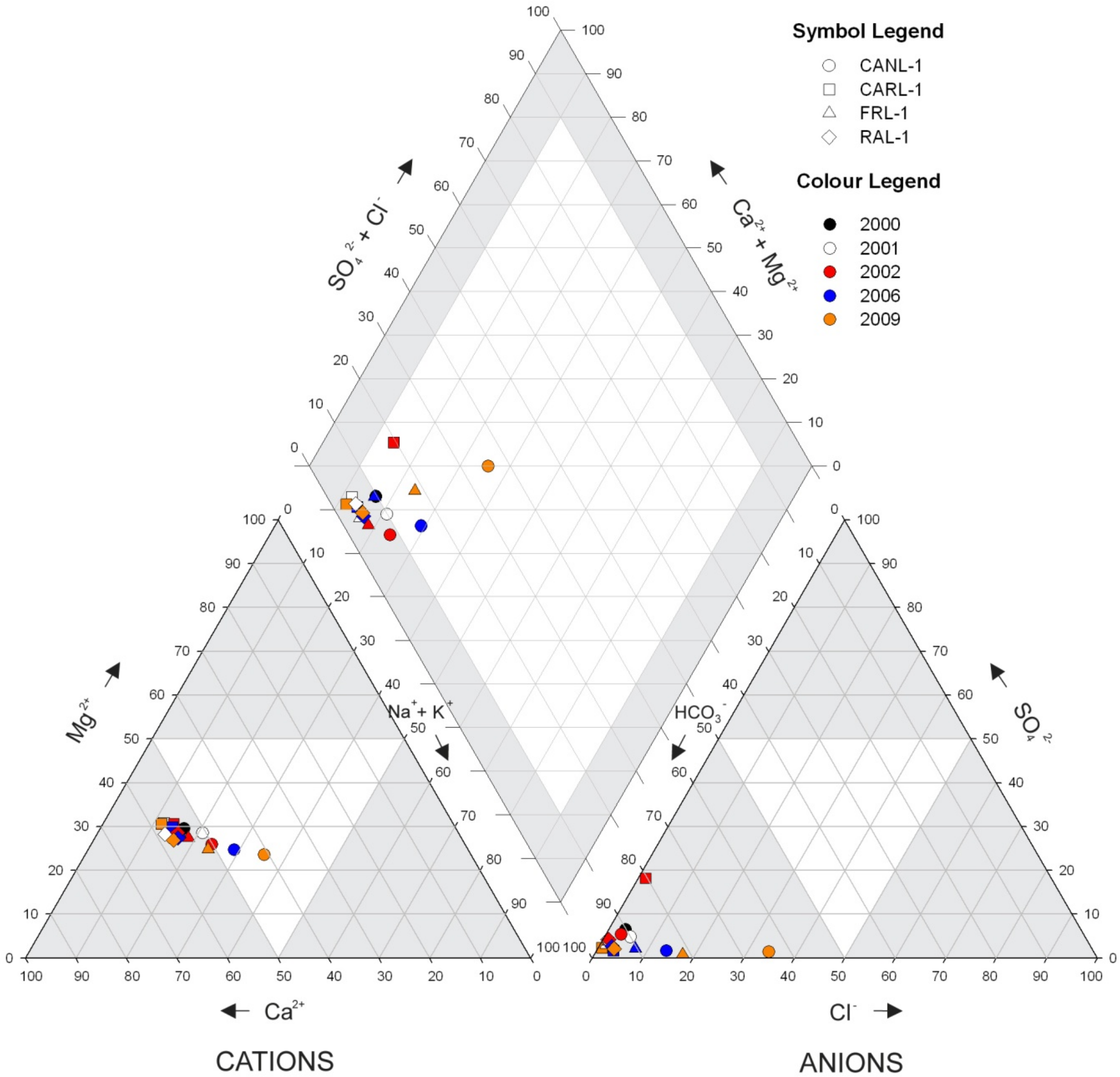


Figure 6.1-6 Piper diagram of fall ion concentrations in GRL-1, KIL-1, and SUL-1 lakes.

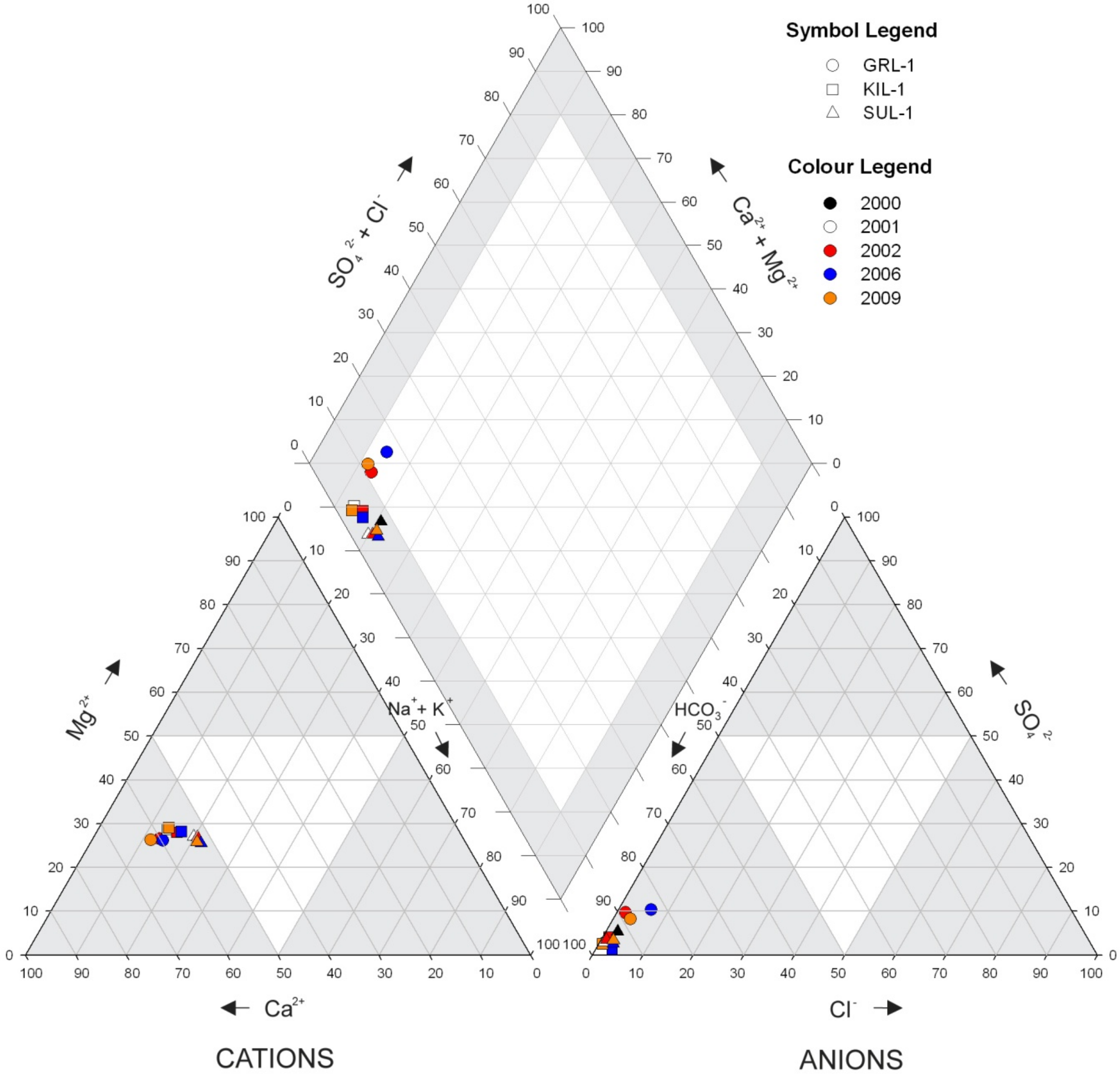
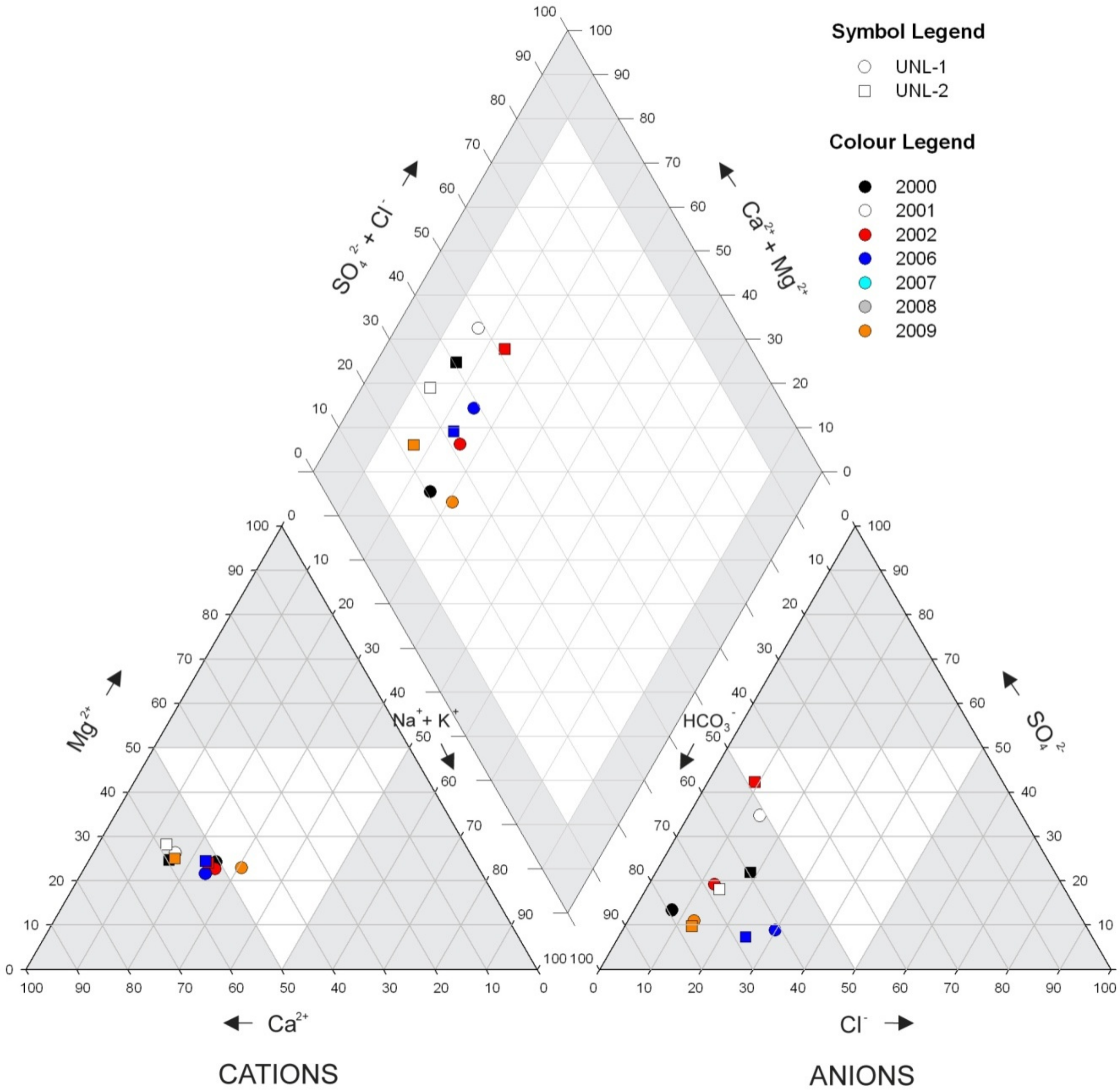


Figure 6.1-7 Piper diagram of fall ion concentrations in UNL-1 and UNL-2 lakes.



6.2 FISH ASSEMBLAGE MONITORING PILOT STUDY

6.2.1 Overview of the 2009 Program

A fish assemblage monitoring (FAM) pilot study was initiated in 2009 by RAMP with the following objectives:

1. Monitor the fish assemblage at reaches where water, sediment and benthos are monitored to provide harmonization among components of RAMP.
2. Develop a monitoring tool to assess potential changes in the fish assemblage of a watercourse within and outside of oil sands development.
3. Document fish habitat and fish assemblages in tributaries to the Athabasca River to develop regional trends in indicators of ecological condition.

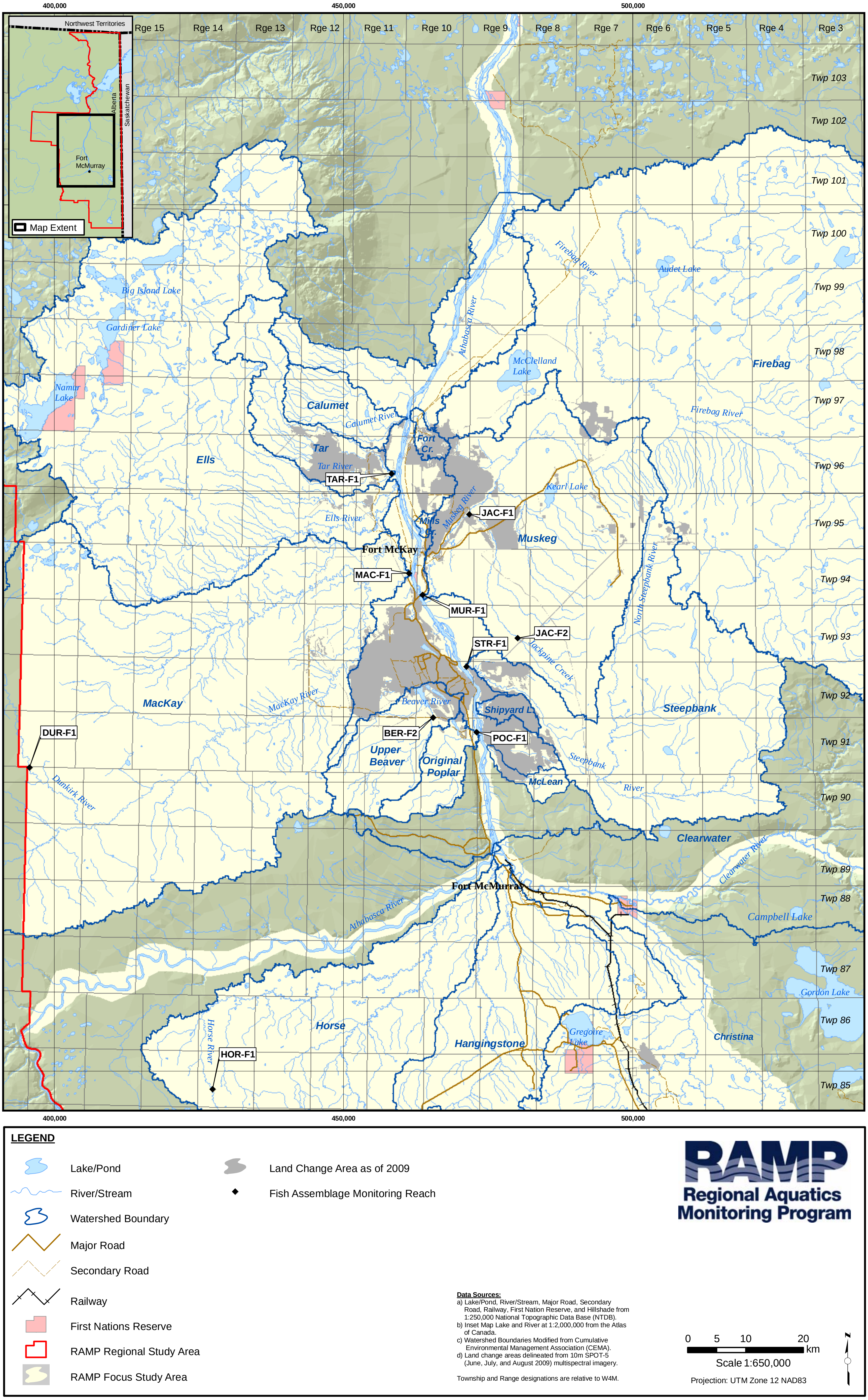
Scientists from Oregon State University (Dr. Robert Hughes and Mr. Thom Whittier), who have done extensive work in fish assemblage monitoring in the United States, assisted with the analyses and writing for this pilot study. The following sections have been modified from their original report to the format of the RAMP Technical Report.

6.2.2 Summary of Field Methods

The methods used to develop a fish assemblage monitoring pilot study for RAMP were adopted from the United States Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP) for stream monitoring programs throughout the United States (Peck *et al.* 2006). The procedures described were modified to include appropriate indicators related to the RAMP FSA. The EMAP methods outline the collection of physical habitat, fish, water and sediment chemistry, and benthic invertebrate variables. In an effort to harmonize the monitoring activities under RAMP, fish and fish habitat sampling for the Fish Assemblage monitoring pilot study was conducted at reaches where the Water Quality, and Benthic Invertebrate Communities and Sediment Quality components conducted sampling in fall 2009 (see Section 3.2.2 and Section 3.3.12 for a detailed approach of sampling methodology for these components).

The FAM pilot study was conducted between September 17 and October 3, 2009 to assess changes in the fish assemblage related to focal projects. The study included sampling at a total of eleven reaches on Athabasca River tributaries within the RAMP FSA where the Water Quality, and Benthic Invertebrate Communities and Sediment Quality components conducted sampling in 2009 (Table 6.2-1). Seven of these reaches are designated as *test*: lower Steepbank, Muskeg, MacKay and Tar rivers, middle Muskeg River and lower Jackpine and Poplar creeks, while the remaining four reaches are designated as *baseline*: Horse River, Dunkirk River, Beaver River and upper Jackpine Creek (Table 6.2-1). Six of the reaches were in depositional habitat and five were in erosional habitat. Average wetted widths of reaches ranged from 5 to 39 m, with nine reaches ≤17 m. The depositional reaches were all ≤10 m wide and the erosional reaches were all ≥12 m wide. The FAM pilot study included reaches of varying stream order and size, upstream and downstream of focal projects, across a representative set of watercourses in the RAMP FSA. Sampling was attempted at the middle reach of the Muskeg River (MUR-F2) but weather conditions and cold water temperatures prevented effective sampling by electrofishing.

Figure 6.2-1 Locations of fish assemblage monitoring reaches in the RAMP Focus Study Area, fall 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_P1_FishAssemblage_20100415.mxd

Table 6.2-1 Location and designation of fish assemblage monitoring reaches, 2009.

Watershed	Reach	Location Description	Reach Designation	Water Quality Station/ Benthic Invertebrate Reach	UTM Coordinates (NAD83, Zone 12)
Steepbank River	STR-F1	In the vicinity of the Steepbank Mine, approximately 0.3 to 1.0 km upstream of the confluence with the Athabasca River	*Test*	STR-1/STR-E-1	D/S: 471017 E / 6319955 N U/S: 471448 E / 6320230 N
Muskeg River	MUR-F1	Approximately 0.2 to 0.6 km upstream of the confluence with the Athabasca River	*Test*	MUR-1/MUR-E-1	D/S: 463511 E / 6332462 N U/S: 463829 E / 6332456 N
	MUR-F2	Downstream of the Canterra Road crossing over the Muskeg River	*Test*	MUR-2/MUR-D-2	D/S: 466312 E / 6339503 N U/S: 466358 E / 6339770 N
Horse River	HOR-F1	Approximately 140 km upstream of the confluence with the Athabasca River	*Baseline*	HOR-1/HOR-E-1	D/S: 427575 E / 6246900 N U/S: 427480 E / 6246775 N
Dunkirk River	DUR-F1	Approximately 25 km upstream of the confluence with the MacKay River	*Baseline*	DUR-1/DUR-E-1	D/S: 395848 E / 6302497 N U/S: 395793 E / 6302640 N
Jackpine Creek	JAC-F1	At the confluence with Muskeg River	*Test*	JAC-1/JAC-D-1	D/S: 471790 E / 6346487 N U/S: 471857 E / 6346414 N
	JAC-F2	Upper portion of the creek	*Baseline*	JAC-2/JAC-D-2	D/S: 480025 E / 6325006 N U/S: 480015 E / 6324906 N
Tar River	TAR-F1	Approximately 100 m upstream of the confluence with the Athabasca River	*Test*	TAR-1/TAR-D-1	D/S: 458378 E / 6353579 N U/S: 458436 E / 6353420 N
Poplar Creek	POC-F1	Approximately 50 m upstream of the confluence with the Athabasca River	*Test*	POC-1/POC-D-1	D/S: 473038 E / 6308819 N U/S: 472962 E / 6308660 N
MacKay River	MAR-F1	Approximately 100 m upstream of the confluence with the Athabasca River	*Test*	MAR-1/MAR-E-1	D/S: 461537 E / 6336014 N U/S: 461125 E / 6336423 N
Beaver River	BER-F2	Upstream of the Petro-Canada Road crossing	*Baseline*	BER-2/BER-D-2	D/S: 465487 E / 6311289 N U/S: 472962 E / 6311134 N

Fish Sampling and Handling

Fish sampling was carried out from the downstream end of the benthic invertebrate communities sampling reach and moving upstream for a length equal to 40 times the average channel width (Peck *et al.* 2006). The measurement for the appropriate length of sampling reach was determined to be adequate to capture 95% of the expected fish species (Hughes *et al.* 2002).

All fish sampling was carried out by a two-person field crew using a Smith-Root 12B-POW battery-powered electrofishing unit or a Smith-Root 2.5 GPP portable boat electrofishing unit (for reaches BER-F2 and MUR-F2, where depths were greater than 1 m) and a standard dip net, dependent on the depth of the watercourse. The dip net was fitted with a fine mesh net (0.125 in) to ensure that fish of all sizes could be captured. Fish sampling was conducted from one wetted bank to the other within each reach within suitable fish habitat for all species present in the reach.

All captured fish were carefully identified to species, measured for total length (± 1.0 mm) and weight (± 0.01 g) using an Ohaus Scout Pro digital balance that was calibrated prior to each measurement. An external pathology examination was also performed. The fish were then revived in fresh water, with monitoring at regular intervals to ensure full recovery, and then released back into the watercourse near the original capture location.

Fish Habitat Assessments

Habitat assessments were completed at ten transects equally spaced within the length of reach sampled. Habitat assessment methods involved recording a range of variables relating to channel morphology, substrate, water quality, and stream cover similar to that outlined in RAMP (2009b) and Peck *et al.* (2006). The following information was collected at each transect:

- Habitat type (classifications in Table 6.2-2);
- Wetted width (m);
- Maximum depth (m);
- Velocity and depth (m/sec) (at 25%, 50%, and 75% of the wetted width);
- Overhead and instream cover (%) (classifications in Table 6.2-3);
- Substrate (dominant and subdominant particle size) (classifications in Table 6.2-4);
- Bank slope (°);
- Bank height (m); and
- Large and small woody debris (count of debris in length/size classes).

In situ water quality variables including temperature, dissolved oxygen, and conductivity and were measured using hand-held probes (temperature, conductivity, pH) and a LaMotte Winkler titration kit (dissolved oxygen) and collected at the upstream, middle, and downstream transects of each reach.

Table 6.2-2 Habitat type categories and codes for the fish assemblage monitoring pilot study (adapted from Peck *et al.* 2006).

Class (code)	Description
Plunge pool (PP)	Pool at base of plunging cascade or falls
Trench pool (PT)	Pool-like trench in the centre of the stream
Lateral Scour Pool (PL)	Pool scoured along a bank
Backwater Pool (PB)	Pool separated from main flow off the side of the channel (large enough to offer refuge to small fishes). Includes sloughs (backwater with vegetation), and alcoves (a deeper area off a wide and shallow main channel).
Impoundment Pool (PD)	Pool formed by impoundment above dam or constriction
Pool (P)	Pool (unspecified type)
Glide (GL)	Water moving slowly, with a smooth, unbroken surface. Low turbulence.
Riffle (RI)	Water moving, with small ripples, waves and eddies-waves not broken, surface tension not broken. Sound: babbling, gurgling
Rapid (RA)	Water movement rapid and turbulent, surface with intermittent white water with breaking waves. Sound: continuous rushing, but not as loud as cascade.
Cascade (CA)	Water movement rapid and very turbulent over steep channel bottom. Much of the water surface is broken in short, irregular plunges, mostly whitewater. Sound: roaring.
Falls (FA)	Free falling water over a vertical or near vertical drop into plunge, water turbulent and white over high falls. Sound: splash to roar.
Dry Channel (DR)	No water in the channel or flow is submerged under the substrate.

Table 6.2-3 Percent cover rating for instream and overhead cover at each transect for the fish assemblage monitoring pilot study (adapted from Peck *et al.* 2006).

Code	Percent Cover
0	absent, zero cover
1	sparse, <10%
2	moderate, 10-40%
3	heavy, 40-75%
4	very heavy, >75%

Table 6.2-4 Substrate size class codes for the fish assemblage monitoring pilot study (adapted from Peck *et al.* 2006).

Code	Description
RS	bedrock (smooth) - larger than a car
RR	bedrock (rough) - larger than a car
RC	asphalt/concrete
XB	large boulder (1000-4000mm) - metre stick to a car
SB	small boulder (250-1000mm) - basketball to a metre stick
CB	cobble (64-250mm) - tennis ball to basketball
GC	coarse gravel (16-64mm) - marble to tennis ball
GF	fine gravel (2-16mm) - ladybug to marble
SA	sand (0.06 to 2 mm) - gritty, up to ladybug size
FN	silt/clay/muck - not gritty
HP	hardpan - firm consolidated fine substrate
WD	wood - any size

6.2.3 Analytical Approach

Fish Assemblage Analyses

Three approaches were used to evaluate the fish assemblage monitoring data:

1. An assemblage tolerance index (ATI).
2. Ordinations of species presence and abundances.
3. Development of fish species metrics of ecological condition.
4. Index of Biotic Integrity.

Assemblage Tolerance Index (ATI) The Assemblage Tolerance Index was developed by Whittier *et al.* (2007a) for stream and river fish assemblages in western United States to quantify a species tolerance to an overall human disturbance gradient. In Whittier *et al.* (2007a), the human-disturbance gradient was the first principal component from a Principal Component Analysis (PCA) of three water chemistry, three site-scale physical habitat, and three watershed-scale measures of anthropogenic disturbance. The tolerance value for each species was based on its abundance-weighted average of the site disturbance scores at each site where it was collected. For species in the RAMP FSA not assessed by Whittier *et al.* (2007a), a number was assigned based on species similarity to those with calculated values.

Fish Assemblage Ordinations A non-metric multi-dimension scaling (MDS) ordination was conducted to calculate a similarity (or dissimilarity) measure for all pairs of reaches, based on species in common, and those found at one reach or the other (but not both). The plot shows the arrangement of reaches in multi-dimensional species space, such that reaches with similar assemblages are near each other with greater distance between reaches with more dissimilar assemblages. The greatest amount of information about assemblage patterns is usually found on the first one, two or three axes. Plots of reaches on those axes helps visualize the relationships among reaches, based on the species present.

Fish Assemblage Metrics A fish species characteristic matrix was completed for all species captured in the pilot study, which included characteristics such as habitat and temperature preferences, trophic guild, migratory patterns and tolerance values. Combinations of these characteristics define which species are used in each candidate metric for an index of biotic integrity. Over 200 candidate metrics have been proposed and evaluated in various US EPA EMAP assessments for fish assemblages in streams and rivers (Whittier *et al.* 2007b). Metrics applicable to a study depend on the species captured, the range of values for each metric, and the detection of differences between least and most disturbed reaches (i.e., *test* versus *baseline*). Not all 200 candidate metrics are applied to every fish assemblage study given some metrics are species and habitat-specific. For most species, characteristics were already developed for the USEPA western EMAP (Environmental Monitoring and Assessment Program) survey. Additional information was collected from Scott and Crossman (1973) for species not collected in the western EMAP survey.

There are three steps in determining the appropriate metrics for an Index of Biotic Integrity:

1. Remove all metrics for those species not captured in the pilot study.
2. Determine if there was sufficient range of values for each metric. Metrics will fail this test if the minimum value equals the 75^{Th} percentile value, the maximum value equals the 25^{th} percentile or, in the case of species richness metrics, the total range of values is less than two.
3. Determine if a metric can distinguish between least-disturbed and most-disturbed reaches, or between *test* and *baseline* reaches using a t-test and remove metrics with low "signal to noise" ratio in repeated sampling visits.

The remaining metrics are used to develop an index of biotic integrity for each reach to compare its tolerance to any disturbances.

Index of Biotic Integrity The behaviour of the metrics was evaluated, using principal component analysis, to determine whether metrics were positively or negatively associated with *test* and *baseline* reaches. The metrics were scored by scaling their values to range from 0 to 10 using their minimum and maximums values. The sum of the metric scores was scaled to a range of 0 to 100 to produce a "pseudo-Index of Biotic Integrity". An Index of Biotic Integrity was conducted as a demonstration of the process used by Whittier *et al.* (2007b) for EMAP assessments.

Water Quality

Water quality data collected in fall 2009 was analyzed to look for potential disturbance gradients across reaches and for differences between *baseline* and *test* reaches. A series of principal component analyses (PCAs) were conducted on nutrients, metals (log-transformed), and ions.

Benthic Invertebrate Communities

Benthic invertebrate community measurement endpoints were compared between reaches to determine if differences were observed between *test* and *baseline* reaches of similar habitat type. Measurement endpoints used for the Benthic Invertebrate Communities component: species richness, abundance, Simpson's Diversity, evenness, and %EPT were compared across reaches to assess whether a disturbance gradient could be established (i.e., lower values in measurement endpoints in *test* reaches compared to *baseline* reaches).

6.2.4 Pilot Study Results

Fish Assemblage Monitoring

Table 6.2-5 provides a summary of the length and width of a watercourse that was sampled at each reach. A total of 16 fish species were collected during the FAM pilot study. Fish species richness per reach ranged from three to nine and number of individuals captured ranged from seven to 84 (Table 6.2-6). An unidentified young-of-year sucker was collected at *test* reach MUR-F1 and was treated as a longnose sucker given this was the only sucker species captured at this reach (i.e., data were combined). Four unknown fish were collected at *test* reach STR-F1 and were removed from the dataset. A single fish was collected at *test* reach MUR-F2 and likely not representative of the fish assemblage at this reach given that electrofishing was not effective at water temperatures observed on the sampling day (2°C); therefore, this reach was removed from most fish assemblage analyses. Generally, more fish were captured at *baseline* reaches compared to *test* reaches but there was no pattern in species richness between *baseline* and *test* reaches.

To assess whether physical habitat with respect to stream size and order was predictive of the fish assemblage in a watercourse, stream width was compared to the number of fish captured, capture efficiency (catch per unit effort), and species richness, results across reaches (Figure 6.2-2). There was no strong relationship between species richness, number of fish captured or catch per unit effort (CPUE) and stream width for depositional or erosional habitats. With the exception of species richness in depositional habitat, all measurement endpoints decreased with increasing stream width, which is not expected (Figure 6.2-2). Sampling efficiency using backpack electrofishing in larger streams may have been a factor in these decreasing, although weak relationships.

Table 6.2-5 Size and length of fish assemblage monitoring reaches, fall 2009.

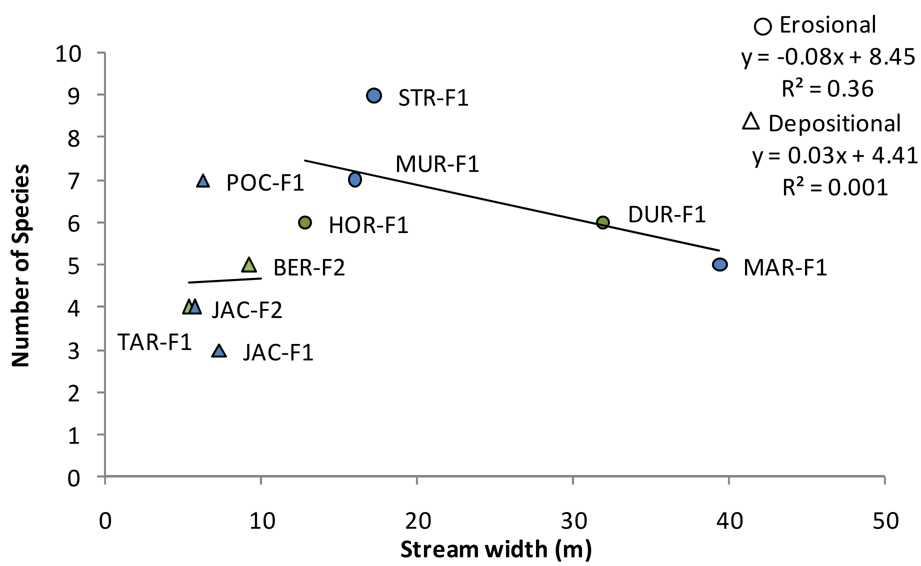
Watercourse	Reach	Habitat Type	Designation	Effort (sec)	Reach Length (m)	Average Wetted Width (m)
Beaver River	BER-F2	Depositional	*baseline*	1,534	315	9.2
Dunkirk River	DUR-F1	Erosional	*baseline*	1,492	250	31.9
Horse River	HOR-F1	Erosional	*baseline*	2,360	400	12.8
Jackpine Creek	JAC-F1	Depositional	*test*	2,221	298	7.3
Jackpine Creek	JAC-F2	Depositional	*baseline*	1,352	140	5.3
MacKay River	MAR-F1	Erosional	*test*	2,980	468	39.4
Muskeg River	MUR-F1	Erosional	*test*	2,051	400	16.0
Muskeg River	MUR-F2*	Depositional	*test*	870	468	10.0
Poplar Creek	POC-F1	Depositional	*test*	1,678	298	6.2
Steepbank River	STR-F1	Erosional	*test*	3,652	700	17.2
Tar River	TAR-F1	Depositional	*test*	1,552	200	5.7

* Sampling not completed due to poor weather conditions and water temperatures too low to effectively sample with electrofishing.

Table 6.2-6 Number of fish captured by species at FAM reaches, fall 2009.

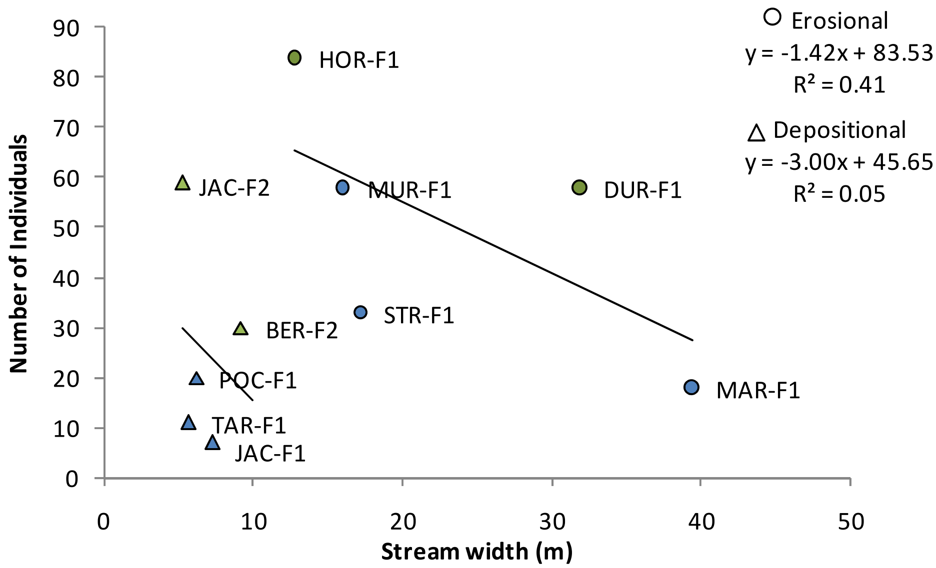
Species	Reach										
	BER-F2	DUR-F1	HOR-F1	JAC-F1	JAC-F2	MAR-F1	MUR-F1	MUR-F2	POC-F1	STR-F1	TAR-F1
Arctic grayling	-	-	-	-	-	-	-	1	-	-	-
brook stickleback	1	-	1	-	14	1	3	-	4	-	2
burbot	-	-	-	-	-	-	1	-	-	-	-
fathead minnow	2	-	-	-	-	-	-	-	-	-	-
lake chub	10	2	12	1	40	1	4	-	1	2	4
longnose dace	-	1	2	-	-	-	-	-	-	1	-
longnose sucker	-	11	1	2	-	-	5	-	-	2	-
northern redbelly dace	-	-	-	-	-	-	-	-	-	16	-
northern pike	-	-	-	-	-	1	-	-	1	-	1
pearl dace	-	22	-	-	3	-	-	-	-	2	-
slimy sculpin	-	20	47	-	-	-	43	-	-	2	-
spoonhead sculpin	-	-	-	-	-	9	1	-	-	-	-
spottail shiner	-	-	-	-	-	-	-	-	1	-	-
sucker sp.	-	-	-	-	-	-	1	-	-	-	-
trout-perch	2	2	21	-	-	6	-	-	5	1	-
unknown sp.	-	-	-	-	-	-	-	-	-	5	-
walleye	-	-	-	-	-	-	-	-	4	1	-
white sucker	15	-	-	4	2	-	-	-	4	1	4
Total Fish Captured	**30**	**58**	**84**	**7**	**59**	**18**	**58**	**1**	**20**	**33**	**11**
Total No. Species	**5**	**6**	**6**	**3**	**4**	**5**	**7**	**1**	**7**	**9**	**4**

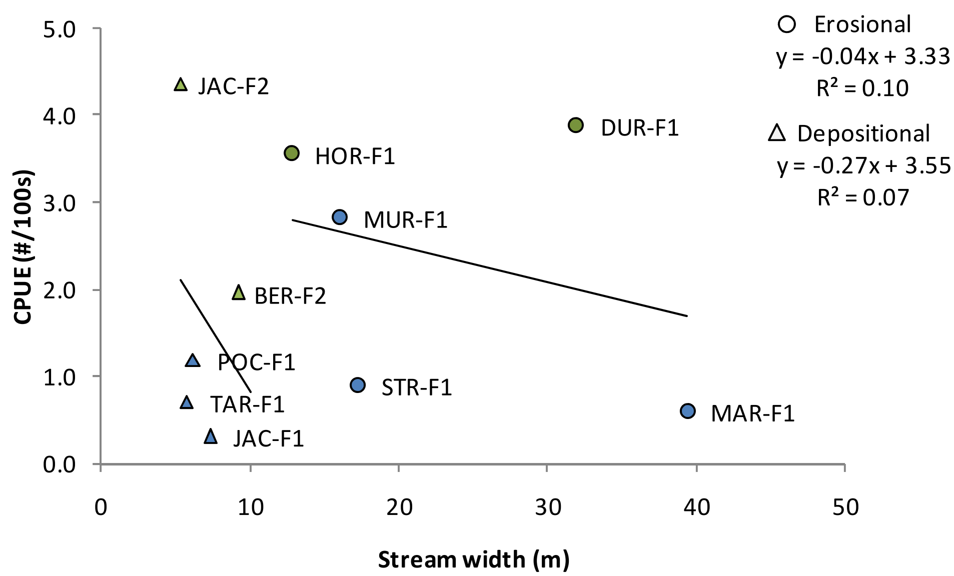
Figure 6.2-2 Stream width (m) versus species richness, number of fish captured, and CPUE at FAM reaches, fall 2009.



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Figure 6.2-2 (Cont'd.)

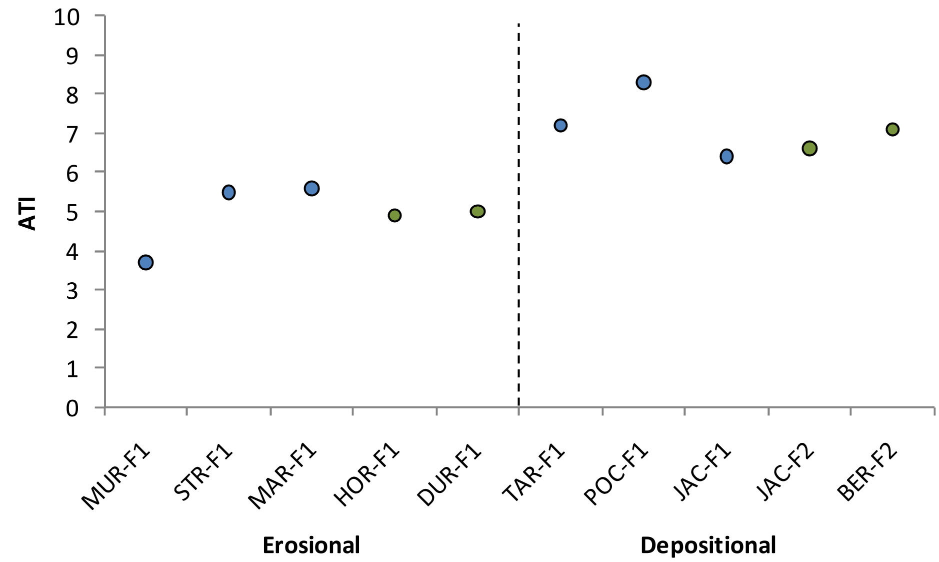




Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

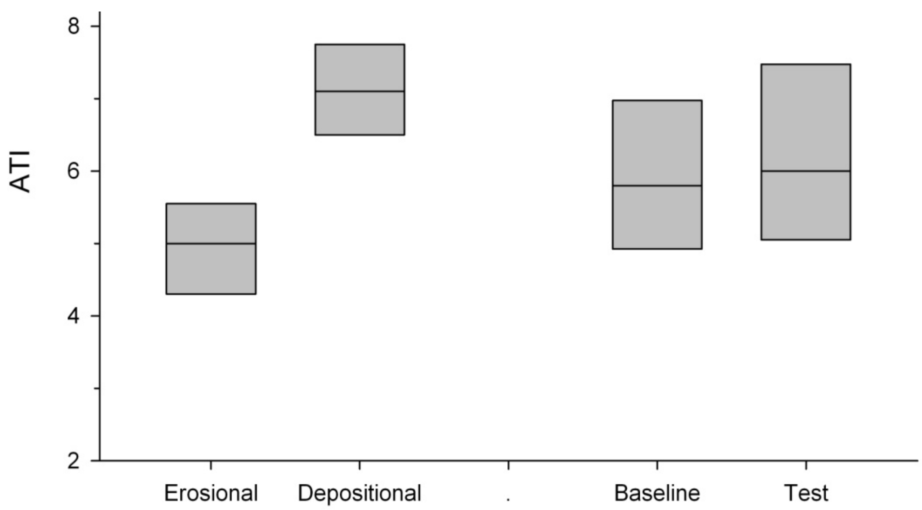
Assemblage Tolerance Index The ATI values for fish collected in the FAM pilot study ranged from 2.0 (sensitive or intolerant) to 9.4 (very tolerant) with a median of 6.8 (moderately-tolerant) (Figure 6.2-3). There were no differences in ATI values between *baseline* and *test* reaches of either habitat type but ATI values were significantly lower (less tolerant, p=0.002) for erosional reaches than for depositional reaches (Figure 6.2-4).

Figure 6.2-3 ATI values for each FAM reach by habitat type, fall 2009.



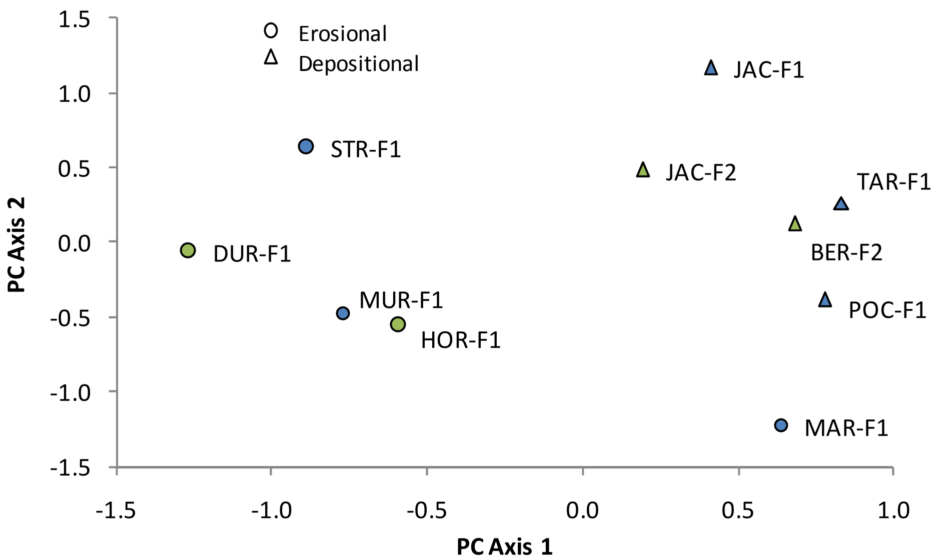
Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Figure 6.2-4 Mean ATI value for comparisons between reaches of erosional and depositional habitat and between *baseline* and *test* reaches.



Fish Assemblage Ordination The ordination analysis of species composition of FAM reaches indicated that reaches of similar size, stream order, and habitat type were similar (Figure 6.2-5). In both species abundance and species presence/absence, *baseline* reaches HOR-F1 and DUR-F1 were similar to *test* reaches MUR-F1 and STR-F1 (similar axis scores); *test* reaches TAR-F1 and POC-F1 were similar to *baseline* reach BER-F2 and the two reaches on Jackpine Creek (*test* reach JAC-F1 and *baseline* reach JAC-F2) were similar to each other in species composition. In addition, erosional and depositional reaches separated fairly well along axis one, with the exception of *test* reach MAR-F1, which was more similar to the depositional reaches, likely due to low capture numbers at this reach despite the large size of this watercourse.

Figure 6.2-5 Ordination of five fish assemblage metrics used in the Index of Biotic Integrity.



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Metrics for an Index of Biotic Integrity (IBI) 200 candidate metrics were initially evaluated for the FAM pilot study, proposed in various USEPA EMAP assessments for fish assemblages in streams and rivers (Whittier *et al.* 2007b). After removing metrics for those species not captured in the pilot study and assuming that all fish species captured are native to the region, 112 candidate fish assemblage metrics remained. The next step was to determine if there was sufficient range of values for each metric. Metrics will fail this test if the minimum value equals the 75Th percentile value, the maximum value equals the 25th percentile or, in the case of species richness metrics, the total range of values is less than two. Ideally the range of species richness values would be at least four, but this is not always attainable for an area such as the RAMP FSA which is generally species poor in comparison to areas in the United States where these surveys were developed. Twenty-seven candidate metrics failed the range test.

To be useful in a biological assessment, a metric needs to be able, at a minimum, to distinguish between least-disturbed and most-disturbed reaches, or between *baseline* and *test* reaches. A t-test was conducted on the remaining 85 candidate metrics and only six candidate metrics showed significant differences between *baseline* and *test* reaches. Within those six metrics were two pairs of metrics that were based on the same species characteristic, with high correlation in one of these pairs, leaving five (non-redundant) metrics: long-lived species, % long-lived species, number of individuals collected, % individuals as non-tolerant water column feeders, and piscivorous species. The number of individuals collected is usually a very noisy metric, with low “signal to noise” ratio in repeated sampling visits, and not a useful metric to use in an IBI.

Table 6.2-7 Fish species characteristics used to developed the pseudo-Index of Biotic Integrity.

Species	Habitat[1]	Lotic[2]	Migratory Habit[3]	Temperature Preference	Trophic Level[4]	Reproductive Guild[5]	Long-Lived[6]	Tolerance Value[7]
longnose sucker	B	X	P	Cold	I	A12	X	4.6
white sucker	B	X	P	Cool	O	A12	X	7.6
slimy sculpin	BH	R		Cold	I	B		3.0*
spoonhead sculpin	BH	X		Cold	I	B		3.0*
fathead minnow	WC			Warm	O	B		8.3
lake chub	WC			Cool	I	A12		5.5
longnose dace	BH	R		Cool	I	A12		6.2
northern redbelly dace	B			Cool	O	A15		7.0*
pearl dace	WC			Cool	O	A12		6.7
spottail shiner	WC	L		Cool	O	A12		7.7
northern pike	WCH			Cool	P.	A15	X	7.8
burbot	BH	X	P	Cold	IP	A13	X	2.0*
brook stickleback	WCH			Cool	I	B24		9.4
walleye	WC	L		Cool	P	A12	X	8.7
trout-perch	BH	X		Cool	I	A13		8.4
Arctic grayling	WCH	R	P	Cold	I	A12	X	2.0

1 Habitat: B=benthic, WC=water column, H=hider, WCH=water column and hider

2 Lotic X=prefers flowing water, L=prefers large rivers, R=rheophilic (adapted to fast water)

3 Migratory Habit: P=potamodromous (migrates to/from large rivers)

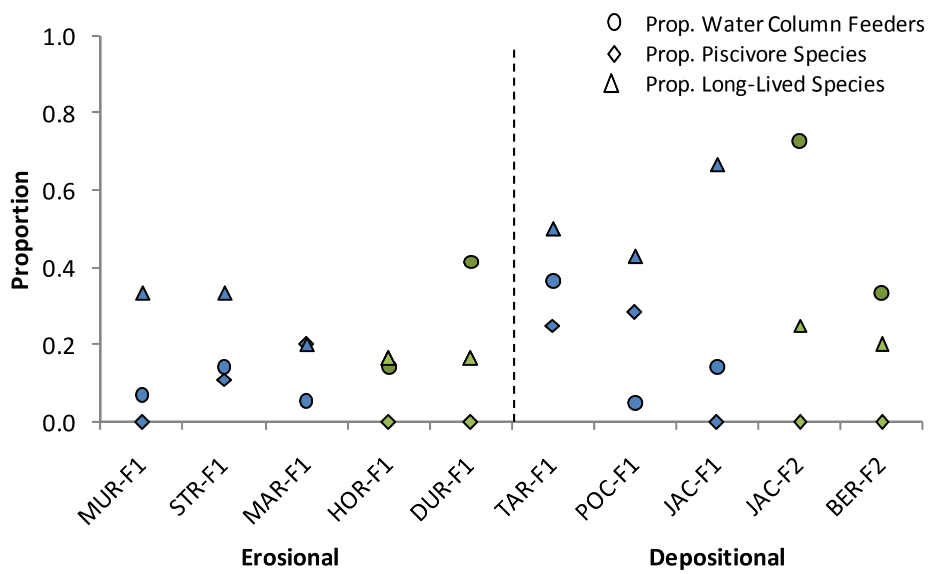
4 Trophic Level: I=Invertivore, O=Omnivore, P=Piscivore, IP=Invertivore/Piscivore

5 Reproductive guild (Simon 1999): A12=lithopelagophilic, A13=lithophilic, A15=phyotphilic, B=nest-guarder

6 Long-lived: age > 8 years

7 Tolerance value: tolerance to general human disturbance, relative to a range of 0 (very sensitive) to 10 (very tolerant); (most values from Whittier *et al.* 2007a); * judgment-based scores from values for similar species

Figure 6.2-6 Proportion of sensitive water column feeders, piscivore species, and long-lived species captured at FAM reaches, fall 2009.



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

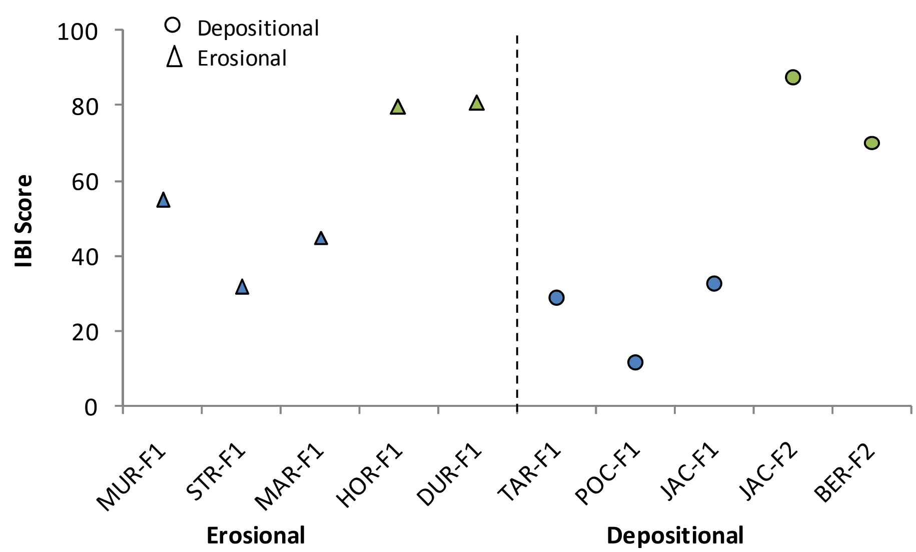
Index of Biotic Integrity The limited set of metrics, the small number of reaches, and the absence of a disturbance gradient based on data from supporting components results in limited data to be able to calculate an index of biotic integrity. Therefore, a pseudo-Index of Biotic Integrity was conducted as a demonstration of the process used by Whittier *et al.* (2007b) for EMAP assessments and how it can be applied to fish assemblage data collected for the RAMP FSA. The behaviour of the five metrics was evaluated, using principal component analysis, to determine whether metrics were positively or negatively associated with *test* and *baseline* reaches. The number of individuals collected and the percent of non-tolerant water column feeders were higher at *baseline* reaches versus *test* reaches (Figure 6.2-6). In contrast, the two long-lived species metrics and the piscivore species metric were lower at *baseline* reaches compared to *test* reaches, which is not what ecological theory would predict (Karr 1981, Karr *et al.* 1986). The metrics were scored by scaling their values to range from 0 to 10 using their minimum and maximums values. The sum of the metric scores was scaled to a range of 0 to 100 to produce a pseudo-Index of Biotic Integrity (Table 6.2-8, Figure 6.2-7). While the pseudo-IBI showed a strong relationship between *test* and *baseline* reaches (i.e., higher IBI scores are *baseline* reaches), there are many caveats related to the data and to the index development to consider this as anything other than a demonstration of the process of developing this type of index.

Table 6.2-8 Fish collection data and assemblage indexes.

Reach	Watercourse	Assemblage Tolerance Index	Pseudo-Index of Biotic Integrity
BER-F2	Beaver River	7.1	70.0
DUR-F2	Dunkirk River	5.0	80.7
HOR-F1	Horse River	4.9	79.5
JAC-F1	Jackpine Creek	6.4	32.8
JAC-F2	Jackpine Creek	6.6	87.5
MAR-F1	MacKay River	5.6	44.9
MUR-F1	Muskeg River	3.7	55.0
MUR-F2	Muskeg River	-	-
POC-F1	Poplar Creek	8.3	11.7
STR-F1	Steepbank River	5.5	31.7
TAR-F1	Tar River	7.2	28.7

Note: The assemblage tolerance index (Whittier *et al.* 2007a) scores are relative to a range of 0 to10; high scores indicate assemblages dominated by fish tolerant of human disturbance. There are too few reaches to adequately assess metric and index behaviour. The pseudo-IBI was based on 5 fish assemblage metrics that distinguished between *baseline* and *test* reaches. ATI and pseudo-IBI scores were not calculated for MUR-F2 due to low catch (1 individual).

Figure 6.2-7 IBI scores for FAM reaches, fall 2009.



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Water Quality

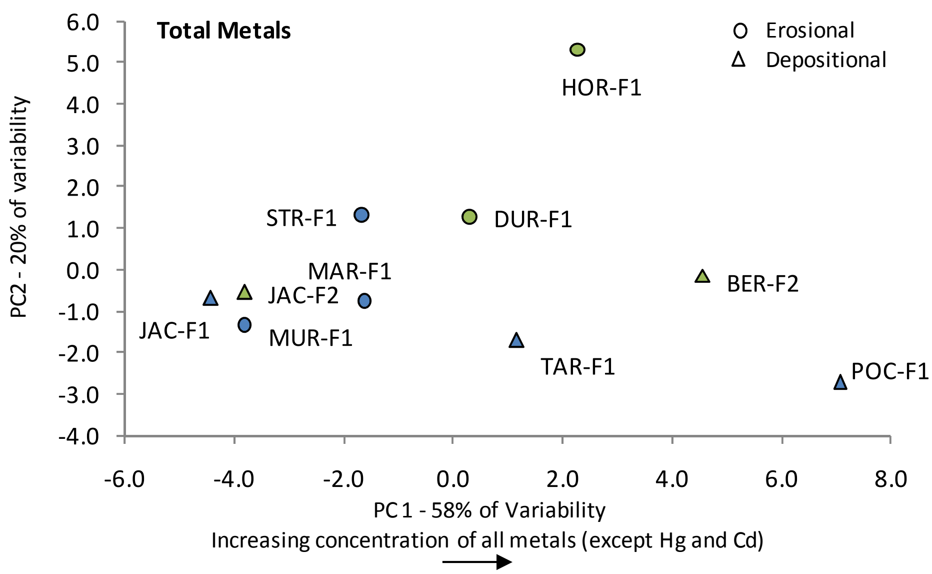
Metals A PCA was conducted on all metals available in the water quality dataset. The first principal component (PC1) accounted for 58% of the variability in the data and was associated with a general increase in concentrations for all metals, with the exception of total mercury and total cadmium, which were not correlated with PC1 (Figure 6.2-8). The second principal component (PC2) accounted for 20% of variability in the data. PC2 was positively correlated with several metals and positively and strongly with beryllium, cadmium, mercury, and zinc and negatively and strongly correlated with barium, lead, strontium, thallium, and uranium. Total metals were not associated with a disturbance gradient between *baseline* and *test* reaches.

Nutrients A PCA was conducted on total nitrogen, total phosphorus, and ammonia (Figure 6.2-8). PC1 accounted for 59% of the variability in the data and was associated with increasing concentrations of nutrients. PC2, accounting for 23% of the variability, was positively associated with concentrations of ammonia. *Baseline* reaches such as HOR-F1 and DUR-F1 had higher concentrations of nutrients compared to some of the *test* reaches (i.e., POC-F1 and TAR-F1).

Ions A PCA was conducted on 13 water quality measurement endpoints generally associated with ionic strength. PC1 accounted for 60% of the variability in the data, and was positively associated with all measurement endpoints, with the exception of those related to natural organics (i.e., DOC and color), which were negatively associated with PC1 and positively associated with PC2 (Figure 6.2-8). The *baseline* reach HOR-F1 had distinctly low ionic strength and high organics. There was no association between ionic strength and reach designation (i.e., *baseline* versus *test*).

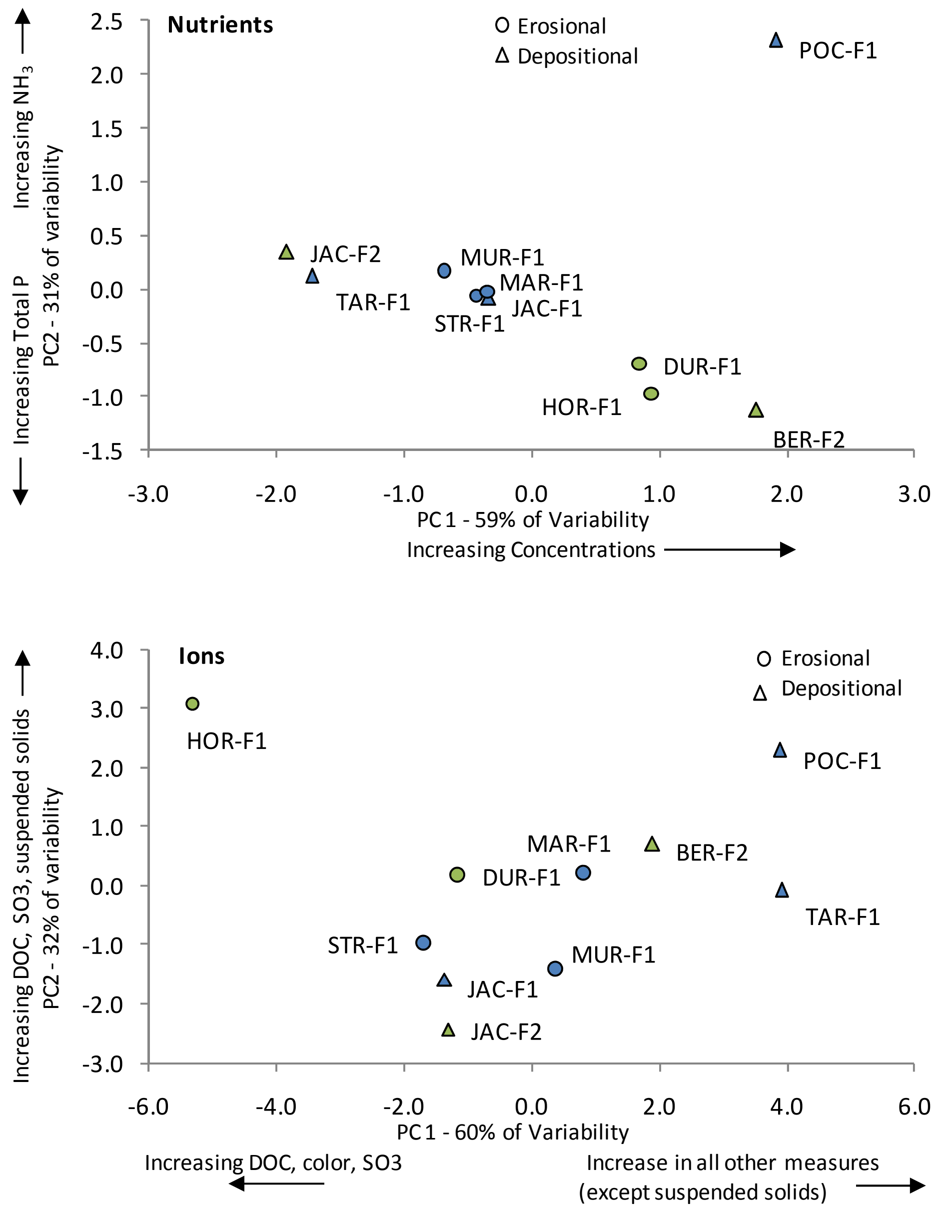
General Organics A PCA was conducted on three general organics: naphthenic acids, total phenol, and recoverable hydrocarbons. Concentrations of the organics were similar across reaches (Figure 6.2-9). The *baseline* reach HOR-F1 had the highest concentrations for both measures, while *test* reaches TAR-F1 and STR-F1 had relatively low values for both.

Figure 6.2-8 PCA scores for total metals, nutrients, ions and organic in water sampled at FAM reaches, fall 2009.



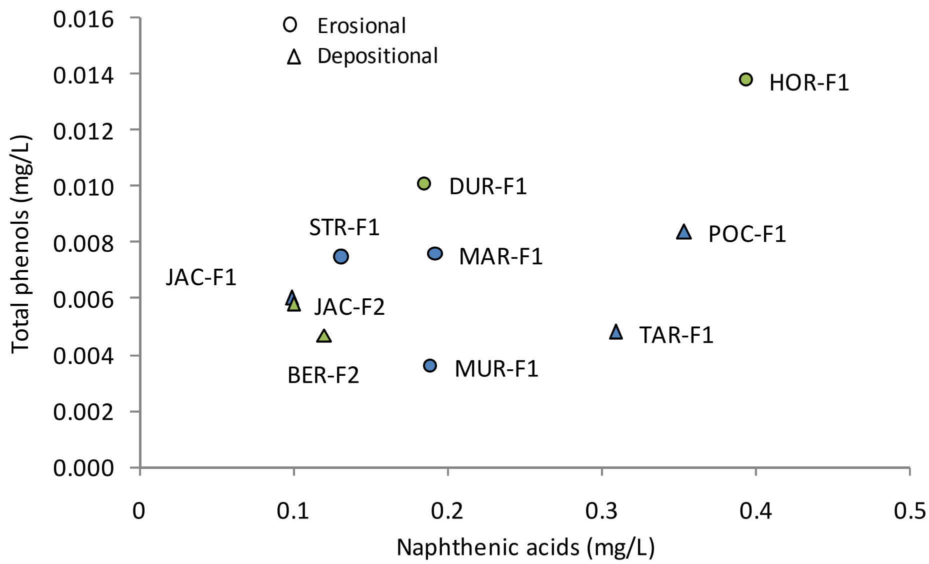
Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Figure 6.2-8 (Cont'd.)



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Figure 6.2-9 Total phenols versus naphthenic acids in *test* and *baseline* reaches sampled in the FAM pilot study, fall 2009.



Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Benthic Invertebrate Communities

Benthic invertebrate community measurement endpoints were compared between reaches to determine if differences were observed between *test* and *baseline* reaches of similar habitat type. For all measurement endpoints, with the exception of %EPT (i.e., sensitive taxa) in erosional reaches, there were no negative changes in *test* reaches compared to *baseline* reaches. In general, the habitat type appeared to have a greater influence on these assemblages than did potential disturbance (Figure 6.2-10).

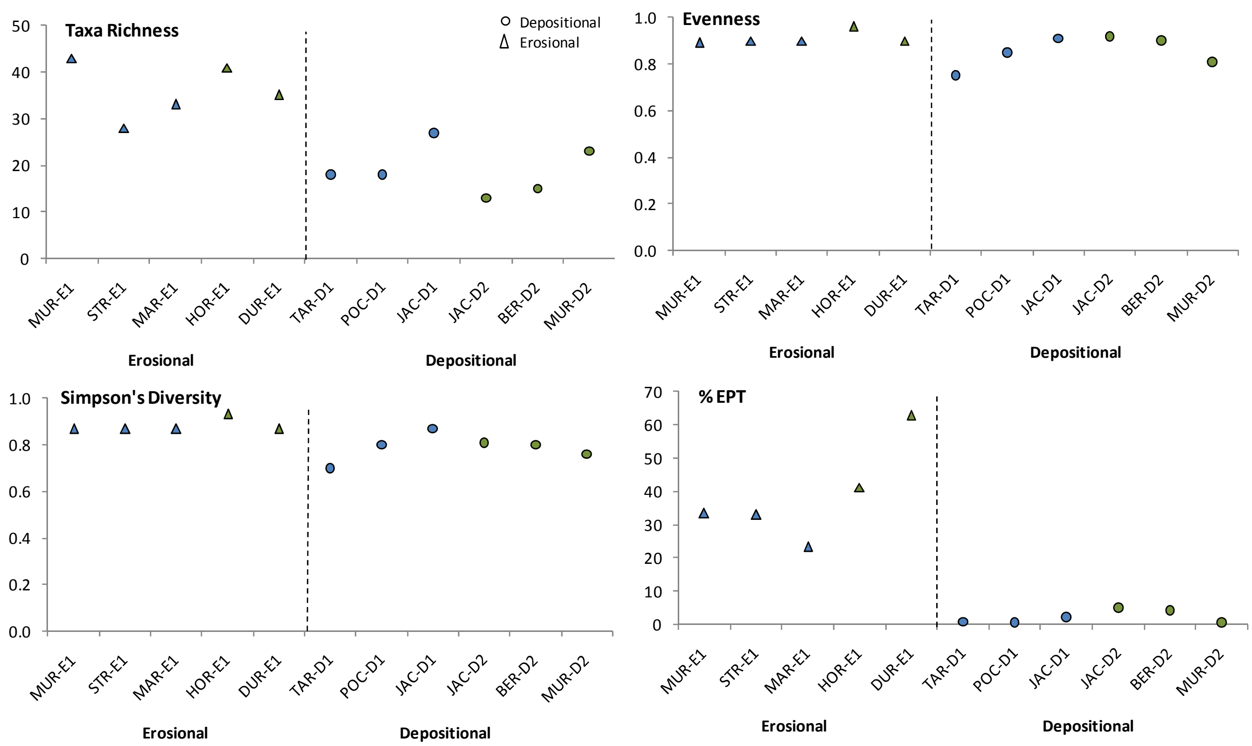
Based on water quality and benthic invertebrate community measurement endpoints, a disturbance gradient across reaches or between *test* and *baseline* reaches was not exhibited.

6.2.5 Discussion and Recommendations

The results from the Fish Assemblage Monitoring pilot study indicated that just characterizing *baseline* reach assemblages is not sufficient for developing and evaluating metrics and indexes of ecological condition. This type of assessment usually requires characterization of a set of highly disturbed reaches, or along a disturbance gradient, which provides a range in disturbance to allow adequate characterization of fish assemblage changes that occur with increasing disturbance. The determination of highly disturbed conditions (as with *baseline* condition) needs to be based on physical and chemical measures of disturbance (Whittier *et al.* 2007c). That signal was not found in the data from the pilot study. This may be the result of not sampling any highly disturbed reaches or from a lack of any substantial stream disturbance in watercourses currently monitored by RAMP.

To ascertain a disturbance gradient, sampling several clearly disturbed stream reaches lying within focal project leases or within streams reaches that have been rerouted or channelized around focal projects is recommended.

Figure 6.2-10 Measurement endpoints for benthic invertebrate communities at FAM reaches, fall 2009.



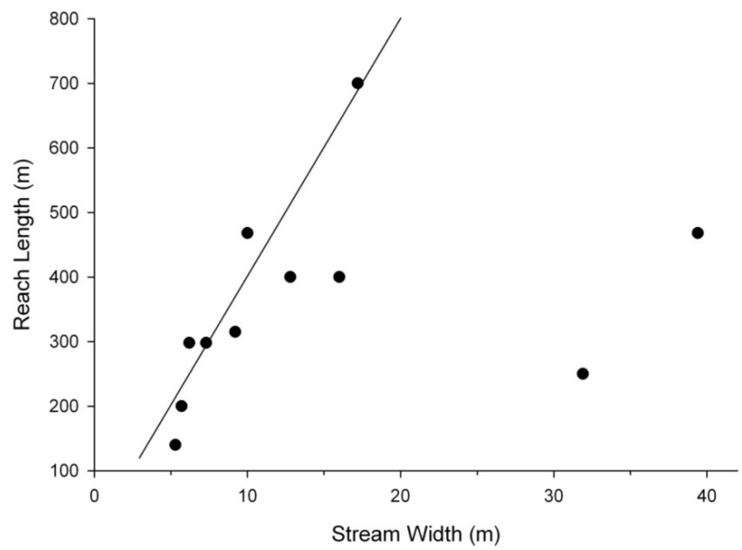
Note: Blue refers to *test* reaches and green refers to *baseline* reaches.

Considerations for future fish assemblage monitoring include the following:

1. The number of individuals collected in the pilot study was generally too low to provide confidence that the relative abundance of fish species adequately represent the assemblage structure. Ideally, the number of individuals in a sample should approximate 30 times the expected number of species to reduce the effect of rare species on IBI and metric scores (Hughes and Peck 2008, Kanno *et al.* 2009, Dubling *et al.* 2004).

2. Assuming that the 12 common stream species captured, with the exception of northern pike, burbot, walleye, and Arctic grayling, are expected at a reach, a sufficient stream sample should contain 360 individuals under this guideline and a sufficient river sample should contain 480 individuals. In some cases, the electrofishing sample reach should have been longer with the expected length to be along the line in Figure 6.2-11. If the recommend sampling reach for wadeable streams of 40 times the wetted width, with a minimum of 150 m (Peck *et al.* 2006) does not yield the expected number of individuals, the distance should be increased or the electrofishing intensity at the reach should be increased.

Figure 6.2-11 Expected length[1] of sampling reach for a measured stream width to obtain adequate fish counts and species richness for fish assemblage monitoring, based on the pilot study reach sizes.



[1] Solid line indicates the reach length for a measured stream width.

3. Reaches greater than 10 m wide are difficult to adequately sample with a single two-person backpack electrofishing crew. It seems clear that the two reaches >30 m wide were under sampled because the expected pattern is increased species richness with increased stream width, all else being equal (Fausch *et al.* 1984). For reaches exceeding a width of 10 m, a bank or towed electrofisher is recommended. For those >30 m wide, a boat/raft electrofisher is recommended. Both gears produce a much larger electrical field than a backpack electrofisher and reduce the number of fish that evade capture. Because boat/raft electrofishing is most effective near shore and the entire channel width is not fished, the distance fished may need to be increased to 100 times the wetted width to ensure a sufficient catch of individuals (Flotemersch *et al.* in press, Hughes *et al.* 2002, Hughes and Herlihy 2007). Although effective sampling at each reach needs to be taken into account, the reach-scale design should be developed so that each reach can be completed in a single day because it is more valuable for monitoring to collect information from two reaches than from one reach over two days.

4. Eleven reaches are too few to rigorously develop and evaluate biological assemblage metrics and indexes, especially with low catch rates at these reaches. The number of reaches and years of sampling needed to detect change over time and between reaches (e.g., *baseline* versus *test*) is dependent on the power with which one wants to detect change and on the size of the reach-scale, year, and interaction components of variance (Larsen *et al.* 2004).

Based on assessments of variability in biological data from various EMAP surveys, the following recommendations are provided:

1. For both fish and benthic invertebrate communities, the differences between depositional and erosional reaches overwhelmed any signal of disturbance in reaches. Future biological assessments may need to stratify sampling and data evaluation by habitat type, or at least account for these differences, post-sampling.

2. A minimum of 30 *baseline* reaches for each habitat type (i.e., erosional and depositional habitats) should be sampled for comparisons with *test* reaches of each habitat type. For example, Smith and Jones (2005) estimated that 15-119 randomly selected reaches stratified by stream order were necessary to detect 80-100% of the estimated number of fish species in streams draining to the Laurentian Great Lakes.

3. A rotating panel design (Urquhart and Kincaid 1999, Dobbie *et al.* 2008) can provide very good estimates of the components of sampling variability (e.g., error estimates for the sample and year-to-year variability) which can inform power analyses of the number of reaches needed to detect various levels of change and differences between a *test* reach and *baseline* reaches). The rotating panel design of *baseline* reaches could be spread over four or five years, to reduce annual costs. A sampling design of twelve reaches (with a few within-year repeat samples) in each of five years would be sufficient to develop a good regional *baseline* data set with which to develop biological metrics and indexes, for the two habitat types.

4. Continued sampling of a subset of *baseline* reaches over time would be important for detecting and accounting for possible long-term trends in regional *baseline* conditions. A survey statistician could assist in developing an appropriate monitoring design.

5. Although the metric screening process of Whittier *et al.* (2007b) was applied for this pilot study, recent (unpublished) research on developing multi-metric analyses has shown that redundant metrics are still useful as long as they are responsive to an anthropogenic disturbance gradient. The goal, however, is to have at least ten to twelve metrics to increase precision, which can be developed with more robust and longer datasets.

An alternative (or concurrent) approach to developing biological indexes of stream condition would be to use ideas from Karr (1981) and Karr *et al.* (1986) of characterizing assemblage metrics at a large number of least-disturbed reaches and developing ecologically-based models of how those metrics would change due to stresses related to oil sands development, if few disturbance controls were in place, although, as previously noted, with the current limited data, at least two metrics showed the opposite response to disturbance than expected. The conceptual models developed for the mid-western USA agricultural plains in Karr (1981) and Karr *et al.* (1986) may not apply to watercourses in the RAMP FSA.

An evaluation of the potential toxicity effects of PAHs was not conducted, however, concentrations of PAHs in *baseline* and *test* reaches relative to their toxicity criteria, suggest a need to evaluate the possibility that these chemicals, whether distributed via the atmosphere or historically, may be having long term effects. Those effects may have already occurred at hormonal, cellular, tissue, organ, organism, population, assemblage, or community levels throughout the region and creating a background condition against which we cannot detect more subtle changes. Thus, it may be useful to also survey fish assemblages in nearby watersheds that are outside the oil sands region, to more firmly establish the context for data from the RAMP FSA.

Little is known about boreal forest stream health, how assemblages actually respond to disturbance, and the range of natural variability in biological assemblages, which renders results for studies in the RAMP FSA difficult to interpret. One objective of the Fish Assemblage Monitoring study, if it continues in RAMP, should be to design and implement a monitoring program to address these gaps in literature on this topic. Defining ranges of natural variability will be essential to assuring effective monitoring, with defensible results. In addition to being a direct benefit to the objectives established by RAMP (RAMP 2009b), this knowledge will also advance scientific understanding of boreal forest streams and rivers in Canada, particularly in northern Alberta.

7.0 REGIONAL SYNTHESIS

This part of the RAMP 2009 Technical Report presents regional assessments of the status of aquatic environmental resources considered by RAMP and the possible influence of focal projects plus other oil sands developments on those resources at the regional level. This regional assessment consists of two parts for the Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality, and Fish Population components:

- An assessment for the Athabasca River, representing the ultimate receiving environment for potential aquatic effects of focal projects and other oil sands developments in the Athabasca oil sands region; and
- A regional assessment for the rest of the RAMP FSA, represented by the watersheds and lakes considered in Section 5.

This section concludes with a presentation of the 2009 results for the Acid-Sensitive Lakes component which by its design is regional in scope.

7.1 CLIMATE AND HYDROLOGY

7.1.1 Summary of Hydrologic Conditions in the Athabasca River

The estimated effects of focal projects plus other oil sands development in the RAMP FSA on hydrologic conditions of the Athabasca River for 2009 are summarized in Table 7.1-1. Mean open-water season discharge, mean winter discharge, annual maximum daily discharge, and open-water season minimum daily discharge are all calculated to be lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph; values of these measurement endpoints are less than what they would have been in the absence of focal projects plus other oil sand development activities. The percent change varies with the specific measurement endpoint being considered. The impact on low flows is greater in percentage terms than on high flows, because the withdrawals from the Athabasca River are proportionately larger during low-flow than during high-flow periods. The estimated changes in hydrologic measurement endpoints for the Athabasca River for 2009 are assessed as **Negligible-Low**.

Table 7.1-1 Summary of hydrologic conditions of the Athabasca River in 2009 with respect to oil sands developments.

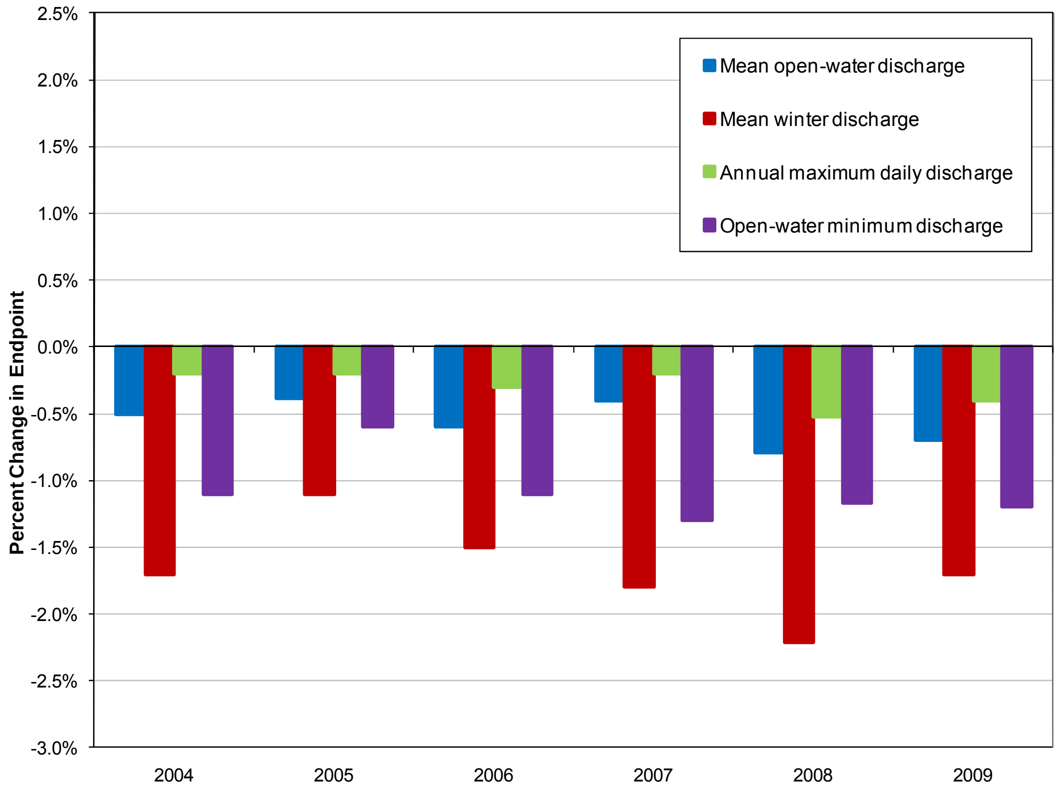
Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from Observed *Test* Hydrograph (m^3/s)	Relative Change	Assessment
Mean open-water (1 May to 31 October) season discharge	745	740	-0.7%	Negligible-Low
Mean winter (1 November to 31 March) discharge	213	209	-1.7%	Negligible-Low
Annual maximum daily discharge	1,773	1,766	-0.4%	Negligible-Low
Open-water season minimum daily discharge	281	278	-1.2%	Negligible-Low

Note: Measurement endpoints are calculated from estimated *baseline* and observed *test* hydrographs at Station S24, Athabasca River below Eymundson Creek

Note: Focal projects plus other oil sands development that were active as of 2009 are included in this analysis.

Trends in the values of these measurement endpoints are provided in Figure 7.1-1. All differences in the values of all hydrologic measurement endpoints between observed *test* hydrographs and estimated *baseline* hydrographs for the Athabasca River from 2004 to 2009 have been assessed as **Negligible-Low**.

Figure 7.1-1 Changes in values of hydrologic measurement endpoints in Athabasca River as a result of focal projects plus other oil sands developments.



Note: Measurement endpoints are calculated from estimated *baseline* and observed *test* hydrographs at Station S24, Athabasca River below Eymundson Creek.

7.1.2 Regional Assessment of Hydrologic Conditions at the RAMP FSA Level

The assessed change in each watershed in 2009 for each hydrologic measurement endpoint is summarized in Table 7.1-2. Most of the hydrological assessments are assessed as **Negligible-Low** with the exception of the Muskeg River, Tar River, Poplar Creek, Mills Creek and Fort Creek watersheds in which calculated hydrologic changes range from **Negligible-Low** to **High**, depending on the measurement endpoint. The focal projects and other oil sands development activities influencing these assessments, in order of decreasing importance, are:

- water withdrawals, releases, and diversions;
- closed-circuited land area creating a loss of flow to natural watercourses that would have otherwise occurred; and

- land area that is not closed-circuited creating increased flows to natural watercourses that would have otherwise not occurred.

Table 7.1-2 Summary of 2009 hydrologic assessment for RAMP FSA watersheds.

Watershed	Hydrologic Measurement Endpoint			
	Mean Open-Water Season Discharge	Mean Winter Discharge	Annual Maximum Daily Discharge	Minimum Open-Water Season Discharge
Athabasca River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Muskeg River	Negligible-Low	High (+)	Moderate (-)	High (+)
Steepbank River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Tar River	High (-)	*not measured*	High (-)	Moderate (-)
MacKay River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Calumet River	Negligible-Low	*not measured*	*not measured*	*not measured*
Ells River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Firebag River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Christina River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Hangingstone River	Negligible-Low	*not measured*	Negligible-Low	Negligible-Low
Poplar Creek	High (+)	*not measured*	Negligible-Low	Negligible-Low
Mills Creek	High (-)	High (-)	High (-)	High (-)
Fort Creek	Moderate (+)	*not measured*	Moderate (+)	Moderate (+)

Assessments based on comparisons of calculated incremental change in hydrologic measurement endpoints with criteria used in Section 5.0: Negligible-Low: ± 5%; Moderate: ±15%; High: > ± 15%.

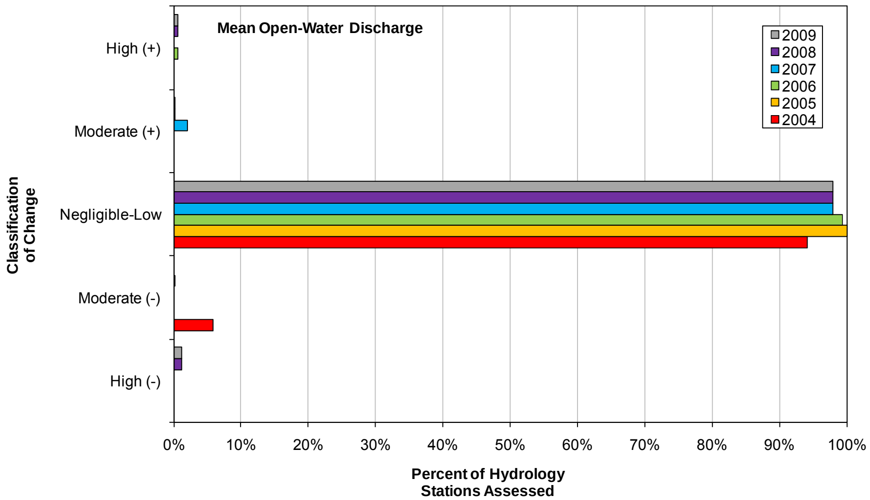
"not measured" means hydrologic information was not obtained for times of year for which the measurement endpoint is applicable.

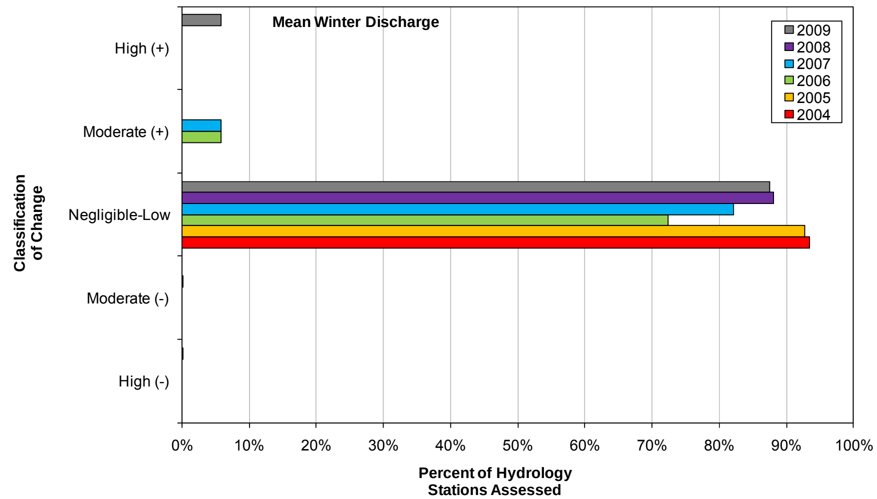
Direction indicators (+ or -) indicate a calculated increase or decrease in discharge in observed *test* conditions as compared to estimated discharge in estimated *baseline* conditions. Direction indicators are shown only for differences of 5% or greater (i.e., Moderate or High).

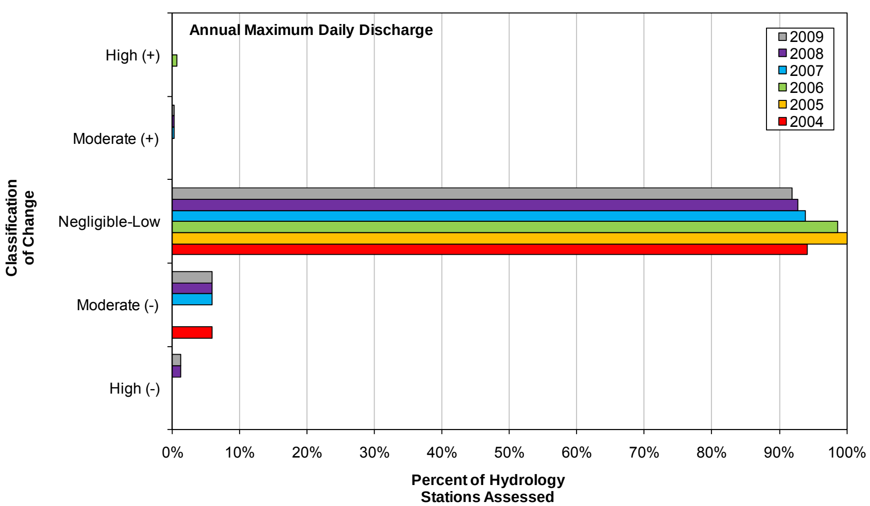
The hydrologic changes from focal projects plus all other oil sands developments in the RAMP FSA are estimated to be only marginally greater than the hydrologic changes from only focal projects.

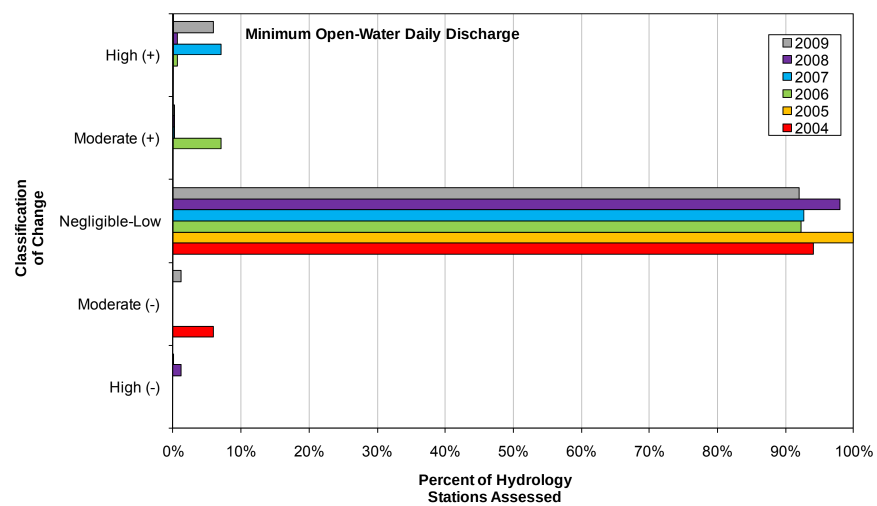
The average estimated percent change from 2004 to 2009 in each of the four measurement endpoints are presented in Figure 7.1-2, which shows the percentage of stations assessed each year falling under each classification. In all cases, most of the assessed stations in the RAMP FSA have exhibited **Negligible-Low** hydrologic changes.

Figure 7.1-2 Change in hydrologic measurement endpoints among hydrology stations monitored by RAMP, 2004 to 2009.









7.2 WATER QUALITY

This section examines concentrations of various water quality measurement endpoints at a regional scale. For all measurement endpoints examined below (with the exception of naphthenic acids, for which only one year of data with low detection limits exist), water quality data are presented by group (cluster, see Section 3.2.7.2 and Table 3.2-6), by year (i.e., all historical *baseline* data versus 2009 data), and by station designation (*baseline* versus *test*) for 2009. The regional analysis includes a subset of key measurement endpoints presented in Section 5 and other measurement endpoints with concentrations that frequently exceeded water quality guidelines in 2009.

7.2.1 Water Quality Variables Associated with Oil Sands Development

7.2.1.1 Naphthenic Acids

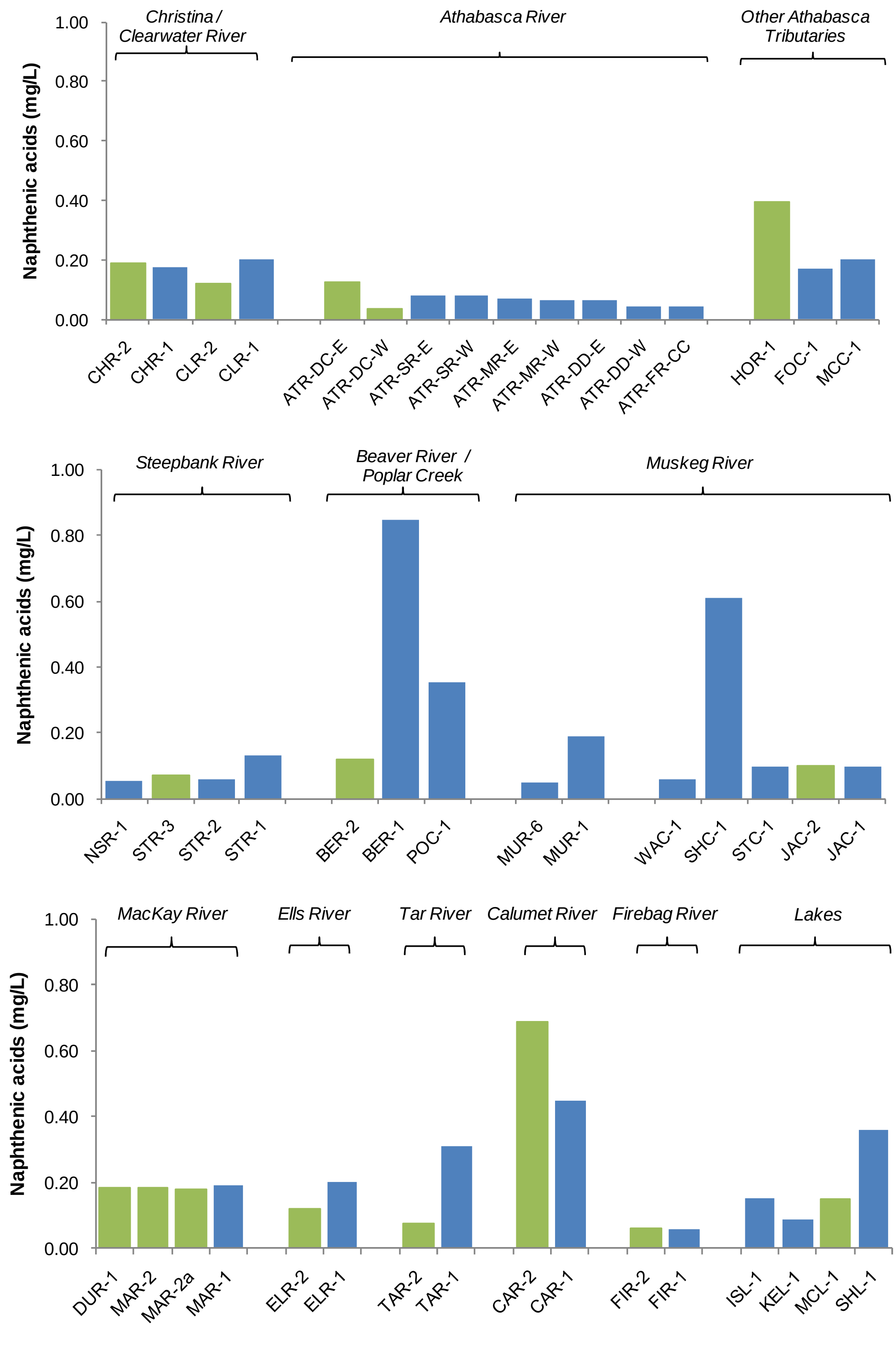
Naphthenic acids are natural constituents of petroleum hydrocarbons, including the bitumen found in the Athabasca oil sands region (Scott *et al.* 2005). Naphthenic acids are released during processing of bitumen, and may occur at high concentrations in oil sands process tailing waters. Naphthenic acids are a key measurement endpoint for the RAMP Water Quality component because they are specific indicators of bitumen-related hydrocarbons.

From 1997 to 2008, naphthenic acids were measured with a method detection limit of 1 mg/L. Following investigation of alternative analytical methods for screening-level measurement of naphthenic acids in 2008, Alberta Research Council (ARC) was contracted to undertake analysis of naphthenic acids using a higher-resolution method, which enabled analytical detection limits as low as 0.02 mg/L for fall 2009 water quality samples. Recent studies of naphthenic acids in ambient waters of the Athabasca oil sands region had demonstrated that background concentrations of naphthenic acids may be as high as 0.4 mg/L; the lower detection limit was expected to allow quantification of naphthenic acids concentrations in the various waterbodies of the RAMP FSA, and allow screening of concentrations relative to these *baseline* concentrations.

Concentrations of naphthenic acids in waters collected by RAMP in fall 2009 are provided in Figure 7.2-1. Concentrations at all stations were below the previous analytical detection limit of 1 mg/L, ranging from 0.035 (*baseline* station ATR-DC-W) to 0.848 mg/L (*test* station BER-1).

In the Athabasca River mainstem, concentrations were highest (0.127 mg/L) along the east bank at *baseline* station ATR-DC-E and lowest along the west bank at this same station (*baseline* station ATR-DC-W: 0.035 mg/L). Water quality typically is different between the east and west banks of the Athabasca River at *baseline* station ATR-DC due to the influence of flow from the Clearwater River along the eastern side of the river (see Section 5.1). The higher concentration along the east bank at *baseline* station ATR-DC may be related to influence from the lower Clearwater River at *test* station CLR-1 which had a concentration of naphthenic acids in fall 2009 of 0.205 mg/L (Figure 7.2-1). Water from the Horse River (*baseline* station HOR-1), which joins the Athabasca River at Fort McMurray on its east bank, had a concentration of naphthenic acids in fall 2009 of 0.393 mg/L which was higher than Athabasca River mainstem stations (Figure 7.2-1). Concentrations were similar along east and west banks at all other stations downstream in the Athabasca River mainstem, and steadily decreased moving downstream (Figure 7.2-1).

Figure 7.2-1 Concentration of naphthenic acids in waters of the RAMP FSA, fall 2009.



Note: Blue refers to *test* stations and green refers to *baseline* stations.

Concentrations of naphthenic acids were higher in waters of all tributaries of the Athabasca River than in the Athabasca River mainstem including (from upstream to downstream) the Horse River (*baseline* station HOR-1), Steepbank River (*test* station STR-1), McLean Creek (*test* station MCC-1), Poplar Creek (*test* station POC-1), Beaver River (*test* station BER-1), Muskeg River (*test* station MUR-1), Mackay River (*test* station MAR-1), Ells River (*test* station ELR-1), Tar River (*test* station TAR-1), Calumet River (*test* station CAR-1), Fort Creek (*test* station FOC-1) and Firebag River (*test* station FIR-1) (Figure 7.2-1). The highest concentrations were measured at the mouth of the Beaver River (*test* station BER-1, 0.848 mg/L) and the mouth of the Calumet River (*baseline* station CAR-1, 0.446 mg/L); the lowest concentration was measured at the mouth of the Firebag River (*test* station FIR-1, 0.061 mg/L) (Figure 7.2-1). In the Muskeg River watershed, most tributaries had similar concentrations of naphthenic acids with the exception of Shelley Creek (*test* station SHC-1), which had the third-highest measured concentration of all stations in fall 2009. Concentrations of naphthenic acids increased with distance downstream in the tributaries with the exception of the Calumet River, where concentrations in the upper portion of the river (*baseline* station CAR-2) were the second-highest concentration of naphthenic acids measured in fall 2009 in the RAMP FSA (0.686 mg/L). Concentrations of naphthenic acids in lakes in fall 2009 were similar to those measured in tributaries (Figure 7.2-1), with the order of decreasing concentration in lakes being Shipyard Lake (*test* station SHL-1), Isadore's Lake (*test* station ISL-1), McLelland Lake (*baseline* station MCL-1), with lowest concentrations in Kearl Lake (*test* station KEL-1).

Naturally occurring organic acids not associated with petroleum hydrocarbons, also are known to influence measured concentrations of total naphthenic acids, depending on the method used (J. Martin, University of Alberta, *pers. comm.* 2010). Further assessment of the ARC analyses used by RAMP in 2009, and other methods, is necessary to fully understand the range, variability, and sources of naphthenic acids in waterbodies of the RAMP focus study area. This will be pursued further by RAMP in 2010.

7.2.2 Other Water Quality Variables

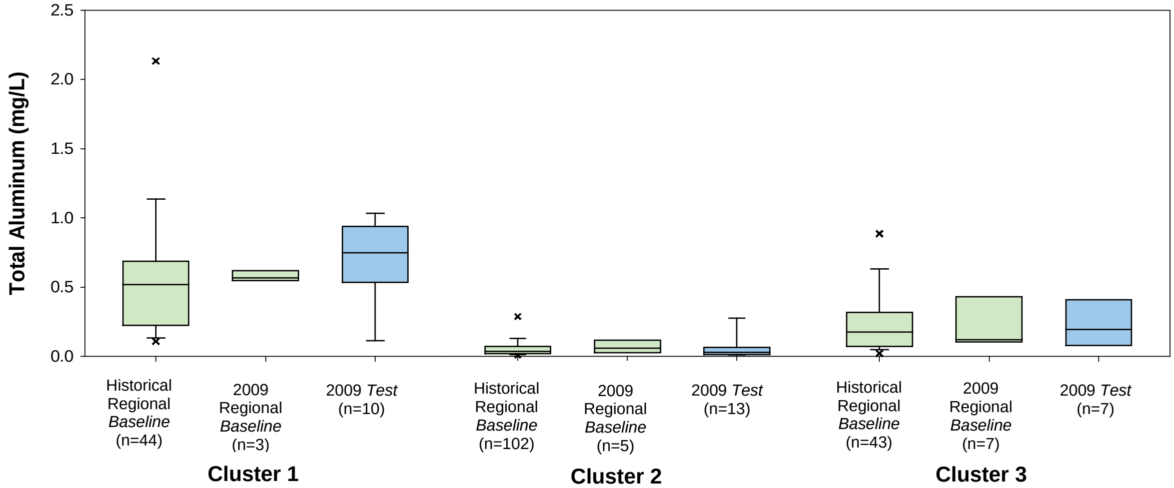
7.2.2.1 Aluminum

There are differences in concentrations of aluminum among regional clusters of water quality stations (Figure 7.2-2). Concentrations of aluminum in the eastern and western tributaries of the Athabasca River (Cluster 2 and Cluster 3, respectively) generally are low compared to concentrations in the Athabasca and Clearwater rivers (Cluster 1).

Median concentrations of total aluminum in 2009 at stations in the Athabasca and Clearwater rivers (Cluster 1) designated as *test* were generally higher than those at designated as *baseline* (Figure 7.2-2).

In 2009, the median concentration of total aluminum for stations in Clusters 2 and 3 generally was similar to historical *baseline* concentrations and all concentrations in these clusters in 2009 were within the range of historical *baseline* concentrations (Figure 7.2-2). Median and inter-quartile (i.e., 25th and 75th percentiles) concentrations at *test* stations in 2009 were similar to, or less than, those in 2009 at *baseline* stations in Clusters 2 or 3. Median concentrations for both *baseline* and *test* stations in Cluster 3 in fall 2009 were higher than the majority of historical *baseline* observations collected since 1997, although the 5th to 95th percentile range for the groups of *test* and *baseline* stations was still within the 5th to 95th percentile range of historical *baseline* concentrations (Figure 7.2-2).

Figure 7.2-2 Concentration of total aluminum in waters of the RAMP FSA, 2009 and historical data.

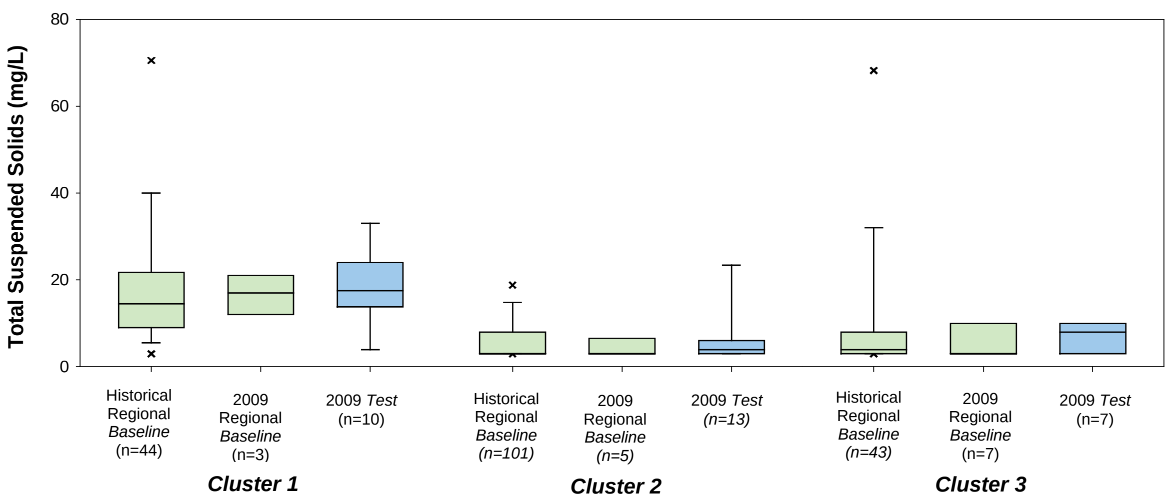


Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: The CCME water-quality guideline for protection of aquatic life for total aluminum is 0.1 mg/L.

Aluminum is the most abundant metal on Earth and is a dominant metal in natural clays of the lower Athabasca region (Czarnecka and Gillot 1980). It commonly occurs in aquatic environments in particulate form, which is not readily bioavailable; its aquatic toxicity is strongly associated with its dissolved form, whose toxicity is highly dependent on pH, hardness, and dissolved organic carbon; increases in any of these variables generally reduces aluminum toxicity (Butcher 1988). In the complete RAMP water quality dataset, concentration of total aluminum is more highly correlated with concentration of total suspended solids than any other variable (as of 2008, r_s=0.760, n=396, r_{crit}=|0.099|). Concentrations of total suspended solids in the RAMP FSA, within and among clusters, and between 2009 and historical observations show a similar distribution to those of total aluminum (Figure 7.2-3), with highest TSS concentrations being measured in the Athabasca River mainstem.

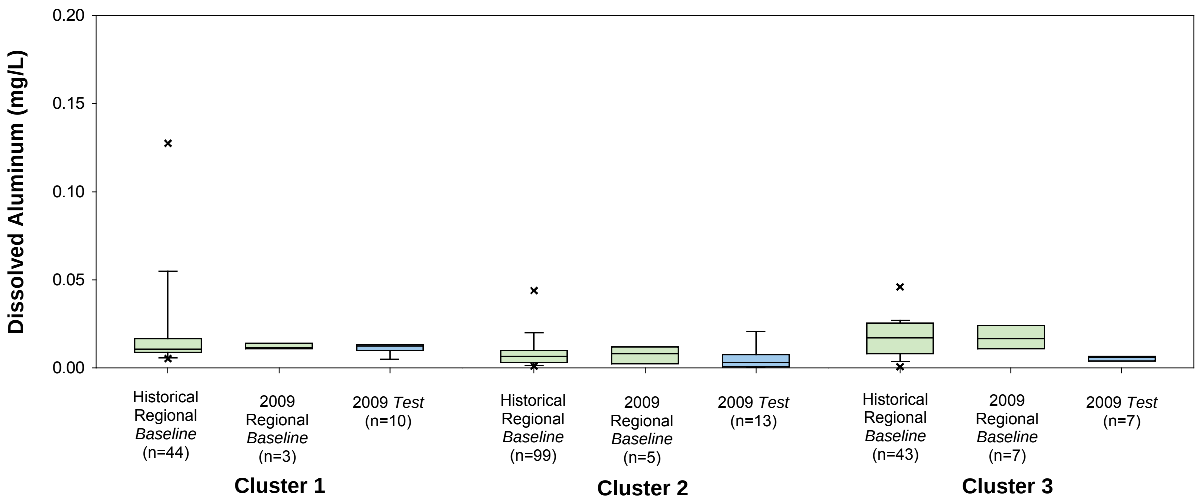
Figure 7.2-3 Concentration of total suspended solids in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

In fall 2009, concentrations of dissolved aluminum at all stations sampled in the RAMP FSA were below the British Columbia guideline for dissolved aluminum (Figure 7.2-4), with the exception of the upper Tar River (*baseline* station TAR-2, 0.0515 mg/L) and the Horse River (*baseline* station HOR-1, 0.146 mg/L).

Figure 7.2-4 Concentration of dissolved aluminum in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: The British Columbia water-quality guideline for dissolved aluminum is 0.05 mg/L (30-day chronic guideline) (British Columbia 2006).

Concentrations of dissolved aluminum have been consistently low throughout the RAMP FSA since 1997, with the exception of a single concentration of 1.1 mg/L measured at *baseline* station ATR-DC-W in fall 2001 (not shown in Figure 7.2-4). The range in concentrations of dissolved aluminum at *test* stations in the RAMP FSA in fall 2009 was generally below the range of both 2009 and historical *baseline* concentrations (Figure 7.2-4).

7.2.2.2 Iron

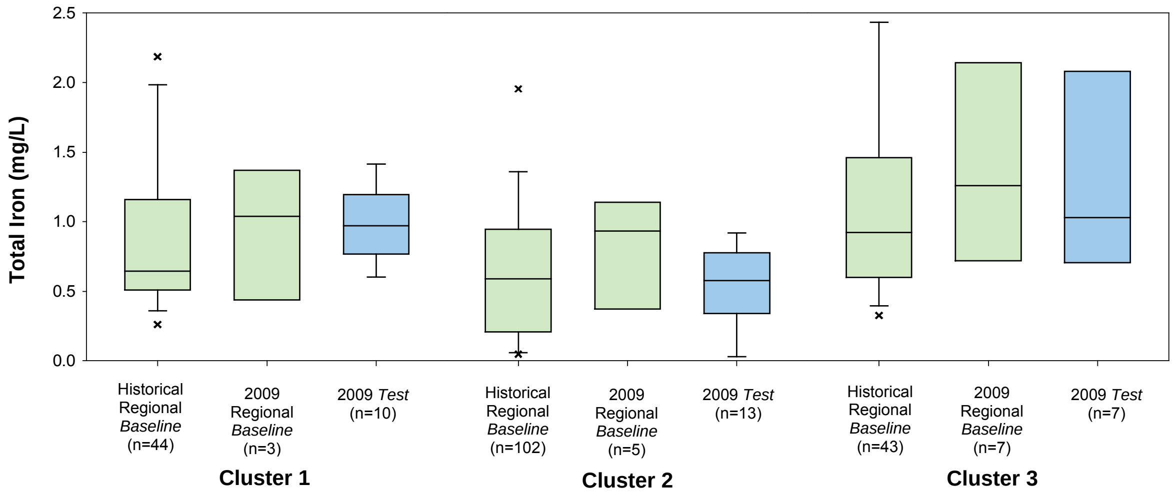
Concentrations of iron in rivers of the RAMP FSA frequently exceed guidelines for protection of aquatic life (Figure 7.2-5, Figure 7.2-6).

In the RAMP FSA, concentrations of both total and dissolved iron have frequently exceeded guidelines for the protection of aquatic life (Figure 7.2-5, Figure 7.2-6), and maximum concentrations of total iron have generally been higher than those for dissolved iron. Concentrations of total and dissolved iron in 2009 were generally similar or lower at *test* stations than at *baseline* stations for all clusters, and concentrations at all stations sampled in 2009 were within the historical range of regional *baseline* concentrations (Figure 7.2-5, Figure 7.2-6). The median concentration of dissolved iron observed in 2009 among *baseline* stations in all clusters also exceeded the British Columbia guideline of 0.35 mg/L.

7.2.2.3 Arsenic

Concentrations of total arsenic in waters of the RAMP FSA in fall 2009 generally were similar or lower at *test* stations than *baseline* stations and concentrations at *baseline* and *test* stations in 2009 were within the 5th to 95th percentile range of historical regional *baseline* concentrations (Figure 7.2-7). All concentrations of total arsenic measured by RAMP since 1997 have been below the CCME guideline of 0.005 mg/L for protection of aquatic life and the Health Canada guideline of 0.010 mg/L for drinking water (CCME 2007, Health Canada 2007).

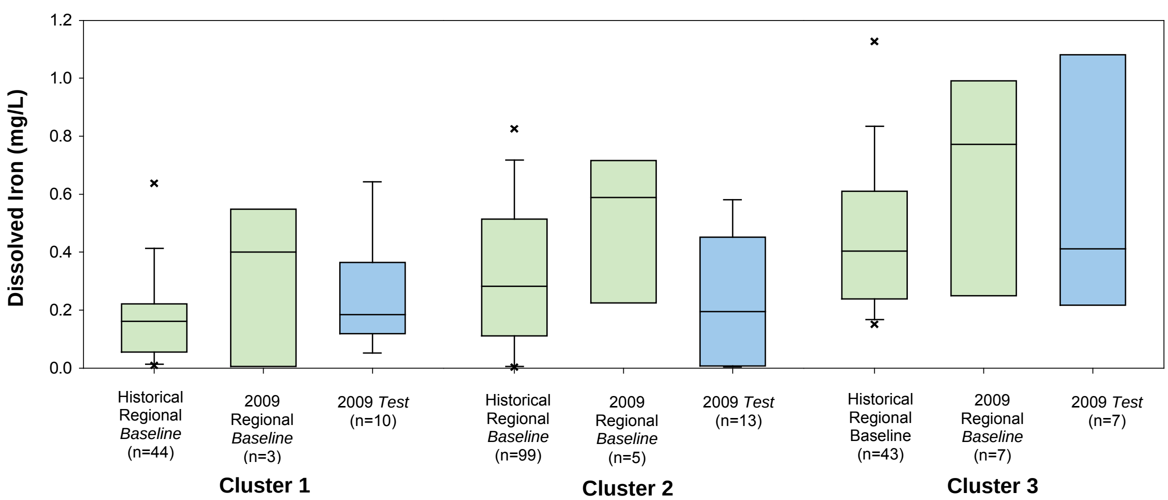
Figure 7.2-5 Concentration of total iron in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: The CCME water-quality guideline for protection of aquatic life for total iron is 0.3 mg/L. CCME does not provide supporting information regarding the foundation of this guideline; the CCME guideline for iron in drinking water (also 0.3 mg/L) is aesthetics-based. There is no surface water quality guideline for the protection of aquatic life for iron for Alberta. British Columbia published a revised guideline for protection of aquatic life in 2008 of 1.0 mg/L for total iron, and indicated that background concentrations should be used in cases where iron naturally exceeds the total iron guideline (British Columbia 2008). There is no national standard for iron in the United States; most state-based standards are 1.0 mg/L or higher (e.g., Government of Iowa 2005).

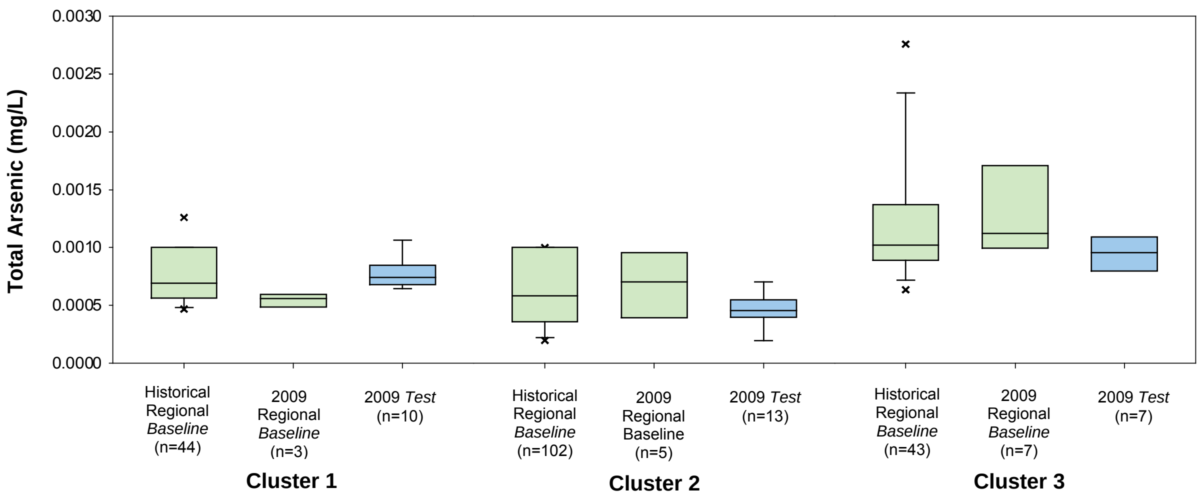
Figure 7.2-6 Concentration of dissolved iron in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: There is no surface water quality guideline for the protection of aquatic life for iron for Alberta. British Columbia published a revised guideline for protection of aquatic life in 2008 of 0.35 mg/L for dissolved iron (British Columbia 2008). There is no national standard for iron in the United States; most state-based standards are 1.0 mg/L or higher (e.g., Government of Iowa 2005).

Figure 7.2-7 Concentration of total arsenic in waters of the RAMP FSA, 2009 and historical data.



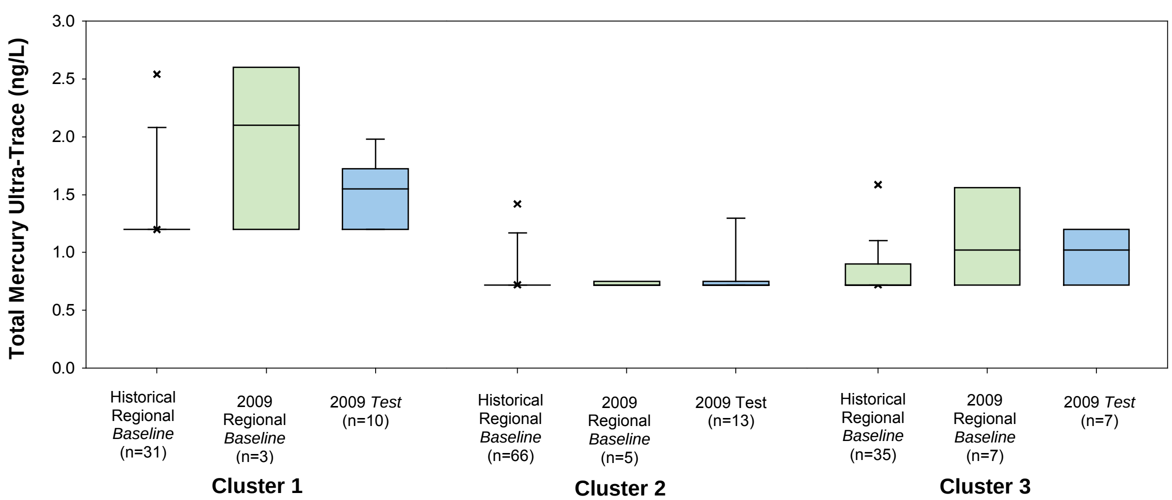
Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: The CCME water-quality guideline for protection of aquatic life for total arsenic is 0.005 mg/L and the Health Canada guideline for drinking water for total arsenic is of 0.010 mg/L (CCME 2007, Health Canada 2007).

7.2.2.4 Mercury

Concentrations of total mercury in waters of the RAMP FSA in fall 2009 were similar or higher at *baseline* stations than *test* stations (Figure 7.2-8). The range of concentrations of total mercury measured in fall 2009 was generally higher at both *baseline* and *test* stations than the range of historical *baseline* concentrations.

Figure 7.2-8 Concentration of total mercury in waters of the RAMP FSA, 2009 and historical data.

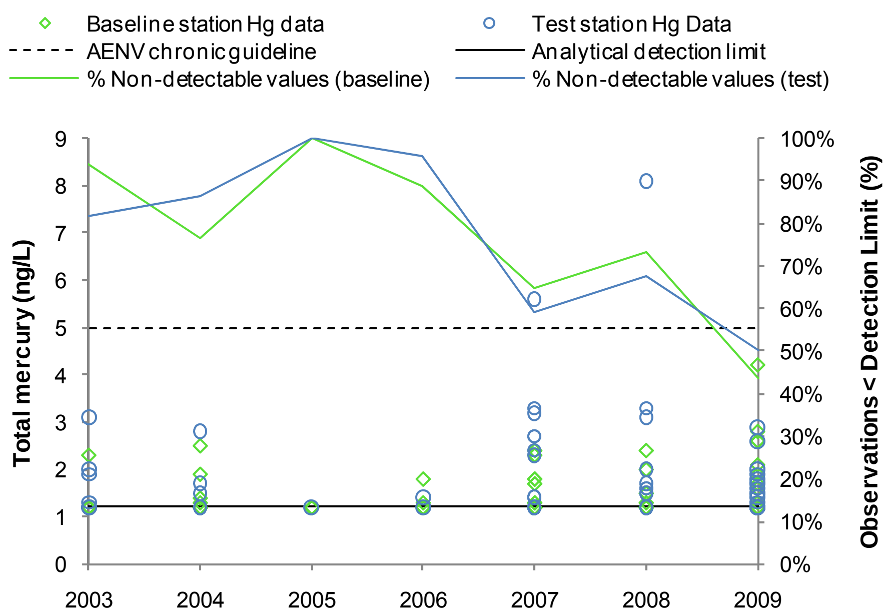


Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Note: The AENV chronic guideline for the protection of aquatic life is 5 ng/L (AENV 1999b).

Although all concentrations of total mercury measured at all stations in fall 2009 were below the AENV chronic guideline of 5 ng/L (Figure 7.2-8), a larger percentage of measurements were above the analytical detection limit of 1.2 ng/L than in previous years (Figure 7.2-9). This increased frequency of detecting low concentrations of total mercury in waters of the RAMP FSA was also described in RAMP (2009a). Changes over time in the frequency of which concentrations of total mercury have been detectable have been similar between *test* and *baseline* stations since ultra-trace mercury measurements began in 2003 (Figure 7.2-9), suggesting any cause of this change is not location-specific. Increases in the concentration of mercury in aquatic environments of northern Canada have been seen in other studies, with speculation that warmer temperatures and higher biological productivity may be factors in these trends (e.g., Evans *et al.* 2005, Carrie *et al.* 2010).

Figure 7.2-9 Concentration of total mercury and frequency of non-detectable concentrations in RAMP FSA, 2003 to 2009.

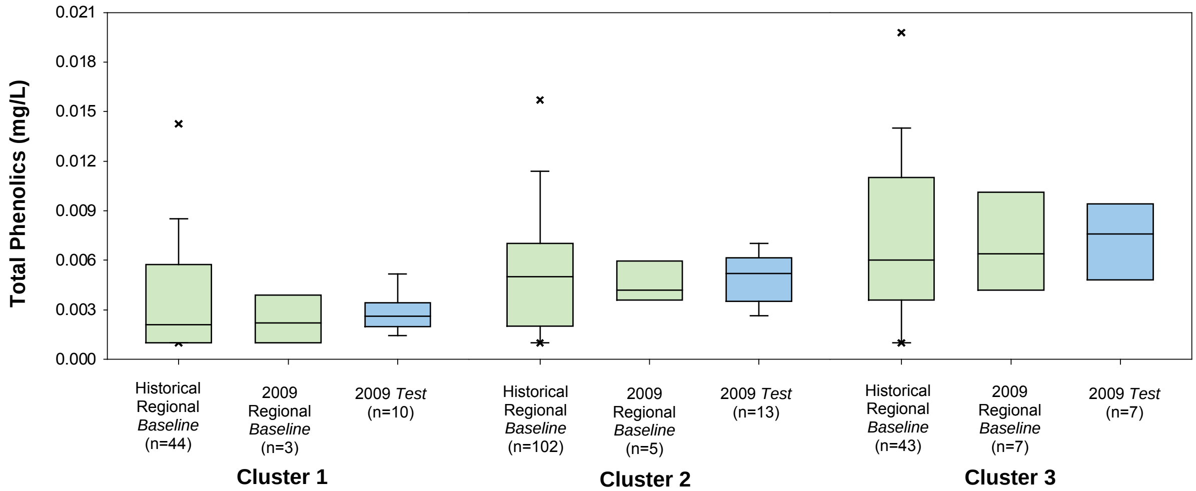


7.2.2.5 Total Phenols

Phenols are a large, complex group of acidic compounds that are hydroxyl derivatives of aromatic hydrocarbons. They are produced through the natural decomposition of plant materials, but also may occur in coal tar (CCME 1999a, Government of British Columbia 2002).

Concentrations of phenols at several stations in the RAMP FSA exceeded the AENV chronic guideline for concentrations of phenolics in fall 2009 at both *baseline* and *test* stations (Figure 7.2-10); all measured concentrations of phenols in 2009 were within the range of historical concentrations. Median concentrations of phenols in 2009 at *test* stations were higher than at *baseline* stations for all clusters. The highest concentration of phenols in fall 2009 was 0.0138 mg/L, measured in the Horse River (*baseline* station HOR-1). All concentrations of phenols in fall 2009 and historically have been below the BC guideline of 0.05 mg/L.

Figure 7.2-10 Concentration of total phenols in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

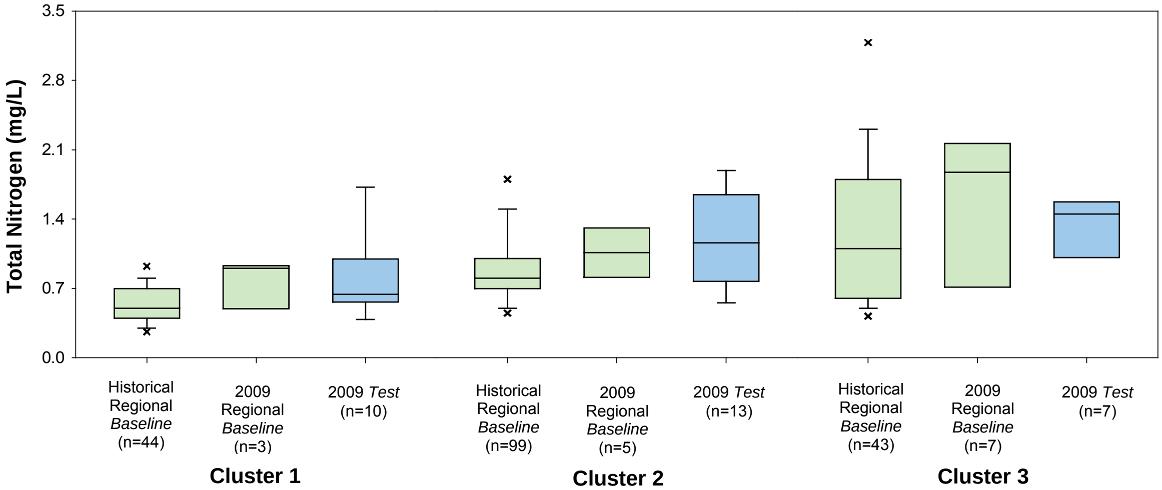
Note: Although there is a CCME guideline for the protection of aquatic life for phenols (0.004 mg/L, or 4 µg/L), this guideline is specific for mono- and dihydric-phenols (i.e., those with one or two hydroxyl groups), and is therefore not applicable to the water quality variable analyzed for RAMP, which encompasses a wide variety of phenolic compounds, including polyhydric species. AENV (1999b) provides a chronic guideline for "phenolics" of 0.005 mg/L (5 µg/L), which was derived from interim guidelines prepared by the Alberta government in 1977; this guideline was used as a screening value in Section 5.0. British Columbia (2006) presents water quality guidelines for specific phenol compounds (i.e., 3- and 4-hydroxyphenol) and for all other non-halogenated phenols of 0.05 mg/L (50 µg/L).

7.2.2.6 Nutrients

Dissolved nitrogen and phosphorus are key water quality variables affecting the primary productivity of aquatic ecosystems. In the majority of observations in the RAMP water quality dataset, most nitrogen is comprised of organic nitrogen, as indicated by the very strong correlation between total nitrogen and total Kjeldahl nitrogen, which includes organic nitrogen and free ammonium, and the frequent absence of detectable concentrations of inorganic nitrogen (i.e., nitrate-nitrite or ammonium). Concentrations of total nitrogen are correlated with dissolved organic carbon (DOC) in the RAMP water quality dataset, further suggesting that most nitrogen in waters in the RAMP FSA is organically-bound. Concentrations of total nitrogen are generally higher in stations in Clusters 2 and 3 (tributaries to the Athabasca River) which also exhibit higher DOC (Figure 7.2-11, Figure 7.2-12). Concentrations of total nitrogen generally have been lowest in the Athabasca River mainstem (Cluster 1).

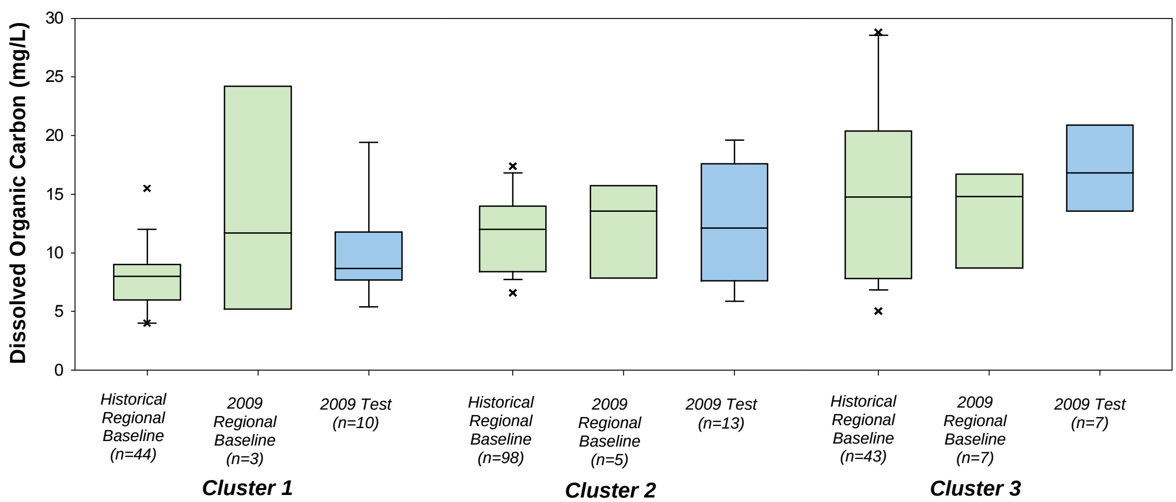
Medians and ranges of total nitrogen concentrations measured in fall 2009 for both *baseline* and *test* stations were generally higher than those observed historically in the RAMP FSA, particularly in smaller tributaries to the Athabasca (i.e., Clusters 2 and 3). Median concentrations in 2009 were higher for *baseline* stations than *test* stations in Clusters 1 and 3 (i.e., Athabasca/Clearwater and western tributaries), but higher in *test* stations than *baseline* stations in Cluster 2 (i.e., eastern tributaries). The highest concentration of total nitrogen in 2009 in Cluster 2 was measured at stations in the Muskeg and Steepbank watersheds; with *test* stations MUR-1, MUR-6, WAC-1, and JAC-1 in the Muskeg watershed and *test* station STR-1 and *baseline* station STR-3 in the Steepbank watershed having concentrations of total nitrogen above 1.5 mg/L.

Figure 7.2-11 Concentration of total nitrogen in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

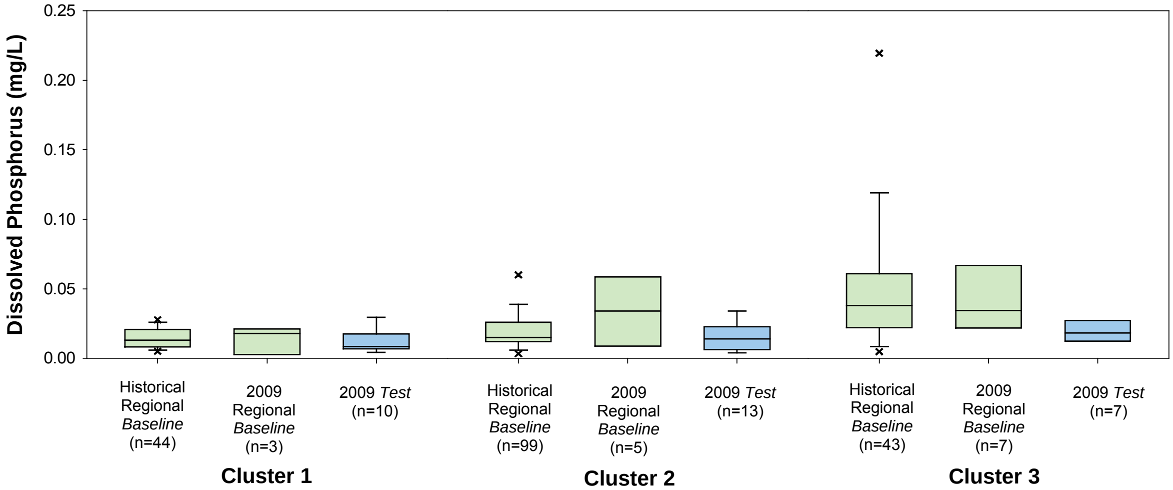
Figure 7.2-12 Concentration of dissolved organic carbon in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

In fall 2009, median concentrations of total dissolved phosphorus at *test* stations in all clusters were below median values at *baseline* stations (Figure 7.2-13); fall 2009 concentrations also were generally within the range of historical regional *baseline* values.

Figure 7.2-13 Concentration of total dissolved phosphorus in waters of the RAMP FSA, 2009 and historical data.



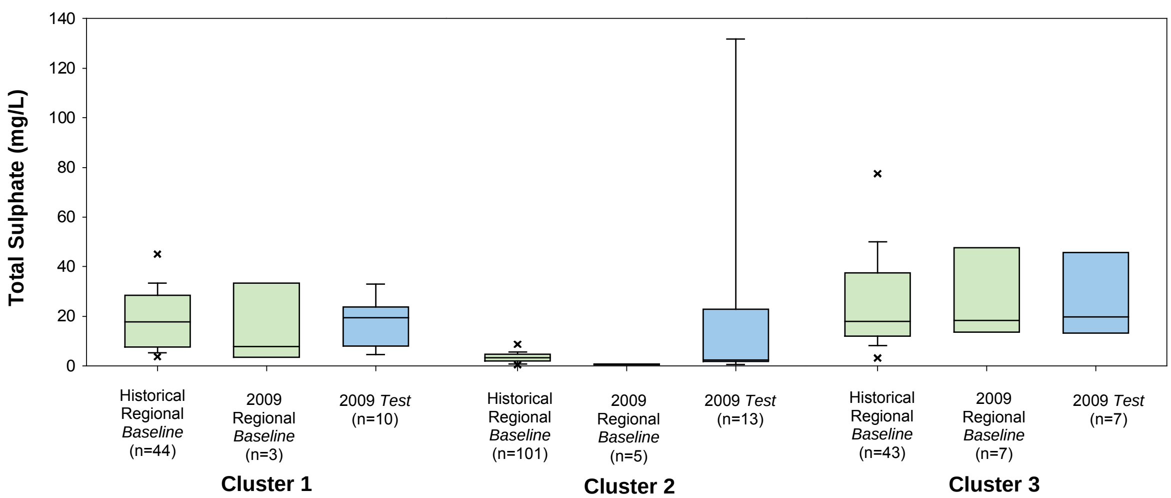
Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

7.2.2.7 Major Ions

Although median concentrations of sulphate, chloride and total dissolved solids within each cluster generally were similar between *baseline* and *test* stations in fall 2009 (Figure 7.2-14 to Figure 7.2-16), the 95th percentile concentration for the 2009 *test* stations was greater than for 2009 or historical *baseline* stations for both the eastern and western tributaries to the Athabasca River (i.e., Clusters 2 and 3). This is due to ion concentrations in 2009 being above regional *baseline* concentrations in:

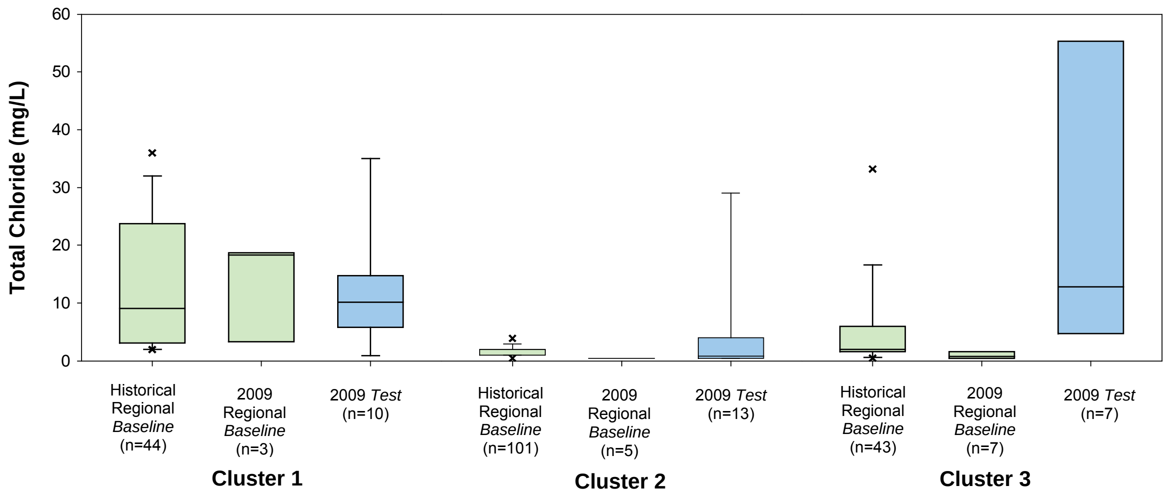
- Isadore's (*test* station ISL-1) and Shipyard (*test* station SHL-1) lakes, Shelley Creek (*test* station SHC-1), and Fort Creek (*test* station FOC-1) in Cluster 2; and
- The lower Beaver River (*test* station BER-1) and lower Poplar Creek (*test* station POC-1) in Cluster 3.

Figure 7.2-14 Concentration of total sulphate in waters of the RAMP FSA, 2009 and historical data.



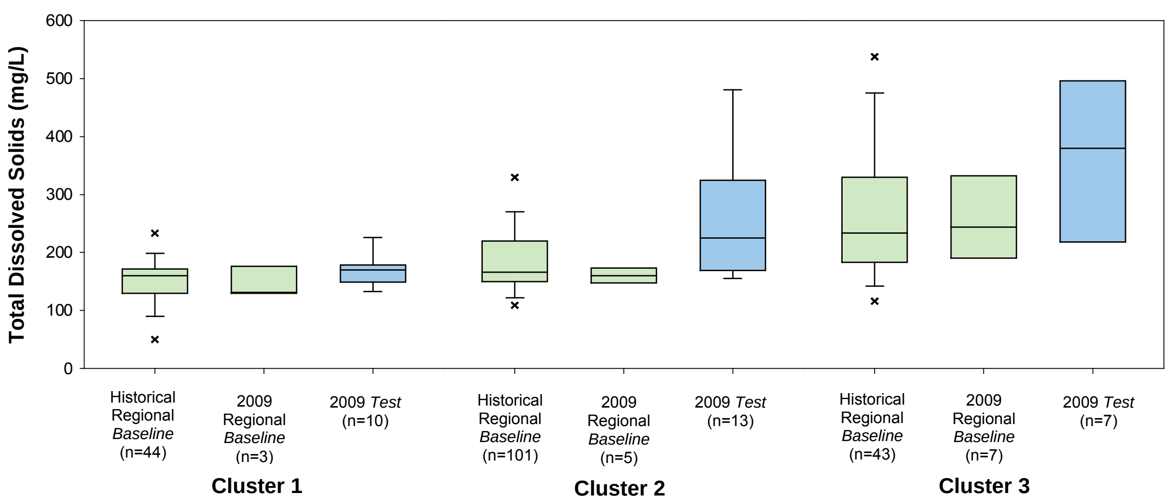
Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Figure 7.2-15 Total chloride in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

Figure 7.2-16 Concentration of total dissolved solids in waters of the RAMP FSA, 2009 and historical data.



Note: Boxes are 25th and 75th percentiles, median (50th percentile) is central line within each box, error bars describe 5th and 95th percentiles, symbols (×) are individual data points outside of 5th to 95th percentiles.

7.2.3 Cumulative Effects on Water Quality in the Athabasca River

As of 2009, few changes in water quality in the Athabasca River mainstem downstream of Fort McMurray are apparent (Section 5.1); the only statistically significant increasing trend observed at stations downstream of Fort McMurray that was not also observed upstream was an increase in the concentration of sulphate at the AENV Old Fort station.

Hebben (2009), Glozier *et al.* (2009) and Squires *et al.* (2010) recently assessed trends in water quality in the lower Athabasca River and Athabasca River Delta (ARD). These researchers generally used long-term government datasets, which included different and generally longer time periods than that available in the RAMP water quality dataset. Trend-analysis methods and conclusions varied between authors. Common results of these studies included increases in concentrations of sulphate and total phosphorus at stations in the vicinity of the AENV Old Fort water quality station. Trends of increasing concentrations are reported for dissolved phosphorus and nitrogen in Glozier *et al.* (2009), sodium in Hebben (2009) and Squires *et al.* (2010), and turbidity in Hebben 2009 and Squires *et al.* (2010). Hebben (2009) also reported increasing flow-adjusted concentrations of total arsenic and total aluminum, consistent with seasonally-weighted trend analyses at the AENV stations, Fort McMurray (aluminum and arsenic) and Old Fort (aluminum), also presented in this report (Section 5.1, Figure 5.1-9). There were no other upward trends in metals reported in any studies.

7.2.4 Summary

With some exceptions, water quality data collected by RAMP in fall 2009 was similar for all key measurement endpoints between *test* and *baseline* stations, and most data from *baseline* and *test* stations in 2009 were within the range of previously-measured concentrations. Exceptions and general observations regarding regional water quality characteristics include:

- concentrations of several dissolved ions that exceeded regional *baseline* concentrations in small tributaries and flood-plain lakes of the Athabasca River, including Beaver River, Poplar Creek, Isadore's Lake and Shipyard Lake;
- a general increase in frequency of measurable concentrations of mercury among all baseline and test stations monitored by RAMP; and
- generally higher dissolved organic matter and total nitrogen (comprised predominantly of organic nitrogen) at both *baseline* and *test* stations sampled by RAMP in 2009 relative to previous years.

Few trends in water quality were observed in the Athabasca River mainstem in this report and in other studies in the lower Athabasca River near the Athabasca River Delta (ARD), that were not also measured upstream of Fort McMurray.

7.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

7.3.1 Regional Assessment of Benthic Invertebrate Community Conditions at the RAMP FSA Level

7.3.1.1 Athabasca River Delta

The variations in benthic invertebrate community measurement endpoints in the ARD reaches are classified as **Negligible-Low.** The values of the benthic invertebrate community measurement endpoints in fall 2009 were within the range of historical values for the ARD, and there are no trends over time in the value of the measurement endpoints that would indicate a degradation of community composition.

7.3.1.2 Athabasca River Tributaries and RAMP FSA Lakes

Table 7.3-1 provides the classification of results of benthic invertebrate communities in *test* reaches of tributaries of the Athabasca River and *test* lakes within the Athabasca River watershed compared to regional *baseline* conditions in 2009. The lower reach of Poplar Creek as well as Isadore's Lake were the only sampled locations in 2009 containing benthic invertebrate communities with conditions that did not have **Negligible-Low** differences from regional *baseline* conditions. All other locations sampled in 2009 had benthic invertebrate communities with conditions that had **Negligible-Low** differences from regional *baseline* conditions. At these sampled locations differences between values of benthic invertebrate community measurement endpoints and *baseline* reaches were either statistically insignificant or significant but weak relative to the background variation, and values of benthic invertebrate community measurement endpoints in these reaches were within regional *baseline* conditions (Figure 7.3-1 to Figure 7.3-5).

Of note, the assessment of **Negligible-Low** differences in benthic invertebrate communities in the lower Tar River in 2009 as compared to regional *baseline* conditions suggested recovery of the benthic fauna from changes that had occurred in previous years (RAMP 2009a). It appears that changes in values of benthic community measurement endpoints in *test* reaches compared to *baseline* reaches are localized in nature and potentially reversible in some cases.

Table 7.3-1 Summary of classification of results in *test* reaches/lakes sampled in the Benthic Invertebrate Communities component, 2009.

Reach/Lake	Reach Name	Habitat Type	Classification
Athabasca River Delta	FLC, GIC, BPC	Depositional	Negligible-Low
Calumet River, lower reach	CAR-D-1	Depositional	Negligible-Low
Christina River, lower reach	CHR-D-1	Depositional	Negligible-Low
Jackpine Creek, lower reach	JAC-D-1	Depositional	Negligible-Low
Steepbank River, lower reach	STR-E-1	Erosional	Negligible-Low
MacKay River, lower reach	MAR-E-1	Erosional	Negligible-Low
Muskeg River, lower reach	MUR-E-1	Erosional	Negligible-Low
Muskeg River, middle reach	MUR-D-2	Depositional	Negligible-Low
Muskeg River, upper reach	MUR-D-3	Depositional	Negligible-Low
Poplar Creek, lower reach	POC-D-1	Depositional	Moderate
Tar River, lower reach	TAR-D-1	Depositional	Negligible-Low
Isadore’s Lake	ISL-1	Depositional	High
Kearl Lake	KEL-1	Depositional	Negligible-Low
Shipyard Lake	SHL-1	Depositional	Negligible-Low

Figure 7.3-1 Variations in total benthic invertebrate community abundance across years for rivers and lakes in the RAMP FSA.

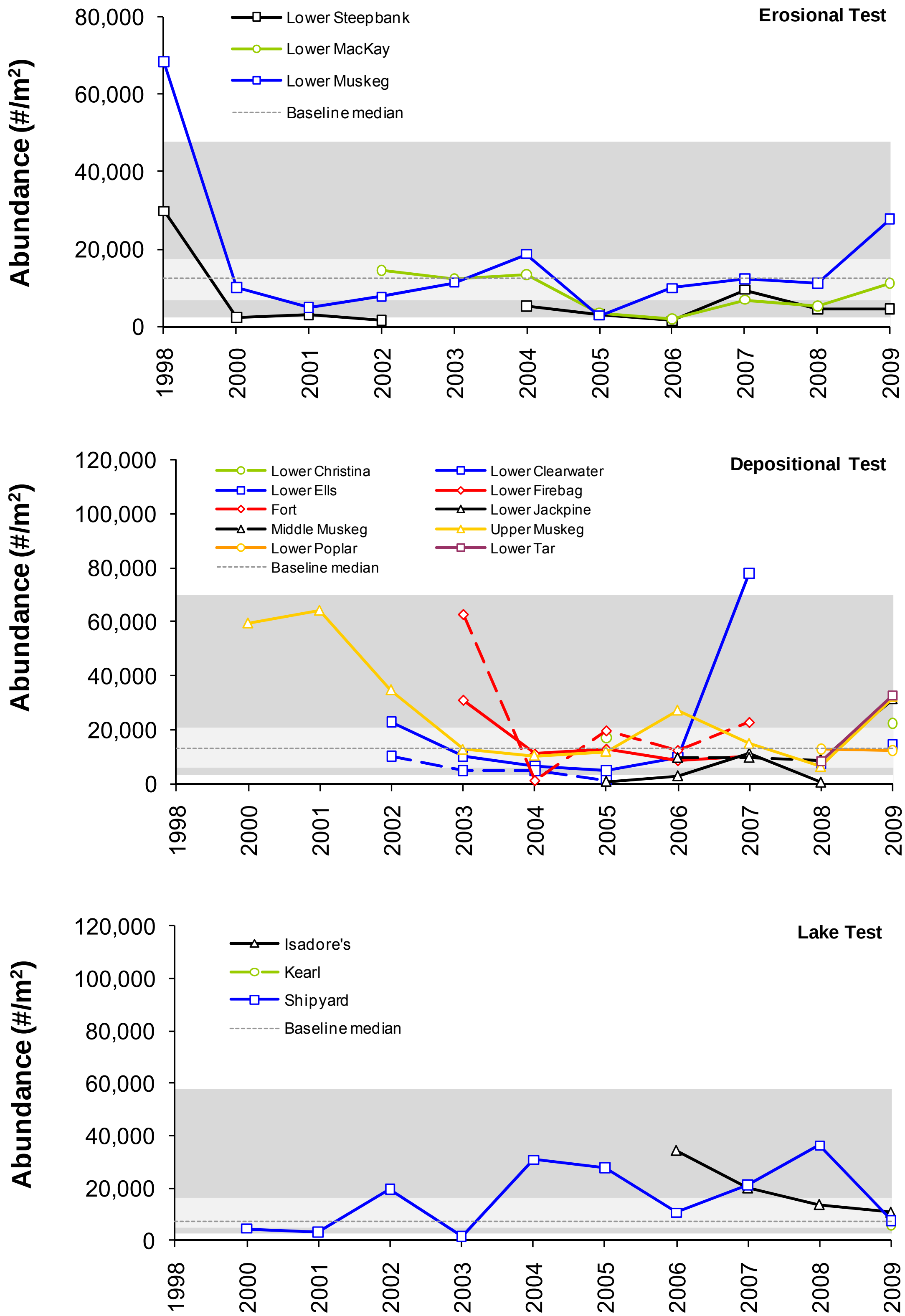


Figure 7.3-2 Variations in benthic invertebrate community taxa richness across years for rivers and lakes in the RAMP FSA.

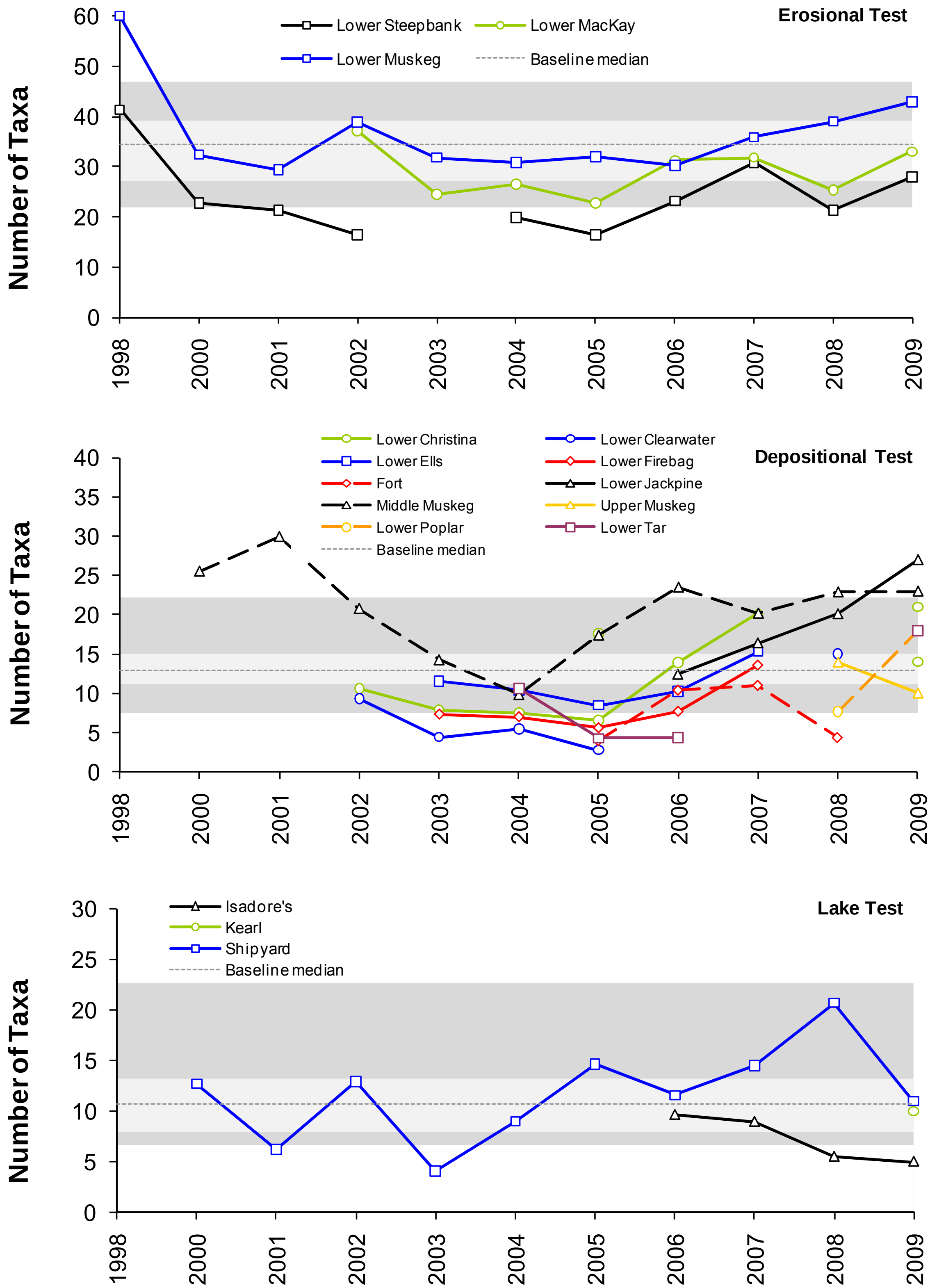


Figure 7.3-3 Variations in benthic invertebrate community Simpson's diversity across years for rivers and lakes in the RAMP FSA.

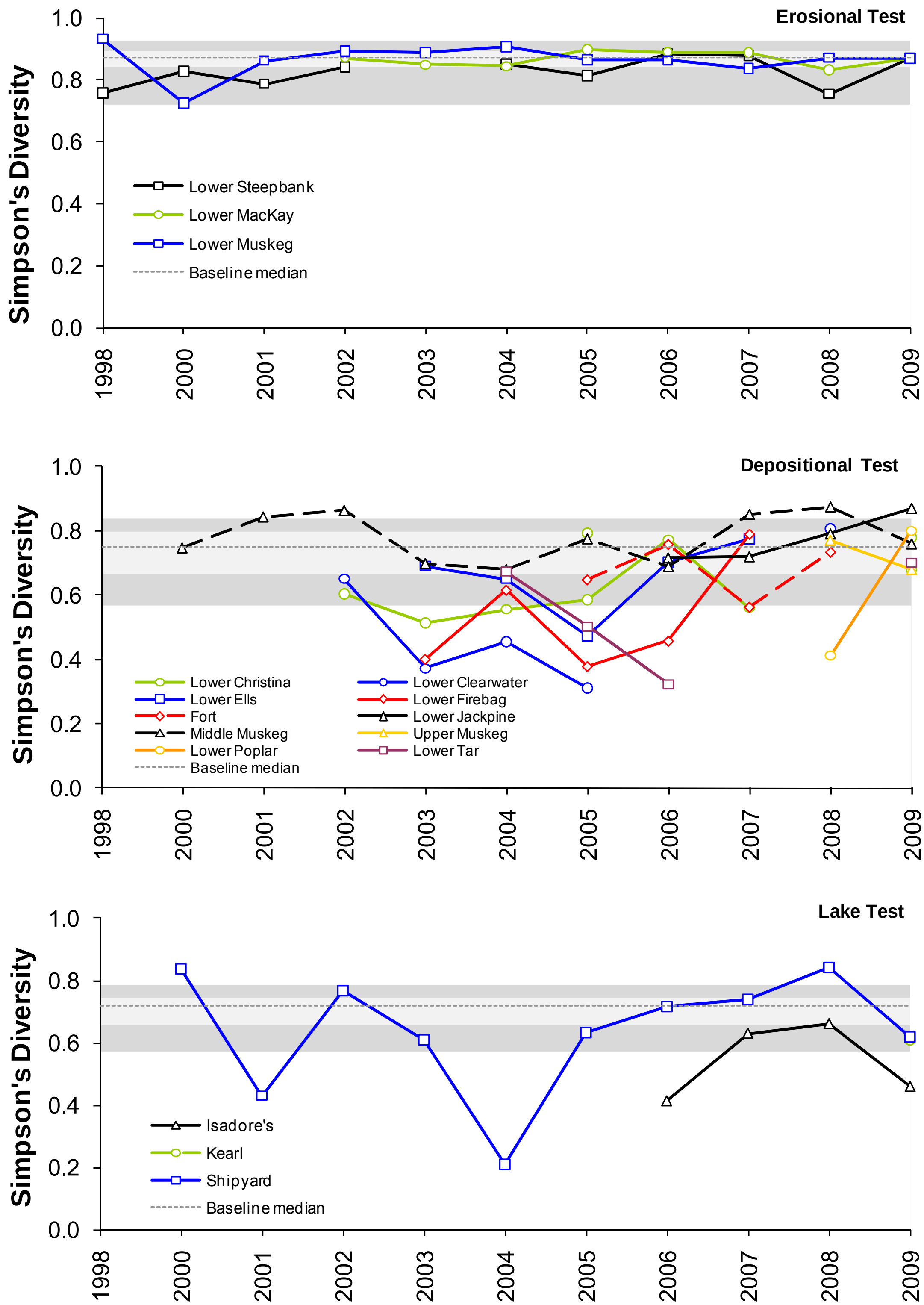


Figure 7.3-4 Variations in benthic invertebrate community evenness across years for rivers and lakes in the RAMP FSA.

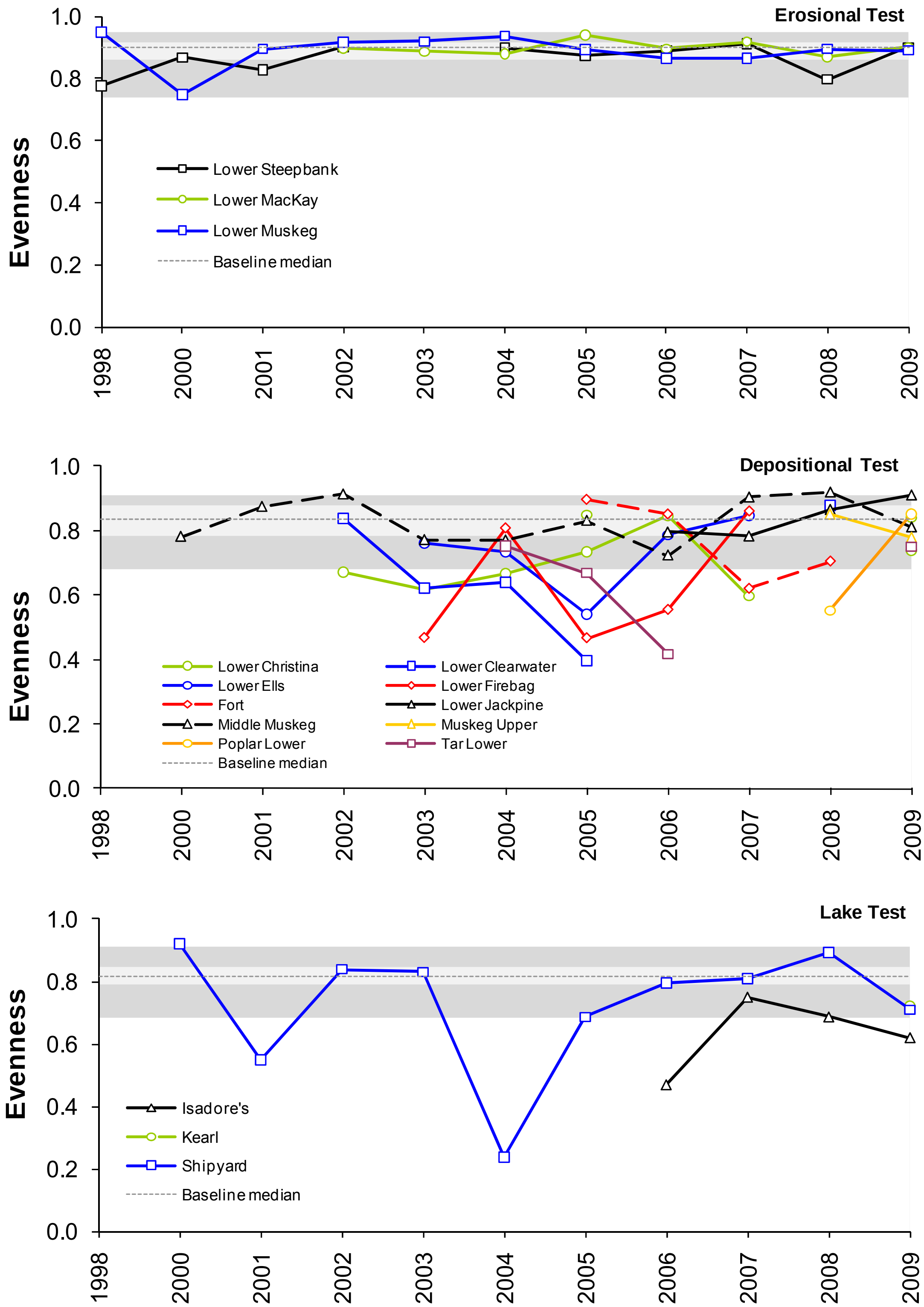
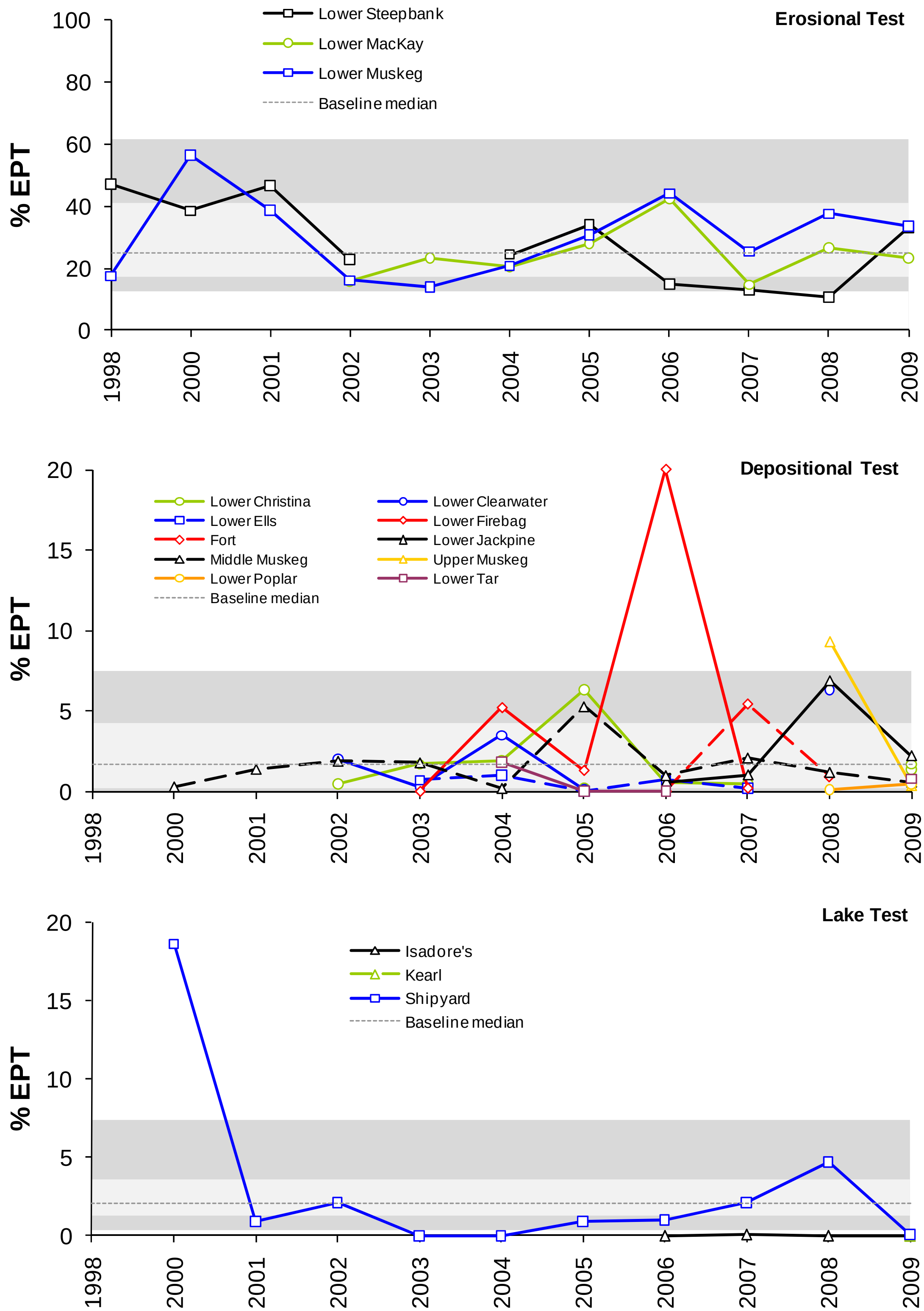


Figure 7.3-5 Variations in benthic invertebrate community percent EPT across years for rivers and lakes in the RAMP FSA.



7.3.2 Sediment Quality

7.3.2.1 Spatial and Temporal Trends in Sediment Quality

Total Hydrocarbons

From 1997 to 2005, concentrations of total hydrocarbons in sediments sampled in the Sediment Quality component were measured using Total Recoverable Hydrocarbons (TRH), a summary variable used by AENV. From 2005 onwards, concentrations of total hydrocarbons sampled in the Sediment Quality component have been assessed using Total Petroleum Hydrocarbons (TPH, which is a sum of four molecular-weight-specific fractions), a summary variable used by CCME (CCME 2001). This change to the CCME four-fraction variable was made because it provided greater resolution of different hydrocarbon fractions and because associated environmental-quality guidelines were concurrently established for these fraction-specific variables, which did not exist for TRH. It should be noted that both TRH and TPH variables were developed for application to assessments of terrestrial soils, rather than aquatic sediments.

Comparison of TRH and TPH data from duplicate samples collected by RAMP in 2005 found a best-fit relationship of [TPH] = 2.183[TRH] (Appendix E in RAMP [2006]). A review of data collected by RAMP using the CCME four-fraction test since 2005 indicates that most hydrocarbons in sediments sampled in the RAMP FSA are comprised of high-molecular-weight species (i.e., those in Fractions 3 and 4, with more than 16 carbon atoms). Fractions 3 and 4 contain heavy oils, asphalts, and many PAHs (of petrogenic or biogenic origin). Concentrations of total PAHs in sediments sampled by RAMP from 2006 to 2009 were correlated with concentrations of F3 and F4 fractions, and with concentrations of TRH (r_s=0.53, 0.47 and 0.52, respectively, Appendix F).

Concentrations of total hydrocarbons in sediments of Athabasca River tributaries since 1997 appear in Figure 7.3-7 showing TRH (1997 to 2005) and TPH (2005 to 2009, shown at a 1:2 vertical scale relative to TRH). Stations designated as *baseline* in 2009 have green background shading, while stations designated as *test* in 2009 have blue background shading. A similar presentation of concentrations of total hydrocarbons in the Athabasca River mainstem and ARD across years is provided in Section 5.1.

Concentrations of total hydrocarbons have been highly variable within and among stations since sampling by RAMP began in 1997, and between *baseline* and *test* stations. Historically, the highest concentrations of total hydrocarbons have been observed in the lower Calumet River, station CAR-1 in 2005, *baseline,* and 2006, *test*, the upper Calumet River in 2005, *baseline* station CAR-2 and 2006, *baseline* station CAR-D-2, Stanley Creek in 2003, *test* station STC-1, Shipyard Lake in 2004, *test* station SHL-1, and McLean Creek in 1999 and 2000, *test* station MCC-1 (Figure 7.3-7). In 2009, the highest concentration of total hydrocarbons in sediments was measured in the lower Calumet River, *test* station CAR-D-1 and lower Poplar Creek, *test* station POC-D-1 (Figure 7.3-7). The concentration of TPH in 2009 at CAR-D-1 was within the range of previously-measured concentrations of TPH at this station, when it was a classified as *baseline* (Section 5.6). The concentration of TPH in 2009 at *test* station POC-D-1 was the highest concentration measured at this station (Figure 7.3-7).

The organic carbon content of sediments may be an important determinant of the concentrations of hydrocarbons, given their hydrophobic nature and tendency to sorb to organic particles, and may confound comparisons among stations and years (e.g., see Lamberson *et al.* 2000). The concentration of total hydrocarbons in the RAMP sediment quality data from 2006 to 2009 was significantly correlated with total organic carbon

(r_s=0.62; Appendix F). Concentrations of total hydrocarbons in sediments normalized to 1% organic carbon are provided in Figure 7.3-8 for 1998 to 2009. Adjustment of concentrations of hydrocarbon for organic content primarily affects concentrations in sediments of lakes, where organic carbon content is typically high.

The highest carbon-normalized concentrations of total hydrocarbons in sediments observed by RAMP since 1997 have occurred in the lower Ells River in 2006 and 2007, *test* station ELR-D-1, the lower Steepbank River in 1997 and 2005, *test* station STR-1, McLean Creek in 1999 and 2005, *test* station MCC-1, the lower Calumet River in 2006, *test* station CAR-D-1, and Fort Creek in 2008, *test* station FOC-1 (Figure 7.3-8). The highest carbon-normalized total hydrocarbon concentrations measured in 2009 were in the lower Calumet River, *test* station CAR-D-1, with a carbon-normalized concentration that was within the historical range of measured carbon-normalized concentrations at this station, and lower Poplar Creek, *test* station POC-D-1, with a carbon-normalized concentration that was the highest carbon-normalized concentration measured to date at this station (Figure 7.3-8).

Based on these observations, and results for the ARD reported in Section 5.1, a regional-level effect of focal projects and other oil sands developments on concentrations of total hydrocarbons in sediments is not suggested, although sediment quality at lower Poplar Creek should be assessed again in the near future.

Polycyclic Aromatic Hydrocarbons (PAHs)

Stations with highest absolute total PAH concentrations over time include the middle Muskeg River *test* station MUR-D-2, the lower Ells River, *test* station ELR-D-1, Stanley Creek, *test* station STC-1, McLean Creek, *test* station MCC-1, and the lower Steepbank River, *test* station STR-1 (Figure 7.3-9). The highest carbon-normalized total PAH concentrations in sediments since 1997 have been measured in the lower Ells River, *test* station ELR-D-1, the upper Steepbank River, *baseline* station STR-3, and McLean Creek, *test* station MCC-1 (Figure 7.3-10). The correlation between total PAHs and TOC in the RAMP sediments dataset (2006 to 2009) was weaker (r_s=0.20) than that between TPH and TOC (r_s=0.62), although total PAHs were correlated with TPH (r_s=0.58). Given the relationship between total PAHs and total hydrocarbons in the dataset, it is not unexpected that most of these stations also exhibited some of the highest observed concentrations of total hydrocarbons.

In 2009, the highest absolute and carbon-normalized concentrations of total PAHs were measured in sediments from the lower Calumet River, *test* station CAR-D-1, lower Poplar Creek, *test* station POC-D-1, and the middle Muskeg River, *test* station MUR-D-2 (Figure 7.3-11). Concentrations of total PAHs in 2009 were within the range of historical observations at *test* station CAR-D-1 and *test* station MUR-D-2, and greater that previously-measured maximum concentrations at *test* station POC-D-1 (Figure 7.3-11). Concentrations of PAHs in sediments of the ARD (Section 5.1) in 2009 were generally lower than or intermediate to concentrations from tributaries with relatively high PAHs and those with relatively low PAHs; this pattern is consistent with historical observations (Evans *et al*. 2002).

Figure 7.3-6 Total hydrocarbon in sediments collected by RAMP in 2009, including concentrations normalized to 1% organic carbon.

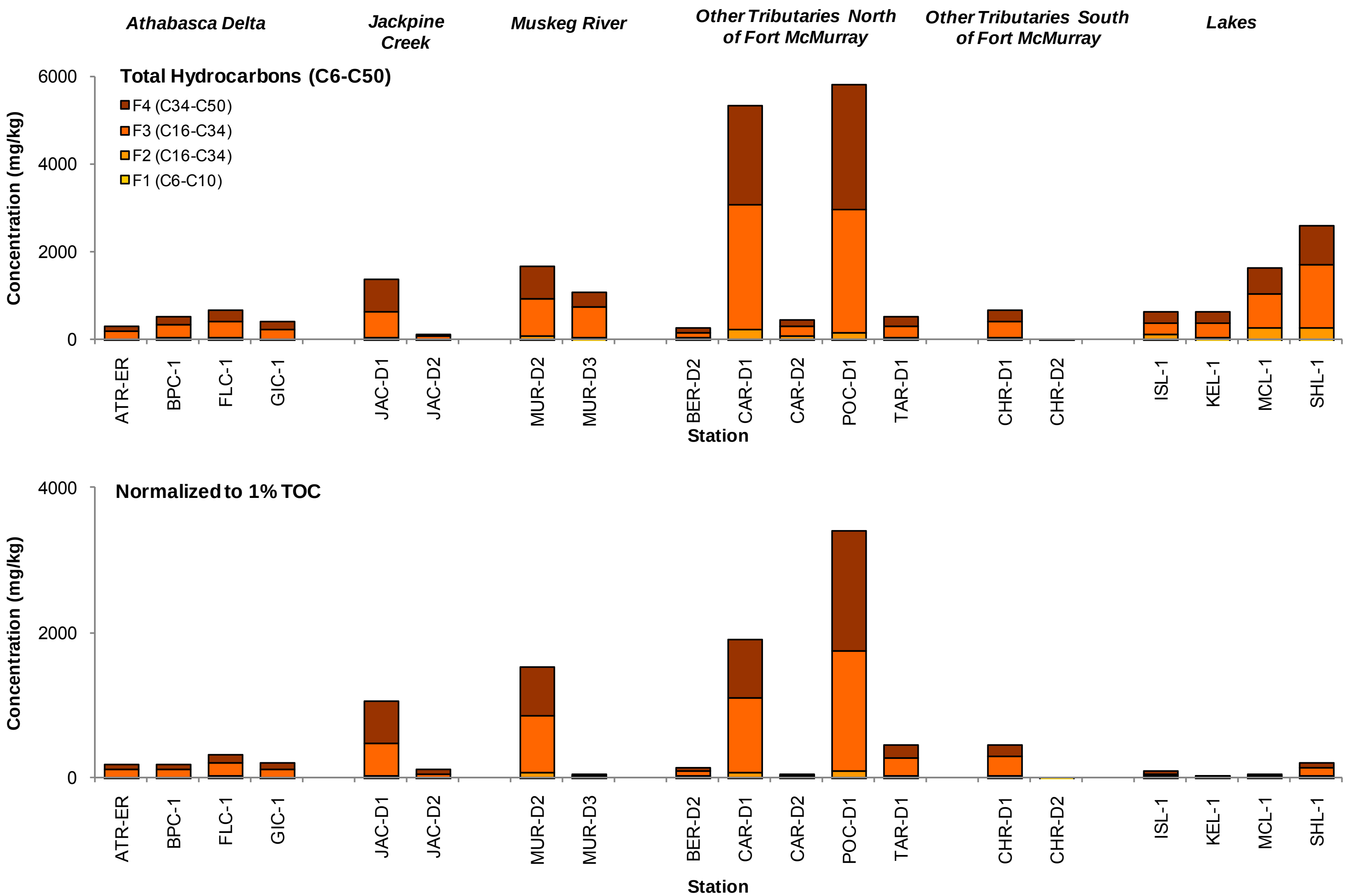


Figure 7.3-7 Concentrations of total hydrocarbons in sediments sampled by RAMP in tributaries to the Athabasca River, 1997 to 2009.

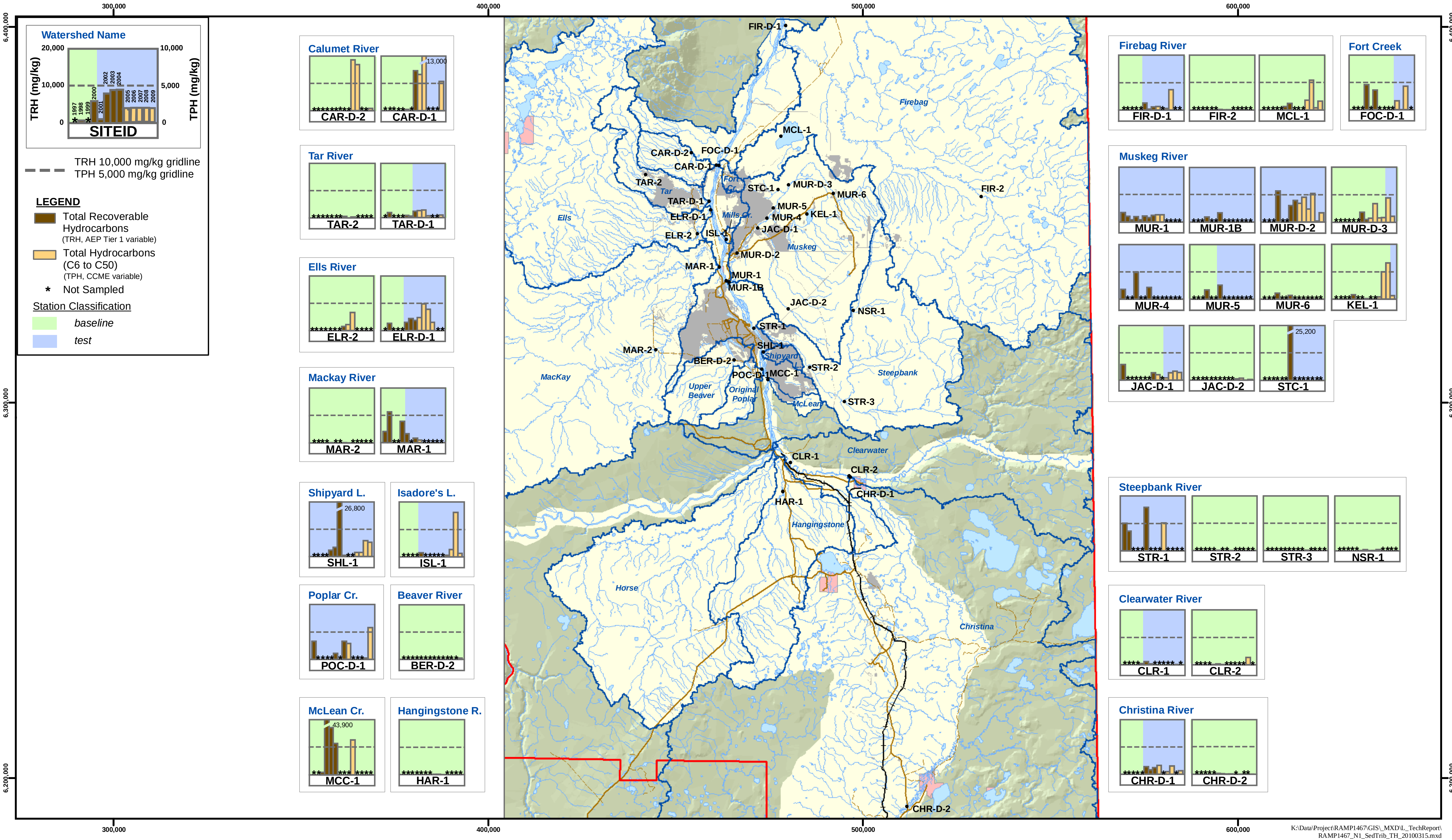


Figure 7.3-8 Carbon-normalized concentrations of total hydrocarbons in sediments sampled by RAMP in tributaries to the Athabasca River, 1997 to 2009.

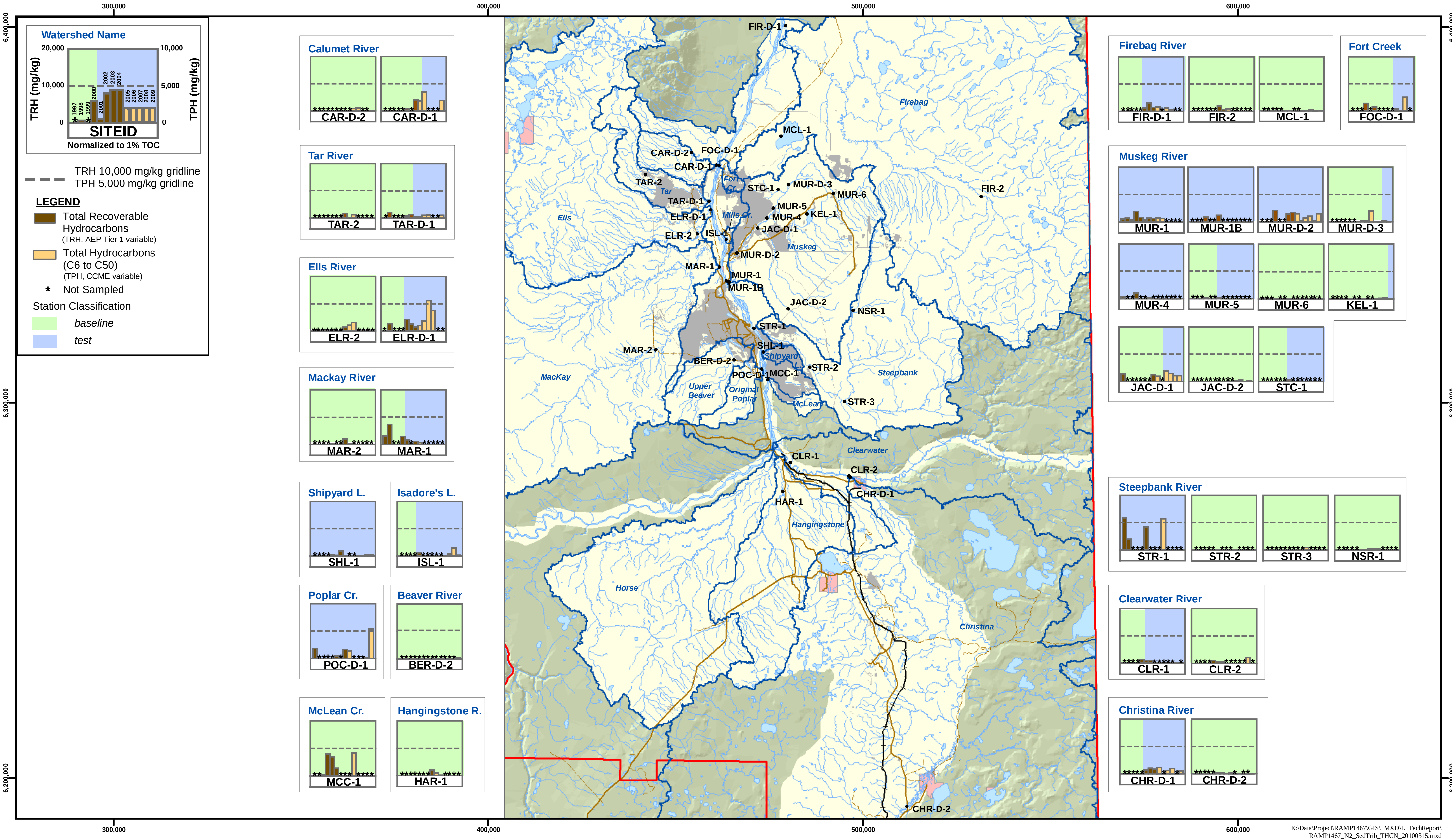


Figure 7.3-9 Concentrations of total PAHs in sediments sampled by RAMP in tributaries to the Athabasca River, 1997 to 2009.

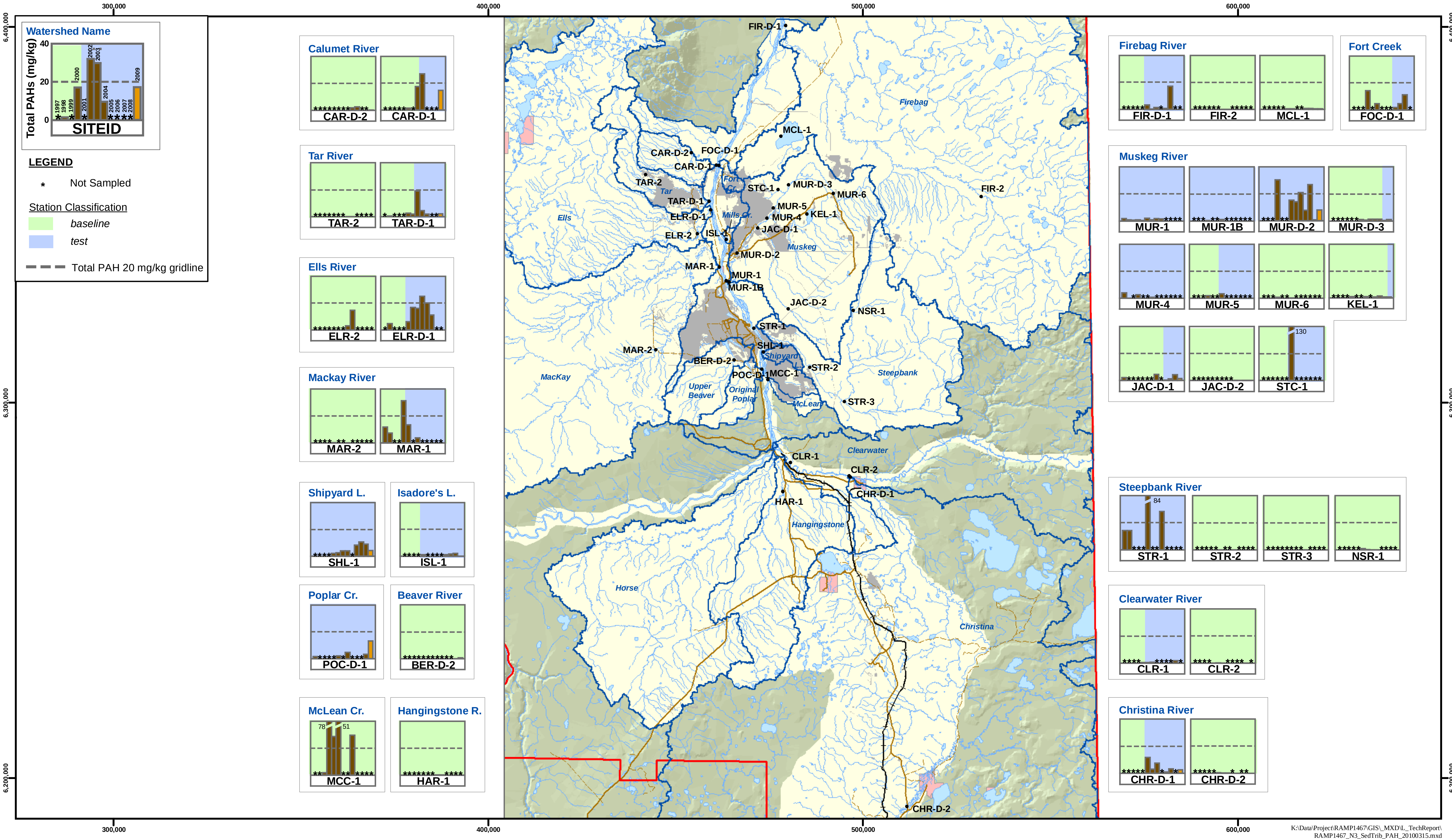
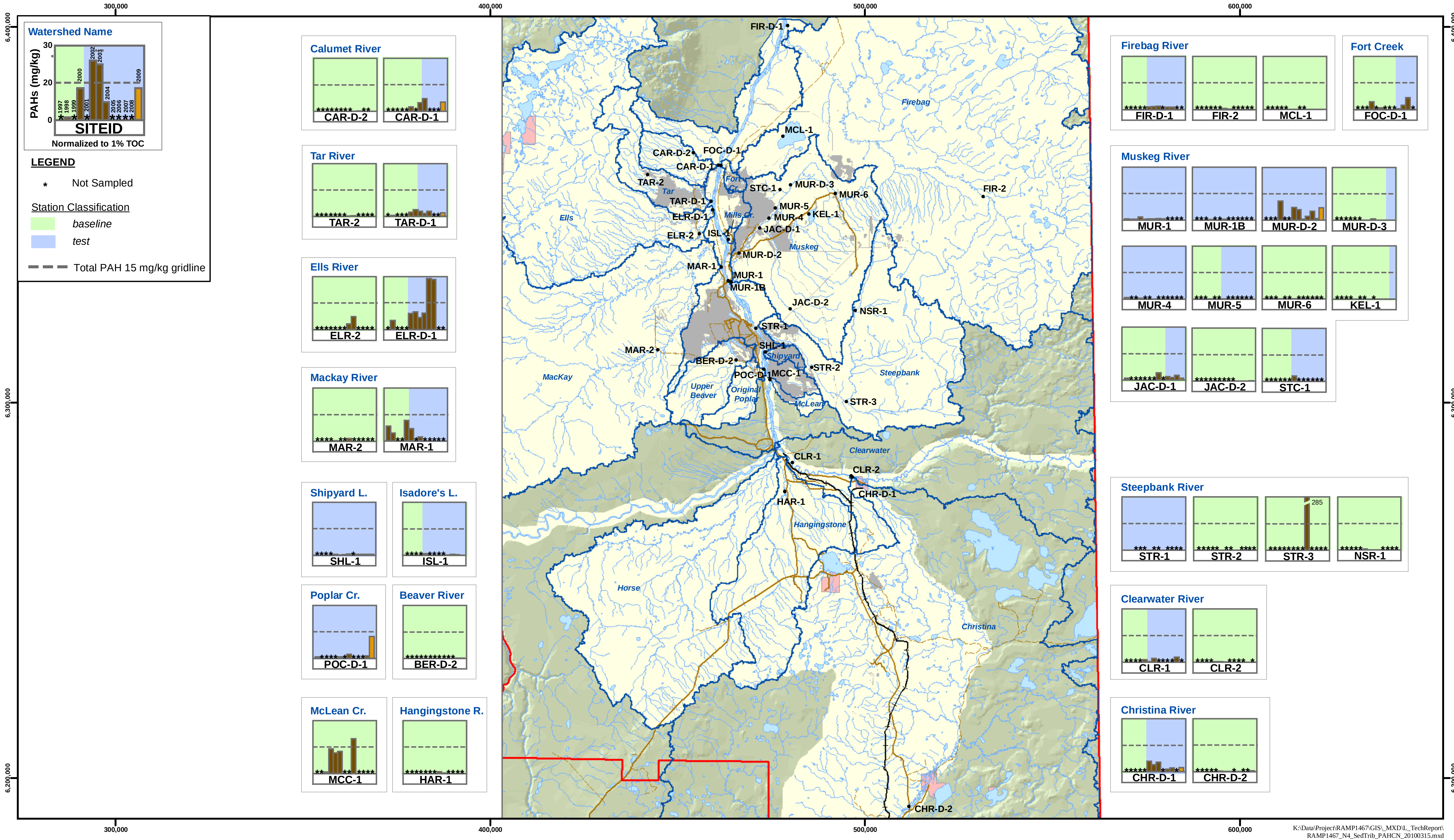


Figure 7.3-10 Carbon-normalized concentrations of total PAHs in sediments sampled by RAMP in tributaries to the Athabasca River, 1997 to 2009.



Concentrations of total PAHs were dominated by alkylated forms, with parent PAHs comprising a very small fraction of total PAH concentrations (Figure 7.3-11). This is consistent with a petrogenic origin of these PAHs, and consistent with observations by others that PAHs in sediments in the lower Athabasca River watershed are petrogenic in origin and predominantly alkylated, in areas either affected or unaffected by oil-sands development (e.g., Wayland *et al*. 2008).

Metals: General

Concentrations of most metals measured in sediments in the RAMP FSA are inter-correlated. Principal component analysis (PCA) found that the first derived principal component (total metals PC1) explained approximately 65% of the total variance of metals concentrations in the RAMP sediments database (2006 to 2009 data, n=48). In addition, 20 of 25 metals included in the PCA were strongly correlated (i.e., r_s>0.75) with total metals PC1. These results indicate a generally consistent composition of metals in sediments throughout the RAMP FSA.

Concentrations of total metals in sediments sampled by RAMP are presented in Figure 7.3-12, both in absolute concentrations and in concentrations normalized to percent fine sediments (i.e., silt plus clay)[1]. Concentrations of total metals in sediments in 2009 were relatively variable among stations (i.e., from below 30 to nearly 500 mg/kg), with highest concentrations in lakes, particularly Isadore's Lake, *test* station ISL-1, and Shipyard Lake, *test* station SHL-1, and stations in the ARD (Figure 7.3-12). The concentration of metals in 2009 was generally more consistent among stations when normalized to percent fine sediments (Figure 7.3-12). The high concentration of metals normalized to percent fine sediments in the upper Muskeg River, *test* station MUR-D-3 and the upper Calumet River, *baseline* station CAR-D-2, in 2009 may be related to low silt and clay content in sediments at these stations (e.g., 98% sand at *test* station MUR-D-3). Concentrations of metals in sediments were similar at all ARD stations, consistent with observations in previous years, and within the highest and lowest concentrations observed in tributaries of the Athabasca River (Figure 7.3-12).

Metals: Arsenic

Arsenic has been frequently been measured in the Sediment Quality component since 1997 at concentrations near or above the CCME Interim Sediment Quality Guideline (ISQG) of 5.9 mg/kg (Figure 7.3-13). The highest concentrations of arsenic measured in sediments have been in the upper Tar River in 2005, *baseline* station TAR-2, the upper Calumet River in 2005, *baseline* station CAR-2 and in Stanley Creek in 2003, *test* station STC-1. The concentration of arsenic in Stanley Creek of 18.5 mg/kg was the only one to have exceeded the CCME Probable-Effects Level (17 mg/kg PEL). It should be noted that these high concentrations of arsenic in sediments were taken from slow-moving or wetland areas and contained large amounts of plant material; for example, sediments at, *test* station STC-1 in 2003 were over 40% organic carbon. Arsenic has been shown to accumulate in plants, although it does not bio-magnify between trophic levels (ATSDR 2007).

[1] Total metals concentrations are correlated with fine sediment fractions in the RAMP sediments database. From 2006 to 2009, total metals PC1 was strongly and positively correlated with % silt (r_s=0.87) and % clay (r_s=0.77) and strongly and negatively correlated with %sand (r_s=-0.85), indicating that concentrations of metals were nearly always higher in fine rather than coarse sediments.

Figure 7.3-11 Concentrations of total parent and alkylated PAH in sediments collected by RAMP in 2009, including concentrations normalized to 1% organic carbon.

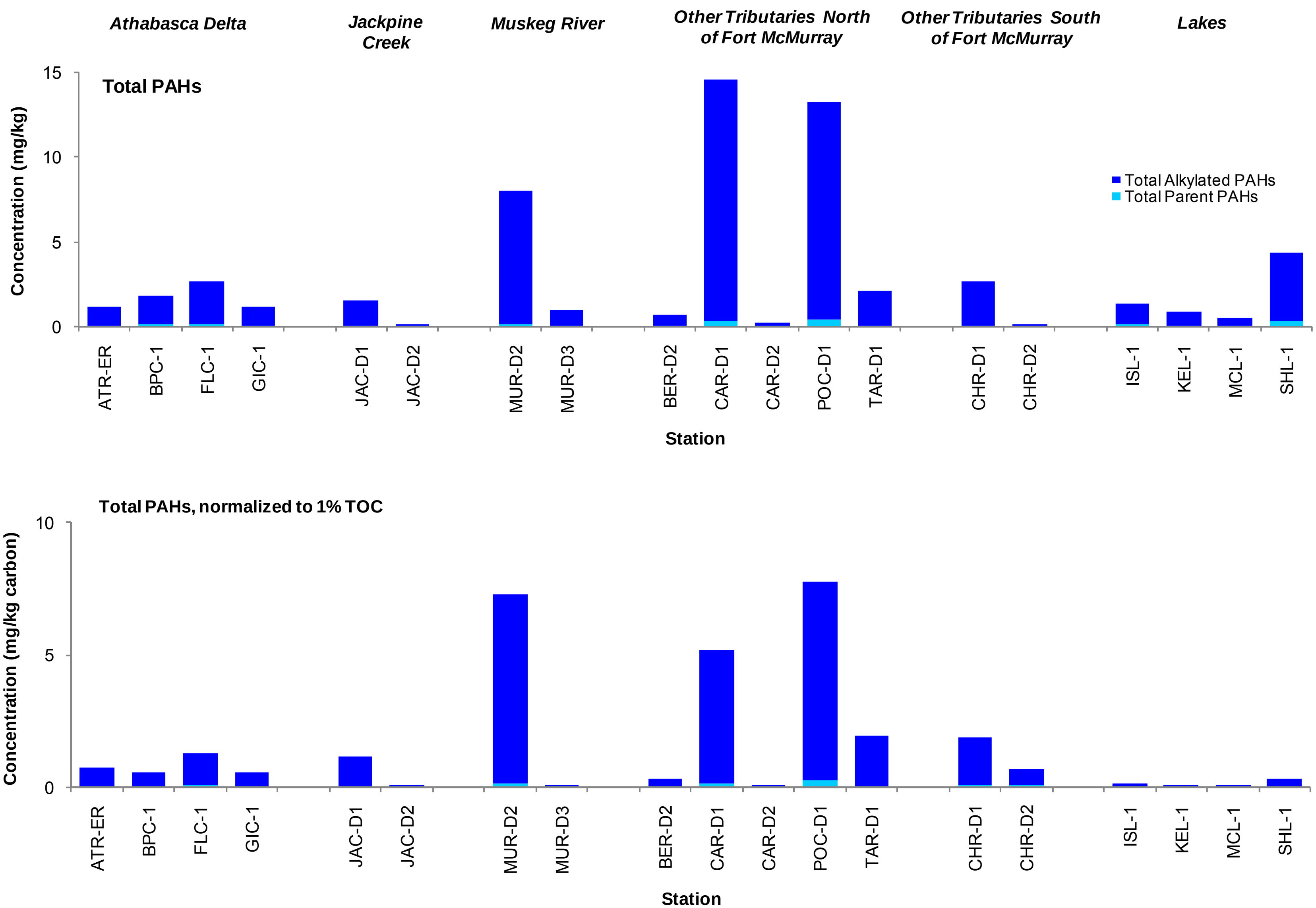
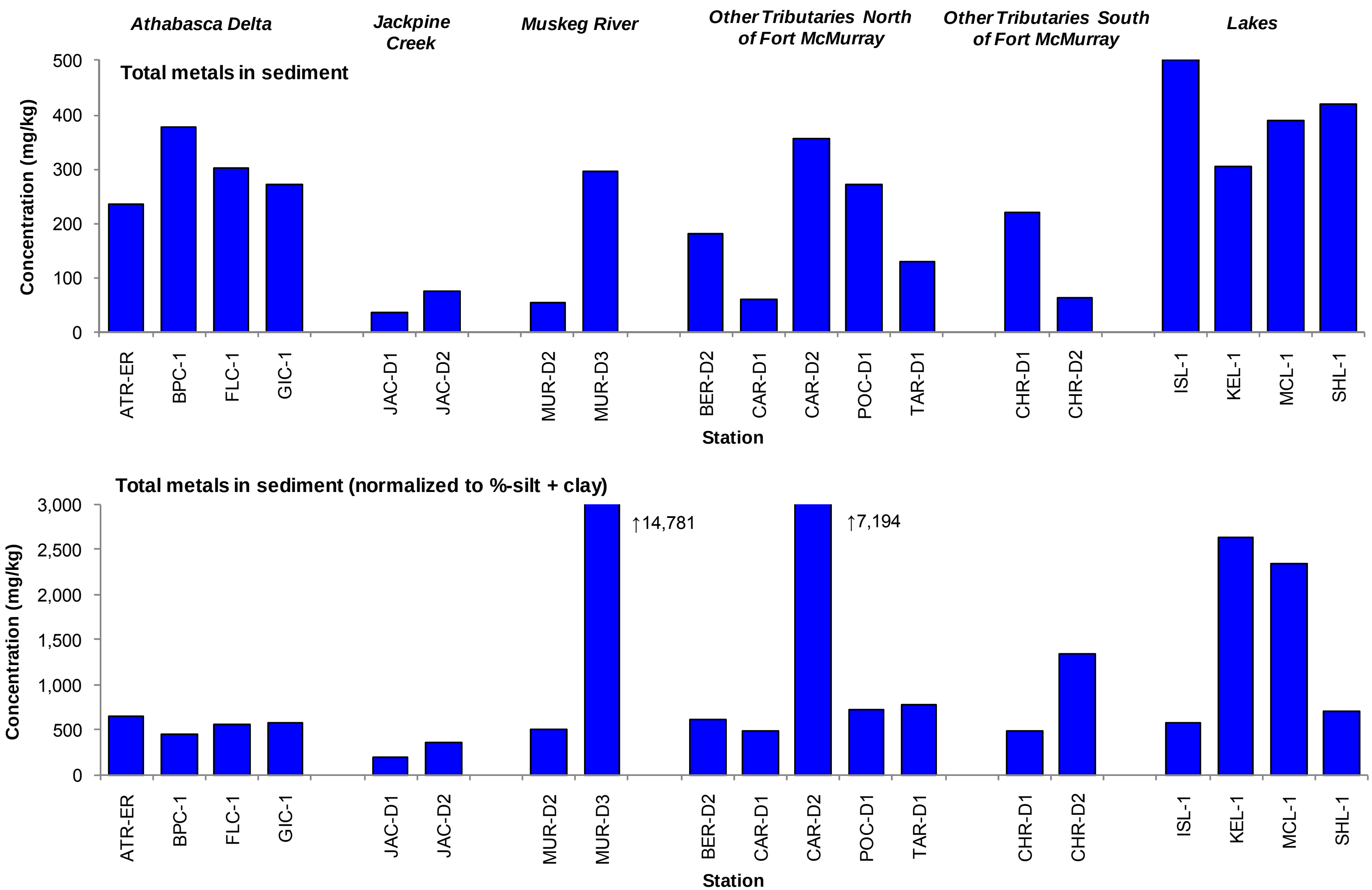


Figure 7.3-12 Total metals concentrations in sediments collected by RAMP in 2009, including concentrations normalized to the fraction of fine sediments (i.e., %silt + %clay).



In 2009, the highest concentrations of arsenic were found in Shipyard Lake, *test* station SHL-1) and lower Poplar Creek, *test* station POC-D-1) (Figure 7.3-13); the concentrations at both these stations in 2009 were within the range of previously-measured concentrations for these stations. There were no consistent differences in concentrations of arsenic in sediments between *baseline* and *test* stations in 2009 or across years, with the potential exception of a temporary increase in concentrations in the lower Tar and Ells rivers from 2002 to 2007. Generally, concentrations of arsenic in sediments collected under the Sediment Quality component since 1997 are consistent with or lower than those measured throughout the Athabasca-Slave-Mackenzie River basins (DeBoer *et al.* 2007).

Sediment Toxicity

Survival and growth of larvae of *Chironomus tentans* and amphipod *Hyalella azteca* in sediments collected from the RAMP FSA (n=5 replicates/test), relative to laboratory controls are shown in Figure 7.3-14 and Figure 7.3-15.

In some *Chironomus* tests, a majority of replicate exposures to sediments from the RAMP FSA exhibited survival below the 95% confidence ellipse of laboratory-control survival, including sediments from the Athabasca River upstream of the Embarrass, *test* station ATR-ER, Fletcher Channel, *test* station FLC-1, lower Jackpine Creek, *test* station JAC-D-1, and *baseline* station JAC-D-2 (Figure 7.3-14). Greater variability in survival of laboratory controls was observed in tests using *Chironomus* in 2008 (RAMP 2009a). No consistent differences in survival are apparent with respect to location in the RAMP FSA or reach classification (*test* versus *baseline*).

Results of sediment tests using the amphipod *Hyalella* were generally less variable than those using *Chironomus*. Survival of *Hyalella* in all sediments tested was similar to laboratory controls, while growth was generally higher in sediments tested than laboratory controls (Figure 7.3-15).

Figure 7.3-13 Concentrations of total arsenic in sediments sampled by RAMP in tributaries to the Athabasca River, 1997 to 2009.

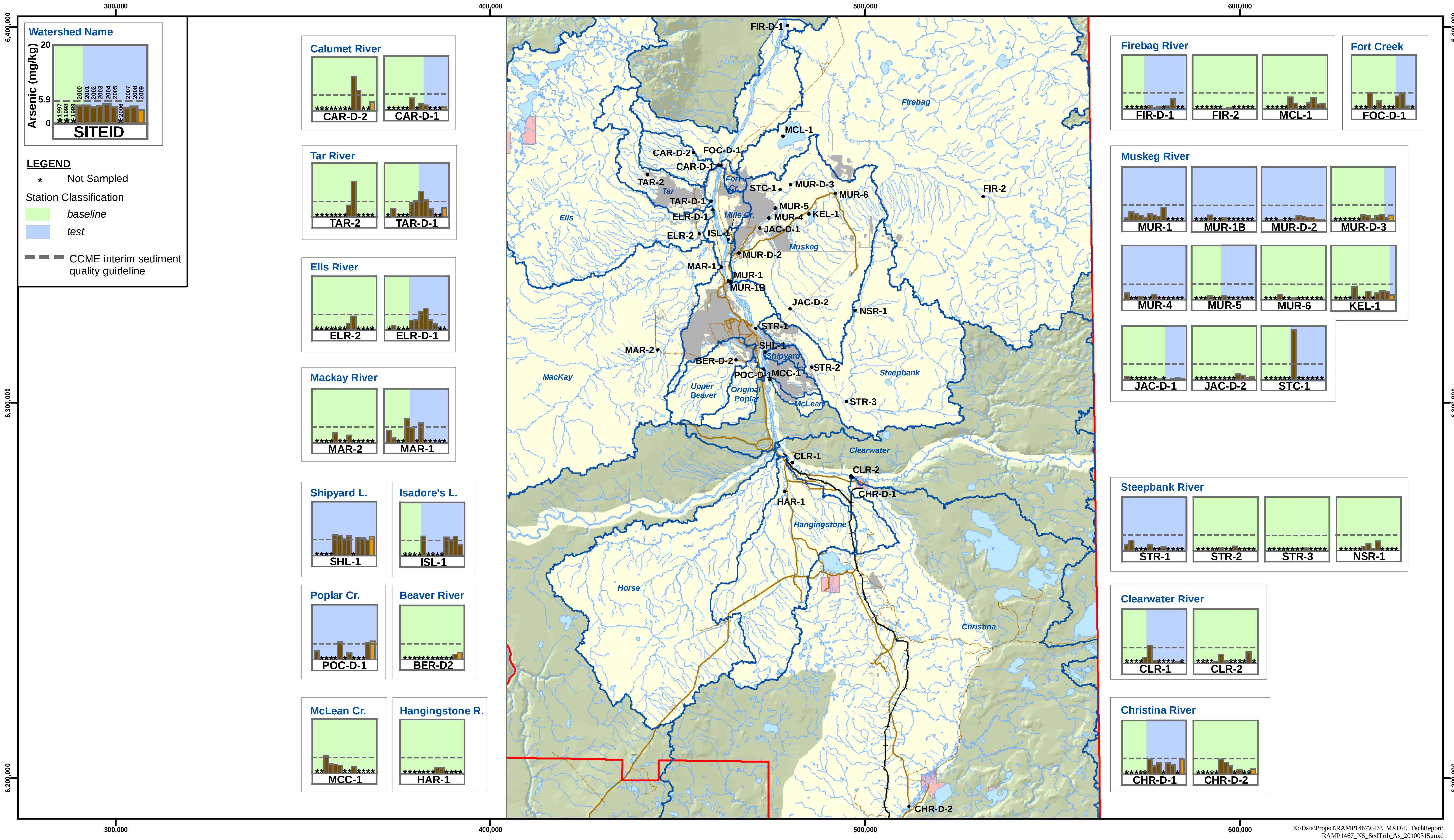


Figure 7.3-14 Survival and growth of *Chironomus* in sediments collected from the RAMP FSA in 2009, relative to laboratory control samples.

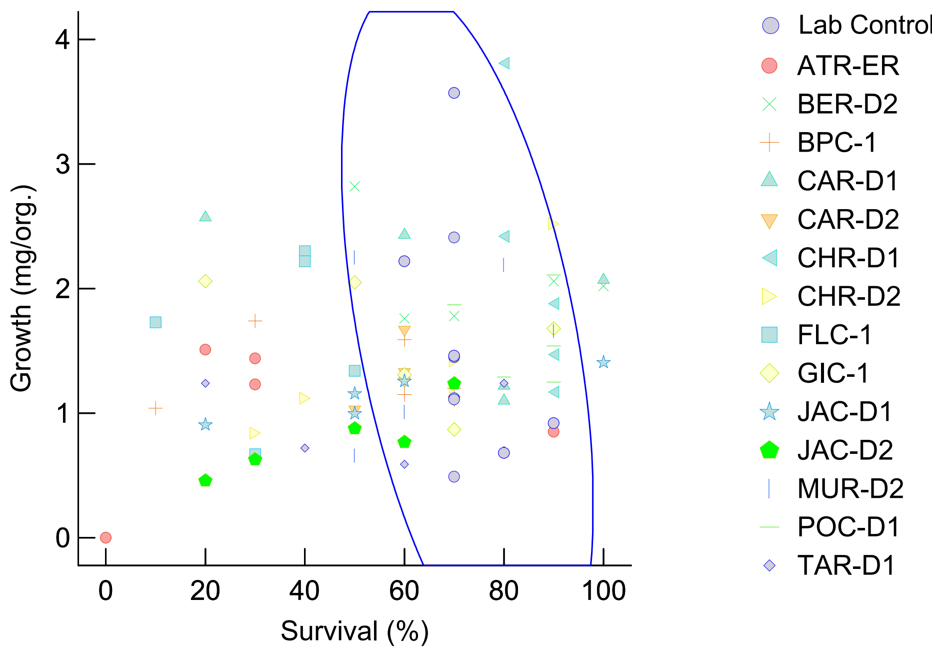
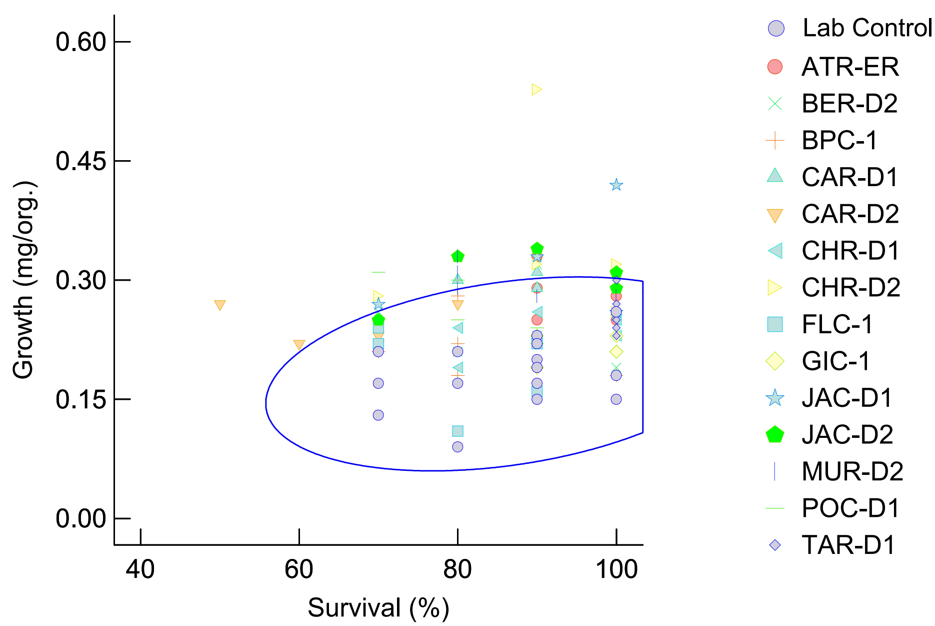


Figure 7.3-15 Survival and growth of *Hyalella azteca* in sediments collected from the RAMP FSA in 2009, relative to laboratory control samples.



7.3.2.2 Relationships Between Sediment Quality and Benthic Invertebrate Community Measurement Endpoints

No moderate or strong correlations between sediment quality and benthic community measurement endpoints were observed in correlation analysis using data from 2006 to 2009, although several weak but statistically-significant correlations were detected (Table 7.3-2).

Generally, benthic invertebrate communities in these depositional environments exhibited higher abundance in sediments with finer particle size with the exception of EPT taxa (i.e., mayflies, stoneflies and caddisflies), which were less abundant in more depositional environments, as would be expected given their preferred habitats are erosional. Although benthic invertebrate community measurement endpoints were correlated with concentrations of total metals, total metals were also strongly correlated with fine, carbon-rich sediments, which also were correlated with higher abundance and lower species richness of benthic invertebrate communities. No correlations of concentrations of total hydrocarbons and PAHs with any benthic invertebrate community measurement endpoint were observed with the exception of F3 hydrocarbons, concentrations of which were significantly and positively correlated with benthic invertebrate abundance. This is likely due to a moderate correlation (r_s=0.62) between concentrations of F3 hydrocarbons and TOC, which also was significantly correlated with abundance (Table 7.3-2).

The results suggest that the depositional nature of habitats (i.e., fine sediments) exerts a stronger influence on benthic invertebrate communities than concentrations of hydrocarbons, PAHs, or metals.

Table 7.3-2 Correlations (Spearman's coefficients) among benthic invertebrate community and sediment quality measurement endpoints, 2006 to 2009.

Sediment Quality Measurement Endpoint	Benthic Invertebrate Measurement Endpoint				
	Abundance	**Taxa Richness**	**Simpson's Diversity**	**Evenness**	**%EPT**
Physical Variables					
% Clay	*0.23*	*-0.35*	-0.19	-0.10	-0.35
% Sand	*-0.29*	0.15	0.19	0.12	*0.38*
% Silt	*0.34*	*-0.25*	-0.21	-0.14	*-0.42*
Total organic carbon	*0.33*	0.05	0.06	0.04	-0.04
Inorganic carbon	*0.34*	-0.15	-0.17	-0.19	*-0.34*
Total carbon	*0.36*	0.01	0.04	0.02	-0.09
Hydrocarbons & PAHs					
CCME F2 (C10-C16)	0.05	0.13	-0.05	-0.10	-0.02
CCME F3 (C16-C34)	*0.28*	0.17	0.13	0.06	-0.02
CCME F4 (C34-C50)	0.17	0.16	0.13	0.06	-0.01
CCME TPH (C6-C50)	0.22	0.20	0.20	0.12	0.04
Total PAHs	0.22	0.11	0.13	0.08	-0.14
Naphthalene	*0.35*	-0.16	-0.12	-0.11	-0.23
Retene	*0.32*	0.16	0.28	0.21	0.09
Metals					
Total metals (PC1)	0.21	*-0.39*	*-0.26*	*-0.32*	*-0.43*

n=72; Critical value of r_s=|0.232|; values in *italics* indicate significant correlation; values in **bold** indicate moderate correlation (i.e., |0.50|>r_s>|0.75|).

7.3.2.3 Summary

Sediments in the RAMP FSA naturally contain hydrocarbons and PAHs at concentrations that may exceed environmental quality guidelines. Spatial and temporal comparisons of sediment quality since monitoring by RAMP began in 1997 do not indicate any consistent trends over time in concentrations of hydrocarbons or metals, any consistent, regional differences in sediment quality between *baseline* and *test* stations, or any relationships between sediment chemistry and composition of benthic invertebrate communities.

7.4 FISH POPULATIONS

The regional synthesis of the 2009 RAMP Fish Population component focuses on fish inventories in the Athabasca River and mercury concentrations in fish tissue. Other parts of the 2009 Fish Population component, including large-bodied fish counting fence on the Muskeg River and sentinel species monitoring are discussed in the appropriate parts of Section 5.

7.4.1 Athabasca River Fish Inventory Program[2]

The results from the fish inventories suggest that, although there is variation in fish inventory measurement endpoints across years, relative abundance, species richness and condition of KIR fish species since 1997 has generally remained within historical *baseline* ranges of values for these measurement endpoints (defined for this analysis as the 5th to 95th percentile of the value of the measurement endpoint from 1986 to 1996, prior to major oil sands development within the RAMP FSA):

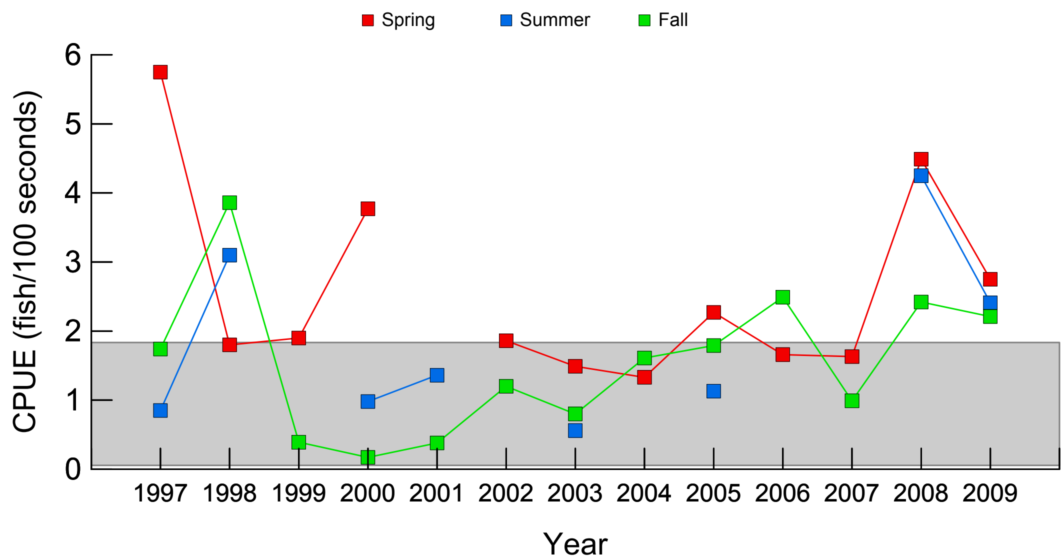
1. The CPUE of all KIR fish species combined (Figure 7.4-1) was generally greater than historical *baseline* ranges for CPUE in 1997 and 1998, and within the historical *baseline* range from 2000 to 2004. The CPUE began increasing in 2005 with values in 2008 and 2009 often greater than the 95th percentile of the regional *baseline* range of CPUE. CPUE values for 2009 in spring, summer, and fall were all greater than the regional *baseline* range for CPUE (Figure 7.4-1).

2. The number of species in the Athabasca River has been relatively consistent over time (Figure 7.4-2) and, including 2009, either within or greater than the historical *baseline* range of species richness for the Athabasca River.

3. The condition (i.e., weight-length relationship) of KIR fish species in the Athabasca River (Figure 7.4-3) has remained within historical *baseline* ranges of condition since 1997, with the exception of condition of goldeye, northern pike and walleye in summer 2008, which were below the 5th percentile of regional *baseline* condition values.

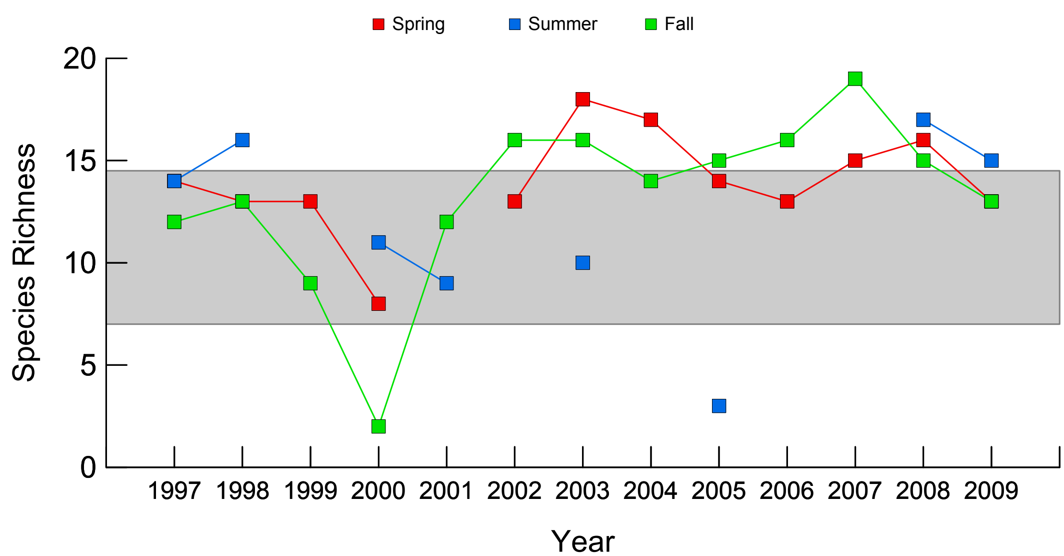
[2] Historical *baseline* ranges in values of fish inventory measurement endpoints cannot be developed for the Clearwater River as fish inventories were not conducted on the Clearwater River prior to major oil sands development in the RAMP FSA. Based on tagging studies conducted by RAMP, it is likely that fish populations using the Athabasca River are the same as ones using the Clearwater River, given the large spatial extent of migration patterns (see Section 5.1 for fish tagging results).

Figure 7.4-1 Catch per unit effort (CPUE) of all KIR fish species combined in the Athabasca River, 1997-2009, relative to the *regional* baseline range (1987-1996).



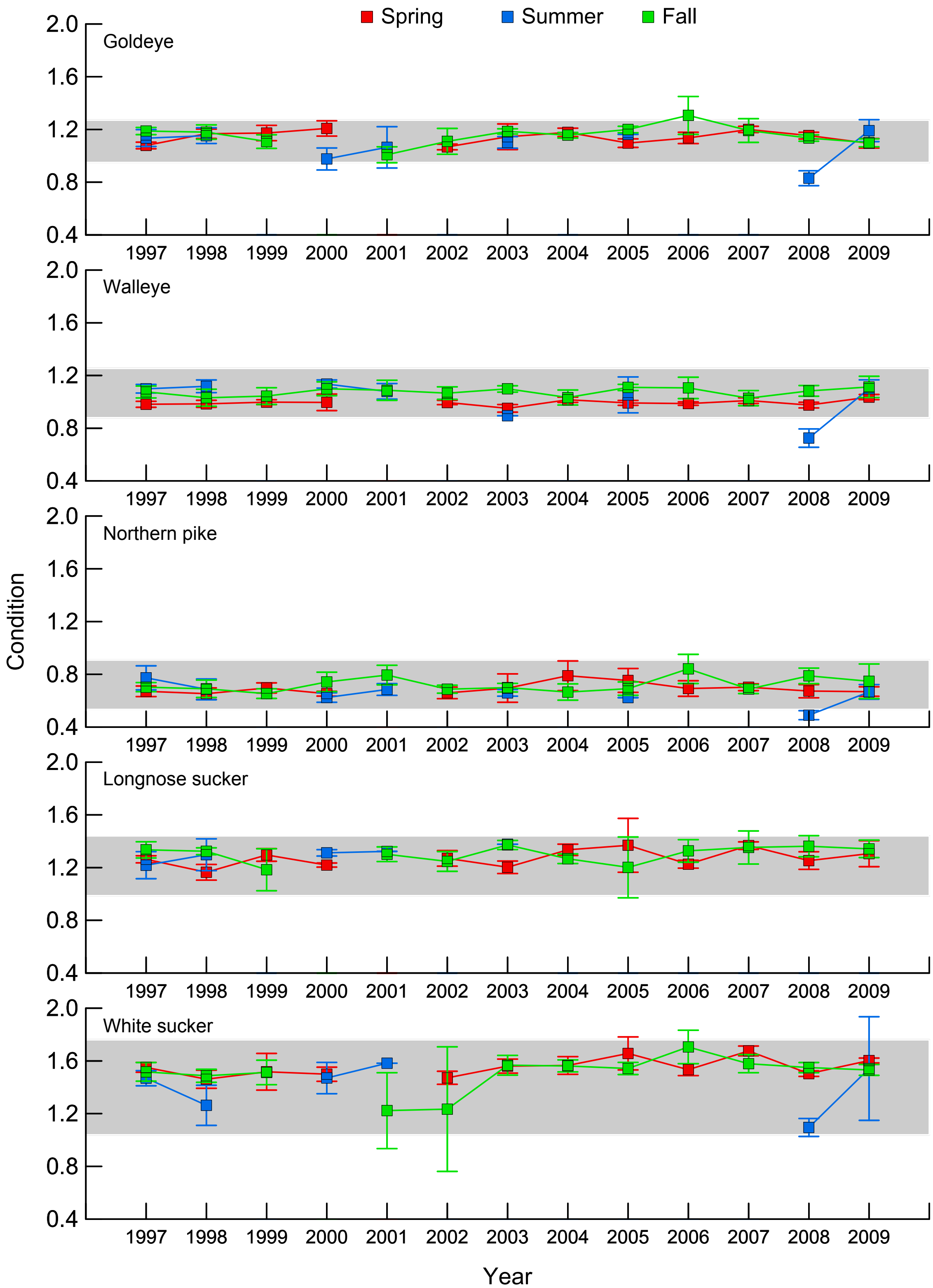
Note: Shaded area is the *baseline* range (5th to 95th percentiles) of CPUE of all KIR fish species from 1986 to 1996, prior to major oil sands development within the RAMP FSA.

Figure 7.4-2 Fish species richness in the Athabasca River, 1997-2009, relative to the regional *baseline* range (1987-1996).



Note: Shaded area is the *baseline* range (5th to 95th percentiles) of species richness of all KIR fish species from 1986 to 1996, prior to major oil sands development within the RAMP FSA.

Figure 7.4-3 Condition of KIR fish species in the Athabasca River, 1997-2009, relative to the regional *baseline* range (1987-1996).



Note: Shaded areas are *baseline* ranges (5th to 95th percentiles) of condition for each KIR fish species from 1986 to 1996, prior to major oil sands development within the RAMP FSA; error bars are 95% confidence intervals.

7.4.2 Mercury in Fish Tissue

To provide a regional context for the results from the 2009 RAMP fish tissue program (described in detail in Sections 5.9 and 5.12), Figure 7.4-4 to Figure 7.4-6 provide regional descriptions of fish tissue mercury concentrations related to human consumption guidelines (see Section 3.4.7.6) in lakes and rivers in northern Alberta (AOSERP 1977, Grey *et al.* 1995, Golder 2004, NRBS 1996, RAMP 2003, RAMP 2004, RAMP 2008, RAMP 2009a).

Lake Whitefish A summary of the 2009 fish tissue results for lake whitefish and the regional context for these results is as follows:

1. 0% of lake whitefish collected from Jackson Lake exceeded the Health Canada subsistence fisher and general consumer guidelines.

2. The mean concentration of mercury in lake whitefish in all waterbodies in the regional dataset was below the Health Canada subsistence consumption guideline (Figure 7.4-4).

Northern Pike A summary of the 2009 fish tissue results for northern pike and the regional context for these results is as follows:

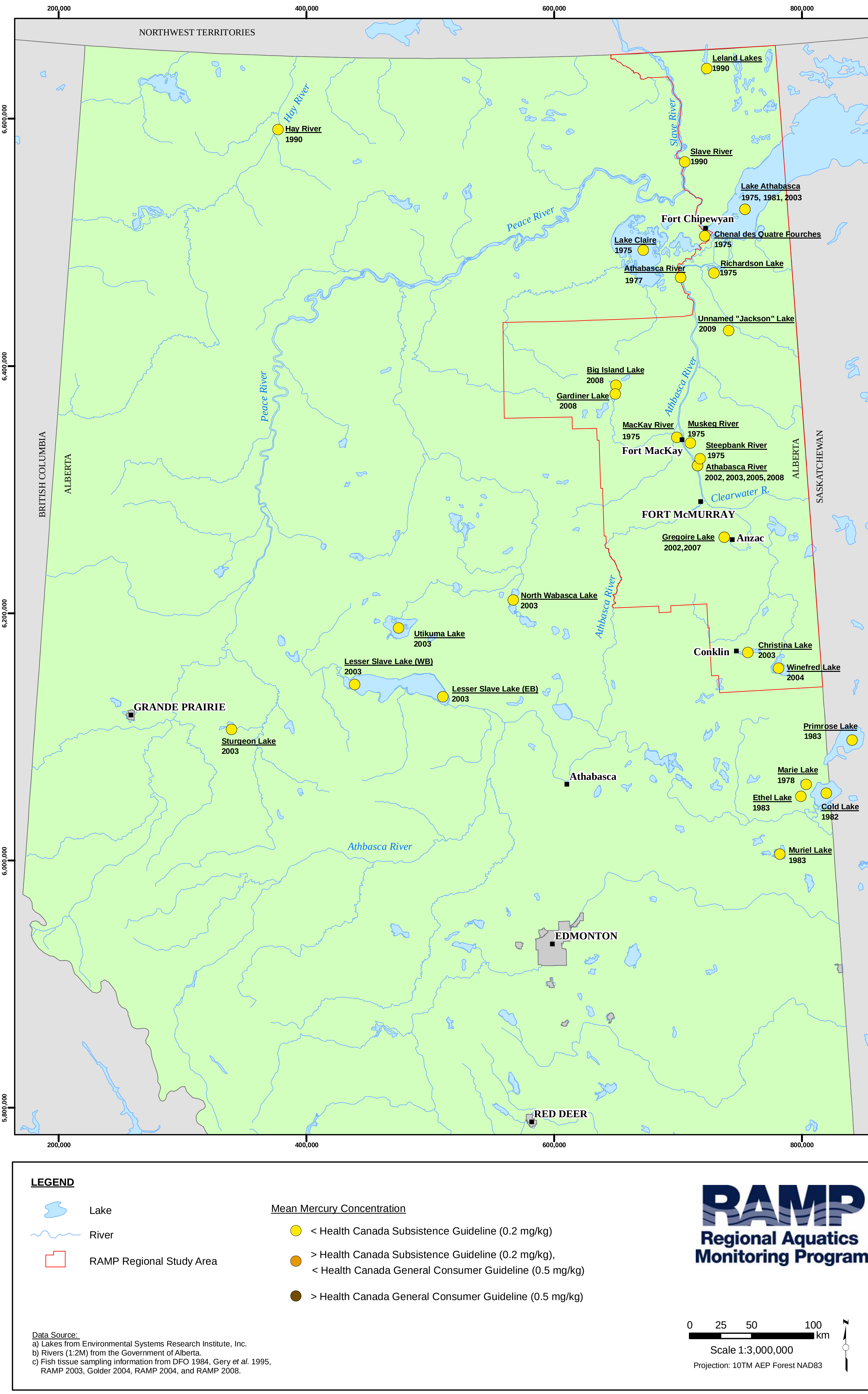
1. 10% (two individuals greater than 600 mm in length) of northern pike collected from the Clearwater River exceeded the Health Canada subsistence fisher guideline (0.2 mg/kg), while 0% exceeded the general consumer guideline (0.5 mg/kg). The single northern pike captured in Jackson Lake did not exceed the Health Canada subsistence fisher guideline.

2. The low incidence of exceedances of Health Canada guidelines for mercury concentration in fish tissue in northern pike in RAMP FSA waterbodies is in contrast to data presented in Evans *et al.* (2005) that show mercury concentrations exceeding the Health Canada subsistence guideline in northern areas in Canada (North West Territories, Nunavut, and Québec) in at least 50% of all northern pike captured. Results from northern pike sampling by RAMP have only observed this incidence in northern pike greater than 600 mm fork length.

3. In waterbodies sampled for northern pike, mean mercury concentrations in 55% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, mean mercury concentrations in 38% of the waterbody-year combinations exceeded the Health Canada subsistence fisher guideline, and mean mercury concentrations in 6% of the waterbody-year combinations exceeded the Health Canada general consumer guideline (Figure 7.4-5).

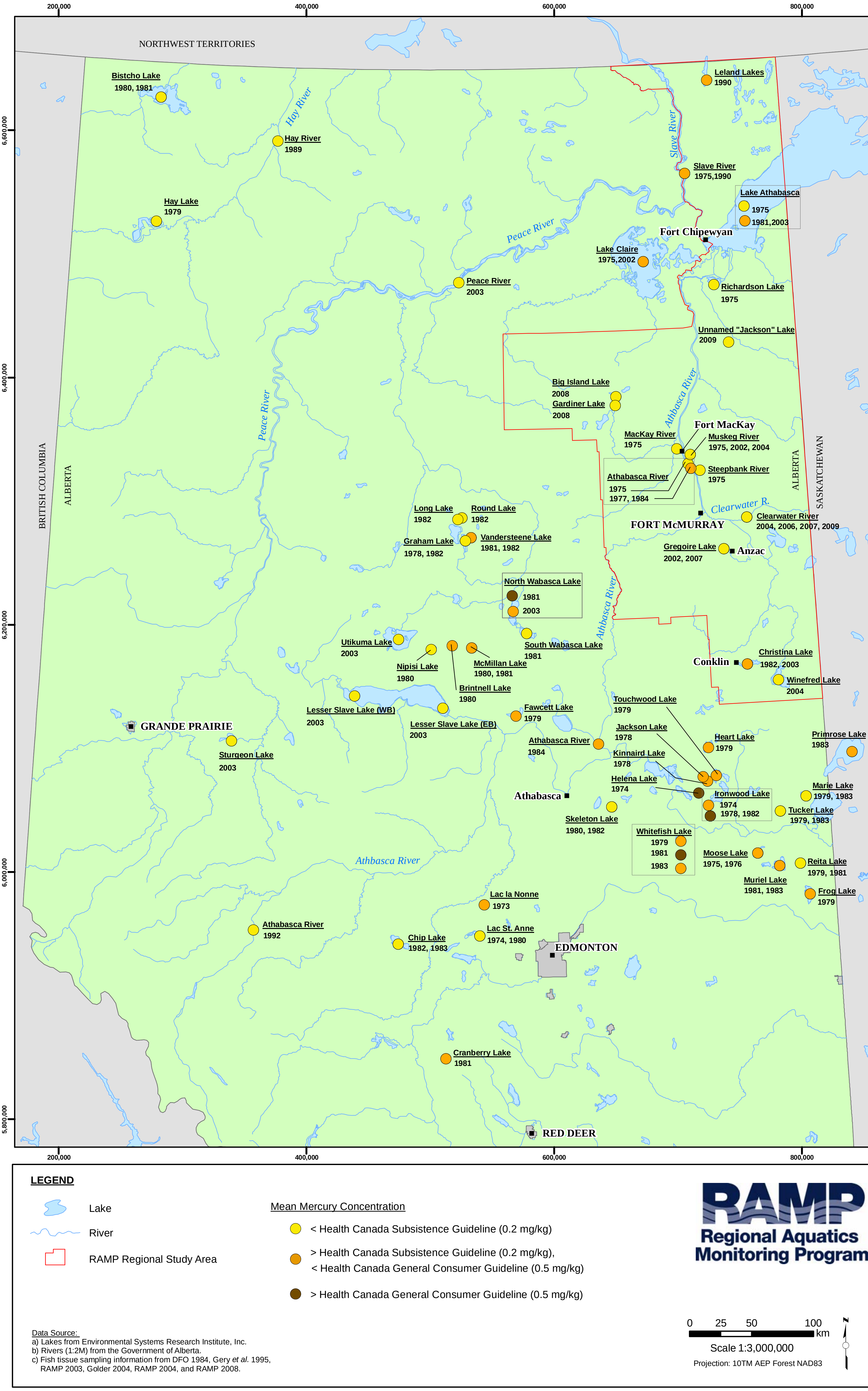
4. The waterbody-year combinations with mean mercury concentrations in northern pike that exceeded the Health Canada general consumer guideline were all located outside and to the south of the RAMP FSA and years prior to any major oil sands development (Figure 7.4-5).

Figure 7.4-4 Mean mercury concentrations in lake whitefish from lakes and rivers in northern Alberta, 1975-2009.



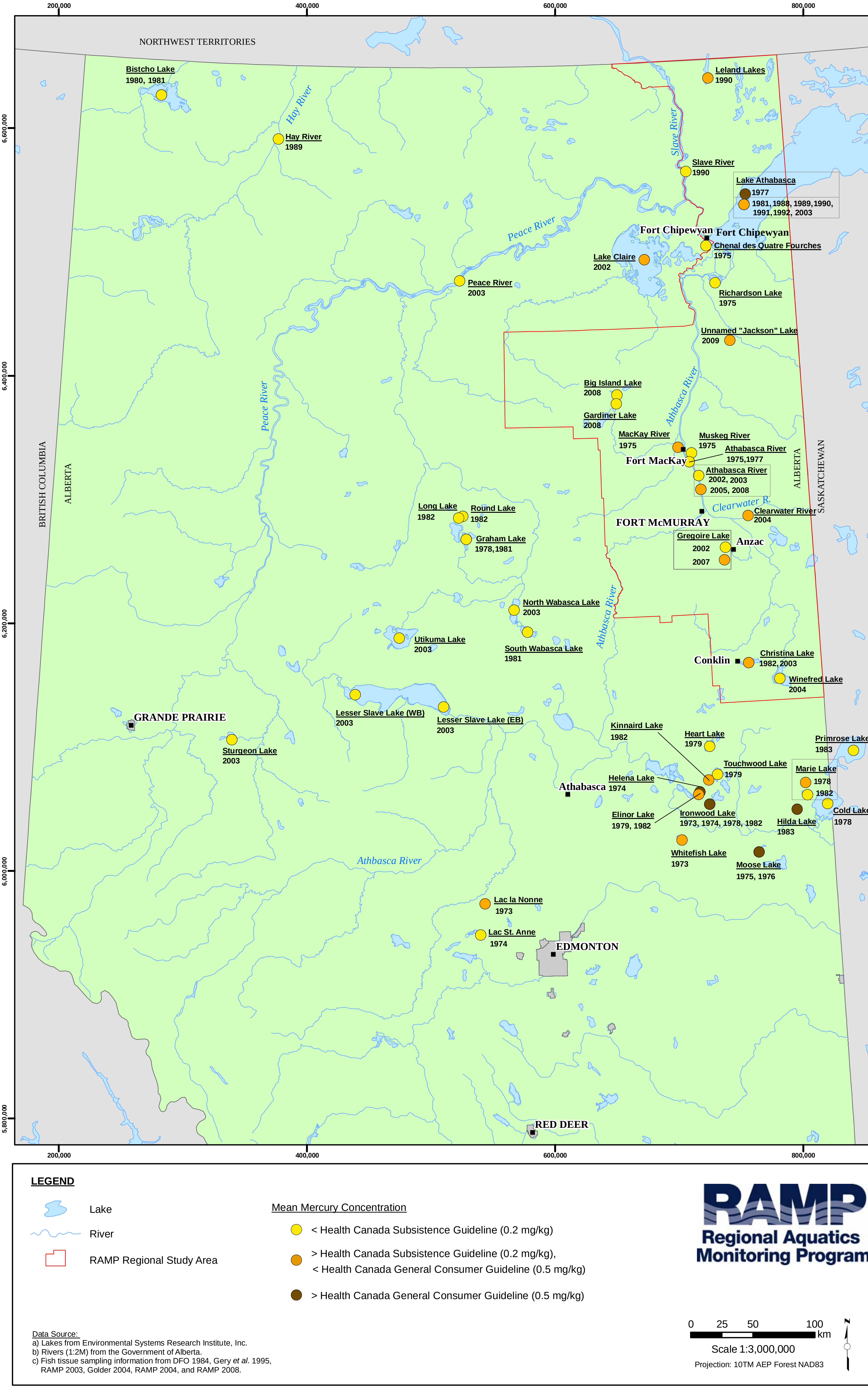
K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_P2_FishMercuryLKWH_20100315.mxd

Figure 7.4-5 Mean mercury concentrations in northern pike from lakes and rivers in northern Alberta, 1975-2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_P3_FishMercuryNRPK_20100315.mxd

Figure 7.4-6 Mean mercury concentrations in walleye from lakes and rivers in northern Alberta, 1975-2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_P4_FishMercuryWALL_20100315.mxd

There is no clear spatial or temporal trend in mean mercury concentration in northern pike in waterbodies increasing from above or below a given Health Canada consumption guideline in northern Alberta (Figure 7.4-5). In particular, for waterbodies within the RAMP RSA where mercury in northern pike has been measured for a number of years (i.e., Clearwater River, Muskeg River, Athabasca River, and Lake Athabasca), there have been some cases where concentrations increased from below to above the Health Canada subsistence guideline but these increases occurred in the early 1980s, and concentrations have generally remained consistent since then (Figure 7.4-5).

Walleye A summary of the 2009 fish tissue results for walleye and the regional context for these results is as follows:

1. 59% of walleye collected from Jackson Lake exceeded the Health Canada subsistence fish guideline and one of these fish exceeded the general consumer guideline.

2. In waterbodies sampled for walleye, mean mercury concentrations in 50% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, 36% of waterbody-year combinations exceeded the Health Canada subsistence fisher guideline, and 14% of waterbody-year combinations exceeded the Health Canada general consumer guideline (Figure 7.4-6).

3. The waterbody-year combinations with mean mercury concentrations in walleye that exceeded the Health Canada general consumer guideline were all located outside and to the south of the RAMP FSA and years prior to any major oil sands development (Figure 7.4-5).

4. With the exception of Lake Athabasca, all waterbodies where the mean mercury concentration exceeded the general consumer guideline were located outside and to the south of the RAMP FSA and in years prior to 1984 (Figure 7.4-6). The exceedance of the Health Canada general consumer guideline for mercury in walleye in Lake Athabasca was measured in 1977; since then, the mean mercury concentration in walleye in Lake Athabasca has been below the Health Canada general consumer guideline (Figure 7.4-6).

5. For the Athabasca River and Gregoire Lake located in the RAMP FSA, there have been some incidences of increases in mercury concentrations from below to above the Health Canada subsistence guideline in recent years (RAMP 2008, RAMP 2009a) resulting in specific consumption guidelines established for these waterbodies (GOA 2009b).

As mentioned in Section 2.2, there is muskeg dewatering and land clearing occurring in the RAMP FSA which could lead to increased levels of inorganic mercury in watercourses (Grigal 2003). Inorganic mercury is methylated by anaerobic activity in water and taken up by fish in this form, resulting in increases in mercury in muscle tissue of fish in these watercourses. However, the spatial patterns and temporal trends of available mercury data in water of rivers and lakes within the RAMP FSA do not indicate such an increase is occurring (Figure 7.4-4 to Figure 7.4-6).

7.5 ACID-SENSITIVE LAKES

This section presents the results of the Acid-Sensitive Lakes (ASL) component of RAMP for 2009.

7.5.1 Among-Year Comparison of ASL Measurement Endpoints

The results of the among-year comparisons of the ASL measurement endpoints conducted using ANOVA are similar to those reported for previous years; nitrate was the only ASL measurement endpoint to show a significant change in concentration over the eight years (Table 7.5-1). The decrease in concentration of nitrate in RAMP ASL lakes between 2002 and 2009 is the opposite of what would be expected in an acidification scenario triggered by nitrogen emissions.

Table 7.5-1 Summary of nitrate concentrations in the RAMP ASL lakes, 2002-2009.

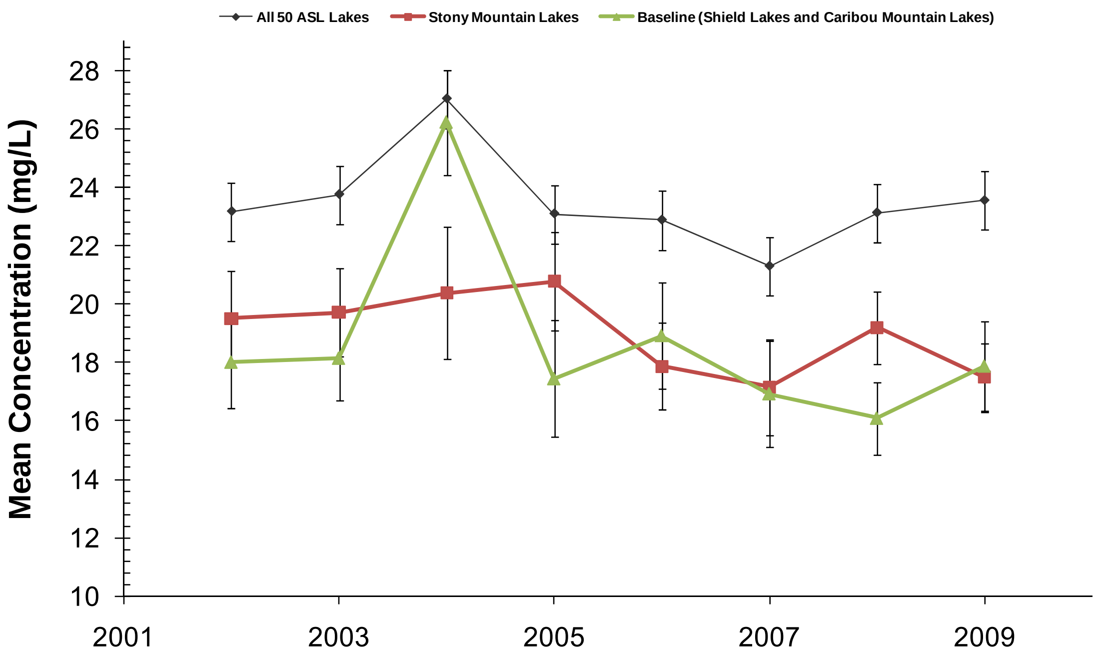
	2002	2003	2004	2005	2006	2007	2008	2009
N	49	50	50	49	48	48	49	50
Mean (mg/L)	44.0	7.5	32.3	11.5	12.9	16.1	13.5	11.5
Median (mg/L)	5.3	0.5	1.0	2.9	5.4	2.0	3.0	3.0
Standard Deviation	114.0	22.3	101.0	28.7	28.1	50.6	41.8	26.1
Coefficient of Variation (%)	260	298	313	250	217	315	309	227

ANOVA using the General Linear Model was applied to all ASL measurement endpoints over all 50 RAMP ASL lakes as well as to selected subregional groups of RAMP ASL lakes. There were no significant relationships between any of the ASL measurement endpoints and year in the 50 RAMP ASL lakes with the exception of DOC ($p = 0.044$), in which the concentration of DOC declined in 29 of the 50 RAMP ASL lakes over the sampling period. Significant relationships between concentration of DOC and year were also obtained for (Figure 7.5-1):

- Lakes in the Stony Mountain region ($p=0.029$), a subregion with high sensitivity to acid deposition (Section 3.5, Figure 3.5-1) and in which eight out of ten RAMP ASL lakes had a decline in concentration of DOC over the sampling period; and
- Lakes in the Canadian Shield and Caribou Mountain subregions, combined ($p=0.031$), subregions that are farthest of all the RAMP ASL lakes from oil sands development and should not show any effects from acid deposition, and in which also eight out of ten RAMP ASL lakes had a decline in concentration of DOC over the sampling period.

These results suggest that the significant decline in concentration of DOC calculated for the 50 RAMP ASL lakes is a natural phenomenon rather than a response to acidification. In addition, a response to acidification would have been expected first in Gran alkalinity or in pH rather than DOC and significant between-year differences in these ASL measurement endpoints were not detected.

Figure 7.5-1 Concentrations of Dissolved Organic Carbon (± 1SE) in all the 50 RAMP ASL lakes combined, the Stony Mountain lakes and the *baseline* lakes.



7.5.2 Critical Loads of Acidity and Critical Load Exceedances

Table 7.5-2 presents the estimates of the critical loads of acidity for each RAMP ASL lake between 2002 and 2009 estimated by the hydrometric and isotopic mass balance (IMB) methods; the summary statistics for the critical loads are provided in Table 7.5-3. In general, the IMB-derived critical load values were greater than the hydrometrically-derived values. Using the hydrometrically-derived runoff, the critical loads in 2009 ranged from -0.109 keq H^+/ha/yr to 1.952 keq H^+/ha/yr with a median of 0.229 keq H^+/ha/yr while using the isotopically-derived runoff, critical loads ranged from -0.546 keq H^+/ha/yr to 3.38 keq H^+/ha/yr with a median CL of 0.387 keq H^+/ha/y (Table 7.5-3). Mean critical loads in 2009 for the two methods (hydrometric and IMB) in the six subregions are provided in Table 7.5-4.

Low critical loads calculated for RAMP ASL lakes in the Stony Mountains, Birch Mountains, and Canadian Shield subregions are consistent with the findings of previous years (RAMP 2005, 2006, 2007). Negative critical loads were calculated for many of the lakes, especially in the Stony Mountains subregion. By the critical load criterion, these lakes are the most acid-sensitive of the RAMP ASL lakes.

7.5.2.1 Comparison of Critical Loads of Acidity to Modeled Potential Acid Input

Lakes having a modeled potential acid input (PAI) greater than the critical load are identified in Table 7.5-3. Based on the IMB-calculated critical loads, the percentage of such lakes ranged from a low of 22.4% (11 of 49 lakes) in 2005 to a high of 44.7% (21 of 47 lakes) in 2007 (Table 7.5-3).

Table 7.5-2 Critical loads[1] of acidity in the RAMP ASL Lakes, 2002 to 2009.

Nox-Sox GIS No.	Original RAMP Designation	Critical Load (keq H+/ha/y)																
		PAI 2006	2002 Hydro	2002 IMB	2003 Hydro	2003 IMB	2004 Hydro	2004 IMB	2005 Hydro	2005 IMB	2006 Hydro	2006 IMB	2007 Hydro	2007 IMB	2008 Hydro	2008 IMB	2009 Hydro	2009 IMB
Stony Mountains Subregion																		
168	A21	0.186	-0.089	-0.069	-0.079	-0.080	-0.087	-0.097	-0.118	-0.130	-0.081	-0.099	-0.070	-0.051	-0.069	-0.110	-0.060	-0.065
169	A24	0.177	-0.124	-0.182	-0.071	-0.137	-0.205	-0.391	-0.132	-0.509	-0.104	-0.252	-0.033	-0.070	-0.083	-0.225	-0.080	-0.187
170	A26	0.186	-0.030	-0.015	-0.028	-0.019	-0.036	-0.028	-0.047	-0.052	-0.045	-0.041	-0.012	-0.008	0.003	0.004	-0.022	-0.018
167	A29	0.145	-0.028	-0.072	-0.019	-0.052	-0.002	-0.006	0.004	0.016	0.033	0.099	-0.002	-0.005	-0.033	-0.210	0.011	0.037
166	A86	0.117	0.094	0.065	0.101	0.146	0.109	0.193	0.110	0.262	0.100	0.213	0.104	0.150	0.141	0.515	0.133	0.257
287	25	0.179	-0.056	-0.089	-0.055	-0.129	-0.075	-0.190	-0.077	-0.273	-0.068	-0.194	-0.032	-0.025	-0.040	-0.145	-0.058	-0.143
289	27	0.175	0.019	0.036	0.029	0.078	0.035	0.087	0.035	0.159	0.030	0.093	0.044	0.095	0.030	0.112	0.033	0.095
290	28	0.181	0.004	0.001	0.033	0.020	-0.008	-0.004	-0.007	-0.004	0.012	0.007	-0.014	-0.007	0.003	0.002	0.002	0.001
342	82	0.120	0.208	0.065	0.181	0.060	0.165	0.120	0.125	0.158	0.182	0.119	0.122	0.012	0.090	0.117	0.099	0.066
354	94	0.141	0.322	0.711	0.225	0.679	0.213	0.816	0.226	1.046	0.179	0.428	0.186	0.152	0.220	1.425	0.226	0.753
West of Fort McMurray Subregion																		
165	A42	0.121	0.388	0.386	0.373	0.890	0.553	1.416	0.706	2.189	0.455	1.008	0.359	0.729	0.419	2.226	0.526	1.398
171	A47	0.120	0.217	0.107	0.167	0.173	0.152	0.133	0.253	0.497	0.207	0.154	0.168		0.332	0.830	0.233	0.244
172	A59	0.076	0.038	0.006	0.001	0.000	0.002	0.001	-0.023	-0.017	-0.075	-0.026	-0.061	-0.017	0.046	0.038	0.032	0.014
223	P94	0.258	1.120	0.118	1.031	0.097	1.054	0.124	1.399	1.280	1.004	0.200	0.829	0.088	0.996	0.339	0.982	0.263
225	P96	0.238	0.745	0.122	0.595	0.265	0.666	0.234	0.825	1.507	0.669	0.384	0.506	0.201	0.574	0.416	0.568	0.364
226	P97	0.353	0.328	0.089	0.346	0.344	0.266	0.205	1.377	2.708	0.238	0.194	0.277	0.169	0.373	0.292	0.301	0.267
227	P98	0.307	0.969	0.287	0.956	1.150	0.917	0.583	0.462	0.862	1.042	0.954	0.857	0.463	1.071	1.073	0.981	0.905
267	1	0.214	1.055	0.195	1.024	0.398	0.994	0.350	1.091	0.939	0.732	0.413	0.630	0.146			0.863	0.318
Northeast of Fort McMurray Subregion																		
452	L4	0.222	0.070	0.098	0.070	0.096	0.078	0.073	0.143	0.270	0.073	0.093	0.095	0.066	0.100	0.271	0.092	0.135
470	L7	0.646	0.170	0.176	0.190	0.143	0.141	0.075	0.307	0.316	0.707	0.769	0.357	0.159	0.238	0.235	0.233	0.195
471	L8	0.607	0.528	0.346	0.622	0.611	0.527	0.439	0.659	1.138	0.340	0.627	0.527	0.228	0.567	0.591	0.491	0.527
400	L39	0.085	0.157	1.155	0.157	0.958	0.144	0.788	0.073	0.769	0.316	1.571	0.251	0.793	0.204	1.457	0.170	1.086
268	E15	0.206	0.520	1.363	0.465	2.226	0.400	1.489	0.505	2.381	0.092	0.273	0.421	0.417	0.509	2.050	0.532	1.810
182	P23	0.250	0.294	0.360	1.084	1.260	2.017	1.442	2.008	4.101	0.443	0.351	1.333	2.010	0.199	0.066	1.952	2.169
185	P27	0.220	0.035	0.044	0.017	0.016	-0.095	-0.071	0.233	0.280	-0.030	-0.028	0.035	0.034	0.041	0.052	0.019	0.020

Shaded values represent critical loads exceeding modeled Potential Acid Input, obtained from the 2006 Deer Creek Joslyn North Mine EIA, Deer Creek Energy (2006) for Stony Mountains, west of Fort McMurray, northeast of Fort McMurray, and Birch Mountains subregions and from Foster *et al*. (2001) for Canadian Shield and Caribou Mountains subregions.

[1] Estimate of PAI was based on SO_2 deposition alone except for lakes receiving nitrogen deposition above a threshold value of 9 kg/ha/y.

Hydro – runoff estimated using traditional hydrometric methods; IMB – runoff estimated using analysis of heavy isotopes of oxygen and hydrogen.

Table 7.5-2 (Cont'd.)

Nox-Sox GIS No.	Original RAMP Designation	Critical Load (keq H^+/ha/yr)																
		PAI 2006	2002 Hydro	2002 IMB	2003 Hydro	2003 IMB	2004 Hydro	2004 IMB	2005 Hydro	2005 IMB	2006 Hydro	2006 IMB	2007 Hydro	2007 IMB	2008 Hydro	2008 IMB	2009 Hydro	2009 IMB
Northeast of Fort McMurray Subregion (Cont'd.)																		
209	P7	0.195	0.141	0.898	0.163	0.809	0.112	0.355	0.089	0.651	0.109	0.428	0.143	0.423	0.311	2.593	0.155	0.818
270	4	0.181	1.382	3.392	1.318	4.505	1.408	5.008	1.705	8.061	1.037	4.614	0.904	1.336	1.021	3.974	0.987	3.380
271	6	0.133	1.293	2.459	1.449	2.672	1.931	6.400	1.369	7.360	1.009	3.576	0.856	2.332	0.873	3.082	0.810	2.572
418	Kearl Lake	0.367	1.254		1.280	2.854	1.290	2.410	1.664	5.309	1.192	1.783	1.293	0.811	1.551	2.670	1.466	2.331
Birch Mountains Subregion																		
436	L18	0.122	0.235	1.815	0.239	2.803	0.226	2.334	0.313	2.802	0.225	2.393	0.231	1.325	0.269	3.245	0.255	2.446
442	L23	0.094	0.087	0.268	0.074	0.366	0.065	0.277	0.074	0.378	0.059	0.330	0.074	0.305	0.093	0.445	0.085	0.389
444	L25	0.096	0.088	0.632	0.097	1.072	0.099	0.988	0.134	0.977	0.109	1.107	0.111	0.636	0.119	1.401	0.140	1.259
447	L28	0.056	-0.016	-0.083	-0.025	-0.155	0.002	0.006	-0.025	-0.246	-0.039	-0.214	0.001	0.006	0.008	0.044	-0.017	-0.097
448	L29	0.086	-0.127	-0.682	-0.090	-0.502	-0.073	-0.487	-0.111	-0.713	-0.117	-0.419	-0.025	-0.076	-0.088	-0.386	-0.109	-0.546
454	L46	0.097	0.394	0.511	0.375	0.675	0.365	0.395	0.374	1.160	0.303	0.492	0.482	0.357	0.480	0.592	0.333	0.518
455	L47	0.074	0.282	0.724	0.241	0.858	0.958	1.750	0.324	2.267	0.272	1.146	0.286	0.492	0.301	1.403	0.318	1.159
457	L49	0.085	0.301	0.629	0.260	0.938	0.283	0.495	0.234	1.580	0.210	0.722	0.205	0.279	0.247	0.960	0.243	0.792
464	L60	0.078	0.408	0.368	0.420	0.693	0.501	0.511	0.422	0.831	0.319	0.419	0.356	0.246	0.395	0.620	0.325	0.423
175	P13	0.145	1.198	0.405	1.235	0.348	2.149	0.654	1.449	1.503	1.099	0.632	0.818	0.305	0.959	0.822	1.454	0.782
199	P49	0.172	0.245	0.111	0.215	0.152	0.237	0.174	0.247	0.199	0.305	0.214	0.191	0.080	0.293	0.140	0.187	0.115
Canadian Shield Subregion																		
473	A301	0.014[2]	0.210	0.107	0.194	0.129	0.189	0.101	0.264	0.334	0.197	0.167			0.230	0.214	0.225	0.180
118	L107	0.007[2]	0.118	2.116	0.116	2.351	0.114	1.850	0.168	2.754	0.109	2.075	0.101	1.478	0.133	2.813	0.121	2.171
84	L109	0.014[2]	0.409	0.182	0.394	0.209	0.341	0.148	0.496	0.334	0.386	0.156	0.294		0.441	0.247	0.435	0.190
88	O-10	0.014[2]	0.178	0.275	0.189	0.316	0.138	0.204			0.166	0.289			0.251	0.407	0.280	0.385
90	R1	0.014[2]	0.318	0.348	0.311	0.483	0.279	0.355	0.408	0.559	0.311	0.450	0.418	0.568	0.422	0.619	0.325	0.444
Caribou Mountains Subregion																		
146	E52	0.027[2]	0.377	1.149	0.365	1.437	0.350	1.047	0.531	2.552	0.349	2.019	0.347	2.431	0.455	4.212	0.449	2.364
152	E59	0.027[2]	0.023	0.549	0.025	0.637	0.026	0.465	0.031	1.065	0.021	0.665	0.025	0.632	0.028	0.864	0.029	0.792
89	E68	0.027[2]	0.258	0.532	0.274	0.484	0.223	0.270	0.395	1.423	0.262	0.785	0.216	0.584	0.195	0.466	0.196	0.469
97	O-2 E67	0.027[2]	0.002	0.008	0.002	0.011	0.003	0.009	0.045	0.649	0.005	0.078	0.007	0.025	0.007	0.031	0.007	0.050
91	O-1/E55	0.027[2]	2.424	7.576	2.253	8.000	1.794	4.217	0.981	2.773	1.457	4.288	1.254	4.986	1.291	6.569	0.847	2.887

Shaded values represent critical loads exceeding modeled Potential Acid Input, obtained from the 2006 Deer Creek Joslyn North Mine EIA, Deer Creek Energy (2006) for Stony Mountains, west of Fort McMurray, northeast of Fort McMurray, and Birch Mountains subregions and from Foster *et al*. (2001) for Canadian Shield and Caribou Mountains subregions.

1 Estimate of PAI was based on SO_2 deposition alone except for lakes receiving nitrogen deposition above a threshold value of 9 kg/ha/y.

Hydro – runoff estimated using traditional hydrometric methods; IMB – runoff estimated using Isotopic Mass Balance technique

Table 7.5-3 Summary of Critical Loads in ASL lakes, 2002 to 2009.

	2002		2003		2004		2005		2006		2007		2008		2009	
	Hydro	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**	**Hydro**	**IMB**
No. of Lakes	50	49	50	50	50	50	49	49	50	50	48	47	49	49	50	50
Minimum CL	-0.127	-0.682	-0.090	-0.502	-0.205	-0.487	-0.132	-0.713	-0.117	-0.419	-0.070	-0.076	-0.088	-0.386	-0.109	-0.546
Maximum CL	2.424	7.576	2.253	8.000	2.149	6.400	2.008	8.061	1.457	4.614	1.333	4.986	1.551	6.569	1.952	3.380
Average CL	0.369	0.604	0.376	0.827	0.419	0.754	0.443	1.315	0.316	0.710	0.322	0.537	0.331	1.010	0.356	0.736
Median CL	0.226	0.268	0.204	0.357	0.201	0.274	0.253	0.831	0.208	0.367	0.210	0.228	0.238	0.466	0.229	0.387
No. Lakes in which the PAI is greater than the CL	21	21	19	18	20	18	16	11	19	15	19	21	18	17	19	17
Percent Lakes in which the PAI is greater than the CL	42.0	42.9	38.0	36.0	40.0	36.0	32.7	22.4	38.0	30.0	39.6	44.7	36.7	34.7	38.0	34.0

Table 7.5-4 Mean critical loads from hydrometric and isotopic mass balance methods for each subregion, 2009.

Subregion	Critical Load (keq H^+/ha/yr)	
	Hydrometric	IMB
Stony Mountains	0.028	0.08
West of Fort McMurray	0.561	0.472
Northeast of Fort McMurray	0.628	1.368
Birch Mountains	0.292	0.658
Canadian Shield	0.277	0.674
Caribou Mountains	0.306	1.312

The percentage of RAMP ASL lakes in which the modeled PAI is greater than the critical load in 2009 (34% to 38%, Table 7.5-3) is higher than the 8% of 399 regional lakes reported in a study conducted for the NOxSOx Management Working Group within CEMA (WRS 2006). The higher proportion in the RAMP ASL lakes reflects a bias in the selection of RAMP ASL lakes in which poorly-buffered lakes in the region were chosen preferentially (Appendix H). The estimates of PAI are also biased high. By incorporating both approved and existing industries in the calculation of the PAI (Section 3.5.6.2), the estimates of PAI reported in Table 7.5-2 represent future risk, not current risk, to the RAMP ASL lakes.

A modeled PAI greater than the critical load of a lake does not mean that acidification is imminent but that there is a potential risk of acidification. Other factors, such as the influence of highly-buffered groundwater seepage to each lake must also be considered in assessing the risks of acidification. Table 7.5-5 summarizes the key chemical characteristics of the lakes having the modeled PAI greater than the critical load. As expected, these are small lakes of low pH, low conductivity, low ANC, and high in DOC. A large proportion of these lakes are found in the Stony and Birch Mountain subregions.

7.5.3 Trends in ASL Measurement Endpoints in Individual Lakes

7.5.3.1 Mann-Kendall Trend Analysis

There are fewer significant trends in values of ASL measurement endpoints in 2009 than in previous years (Table 7.5-6):

1. A significant decrease in pH over time was detected in only one lake (Lake 342, Stony Mountains subregion). This lake was also identified in 2008 as having experienced a significant decrease in pH over time but this pH decline was not accompanied by an increase in concentration of sulphate or nitrates that would account for this decrease. An exceptionally low value of pH (6.1) was measured for this lake in 2008 that was more than two standard deviations (SD) below the long-term mean (Figure 7.5-2). In 2009, the pH in this lake increased to a value near the historical mean.
2. No significant decreases in the concentration of Gran alkalinity over time were detected in any of the 50 ASL lakes.

Table 7.5-5 Chemical characteristics of lakes having the modeled PAI greater than the critical load in 2009.

Lake	Original Name	Subregion	pH	Gran Alkalinity (μeq/L)	Conductivity (μS/cm)	DOC (mg/L)	Lake Area (km^2)
168	A21	Stony Mountains	5.15	8.4	14.28	17.8	1.4
169	A24	Stony Mountains	4.75	-10.2	13.89	17.3	1.1
170	A26	Stony Mountains	5.63	16.4	13.20	14.9	0.7
167	A29	Stony Mountains	5.91	39.6	12.99	15.6	1.1
287	25	Stony Mountains	4.98	-5.2	12.37	14.2	1.9
289	27	Stony Mountains	6.44	68.2	16.14	12.7	1.9
290	28	Stony Mountains	5.81	46.2	15.97	18.4	0.5
342	82	Stony Mountains	6.45	113.4	21.60	24.1	2
172	A59	West of Fort McMurray	5.12	53.4	24.10	36.9	2.2
226	P97	West of Fort McMurray	6.65	223.8	40.80	36.6	0.2
452	L4	Northeast of Fort McMurray	6.12	88.2	21.90	25.9	0.7
470	L7	Northeast of Fort McMurray	6.46	153.0	28.00	29.2	0.3
471	L8	Northeast of Fort McMurray	6.97	336.2	44.00	23.3	0.6
185	P27	Northeast of Fort McMurray	5.31	48.4	21.40	28.7	0.1
447	L28	Birch Mountains	5.35	27.2	19.13	29.4	1.3
448	L29	Birch Mountains	4.35	-52.0	17.22	20.8	0.7
199	P49	Birch Mountains	6.56	112.6	24.80	18.7	0.1

These are lakes with PAI greater than critical load, regardless of the method of calculation (hydrometric or isotopic).

3. Significant increases in the concentration of sulphate over time were detected in two lakes (Lake 268, Northeast of Fort McMurray subregion and Lake 118, Canadian Shield subregion). A significant increase in the concentration of sulphate in Lake 268 was also detected in 2008, along with a significant decrease in concentration of Gran alkalinity. A significant decrease in the concentration of Gran alkalinity in Lake 268 was not detected in 2009. The control plot for sulphate in Lake 268 indicates that for the past two years sulphate concentrations have returned to the historic mean after an unusually high value in 2007 (Figure 7.5-2). The control plots for Lake 118 show that year-to-year changes in sulphate in Lake 118 are too small to be considered a significant trend (Figure 7.5-2). In any event, concentrations of sulphate in Lake 118 decreased in 2009 to a value less than the historic mean.

4. A significant increase in concentration of nitrates over time was detected in only one lake (Lake 209, Northeast of Fort McMurray subregion). Examination of the control chart for Lake 209 (Figure 7.5-2) indicates that nitrate concentrations in this lake are extremely low with a mean value of 5.46 μg/L. Only one value (2009) approaches the two standard deviation control limit of 20 μg/L.

5. Significant decreases in concentrations of DOC over time were detected in two lakes (Lake 271, Northeast of Fort McMurray subregion and Lake 97, Caribou Mountains). A significant decline in the concentration of DOC over time in Lake 97 was also detected in 2008. The control plots for both lakes

(Figure 7.5-2) indicate that concentrations of DOC in both of these lakes have remained within ± 2SD throughout the sampling period.

6. Significant increases in the sum of base cation concentrations over time were detected in Lakes 166 and 167 in the Stony Mountains subregion, Lake 171 in the Birch Mountains subregion, and Lake 91 in the Caribou Mountains subregion. Acidification should initially result in an increase in base cations as these ions are stripped from soils in catchments receiving acid deposition. None of the increases in the sum of base cation concentrations was associated with a significant increase in concentration of sulphate in these lakes, suggesting that these trends cannot be attributed to acidification. In addition, the control plots for these lakes (Figure 7.5-2) indicate that concentrations of DOC in both of these lakes have remained within ± 2SD throughout the sampling period.

7.5.3.2 Control Charting of ASL Measurement Endpoints

Ten lakes were selected for control charting based on an acidification risk factor calculated from the ratio of PAI to the value of the critical load from Table 7.5-3. The greater this ratio in a lake, the greater is the risk for acidification. The ten lakes with the highest ratios are indicated in Table 7.5-7. All but one of these lakes are found in the Stony Mountains, Birch Mountains and Muskeg River Uplands subregions. If acidification is occurring, it should be evident first in these lakes.

As in 2008, the control plots for pH, Gran alkalinity, sulphates, nitrates and DOC for the ten lakes indicate that only isolated exceedances of the 2 SD warning limits occurred during the 8 to 11 year sampling period for these lakes (Figure 7.5-3 to Figure 7.5-8). Exceedances of the ± 2 SD control limits in a direction indicative of acidification occurred for pH in Lake 342; the sum of base cations in Lakes 170, 290, and 167; Gran alkalinity in Lake 289; sulphate in Lakes 167, 470 and 342 and DOC in Lake 172. In almost all these cases, concentrations of these measurement endpoints in these lakes returned to within the ± 2 SD control limit the following year.

Control plots for Gran alkalinity for each of the fifty RAMP ASL lakes are shown in Figure 7.5-9. This figure permits tracking of potential changes in this ASL measurement endpoint over all the lakes and subregions. Included in Figure 7.5-9 is a relative ranking of the acid-sensitivity of each RAMP ASL lake based on this measurement endpoint.

7.5.4 Summary of Conditions

These results of the analysis of 2009 RAMP ASL lake data in conjunction with the historical RAMP ASL lake dataset suggest that there has been no significant change in the overall chemistry of the 50 RAMP ASL lakes in 2009 compared to previous years. A long-term decline is noted for DOC but this appears to be a natural regional trend. Based on the analysis of among-year differences in concentrations of ASL measurement endpoints, as well as trend analysis and control plotting of concentrations of ASL measurement endpoints on individual RAMP ASL lakes, there is no overwhelming evidence to conclude that there have been any significant changes in lake chemistry in the RAMP ASL lakes attributable to acidification.

Table 7.5-6 Results of Mann-Kendall trend analyses on measurement endpoints for acid-sensitive lakes.

Lake ID	Original RAMP Designation	pH		Gran Alkalinity		Sulphate		Nitrates and Nitrites		Dissolved Organic Carbon		Sum of Base Cations		Potential Acid Input (keq H^+/ha/yr)
		S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	
168	A21		0.62		-0.72		-2.02		-0.78		-1.40		-1.40	0.186
169	A24		0.78		-1.15		0.00		-0.39		0.47		0.47	0.177
170	A26		0.31		1.61		-0.93		0.16		-0.23		0.00	0.186
167	A29		1.02		2.33		0.00		0.16		0.62		2.34	0.145
166	A86		0.00	20			0.72		0.00		1.07		2.86	0.117
287	25	-12		-10		4		11		-14		-4		0.179
289	27	-4		12		14		17		2		14		0.175
290	28	2		10		-2		-14		-12		-6		0.181
342	82	-22		-5		-8		-1		-8		-20		0.120
354	94	-10		4		12		0		-6		-8		0.141
165	A42		1.40		1.43		-1.09		0.73		0.31		1.09	0.121
171	A47		1.71		1.61		0.16		-0.62		1.09		2.49	0.120
172	A59		-1.33		-0.89		-1.40		-0.47		-0.16		0.00	0.076
223	P94	-15		-5		-2		-9		8		-12		0.258
225	P96	0		-2		4		3		0		-14		0.238
226	P97	-4		4		8		-2		10		0		0.353
227	P98	6		4		0		0		2		2		0.307
267	1	1		-3		-5		7		-1		-11		0.214
452	L4		0.08		0.36		-0.78		0.00		0.47		0.00	0.222
470	L7		0.08		0.72		0.16		0.39		0.00		0.16	0.646
471	L8		0.00		-1.07		0.47		0.00		0.00		-1.87	0.607
400	L39		0.39		0.36		-0.16		0.47		1.40		-0.62	0.085
268	E15 (L15b)		-0.36		-1.07		2.15		-0.09		0.00		-0.89	0.206
182	P23	2		8		6		14		12		4		0.250

Note: Numbers represent the S or Z statistic used in the analysis. Negative values represent overall decreases in a variable and positive values represent increases.

Note: Shaded values are statistically significant – red in a direction consistent with an acidification scenario, green in a direction inconsistent with acidification.

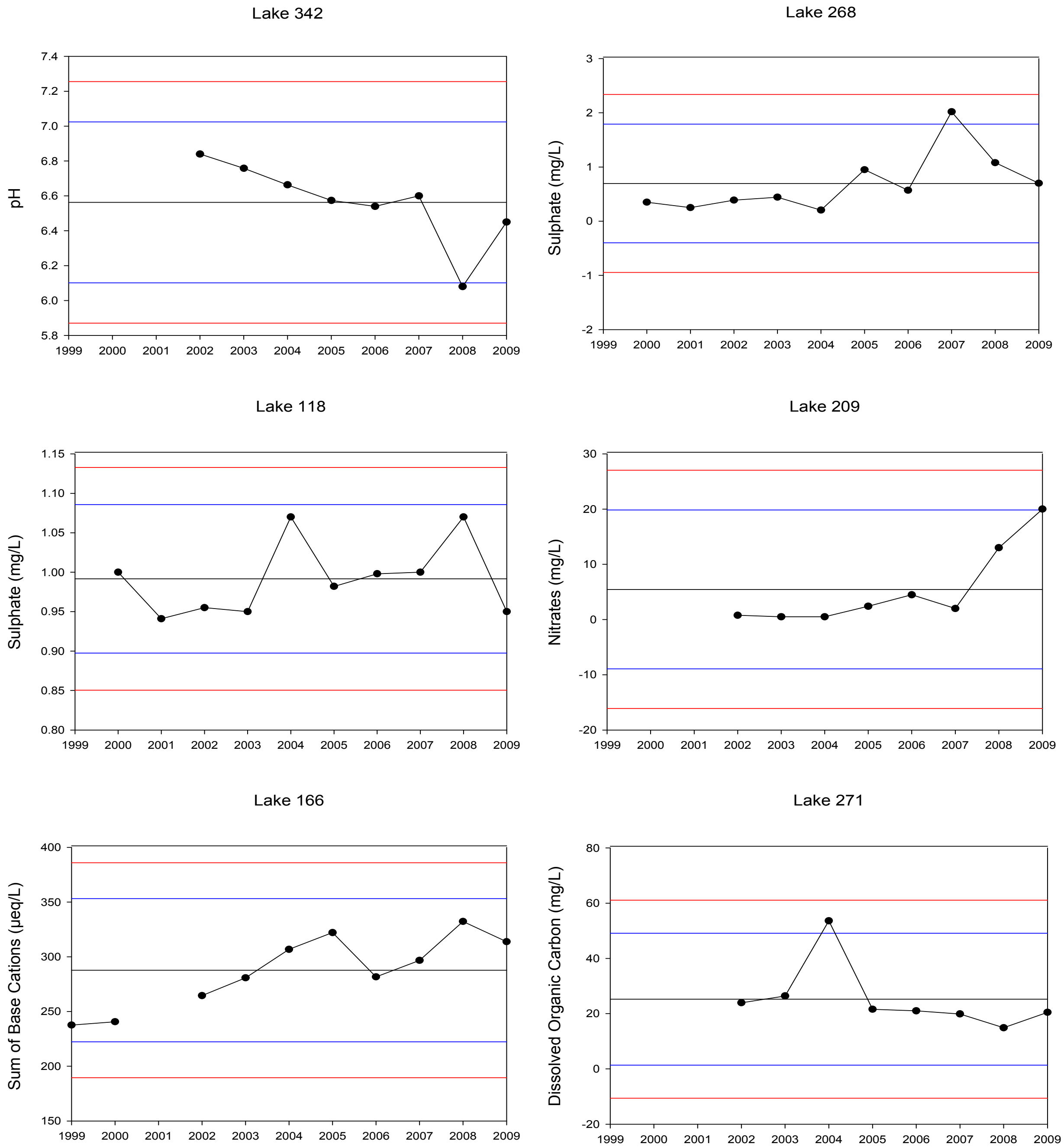
Table 7.5-6 (Cont'd.)

Lake ID	Original RAMP Designation	pH		Gran Alkalinity		Sulphate		Nitrates and Nitrites		Dissolved Organic Carbon		Sum Base Cations		Potential Acid Input (keq H^+/ha/yr)
		S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	
185	P27	-5		10		2		3		4		2		0.220
209	P7	-7		14		3		19		-10		4		0.195
270	4	-10		-2		12		3		-8		-16		0.181
271	6	-4		-6		16		1		-18		-18		0.133
418	Kearl L.	5		9		-1		-2		7		5		0.367
436	L18		1.33		3.22		1.56		-1.62		-0.31		1.40	0.122
442	L23		0.78		1.43		-1.71		1.02		-0.62		-0.78	0.094
444	L25		1.02		1.25		-0.93		-0.72		-0.16		1.71	0.096
447	L28		1.25		1.07		-0.78		-1.33		0.62		0.00	0.056
448	L29		0.18	-11			-1.07		0.00		0.00		-0.36	0.086
454	L46		-1.25		0.36		-1.25		-0.47		1.40		-1.40	0.097
455	L47		0.31		0.54		-0.16		0.16		1.56		0.00	0.074
457	L49		-1.02		-0.72		-1.64		0.31		1.56		-2.65	0.085
464	L60		-0.62		1.79		-1.87		0.16		1.95		-1.56	0.078
175	P13	-12		0		-12		6		-2		-2		0.145
199	P49	6		3		6		17		-8		-10		0.172
473	A301	16		-5		16		12		-12		-6		0.014
118	L107		2.15	13			2.16		0.54		0.00		-1.43	0.007
84	L109		0.70		-1.07		0.47		-1.25		0.47		-1.40	0.014
88	O-10	20		4		3		-6		-2		-12		0.014
90	R1		1.40		1.43		0.93		0.08		-0.31		0.78	0.014
146	E52		0.47		2.86		0.31		-0.47		-0.16		1.56	0.027
152	E59		0.62		2.33		-2.02		0.00		0.00		1.71	0.027
89	E68		-1.79		-0.18		-2.33		-0.54		-0.54		-2.15	0.027
91	O-1/E55		-0.08		0.09		-0.93		-1.25		0.93		2.65	0.027
97	O-2 E67		1.87		2.33		0.31		-1.71		-2.02		-3.27	0.027

Note: Numbers represent the S or Z statistic used in the analysis. Negative values represent overall decreases in a variable and positive values represent increases.

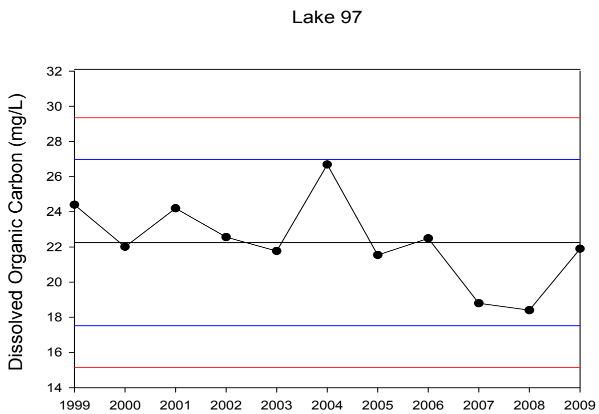
Note: Shaded values are statistically significant – red in a direction consistent with an acidification scenario, green in a direction inconsistent with acidification.

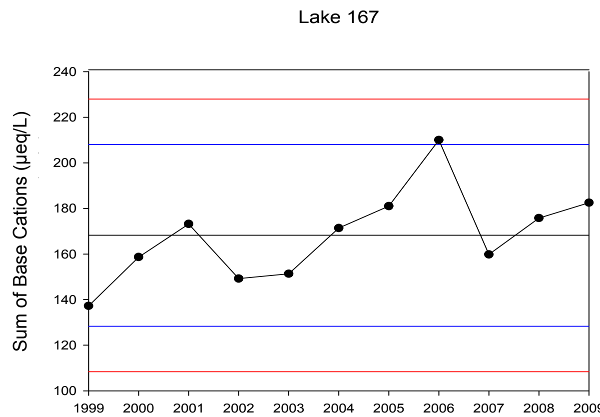
Figure 7.5-2 Control charts of measurement endpoints showing significant trends in the Mann-Kendall Trend Analysis.

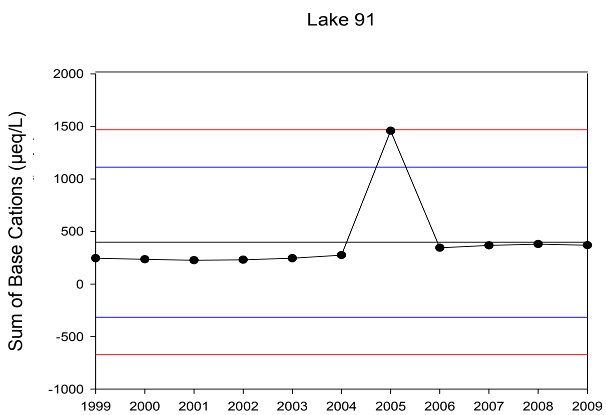


Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-2 (Cont'd.)







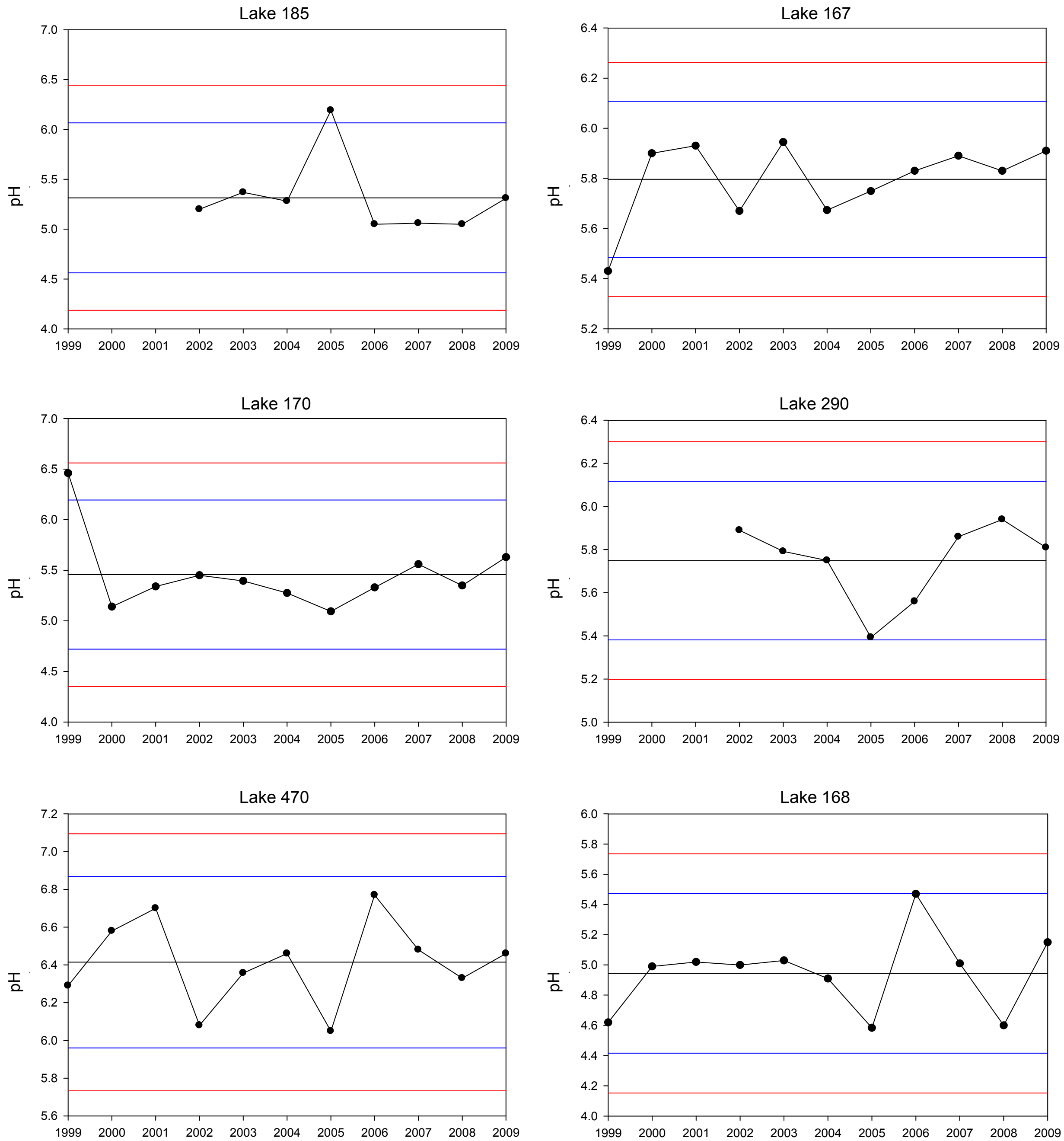
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Table 7.5-7 Acidification risk factor for individual RAMP ASL Lakes.

Lake No.	Original Designation	Subregion	Critical Load (keq H^+/Ha/yr)	PAI (keq H^+/ha/yr)	Acidification Risk Factor PAI/CL
84	L109	Canadian Shield	0.190	0.014	0.074
88	O-10	Canadian Shield	0.385	0.014	0.036
89	E68	Caribou Mountains	0.469	0.027	0.058
90	R1	Canadian Shield	0.444	0.014	0.032
91	O-1/E55	Caribou Mountains	0.050	0.027	0.538
97	O-2 E67	Caribou Mountains	2.887	0.027	0.009
118	L107	Canadian Shield	2.171	0.007	0.003
146	E52	Caribou Mountains	2.364	0.027	0.011
152	E59	Caribou Mountains	0.792	0.027	0.034
165	A42	West of Fort McMurray	1.398	0.121	0.087
166	A86	Stony Mountains	0.257	0.117	0.454
167	A29	Stony Mountains	0.037	0.145	3.962
168	A21	Stony Mountains	-0.065	0.186	2.884
169	A24	Stony Mountains	-0.187	0.177	0.948
170	A26	Stony Mountains	-0.018	0.186	10.08
171	A47	West of Fort McMurray	0.244	0.120	0.492
172	A59	West of Fort McMurray	0.014	0.076	5.401
175	P13	Birch Mountains	0.782	0.145	0.185
182	P23	Northeast of Fort McMurray	2.169	0.250	0.115
185	P27	Northeast of Fort McMurray	0.020	0.220	10.80
199	P49	Birch Mountains	0.115	0.172	1.497
209	P7	Northeast of Fort McMurray	0.818	0.195	0.239
223	P94	West of Fort McMurray	0.263	0.258	0.979
225	P96	West of Fort McMurray	0.364	0.238	0.654
226	P97	West of Fort McMurray	0.267	0.353	1.324
227	P98	West of Fort McMurray	0.905	0.307	0.339
267	1	West of Fort McMurray	0.318	0.214	0.672
268	E15	Northeast of Fort McMurray	1.810	0.206	0.114
270	4	Northeast of Fort McMurray	3.380	0.181	0.054
271	6	Northeast of Fort McMurray	2.572	0.133	0.052
287	25	Stony Mountains	-0.143	0.179	1.254
289	27	Stony Mountains	0.095	0.175	1.841
290	28	Stony Mountains	0.001	0.181	210.6
342	82	Stony Mountains	0.066	0.120	1.817
354	94	Stony Mountains	0.753	0.141	0.187
400	L39	Northeast of Fort McMurray	1.086	0.085	0.078
418	Kearl L.	Northeast of Fort McMurray	2.331	0.367	0.157
436	L18	Birch Mountains	2.446	0.122	0.050
442	L23	Birch Mountains	0.389	0.094	0.242
444	L25	Birch Mountains	1.259	0.096	0.076
447	L28	Birch Mountains	-0.097	0.056	0.577
448	L29	Birch Mountains	-0.546	0.086	0.157
452	L4	Northeast of Fort McMurray	0.135	0.222	1.649
454	L46	Birch Mountains	0.518	0.097	0.187
455	L47	Birch Mountains	1.159	0.074	0.064
457	L49	Birch Mountains	0.792	0.085	0.107
464	L60	Birch Mountains	0.423	0.078	0.185
470	L7	Northeast of Fort McMurray	0.195	0.646	3.309
471	L8	Northeast of Fort McMurray	0.527	0.607	1.152
473	A301	Canadian Shield	0.180	0.014	0.078

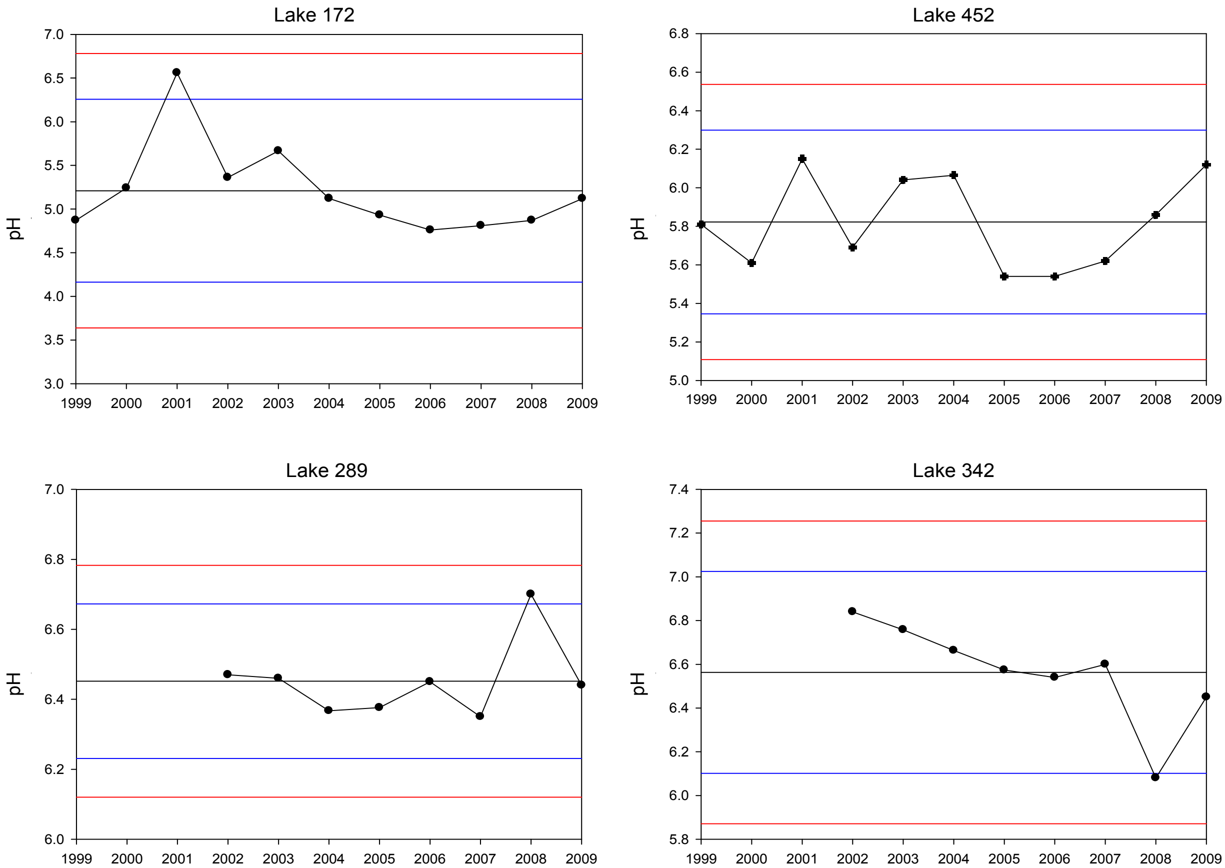
Shaded lakes represent those lakes most at risk to acidification.

Figure 7.5-3 Shewhart control charts of pH in the ten RAMP ASL lakes most at risk to acidification.



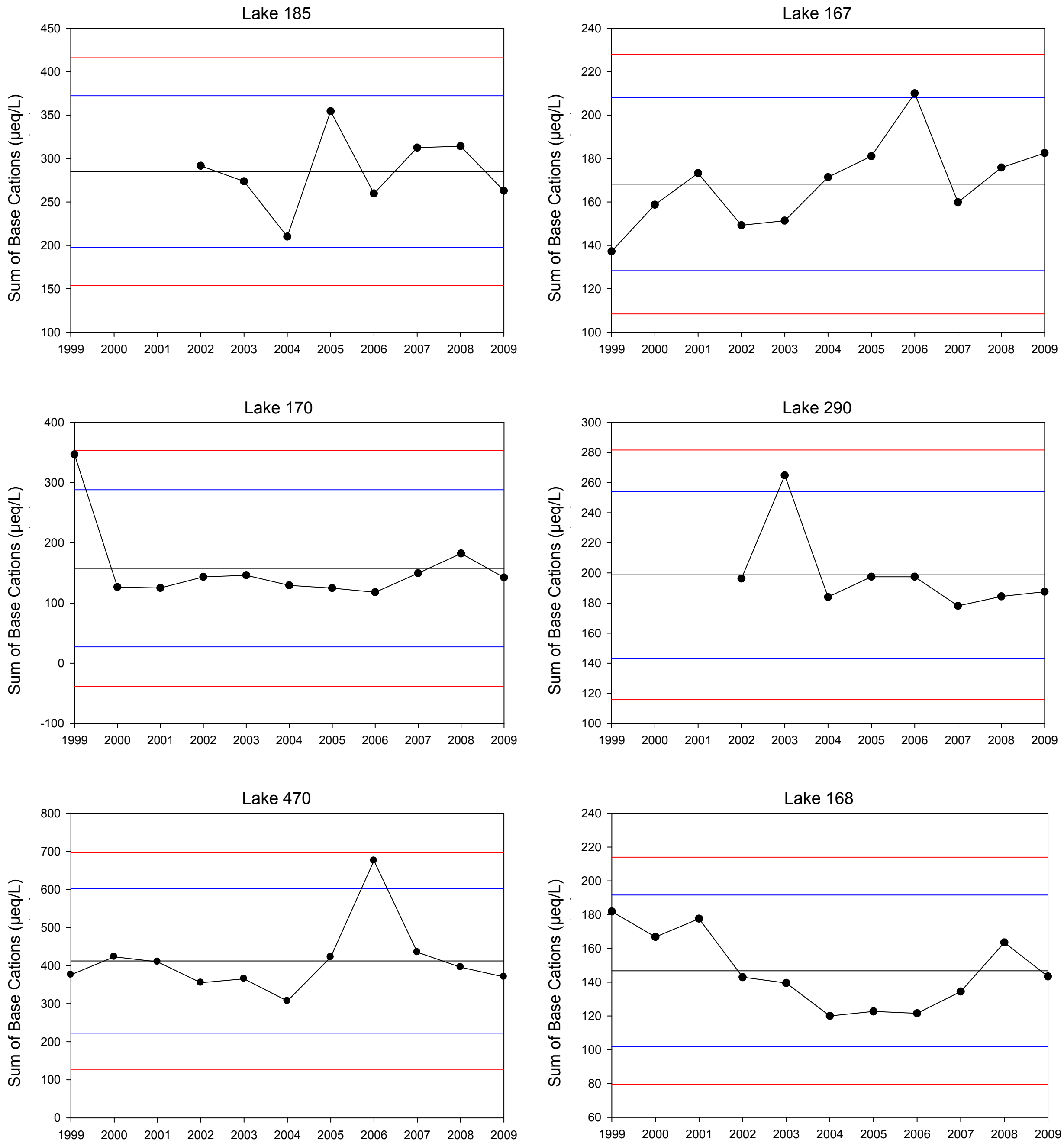
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-3 (Cont'd.)



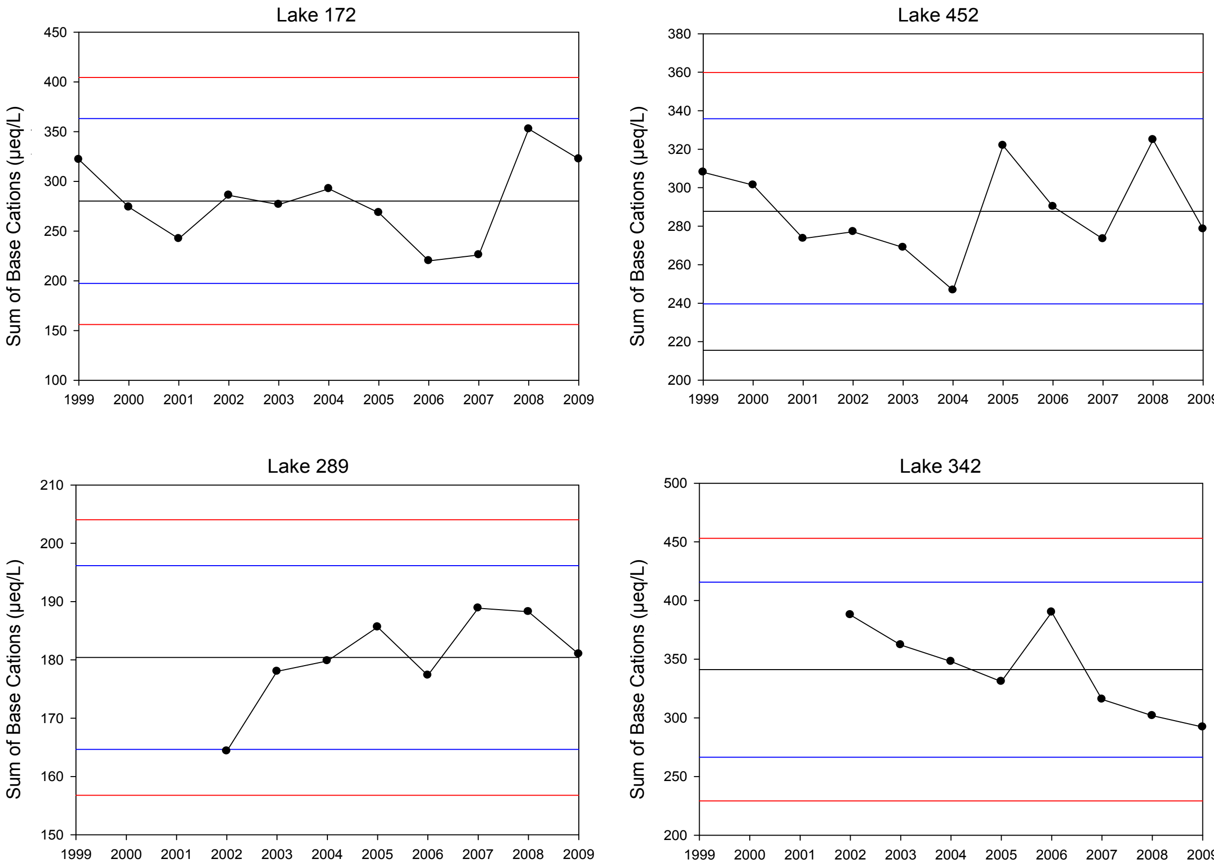
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-4 Shewhart control charts of the sum of base cations in the ten RAMP ASL lakes most at risk to acidification.



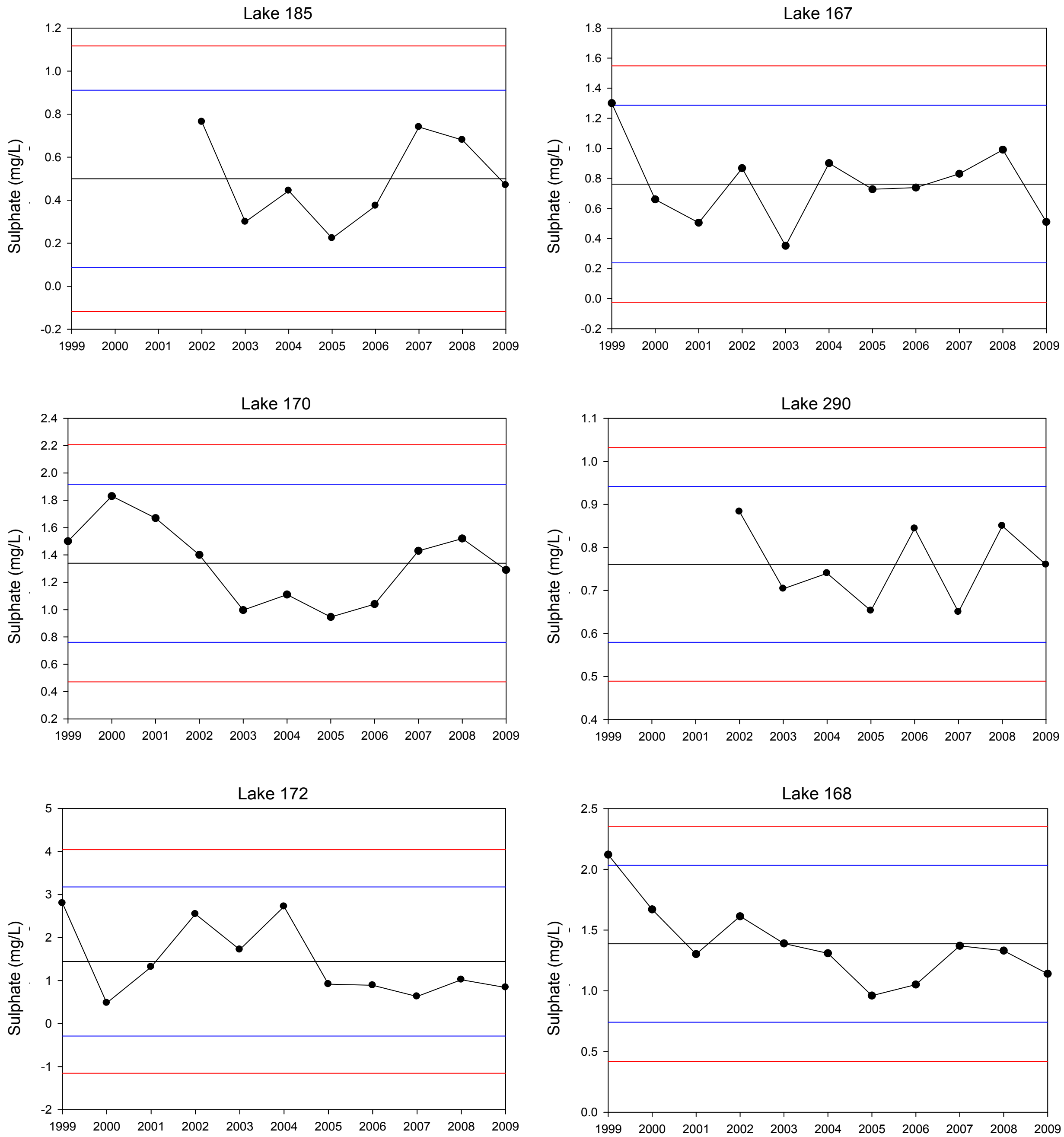
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-4 (Cont'd.)



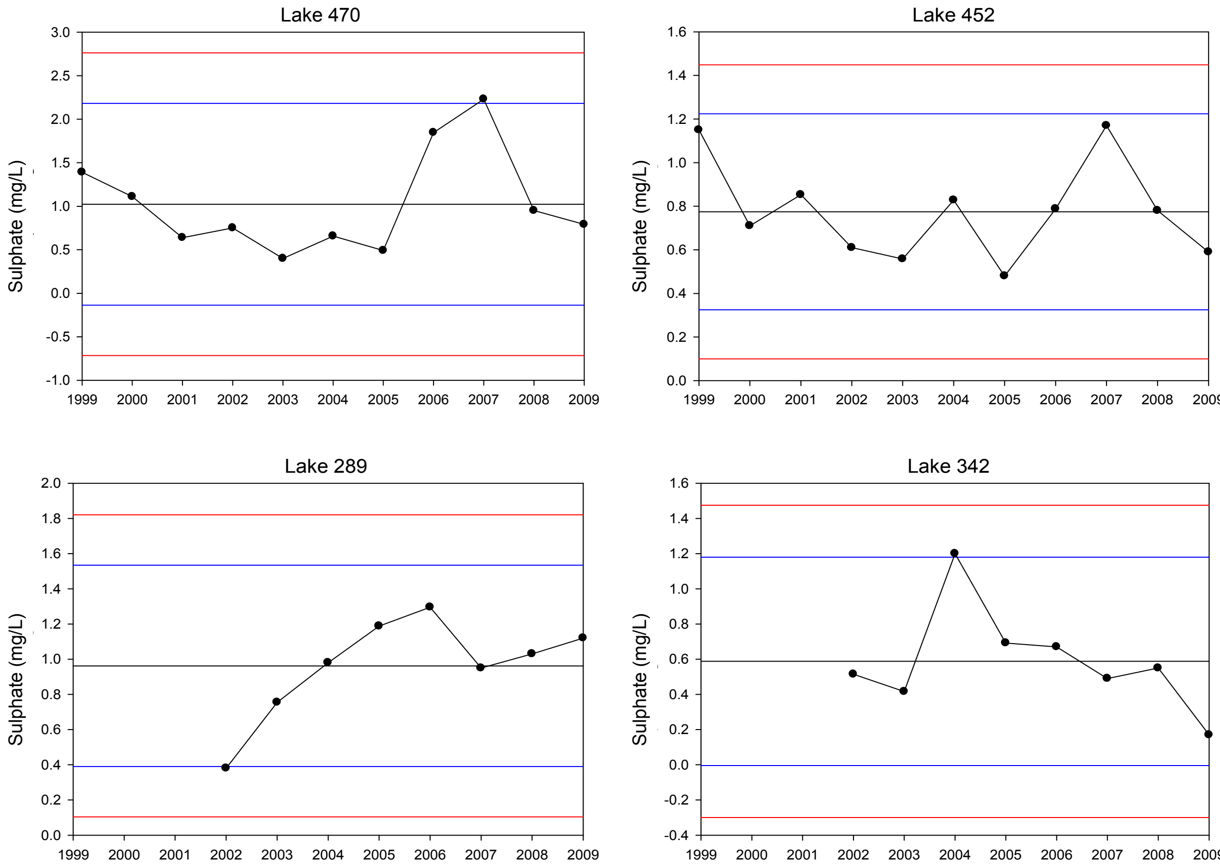
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-5 Shewhart control charts of sulphate in the ten RAMP ASL lakes most at risk to acidification.



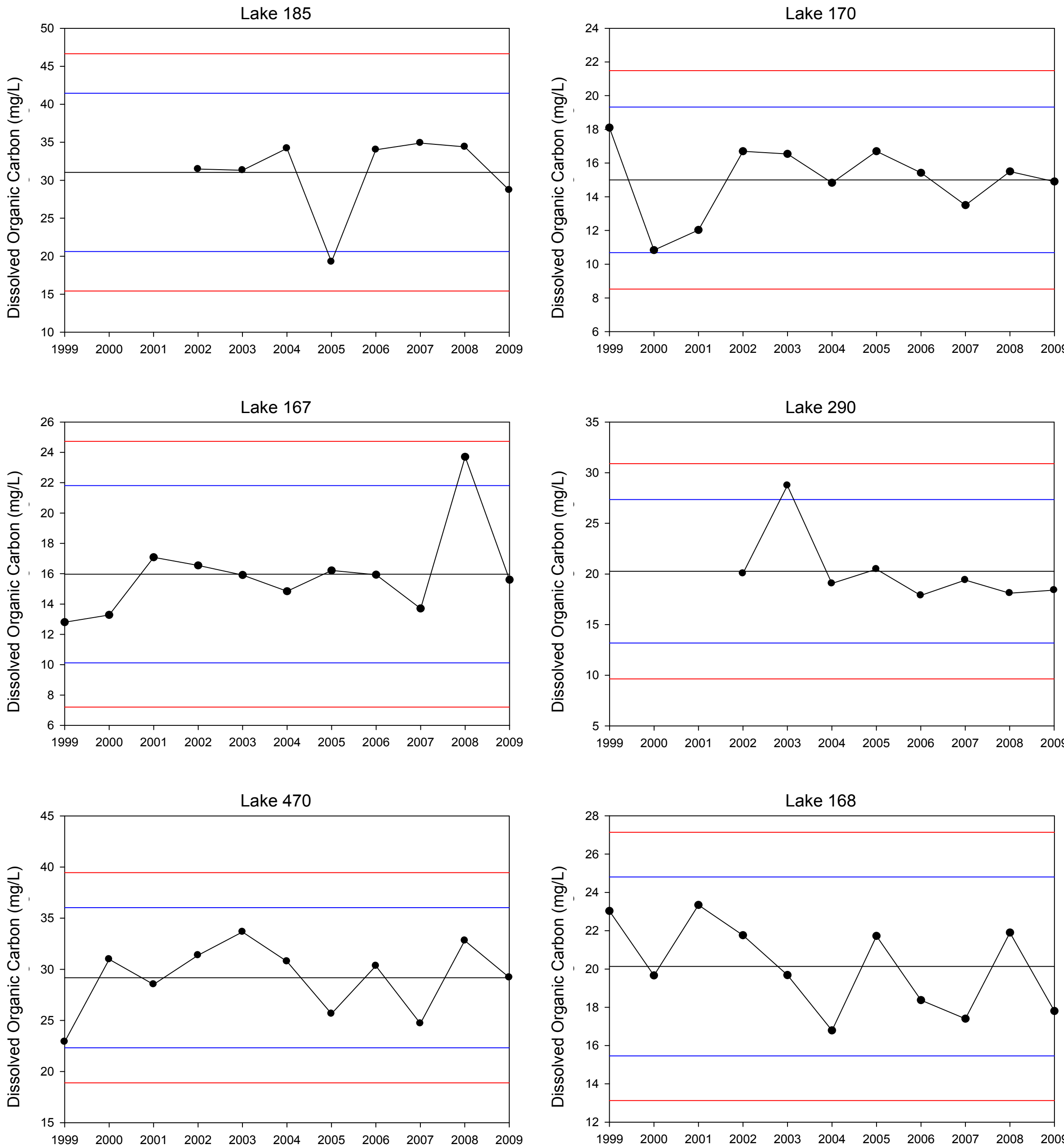
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-5 (Cont'd.)



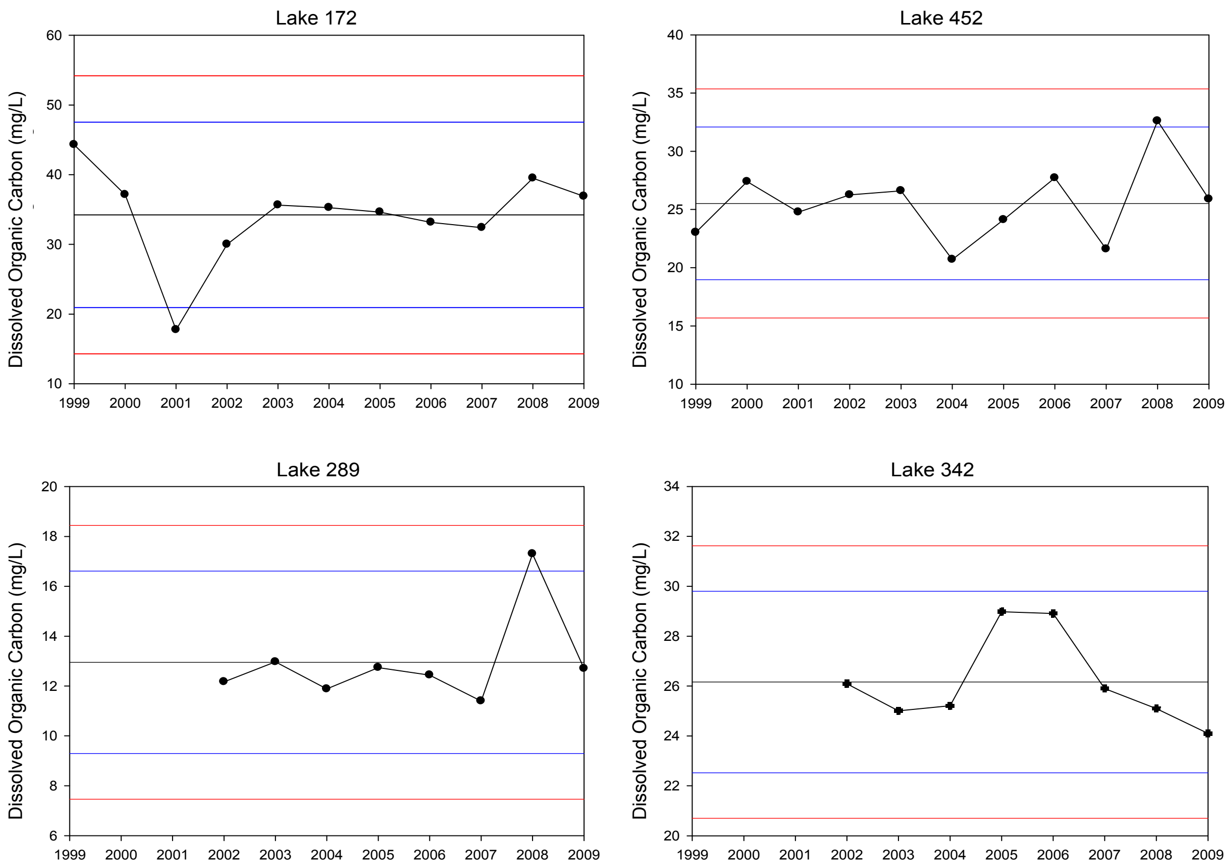
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-6 Shewhart control charts of dissolved organic carbon in the ten RAMP ASL lakes most at risk to acidification.



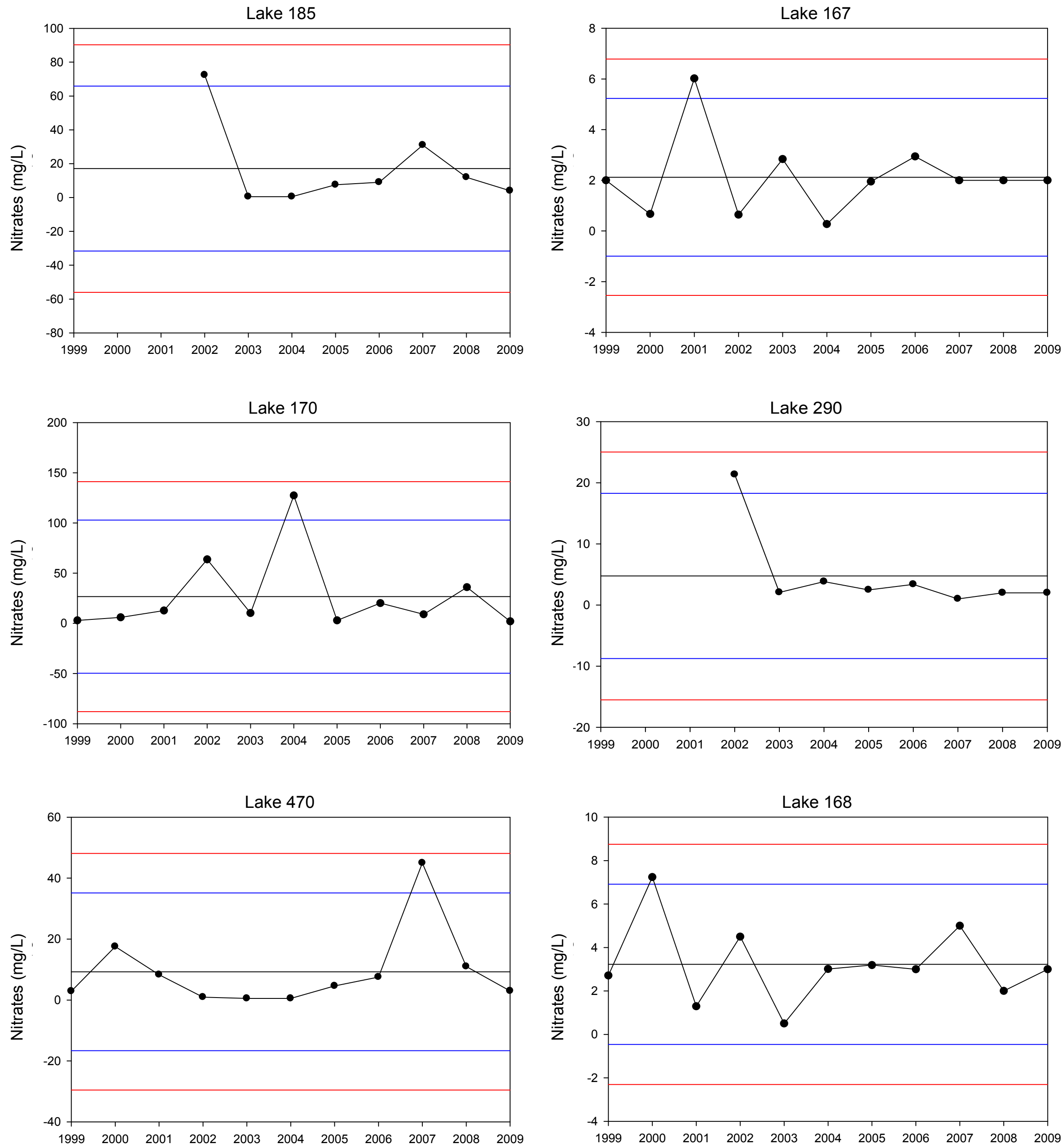
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-6 (Cont'd.)



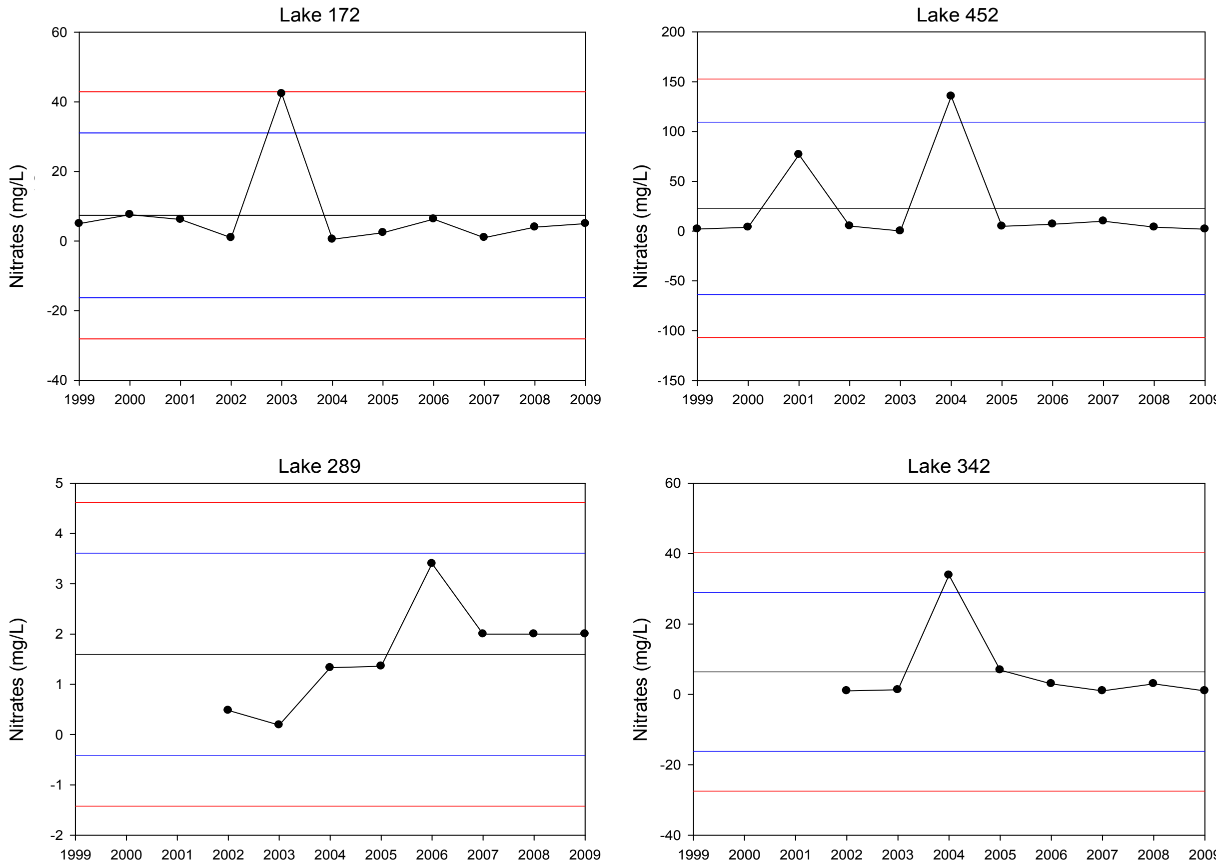
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-7 Shewhart control charts of nitrates in the ten RAMP ASL lakes most at risk to acidification.



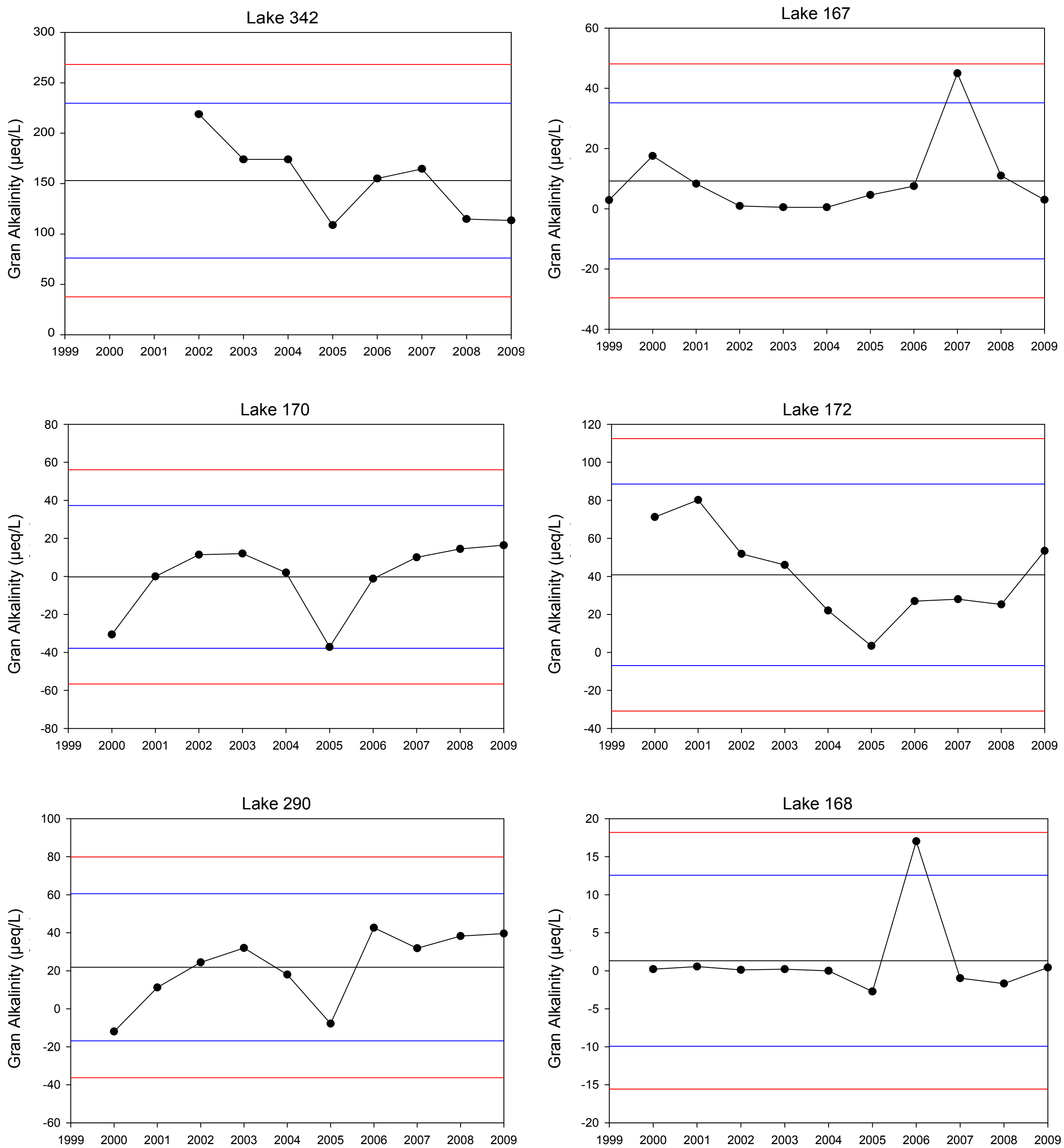
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-7 (Cont'd.)



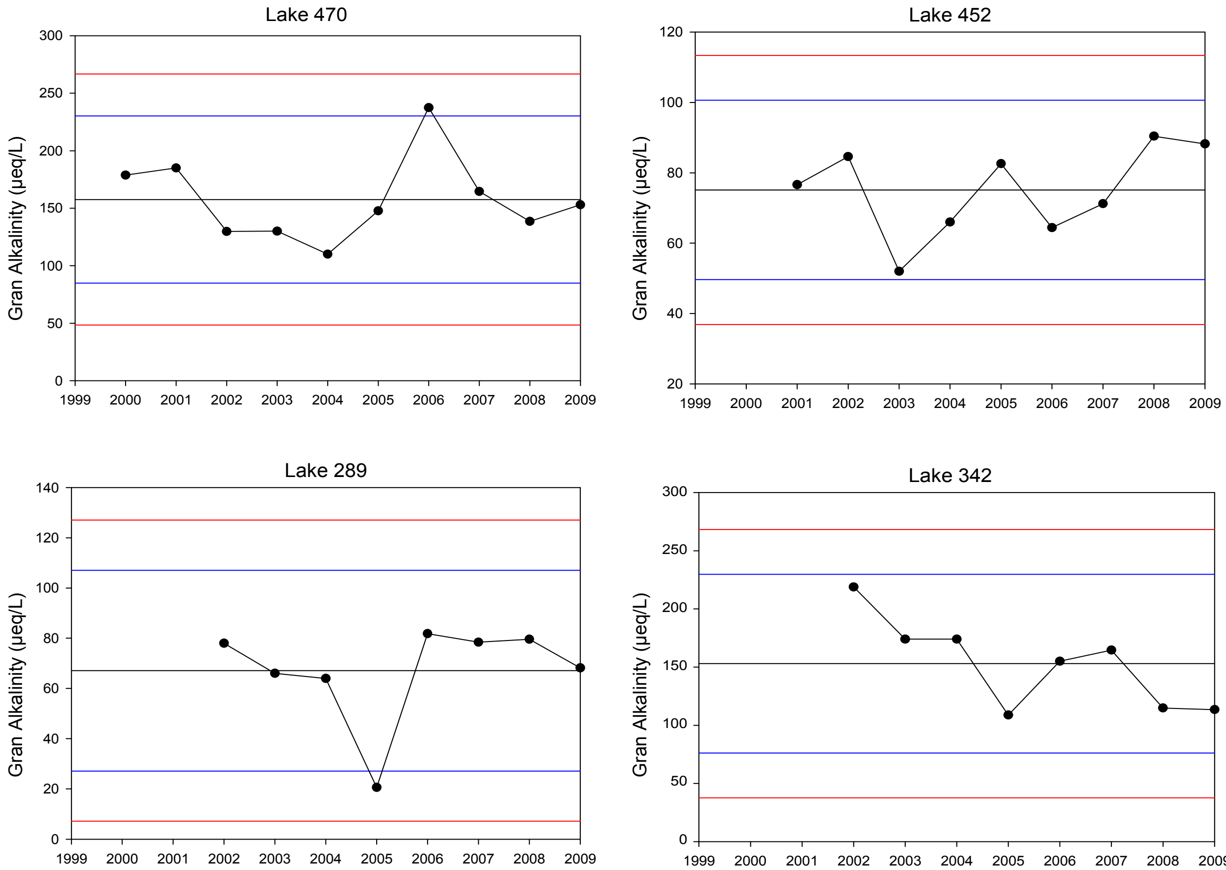
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line – mean

Figure 7.5-8 Shewhart control charts of Gran alkalinity in the ten RAMP ASL lakes most at risk to acidification.



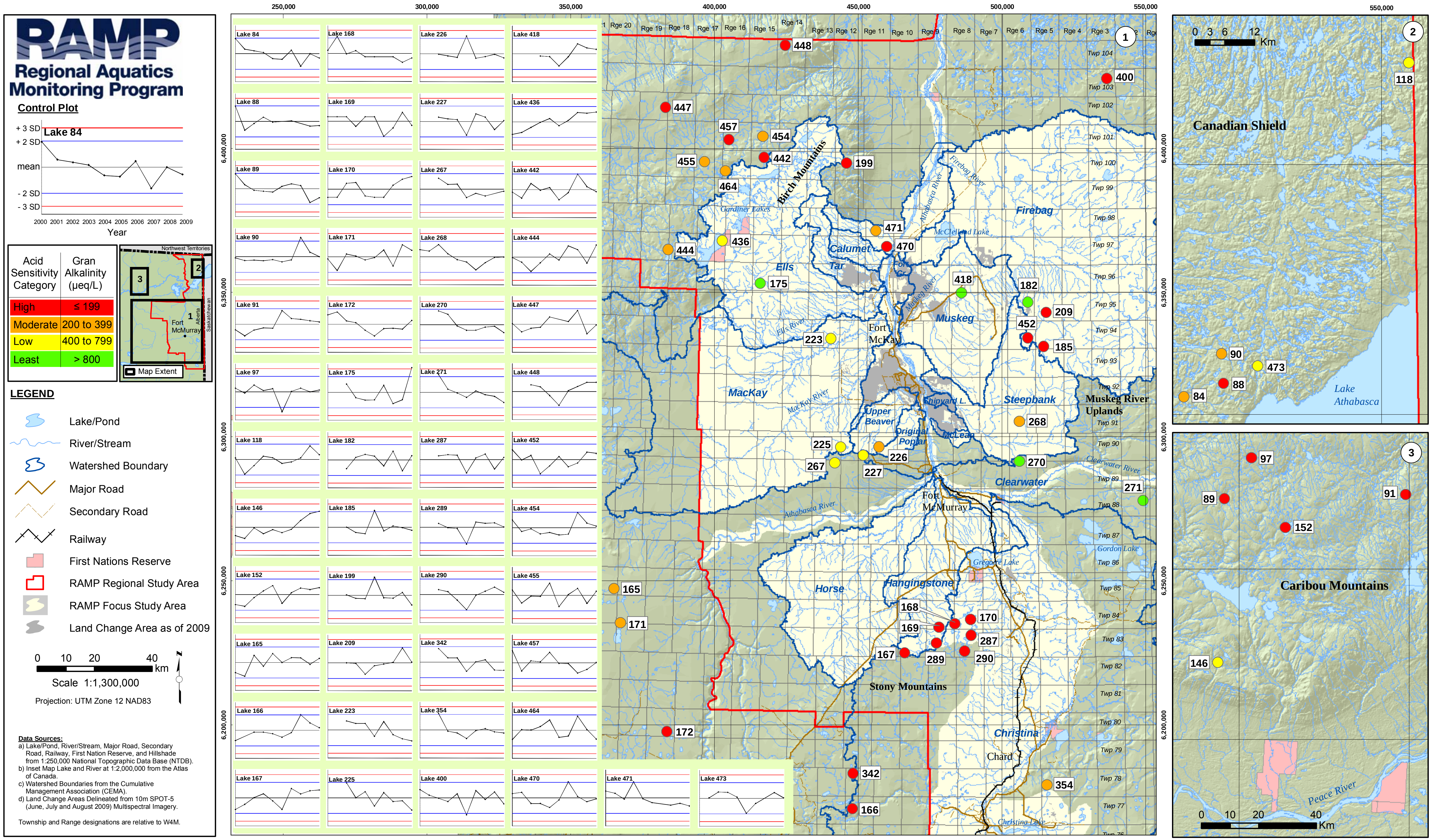
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 7.5-8 (Cont'd.)



Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line – mean

Figure 7.5-9 Control charts of Gran alkalinity in each ASL Lake (2000-2009) and the acid sensitivity of each lake in 2009.



K:\Data\Project\RAMP1467\GIS_MXD\L_TechReport\RAMP1467_Q_ASLGranAlk_20100415.mxd

8.0 CONCLUSIONS AND RECOMMENDATIONS

The 2009 RAMP monitoring program results have been discussed in detail, in Section 5 and Section 7. This section provides a summary of results for each component of RAMP. Based on results presented in Section 5 and the Acid-Sensitive Lake results in Section 7, Table 8.2-1 provides a summary of the 2009 RAMP monitoring program results, by watershed and component. In addition to the summary of results, overall conclusions as well as general comments and recommendations for each component for consideration by the RAMP Technical Program Committee and the RAMP Steering Committee are presented. The sampling program is designed one year in advance for RAMP, therefore recommendations for each component presented to the RAMP Technical Committee are implemented immediately if possible within the current sampling program or introduced into the program design for the following year.

8.1 CLIMATE AND HYDROLOGY

The outlets of most major watersheds in the RAMP FSA are monitored by RAMP, operators of focal projects, or federal or provincial governments, and provide the basis for assessing potential effects of focal projects and other oil sands developments. Due to continued oil sands development in the region, an increasing number of the hydrometric stations in the network have changed over time from *baseline* to *test* stations due to the presence of upstream oil sands developments. Additional monitoring stations are being added to compensate for this trend so that hydrometric data continues to be captured in *baseline* watersheds as well as for *test* locations.

Most of the hydrological changes in the RAMP FSA in fall 2009 were assessed as **Negligible-Low**, with the exception of the Muskeg, Tar, Poplar, Mills Creek and Fort Creek watersheds in which hydrologic changes ranged from **Negligible-Low** to **High**, depending on the measurement endpoint (Table 8.2-1). The focal projects and other oil sands developments contributing to hydrologic changes in the RAMP FSA in 2009, in order of decreasing importance, were:

- water withdrawals, releases, and diversions;
- closed-circuited land area creating a loss of flow to natural watercourses that would have otherwise occurred; and
- land area that is not closed-circuited creating increased flows to natural watercourses that would have otherwise not occurred.

The hydrologic changes from focal projects plus other oil sands developments in the RAMP FSA are estimated to be only marginally greater than the hydrologic changes from only focal projects.

Many of the water withdrawals and releases within the RAMP FSA are reported on an annual and sometimes monthly time-step. Hydrologic assessments would be significantly improved with reporting of water withdrawals and releases at a finer time scale. Provision of data describing water withdrawals and releases on a finer time scale, such as daily values, would make it possible to conduct more effective analysis of flow regimes in the RAMP FSA, particularly during low-flow periods.

The hydrologic assessment would also be improved by utilizing a water-year approach in the reporting and analysis of climatic and hydrometric conditions. Currently winter flow effects are analyzed and reported for a split winter season (January 1 to April 30 and November 1 to December 31 of the same calendar year). The winter results would likely be more meaningful if assessed for a continuous time period of November 1 to April 30, thereby assessing a complete winter-flow season.

Recommendations for improvement to the Climate and Hydrology component include:

- monitoring the Athabasca River downstream of the Firebag River confluence;
- monitoring at the mouth of the Christina River;
- establishing a climate station south of Fort McMurray; and
- conducting an evaluation of additional hydrometric measurement endpoints that incorporate additional aspects of the hydrologic regime such as the timing and frequency of flow conditions.

8.2 WATER QUALITY

Water quality in the following waterbodies in 2009 exhibited changes from historical and/or regional *baseline* conditions:

- **Shelley Creek (tributary to the Muskeg River)** High concentrations of several ions and metals relative to regional *baseline* conditions, although these concentrations were similar to those observed at this station in 1999, previous to any oil sands development in the watershed;
- **Isadore's Lake** Although water quality remains generally within regional *baseline* conditions, increasing concentrations of several major ions are evident, including calcium, magnesium and sulphate;
- **Shipyard Lake** Although water quality remains generally within regional *baseline* conditions, concentrations of sodium and chloride have increased to concentrations well above regional *baseline* conditions;
- **Lower Beaver River** High concentrations of several ions compared to regional *baseline* conditions;
- **Lower Poplar Creek** High concentrations of several ions compared to regional *baseline* conditions;
- **Lower Christina River** High concentrations of several ions and total nitrogen compared to regional *baseline* conditions; and
- **Horse River** High concentrations of total nitrogen, dissolved phosphorus and total mercury in this *baseline* river compared to regional *baseline* conditions.

With the exception of these changes in measurement endpoints, water quality in the RAMP FSA in 2009 did not indicate significant differences from regional *baseline* conditions (Table 8.2-1).

Additionally, although concentrations of almost all water quality measurement endpoints in the Athabasca River mainstem were within regional *baseline* conditions, increasing trends in sulphate observed downstream of Fort McMurray and oil sands development compared to concentrations upstream of Fort McMurray may indicate localized changes in water quality in this part of the river.

If possible, additional *baseline* stations should be established for ongoing RAMP water quality sampling, particularly stations that are expected to remain *baseline* in designation given the steady decline in the number of stations designated *baseline* in the current RAMP water quality design, and the need to continually update the understood range of natural variability of water quality in the region.

Table 8.2-1 Summary assessment of RAMP 2009 monitoring results.

Watershed/Region	Differences Between *Test* and *Baseline* Conditions: Hydrology	Water Quality	Benthic Invertebrate Communities	Sediment Quality	Fish Populations: Sentinel Species	Fish Populations: Health Risk from Metals and Organics in Fish Tissue: Human Health: Sp.	Size	Sub.	Gen.	Fish Health	Fish Palatability	Acid-Sensitive Lakes: Variation from Long-Term Average Potential for Acidification
Athabasca River	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-	-	-
Athabasca Delta	-	-	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
Muskeg River	High	Negligible-Low	Negligible-Low	-	Moderate	-	-	-	-	-	-	-
Steepbank River	Negligible-Low	Negligible-Low	Negligible-Low	-	Negligible-Low	-	-	-	-	-	-	-
Tar River	High	Negligible-Low	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
MacKay River	Negligible-Low	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-	-
Calumet River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
Firebag River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
Ells River	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-	-	-
Christina River	Negligible-Low	Moderate	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
Clearwater River	nm	Negligible-Low	-	-	-	NRPK	all sizes	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	-
Fort Creek	Moderate	Negligible-Low	-	-	-	-	-	-	-	-	-	-
Beaver River	-	Moderate	-	-	-	-	-	-	-	-	-	-
McLean Creek	-	Negligible-Low	-	-	-	-	-	-	-	-	-	-
Mills Creek	High	-	-	-	-	-	-	-	-	-	-	-
Poplar Creek	High	Moderate	Moderate	Negligible-Low	-	-	-	-	-	-	-	-
Shipyard Lake	-	Moderate	Negligible-Low	Negligible-Low	-	-	-	-	-	-	-	-
Isadore's Lake	nm	Moderate	High	Negligible-Low	-	-	-	-	-	-	-	-
Unnamed "Jackson" Lake	-	-	-	-	-	LKWH	all sizes	Negligible-Low	Negligible-Low	All species Negligible-Low	-	-
						WALL	>400 mm	High	Moderate			-
						NRPK	all sizes	Negligible-Low	Negligible-Low			-
Stony Mountains	-	-	-	-	-	-				-	-	Negligible-Low
West of Fort McMurray	-	-	-	-	-	-				-	-	Negligible-Low
Northeast of Fort McMurray	-	-	-	-	-	-				-	-	Negligible-Low
Birch Mountains	-	-	-	-	-	-				-	-	Moderate
Canadian Shield	-	-	-	-	-	-				-	-	Negligible-Low
Caribou Mountains	-	-	-	-	-	-				-	-	Negligible-Low

Legend and Notes

- Negligible-Low
- Moderate
- High

"-" program was not completed in 2009.

nm — not measured in 2009.

Hydrology: Calculated on differences between observed *test* and estimated *baseline* hydrographs: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.
Note: As not all hydrology measurement endpoints are calculated for each watershed because of differing lengths of the hydrographic record for 2009, hydrology results above are for those endpoints that were calculated.
Note: mean winter discharge and minimum open-water season discharge in the Muskeg River watershed were assessed as High, annual maximum daily discharge which was assessed as Moderate, and mean open-water season discharge was classified as Negligible-Low.

Water Quality: Classification based on adaptation of CCME water quality index.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparisons to regional *baseline* conditions.

Sediment Quality: Classification based on adaptation of CCME sediment quality index.

Fish Populations (fish tissue): Uses various USEPA and Health Canada criteria for risks to human health, fish health, and tainting from fish tissue concentrations of various substances. LKWH-lake whitefish; WALL-walleye; NRPK-northern pike
Note: The classification of risk to human health for fish populations was Negligible-Low below the size class specified.
Note: For Fish Population Human Health Classification - Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada.
Fish Populations (sentinel species): Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2005) see Section 3.4.7.3 for a detailed description of the classification methodology.

Acid-Sensitive Lakes: Classification based the frequency in each region with which values of seven measurement endpoints in 2009 were more than twice the standard deviation from their long-term mean in each lake.

8.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

8.3.1 Benthic Invertebrate Communities

The strength of the Benthic Invertebrate Communities component is the development of *baseline* data from multiple watercourses in *baseline* condition. Replication within watercourses and over time is enabling the component to characterize the *baseline* range of variability in measurement endpoints that describe benthic invertebrate community composition including abundance, richness, Simpson's diversity, evenness and percent of the fauna as sensitive mayflies, stoneflies and caddisflies. Statistical analyses can be used to test for variations in time trends from before to after development of focal projects and other oil sands development, or spatially between *baseline* and *test* reaches. Because the large sample sizes of the benthic invertebrate community dataset, the statistical power of these tests is very high. This means that the detection of changes is inevitable, as was the case in 2009. The regional *baseline* data, however, typically showed that the significant time trends or spatial variations were more often than not subtle in comparison to natural background variability. Key findings from this 2009 program are as follows (Table 8.2-1):

1. The variations in benthic invertebrate community measurement endpoints in the Athabasca River Delta are classified as **Negligible-Low**. The values of the benthic invertebrate community measurement endpoints in the ARD in fall 2009 were within the range of historical values for this part of the RAMP FSA, and there are no trends over time in the value of the measurement endpoints that would indicate a degradation of community composition.

2. The variations in benthic invertebrate community measurement endpoints in all *test* reaches of tributaries of the Athabasca River and *test* lakes within the Athabasca River watershed that were sampled had **Negligible-Low** differences from *baseline* conditions with the exception of the lower reaches of Poplar Creek and Jackpine Creek as well as Isadore's Lake. Differences between benthic invertebrate community measurement endpoints and *baseline* reaches at all but these three sampled locations were either statistically insignificant or significant but weak relative to the *baseline* variation, and measurement endpoints in these reaches were within regional *baseline* conditions.

3. Of note, the assessment of **Negligible-Low** differences in benthic invertebrate communities in the lower Tar River in 2009 as compared to regional *baseline* conditions suggests recovery of the benthic fauna from changes that had occurred in previous years. It appears that changes in values of benthic community measurement endpoints in *test* reaches compared to *baseline* reaches are localized in nature and potentially reversible in some cases.

While the Benthic Invertebrate Communities component has developed a robust temporal database of benthic invertebrate communities in *baseline* condition, the change in the designation of the upper Muskeg River from *baseline* to *test* in 2009 represents a trend of a continuous loss of *baseline* sampling locations against which to judge potential future changes. This is particularly the case for depositional habitat. The regional *baseline* conditions, however, provides an ultimate test of the significance of variations from year to year, reach to reach, and lake to lake.

The inclusion of Poplar Creek and the lower Tar River in the sampling design for the component as *test* reaches where changes are anticipated demonstrates that the sampling methods, level of taxonomy and statistical data processing do detect changes that are meaningful and interpretable.

8.3.2 Sediment Quality

Sediments in the RAMP FSA naturally contain concentrations of hydrocarbons and PAHs that may exceed environmental-quality guidelines.

In 2009, differences in sediment quality from regional *baseline* conditions were assessed as **Negligible-Low** at all sampling locations (Table 8.2-1). Concentrations of metals, hydrocarbons and PAHs in sediments were generally within previously-measured concentrations throughout the RAMP FSA with the exception of lower Poplar Creek where concentrations of hydrocarbons and PAHs were consistently higher in 2009 than in previous sampling years, but still within the range of regional *baseline* concentrations.

Spatial and temporal comparisons of sediment quality from 1997 to 2009 do not indicate any consistent trends over time in concentrations of hydrocarbons or metals, any consistent differences in sediment quality between *baseline* and *test* stations, or any correlations between sediment chemistry and benthic invertebrate community composition indicative of a negative influence of sediment-borne chemicals on benthic invertebrate community structure. Sediment toxicity tests showed survival and growth rates for organisms in sediments from all evaluated *baseline* and *test* stations generally similar or greater than those observed in laboratory-control sediments.

If possible, additional *baseline* stations should be established for ongoing RAMP sediment quality sampling (harmonized with depositional benthos sampling reaches), particularly stations that are expected to remain *baseline* in designation given the steady decline in the number of stations designated *baseline* in the current RAMP sediment quality design, and the need to continually update the understood range of natural variability of sediment quality in the region.

8.4 FISH POPULATIONS

The 2009 RAMP Fish Population component consisted of:

- Large-bodied fish counting fence on the Muskeg River;
- Fish inventories on the Athabasca and Clearwater rivers;
- Chemical analyses of fish tissue from the Clearwater River;
- Sentinel species monitoring on the following tributaries: Horse River, Dunkirk River, Steepbank River and Muskeg River; and
- Chemical analyses of fish tissue collected from a regional unnamed lake, known locally as "Jackson" Lake.

Assessing potential changes in fish populations from focal projects and other oil sands developments is an ongoing challenge due to limitations in the ability to effectively sample all fish populations in the RAMP FSA and the fact that not all elements of the Fish Populations component are conducted every year, resulting in limited temporal data. In addition to these challenges, large-bodied fish are highly migratory between and within waterbodies in the RAMP FSA, making it difficult to differentiate differences between natural variability in fish populations and potential changes related to focal projects and other oil sands developments. Recognizing these limitations, a Fish Assemblage Monitoring pilot study was conducted in 2009 as a potential new approach to monitoring fish populations in the RAMP FSA.

8.4.1 Summary of 2009 Results

8.4.1.1 Muskeg River Fish Fence

2009 was the final year for a spring fish fence operation on the Muskeg River based on requirements undertaken by RAMP to obtain three years of fish fence data (i.e., 2003, 2006, and 2009). Generally, lower numbers of fish species with the exception of white sucker was observed in 2009 compared to the two previous years of fish fence operations.

Installing a fence in the Muskeg River was considered in every year from 2003 to 2009, but construction was commonly interrupted by high flow conditions. The result is that there are now large-bodied fish counts in the lower Muskeg River for three low-freshet spring seasons and no large-bodied fish counts in years of high-flow conditions. Despite the consistency in flows across the three years of fish fence operations, the dominant runs of white sucker, longnose sucker and northern pike were variable, with increases in the number of white sucker and a decrease in the number of northern pike and longnose sucker using the Muskeg River for spawning, as well as Arctic grayling and walleye. Given the intermittent years of fish fence operation, it is difficult to determine whether the increase in white sucker use of the Muskeg River and the decrease in use by other species in the spring spawning season represent a consistent trend or natural variability. In addition, it is unknown whether there is a greater abundance of other fish species in high freshet years when a fish fence was not operational or whether the period of fish fence operations did not coincide with the timing of these species migrating up the Muskeg River.

8.4.1.2 Fish Inventory

In 2009, the analysis of the Athabasca River and Clearwater River fish inventories focused on seasonal trends over time of catch per unit effort, fish condition, and length-frequency distributions for large-bodied fish.

Current and historical fish inventory data from the Athabasca and Clearwater rivers indicated significant differences in measurement endpoints among years for KIR fish species. Statistically-significant differences among years were detected for condition and length-frequency distributions in the Athabasca River but there were no other significant trends that would suggest a consistent negative or positive change in fish populations over time. As such, it is likely that the observed variability in these measurement endpoints reflects a natural fluctuation in population size or growth of fish in these rivers.

A summer inventory was initiated in 2008 on the Athabasca River and in 2009 on the Clearwater River to focus on a sampling period when fish populations were assumed to be less migratory and reflective of the local environment. Initial results indicate similar species richness and composition in summer compared to spring and fall, but with a greater number of juvenile individuals. A summer inventory will continue to take place each year to develop a time series of data.

8.4.1.3 Fish Tissue

In 2009, the potential risk to human health related to fish consumption was assessed using individual and composite fish tissue samples of northern pike collected from the Clearwater River and individual fish tissue samples (walleye, northern pike and lake whitefish) from “Jackson” Lake. The average mercury concentration in northern pike from the Clearwater River was below the Health Canada subsistence fisher consumption guideline (0.2 mg/kg) indicating a **Negligible-Low** risk to human health of subsistence fishers and general consumers (Table 8.2-1).

The average mercury concentration in lake whitefish and the single northern pike from “Jackson” Lake were below the Health Canada subsistence fisher consumption guideline for all size classes, indicating a **Negligible-Low** risk to human health (Table 8.2-1). The average mercury concentration in walleye from “Jackson” Lake exceeded the Health Canada subsistence fisher guideline in fish greater than 400 mm in length indicating a **High** risk to human health of subsistence fishers and a **Moderate** risk to general consumers for consumption of fish of that size or greater. Concentrations of mercury in northern pike in relation to weight, from the Clearwater River were within the 95% confidence interval of mercury concentrations in fish from other waterbodies in northern Alberta sampled from 1975 to 2009, including those beyond the influence of focal projects and other oil sands developments. Similar results were observed for mercury concentrations in lake whitefish, northern pike, and walleye from “Jackson” Lake.

All measured tainting compounds in northern pike muscle tissue from the Clearwater River were below guideline concentrations indicating a **Negligible-Low** influence on fish palatability (Table 8.2-1).

Concentrations of metals in northern pike were below sublethal effects and no-effects criteria indicating a **Negligible-Low** risk to northern pike health (Table 8.2-1).

8.4.1.4 Sentinel Species Monitoring

Steepbank River

No slimy sculpin were captured in summer and only a small number were captured in fall at the lower Steepbank River *test* site in 2009, which may be indicative of limited recruitment potential of young fish, limited resource availability (e.g. food, preferred habitat), or increased competition. Low numbers have been observed at this site in previous sampling events, with the lowest capture success in 2009. The low number of slimy sculpin collected at the lower Steepbank River *test* site made it impossible to conduct statistical comparisons between this site and *baseline* sites.

The low number of young slimy sculpin captured at the upper Steepbank River *test* site may indicate limited potential recruitment evident from a low proportion of young individuals or unsuitable habitat for young fish (i.e., smaller substrate size). The condition of slimy sculpin at the *test* site of the upper Steepbank River in 2009 indicated a **Negligible-Low** difference from condition of slimy sculpin at the *baseline* sites in the Horse and Dunkirk rivers. A comparison across years was not possible given this is the first year of sentinel species monitoring when this site was designated as *test* (it was designated as *baseline* in 2004 and 2006).

Lower Muskeg River

The 2009 sentinel species results for the Muskeg River *test* site indicated a high proportion of young-of-year slimy sculpin, suggesting increased recruitment of young individuals but a lower proportion of adult slimy sculpin compared to the *baseline* sites, which may indicate that this area of the Muskeg River is not preferable for adult individuals (i.e., larger substrate for adult fish) but good spawning and rearing habitat. The condition of slimy sculpin at the *test* site of the Muskeg River indicated a **Moderate** difference from condition of slimy sculpin at the *baseline* sites (Horse and Dunkirk rivers) but this difference has not been observed across all years in which sentinel species monitoring was conducted.

8.4.2 Recommendations

RAMP may wish to consider the following recommendations to establish more robust protocols during the fish inventories:

1. Inventory protocols for the Athabasca and Clearwater rivers should continue to be refined and standardized. A full community assessment, rather than just focusing on large-bodied species, should be considered with emphasis on fishing effort and sampling techniques consistent among reaches.

2. In response to community concerns regarding the health of fish in watercourses within the RAMP FSA, more thorough protocols for assessing fish pathology in individual fish was developed in 2009 and will continue to be used in future programs. In addition, RAMP is currently working with a fish pathologist to develop a better understanding of abnormalities in fish in Northern Alberta. A subsample of fish with abnormalities submitted to the fish pathologist for analysis should be considered in conjunction with RAMP's Fish Health Program, which engages anglers within the region to submit fish for analyses.

In collaboration with ASRD, RAMP should continue to develop a database of mercury in fish tissue from lakes and rivers within the RAMP FSA, both beyond focal project development and downstream of development given increased community concern regarding the safe consumption of fish. Based on community concerns, RAMP should continue to analyze for mercury in fish from the Athabasca and Clearwater rivers to monitor trends over time in relation the consumption guidelines established by the Government of Alberta for these specific watercourses (GOA 2009b).

The sentinel species monitoring for slimy sculpin is on a three-year rotation and is not scheduled to be conducted again until 2012. Given the lag-time in returning to the Steepbank and Muskeg rivers to monitor slimy sculpin under this program, RAMP may wish to consider re-sampling both *test* sites (STR-E and MR-E) of the Steepbank and Muskeg rivers in 2010 to determine whether the absence of slimy sculpin was due to natural variability or whether the population is in decline in the lower portion of this watercourse.

8.5 ACID-SENSITIVE LAKES

Based on established criteria, over 60% of the lakes in the ASL component are considered highly sensitive or moderately sensitive to acidification. There have been only minor changes in the chemistry of the 50 ASL study lakes as a whole over the eight years of monitoring (2002 to 2009), with concentrations of nitrate and dissolved organic carbon (DOC) being the only ASL measurement endpoints to show significant changes over the sampling period. The changes in nitrate were not consistent with an acidification scenario and there is no indication that acidification is occurring in the ASL lakes from nitrogen deposition. There was a significant decrease in the concentration of DOC in the RAMP lakes, particularly in the Northeast of Fort McMurray subregion, but this decline was also observed in *baseline* lakes in the Caribou Mountains and Canadian Shield subregion that have little exposure to NO_xSO_x emissions from oil sands developments. The significant decline in the concentration of DOC in RAMP ASL lakes is therefore a natural phenomenon rather than a response to acidification.

Critical loads of acidity were calculated using the Henriksen critical load model modified to account for the contributions of both strong and weak organic acids and using values of runoff derived both from traditional hydrometric methods and isotopic enrichment. Using the runoff derived hydrometrically, critical loads in 2009 ranged from -0.109 to 1.952 keq H+/ha/y with a median value of 0.229 keq H+/ha/y. Using the runoff values derived from measurements of isotopic enrichment, critical loads in 2009 ranged from -0.546 to 3.380 keq H+/ha/y with a median value of 0.387 keq H+/ha/y. Lakes located in the upland regions (Stony Mountains, Birch Mountains, and Caribou Mountains) and in the Canadian Shield subregion had the lowest critical load values and were therefore the most acid-sensitive. The critical loads of acidity were compared to modeled rates of acid deposition for each RAMP ASL lake. Rates of critical load exceedance in 2009 were 38% (19 of 50 ASL lakes) using hydrometrically-derived runoff estimates and 34% (17 of 50 ASL lakes) using runoff estimates based on isotopic enrichment.

Time trend analysis (Mann-Kendall) was applied to key measurement endpoints in all 50 RAMP ASL lakes to detect changes that might indicate incipient acidification. As in previous years, most of the significant trends in measurement endpoints were either natural events (e.g., the decline in concentrations of DOC), small and within analytical error or inconsistent with any reasonable acidification scenario. In several cases, trends observed in previous years were reversed with values returning to historical averages.

The Birch Mountains subregion had the highest rate of measurement endpoints exceeding two standard deviations of the mean for each lake in a direction indicative of acidification. Following the criteria outlined in Section 3.5.6.3, this subregion was classified as having a Moderate variation from long-term average potential for acidification (Table 8.2-1). All other subregions were classified as having **Negligible-Low** variation from long-term average potential for acidification.

9.0 REFERENCES

Adams, S.M., A.M. Brown and R.W. Goede. 1993. A quantitative health assessment index for rapid evaluation of fish condition in the field. Transactions of the American Fisheries Society. 122: 63-73.

AENV (Alberta Environment). 1990. Selected methods for the monitoring of benthic invertebrates in Alberta rivers. Environmental Quality Monitoring Branch, Environmental Assessment Division, Edmonton, AB. 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.

AENV. 2006. Aquatic Ecosystems Field Sampling Protocols. Alberta Environment Publication No: T/883. ISBN 0-7785-5079-6.

AENV. 2007. Water Management Framework: Instream flow needs and water management system for the Lower Athabasca River. Alberta Environment Fisheries and Oceans Canada, February 2007, 37 pp.

AEP (Alberta Environment Protection). 1990. A Review of Approaches for Setting Acidic Deposition Limits in Alberta. Special Report of Alberta Environment. 63 pp.

Alberta Labour Market Information. 2009. Fort McMurray – Alberta Labour market Information. www.woodbuffalo.net/linksFACTSProj.html

Anderson, A.M. 1990. Selected methods for the monitoring of benthic invertebrates in Alberta rivers. Environmental Quality Monitoring Branch, Environmental Assessment Division, Alberta Environment.

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.

AOSERP. 1977. Survey of baseline levels of contaminants in aquatic biota of the AOSERP study area. Prepared by: A. Lutz and M. Hendzel. Prepared for: Alberta Oil Sands Environmental Research Program. June 1977. 66 p.

ATSDR (Agency for Toxic Substances and Disease Registry). 2007. Toxicological Profile for Arsenic. Prepared for U.S. Department of Health and Human Services, Public Health Service, by Syracuse Research Corp. Atlanta. 499 p.+app.

AXYS. 2005. Albian Sands Energy Inc. Muskeg River Mine Expansion Project, Aquatic Environmental Setting Report. Prepared by AXYS Environmental for Albian Sands. February 2005.

B.C. 2003. Ambient Water Quality Guidelines for Boron. Overview Report.

B.C. 2006. A Compendium of working water quality guidelines for British Columbia. Updated August 2006. http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html.

British Columbia. 2008. Ambient Aquatic Life Guideline for Iron. Overview Report. Water Stewardship Division, BC Ministry of Environment. March 2008. Available online at http://www.env.gov.bc.ca/wat/wq/BC guidelines/iron/iron_overview.pdf.

Back, W., and B.B. Hanshaw. 1965. Chemical geohydrology. Adv. Hydrosci 2: 49-109.

Bailey, R.C., R.H. Norris, and T.B. Reynoldson. 2004. Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach. Kluwer Academic Publishers.

Baker, R.F., P.J. Blanchfield, M.J. Patterson, R.J. Flett, and L. Wesson. 2004. Evaluation of nonlethal methods for the analysis of mercury in fish tissue. Trans. Am. Fish. Soc. 133: 568-576.

Barton, D.R. and M.A. Lock. 1979. Numerical abundance and biomass of bacteria, algae and macrobenthos of a large northern river, the Athabasca. Int. Revue ges. Hydrobiol. 64:345-359.

BC MOE 1982. British Columbia Ministry of Environment Procedure Manual. Volume 6, Section 9, Subsection 01, p. 5-72.

BC MOE (British Columbia Ministry of Environment). 2009. Manual of British Columbia Hydrometric Standards. Version 1.0. Prepared by: Ministry of Environment Science and Information Branch for the Resources Information Standards Committee. March 2009.

Bennett, K.E., J.J. Gibson, and P.M. McEachern. 2008. Water-yield estimates for critical loadings assessment: Comparisons of gauging methods versus an isotopic approach. Can, J. Fish. Aquat, Sci. 65:83-99.

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.

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.

Butcher, G.A. 1988. Water Quality Criteria for Aluminum: Technical Appendix. BC Ministry of Environment and Parks, Victoria, British Columbia.

Butcher, G.A. 2001. Water quality criteria for aluminum. Overview report. British Columbia Ministry of Water, Land and Air Protection, Victoria, BC.

Canfield, T.J, N.E. Kemble, W.G. Brumbaugh, F.J, Dwyer, C.G. Ingersoll, and J.F. Fairchild. 1994. Use of benthic invertebrate community structure and the sediment quality triad to evaluate metal-contaminated sediment in the upper Clark Fork River, Montana. Environmental Toxicology and Chemistry 13: 1999-2012.

Carrie, J., F. Wang, H. Sanei, R.W. Macdonald, P.M. Outridge, G.A. Stern. 2010. Increasing contaminant burdens in an Arctic fish, burbot (*Lota lota*), in a warming climate. Environ. Sci. Tech. 44(1): 316-322.

CASA. 1996. Final report of the Target Loading Subgroup on Critical and Target Loading in Alberta. Publication of the Clean Air Strategic Alliance, Edmonton, Alberta 13pp.

CCME (Canadian Council of Ministers of the Environment). 1999a. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

CCME. 2001. Canada-wide standards for petroleum hydrocarbons (PHCs) in soil: scientific rationale. Supporting technical document.

CCME. 2002. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, updated 2002.

CCME. 2007. Canadian water quality guidelines for the protection of aquatic life. Canadian Council of Ministers of the Environment, updated 2007.

CCME. 2008. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil. Canadian Council of Ministers of the Environment, updated January 2008.

CEMA (Cumulative Environmental Management Association). 2001. Sustainable Ecosystem Working Group, Terms of Reference and Work Plan.

CEMA. 2004. Development of reach specific water quality objectives for variables of concern in the lower Athabasca River: Identification of variables of concern and assessment of the adequacy of available guidelines.

Chen, Y. and H.H. Harvey. 1999. Spatial structuring of length-at-age of the benthivorous white sucker (Catostomus commersoni) in relation to environmental variables. Aquatic Living Resources. 12: 351-362.

Clements, W.H. 1994. Benthic invertebrate community responses to heavy metals in the upper Arkansas River Basin, Colorado. Journal of the North American Benthological Society 13: 30-40.

Clements, W.H., D.S. Cherry, and J. Cairns. 1988. The impact of heavy metals on macroinvertebrate communities: a comparison of observational and experimental results. Canadian Journal of Fisheries and Aquatic Sciences 45: 2017-2025.

Clements, W.H., D.S. Cherry, and J.H. Van Hassel. 1992. Assessment of the impact of heavy metals on benthic communities at the Clinch River (Virginia): evaluation of an index of community sensitivity. Canadian Journal of Fisheries and Aquatic Sciences 49: 1686-1694.

Clifford, H.F. 1991. Aquatic Invertebrates of Alberta. University of Alberta Press. Edmonton, AB.

Colavecchia, M.V., S.M. Backus, P.V. Hodson, and J.L. Parrott. 2004. Toxicity of oil sands to early life stages of fathead minnows (Pimephales promelas). Environmental Toxicology and Chemistry. 23:1709-1718.

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Sciences. Second Edition. Lawrence Erlbaum Associates. Hillsdale, New Jersey.

Cover, M.R., C.L. May, W.E. Dietrich, and V.H. Resh. 2008. Quantitative linkages among sediment supply, streambed fine sediment, and benthic macroinvertebrates in northern California streams. Journal of the North American Benthological Society 27: 135-149.

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 and Keys to the Immature Black Flies of Alberta (Diptera: Simuliidae). Mem. ent. Soc. Can. 136.

Czarnecka, E. and J.E. Gillot. 1980. Formation and characterization of clay complexes with bitumen from Athabasca oil sand. Clays and Clay Materials 3: 197-203.

Danehy, R.J., N.H. Ringler, S.V. Stehman, and J.M. Hassett. 1998. Variability of fish densities in a small catchment. Ecology of Freshwater Fish. 7: 36-48.

Death, R.G. 1995. Spatial patterns in benthic invertebrate community structure: products of habitat stability or are they habitat specific? Freshwater Biology 33: 455-467.

DeBoer, D., M.S. Evans, K.F. Ali, R. Froess, M. Davies, D. Halliwell. 2007. Water and sediment geochemistry in the Mackenzie River basin. Presented at the 60th Canadian Water Resources Association (CWRA) National Conference, Saskatoon, SK, June 2007.

Deer Creek Energy (Deer Creek Energy Ltd.). 2006. Integrated Application for Joslyn North Mine Project. Submitted to Alberta Energy Utilities Board and Alberta Environment.

DFO (Department of Fisheries and Oceans Canada). 1984. Integrated Commercial and Survey Report (for Mercury Concentrations in fish species). Government of Canada Department of the Fisheries and Oceans, Southern Operations Directorate Western Region. 167pp.

DFO and EC (Department of Fisheries and Oceans and Environment Canada). 1995. Further guidance for the invertebrate community survey for aquatic environmental effects monitoring related to federal Fisheries Act requirements. EEM 2, February 1995.

Dion, R., M. Richardson, L. Roy, and F.G. Whoriskey. 1994. Spawning patterns and interspecific matings of sympatric white (Catostomus commersoni) and longnose (C. catostomus) suckers from the Grouin reservoir system, Quebec. Canadian Journal of Zoology. 72: 195-200.

Dobbie, M.J., B.L. Henderson, and D.L. Stevens, Jr. 2008. Sparse sampling: spatial design for monitoring stream networks. Statistics Survey 2:113-153.

Driscoll, C.T., R.M. Newton, C.P. Gubala, J.P. Baker, and S.W. Christensen. 1991. Case Study – Adirondack Mountains. In: (ed D.F. Charles) Acidic Deposition and Aquatic Ecosystems. Springer Verlag, New York. pp. 133-202.

Dußling U., R. Berg, H. Klinger, and C. Wolter. 2004. Assessing the ecological status of river systems using fish assemblages. In Handbuch angewandte Limnologie, VIII-7.4, 20. Erg.Lfg. 12/04. C. Steinberg, W. Calmano, H. Klapper and R-D. Wilken (eds.). Ecomed: Landsberg am Lech, Germany; 1-84.

Edmunds, G.F., Jr., S.L. Jensen, and L. Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press. Minneapolis. 330pp.

Edwards, E. A. 1983. Habitat suitability index models: Longnose sucker. U.S. Dept. Int., Fish Wildl. Servo FWS/OBS-82/10.35. 21 pp.

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 by EVS Consultants for Environment Canada, North Vancouver, BC. 81 pp.

Environment Canada. 2002. Metal mining guidance document for aquatic environmental effects monitoring. June 2002.

Environment Canada. 2003. Corrections for the Metal Mining EEM Guidance Document for Aquatic Environmental Effects Monitoring. July 2003. Ottawa.

Environment Canada. 2005. Revised pulp and paper EEM guidance document. Environment Canada. July 2005.

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.

ERCB (Energy Resources Conservation Board). 2009. Alberta's Energy Reserves 2009 and Supply/Demand Outlook 2009-2018. Energy Resources Conservation Board. ST98-2009. June 2009.

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.

Evans, M.S, D. Muir, W.L. Lockhart, G. Stern, M. Ryan, and P. Roach. 2005. Persistent organic pollutants and metals in the freshwater biota of the Canadian sub-Arctic and Arctic: An overview. Science of the Total Environment. 351-352: 94-147.

Faria, M.S., R.J. Lopes, J. Malcato, A.J. Nogueira, and A.M. Soares. 2008. In situ bioassays with Chironomus riparius larvae to biomonitor metal pollution in rivers and to evaluate the efficiency of restoration measures in mine areas. Environmental Pollution 151: 213-221.

Fausch, K.D., J.R. Karr, and P.R. Yant. 1984. Regional application of an Index of Biotic Integrity based on stream fish communities. Transactions of the American Fisheries Society 113: 39-55.

Flotemersch, J.E., J.B. Stribling, R.M. Hughes, L. Reynolds, M.J. Paul, and C. Wolter. *In Press*. Site length for biological assessment of boatable rivers. River Research & Applications.

Forsius, M., J. Kamari, and M. Posch. 1992. Critical loads for Finnish lakes: Comparison of three steady state models. Environ. Pollut 77(2-3): 185-193.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice Hall, Inc. Englewood Cliffs, NJ.

Galloway, B.J., K.R. Munkittrick, S. Currie, M.A. Gray. R.A Curry, and C.S. Wood. 2003. Examination of the responses of slimy sculpin (Cottus cognatus) and white sucker (Catostomus commersoni) collected on the Saint John River (Canada) downstream of pulp mill, paper mill, and sewage discharges. Environmental Toxicology and Chemistry, 22 (12): 2898-2907.

Gauch, H.G. Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press.

Gibbons, W.N. and K.R. Munkittrick. 1994. A sentinel monitoring framework for identifying fish population responses to industrial discharges. Journal of Aquatic Ecosystem Health. 3: 227-237.

Gibson J.J., E.E. Prepas, and P. McEachern. 2002. Quantitative comparison of lake throughflow, residency and catchment runoff using stable isotopes: modelling and results from a regional survey of Boreal lakes. J. Hydrol. 262: 128-144.

Gibson, J.J. 2002. Short-term evaporation and water budget comparisons in shallow Arctic lakes using non-steady isotope mass balance. J. Hydrol. 264: 242-261.

Gibson, J.J. and T.W.D Edwards. 2002. Regional water balance trends and evaporation-transpiration partitioning from a stable isotope survey of lakes in northern Canada. Global Biogeochemical Cycles. 16: 10-1 to 10-14.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Company, New York, NY. 320 pp.

Gilliam, J.F., D.F. Fraser, and A.M. Sabat. 1989. Strong effects of foraging minnows on a stream benthic invertebrate community. Ecology 70: 445-452.

Glozier, N.E., D.B. Donald, R.W. Crosley, and D. Halliwell. 2009. Wood Buffalo National Park Water Quality: Status and Trends from 1989-2006 in Three Major Rivers; Athabasca, Peace and Slave. Environment Canada, Saskatoon, SK. May 2009.

GOA (Government of Alberta). 2009a. Industry Profiles: mining and oil and gas extraction industry. September 2009. 8 p.

GOA (Government of Alberta). 2009b. Human Health Risk Assessment: Mercury in Fish The Regional Aquatics Monitoring Program (RAMP). Alberta Health and Wellness. October 2009.

Golder. 1996. Aquatic baseline report for the Athabasca, Steepbank, and Muskeg Rivers in the vicinity of the Steepbank and Aurora Mines. Prepared for Suncor Inc., Oil Sands Group.

Golder. 2000. Oil Sands Regional Aquatics Monitoring Program (RAMP) 1999. Submitted to RAMP Steering Committee. May 2000.

Golder. 2001. Oil Sands Regional Aquatics Monitoring Program (RAMP) 2000. Final report for the RAMP Steering Committee.

Golder. 2002. Oil Sands Regional Aquatics Monitoring Program (RAMP) Program design and rationale – Version 2. A report to the RAMP Steering Committee.

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.

Golder. 2004. Fish contaminant study for Treaty 8 First Nation Communities in Northern Alberta-Data Report. Prepared for Alberta Treaty 8 Health Authority. Edmonton, AB.

Government of Canada. 2008 Technical guidance document for Water Quality Index practitioners reporting under the Canadian Environmental Sustainability Indicators (CESI) initiative 2008. 48 pp.

Government of Iowa. 2005. Iron criteria and implementation for Iowa surface waters. Iowa Department of Natural Resources Water Quality Standards. Available online at http://www.iowadnr.com/water/standards/iron.html.

Gray, M.A., R.A., and K.R. Munkittrick. 2002. Non-lethal sampling methods for assessing environmental impacts using a small-bodied sentinel fish species. Water Quality Research Journal of Canada. 37: 195-211.

Grey, B.J., S.M. Harbicht, and G.R. Stephens. 1995. Mercury in fish from rivers and lakes in southwestern Northwest Territories. Northern Water resources Studies – Northern Affairs Program.

Griffith, M.B. and M. Kravitz. 2008. Relationships among exceedances of sediment guidelines, the results of ambient sediment toxicity tests, and community metrics in estuarine systems. Estuaries and Coasts 31:101-114.

Grigal, D.F. 2003. Mercury sequestration in forest and peatlands. Journal of Environmental Quality 32: 393-405.

Güler, C., G.D. Thyne, J.E. McCray, and A.K. Turner. 2004. Evaluation of graphical and multivariate statistical methods for classification of water chemistry data. Hydrogeology Journal, 10: 455-474.

Hamel, P., P. Magnan, M. Lapointe, and P. East. 1997. Timing of spawning and assessment of a degree-day model to predict the in situ embryonic developmental rate of white sucker, Catostomus commersoni. Canadian Journal of Fisheries and Aquatic Science. 54: 2040-2048.

Hatfield. 2010. Nexen Lakes Wetlands Monitoring Program. Prepared by: Hatfield Consultants. Prepared for: Nexen Inc. April 2010.

Health and Welfare Canada. 1979. Methylmercury in Canada — exposure of Indian and Inuit residents to methylmercury in the Canadian environment. Health and Welfare Canada, Medical Services Branch, Ottawa Ontario. 200 pp.

Health Canada. 2007. Canadian Standards ("Maximum Limits") for Various Chemical Contaminants in Foods. http://www.hc-sc.gc.ca/fn-an/securit/chem-chim/contaminants-guidelines-directives-eng.php.

Hebben, T. 2009. Analysis of Water Quality Conditions and Trends for the Long-Term River Network: Athabasca River, 1960-2007. Alberta Environment, Edmonton, AB. March 2009.

Henriksen, A. and M. Posch. 2001. Steady-state models for calculating critical loads of acidity for surface waters. Water Air Soil Pollut.: Focus 1: 375-398.

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.

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.

Hughes, R.M., P.R. Kaufmann, A.T. Herlihy, S.S. Intelmann, S.C. Corbett, M.C. Arbogast and R.C. Hjort. 2002. Electrofishing distance needed to estimate fish species richness in raftable Oregon rivers. North American Journal of Fisheries Management 22:1229-1240.

Hughes, R.M., and A.T. Herlihy. 2007. Electrofishing distance needed to estimate consistent IBI scores in raftable Oregon rivers. Transactions of the American Fisheries Society 136:135-141.

Hughes R.M., and D.V. Peck. 2008. Acquiring data for large aquatic resource surveys: the art of compromise among science, logistics, and reality. Journal of the North American Benthological Society 27:837-859.

INAC (Indian Northern Affairs Canada). 2003. Northern Contaminants Program-Canadian Arctic Contaminants Assessment Report II, updated 2006. http://www.ainc-inac.gc.ca/nth/ct/ncp/pubs/hig/hil-eng.pdf

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.

Jones, R.D. and J.N. Boyer. 2002. FY2001 Annual Report of the Water Quality Monitoring Project for the Water Quality Protection Program in the Florida Keys National Marine Sanctuary. Southeast Environmental Research Center Technical Report #T181. Florida International University, Miami, FL. 48 p.

Kanno Y., J.C. Vokoun, D.C. Dauwalter, R.M. Hughes, A.T. Herlihy, T.R. Maret, and T.M. Patton. 2009. Influence of rare species on electrofishing distance–species richness relationships at stream sites. Transactions of the American Fisheries Society 138:1240-1251.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6):21-27.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5.

Kiffney, P.M. and W.H. Clements. 1996. Size-dependent response of macroinvertebrates to metals in experimental streams. Environmental Toxicology and Chemistry 15: 1352-1356.

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.

Kilgour, B.W., K.M. Somers, and D.E. Matthews. 1998. Using the normal range as a criterion for ecological significance in environmental monitoring and assessment. Écoscience, 5:542-550.

Kilgour, B.W., K.R. Munkittrick, C.B. Portt, K. Hedley, J. Culp, S. Dixit, and G. Pastershank. 2005. Biological criteria for municipal wastewater effluent monitoring programs. Water Quality Research Journal of Canada, 40:374-387.

Kilgour, B.W., M.G. Dube, K. Hedley, C.B. Portt, and K.R. Munkittrick. 2007. Aquatic Environmental Effects Monitoring guidance for environmental assessment practitioners. Environmental Monitoring and Assessment 130: 423-436.

Klemm, D.J., P.A. Lewis, F. Fulk, and J.M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. Environmental Monitoring.

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.

Krantzberg, G. 1994. Spatial and temporal variability in metal bioavailability and toxicity of sediment from Hamilton Harbour, Lake Ontario. Environmental Toxicology and Chemistry 13: 1685-1698.

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 (4): 31 p.

Lamberson, J.O., T.H. DeWitt, and R.C. Swartz. 2000. Assessment of Sediment Toxicity to Marine Benthos. In: G.A. Burton (ed.). Sediment Toxicity Assessment. Lewis Publishers Inc., Chelsea, MI. Pgs. 183-213.

Larsen, D.P., P.R. Kaufmann, T.M. Kincaid, and N.S. Urquhart. 2004. Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences. 61:283-291.

Lau, Y.K. 1982. Precipitation chemistry. Air Quality Control Branch, Pollution Control Division, Alberta Environment. Edmonton, Alberta. 75 pp.

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. 79 pp.

Lipkovich, I. and E. Smith. 2002. Biplot and Singular Value Decomposition Macros for Excel©. Journal of Statistical Software, 7(5).

Lister, A., V. Nero, A. Farwell, D.G. Dixon, and G. Van Der Kraak. 2008. Reproductive and stress hormone levels in goldfish (Carassius auratus) exposed to oil sands process-affected water. Aquatic Toxicology. 87: 170-177.

Lockhart, W.L., G.A. Stern, G. Low, M. Hendzel, G. Boila, P. Roach, M.S. Evans, B.N. Billeck, L. DeLaronde, S. Friesen, K. Kidd, S. Atkins, D.C.G. Muir, M. Stoddart, G. Stephens, S. Stephenson, S. Harbicht, N. Showshoe, B. Grey, S. and Thompson, N. DeGraff. 2005. A history of total mercury in edible muscle of fish from lakes in northern Canada. Science of the Total Environment. 351-352: 427-463.

Lowell, R.B., S.C. Ribey, I.K. Ellis, E.L. Porter, J.M. Culp, L.C. Grapentine, M.E. McMaster, K.R. Munkittrick, and R.P. Scroggins. 2003. National assessment of the pulp and paper environmental effects monitoring data. National Water Research Institute, NWRI Contribution No. 03-521.

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.

Martin, J. 2009. Personal Communication (Telephone conversation with Martin Davies regarding concentrations of naphthenic acids in the Athabasca River).

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. 1996. An Introduction to the Aquatic Insects of North America, 3rd ed. Kendall/Hunt Pub. Co., Dubuque, Iowa.

Miller, L.M., L., Kallemeyn, and W. Senanan. 2001. Spawning-site and natal-site fidelity by northern pike in a large lake: mark-recpature and genetic evidence. Transactions of the American Fisheries Society. 130:307-316.

Millward, R.N., K.R. Carman, J.W. Fleeger, R.P. Gambrell, and R. Portier. 2004. Mixtures of metals and hydrocarbons elicit complex responses by a benthic invertebrate community. Journal of Experimental Marine Biology and Ecology 310: 115-130.

Morrison, L.W. 2008. Use of Control Charts to Interpret Environmental Monitoring Data. Natural Areas Journal 28(1): 66-73.

Moyle, P.B. and J.J. Cech. 2004. Fishes: An introduction to ichthyology. Prentice Hall, Upper Saddle River, NJ. 726 p.

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). 236 p.

NRBS. 1996. Contaminants in Environmental Samples: mercury in the Peace, Athabasca, and Slave River Basins. Northern River Basins Study Project Report No. 105. 66 p.

Oilsands review. 2009. Oilsands review: the unconventional oil authority. November 2009.

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.

Olson, D.E. and W.J. Scidmore. 1963. Homing tendency of spawning white suckers in Many Point Lake, Minnesota. Transactions of the American Fisheries Society. 92: 13-16.

Olson, D.E. and W.J. Scidmore. 1962. Homing behaviour of spawning walleye. Transactions of the American Fisheries Society. 91: 355-361.

Paine, M.D., P.M. Chapman, P.J. Allard, M.H. Murdock, and D. Minifie. 1996. Limited bioavailability of sediment PAH near an aluminum smelter: contamination does not equal effects. Environmental Toxicology and Chemistry 15: 2003-2018.

Pappas, S., Environmental Monitoring Scientist, Environment Canada, Vancouver, personal communication. Meeting December 23, 2009, Vancouver, BC.

Peck, D.V., A.T. Herlihy, B.H. Hill, R.M. Hughes, P.R. Kaufmann, D.J. Klemm, J.M. Lazorchak, F.H. McCormick, S.A. Peterson, P.L. Ringold, T. Magee, and M.R. Cappaert. 2006. Environmental Monitoring and Assessment Program - Surface Waters Western Pilot Study: field operations manual for wadeable streams. EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, DC.

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.

Peterson, C.H. 2001. The “Exxon Valdez” oil spill in Alaska: acute, indirect, and chronic effects on the ecosystem. Advances in Marine Biology 39:1-103.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. Bioscience. 47: 769-784.

Rada, R.G., J.G. Wiener, M.R. Winfrey, and D.E. Powell. 1989. Recent increases in atmospheric deposition of mercury to north-central Wisconsin lakes inferred from sediment analyses. Archives of Environmental Contamination and Toxicology 18(1-2): 175-181.

RAMP. 2004. RAMP 2003 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants Ltd., Jacques-Whitford Ltd., Mack, Slack, and Associates Inc., and Western Resource Solutions. April 2004.

RAMP. 2005. RAMP 2004 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants Ltd., Stantec Consulting Ltd., Mack, Slack, and Associates Inc., and Western Resource Solutions. April 2005, revised November 2005.

RAMP. 2006. RAMP 2005 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants, Stantec Consulting Ltd., Mack, Slack, and Associates Inc., and Western Resource Solutions. April 2006.

RAMP. 2007. RAMP 2006 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants, Stantec Consulting Ltd., Mack, Slack, and Associates Inc., and Western Resource Solutions. April 2007.

RAMP. 2008. RAMP 2007 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants, Stantec Consulting Ltd., Klohn Crippen Berger Ltd., and Western Resource Solutions. April 2008.

RAMP. 2009a. RAMP 2008 Technical Report. Prepared for the RAMP Steering Committee by Hatfield Consultants, Kilgour and Associates Ltd., Klohn Crippen Berger Ltd., and Western Resource Solutions. April 2009.

RAMP. 2009b. RAMP Technical design and rationale document. Prepared for the RAMP Steering Committee by Hatfield Consultants, Kilgour & Associates Ltd., Klohn Crippen Berger Ltd., and Western Resource Solutions. December 2009.

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.

Rideout, R.M., G.A. Rose, and M.P. Burton. 2005. Skipped spawning in female iteroparous fishes. Fish and Fisheries. 2005: 50-72.

RMWB (Regional Municipality of Wood Buffalo). 2009. The Regional Municipality of Wood Buffalo Census 2008. June 2009. 21 pp.

Rooke, J.B. and G.L. Mackie. 1982. 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 & Hall, New York, 488 pp.

Saffron, K. A. and D.O. Trew. 1996. Sensitivity of Alberta lakes to acidifying deposition: An update of maps with emphasis on 109 northern lakes. Water Management Division, Alberta Environmental Protection, Edmonton, Alberta. 70 pp.

Salmi, T., A. Maatta, P. Anttila, T.T. Ruoho-Airola, and T. Amnell. 2002. Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates - The Excel Template Application MAKESENS. Report published by the Finnish Meteorological Institute, Helsinki.

Scoggins, M., N.L. McClintock, L. Gooselink, and P. Bryer. 2007. Occurrence of polycyclic aromatic hydrocarbons below coal-tar-sealed parking lots and effects on stream benthic macroinvertebrate communities. Journal of the North American Benthological Society 26: 694-707.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184. 966 p.

Scott, A.C., M.D. Mackinnon, and P.M. Fedorak. 2005. Naphthenic Acids in Athabasca Oil Sands Tailings Waters Are Less Biodegradable than Commercial Naphthenic Acids. Environ. Sci. Technol. 39 (21): 8388-8394.

Shewhart, W.A. 1931. Economic control of quality of the manufactured product. Van Nostrand. New York, NY.

Smith K.L. and Jones M.L. 2005. Watershed-level sampling effort requirements for determining riverine fish species composition. Canadian Journal of Fisheries and Aquatic Sciences 62:1580-1588.

SPSS Inc. 2000. SYSTAT, Version 10. Evanston, IL.

Squires, A.J., C.J. Westbrook, and M.G. Dubé. 2009. An approach for assessing cumulative effects in a model river, the Athabasca River basin. Integrated Environmental Assessment and Monitoring 6(1): 119-134.

Stewart, K.W. and B.P. Stark. 1988. Nymphs of North American Stonefly Genera (Plecoptera), Ent. Soc. America, Lanham, Maryland. 460 pp.

Strategy West Inc. 2009. Existing and Proposed Canadian Commercial Oil Sands Projects. Prepared by: R.B. Dunbar. Strategy West Inc. February 2009. 12 pp.

Syncrude Canada Ltd. 1977. Water quality and aquatic resources of the Beaver Creeek Diversion System, 1977. Prepared by L.R. Noton and N.R. Chymko, Chemical and Geological Laboratories Ltd. for Syncrude Canada Ltd. Environmental Research Monograph 1978-3.

ter Braak, C.J.F. & Šmilauer, P. 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Ithaca, NY, USA.

Teskey, H.J. 1969. Larvae and Pupae of Some Eastern North American Tabanidae (Diptera). Mem. Ent. Soc. Can. 63.

Tetreault, G.R., M.E. McMaster, D.G. Dixon, and J.L. Parrott. 2003a. Using reproductive endpoints in small forage fish species to evaluate the effects of Athabasca oil sands activities. Environmental Toxicology and Chemistry. 22:2775-2782.

Tetreault, G.R., M.E. McMaster, D.G. Dixon, and J.L. Parrott. 2003b. Physiological and biochemical responses of Ontario slimy sculpin (Cottus cognatus) to sediment from the Athabasca oil sands area. Water Quality Research Journal of Canada. 38: 361-377.

Trippel, E.A. and H.H. Harvey. 1989. Missing opportunities to reproduce: an energy dependent or fecundity gaining strategy in white sucker (Catostomus commersoni)? Canadian Journal of Zoology. 67: 2180-2188.

Twomey, K.A., K.L. Williamson, and P.C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: White sucker. U.S. Fish Wildl. Servo FWS/OBS-82/10.64. 56 pp.

US EPA (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.

US EPA (United States Environmental Protection Agency). 2006. National Recommended Water Quality Criteria for Priority Toxic Pollutants.

Ullrich, S.M., T.W. Tanton, and S.A. Abdrashitova. 2001. Mercury in the aquatic environment: A review of factors affecting methylation. Critical Reviews in Environmental Science and Technology, 31(3): 241-293.

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.

Urquhart, N.S., and Kincaid, T.M. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological and Environmental Statistics 4, 404-414.

Walton, B.D. 1980. The reproductive biology, early life history and growth of white suckers, Catostomus commersoni, and longnose suckers, C. catostomus, in the Wi 11 ow Creek-Chai n Lakes System, Alberta. Alberta Dept. Energy Nat. Resour. Fish Res. Rep. 23.

Wayland, M., J.V. Headley, K.M. Peru, R. Crosley, and B.G. Brownlee. 2008. Levels of polycyclic aromatic hydrocarbons and dibenzothiophenes in wetland sediments and aquatic insects in the oil sands area of Northeastern Alberta, Canada. Environ. Monit. Assess. 136: 167-182.

Westfall, M.J., Jr. and M.L. May. 1996. Damselflies of North America. Scientific Publishers, Gainesville, Florida. 649 pp.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems. 3rd Ed. Academic Press. San Diego. 1006p.

Whittier, T.R., R.M. Hughes, G.A. Lomnicky, and D.V. Peck. 2007a. Fish and amphibian tolerance values and an assemblage tolerance index (ATI) for western USA streams and rivers. Transactions of the American Fisheries Society 136:254-271.

Whittier, T.R., R.M. Hughes, J.L. Stoddard, G.A. Lomnicky, D.V. Peck and A.T. Herlihy. 2007b. A structured approach for developing indices of biotic integrity: three examples from western USA streams and rivers. Transactions of the American Fisheries Society 136:718-735.

Whittier, T.R., J.L. Stoddard, D.P. Larsen, and A.T. Herlihy. 2007c. Selecting reference sites for stream biological assessments: best professional judgment or objective criteria. Journal of the North American Benthological Society 26:349-360.

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.

Wrona, F.J., M. Culp, and R.W. Davies. 1982. Macroinvertebrate Subsampling: a Simplified Apparatus and Approach. Canadian Journal of Fisheries Aquatic Science. 39:1051-1054.

WRS (Western Resource Solutions). 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.

WRS (Western Resource Solutions). 2006. Critical Loads of Acidity to Lakes in the Athabasca Oil Sands Region – Modification of the Henriksen Model for Lake

Organic Content. Final report to: NOx-SOx Management Working Group, Fort McMurray, Alberta. January, 2006.

WSC (Water Survey of Canada). 2001. Hydrometric Technician Career Development Program. http://www.smc-msc.ec.gc.ca/wsc/CDP/.

Zloty, J. and G. Pritchard. 1997. Larvae and Adults of Ameletus Mayflies (Ephemeroptera: Ameletidae) from Alberta. Can Ent. 129:251-289.

10.0 GLOSSARY AND LIST OF ACRONYMS

10.1 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).
Baseline	*Baseline* is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 2008) or were (prior to 2008) upstream of all focal projects; data collected from these locations are to be designated as *baseline* for the purposes of data analysis, assessment, and reporting. The terms *test* and *baseline* depend solely on location of the aquatic resource in relation to the location of the focal projects to allow for long-term comparison of trends between *baseline* and *test* stations.
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 Effort — 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 limit. 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 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).

CONRAD	Canadian Oil Sands Network for Research and Development
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.
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 river, 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.
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*).
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.

Operational — The term used to characterize data and information gathered from stations that are designated as exposed.

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.

Health Assessment 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 HAI is calculated by summing the index values for each species and dividing by the total number of individuals captured of that species. The HAI value increases as the number and severity of anomalies 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.
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.
Runoff depth	Streamflow volume divided by catchment area.
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, walleye).

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.

Test ***Test*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches) downstream of a focal project; data collected from these locations are designated as ***test*** for the purposes of analysis, assessment, and reporting. The use of this term does not imply or presume that effects are occurring or have occurred, but simply that data collected from these locations are being tested against baseline conditions to assess potential changes.

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.
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.

10.2 LIST OF ACRONYMS AND ABBREVIATIONS

ADL	analytical detection limit
AED	Alberta Economic Development
AENV	Alberta Environment
AEP	Alberta Environment Protection
Albian	Albian Sands Energy Inc.
ALPAC	Alberta-Pacific Forest Industries Inc.
ANC	acid neutralizing capacity
ANC_{org}	ANC attributable to weak organic acids
ANCOVA	analysis of covariance
ANOVA	analysis of variance
AOSERP	Alberta Oil Sands Environmental Research Program
APHA	American Public Health Association
ARC	Alberta Research Council
ARC-Vegreville	Alberta Research Council located in Vegreville
ARD	Athabasca River Delta
ASL	acid-sensitive lakes
ASRD	Alberta Sustainable Resource Development
AURIVAS	Australian River Assessment System
AWI	Alberta Wetland Inventory
AXYS	AXYS Analytical Services
BCI	Bray-Curtis index
BC MOELP	BC Ministry of Environment, Lands and Parks
Birch Mountain	Birch Mountain Resources Ltd.
BOD	biochemical oxygen demand
CA	correspondence analyses
CAEAL	Canadian Association for Environmental Analytical Laboratories
CCME	Canadian Council of Ministers of the Environment
CEA	cumulative effects assessment
CEMA	Cumulative Environmental Management Association
CFIA	Canadian Food Inspection Agency

CIR	false-colour infrared
CL	critical load
CNRL	Canadian Natural Resources Limited
COC	chain of custody
CONRAD	Canadian Oil Sands Network for Research and Development
CPUE	catch-per-unit-effort
CVAFS	cold vapour atomic fluorescence spectrophotometry
CWD	clean water discharge
CWQG	Canadian Water Quality Guidelines
Deer Creek	Deer Creek Energy Ltd.
Devon	Devon Canada Corporation
DFO	Fisheries and Oceans Canada
DIC	dissolved inorganic carbon
DL	detection limit
DO	dissolved oxygen
DOC	dissolved organic carbon
EEM	environmental effects monitoring
EIA	environmental impact assessment
ENGO	environmental non-government organization
EPEA	Environment Protection & Enhancement Act
EPI	external pathology index
EPT	Ephemeroptera, Plecoptera and Trichoptera
ERCB	Energy Resources Conservation Board
ETL	Enviro-Test Laboratories
EUB	Alberta Energy and Utilities Board
FAM	Fish Assemblage Monitoring
Flett	Flett Research Ltd
FMA	Forest Management Agreement
FMIS	Fisheries Management Information System
FSA	Focus Study Area
FWI	field work instructions

FWIN	Fall Walleye Index Netting
GIC	Goose Island Channel
GPS	global positioning system
GSI	gonad somatic index
HAI	health assessment index
Hg	Mercury
HI	hazard index
HQ	hazard quotient
Hydroqual	Hydroqual Laboratories
Husky	Husky Energy
Imperial Oil	Imperial Oil Resources
IBI	Index of Biotic Integrity
IFN	instream flow needs
IQR	inter-quartile range
IRC	industry relations corporation
ISQG	Interim Freshwater Sediment Quality Guidelines
JACOS	Japan Canada Oil Sands Limited
KIR	key indicator resource
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
MSS	Multi-Spectral Scanner
Nexen	Nexen Inc.
NRBS	Northern River Basins Study
NSMWG	NO_x and SO_x Management Working Group
NWRI	National Water Research Institute
OCA	objective classification analysis
PAH	polycyclic aromatic hydrocarbon
PAI	potential acid input

PC	principal component
PCA	principal component analysis
PEL	probable effect level
PI	pathology index
ppb	parts per billion
ppm	parts per million
ppq	parts per quadrillion
QA	quality assurance
QAP	quality assurance plan
QC	quality control
RAMP	Regional Aquatics Monitoring Program
RCA	reference condition approach
RIC	Resources Inventory Committee
RIVPACS	River Invertebrate Prediction and Classification System
RMWB	Regional Municipality of Wood Buffalo
RSA	regional study area
RSDS	regional sustainable development strategy
SAGD	steam assisted gravity discharge
SBC	ratio of alkalinity to base cations
SD	standard deviation
SE	standard error
Shell	Shell Canada Limited
SOP	Standard Operating Procedures
SQI	Sediment Quality Index
STP	sewage treatment plant
Suncor	Suncor Energy Inc.
SWE	snow water equivalent
SWI	specific work instruction
Syncrude	Syncrude Canada Ltd.
TCU	total colour units
TDG	transportation of dangerous goods
TDN	total dissolved nitrogen

TDP	total dissolved phosphorus
TDS	total dissolved solids
TEEM	Terrestrial Environmental Effects Monitoring Committee
TEH	total extractable hydrocarbon
TEK	Traditional Ecological Knowledge
TIE	toxicity identification evaluation
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
Total E&P	Total E&P Canada Ltd.
TM	Thematic Mapper
TN	total nitrogen
TP	total phosphorus
TPH	Total Petroleum Hydrocarbons
TRH	total recoverable hydrogen
TrueNorth	TrueNorth Energy L.P.
TSS	total suspended solids
TVH	total volatile hydrocarbon
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTF	underground test facility
UTM	universal transverse mercator
VOC	volatile organic compounds
WBEA	Wood Buffalo Environmental Association
WHMIS	Workplace Hazardous Information Materials Information Systems
WRS	Western Resource Solutions Ltd.
WQI	Water Quality Index
WSC	Water Survey of Canada
WWG	Water Working Group (CEMA)
YOY	young of the year