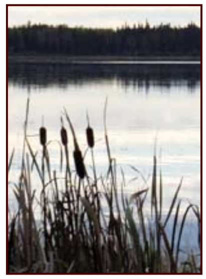
Regional Aquatics Monitoring Program




2010 TECHNICAL REPORT

FINAL

REGIONAL AQUATICS MONITORING PROGRAM

2010 Technical Report

FINAL

Prepared for:

RAMP STEERING COMMITTEE

Prepared by:

The RAMP 2010 Implementation Team

Consisting of:

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

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The RAMP chairperson during the 2010 program year was Andrews Takyi (Total E&P). Tomas Romero (ConocoPhillips) was chair of the Technical Program Committee, Neil Rutley (Nexen) was chair of the Finance Sub-committee and Erin Johnston (January to September 2010)/National Public Relations (October 2010 to April 2011) served as Communications Coordinator for RAMP.

RAMP is a multi-stakeholder environmental monitoring program that is composed of representatives from industry; municipal, provincial and federal governments and local First Nations groups. 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 Canada Energy, ConocoPhillips, Husky, and ASRD for their contribution towards the fish inventory program;
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- AENV for conducting field work required for the Acid-Sensitive Lakes component; and
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- University of Alberta Limnological Laboratory (chemical analyses);

2010 IMPLEMENTATION TEAM

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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 Regional Municipality of Wood Buffalo. 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 2010, RAMP was funded by Suncor Energy Inc., Syncrude Canada Ltd., Shell Canada Energy, Canadian Natural Resources Limited, Imperial Oil Resources, Nexen Inc., Husky Energy, Total E&P Canada Ltd., MEG Energy Corp., Dover Operating Corp., ConocoPhillips Canada, Devon Energy Corp., and Hammerstone Corporation. Non-funding participants included municipal, provincial and federal government agencies and one First Nations 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 those parts of the following watersheds where oil sands and other developments are occurring or planned:

- 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 occurring in the Athabasca oil sands region.

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:

1. 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.

2. 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.

3. 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.

4. 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.

5. 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 2010 Technical Report to define those projects owned and operated by the 2010 industry members of RAMP listed above which were under construction or operational in 2010 in the RAMP FSA. For 2010, these projects included a number of oil sands projects and a limestone quarry project.

2010 RAMP industry members do have other projects in the RAMP FSA that were in the application stage as of 2010, or had received approval in 2010 or earlier, but construction had not yet started as of 2010. These projects are noted throughout this technical report, but are not designated as focal projects, as these projects in 2010 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 2010 Technical Report to define those oil sands projects operated by non-RAMP members located within the RAMP FSA.

A weight-of-evidence approach is used for the analysis of RAMP data by applying multiple analytical methods to interpret results and determine whether any changes have occurred due to focal projects and other oil sands developments. 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 (criteria used in focal project EIAs, AENV and CCME water quality and sediment quality 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 2010 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 2010) or were (prior to 2010) 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 2010 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 2010, it is estimated that approximately 88,000 ha of the RAMP FSA had undergone land change from focal projects and other oil sands developments. The percentage of the area of watersheds with land change as of 2010 varies from less than 1% for many watersheds (MacKay, Ells, Christina, Hangingstone, Horse, and Firebag rivers), to 1% to 5% for the Calumet, Poplar and Steepbank watersheds, 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 2010 MONITORING RESULTS

A tabular summary of the 2010 results by watershed and component is presented at the end of this Executive Summary.

Lower Athabasca River and Athabasca River Delta

Hydrology The mean open-water period (May to October) discharge, open-water minimum daily discharge, annual maximum daily discharge, and mean winter discharge at RAMP Station S24, Athabasca River below Eymundson Creek, calculated from the observed *test* hydrograph at are 0.6%, 1.7%, 0.4% and 0.8% lower, respectively, than from the estimated *baseline* hydrograph. These differences are all classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2010 between most *test* and *baseline* stations in the Athabasca River and regional *baseline* conditions were **Negligible-Low** with the exception of the *baseline* station at Donald Creek on the east bank of the Athabasca River, which showed **Moderate** differences from regional *baseline* conditions. Concentrations of water quality measurement endpoints at *test* stations were generally similar to those at the upstream *baseline* stations and consistent with regional *baseline* conditions. Concentrations of total mercury exceeded the AENV chronic guideline at all stations and showed a general decrease from upstream to downstream on the Athabasca River; total aluminum, total nitrogen, chloride, total arsenic, and other metals also exhibited a similar longitudinal trends. Concentrations of these measurement endpoints were also generally higher along the east bank of the river, suggesting an influence of the Clearwater River on water quality. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem in fall 2010 was consistent with previous sampling years.

Benthic Invertebrate Communities and Sediment Quality Benthic invertebrate communities were monitored at four locations in the Athabasca River Delta (ARD) in fall 2010:

1. Differences in the benthic invertebrate communities in Big Point Channel in fall 2010 from historical conditions are classified as **Negligible-Low** because there were no significant time trends in any measurement endpoints at this reach and values of all measurement endpoints were within historical conditions for the ARD reaches and within previously-measured values for this reach.

2. Differences in the benthic invertebrate communities in Fletcher Channel in fall 2010 from historical conditions are classified as **High** because there have been significant decreases over time in diversity, evenness, and percent EPT (i.e., percent of the benthic invertebrate community comprised of Ephemeroptera, Plecoptera, and Tricoptera, three types of benthic invertebrates that are sensitive to change in their environmental conditions). A significant increase in total abundance is potentially indicative of an increase in available nutrients.

3. Differences in the benthic invertebrate communities in Goose Island Channel in fall 2010 are classified as **Negligible-Low** because there were no significant time trends in any measurement endpoint. Values of all measurement endpoints were within historical conditions for the ARD reaches and within previously-measured values for this reach with the exception of taxa richness, which was lower in 2010 than previous years.

4. The benthic invertebrate community in the Embarras River in 2010 was significantly different in richness, diversity and evenness from the benthic invertebrate communities of the other ARD reaches. The relatively high abundance of mayflies and caddisflies in the Embarras River indicates that the community is robust and healthy. Differences in measurement endpoints for benthic invertebrate communities in the Embarras River are classified as **Negligible-Low** because the measured differences did not imply a negative difference between the benthic invertebrate community from the Embarras River and historical conditions for the other ARD reaches.

Concentrations of sediment quality measurement endpoints at all five stations in the ARD were similar to previously-measured concentrations with generally low hydrocarbon, metals and PAH concentrations. However, since the beginning of RAMP sampling in 1999, an increase in concentrations of total PAHs has been observed in Big Point Channel, although this trend is not evident in concentrations of carbon-normalized total PAHs. Percent of total organic carbon has increased in Fletcher Channel likely related to the increasing proportion of fines in sediments over time, first observed in 2007 and could be indicative of decreasing water flow in this small channel. The PAH Hazard Index was historically high in Fletcher Channel and the Embarras River and above the potential chronic toxicity threshold value of 1.0. Increased Hazard Index (HI) values at these stations were related to low concentrations of total hydrocarbons rather than high concentrations of total PAHs. The increase in HI values suggests greater bioavailability of PAHs in sediments. Acute and chronic toxicity data for these sediments were inconclusive with historically low survival but historically high growth of *Hyalella* and high survival but low growth of *Chironomus* in Fletcher Channel.

Fish Populations (fish inventory) 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. A shift in species dominance from white sucker to walleye was observed in spring, from goldeye to northern pike in summer, and from walleye to goldeye in fall, although lake whitefish dominates the catch in fall.

As of 2010, 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 for some of the large-bodied Key Indicator Resource (KIR) species. However, the variability in this measurement endpoint among years does not indicate consistent negative or positive changes in the fish populations and likely reflects natural variability over time.

The fish health assessment has indicated that abnormalities observed in 2010 in all species were within the historical range and consistent with historical studies done in the upper Athabasca River, ARD, and Peace and Slave rivers.

Fish Populations (sentinel species) As outlined in RAMP (2009b), the Athabasca River sentinel species program was developed to evaluate spatial differences in measurement endpoints between *baseline* and *test* sites. In addition, results from the 2010 study can be compared to past sentinel programs to assess possible trends over time. Based on the differences in measurement endpoints in trout-perch, the following assessments were made:

- Female trout-perch at the *test* site upstream of the Muskeg River and male and female trout-perch at the *test* site downstream of the Muskeg River indicated a **Negligible-Low** difference from the upstream *baseline* site because none of the measurement endpoints exceeded the effects criteria;
- Male trout-perch at the *test* site upstream of the Muskeg River indicated a **Moderate** difference from the upstream *baseline* site because weight-at-age exceeded the effects criteria;
- Male trout-perch at the *test* site downstream of the Firebag River indicated a **Moderate** difference from upstream *baseline* site because weight-at-age exceeded the effects criteria; and
- Female trout-perch at the *test* site downstream of the Firebag River indicated a **Moderate** difference from the upstream *baseline* site because weight-at-age, GSI and condition exceeded the effects criteria; however, this response was not observed in previous sentinel programs.

Generally, there is little evidence to suggest that characteristics of trout-perch populations between sites and across years on the Athabasca River have changed due to increasing activities from the focal projects and other oil sands developments given that trout-perch from sites closer to intense oil sands activity do not show substantial differences from *baseline* fish, suggesting that female trout-perch at the *test* site downstream of the Firebag River are responding to localized conditions unrelated to oil sands development.

Muskeg River Watershed

Hydrology The calculated mean open-water discharge and the annual maximum daily flow at WSC Station 07DA008 (RAMP Station S7, lower Muskeg River) are 1.7% and 3.0% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph for the station, respectively. These differences are classified as **Negligible-Low** The calculated mean winter discharge and the open-water period minimum daily discharge are 52.1% and 64.1% higher in the observed *test* hydrograph at WSC Station 07DA008 (RAMP Station S7) than in the estimated *baseline* hydrograph, respectively. These differences are classified as **High**.

Water Quality Differences in water quality in fall 2010 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions are classified as **Negligible-Low.** While concentrations of a number of water quality measurement endpoints in the Muskeg River watershed in fall 2010 were outside the range of previously-measured minimum and maximum concentrations, including total mercury, total nitrogen and total aluminum, water quality at most stations in the Muskeg River watershed were generally consistent with regional *baseline* conditions.

Benthic Invertebrate Communities and Sediment Quality Benthic invertebrate communities were monitored at five *test* reaches in the Muskeg River watershed in fall 2010:

1. Differences in the benthic invertebrate community at the lower *test* reach of the Muskeg River as of fall 2010 are classified as **Negligible-Low** because values of all measurement endpoints for benthic invertebrate communities in fall 2010 were within the range of regional *baseline* erosional reaches. There was, however, a significant trend in CA Axis 1 scores over time reflecting a modest increase in percent of the fauna as tubificid worms and decrease in the percent of the fauna as chironomids, mayflies, stoneflies and caddisflies.
2. Differences in the benthic invertebrate community at the middle *test* reach of the Muskeg River as of fall 2010 are classified as **Negligible-Low** because, although there was a

significant decrease in total abundance over time, the statistical signal explained less than 20% of the variation in annual means. In addition, all measurement endpoints for benthic invertebrate communities in fall 2010 were within the range of regional *baseline* depositional reaches with the exception of taxa richness, which exceeded the range of regional *baseline* conditions, implying an improvement in the benthic invertebrate community at the middle *test* reach.

3. Differences in the benthic invertebrate community at the upper *test* reach of the Muskeg River as of fall 2010 are classified as **Moderate** because taxa richness was significantly lower in the period when this reach was *test* compared to the *baseline* period. There was also a significant decrease in CA Axis 1 scores over time in the *test* period, reflecting a shift to higher relative abundance of chironomids and bivalves at this reach over time.

4. Differences in the benthic invertebrate community at the lower *test* reach of Jackpine Creek as of fall 2010 are classified as **Negligible-Low** because there have been no significant changes over time in measurement endpoints for benthic invertebrate community that would imply negative trends in benthic invertebrate community conditions, and values of all measurement endpoints in fall 2010 were within the range of values for regional *baseline* conditions.

5. Differences in the benthic invertebrate community in Kearl Lake as of fall 2010 are classified as **Moderate** compared to historical years because there has been a significant decrease in the percent EPT in the period that Kearl Lake has been designated as *test*.

Sediment quality at all five Muskeg River watershed stations sampled in fall 2010 was generally consistent with that of previous years and regional *baseline* conditions with the exception of predicted PAH toxicity, which was higher than historical values at several stations, particularly the middle *test* station of the Muskeg River. Concentrations of total PAHs at these stations were within previously-measured concentrations. Differences in sediment quality in fall 2010 at all five stations in the Muskeg River watershed were assessed as **Negligible-Low** compared to regional *baseline* conditions.

Steepbank River Watershed

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge at WSC Station 070A006 (RAMP Station S38, lower Steepbank River) are 0.28% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low.**

Water Quality Differences in water quality in fall 2010 at all four water quality monitoring stations in the Steepbank River watershed compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**. While concentrations of a number of water quality measurement endpoints in the Steepbank River watershed in fall 2010 were outside the range of previously-measured values, water quality conditions at stations in the Steepbank River watershed in fall 2010 were generally consistent with regional *baseline* fall conditions. The ionic composition at all water quality monitoring stations in the Steepbank River watershed in fall 2010 was consistent with previous years.

Benthic Invertebrate Communities The values of measurement endpoints of the benthic invertebrate community at the lower *test* reach of the Steepbank River have remained generally stable across time and consistent to those for the upper *baseline* reach, with a presence of fauna typically associated with a robust healthy community including a high relative abundance of EPT taxa. The differences in abundance and richness in the lower *test* reach of the Steepbank River indicate a **Moderate** difference from the upper *baseline* reach because the statistical signal in time trends between the two reaches was strong, explaining more than 20% of the variance. Lower abundance and richness compared to the median *baseline* conditions have been evident since 2000 but are not significant. There were no exceedances of values of measurement endpoints outside of the range of *baseline* conditions.

Tar River Watershed

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for the Tar River near the mouth (RAMP Station S15A) are 19.1% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **High**.

Water Quality Differences in water quality observed in fall 2010 between the Tar River and regional *baseline* fall conditions were **Negligible-Low,** which is verified by the continued improvement in water quality conditions at the lower *test* station on the Tar River since 2008 when water quality was assessed as being measurably different from regional *baseline* conditions. Most water quality measurement endpoints at the lower *test* station in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* concentrations.

Benthic Invertebrate Communities and Sediment Quality Differences in the benthic invertebrate community at the lower *test* reach of the Tar River as of fall 2010 are classified as **Moderate** because there were significant differences in total abundance, taxa richness, diversity and evenness from before to after the reach was designated as *test*. Values of measurement endpoints for benthic invertebrate communities in fall 2010 at the lower *test* reach were within the range of regional *baseline* conditions for depositional reaches. Differences in sediment quality observed in fall 2010 between the lower *test* station of the Tar River and regional *baseline* conditions were **Negligible-Low**. Concentrations of sediment quality measurement endpoints were within historical ranges in fall 2010, including total PAHs and predicted PAH toxicity, although the concentration of carbon-normalized PAH in fall 2010 represented a historical maximum concentration for the lower *test* station.

MacKay River Watershed

Hydrology The 2010 mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge at WSC Station 07DB001 (RAMP Station S26, lower MacKay River) calculated from the observed *test* hydrograph are 0.03% lower than from the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2010 at both *test* and *baseline* stations in the MacKay River watershed relative to regional *baseline* water quality conditions were assessed as **Negligible-Low**. Concentrations of several water quality measurement endpoints in the MacKay River watershed in fall 2010 were outside the range of previously-measured concentrations, possibly due to water levels and flows that were greater than typical conditions. Water quality was generally consistent with regional *baseline* conditions and the ionic composition of water at both stations in fall 2010 was consistent with previous years and continued to show little year-to-year variation.

Benthic Invertebrate Communities Differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of the MacKay River are classified as **Negligible-Low** because, although there were significant decreases in abundance and richness in the *test* period compared to the *baseline* period and a decrease in abundance during the *test* period, the statistical signal in the differences over time explained less than 10% of the variance in total abundance and richness. Differences in the benthic invertebrate community at the middle *test* reach of the MacKay River as of fall 2010 are classified as **Moderate** because there was a significant decrease in total abundance over time in the *test* period, explaining more than 20% of the variation in annual mean abundance.

Calumet River Watershed

Hydrology For the 2010 WY, the mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for RAMP Station S16A, lower Calumet River, are estimated to be 1.0% lower than the corresponding values from the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at the lower *test* station and upper *baseline* station of the Calumet River showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of most water quality measurement endpoints in the Calumet River in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* conditions. The ionic composition of water at the lower *test* station was consistent with previous years while the ionic composition of water at the upper *baseline* station had lower relative bicarbonate concentrations relative to previous years.

Firebag River Watershed

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge at WSC Station 07DC001 (RAMP Station S27, lower Firebag River) are 0.09% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated mean winter discharge is 0.08% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at the lower *test* station and upper *baseline* station of the Firebag River showed **Negligible-Low** differences from regional *baseline* water quality conditions. The ionic composition of water in fall 2010 at both Firebag River stations and in McClelland Lake was consistent with previous sampling years and concentrations of most water quality measurement endpoints in fall 2010 were within the range of regional *baseline* concentrations at the *test* and *baseline* stations in the Firebag River. Concentrations of several water quality measurement endpoints in the Firebag River watershed were near or outside previously-measured minimum concentrations (typically major ions) or maximum concentrations (including total suspended solids, several total metals, total phenols, and DOC), likely as a result of high river discharges in fall 2010.

Benthic Invertebrate Communities and Sediment Quality Differences in the measurement endpoints for benthic invertebrate communities at the lower *test* reach of the Firebag River and in McClelland Lake are classified as **Negligible-Low** because, while there were significant changes in the values of a number of measurement endpoints over the period that these two locations have been designated as *test*, none of these significant differences (increases over time in taxa richness, diversity, evenness at the lower *test* reach of the Firebag River, and increase in total abundance in McClelland Lake) suggest negative changes in the benthic invertebrate communities. Differences in sediment quality observed in fall 2010 between the lower *test* station on the Firebag River and regional *baseline* conditions are classified as **Negligible-Low**. Most sediment quality measurement endpoints were within or below previously-measured concentrations at the lower *test* station of the Firebag River and in McClelland Lake.

Ells River Watershed

Hydrology The calculated mean winter discharge, open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge at Ells River above Joslyn Creek (RAMP Station S14A) are 0.01% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2010 between the Ells River and regional *baseline* fall conditions are classified as **Negligible-Low**. Water quality conditions were consistent with previous years for the lower *test* station and middle *baseline* station of the Ells River and the fall 2010 concentrations of water quality measurement endpoints at these stations were generally within the range of previously-measured concentrations and regional *baseline* conditions. Water quality at the upper *baseline* station of the Ells River in fall 2010 was similar to that at the other two stations, located further downstream.

Benthic Invertebrate Communities and Sediment Quality Differences in benthic invertebrate communities at the lower *test* reach of the Ells River as of fall 2010 are classified as **Negligible-Low** because, while there were significant changes in the values of a number of benthic invertebrate community measurement endpoints over the period this reach has been designated as *test*, none of these significant differences (increases over time in taxa richness and diversity) suggest negative changes in the benthic invertebrate community. Differences in sediment quality observed in fall 2010 between the lower *test* station of the Ells River and regional *baseline* conditions were **Negligible-Low** with nearly all measurement endpoints within previously-measured concentrations.

Clearwater-Christina River System

Hydrology The calculated mean open-water period (May to October) discharge, annual maximum daily discharge and open-water minimum discharge at the mouth of the Christina River are 0.02% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at both stations on the Clearwater River and both stations on the Christina River showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of several water quality measurement endpoints were outside the range of previously-measured concentrations in fall 2010. However, these differences generally were consistent with higher river discharges at the time of sampling and may have been the result of historically-high concentrations of suspended materials and some metals known to occur mainly in particulate form, as well as historically-low concentrations of some ions associated with groundwater inputs.

Fish Populations (fish inventory) Species richness in 2010 was lower in spring relative to the historical average (2003 to 2009) but within the historical range, lower in summer compared to 2009 when a summer inventory was first conducted, and higher in fall relative to the historical average. Relative abundance of each species was variable over time with no clear trends; the dominant species in each season has remained consistent over time. There has been significant variability in condition of large-bodied KIR species in the Clearwater River over time with no clear increasing or decreasing trends that would indicate a change in the health of fish in the river. Condition cannot necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region.

Hangingstone River Watershed

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge at WSC Station 07CD004 are 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These estimated watershed-level effects are classified as **Negligible-Low**.

Miscellaneous Aquatic Systems

Isadore's Lake and Mills Creek The calculated mean open-water discharge, minimum daily discharge, annual maximum daily discharge, and mean winter discharge are 33% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph for Mills Creek. This difference is classified as **High**.

The water level of Isadore's Lake was above historical upper quartile values until early April, at which time monitoring temporarily ceased due to equipment malfunction. When monitoring resumed in late-June, the water level varied between the historical median and upper quartile values until the end of the 2010 WY.

Differences in water quality in fall 2010 between Mills Creek and regional *baseline* fall conditions are classified as **Negligible-Low**. While concentrations of a number of water quality measurement endpoints were outside regional *baseline* concentrations at the *test* station on Mills Creek, the WQI value of Mills Creek in fall 2010 was 84.1. With respect to Isadore's Lake, the ionic composition of water in fall 2010 was dominated by bicarbonate as in past sampling years, and concentrations of water quality measurement endpoints were within the range of previously-measured concentrations and regional *baseline* concentrations. However, increasing concentrations of several major ions have been observed in recent years (including chloride, sodium and sulphate), which are entering the lake from Mills Creek.

Differences in the benthic invertebrate community in Isadore's Lake as compared to historical conditions are classified as **Negligible-Low.** There were no significant time trends in any of the values of measurement endpoints for benthic invertebrate community in Isadore's Lake in fall 2010 and all measurement endpoints were within the range observed in previous years.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2010 in Shipyard Lake were within previously-measured concentrations with few exceptions. The ionic composition of water in Shipyard Lake continues to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, likely a result of reduced surface-water inflow and increased groundwater influence in the lake associated with focal projects in the upper portion of the Shipyard Lake watershed.

Differences in the benthic invertebrate community in Shipyard Lake as compared to historical conditions are classified as **Negligible-Low** because, while there were significant changes in a number of measurement endpoints over the period that the lake has been designated as *test*, none of these significant differences (increases over time in total abundance and taxa richness) suggest negative changes in the benthic invertebrate community.

Poplar Creek and Beaver River The calculated mean open-water discharge (May to October) at WSC Station 07DA007 (RAMP Station S11, lower Poplar Creek) is 23.5% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **High**. The annual maximum daily discharge is 0.9% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**. The open-water minimum daily discharge is 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Differences in water quality in fall 2010 between the *test* stations on Poplar Creek and the lower Beaver River and the *baseline* station on the upper Beaver River and regional *baseline* conditions were classified **Negligible-Low.** Concentrations of most water quality measurement endpoints were within previously-measured concentrations at *test* stations on Poplar Creek and the lower Beaver River and the *baseline* station on the upper Beaver River and were generally consistent with regional *baseline* conditions in fall 2010.

Differences in the benthic invertebrate community at the lower *test* reach of Poplar Creek is classified as **Moderate** because of the significantly lower percent EPT compared to the upper *baseline* reach of the Beaver River. Differences in sediment quality observed in fall 2010 in the lower *test* station on Poplar Creek and the upper *baseline* station on Beaver River compared to regional *baseline* conditions were **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within or below previously-measured concentrations at both reaches.

McLean Creek The differences in water quality between the *test* station on McLean Creek and regional *baseline* conditions are classified as **Negligible-Low**. Concentrations of water quality measurement endpoints at the *test* station on McLean Creek were within previously-measured concentrations and within regional *baseline* conditions in fall 2010. The ionic composition of water at the *test* station in McLean Creek has been stable in recent sampling years compared to variability observed during historical years.

Fort Creek The calculated mean open-water period (May to October) discharge volume at RAMP Station S12 is 11.4% greater in the observed *test* flow volume than in the estimated *baseline* flow volume. This difference is classified as **Moderate**. In addition to changes in flow volume, variability in daily flow has also increased due to focal project activity in the watershed.

Differences in water quality in fall 2010 between the *test* station on Fort Creek and regional *baseline* fall conditions are classified as **Negligible-Low**. This indicates an improvement in water quality from 2009 with most water quality measurement endpoints within the range of previously-measured concentrations and within regional *baseline* water quality conditions.

Differences in the benthic invertebrate community at the lower *test* reach of Fort Creek are classified as **High** because of significant decreases over time in taxa richness and evenness, and because taxa richness, diversity and evenness in fall 2010 were below the 5th percentile of regional *baseline* conditions. There was also a shift in dominant taxa from chironomids in the *baseline* period to the more tolerant tubificid worms at the lower *test* reach of Fort Creek in the *test* period suggesting a negative change in the benthic invertebrate community. Differences in sediment quality observed in fall 2010 between the *test* station on Fort Creek and regional *baseline* conditions were **Negligible-Low** with nearly all sediment quality measurement endpoints within previously-measured concentrations.

Regional Lakes (fish tissue) Muscle tissue analysis for mercury was conducted on target fish species captured in fall 2010 from Brutus, Keith and Net lakes in collaboration with ASRD's Regional Lakes FWIN program. The classification of the results of this program is based on the potential risk to subsistence fishers and general consumers. Mercury concentrations in all northern pike and 73% of walleye from Brutus Lake in 2010 exceeded the Health Canada guideline for subsistence fishers, and mercury concentrations in two walleye exceeded the guidelines for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye. Given that all northern pike and most walleye exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike and walleye, dependent on the quantity of fish consumed. Mercury concentrations in fish from Brutus Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes. Mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health.

Mercury concentrations in lake whitefish and northern pike from Keith Lake were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Mercury concentrations in fish from Keith Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes.

Mercury concentrations in all captured walleye and all but one northern pike from Net Lake in 2010 exceeded the Health Canada guideline for subsistence fishers. The majority of walleye and two northern pike exceeded the guideline for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye and to general consumers consuming walleye, given most fish exceeded the guideline for general consumers. Given that all northern pike exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike, dependent on the quantity of fish consumed. With the exception of two fish, mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Overall, the mercury concentrations in fish sampled from Net Lake were higher in northern pike and walleye compared to mercury concentration in fish from other regional lakes.

Acid-Sensitive Lakes

The results of the analysis of the 2010 ASL component lakes data compared to historical data suggest that there has been no significant change in the overall chemistry of the 50 ASL component lakes over time. A long-term decline is noted for DOC but this appears to be a regional trend that may reflect other causes or factors other than acidifying emissions. Based on the analysis of among-year differences in concentrations of measurement endpoints, as well as trend analysis and control plotting of measurement endpoints on individual lakes, there is no evidence to suggest that there have been any significant changes in lake chemistry in the ASL lakes attributable to acidification.

The *baseline* subregion of the Caribou Mountains had the highest rate of measurement endpoints exceeding two standard deviations of the mean for each lake in a direction indicative of acidification. The observed differences were classified as **Moderate**, which is unexpected given that the Caribou Mountain lakes are remote from sources of acidifying emissions and considered *baseline* lakes. All three exceedances in measurement endpoints in the Caribou Mountain subregion were attributable to Lake 146/CM1, which had water chemistry in 2010 that was uncharacteristic of the subregion. The remaining subregions were classified as **Negligible-Low**.

Summary and Recommendations

The following table provides a summary of the 2010 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 for consideration during the design of monitoring in future years of RAMP:

- Continue monitoring existing climate and hydrometric stations to enhance record length and data availability;

- Expand the climate and hydrologic monitoring network to support provision of baseline and test hydrometric information and regional climate data;

- Evaluate additional hydrometric measurement endpoints and indicators (such as the timing and frequency of flow conditions) that would further support RAMP assessment and understanding of aquatic conditions;

- Conduct water balance assessments as a consistent approach applicable to tributary watersheds, independent of the length of the data record, and, as possible, continue to refine inputs such as the time-step of industrial data;

- Add *baseline* stations to the RAMP sampling design, particularly stations that are expected to remain *baseline* well into the future given the steady decline in the number of stations designated as *baseline* in the current RAMP design, and the need to continually update the ranges of natural variability (i.e., *baseline* conditions) in the RAMP FSA.

- Add seasonal sampling of water quality to assess any differences in water quality that may occur across seasons.

- Include PAHs analyses in water samples. Analyses of PAHs were eliminated from the Water Quality component given the concentrations were always below detection limits. However, with improvements in analytical detection limits over time, analyses of these compounds should be revisited.

- Analyze sediment core data to address questions related to historical increases in PAHs and other hydrocarbons in sediments in the ARD. There is several research programs planned to collect sediment cores from the ARD in 2010, which would be very helpful in clarifying historical trends in sediment quality.

- Consider the use of sediment traps in some channels (especially Fletcher Channel), to estimate sediment deposition rates (which may be changing over time as natural succession occurs in the ARD) and also to specifically assess concentrations of hydrocarbons and metal in sediments deposited in the ARD in a given year.

- Add a *baseline* reach upstream of oil sands development on the Athabasca River for the Fish Populations fish inventories. Although fish are highly migratory through the Athabasca River, it will help to provide more information on their habitat range and utility of the river.

- Collect ageing structures from large-bodied KIR species during the Athabasca and Clearwater inventories. Collection of ageing structures has been done historically and needs to be reinstated to assess recruitment rates in these fish populations.

- Continue to develop more thorough protocols for assessing fish pathology in individual fish. 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.

- 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. Given the variability in mercury concentrations in fish across lakes, it is necessary to continue sampling lakes in the region so that data can be provided to Alberta Health and Wellness and Health Canada in order to establish human consumption guidelines for lakes commonly used for sportfishing.

- Continue to analyze for mercury in fish from the Athabasca and Clearwater rivers to monitor trends over time in to relation the specific consumption guidelines established by the Government of Alberta for these watercourses.

- Continue collaboration with Environment Canada during the fish assemblage and sentinel species monitoring to assess the ecological and physiological changes that may occur in fish populations due to oil sands development.

Summary assessment of RAMP 2010 monitoring results.

Watershed/Region	Differences Between *Test* and *Baseline* Conditions					Fish Populations: Human Health Risk from Mercury in Fish Tissue[6]			Acid-Sensitive Lakes: Variation from Long-Term Average Potential for Acidification[7]
	Hydrology[1]	Water Quality[2]	Benthic Invertebrate Communities[3]	Sediment Quality[4]	Sentinel Fish Species[5]	Species	Subs. Fishers	General Cons.	
Athabasca River	🟡	🟡	-	-	🟡 / 🟠	-	-	-	-
Athabasca River Delta	-	-	🟡 / 🟤	n/a	-	-	-	-	-
Muskeg River	🟤	🟡	🟡 / 🟠	🟡	-	-	-	-	-
Jackpine Creek	nm	🟡	🟡	🟡	-	-	-	-	-
Kearl Lake	nm	🟡	🟠	n/a	-	-	-	-	-
Steepbank River	🟡	🟡	🟠	-	-	-	-	-	-
Tar River	🟤	🟡	🟠	🟡	-	-	-	-	-
MacKay River	🟡	🟡	🟡 / 🟠	-	-	-	-	-	-
Calumet River	🟡	🟡	-	-	-	-	-	-	-
Firebag River	🟡	🟡	🟡	🟡	-	-	-	-	-
McClelland Lake	nm	n/a	🟡	n/a					
Ells River	🟡	🟡	🟡	🟡	-	-	-	-	-
Christina River	🟡	🟡	-	-	-	-	-	-	-
Clearwater River	nm	🟡	-	-	-	-	-	-	-
Hangingstone River	🟡	-	-	-	-	-	-	-	-
Fort Creek	🟠	🟡	🟤	🟡	-	-	-	-	-
Beaver River	-	🟡	-	-	-	-	-	-	-
McLean Creek	-	🟡	-	-	-	-	-	-	-
Mills Creek	🟤	🟡	-	-	-	-	-	-	-
Isadore's Lake	nm	n/a	🟡	n/a					
Poplar Creek	🟤	🟡	🟠	🟡	-	-	-	-	-
Shipyard Lake	-	n/a	🟡	n/a	-	-	-	-	-
Brutus Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						WALL	🟤	🟠	
						NRPK	🟤	🟠	
Keith Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						NRPK	🟡	🟡	
Net Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						WALL	🟤	🟤	
						NRPK	🟤	🟠	
Stony Mountains	-	-	-	-	-	-			🟡
West of Fort McMurray	-	-	-	-	-	-			🟡
Northeast of Fort McMurray	-	-	-	-	-	-			🟡
Birch Mountains	-	-	-	-	-	-			🟡
Canadian Shield	-	-	-	-	-	-			🟡
Caribou Mountains	-	-	-	-	-	-			🟠

Legend and Notes

🟡 Negligible-Low change

🟠 Moderate change

🟤 High change

"-" program was not completed in 2010.

nm - not measured in 2010.

n/a - classification could not be completed because there were no *baseline* conditions to compare against.

1 **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 2010, hydrology results above are for those endpoints that were calculated.

Note: All calculated hydrology measurement endpoints in the Muskeg River watershed were assessed as Negligible-Low with the exception of Annual Maximum Daily Discharge which was assessed as Moderate.

Note: All calculated hydrology measurement endpoints in the Fort Creek watershed were assessed as High with the exception of Annual Maximum Daily Discharge which was assessed as Negligible-Low.

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

Note: Water quality at all stations in the Athabasca River was assessed as Negligible-Low with the exception of station ATR-DC-E, which was assessed as Moderate.

3 **Benthic Invertebrate Communities:** Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches or between *baseline* and *test* periods or trends over time for a reach as well as comparison to regional *baseline* conditions.

Note: Benthic invertebrate communities at the lower and middle reaches of the Muskeg River were assessed as Negligible-Low and benthic invertebrate communities at the upper reach was assessed as Moderate.

Note: Benthic invertebrate communities at all reaches in the Athabasca River Delta was assessed as Negligible-Low with the exception of Fletcher Channel, which was assessed as High.

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

5 **Fish Populations (sentinel species):** Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2010). See Section 3.2.4.3 for a detailed description of the classification methodology.

Note: Differences in trout-perch populations at all *test* sites in the Athabasca River were assessed as Negligible-Low with the exception of *test* Site 3 and *test* Site 5, which was assessed as Moderate.

6 **Fish Populations (fish tissue):** Uses Health Canada criteria for risks to human health.

LKWH-lake whitefish; WALL-walleye; NRPK-northern pike

Note: For Fish Population Human Health Classification - Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada.

7 **Acid-Sensitive Lakes:** Classification based the frequency in each region with which values of seven measurement endpoints in 2010 were more than twice the standard deviation from their long-term mean in each lake.

1.0 INTRODUCTION

This document is the 2010 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 286.6 billion m^3 (1.8 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 27.0 billion m^3 (169.9 billion barrels) of remaining established bitumen reserves[1] (ERCB 2010) being equivalent to approximately 13% of the world's known reserves of conventional crude oil (US Energy Information Administration 2009). Total bitumen deposits in the Athabasca oil sands region are the largest of Alberta's three oil sands regions, containing almost 82% of the total provincial reserves, with the total deposits in the Cold Lake and Peace River areas being significantly smaller (ERCB 2010).

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 2009, and 3.5% of the estimated established bitumen reserves of the Athabasca oil sands region had been extracted by the end of 2009 (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)			1,481,936
Estimated Established Reserves			145,246*
Established Reserves under Active Development as of 31 December 2009			24,971
	Mineable	23,479	
	in situ	1,491	
Cumulative Production as of 31 December 2009			5,125
	Mineable	4,491	
	in situ	634	
Remaining Established Reserves			140,121

Data from ERCB (2010); all figures are as of December 31, 2009.

* 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.

The increasing development of the Athabasca oil sands resource has been accompanied by an increase in environmental monitoring and research conducted in the Athabasca oil

[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 2010). Remaining established bitumen reserves are established bitumen reserves less cumulative bitumen production.

sands region and increasing interest among stakeholders in ensuring that measures in place to monitor any potential effects on the environment are effective. Environmental monitoring and research has been a prominent topic of discussion among regulators, media, and concerned stakeholders. The organizations involved in long-term environmental monitoring and research programs in the Athabasca oil sands region in addition to RAMP include but not limited to:

- Cumulative Environmental Management Association (CEMA) – established in 2000, CEMA develops guidelines and management frameworks on how best to reduce cumulative environmental effects due to industrial development. CEMA's focus includes (but is not limited to): adaptive management of reclaimed terrestrial (CEMA 2010a [ToR]) and aquatic ecosystems (CEMA 2010b [ToR]); guidance for end-pit lake and wetland establishment, acid deposition; land capability; air contaminants; surface water management; and traditional ecological knowledge (TEK).
- Wood Buffalo Environmental Association (WBEA) – monitors and provides 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 fifteen 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 traditional resources in the Athabasca oil sands region; and
  - A human exposure monitoring program, initiated in 2005, designed to monitor human exposure to select air contaminants in the RMWB.
- Environment Canada – as the most active federal monitoring and research agency in the region, Environment Canada executes a number of monitoring programs through the federal Water Act, Fisheries Act, and Canadian Environmental Protection Act. The Water Survey of Canada, which operates several hydrology stations in the area is an example of one of the monitoring programs managed under Environment Canada. The Peace-Athabasca Delta Ecological Monitoring Program (PAD-EMP) is another Environment Canada initiative and falls under the jurisdiction of Parks Canada.
- Government of Alberta – monitors the environment of the Athabasca oil sands region through the following ministries:
  - The Alberta Sustainable Resource Development monitors and manages the fisheries resource in the Athabasca oil sands region and implements an instream flow needs program;
  - Alberta Health and Wellness has implemented human health consumption guidelines for sportfish in several lakes and rivers within the lower Athabasca Region using mercury results collected by RAMP; and
  - Alberta Environment has been monitoring water quality of the Athabasca River since the 1970s and the Muskeg River since the 1990s. Alberta Environment recently initiated intensive, integrated monitoring throughout the Muskeg River watershed as well as a contaminant loading study involving passive water quality samplers throughout the Athabasca oil sands region and historical sediment quality assessments (coring studies).

- Alberta Water Research Institute (AWRI) – serves as a coordinator of research in support of Alberta's provincial water strategy, *Water for Life: A Strategy for Sustainability*. AWRI currently oversees eight projects focusing on water quality, quantity, recycling and management, and other water-related topics, in the Athabasca oil sands region.

- Alberta Biodiversity Monitoring Institute (ABMI) – formally established in 2007, is an independent, not-for-profit organization that monitors plant and animal species and habitats at more than 1,600 sites across the province of Alberta, including 959 sites in the Boreal region where the Athabasca oil sands are situated.

- Canadian Oil Sands Network for Research and Development (CONRAD) – a network of companies, universities and government agencies organized to facilitate collaborative research in science and technology for Alberta oil sands. The research focuses on the following areas: environmental research, *in situ* recovery, surface mining of oil sands, bitumen extraction, and bitumen and heavy oil upgrading.

- Carbon Dynamics, Food Web Structure, and Reclamation Strategies in Athabasca Oil Sands Wetlands (CFRAW) – a partnership between scientists at the universities of Alberta, Saskatchewan, Waterloo and Windsor and sponsoring industry partners. The research venture focuses on carbon dynamics, biological effects of oil sands process materials, and predicting changes in the environment and recommending reclamation strategies (Oilsands Advisory Panel 2010).

- Industry – 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 meet approval requirements.

Finally, several universities, independent scientists, and government research agencies continue to undertake studies in the Athabasca oil sands region to better understand local aquatic resources and their response to regional development (Oilsands Advisory Panel 2010) including but not limited to:

- Natural Sciences and Engineering Research Council of Canada (NSERC);

- University of Alberta: David Schindler Laboratory;

- University of Alberta: Centre for Oil Sands Innovation (COSI);

- University of Saskatchewan – Toxicology Centre and Canada Research Chair in Environmental Toxicology; and

- University of Waterloo – headquarters for the Canadian Water Network (CWN), a program designed to connect Canadian and international water researches with decision-makers, and conducts contaminant fate research and graduate studies related to water management in the Athabasca oil sands region.

1.2 OVERVIEW OF RAMP

The Regional Aquatics Monitoring Program (the Program) 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, regional and publicly-available database[2] 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 RMWB, 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 companies 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 (the Hatfield RAMP Team, consisting in 2010 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.

[2] The database is available on the RAMP website http://www.ramp-alberta.org/ramp/data.aspx.

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 presenting 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 2010, RAMP was funded by Suncor Energy Inc. (Suncor; includes projects formerly under Petro-Canada), Syncrude Canada Ltd. (Syncrude), Shell Canada Energy (Shell), 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), Hammerstone Corp. (Hammerstone; formerly Birch Mountain Resources Ltd.), MEG Energy Corp. (MEG Energy), Devon Energy Corp. (Devon), ConocoPhilips Canada (ConocoPhillips), and Dover Operating Corp.

Figure 1.2-1 RAMP organizational structure[1].

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

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.	Open house events and other community activities, etc.

1 Composition of Steering Committee as of December 2010.

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 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 2010 Municipal Census, had a population of more than 100,000 persons of which approximately 77,000 persons were residents of Fort McMurray and surrounding towns and approximately 23,000 persons were in work-camps (RMWB 2010). The RAMP RSA is bounded by the Alberta-Saskatchewan border on the east, the Alberta-Northwest Territories border on the north, 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.

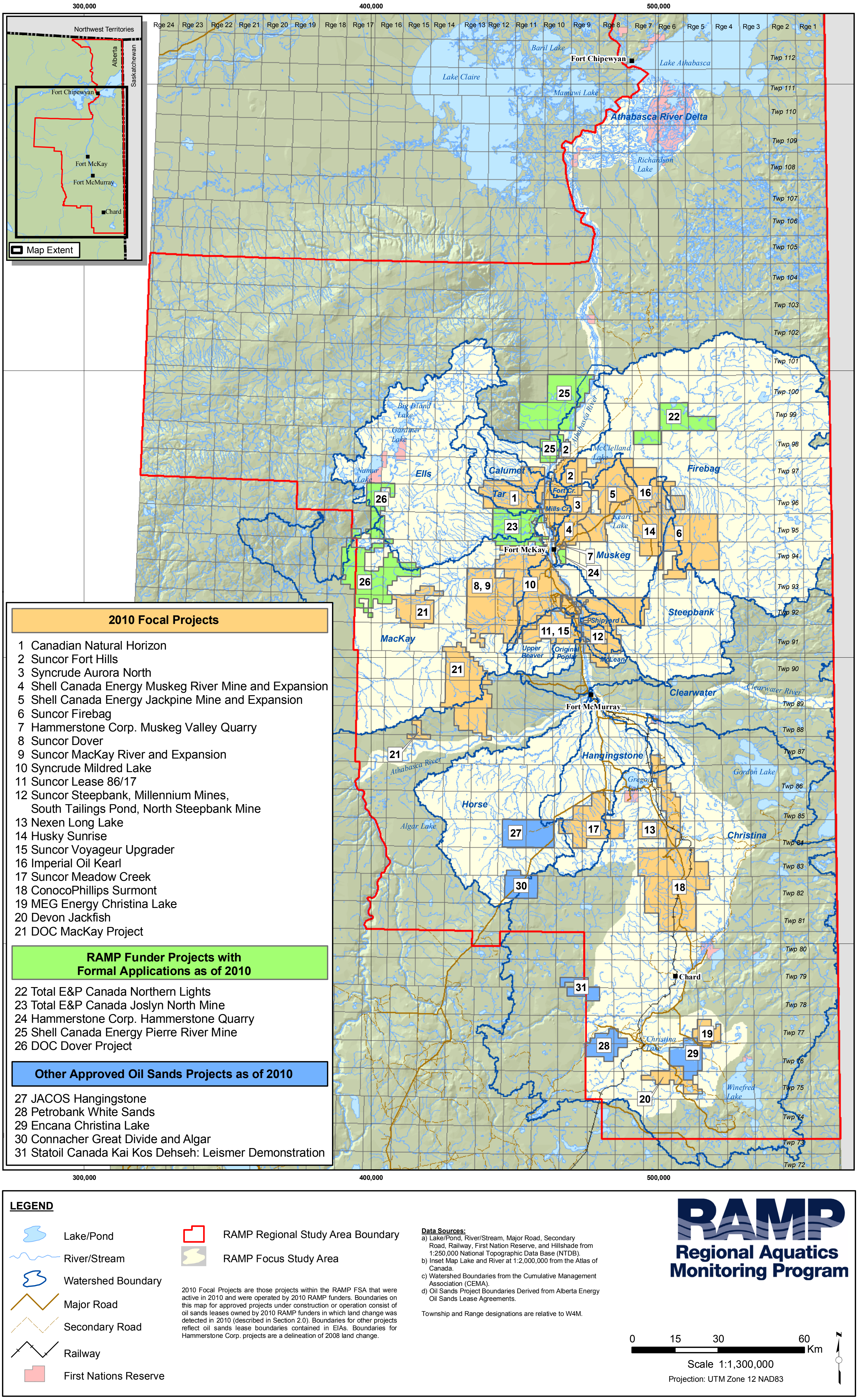
Within the RSA, a Focus Study Area (FSA) is defined by the watersheds in which oil sands development is occurring or is planned, as well as those parts of the Athabasca and Clearwater River channels within the RSA (Figure 1.3-1). Much of the Program's intensive monitoring activity is conducted within 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 assessment of the ecological health of the water quality, sediment quality, and non-fish biota was conducted as part of the Healthy Aquatic Ecosystems component of the initiative (Alberta Environment 2007a). 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 (southern) 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 lower (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 oil sands region lies within this portion of the RAMP FSA and is characterized by an undulating sandy plain containing mixed boreal forest. Approximately 50% of this portion of the RAMP FSA 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.

Figure 1.3-1   RAMP study areas.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_A_StudyArea_20110318.mxd

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 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 upper (southern) portion of the RAMP FSA;

- Hangingstone River – a 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 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 *in situ* 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 Muskeg River Mine and Expansion, Shell Jackpine Mine, Syncrude Aurora 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, the Dover Operating Corp. MacKay and Dover developments, and portions of Syncrude Mildred Lake project area;

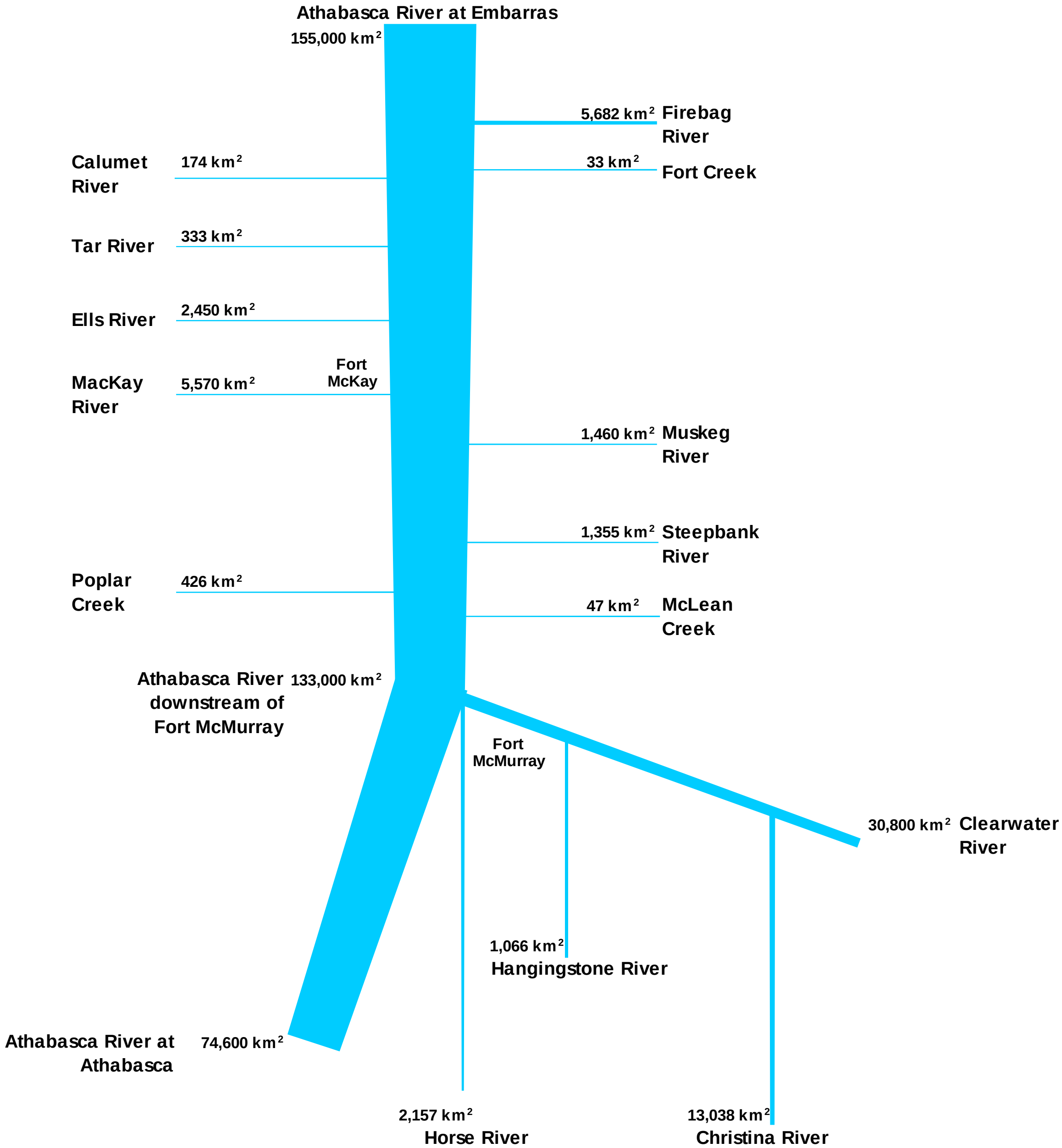
- Ells River – flows from the west and whose watershed includes a small portion of the Canadian Natural Horizon Project, and the approved Total E&P Canada Joslyn North Mine Project; this river is also the drinking water source for Fort McKay;

- Tar River – flows from the west and whose watershed contains most of the Canadian Natural Horizon Project;

- Calumet River –also flows 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, the Husky *in situ* Sunrise project, and the Imperial Oil Kearl Project.

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.

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

- tributaries within watersheds described above such as Muskeg Creek, Jackpine Creek, and Wapasu Creek in the Muskeg River watershed;
- 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 Syncrude Mildred Lake development (Beaver River), Suncor Fort Hills Project (Fort Creek), and Suncor and Syncrude oil sands developments on the west side of the Athabasca River (Poplar Creek);
- 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 2010 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 2010 Technical Report and is defined as those projects owned by 2010 industry members of RAMP (Section 1.2.2) that were under construction or operational in 2010 in the RAMP FSA. For 2010, these projects include a number of oil sands projects and a limestone quarry project (the Hammerstone Muskeg Valley Quarry Project); the focal projects are listed and described in Section 2.

2010 industry members of RAMP do have other projects in the RAMP FSA that were in the application stage as of 2010, or which received approval in 2010 or earlier, but on which construction had not yet started as of 2010. These projects are noted throughout this technical report but are not designated as focal projects.

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 and benthic invertebrates) 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, 2010). 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 2010 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** in rivers, lakes and some wetlands – 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 one or more focal projects; 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 2010) or were (prior to 2010) 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 watersheds affected, or expected to be affected, by focal projects in the area around Fort McMurray. Some watersheds that do not contain 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 analyses 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 anthropogenic 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 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 developments, 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 RAMP because:

- they integrate biologically relevant variations in water, sediment and habitat quality;
- 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 life span of benthic invertebrates (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); and
- 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 Communities component are to:

- collect scientifically defensible *baseline* and historical data to characterize variability in benthic invertebrate communities 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 diversity in areas downstream of focal projects relative to benthic invertebrate communities upstream of focal projects.

The Benthic Invertebrate Communities 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 four 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 the 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 Communities 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 biological 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. Sublethal 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 Populations component is to monitor the health status 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 Populations 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 Populations 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 Populations 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 KIRs 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 Populations 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 abnormalities.

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 Alberta Health and Wellness to develop fish consumption guidelines for waterbodies within the RAMP RSA (GOA 2009). 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 River. 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), Unnamed (Jackson) Lake (2009), Keith Lake (2010), Brutus Lake (2010) and Net Lake (2010).

Sentinel fish species monitoring assesses 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 age, growth, 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 2010) 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 has been conducted on the Muskeg River and 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

Alberta Environment's 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 that 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:

1. The locations of the lakes are selected to represent a gradient in acid deposition from both current and anticipated developments in the RAMP FSA.

2. For scientific validity, the lake selection includes lakes in the Caribou Mountains and Canadian Shield that are distant from the sources of acidifying emissions.

3. 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.

4. The lakes selected for monitoring exhibit moderate to high sensitivity to acidification as defined by a total alkalinity less than 400 µeq/L.

5. 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.

6. 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 2010

The overall analytical approach for the 2010 RAMP Technical Report is a weight-of-evidence approach that 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 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 2009 Technical Reports (RAMP 2005, RAMP 2006, RAMP 2007, RAMP 2008, RAMP 2009a, and RAMP 2010).

Second, the analysis of RAMP results for 2010 compared to previous monitoring years is conducted for the Athabasca River and ARD, as well as at the watershed/river basin level to assess temporal trends.

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 2010.

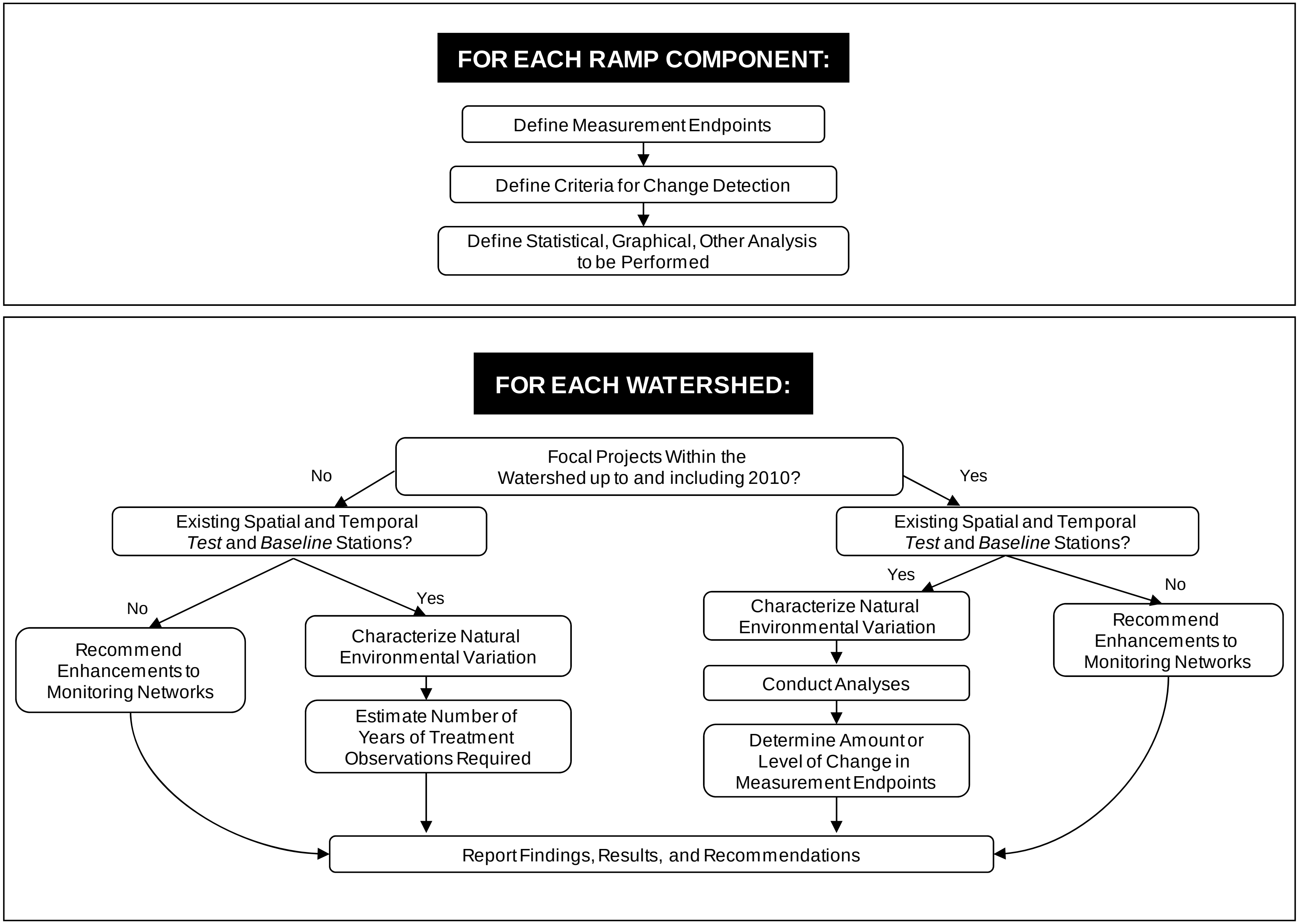


Table 1.4-1 Measurement endpoints and criteria for determination of change used in the analysis for the RAMP 2010 Technical Report.

RAMP Component	Measurement Endpoints Used in 2010 Technical Report[1]	Criteria for Determining Change Used in 2010 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 strong statistically significant difference in any measurement endpoint between *test* and *baseline* reaches/lakes 2. Moderate: strong 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

[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 3.1-4 and Table 3.1-9.

Table 1.4-1 (Cont'd.)

RAMP Component	Measurement Endpoints Used in 2010 Technical Report	Criteria for Determining Change Used in 2010 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: 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	Age Growth Condition Factor Gonadosomatic Index (GSI) Liversomatic Index (LSI)	Comparison to Environment Canada's Environmental Effects Monitoring (EEM) criteria (Environment Canada 2010) where an effect is determined by a difference of ± 10% in condition, ± 25% in age, growth, GSI, and LSI of fish at the *test* reach relative to fish condition at the *baseline* reach. Negligible-Low: no exceedance greater than ± 10% in condition, ± 25% in age, growth, GSI, or LSI of fish at *test* site compared to condition of fish at *baseline* site Moderate: exceedance greater than ± 10% in condition, ± 25% in age, growth, GSI, or LSI of fish at *test* site compared to condition of fish at *baseline* site, but not in two consecutive years of sampling including the current year High: exceedance greater than ± 10% in condition ± 25% in age, growth, GSI, or LSI of fish at *test* site compared to condition of fish at *baseline* site, and exceedance observed in two consecutive years of sampling including the current year
Acid-Sensitive Lakes	Critical Load of acidity pH Gran alkalinity Base cation concentrations Nitrate plus nitrite concentrations Dissolved Organic Carbon 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 2010 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 3.1-4 and Table 3.1-9.

1.5 ORGANIZATION OF THE RAMP 2010 TECHNICAL REPORT

Together with this Introduction, the RAMP 2010 Technical Report contains nine sections within which the results of the 2010 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 2010 – This section contains:

- a description of the activities in 2010 for each of the focal projects;
- a list of projects owned by 2010 industry members of RAMP that were in the application stage as of 2010, or which received approval in 2010 (or earlier) but were not in the construction phase as of 2010;
- a list of active oil sands projects in the RAMP study areas owned or operated by companies that were not members of RAMP in 2010;
- a list of report focal project withdrawal and discharge locations; and
- a summary of land change occurring up to 2010 as a result of development of focal projects.

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

Section 3: 2010 RAMP Monitoring Activities – This section of the report contains concise descriptions of the RAMP monitoring program that was conducted in 2010 for each RAMP component, and includes:

- an overview of the 2010 program;
- a description of any other information that was obtained (i.e., information from regulatory agencies, 2010 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 2010 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 then presents 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 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 over time and space; and
- a description and explanation of the criteria that were used in assessing whether or not changes in the selected measurement endpoints have occurred.

Section 4: Climatic and Hydrologic Characterization of the RAMP Focus Study Area in 2010 – This section of the report describes the 2010 water year (WY) (November 1, 2009 to October 31, 2010) and how the 2010 WY 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 2010 Results – This is the main results section of the RAMP 2010 Technical Report, consisting of two major parts:

- Section 5.1 is the report of 2010 findings for the mainstem Athabasca River and the Athabasca River Delta;
- Sections 5.2 to 5.11 are watershed-level reports of the 2010 findings for hydrology, water quality, benthic invertebrate communities and sediment quality, and fish populations; and
- Section 5.12 is the report of 2010 findings for the Acid-Sensitive lakes component.

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 have been initiated 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: Conclusions and Recommendations – This section of the report contains a summary of the findings, conclusions, and recommendations from RAMP 2010. The recommendations include proposed changes to the RAMP monitoring network for future years based on the results for 2010.

The main report concludes with **Section 8: References** and **Section 9: 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.

All RAMP data is publicly available on the RAMP website (www.ramp-alberta.org). The database is updated each year following the completion of the RAMP Technical Report.

2.0 SUMMARY OF FOCAL PROJECT ACTIVITIES IN 2010

This section provides information on oil sands and other developments in the RAMP Focus Study Area (FSA) needed to conduct the assessment of the 2010 monitoring results. In particular, this information is important for confirming the classification of sampling stations as *baseline* or *test* as oil sands development continues to expand over time. Five 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 2010; summary of focal project water withdrawal and discharge locations, and RAMP FSA land change analysis for 2010.

2.1 DEVELOPMENT STATUS OF FOCAL PROJECTS

The development status of all projects as of the end of 2010 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 2010 monitoring results for all RAMP components.

2.2 DEVELOPMENT STATUS OF OTHER OIL SANDS PROJECTS

There were five approved oil sands projects active in the RAMP FSA in 2010 whose operators were not members of RAMP in 2010 (Table 2.3-1). This information is used in specific analyses conducted in the Water Quality component (Section 3.2.2.2, Table 3.2-3) and Benthic Invertebrate Communities component (Section 3.2.3.1).

2.3 SUMMARY OF FOCAL PROJECT ACTIVITIES IN 2010

The information provided in this section is used to interpret the 2010 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 3.2.1.4).

2.3.1 Suncor Energy Inc.

Development activities had occurred for nine of Suncor's 13 focal projects as of 2010 (i.e., projects with a specified first year of disturbance, Table 2.3-1). Suncor focal project activities in 2010 included:

- Steepbank, Millennium, and Voyageur projects - discharge of approximately 5.96 million m^3 of water from holding ponds and site drainage at the Voyageur Upgrader to the Athabasca River and withdrawal of approximately 69.76 million m^3 of water from the Athabasca River.
- Firebag and MacKay projects - these *in situ* projects were operational in 2010 with withdrawals from groundwater sources and no discharges to surface waterbodies.
- Fort Hills project - there were no major changes in development reported in 2010.

Table 2.3-1 Status and activities of developments owned by 2010 industry members of RAMP in the RAMP Focus Study Area.

2010 RAMP Industry Member	Development	Focal Projects	Location		Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2010 Status
			Oil Sands Leases	Township-Range-Meridian					
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	√			mine	4,000		2007	Operational
	North Steepbank Mine Extension	√	Lease 25, Lease 97, Fee Lot 1	92,93-9-W4M	mine	180,000	2006	2007	Operational
	Millennium Debottlenecking	√			mine	23,000		2008	Operational
	Voyageur: Voyageur Upgrader Phase 1	√	Fee Lot 2, Lease 23	91,92-10-W4M	mine	156,000		-	Suspended
	Voyageur: Voyageur Upgrader Phase 2	√			mine	78,000		-	Approved
	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	Construction
	Firebag Phase 4	√			*in situ*	62,500	--	--	Approved
	Firebag Phase 5	√			*in situ*	62,500	--	--	Approved
	Firebag Phase 6	√			*in situ*	62,500	--	--	Approved
	Firebag Stages 3-6 Debottlenecking	√			*in situ*	23,500	--	--	Application
	Fort Hills (Phase 1)	√	7598060T05, 7281020T52, 7400120008	96-11-W4M, 97,98-10-W4M	mine	165,000	2001	2005	Approved
	Fort Hills debottleneck				mine	25,000		--	Approved
	MacKay River	√	7282030T75	92, 93-12-W4M	*in situ*	33,000	1998	2000	Operational
	MacKay River Expansion		7282030T75, 728004AT22, 7187060328	92, 93-12-W4M	*in situ*	40,000	2006	--	Approved
	Meadow Creek Phase 1/2	√	7281010T58, 7283010T81	84,85-8,9,10-W4M	*in situ*	80,000	2001	--	Approved
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	2006	Operational
Shell Canada Energy	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	Approved
	Jackpine Mine (Phase 1A)	√	Lease 13	95-8-W4, 95-9-W4	mine	100,000	2002	2006	Operational
	Jackpine Mine (Phase 1B)				mine	100,000		--	Approved

Note: Information in this table obtained from Oilsands Developers Group (2010), Strategy West Inc. (2009), Government of Alberta (2010a,b,c), Alberta Labour Market Information (2009), ConocoPhillips (2011), MEG Energy (2010, 2011), AENV (2011), 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 Canada Energy 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.)

2010 RAMP Industry Member	Development	Focal Projects	Location: Oil Sands Leases	Location: Township-Range-Meridian	Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2010 Status
Shell Canada Energy (Cont'd.)	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 (Phase 1/2)		Lease 309, 310, 351, 352	97,98,99-10,11-W4M	mine	200,000	2007	--	Application
Canadian Natural Resources Ltd.	Horizon Phase 1	√	Lease 18	96-11/12-W4M, 96-13-W4M, 97-11-W4M, 97-12-W4M, 97-13-W4M	mine	110,000	2002	2004	Operational
	Horizon Tranche (Phase 2/3/4)	√			mine	135,000	--	--	Approved
Imperial Oil Resources	Kearl Lake Phase 1	√	Leases 6, 87, 36 31A, 88	95,96,97-6-W4M, 95,96,97-7-W4M, 95,96,97-8-W4M	mine	110,000	2005	2009	Under Construction
	Kearl Lake (Phases 2 & 3)	√				200,000			Approved
Nexen Inc.	Long Lake Project Phase 1	√	Lease 27	85-6-W4M	*in situ*	72,000	unknown	2003	Operational
	Long Lake South Project (Phase 1)				*in situ*	70,000	2003	2004	Approved
	Long Lake South Project (Phase 2)								Approved
Total E&P Canada Ltd.	Joslyn, SAGD Phase I		7280060T24, 7404110452, 7405070799	94,95,96-11-W4M, 94-12-W4M	*in situ*	2,000	unknown	2003	Suspended
	Joslyn, SAGD Phase II	√			*in situ*	10,000	2004	2005	Suspended
	Joslyn, SAGD Phase IIIA/B				*in situ*	30,000	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	115,000	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
	Phase2-3					140,000	--	--	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
ConocoPhillips Canada	Surmont Phase 1	√		81,82,83-5,6,7-W4M	in-situ	27,000	2001	2004	Operating
	Surmont Phase 2	√			in-situ	83,000		2010	Construction
Devon Energy Corp.	Jackfish Phase 1	√		75,76-6,7-W4M	*in-situ*	35,000	2003	2005	Operating
	Jackfish Phase 2	√			*in-situ*	35,000	2006	2008	Construction
	Jackfish Phase 3	√			*in-situ*	35,000	2010	2011	Application
MEG Energy Corp.	Christina Lake Phase 1	√		76,78-4,6-W4M	*in-situ*	3,000	2004	2005	Operating
	Christina Lake Phase 2	√			*in-situ*	22,000	2005	2007	Operating
	Christina Lake Phase 2B	√			*in-situ*	35,000	2007	2007	Approved
	Christina Lake Phase 3A	√			*in-situ*	75,000	2008	--	Application
	Christina Lake Phase 3B	√			*in-situ*	75,000	2009	--	Application
Dover Operating Corp.	MacKay River	√		92, 93-12-W4M	*in-situ*	150,000	2010	2010	Application
	Dover Central			92-96-12-W4M	*in-situ*	250,000	2010	2010	Application

Note: Information in this table obtained from Oilsands Developers Group (2010), Strategy West Inc. (2009), Government of Alberta (2010a,b,c), Alberta Labour Market Information (2009), ConocoPhillips (2011), MEG Energy (2010, 2011), AENV (2011), 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 Canada Energy 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 2010.

Operator	Field or Area	Location (Township and Range)	Type of Operation
Cenovus (formerly 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	*in situ*
Japan Canada	Hangingstone	NW26, N27, N28, 33, 34, W35-84-11W4M	*in situ*
Petrobank Whitesands	Whitesands	12, 13-77-9W4M	*in situ*
Statoil Canada Kai Kos Dehseh	Leismer Demonstration	19 to 21, 26, 28, 29 to 33-78-9W4M	*in situ*
Connacher	Great Divide and Algar	NW16, NE17, SE20, 21-82-12W4	*in situ*

Information obtained from OSDG (2010)

2.3.2 Syncrude Canada Ltd.

Syncrude's focal projects in 2010 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 2010 included:

- withdrawal of 34.13 million m^3 from the Athabasca River;
- discharge of 0.32 million m^3 of treated domestic sewage to the Athabasca River; and
- a diversion of 9.31 million m^3 of water from muskeg dewatering or surface runoff to Stanley Creek as part of the Aurora Clean Water Diversion system.

2.3.3 Shell Canada Energy

Shell Canada Energy focal projects in 2010 were the Muskeg River Mine, Muskeg River Mine expansion and debottlenecking operation, and Jackpine Mine (Phase 1A) (Table 2.3-1). Shell Canada Energy focal project activities in 2010 included:

- Muskeg River Mine - water withdrawal from the Athabasca River totaling 13.6 million m^3. In 2010, the Muskeg River Mine facility was a zero water-discharge operation, with all tailings water and local drainage being recycled for project operations; and
- Jackpine Mine - water withdrawals of 1.34 million m^3 from the Athabasca River, 0.12 million m^3 from Shelley Creek, and 1.05 million m^3 from groundwater sources, release of 0.19 million m^3, 0.39 million m^3, and 0.06 million m^3 of water collected from site runoff and muskeg dewatering out of settling ponds to Shelley Creek, Jackpine Creek, and Khahago Creek, respectively.

2.3.4 Canadian Natural Resources Ltd.

The Canadian Natural Horizon project was operational in 2010 (Table 2.3-1); Horizon project activities in 2010 included:

- permanent alteration of the main channel drainage pattern of the Tar River to a diversion channel that flows into the compensation lake and a second diversion channel from the compensation lake to the lower Tar River (construction of the diversion channels occurred in 2008); and

- water withdrawal of 15.2 million m^3 from the Athabasca River.

2.3.5 Nexen Inc.

The Nexen Inc. Long Lake Phase 1 project was operational in 2010 (Table 2.3-1). Long Lake Phase 1 project activities in 2010 included:

- muskeg dewatering of 0.21 million m^3;
- water discharge of 0.04 million m^3 to water recycle ponds or the surrounding environment; and
- water withdrawal of 0.0004 million m^3 from lakes in the vicinity of the project.

2.3.6 Imperial Oil Resources

The Imperial Oil Resources Kearl Project was under construction in 2010 (Table 2.3-1); Kearl project activities in 2010 included:

- muskeg dewatering from November 2009 to October 2010, with a discharge of approximately 3.9 million m^3 of water to the Muskeg River watershed;
- water discharge from site ponds of 0.091 million m^3 to the Athabasca River and 0.005 million m^3 to the Muskeg River watershed;
- water diversion of 0.06 million m^3 from Kearl Lake to the Kearl compensation lake; and
- water withdrawal of 0.53 million m^3 from site ponds, 0.003 million m^3 from Kearl Lake, 0.01 million m^3 from the Firebag River, and 0.1 million m^3 from the Athabasca River.

2.3.7 Total E&P Canada Ltd.

The Total E&P Joslyn North Mine Project was in the application phase in 2010 (Table 2.3-1); preliminary activities for the Joslyn North Mine project in 2010 included:

- land clearing for winter access road and a drilling program in the Ells River/Joslyn Creek watershed; and
- withdrawals from the Ells River of approximately 0.006 million m^3, 0.004 million m^3 from Joslyn Creek and 0.003 million m^3 from various beaver ponds in the Tar and Ells watersheds for construction of the winter access road.

2.3.8 Husky Energy

The Husky Energy Sunrise Project was under construction in 2010 (Table 2.3-1); Sunrise Project activities in 2010 included:

- water withdrawals of 0.08 million m^3 from well pads; and
- water discharge of 0.29 million m^3 from site runoff to the Wapasu Creek headwaters.

2.3.9 Hammerstone Corp.

The Hammerstone Muskeg Valley Quarry Project was operational in 2010 (Table 2.3-1) with water discharges of approximately 0.18 million m^3 into an unnamed tributary of the Muskeg River.

2.3.10 ConocoPhillips Canada

The ConocoPhillips Surmont Phase 1 Project was operational in 2010 (Table 2.3-1) but does not require surface water withdrawals for production and did not discharge into any waterbodies within the lease. There were no major changes in development reported in 2010.

2.3.11 Devon Energy Canada

Devon Canada became a new member of RAMP in 2010 for monitoring requirements of the Jackfish projects. The Devon Canada Jackfish Phase 1 Project was operational in 2010 (Table 2.3-1) but did not require surface water withdrawals for production and has no direct discharges to waterbodies. There were no major changes in development reported in 2010.

2.3.12 Dover Operating Corp.

Dover Operating Corp. became a new member of RAMP in 2010 for monitoring requirements of the MacKay and Dover projects. The Dover Operating Corp. MacKay and Dover Projects were in the application phase in 2010 (Table 2.3-1) and; therefore, no development was occurring during the 2010 monitoring program.

2.3.13 MEG Energy Corp.

MEG Energy became a new member of RAMP in 2010 for monitoring requirements of the Christina Lake Project. The MEG Energy Christina Lake Project Phase 1 was in the operational phase in 2010 (Table 2.3-1). There were no major changes in development reported in 2010.

2.4 WATER USE RELATED TO FOCAL PROJECT ACTIVITIES IN 2010

Oil sands development requires water in their process, primarily from surface water in adjacent waterbodies to development or from groundwater sources. To accurately assess the hydrologic conditions of each watershed for the RAMP Climate and Hydrology Component, water withdrawal and discharge data is collected from RAMP industry members and incorporated into the hydrologic water balance model outlined in Section 3.2.1.4. The source of water withdrawals and location of discharge points in the RAMP FSA for each focal project are provided in Figure 2.4-1 and Table 2.4-1.

Figure 2.4-1 Locations of surface water withdrawals and discharges from focal project activities, 2010.

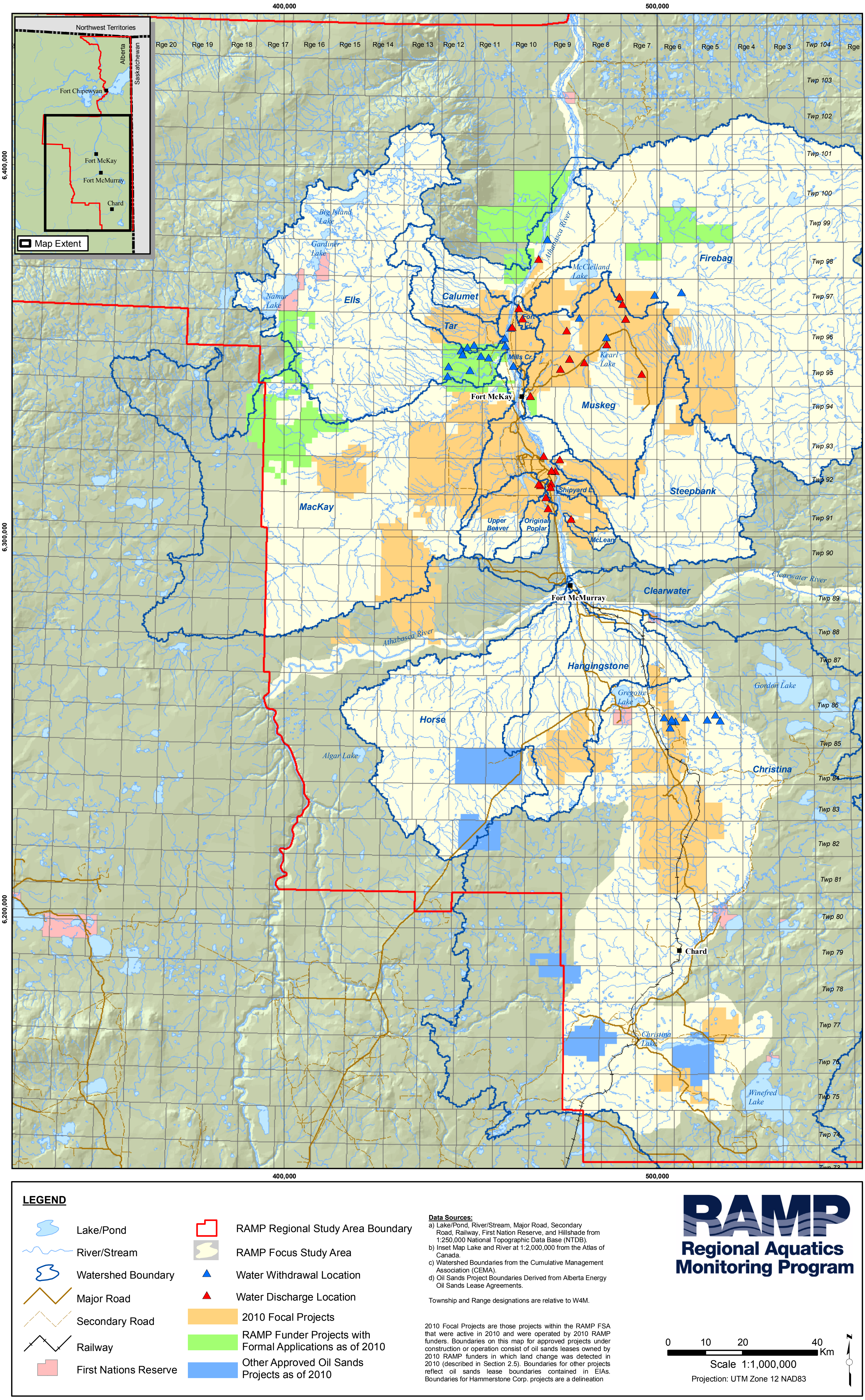


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Table 2.4-1 Surface water withdrawal and discharge information for focal project activities, 2010.

Watershed	Industry Presence - RAMP Members (Type)[1]	Water Withdrawal Source	Water Discharge Location
Athabasca River and Minor Tributaries	Imperial Oil Resources (SM)	Athabasca River watershed (2 locations) Athabasca River*	none reported
	Shell Canada Energy (SM)	Athabasca River*	none reported
	Syncrude Canada Ltd. MRM (SM)	Athabasca River*	Stanley Creek* Athabasca River*
	Canadian Natural Resources Ltd. (SM)	Athabasca River*	none reported
	Suncor Energy (SM)	Athabasca River*	Pond C and E*
Mills Creek	Suncor Energy (SM)	none reported	none reported
Shipyard Lake	Suncor Energy (SM)	none reported	none reported
Calumet	Canadian Natural Resources Ltd (SM)	none reported	none reported
Christina	Nexen (SAGD)	Long Lake Pushup Lake* Birch Lake* Various unnamed lakes (5) Unnamed Lake*	none reported
Ells	Total E&P Joslyn North Mine	Ells River (2 locations)* Joslyn Creek (2 locations)* Various beaver ponds (4)*	none reported
Firebag	Imperial Oil Resources (SM)	Firebag River* Firebag River Watershed*	none reported
Fort Creek	Suncor Energy (SM)	none reported	none reported
Hangingstone	Suncor Energy (SAGD)	none reported	none reported
Horse	No RAMP members	none reported	none reported
MacKay	Athabasca Oil Sands Corp. (SAGD)	none reported	none reported
	Suncor Energy (SAGD)	none reported	none reported
McLean	Suncor Energy (SM, SAGD)	McLean Creek	McLean Creek
Muskeg	Hammerstone (aggregate)	none reported	Various tributaries to Muskeg River (3)*
	Husky Energy (SAGD)	none reported	run-off, well pads
	Imperial Oil Resources (SM)	Muskeg River watershed* Kearl Lake Kearl Lake watershed*	Muskeg River watershed (3)
	Shell Canada Energy Jackpine (SM)	Muskeg River*	Shelley Creek Khahago Creek Jackpine Creek
Original Poplar	Suncor Energy (SM)	none reported	none reported
Steepbank	Suncor Energy (SM, SAGD)		Pond A East Steepbank South Mine Drainage Weir #1 Industrial Run-Off (2)
Tar	Total E&P Joslyn North Mine	Various beaver ponds (2)	none reported
Upper Beaver	Syncrude Canada Limited (SM)	Poplar Creek	none reported

[1] Type: SAGD - Steam Assisted Gravity Drainage (in situ extraction), SM - Surface Mine.

* Data reported was used in the hydrologic water balance model.

2.5 LAND CHANGE AS OF 2010 RELATED TO DEVELOPMENT ACTIVITIES

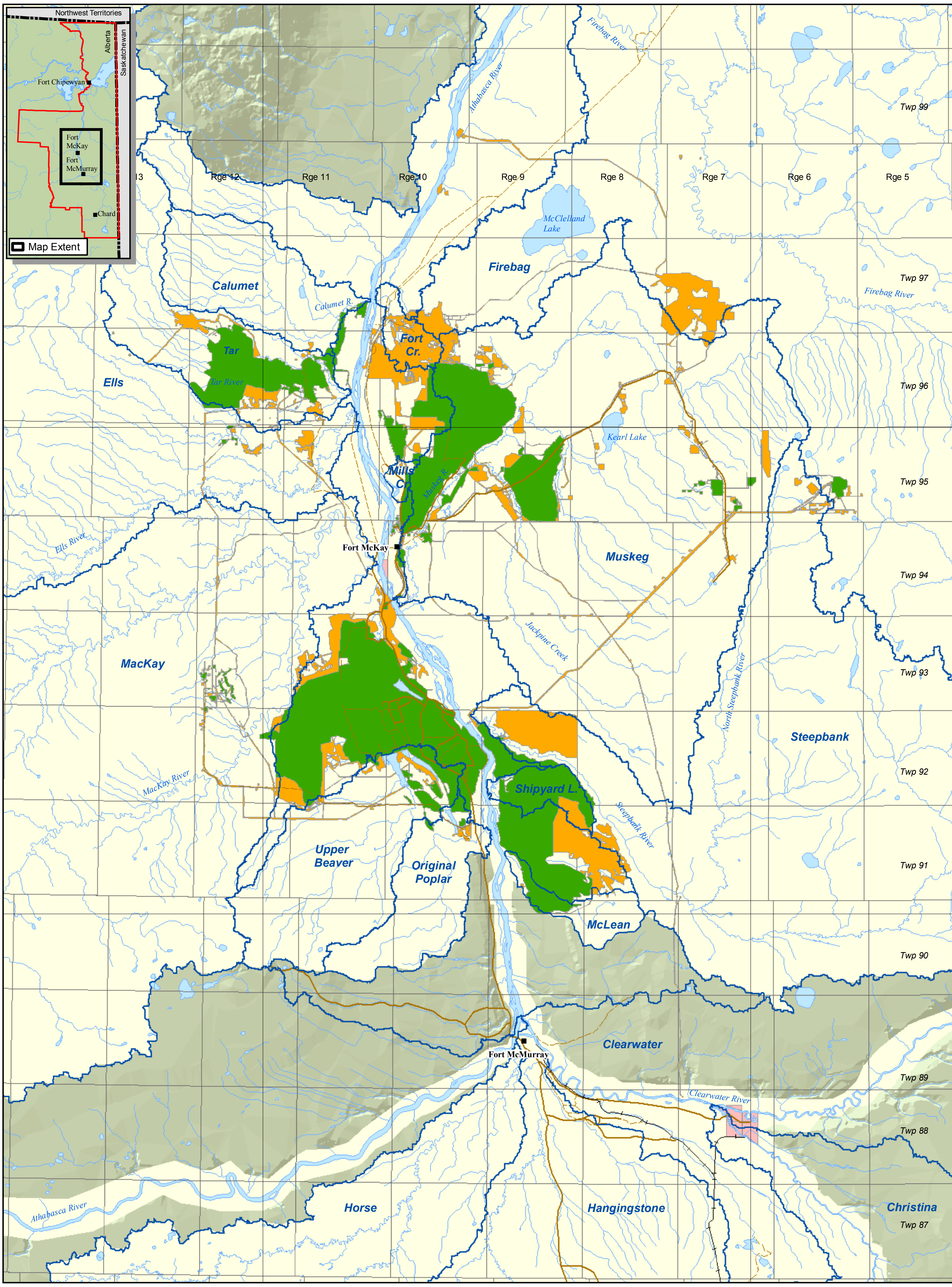
Land change, as of 2010 related to development activities, was estimated with satellite imagery in conjunction with more detailed maps of operations provided by a number of RAMP industry members. Seven SPOT-5 10 m resolution images (four north of Fort McMurray and three south of Fort McMurray) taken on June 19, July 17, July 27, August 11, August 24, August 25, and August 26, 2010 and one Landsat-5 30 m resolution image (south of Fort McMurray) taken on October 3, 2010 were obtained. A land change classification protocol was developed and applied to the imagery to identify and delineate two types of land change in 2010 from the projects listed in Table 2.3-1 and Table 2.3-2. 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 2010 land change maps.

Land change area as of 2010 is presented in Figure 2.5-1 and Figure 2.5-2 for north and south of Fort McMurray, respectively.

Table 2.5-1 and Table 2.5-2 provide tabular summaries of the total and percent land change 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 2010 within the RAMP FSA is estimated at approximately 86,000 ha for focal projects and 2,100 ha for oil sands projects operated by companies who were not members of RAMP in 2010 for a total of approximately 88,000 ha. The land change area for focal projects increased from 79,000 ha in 2009 but the land change area for oil sands projects operated by companies who were not RAMP members has decreased from 3,400 ha in 2009. This decrease reflects the addition of more companies as new members of RAMP in 2010 (i.e., ConocoPhillips, MEG Energy, Devon Energy, and Dover Operating Corp.); therefore, adding the land change from these companies to the total focal project land change area. The total area of land change represents approximately 2.5% of the area of the RAMP FSA. The percentage of the area of watersheds with land change as of 2010 varies from less than 1% for many watersheds (MacKay, Ells, Christina, Hangingstone, Horse, and Firebag rivers), to 1% to 5% for the Calumet, Poplar and Steepbank watersheds, 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.

Figure 2.5-1 RAMP land change classes derived from SPOT-5 (June and August 2010) satellite imagery, north of Fort McMurray.



LEGEND

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

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 Modified from Cumulative Environmental Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (June and August 2010) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP
Regional Aquatics Monitoring Program

0 5 10 20 Km

Scale 1:425,000

Projection: UTM Zone 12 NAD83

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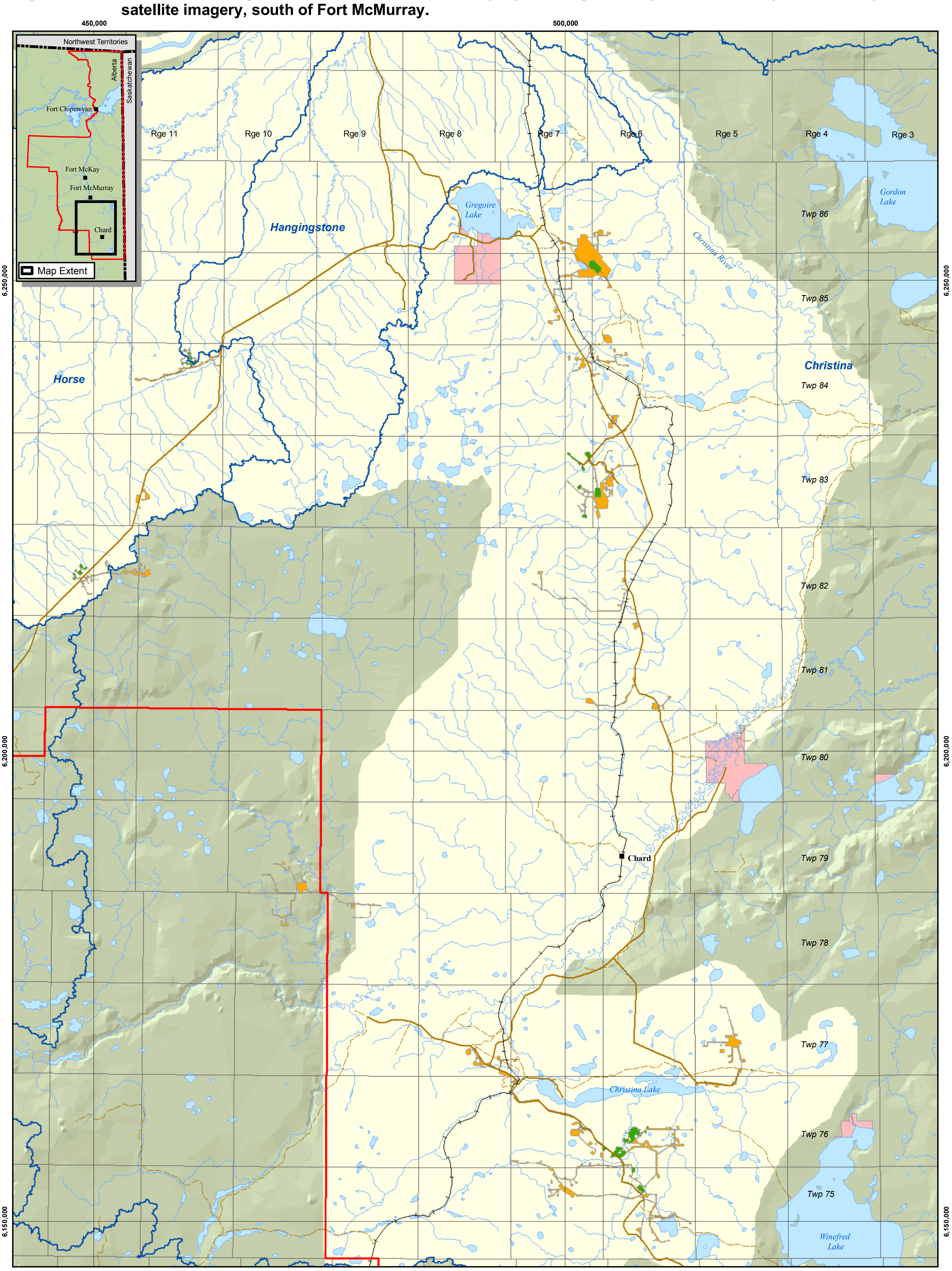
Figure 2.5-2 RAMP land change classes derived from SPOT-5 (July and August 2010) and Landsat-5 (October 2010) satellite imagery, south of Fort McMurray.



LEGEND

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

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 Modified from Cumulative Environmental Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (July and August 2010) and 30m Landsat-5 (October 2010) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP
Regional Aquatics Monitoring Program

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Scale 1:425,000

Projection: UTM Zone 12 NAD83

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Table 2.5-1 Area of watersheds with land change in 2010.

Watershed	Total Watershed Area (ha)	Watershed Area with Land Change (ha)							
		Focal Projects		Other Oils Sands Projects in RAMP FSA		Total		Watershed Total	
		Not-Closed Circuited (ha)	Closed-Circuited (ha)	Not-Closed Circuited (ha)	Closed-Circuited (ha)	Not-Closed Circuited (ha)	Closed-Circuited (ha)	ha	%
Minor Athabasca River Tributaries[2]	160,730	8,593	27,176			8,593	27,176	35,769	22.25
Muskeg	146,000	5,149	12,065			5,149	12,065	17,214	11.79
Steepbank	135,491	4,036	431			4,036	431	4,467	3.30
MacKay	557,000	1,336	441			1,336	441	1,777	0.32
Tar	33,261	1,477	5,870			1,477	5,870	7,347	22.09
Calumet	17,354	35	179			35	179	214	1.23
Firebag	568,174	3,909	257			3,909	257	4,166	0.73
Ells	245,000	775	162			775	162	937	0.38
Christina	1,303,805	3,303	314	1,317	343	4,620	657	5,277	0.40
Hangingstone	106,641			9	47	9	47	56	0.05
Mills Creek	890	47	207			47	207	255	28.62
Shipyard Lake	4,047	546	3,208			546	3,208	3,753	92.75
Fort Creek	3,193	1,966	30			1,966	30	1,996	62.50
Horse	215,741			279	104	279	104	383	0.18
McLean	4,712	83	1,103			83	1,103	1,187	25.19
Original Poplar[1]	13,856	168	307			168	307	475	3.43
Upper Beaver[1]	28,711	794	1,928			794	1,928	2,722	9.48
FSA Total	**3,544,606**	**32,218**	**53,678**	**1,605**	**494**	**33,823**	**54,173**	**87,995**	**2.48**

Only land changes within the RAMP FSA were delineated.

1 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).

2 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 2010 were above RAMP hydrology station S24.

Table 2.5-2 Percent of total watershed areas with land change in 2010.

Watershed	Total Watershed Area (ha)	Watershed Area with Land Change (%)						
		Focal Projects		Other Oil Sands Projects 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[2]	160,730	5.35	16.91	-	-	5.35	16.91	22.25
Muskeg	146,000	3.53	8.26	-	-	3.53	8.26	11.79
Steepbank	135,491	2.98	0.32	-	-	2.98	0.32	3.30
MacKay	557,000	0.24	0.08	-	-	0.24	0.08	0.32
Tar	33,261	4.44	17.65	-	-	4.44	17.65	22.09
Calumet	17,354	0.20	1.03	-	-	0.20	1.03	1.23
Firebag	568,174	0.69	0.05	-	-	0.69	0.05	0.73
Ells	245,000	0.32	0.07	-	-	0.32	0.07	0.38
Christina	1,303,805	0.25	0.02	0.10	0.03	0.35	0.05	0.40
Hangingstone	106,641	-	-	0.01	0.04	0.01	0.04	0.05
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
Fort Creek	3,193	61.57	0.93	-	-	61.57	0.93	62.50
Horse	215,741	-	-	0.13	0.05	0.13	0.05	0.18
McLean	4,712	1.77	23.42	-	-	1.77	23.42	25.19
Original Poplar[1]	13,856	1.21	2.22	-	-	1.21	2.22	3.43
Upper Beaver[1]	28,711	2.77	6.72	-	-	2.77	6.72	9.48
FSA Total	**3,544,606**	**0.91**	**1.51**	**0.05**	**0.01**	**0.95**	**1.53**	**2.48**

Only land changes within the RAMP FSA were delineated.

[1] 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).

[2] 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 2010 were above RAMP hydrology station S24.

3.0 2010 RAMP MONITORING ACTIVITIES

This section contains a description of RAMP monitoring conducted in 2010 and includes the following for each RAMP component:

- Summary of 2010 monitoring activities and field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, owners and operators of the 2010 focal projects, knowledge obtained from local communities, and other sources);
- Description of changes in the monitoring network from the 2009 program;
- Description of the challenges and issues encountered during 2010 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.

Monitoring activities for all RAMP components in 2010 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 2010. Appendix B contains a detailed description of the QA/QC procedures used for RAMP monitoring in 2010.

All 2010 monitoring data collected under RAMP have been added to the RAMP database, which is located in the RAMP member's area website.

3.1 FIELD DATA COLLECTION

3.1.1 Climate and Hydrology Component

The 2010 RAMP Climate and Hydrology monitoring network includes:

- 14 *baseline* streamflow stations;
- Six streamflow stations with less than 5% of the watershed affected by land change due to oil sands development;
- 16 streamflow stations with more than 5% of the watershed affected by land change due to oil sands development;
- 11 stations collecting climate data; and
- an area-wide snowcourse survey program.

The following sections describe the 2010 monitoring activities related to the Climate and Hydrology monitoring network.

3.1.1.1 Overview of 2010 Monitoring Activities

The Climate and Hydrology component monitoring in 2010 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, Horizon, and Steepbank Climate stations. The Steepbank Climate station started full operation of all variables in November 2010;
  - barometric pressure monitoring at three stations;
  - monitoring total precipitation at three additional stations, two of which also measured air temperature and relative humidity; and
  - rainfall, from May 1 to October 31, measured at five hydrometric monitoring stations;
- snow survey monitoring (Figure 3.1-1):
  - three regional snowcourse surveys, at 16 stations, in four distinct bio-geographic locations, conducted during the months of February, March, and April;
- streamflow monitoring (Table 3.1-1, Figure 3.1-2):
  - 14 year-round stations;
  - 14 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 12 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 specific station information for all climate and hydrology stations in the 2010 program.

3.1.1.2 Field Methods

Field methods are described in this section and cover the topics of streamflow measurements, water level surveys, climate station visits, and snow courses. More detail and specific procedures for each component can be found in the RAMP Design and Rationale document (RAMP 2009b).

General

Field crews conducted ten visits in 2010 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 three visits to all winter only 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.

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.

Measurement standards are summarized below:

- Number of verticals: minimum of 20, or at a spacing of 0.05 m in small streams;
- Number of vertical readings for an open-water measurement: one at 60% of the depth below the surface for depths of 0.75 m or less; otherwise one at 20% and one at 80% of the depth;
- Number of vertical readings for a measurement under ice: one at 60% of the effective depth below the bottom of the ice for depths of 0.75 m or less; otherwise one at 20% and one at 80% of the depth;
- Under ice measurements of <0.75 m are subject to a velocity correction of 0.9 due to the addition of the ice as a confining layer, panels measured with two velocity measurements are not subject to any velocity correction; and
- Velocity averaging: at least 20-second averages for the Sontek FlowTracker ADV (Acoustic Doppler Velocimeter) and electromagnetic meters (Marsh McBirney Flo-Mate 2000); and 45 seconds for mechanical meters.

The flow measurements conducted for the RAMP 2010 program utilized a Sontek FlowTracker ADV with the exception of the Athabasca River (Station S24) measurements that utilized the Ott ADC (Acoustic Digital Current) flowmeter.

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):

- Level readings using an automatic level were made to the nearest 0.001 m;
- Surveys were made using two independent benchmarks; and
- Each survey was conducted using two set-ups; the difference between the set-ups was required to be <0.005 m.

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 ensure sufficient levels of anti-freeze and hydraulic fluid were present.

Table 3.1-1 RAMP climate and hydrometric stations operating in 2010.

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	473950	6320500	all year[3]	air temperature, total precipitation, humidity, solar radiation, snow on the ground, barometric pressure, wind speed and direction
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, rainfall
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[2]	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
S16A	Calumet River near the Mouth	458130	6362062	open-water[4]	level, discharge
S19	Tar River Lowland Tributary near the Mouth	457502	6352663	open-water	level, discharge, rainfall
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[2]	level, discharge
S27	Firebag River near the mouth (07DC001)	489553	6388830	Winter[2]	level, discharge
S29	Christina River near Chard (07CE002)	508195	6187926	Winter[2]	level, discharge
S31	Hangingstone Creek at North Star Road	469784	6236095	open-water	level, discharge, rainfall
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, water temperature
S34	Tar River above Canadian Natural Lake	440729	6361689	all year	level, discharge, water temperature
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[2]	level, discharge
S39	Beaver River above Syncrude (07DA018)	465547	6311437	Winter[2]	level, discharge
S40	MacKay River at Petro-Canada Bridge	444888	6314179	all year	level, discharge, water temperature, rainfall
S42	Clearwater River above Christina River (07DC005)	504427	6279665	Winter[2]	level, discharge
S43	Firebag River upstream of Suncor Firebag	531528	6354782	open-water	level, discharge, water temperature, rainfall
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	level, discharge, water temperature

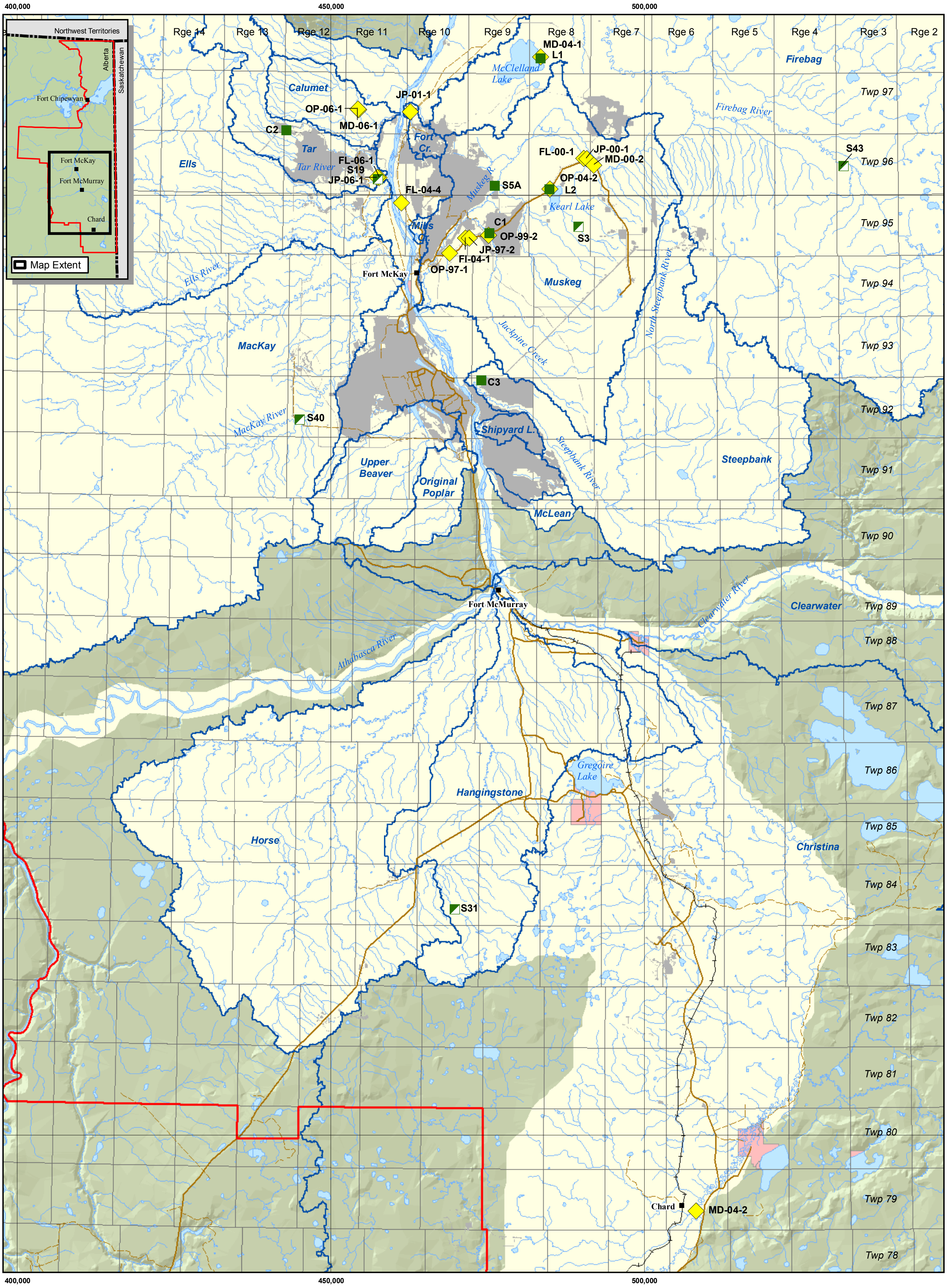
1 UTM coordinate datum is NAD83 Zone 12V.

2 WSC monitors water level and discharge at these stations during the open-water season.

3 Air temperature, relative humidity, solar radiation, snow depth, wind speed and direction, and barometric pressure were installed in November 2010.

4 S16A replaced CR-1 (CNRL) and former RAMP S16 which all monitor the Calumet River near the Mouth.

Figure 3.1-1 Locations of RAMP climate stations and snowcourse survey stations, 2010.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Land Change Area as of 2010
- Year-Round RAMP Climate Station
- Seasonal RAMP Climate Station
- Active RAMP Snowcourse

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 Modified from Cumulative Environmental Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2010) and 30m Landsat-5 (October 2010) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP Regional Aquatics Monitoring Program

0 5 10 20 Km

Scale 1:650,000

Projection: UTM Zone 12 NAD83

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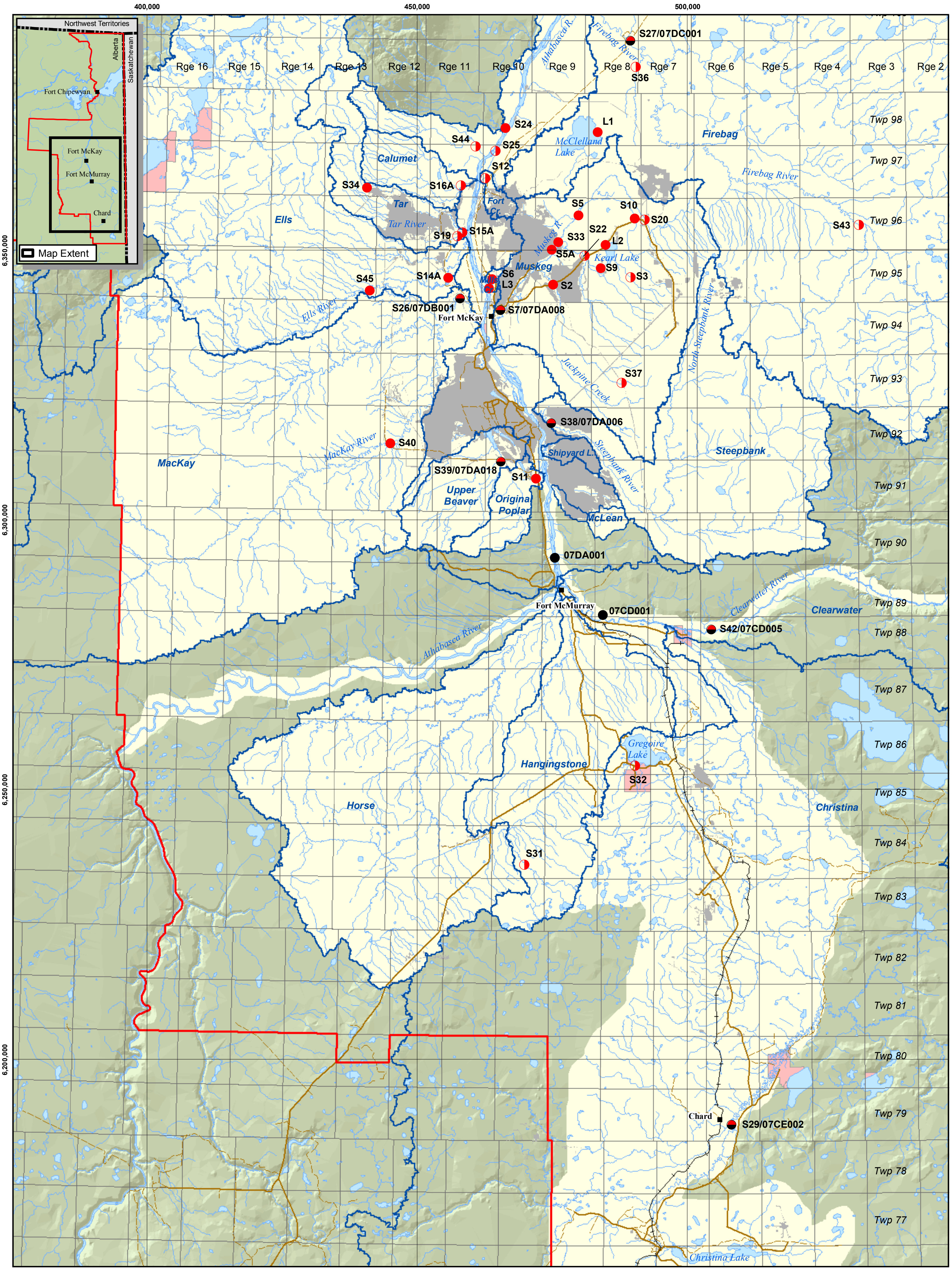
Figure 3.1-2 Locations of RAMP and government hydrometric stations, 2010.



LEGEND

- Lake
- River
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Land Change Area as of 2010

Hydrometric Stations

- Year-Round RAMP
- Seasonal RAMP
- Year-Round RAMP/Water Survey of Canada
- Year-Round Water Survey of Canada

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 Modified from Cumulative Environmental Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2010) and 30m Landsat-5 (October 2010) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP
Regional Aquatics Monitoring Program

0 5 10 20 Km

Scale 1:750,000

Projection: UTM Zone 12 NAD83

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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):

- 40 snow depths were measured in each study plot;
- Snow depth and the mass of a vertical profile of the snowpack were measured four times in each plot to calculate snow density. Forty snow water equivalent (SWE) values were calculated in each plot by multiplying individual snow depth values by mean snow density. A mean SWE value was calculated for each plot; and
- Station photos were taken to provide a visual record of ground snow conditions (e.g., patchiness) and any intercepted snow in treed stands.

3.1.1.3 Changes in Monitoring Network from 2009

New Monitoring Stations

Station 16A, Calumet River near the Mouth, was installed in spring 2010 to monitor water level and discharge of the Calumet River watershed. This station continues the monitoring record in the Calumet River watershed from RAMP Station S16 (2001 to 2004) and CNRL Station CR-1 (2005 to 2009).

Modified Stations

The following modifications and field equipment upgrades were made in 2010 to support station function and data collection reliability:

- A new data logger was installed at the Aurora Climate Station (Station C1) to replace the ageing 15-year old existing data logger. All sensors were replaced with calibrated sensors to support on-going data accuracy.
- The Steepbank Climate Station (Station C3) was upgraded in late October 2010 to include the measurement of air temperature, relative humidity, solar radiation, snow depth, wind speed and direction, and barometric pressure. Station C3 now measures all standard meteorological variables in the lower Steepbank River watershed in a region between Fort McMurray and the Aurora Climate Station (Station C1). The upgraded station became fully operational in early November 2010.
- Four stations: S5 (Muskeg River above Stanley Creek), S6 (Mills Creek at Hwy 63), S7 (Muskeg River near Fort McKay), S24 (Athabasca River below Eymundson Creek) were upgraded with new data loggers and pressure transducers to proactively replace ageing equipment and improve data collection reliability.
- A solar panel was installed at S25 (Susan Lake Outlet) to improve the power supply and data collection reliability.
- Three additional tipping bucket rain gauges were deployed at stations S31 (Hangingstone Creek at North Star Road), S40 (MacKay River at Petro-Canada Bridge), and S43 (Firebag River above Suncor Firebag) for the months of May to October to increase the spatial coverage of rainfall data collection in the region.

- Stations L3 (Isador's Lake), S5A (Muskeg River above Muskeg Creek), S14A (Ells River at CNRL Bridge), and S34 (Tar River above Canadian Natural Lake), were upgraded with calibrated pressure transducers based on a two year exchange cycle for all year-round monitoring stations.

3.1.1.4 Challenges Encountered and Solutions Applied

Wildlife and Environmental Challenges

The pressure transducer and water temperature probe was damaged by beaver activity at Station S2, Jackpine Creek at Canterra Road, after the October field visit prior to freeze-up. The probe was replaced when the creek was ice free on April 26.

At Station S19, Tar River Lowland Tributary near the Mouth, the tipping bucket rain gauge was damaged by wildlife causing a power interruption of 36 days. The station was successfully reactivated on the next field visit.

Wildlife damaged Station S25, Susan Lake Outlet, in August. The station was successfully restored within 15 days after the station was damaged.

Data Logger Malfunctions and Attrition

Station C3, Steepbank Climate Station, required adjustment to support function of the precipitation gauge. The housing of the gauge was successfully realigned with data collection resuming on August 18.

The pressure transducer at Station S37, East Jackpine Creek at the 1,300 ft contour, malfunctioned in late August and was replaced with a newly-calibrated pressure transducer on the September field visit. Data collection successfully resumed within 13 days of the malfunction.

3.1.1.5 Other Information Obtained

Streamflow data from WSC were obtained and incorporated into the RAMP database for stations that are jointly operated by RAMP and WSC. These data are received as provisional and are flagged as such in the database.

3.1.1.6 Summary of Component Data Now Available

Table 3.1-2 summarizes the available climate and hydrology data collected to date for RAMP. Additional climate data collected by WBEA and Environment Canada are available using the following links:

- http://www.wbea.org/
- http://www.climate.weatheroffice.gc.ca/Welcome_e.html

Environment Canada collects climate data at the Fort McMurray AWOS A Station (formerly Fort McMurray A Station until July 2008). Data from this location is utilized within the RAMP 2010 reporting period.

Table 3.1-2 Summary of RAMP data available for the Climate and Hydrology component, 1997 to 2010. (Page 1 of 2)

see symbol key at bottom

Location	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009				2010				2010
	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	W	S	S	F	Status
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	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	n/a
Horizon Climate Station (C2)																																																h	he	he	he	he	he	he	he	he	n/a
Steepbank Climate Station (C3)																																																			c	c	c	c	c	he	n/a
McClelland Lake (L1)																						a	a	a		a	a			a	a	a						c	c	cg	i	i	i	i	i	i	i	i	i	i	i	i	i	i	i	i	n/a
Kearl Lake (L2)																																												i	i	i	i	i	i	i	i	i	i	i	i	i	n/a
Iyinimin Creek above Kearl Lake (S3)						a	a	a		a	a	a						a	a	a		a	a	a		a								a	a			a	a	a			a			a	a	a						a	a	a	n/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	e	e	e	e	e	e	e	e	e	e	e	e	n/a
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	f	cf	cf	cf	cf	cf	f																						
Tar River Lowland Tributary near the Mouth (S19)																						a	a	a		a	a	a		a	a	a		a	a	a	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c			a	a	a	n/a
Christina River near Chard (S29)																						a	a	a		a	a	a		a	a	a																									
Hangingstone Creek at Northstar Road (S31)																																																						a	a	a	n/a
MacKay River at Petro-Canada Bridge (S40)																																																						a	a	a	n/a
Firebag River upstream of Suncro Firebag (S43)																																																						a	a	a	n/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																													d				d				d				d				d				d				d				n/a
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	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	>5% Land Change
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		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2	2t	2t	2t	2	2t	2t	2t	<5% Land Change
Fort Creek at Highway 63 (S12)														2	2	2		2	2	2		2	2	2														2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	>5% Land Change
Ells River above Joslyn Creek (S14)																		2	2	2		2	2	2		2	2	2		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	2	2t	2t	2t	Baseline
Tar River near the Mouth (S15)																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2																	
Tar River near the Mouth (S15A)																																										2	2	2		2t	2t	2t		2t	2t	2t		2t	2t	2t	>5% Land Change
Calumet River near the Mouth (S16)																		2	2	2		2	2	2		2t	2t	2t		2	2	2t																									
Calumet River near the Mouth (S16A)																																																						2	2	2	Baseline
Tar River Upland Tributary (S17)																		2	2	2		2	2	2		2	2	2		1	1	1																									
Upland Calumet River (S18)																		2	2	2																																					
Calumet River Upland Tributary (S18A)																						2	2	2		2	2	2		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		2	2	2		2	2	2		2	2	2		2	2	2	>5% Land Change
Susan Lake Outlet (S25)																						2	2	2														2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	Baseline
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	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	<5% Land Change
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	2	4	4	4	2	4	4	4	2	4	4	4	<5% Land Change
Tar River above CNRL Lake (S34)																																		2	2	2		2	2	2	2	2	2	2	2	2t	2t	2t	2	2t	2t	2t	2	2t	2t	2t	Baseline
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		2	2	2	Baseline
Steepbank River near Fort McMurray (07DA006, S38)																																																	2	4	4	4	2	4	4	4	<5% Land Change
Beaver River above Syncrude (07DA018, S39)																																													2	4	4	4	2	4	4	4	2	4	4	4	Baseline
MacKay River at Petro-Canada Bridge (S40)																																													2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	Baseline
Firebag River upstream of Suncro Firebag (S43)																																																		2	2	2		2t	2t	2t	Baseline
Pierre River near Fort McKay (formerly 07DA013, S44)																																																		2	2	2		2	2	2	Baseline
Ells River above Joslyn Creek Diversion (S45)																																																		2t	2t	2t	2t	2t	2t	2t	Baseline

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 grounc
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.) (Page 2 of 2)

see symbol key at bottom

WATERBODY AND LOCATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009				2010				2010
	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	W	S	S	F	Status
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	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	n/a
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	2t	2t	2t	2t	>5% Land Change
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		2	2	2	>5% Land Change
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	2	2	2	2t	>5% Land Change
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	2t	2t	2t	2t	>5% Land Change
Muskeg River near Fort McKay (07DA008, S7)													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	2	4	4	4	>5% Land Change
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	2	2	2	2	>5% Land Change
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	2	2	2	2	>5% Land Change
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		2	2	2	>5% Land Change
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		2	2	2	>5% Land Change
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	2t	2t	2t	2t	>5% Land Change
East Jackpine Creek near the 1300 m Contour (S37)																																												2		2	2	2		2	2	2		2	2	2	Baseline
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)																																																	2	4	4	4	2	4	4	4	Baseline
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	2	4	4	4	<5% Land Change
Hangingstone River at Highway 63 (S30)																						2	2	2																																	
Hangingstone Creek at North Star Road (S31)																						2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	Baseline
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		2t	2t	2t	Baseline
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	1	1	1t	1t	<5% Land Change
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	1t	1t	1t	1t	>5% Land Change
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	1	1	1	1	>5% Land Change

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 grounc
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)

3.1.2 Water Quality Component

3.1.2.1 Overview of 2010 Monitoring Activities

Monitoring activities for the Water Quality component were conducted in four sampling campaigns in 2010: winter (March 8 to 10); spring (May 13 to 17); summer (July 13 to 14); and fall (September 7 to 15).

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. Water quality was sampled at 45 RAMP stations in 2010. Table 3.1-3 summarizes the location of 2010 water quality sampling stations, seasonal distribution of the sampling effort, and water quality variables measured at each station. Figure 3.1-3 provides the locations of water quality sampling in 2010. Sampling intensity was greatest during the fall campaign, with samples collected from all 2010 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 fall in subsequent years (Table 3.1-3).

3.1.2.2 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 a 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-CC, 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.

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 2010 were analyzed for the RAMP standard variables (Table 3.1-4) in all sampling seasons. All analyses were conducted by ALS Environmental Ltd. (Fort McMurray and Edmonton, Alberta) with the exception of total and dissolved metals (including ultra-trace mercury) and naphthenic acids, which were analyzed by Alberta Innovates Technology Futures (AITF, formerly ARC) in Vegreville, Alberta. Triplicate samples were collected for naphthenic acids analysis at different laboratories, as discussed in Section 3.1.2.4. Samples collected from regional lakes were analyzed for chlorophyll *a* by ALS.

Details of all analytical chemistry methods and associated detection limits for the Water Quality Component are provided in Appendix D.

3.1.2.3 Changes in Monitoring Network from 2009

The 2010 monitoring network for the Water Quality component was the same as the 2009 monitoring network with the following exceptions:

- Ells River (Upstream of Fort Mackay Water Intake), *baseline* station ELR-2A, was added to analyze the water quality in the Ells River upstream of the Fort McKay Water Intake. This station will replace the current ELR-2 water quality station next year.
- Mills Creek, *test* station MIC-1, was added to characterize the water quality in the tributary to Isadore's Lake, in an attempt to determine any upstream contributions to changes in relative ion concentration observed by RAMP in Isadore's Lake in recent years.
- Athabasca River upstream of Donald Creek (both east and west bank), *baseline* stations ATR-DC-W and ATR-DC-E, was sampled during all seasons.
- Shelley Creek, *test* station SHC-1, and Muskeg Creek, *test* station MUC-1, were not sampled based on the program panel design.

3.1.2.4 Changes in Analytical Chemistry Methods from 2009

Until 2008, analysis of naphthenic acids was undertaken by ALS Environmental, using an analytical method based on Fourier Transform Infrared Spectroscopy (FTIR) developed by the University of Alberta, that achieved a method detection limit (MDL) of 1 mg/L. Investigations of water chemistry from tributaries of the lower Athabasca using other, higher-resolution methods indicated that background concentrations of naphthenic acids in the lower Athabasca region typically fall between 0 and 1 mg/L (Dr. M. McKinnon, Syncrude Research, *pers. comm.* 2008; Dr. J. Martin, University of Alberta, *pers. comm.*, 2009).

Table 3.1-3 Summary of sampling for the RAMP 2010 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)	475080	6298313	1	-	-	1	East bank grab
ATR-DC-W	Athabasca River upstream of Donald Creek (west bank)	474799	6298406	1	-	-	1	West bank grab
ATR-DD-E	Athabasca River downstream of all development (east bank)	463727	6367772	1	1	1	1	East bank grab
ATR-DD-W	Athabasca River downstream of all development (west bank)	463179	6368242	1	1	1	1	West bank grab
ATR-FR-CC	Athabasca River upstream of the Firebag River	478031	6377868	-	-	-	1	Cross-channel composite
ATR-MR-E	Athabasca River upstream of the Muskeg River (east bank)	463595	6332064	-	-	-	1	East bank grab
ATR-MR-W	Athabasca River upstream of the Muskeg River (west bank)	463312	6331579	-	-	-	1	West bank grab
ATR-SR-E	Athabasca River upstream of the Steepbank River (east bank)	470994	6319458	-	-	-	1	East bank grab
ATR-SR-W	Athabasca River upstream of the Steepbank River (west bank)	470990	6318943	-	-	-	1	West bank grab
Tributaries to the Athabasca River (Southern)								
Clearwater River								
CLR-1	Clearwater River upstream of Fort McMurray	480758	6284024	-	-	-	1	Mid-channel grab
CLR-2	Clearwater River upstream of Christina River	496119	6280516	-	-	-	1	Mid-channel grab
Christina River								
CHR-1	Christina River upstream of Fort McMurray	496540	6280091	-	-	-	1	Mid-channel grab
CHR-2	Christina River upstream of Janvier	511743	6192347	-	-	-	1	Mid-channel grab
Tributaries to the Athabasca River (Eastern)								
FOC-1	Fort Creek	461564	6363103	-	-	-	7	Mid-channel grab
MCC-1	McLean Creek (mouth)	474637	6306053	-	-	-	1	Mid-channel grab
Steepbank River								
NSR-1	North Steepbank River	497364	6324536	-	-	-	1	Mid-channel grab
STR-1	Steepbank River (mouth)	471290	6320115	1	-	-	1	Mid-channel grab
STR-2	Steepbank River upstream of Suncor Millennium	485803	6309355	-	-	-	1	Mid-channel grab
STR-3	Steepbank River upstream of North Steepbank River	495009	6300228	-	-	-	1	Mid-channel grab
Muskeg River and Muskeg River Tributaries								
MUR-1	Muskeg River (mouth)	463487	6332440	-	-	-	1	Mid-channel grab
MUR-6	Muskeg River upstream of Wapasu Creek	492108	6355706	-	-	-	1	Mid-channel grab
JAC-1	Jackpine Creek (mouth)	474980	6344051	-	-	-	1	Mid-channel grab
JAC-2	Jackpine Creek (upstream)	480063	6324953	-	-	-	1	Mid-channel grab
IYC-1	Iyinimin Creek	489418	6345179	-	-	-	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477381	6356658	-	-	-	1	Mid-channel grab
WAC-1	Wapasu Creek at Canterra Road crossing	490264	6355947	-	-	-	1	Mid-channel grab
Firebag River								
FIR-1	Firebag River (mouth)	479054	6400137	-	-	-	1	Mid-channel grab
FIR-2	Firebag River upstream of Suncor Firebag	531525	6354787	-	-	-	1	Mid-channel grab

Table 3.1-3 (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)	463653	6330938	-	-	-	1	Mid-channel grab
POC-1	Poplar Creek (mouth)	473030	6308789	-	-	-	1	Mid-channel grab
BER-2	Beaver River (upper)	465477	6311276	1	1	1	1	Mid-channel grab
CAR-1	Calumet River (mouth)	460805	6363197	-	-	-	1	Mid-channel grab
CAR-2	Calumet River (upper river)	454045	6366800	-	-	-	1	Mid-channel grab
ELR-1	Ells River (mouth)	459253	6351523	-	-	-	1	Mid-channel grab
ELR-2	Ells River (upstream)	455753	6344915	-	-	-	1	Mid-channel grab
ELR-2A	Ells River (upstream of Fort McKay Water Intake)	454478	6343542	-	-	-	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	440261	6361791	-	1	1	1	Mid-channel grab
MacKay River								
MAR-1	MacKay River (mouth)	461292	6336246	1	1	1	1	Mid-channel grab
MAR-2	MacKay River upstream of Suncor MacKay	444864	6314089	1	1	1	1	Mid-channel grab
MAR-2a	MacKay River upstream of Suncor Dover	449741	6320046	1	1	1	1	Mid-channel grab
Lakes and Wetlands								
ISL-1	Isadore's Lake	463493	6343245	-	-	-	16	Mid-lake grab
KEL-1	Kearl Lake	484897	6348963	-	-	-	16	Mid-lake grab
MCL-1	McClelland Lake	479289	6373871	-	-	-	16	Mid-lake grab
SHL-1	Shipyard Lake	473294	6313090	-	-	-	16	Mid-lake grab
Tributaries to Lakes								
MIC-1	Mills Creek, tributary to Isadore's Lake	463769	6344822	1	1	1	1	Mid-channel 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

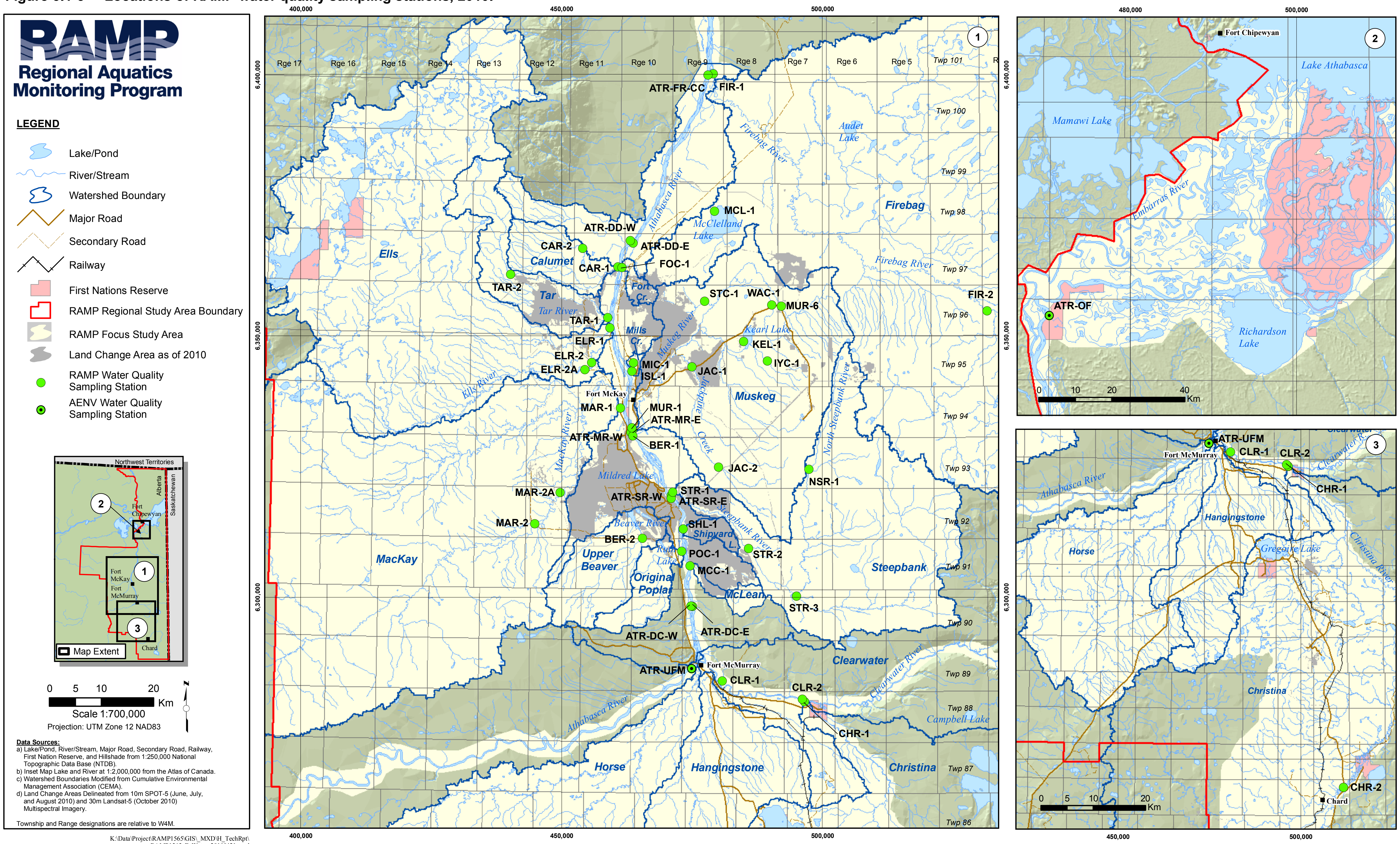


Figure 3.1-3 Locations of RAMP water quality sampling stations, 2010.

Table 3.1-4 RAMP standard water quality variables.[1]

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*[2]
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[3] (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] Details describing analytical methods and detection limit appear in Appendix D.

[2] Chlorophyll *a* sampled at lotic (lake) sampling locations only. In rivers with erosional substrates, chlorophyll *a* in periphyton was also measured (see Section 3.1.3.2).

[3] Total mercury (Hg) measured with a detection limit of 0.6 ng/L (0.0000006 mg/L).

After investigation of alternative methods at various laboratories, the analysis of naphthenic acids was shifted to AITF in 2009 using an Electron-Ionization GC/MS method that initially provided an MDL of 0.1 mg/L (winter, spring and summer 2009), but was then further refined to 0.02 mg/L for analysis of water samples collected by RAMP in fall 2009. The AITF method is one of several different high-resolution methods currently under development by various laboratories to measure naphthenic acids at environmentally relevant concentrations in water; others include ALS Environmental (Edmonton, AB), AXYS Analytical Ltd. (Sidney, BC), and laboratories at the University of Alberta.

Considerable uncertainty currently exists regarding high-resolution analysis of naphthenic acids, what compounds are being measured, what compounds should be measured, and what is the toxicological significance of naphthenic acids as measured by these different tests (see Grewer *et al.* 2010 for further discussion). Given this uncertainty, RAMP collected triplicate samples for naphthenic acids analysis in 2010, and provided them to three different laboratories for analysis and use in method development/verification. In addition to the primary sample sent to AITF, samples also were delivered to ALS Environmental Ltd. in Edmonton, and to the laboratory of Dr. Jon Martin at the University of Alberta. All of these laboratories have developed high-resolution analyses using different methods. Analyses were completed by AITF and ALS in time for consideration in this report; results of analyses from Dr. Martin's laboratory were not yet available at the time of reporting.

AITF modified their analytical method in early 2010 to one substantially different from that used in 2009; this new method measures a different set of compounds than their 2009 method, Naphthenic acids data generated for RAMP samples in 2010 by AITF and ALS Environmental, are provided in Section 6. Details of the different methods used by AITF, and differences between them, are discussed in a memo produced by AITF, included in Appendix D.

Separately, the method detection limit for ultra-trace mercury analysis undertaken for RAMP by AITF was reduced from 1.2 to 0.6 ng/L in fall 2010.

3.1.2.5 Challenges Encountered and Solutions Applied

The new *test* station MAR-2A (mid-Mackay River) was not sampled as planned in fall 2010 because of a typographic error in station coordinates provided to the field crew. This station was sampled in the appropriate location in winter, spring and summer 2010. In future field programs, more detailed maps as well as station coordinates will be used by crews to correctly identify stations in the field, particularly for newly established stations.

3.1.2.6 Other Information Obtained

Sampling for the Water Quality component in 2010 was conducted by the RAMP implementation team, with the exception of two stations on the mainstem Athabasca River (ATR-UFM and ATR-OF) that were sampled by AENV (Table 3.1-3).

3.1.2.7 Summary of Component Data Now Available

Water quality data collected to date by RAMP are summarized in Table 3.1-5. Table 3.1-5 does not include data collected by AENV.

Table 3.1-5 Summary of RAMP data available for the Water Quality component. (Page 1 of 2)

See symbol key below.

Waterbody and Location	Station	1997 W	1997 S	1997 S	1997 F	1998 W	1998 S	1998 S	1998 F	1999 W	1999 S	1999 S	1999 F	2000 W	2000 S	2000 S	2000 F	2001 W	2001 S	2001 S	2001 F
Athabasca River																					
Upstream of Fort McMurray (grab) [a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1																
(west bank) [b]	ATR-DC-W								1								1				3
(east bank) [b]	ATR-DC-E								1								1				3
(middle)	ATR-DC-M																1				
Upstream of the Steepbank River (middle)	ATR-SR-M																1				
(west bank)	ATR-SR-W																1				1
(east bank)	ATR-SR-E																1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																1				
(west bank) [b c]	ATR-MR-W								1								1				1
(east bank) [b c]	ATR-MR-E								1								1				1
Upstream Fort Creek (cross channel)	ATR-FC-CC-D		1	1	1																
(west bank) [b c]	ATR-FC-W								1								1				3
(east bank) [b c]	ATR-FC-E								1								1				3
(middle)	ATR-FC-M																1				
Downstream of all development (cross channel)	ATR-DD-CC																				
(east bank)	ATR-DD-E																				
(west bank)	ATR-DD-W																				
Upstream of mouth of Firebag River	ATR-FR-CC																				
Upstream of the Embarras River (cross channel)	ATR-ER									1							1				3
Embarras River	EMR-1																				
At Old Fort (grab) [d]	ATR-OF													11	11	11	11	11	11	11	11
Athabasca River Delta																					
Big Point Channel [e]	ARD-1											1					1				1
Athabasca River tributaries (Eastern)																					
McLean Creek (mouth)	MCC-1											6	7		6	6	9		6	6	9
(100 m upstream)	MCC-2											6	6								
Steepbank River (mouth)	STR-1	3	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		6	6	7
Muskeg River																					
Mouth [f]	MUR-1			1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1				1
Upstream of Wapasu Creek	MUR-6								1,2		7	7	7		6	6	9		6	6	7

Waterbody and Location	Station	2002 W	2002 S	2002 S	2002 F	2003 W	2003 S	2003 S	2003 F	2004 W	2004 S	2004 S	2004 F	2005 W	2005 S	2005 S	2005 F	2006 W	2006 S	2006 S	2006 F
Athabasca River																					
Upstream of Fort McMurray (grab) [a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC				3				3				1				1	1			1
(west bank) [b]	ATR-DC-W				1				1				1				1				1
(east bank) [b]	ATR-DC-E				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-FC-CC-D																				
(west bank) [b c]	ATR-FC-W				1				1												
(east bank) [b c]	ATR-FC-E				1				1												
(middle)	ATR-FC-M																				
Downstream of all development (cross channel)	ATR-DD-CC	1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1					
(east bank)	ATR-DD-E													1	1	1	1	1	1	1	1
(west bank)	ATR-DD-W													1	1	1	1	1	1	1	1
Upstream of mouth of Firebag River	ATR-FR-CC				1				1				1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER												1								
Embarras River	EMR-1								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								1				1								
Athabasca River tributaries (Eastern)																					
McLean Creek (mouth)	MCC-1		6	6	7		6	6	7		6	6	9		7	7	9		6	6	9
(100 m upstream)	MCC-2																				
Steepbank River (mouth)	STR-1	1			1				1				1				1				1
(upstream of Project Millennium)	STR-2	1			1				1				1				1				1
(upstream of Nt. Steepbank)	STR-3									1	1	1	1	1	1	1	1		1	1	1
North Steepbank River (upstream of Suncor Lewis)	NSR-1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
Fort Creek (mouth)	FOC-1		6	6	7		6	6	7										6	6	7
Muskeg River																					
Mouth [f]	MUR-1				1				1				1				1				1
Upstream of Wapasu Creek	MUR-6		6	6	7		6	6	7		6	6	7		6	6	7		6	6	7

Waterbody and Location	Station	2007 W	2007 S	2007 S	2007 F	2008 W	2008 S	2008 S	2008 F	2009 W	2009 S	2009 S	2009 F	2010 W	2010 S	2010 S	2010 F
Athabasca River																	
Upstream of Fort McMurray (grab) [a]	ATR-UFM	13	11	13	11	11	13	11	13	11	13	11	13	11	13	11	13
Upstream Donald Creek (cross channel)	ATR-DC-CC				1												
(west bank) [b]	ATR-DC-W				1	1			1	1			1	1	1	1	1
(east bank) [b]	ATR-DC-E				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
(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-FC-CC-D																
(west bank) [b c]	ATR-FC-W																
(east bank) [b c]	ATR-FC-E																
(middle)	ATR-FC-M																
Downstream of all development (cross channel)	ATR-DD-CC																
(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-CC				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
Athabasca River Delta																	
Big Point Channel [e]	ARD-1																
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1				9				1				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
(upstream of Nt. Steepbank)	STR-3	1	1	1	1				1				1				1
North Steepbank River (upstream of Suncor Lewis)	NSR-1				1				1				1				1
Fort Creek (mouth)	FOC-1				7		6	6	7		6	6	7				1
Muskeg River																	
Mouth [f]	MUR-1				1				1				1				1
Upstream of Wapasu Creek	MUR-6				7		6	6	7				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)
Frozen to depth (sampling was planned but impossible because of freezing)

√ = allowance made for potential TIE

Table 3.1-5 (Cont'd.) (Page 2 of 2)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
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
Jackpine Creek (mouth) [g]	JAC-1					13	13	13	11	13	13	13	11,1				1				1				1				1
(upper)	JAC-2																												
Shelley Creek (mouth)	SHC-1								11				11,1																
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1				1				1
Stanley Creek (mouth)	STC-1								11				11,1								1	1	1	1	1	1	1	1	1
Iyinimin Creek (mouth)	IYC-1																												
Wapasu Creek (Canterra Road Crossing)	WAC-1								11,2	1			11,1																
Athabasca River tributaries (Western)																													
Poplar Creek (mouth)	POC-1																1				1				1				1
Beaver River (mouth)	BER-1																											1	1
(upper)	BER-2																												
MacKay River (mouth)	MAR-1								1								1				1	1			1				1
(upstream of Suncor MacKay)	MAR-2																					1			1	1	1	1	1
(mid-river, upstream of Suncor Dover)	MAR-2A																												
Dunkirk River (Fish program support)	DUR-1																												
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11					1	1	2	1	1	1	2
(upstream of Total Joslyn Mine)	ELR-2														11	11	11	14											
(upstream of the Fort MacKay water intake)	ELR-2A																												
Tar River (mouth)	TAR-1						1	1	1														1	1	2	1	1	1	2
(upstream of Canadian Natural Horizon)	TAR-2																												
Calumet River (mouth)	CAR-1																						1	1	2	1	1	1	2
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2																												
Firebag River (mouth)	FIR-1																					1	1	1	1	1	1	1	1
(upstream of Suncor Firebag)	FIR-2																					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
(upstream of Christina River)	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8
Christina River (upstream of Fort McMurray)	CHR-1																					1	1	1	3	1	1	1	3
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3
(mid)	CHR-2A																												
Hangingstone River (upstream of Fort McMurray)	HAR-1																												
Horse River (Fish program support)	HOR-1																												
Lake Tributaries																													
Mills Creek	MIC-1																												
Wetlands (Lakes)																													
Kearl Lake (composite)	KEL-1							16+3	16+3								16+3			16	16				1	1			1
Isadore's Lake (composite)	ISL-1							16									16			16	16								
Shipyard Lake (composite)	SHL-1							16			1	16	1			16	1			16	16			16	16			1	1
McClelland Lake (composite)	MCL-1																16			1	16				1				1
Additional Sampling (Non-Core Programs)																													
Unnammed Creek north of Ft. Creek (mouth)	UNC-1																1												
Nexen Lakes	-																		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

Waterbody and Location	Station	2004				2005				2006				2007				2008				2009				2010			
		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	4	10	10	10																								
Jackpine Creek (mouth) [g]	JAC-1		1	1	1				1				1				1				1				1				2
(upper)	JAC-2																				1				1				2
Shelley Creek (mouth)	SHC-1												1				1								1				
Muskeg Creek (mouth)	MUC-1	1	1	1	1				1				1				1	1	1	1	1								
Stanley Creek (mouth)	STC-1	1	1	1	1	1	1	1	1				1				1				1				1				1
Iyinimin Creek (mouth)	IYC-1															1	1				1								1
Wapasu Creek (Canterra Road Crossing)	WAC-1				1				1				1				1				1				1				1
Athabasca River tributaries (Western)																													
Poplar Creek (mouth)	POC-1				1				1				1				1				1				1				1
Beaver River (mouth)	BER-1			1	1			1	1				1				1	1			1				1				1
(upper)	BER-2																		1	1	1	1	1	1	1	1	1	1	1
MacKay River (mouth)	MAR-1	1	1	1	1				1				1				1	1	1	1	1	1	1	1	1				1
(upstream of Suncor MacKay)	MAR-2				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	1	1	1	1
Dunkirk River (Fish program support)	DUR-1																								1				
Ells River (mouth)	ELR-1	1	1	1	2	1	1	1	2				1				1				1				1				1
(upstream of Total Joslyn Mine)	ELR-2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1				1				1				1
(upstream of the Fort MacKay water intake)	ELR-2A																												1
Tar River (mouth)	TAR-1	1	1	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	1	1	2	1	1	1	2				1		1	1	1				1
Calumet River (mouth)	CAR-1	1	1	1	2	1	1	1	2				1				1				1				1				1
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2					1	1	1	2	1	1	1	2	1	1	1	2				1				1				1
Firebag River (mouth)	FIR-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
Athabasca River tributaries (Southern)																													
Clearwater River (upstream of Fort McMurray)	CLR-1	1	7	7	7	1	7	7	7	1	7	7	7		7	7	7				1				1				1
(upstream of Christina River)	CLR-2	1	7	7	7	1	7	7	7		6	6	7		6		7				1				1				1
Christina River (upstream of Fort McMurray)	CHR-1	1	1	1	3	1	1	1	1				1	1			1				1				1				1
(upstream of Janvier)	CHR-2	1	1	1	3	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	1	1				1								
Horse River (Fish program support)	HOR-1																								1				
Lake Tributaries																													
Mills Creek	MIC-1																												1
Wetlands (Lakes)																													
Kearl Lake (composite)	KEL-1			16	16			16	16				16			16	16				16				16				16
Isadore's Lake (composite)	ISL-1			16	16			16	16			16	16			16	16			16	16				16				16
Shipyard Lake (composite)	SHL-1			16	16			16	16			16	16			16	16			16	16				16				16
McClelland Lake (composite)	MCL-1												16				16				16				1				16
Additional Sampling (Non-Core Programs)																													
Unnammed Creek north of Ft. Creek (mouth)	UNC-1																												
Nexen Lakes	-			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

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)
Frozen to depth (sampling was planned but impossible because of freezing)

√ = allowance made for potential TIE

3.1.3 Benthic Invertebrate Communities and Sediment Quality

3.1.3.1 Overview of Benthic Invertebrate Communities Component 2010 Monitoring Activities

Benthic invertebrates were collected from September 4 to 26, 2010. A total of 255 samples were collected from 23 river reaches and four lakes (Table 3.1-6, Figure 3.1-4). As in previous years, river-reach samples were collected in the dominant habitat type found in each reach (Table 3.1-6). 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). These habitat classes do not change from year to year within a reach, so sampling methods used within any reach are the same across sampling events.

3.1.3.2 Field Methods

Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003, 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.

Water levels were high in early September in many of the river reaches because of consistent and heavy rains in the month of August in the Fort McMurray area. Most of the erosional reaches (MacKay River, Steepbank River, upper Firebag River) were high enough that the Neill-Hess cylinder was overtopped, effectively compromising sample integrity (overtopping of the cylinder causes organisms to be flushed from the sample). Sampling of these three rivers was; therefore, postponed until late September when water levels had significantly subsided. Regardless of the receded water levels, there were some replicate stations within reaches where water levels were still too high for correct use of the Neill-Hess cylinder. For those locations, and to avoid not collecting a sample, a D-framed net was used to a collect a "qualitative" kick sample. The protocol used to collect the kick sample following the federal CABIN methodology (Reynoldson *et al*. 2004). Because kick net samples can be collected in many conditions and environments, and because it was considered possible that future sampling of erosional reaches might again be made difficult by high water levels, it was considered appropriate to collect kick net samples synoptically with some Neill-Hess cylinder samples for comparative purposes.

Kick net samples from a station were collected using the following general method. The operator walked and kicked substrate along transects, for three minutes, in a zig-zag fashion, walking from the river's wetted perimeter towards mid channel to a maximum depth of ~ 1 m. Debris produced from kicking was collected in a D-framed net with 400 µm mesh.

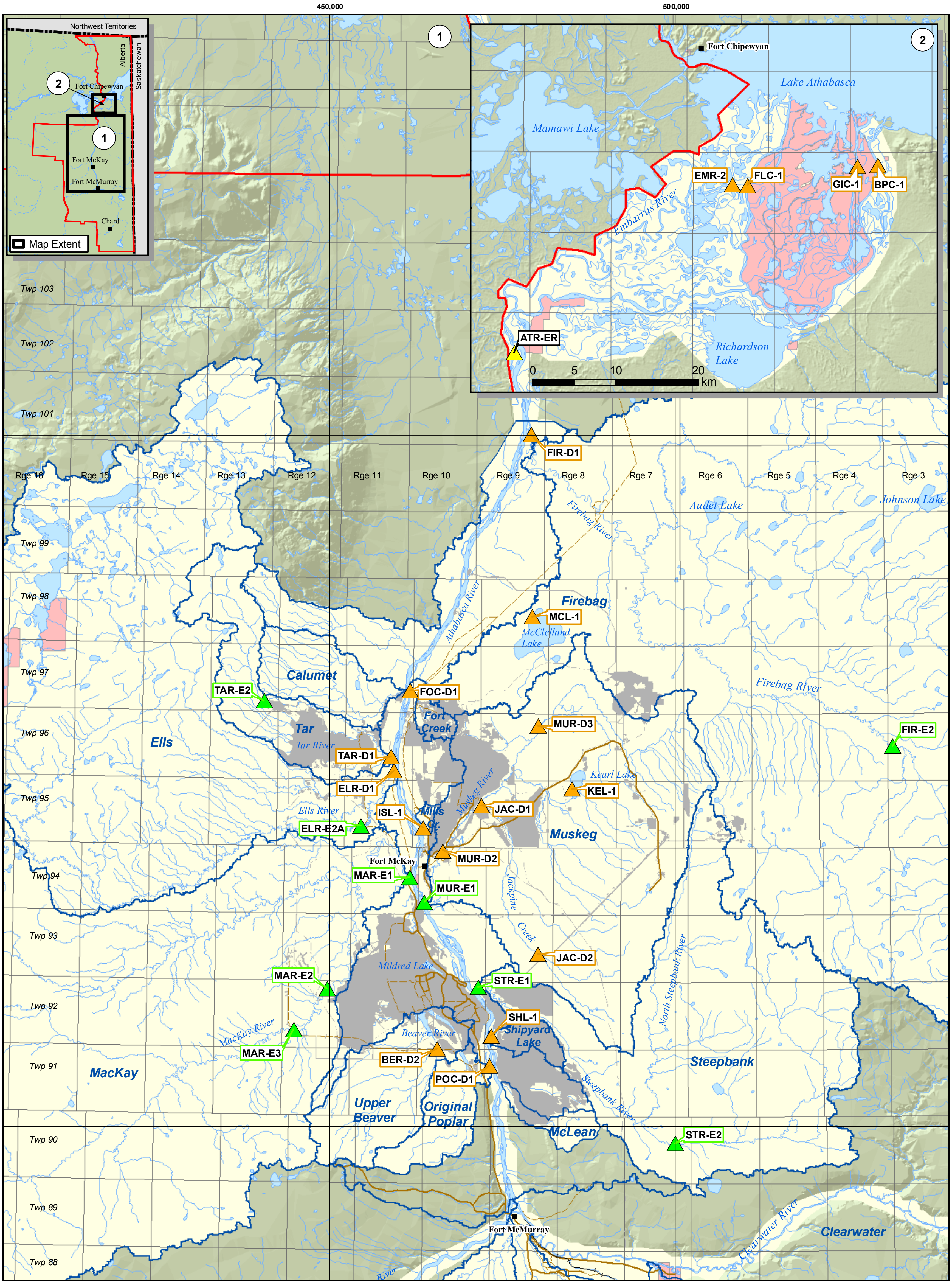
Table 3.1-6 Summary of sampling locations for the RAMP 2010 Benthic Invertebrate Communities component.

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-1	509623	6494028		
Big Point Channel	depositional	FLC-1	512095	6494150		
Fletcher Channel	depositional	GIC-1	496391	6491685		
Embarras River	depositional	EMR-2	494552	6491828		
Steepbank River						
Lower Reach	erosional	STR-E1	471390	6320166	472580	6320179
Upper Reach	erosional	STR-E2	499889	6297605	501116	6297774
Muskeg River						
Lower Reach	erosional	MUR-E1	463616	6332484	464545	6332283
Middle Reach	depositional	MUR-D2	466337	6339834	466551	6340419
Upper Reach	depositional	MUR-D3	480075	6357945	482144	6359791
Jackpine Creek						
Lower Reach	depositional	JAC-D1	471861	6346435	473065	6346315
Upper Reach	depositional	JAC-D2	480029	6324946	480793	6324600
Beaver River						
Upper Reach	depositional	BER-D2	465477	6311276	465192	6311015
Poplar Creek						
Lower Reach	depositional	POC-D1	473030	6308789	472727	6308501
MacKay River						
Lower Reach	erosional	MAR-E1	461544	6336052	460602	6336714
Middle Reach	erosional	MAR-E2	449586	6319964	448836	6318843
Upper Reach	erosional	MAR-E3	444758	6314052	443352	6314110
Tar River						
Lower Reach	depositional	TAR-D1	458850	6353534	458660	6353692
Upper Reach	erosional	TAR-E2	440495	6361644	439875	6362143
Ells River						
Lower Reach	depositional	ELR-D1	459253	6351523	458689	6351578
Upper Reach	erosional	ELR-E2A	454478	6343542	453560	6344179
Firebag River						
Lower Reach	depositional	FIR-D1	479054	6400137	479466	6397396
Upper Reach	erosional	FIR-E2	531292	6355078	531927	6355418
Fort Creek						
Lower Reach	depositional	FOC-D1	461564	6363103	461641	6363087
Lakes[2]						
Kearl Lake	lake	KEL-1	484939	6348866		
McClelland Lake	lake	MCL-1	479218	6373774		
Shipyard Lake	lake	SHL-1	473294	6313090		
Isadore's Lake	lake	ISL-1	463493	6343245		

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

[2] UTM coordinates of first replicate station.

Figure 3.1-4 Locations of RAMP benthic invertebrate community reaches and sediment quality sampling stations, 2010.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Land Change Area as of 2010
- Benthic Invertebrate Communities Sampling Reach
- Benthic Invertebrate Communities Sampling Reach and Sediment Quality Sampling Station
- Sediment Quality Sampling Station

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 Modified from Cumulative Environmental Management Association (CEMA).
d) and Change Areas Delineated from 10m SPOT-5 (June, July, and August 2010) and 30m Landsat-5 (October 2010) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP Regional Aquatics Monitoring Program

0 5 10 20 Km
Scale 1:600,000
Projection: UTM Zone 12 NAD83

K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_G_BenthosSed_20110318.mxd

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 replicate 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 replicate 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) 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.

3.1.3.3 Changes in Monitoring Network from 2009

Benthic invertebrates were collected from the Embarras River (*test* reach EMR-2) and from *baseline* reaches of the MacKay River (MAR-E3) and the Ells River (ELR-E2A) for the first time in 2010.

3.1.3.4 Challenges Encountered and Solutions Applied

Water levels were high in the upper, middle and lower Mackay River, upper and lower Steepbank River, and upper Firebag River during the early part of September. Water levels in those reaches were generally deeper than the height of the Neill-Hess cylinder. These six reaches were; therefore, re-visited in late September after water levels had receded somewhat and to levels below which the Neill-Hess cylinder could collect a valid sample. Samples were also collected with D-framed dip nets (400 µm mesh), from these reaches, following the federal CABIN protocol (see Section 3.1.3.2).

3.1.3.5 Other Information Obtained

As described above, samples of benthic invertebrates were collected using D-framed kick nets in late September from six erosional reaches where water levels had been high in early September. The samples were collected synoptically with Neill-Hess cylinder samples collected in late September. These data will help demonstrate the comparability of the two sampling methods. In the event that water levels are too high in future surveys, kick net sampling may be the only possible means of collecting a benthic sample. The data collected in 2010 may establish the means by which the kick and Neill-Hess samples are comparable. Results of this study are presented in Section 6.

3.1.3.6 Summary of Component Data Now Available

As of 2010, 2,526 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 3.1-7.

3.1.3.7 Overview of Sediment Quality Component 2010 Monitoring Activities

Sediment samples were collected from September 7 to 15, 2010 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 3.1-8, Figure 3.1-4).

3.1.3.8 Summary of Field Methods and Sample Shipping and Analysis

Sediment sampling locations were identified using 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.

Table 3.1-7 Summary of RAMP data available for the Benthic Invertebrate Communities component. (Page 1 of 2)

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009				2010			
				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	W	S	S	F
Athabasca River Delta																																																									
Athabasca River Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1								1				1				1				1
Embarras River	1	depositional	EMR-2																																																								1
Calumet River																																																									
Lower Reach	1,2[1]	depositional	CAR-D1																				2				1				1				1				1																1				
Upper Reach	1	depositional	CAR-D2																												1				1				1				1												1				
Christina River																																																									
Lower Reach	1	depositional	CHR-D1																								1				1				1				1				1				1								1				
Middle Reach	1	erosional	CHR-E2A																																												1												
Upper Reach	1	depositional	CHR-D2																								1				1				1				1				1												1				
Clearwater River																																																									
Downstream of Christina River	1	depositional	CLR-D1																				1				1				1				1				1												1								
Upstream of Christina River	1	depositional	CLR-D2																				1				1				1				1				1												1								
Ells River																																																									
Lower Reach	1	depositional	ELR-D1																												1				1				1				1				1												1
Middle Reach	1	erosional	ELR-E2																												1				1				1				1																
Upper Reach	2	erosional	ELR-E2A																																																								1
Firebag River																																																									
Lower Reach	1	erosional	FIR-D1																												1				1				1				1				1												1
Upper Reach	1	depositional	FIR-E2																												1				1				1				1				1												1
Fort Creek																																																									
Lower Reach	1	depositional	FOC-D1												2								1				1				1								1				1				1				1								1
Hangingstone River																																																									
Lower Reach	1	erosional	HAR-E1																																1				1				1				1				1								
Jackpine Creek																																																									
Lower Reach	1	depositional	JAC-D1																								1				1				1				1				1				1				1				1				1
Upper Reach	1	depositional	JAC-D2																												1				1				1				1				1				1				1				1
MacKay River																																																									
Lower Reach	1	erosional	MAR-E1																1				1				1				1				1				1				1				1				1				1				1
Middle Reach	1	erosional	MAR-E2																								1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	MAR-E3																																																							1
Muskeg River																																																									
Lower Reach	1	erosional	MUR-E1																1				1				1				1				1				1				1				1				1				1				1
Middle Reach	1	depositional	MUR-D2																1				1				1				1				1				1				1				1				1				1				1
Upper Reach	1	depositional	MUR-D3																								1				1				1				1				1				1				1				1				1
Steepbank River																																																									
Lower Reach	1	erosional	STR-E1																1				1				1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	STR-E2																												1				1				1				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, but 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

Table 3.1-7 (Cont'd.) (Page 2 of 2)

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003			
				W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Tar River																															
Lower Reach	1[1]	depositional	TAR-D1																				2				1				1
Historical Upper Reach	1	erosional	TAR-E1																												1
Upper Reach	1	erosional	TAR-E2																												
Beaver River																															
Lower Reach	1	depositional	BER-D2																												
Poplar Creek																															
Lower Reach	1	depositional	POC-D1																												
Wetlands and Lakes																															
Isadore's Lake	1	lake	ISL-1																												
Kearl Lake	1	lake	KEL-1																				1				1				1
McClelland Lake	1	lake	MCL-1																								1				1
Shipyard Lake	1	lake	SHL-1																1				1				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																				

WATERBODY AND LOCATION	2004				2005				2006				2007				2008				2009				2010			
	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
Tar River																												
Lower Reach				1				1				1												1				1
Historical Upper Reach				1				1				1																
Upper Reach																								1				1
Beaver River																												
Lower Reach																				1				1				1
Poplar Creek																												
Lower Reach																				1				1				1
Wetlands and Lakes																												
Isadore's Lake												1				1				1				1				1
Kearl Lake				1				1				1				1				1				1				1
McClelland Lake												1				1				1				1				1
Shipyard Lake				1				1				1				1				1				1				1
Historical Data																												
Historical Data Review																												
5-Year Summary Report																												
Summary Report																												
Locations No Longer in Sample Design																												
Athabasca River																												
Near Fort Creek (east bank)																												
(west bank)																												
Near Donald Creek (east bank)																												
(west bank)																												
Suncor near-field monitoring																												
MacKay River																												
200 m upstream of mouth																												
500 m upstream of mouth																												
1.2 km upstream of mouth																												
Muskeg River																												
50 m upstream of mouth																												
200 m upstream of mouth																												
450 m upstream of mouth																												
Steepbank River																												
50 m upstream of mouth																												
150 m upstream of mouth																												
300 m upstream of mouth																												

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, but 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

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.

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). Metals were analyzed using ICP/MS. PAHs were analyzed using a high-resolution GC/MS method.

Sediments were analyzed for the RAMP standard sediment quality variables (Table 3.1-9), with tests of sediment toxicity to aquatic organisms at a selection of stations sampled. Sediment toxicity tests are conducted at a minimum of every three years at each station and annually for some stations and all the stations in the Athabasca River Delta. Sediment toxicity tests followed published Environment Canada protocols (Environment Canada 2010).

A full list of analytical methods and detection limits for sediment quality variables measured by RAMP in 2010 appears in Appendix E.

3.1.3.9 Changes in Monitoring Network from 2009

Given the three-year sampling rotation, *test* stations ELR-D1 (lower reach on the Ells River), FOC-D1 (mouth of Fort Creek), and FIR-D1 (lower reach on the Firebag River) were sampled in 2010 and not in 2009, and stations CHR-D1 (lower reach on the Christina River), CHR-D2 (upper reach on the Christina River), CAR-D1 (lower reach on the Calumet River), and CAR-D2 (upper reach on the Calumet River) were not sampled in 2010. *Test* station EMR-2 (Embarras River) was added to the sampling network in 2010.

3.1.3.10 Challenges Encountered and Solutions Applied

No challenges were encountered during the Sediment Quality component sampling program in fall 2010.

3.1.3.11 Other Information Obtained

No additional sediment quality information for 2010 was obtained.

3.1.3.12 Summary of Component Data Now Available

Table 3.1-10 summarizes historical sediment quality sampling undertaken by RAMP since 1997.

Table 3.1-8 Summary of sampling for the RAMP Sediment Quality component, September 2010.

Station Identifier and Location		UTM Coordinates (NAD83, Zone12) Easting	Northing	Analytical Package
Athabasca River				
ATR-ER	Athabasca River at Embarras River	468325	6471539	3
Athabasca Delta				
FLC-1	Fletcher Channel	496391	6491685	3
GIC-1	Goose Island Channel	509623	6494028	3
BPC-1	Big Point Channel	512095	6494150	3
Embarras River				
EMR-2	Embarras River	494552	6491828	3
Tributaries to the Athabasca River (Eastern)				
FIR-D1	Firebag River (lower reach)	479054	6400137	3
FOC-D1	Fort Creek	461564	6363103	3
Tributaries to the Athabasca River (Western)				
BER-D2	Beaver River (upper reach)	465477	6311276	3
ELR-D1	Ells River (lower reach)	459253	6351523	3
TAR-D1	Tar River (lower reach)	458850	6353534	3
POC-D1	Poplar Creek	473030	6308789	1
Muskeg River				
MUR-D2	Muskeg River (middle reach)	466337	6339834	1
MUR-D3	Muskeg River (upper reach)	480075	6357945	1
JAC-D1	Jackpine Creek (lower reach)	471861	6346435	3
JAC-D2	Jackpine Creek (upper reach)	480029	6324946	3
Regional Lakes				
KEL-1	Kearl Lake	484939	6348866	1
MCL-1	McClelland Lake	479218	6373774	1
SHL-1	Shipyard Lake	473294	6313090	1
ISL-1	Isadore's Lake	463493	6343245	1
QA/QC				
-	Two sets of split and duplicate samples			1
-	Two rinsate blanks			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*)

Table 3.1-9 RAMP standard sediment quality variables.

Group	Sediment Quality Variable	
Physical variables	Percent sand Percent silt	Percent clay Moisture content
Carbon content	Total inorganic carbon Total organic carbon Total carbon	
Total metals	Aluminum Arsenic Barium Beryllium Boron Cadmium Calcium Chromium Cobalt Copper Iron Lead Magnesium	Manganese Mercury Molybdenum Nickel Potassium Selenium Silver Sodium Strontium Thallium Uranium Vanadium 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 Acenaphthylene Anthracene Benzo(a)anthracene/chrysene Benzo(a)pyrene Benzofluoranthenes Benzo(g,h,i)perylene Biphenyl	Dibenzo(a,h)anthracene Dibenzothiophene Fluoranthene Fluorene Indeno(c,d-123)pyrene Naphthalene Phenanthrene Pyrene
Alkylated PAHs	C1-substituted acenaphthene C1-substituted benzo(a)anthracene/chrysene C2-substituted benzo(a)anthracene/chrysene C1-substituted biphenyl C2-substituted biphenyl C1-substituted 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)[2]	
Sublethal toxicity testing	Survival and growth of the amphipod *Hyalella azteca* Survival and growth of *Chironomus tentans* midge larvae	

[1] Details of analytical methods and detection limits appear in Appendix E.

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

Table 3.1-10 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				2010			
		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	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				3
Athabasca Delta / Lake Athabasca																																																									
Delta composite [c]	ARD-1												3				3																																								
Big Point Channel	BPC-1												3				3				3				3				3								1								1				3				3				3
Goose Island Channel	GIC-1																				3				3				3								1								1				3				3				3
Fletcher Channel	FLC-1																				3				3				3								1								1				3				3				3
Flour Bay	FLB-1																3																																								
Embarras River																																																									
Embarras River	EMR-2																																				1																				3
Athabasca River Tributaries (South of Fort McMurray)																																																									
Clearwater River (upstream of Fort McMurray)	CLR-1/CLR-D1																				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-D1																																								3				1								3				
benthic reach at upper Christina River)	CHR-D2																																								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-D2																																																3				3				3
Poplar Creek (mouth)	POC-1/POC-D1				1																				3								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 3.1-10 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Tributaries (North of Fort McMurray) (cont'd)																													
Ells River (mouth)	ELR-1								1																3				3
(benthic reach at mouth)	ELR-D1																												
(upstream of Total Joslyn Mine)	ELR-2																												
Tar River (mouth)	TAR-1								1																3				3
(benthic reach at mouth)	TAR-D1																												
(upstream of Canadian Natural Horizon)	TAR-2																												
Calumet River (mouth)	CAR-1																								3				
(benthic reach at mouth)	CAR-D1																												
(upstream of Canadian Natural)	CAR-2																												
(benthic reach at upper Calumet)	CAR-D2																												
Fort Creek (mouth)	FOC-1																1								3				
(benthic reach at mouth)	FOC-D1																												
Firebag River (mouth)	FIR-1																								3				3
(benthic reach at mouth)	FIR-D1																												
(upstream of Suncor Firebag)	FIR-2																								3				3
Muskeg River																													
Mouth	MUR-1				1				1				3				1				1				3				3
1 km upstream of mouth	MUR-1b																1												1
Upstream of Canterra Road Crossing	MUR-2																1												3
Upstream of Jackpine Creek	MUR-4				1												1												1
Upstream of Muskeg Creek	MUR-5																1												1
Upstream of Stanley Creek	MUR-D2																												3
Upstream of Wapasu Creek	MUR-6																1												1
(benthic reach - downstream of Jackpine Creek)	MUR-D2																												
(benthic reach - upstream of Stanley Creek)	MUR-D3																												
Muskeg River Tributaries																													
Jackpine Creek (mouth)	JAC-1				1																								
(benthic reach at mouth)	JAC-D1																												
(benthic reach at upper Jackpine Creek)	JAC-D2																												
Stanley Creek (mouth)	STC-1																												1
Wetlands																													
Kearl Lake (composite)	KEL-1																				1								
Isadore's Lake (composite)	ISL-1																				1								
Shipyard Lake (composite)	SHL-1																				1				3				1
McClelland Lake (composite)	MCL-1																								1				1
Additional Sampling (Non-Core Programs)																													
Potential TIE	-																				√								
QA/QC																													
One split and one duplicate sample	-																1				1				1				1

Waterbody and Location	Station	2004				2005				2006*				2007				2008				2009				2010			
		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				3				1																				
(benthic reach at mouth)	ELR-D1												3				3												3
(upstream of Total Joslyn Mine)	ELR-2				3				1																				
Tar River (mouth)	TAR-1				1				1																				
(benthic reach at mouth)	TAR-D1												3												3				3
(upstream of Canadian Natural Horizon)	TAR-2				1				1																				
Calumet River (mouth)	CAR-1				3				3																				
(benthic reach at mouth)	CAR-D1																								3				
(upstream of Canadian Natural)	CAR-2								3																				
(benthic reach at upper Calumet)	CAR-D2												3												3				
Fort Creek (mouth)	FOC-1																												
(benthic reach at mouth)	FOC-D1								3				3				3				3								3
Firebag River (mouth)	FIR-1				1				1																				
(benthic reach at mouth)	FIR-D1												3				1												3
(upstream of Suncor Firebag)	FIR-2				1				1																				
Muskeg River																													
Mouth	MUR-1				3																								
1 km upstream of mouth	MUR-1b																												
Upstream of Canterra Road Crossing	MUR-2				3				3																				
Upstream of Jackpine Creek	MUR-4																												
Upstream of Muskeg Creek	MUR-5																												
Upstream of Stanley Creek	MUR-D2				3				3																				
Upstream of Wapasu Creek	MUR-6																												
(benthic reach - downstream of Jackpine Creek)	MUR-D2												3				3				3				1				1
(benthic reach - upstream of Stanley Creek)	MUR-D3												3				3				3				1				1
Muskeg River Tributaries																													
Jackpine Creek (mouth)	JAC-1				3																								
(benthic reach at mouth)	JAC-D1												3				1				3				3				3
(benthic reach at upper Jackpine Creek)	JAC-D2												3				1				3				3				3
Stanley Creek (mouth)	STC-1																												
Wetlands																													
Kearl Lake (composite)	KEL-1				1								3				3				3				1				1
Isadore's Lake (composite)	ISL-1												3				3				3				1				1
Shipyard Lake (composite)	SHL-1				3								3				3				3				1				1
McClelland Lake (composite)	MCL-1												3				3				3				1				1
Additional Sampling (Non-Core Programs)																													
Potential TIE	-																												
QA/QC																													
One split and one duplicate sample	-				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)

3.1.4 Fish Populations Component

3.1.4.1 Overview of 2010 Monitoring Activities

The following monitoring activities were conducted in 2010 for the Fish Populations component:

- Spring, summer, and fall fish inventories on the Athabasca and Clearwater rivers;
- Trout-perch sentinel species program using lethal sampling methods on the Athabasca River (fall sampling); and
- Tissue analyses on target fish species in three regional lakes: Keith Lake, Net Lake, and Brutus Lake (fall sampling).

Table 3.1-11 summarizes the watercourses sampled and the target fish species for each monitoring activity; sampling locations are presented in Figure 3.1-5. Common and scientific names for each fish species noted in this report are listed in Appendix F.

Table 3.1-11 Summary of 2010 Fish Populations component monitoring activities.

Watercourse	Fish Populations Component Activity		
	Fish Inventory	Fish Tissue	Sentinel Species
Athabasca River	spring, summer and fall, fish community		fall, trout-perch
Clearwater River	spring, summer and fall, fish community		
Regional Lakes (Keith, Net, Brutus lakes)		fall, lake whitefish, walleye and northern pike	

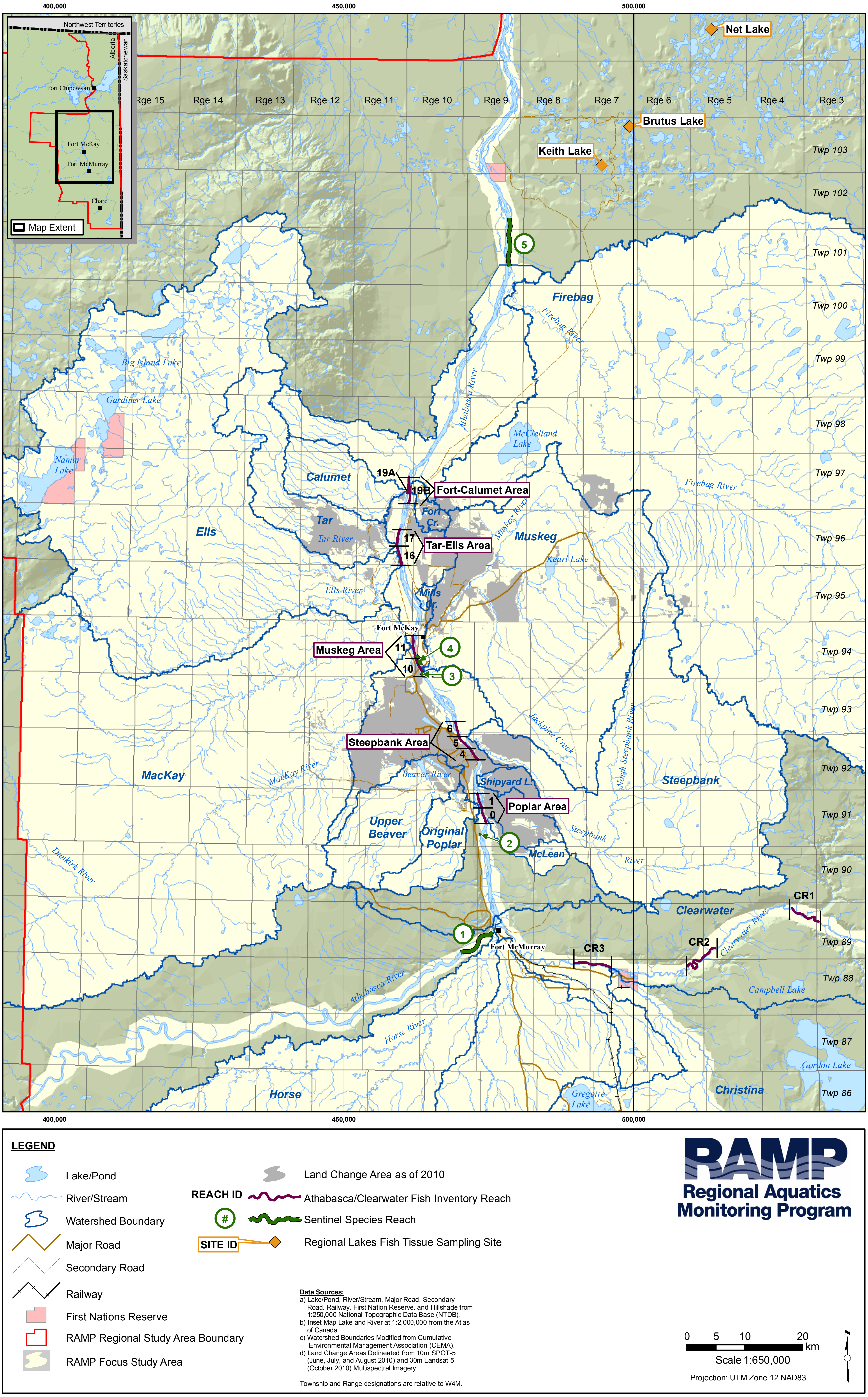
3.1.4.2 Summary of Field Methods

Athabasca River and Clearwater River Fish Inventories

The objectives of the 2010 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.

Figure 3.1-5 Locations of RAMP fish monitoring activities for the 2010 Fish Populations component.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_H_Fish_20110318.mxd

In 2010, 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:

- Goldeye (*Hiodon alosoides*);
- Longnose sucker (*Catostomus catostomus*);
- Northern pike (*Esox lucius*);
- Lake whitefish (*Coregonus clupeaformis*) (Athabasca River only);
- Walleye (*Sander vitreus*); and
- White sucker (*Catostomus commersoni*).

Spring, summer, and fall sampling was conducted between May 10 and June 1, 2010, July 26 and August 6, 2010, and September 20 and October 1, 2010, respectively. Six 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. (Table 3.1-12, Figure 3.1-5). 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 (Table 3.1-12, Figure 3.1-5).

Sampling was primarily conducted on both rivers 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 F) 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.

Table 3.1-12 Fish inventory sampling locations on the Athabasca and Clearwater rivers, 2010.

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[1]	CR1A	531982 E / 6288505 N	529592 E / 6289549 N
		CR1B	529592 E / 6289549 N	527714 E / 6291560 N
Clearwater River	CR2[1]	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

[1] Reaches CR1 and CR2 are designated as *baseline*. All other reaches are designated as *test*.

The total number of abnormalities was calculated by season for all species and compared against previous sampling years. An external pathology assessment was completed by calculating the percentage of pathological abnormalities, including body deformities, growths, tumors, and parasites from the total number of fish captured for all species by year and for all species combined.

Fish Tag Return Assessment

Tagging of key indicator fish species has been a part of the Fish Populations 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.

Regional Lakes Fish Tissue Studies

In 2010, tissue studies were performed on a subsample of fish captured during Alberta Sustainable Resource Development's (ASRD's) fall walleye index netting program (FWIN) (lake whitefish, walleye and northern pike) in three regional lakes: Brutus Lake, Net Lake, and Keith Lake located in the Richardson backcountry north of Fort McMurray (Figure 3.1-5).

Sampling in the lakes took place between September 14 and September 18, 2010 by ASRD. A target of 25 walleye, 25 northern pike, and 25 lake whitefish was set for mercury tissue analysis, with a specific target 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 in 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 all three lakes for tissue analysis for mercury is provided in Table 3.1-13.

Fish were collected by ASRD using experimental multi-mesh gill nets, sacrificed, measured 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 later sampled for mercury analysis. Ageing structures were taken from each individual fish 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-labeled, 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 (Fort McMurray) before being shipped on dry ice to Flett Research Ltd. (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.

Table 3.1-13 Number of lake whitefish, walleye and northern pike capture in each size class for fish tissue analyses of mercury, regional lakes program, 2010.

Lake	Species	Size Class (mm)				
		200-300	301-400	401-500	501-600	601-700
Keith Lake	Lake whitefish	2	6	0	0	0
	Walleye	0	0	0	0	0
	Northern pike	0	0	1	2	1
Net Lake	Lake whitefish	2	6	4	0	0
	Walleye	6	4	8	1	0
	Northern pike	0	1	3	3	1
Brutus Lake	Lake whitefish	2	8	1	0	0
	Walleye	6	4	7	2	0
	Northern pike	0	0	1	5	2

Sentinel Fish Species Monitoring on the Athabasca River

The objective of the sentinel species monitoring program in 2010 was to monitor potential changes in the trout-perch population due to stressors resulting from focal project development by assessing growth, reproduction, and condition. Similar to 2002, sentinel species monitoring in 2010 was carried out at five sites on the Athabasca River (Table 3.1-14 and Figure 3.1-5). A sentinel species program was also completed in 1999 at three of the five sites. Sites ATR-3, ATR-4, and ATR-5 are designated as *test*, while the remaining two sites, ATR-1 and ATR-2 are designated as *baseline*. Trout-perch (*Percopsis omiscomaycus*) was the target sentinel fish species with a target of 40 males and 40 females to be captured per site.

Sampling on the Athabasca River was carried out by a four-person field crew using a Coffelt VVP-15 boat electrofisher, with backpack electrofishers used as supporting methods. Sampling efforts focused on river margins deep enough to be accessible by boat, but shallow enough to provide suitable habitat for trout-perch. The boat electrofisher was configured with two anode boom arrays and multiple dropper cables. The boat's hull acted as the cathode. Electrofishing was performed in a downstream direction, and current was applied in 4 to 5 second bursts at a high frequency (i.e., to catch small-bodied fish) within the designated reach. Stunned trout-perch were captured downstream of the current using dip nets with a fine mesh net (6.35 mm mesh size) to ensure collection of all size classes.

Table 3.1-14 Athabasca River sentinel fish species monitoring sites, 2010.

Site Code	Site Description	UTM Coordinates (NAD 83, Zone 12)[1]
ATR-1	*Baseline* reach upstream of Fort McMurray to provide a baseline population not exposed to Sewage Treatment Plant (STP) discharge or oil sands development.	D/S: 475650 E / 6286679 N U/S: 470302 E / 6283093 N
ATR-2	*Baseline* reach downstream of STP but upstream of Suncor/Syncrude area.	D/S: 473534 E / 6303729 N U/S: 473477 E / 6303388 N
ATR-3	*Test* reach downstream of Suncor discharge and below Beaver River confluence to provide exposure to both Suncor/Syncrude operations.	D/S: 463707 E / 6330992 N U/S: 463407 E / 6331547 N
ATR-4	*Test* reach downstream of Muskeg River confluence and development in Muskeg River watershed.	D/S: 463263 E / 6332929 N U/S: 462534 E / 6334554 N
ATR-5	*Test* reach downstream of all tributary watersheds with oil sands developments (downstream of Firebag River confluence).	D/S: 478852 E / 6401786 N U/S: 478761 E / 6410216 N

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

At sites where shallow water did not permit sampling by boat electrofisher (i.e., reach ATR-1), crews fished using a Smith-Root 12B-POW battery-powered backpack electrofishing unit and a dip net (6.35 mm mesh size), which was placed downstream of the anode prior to and during application of electrical current.

Captured fish were held in large buckets filled with fresh water from the Athabasca River prior to their measurements and dissections. Measurements and dissections were conducted in a controlled lab facility to minimize potential error due to weather conditions. Individual trout-perch were sacrificed with a blow to the head and measured for total length (± 1.0 mm) and weight (± 0.01 g) using an electronic balance that was calibrated prior to each measurement. Dissection of fish was conducted using a scalpel and forceps were used to separate organs from the body. Upon dissection, sex and maturity were determined, and gonad development was classified as immature, maturing, mature, spawning or spent. The gonad tissue and liver were removed and weighed (± 0.001 g). Internal condition of liver, kidney, spleen, hindgut, amount of fat, presence of parasites, and gall bladder were examined (Appendix F).

Otoliths were removed as the ageing structure and stored in coin envelopes. Ageing structures were submitted to North/South Consultants (Winnipeg. MB).

Qualitative habitat assessments were conducted at each reach 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). Water quality was also measured using a YSI 650 meter at each reach and included *in situ* measurements of temperature (ºC), dissolved oxygen (% and mg/L), and specific conductance (µS/cm).

3.1.4.3 Changes in Monitoring Network from 2009

The 2010 Fish Populations component monitoring activities differed from those carried out during 2009 in the following ways:

- In 2009, three years of Muskeg River fish fence monitoring was completed successfully, as required by DFO. Therefore, this monitoring activity was not continued in 2010;
- Given the three-year sampling rotation, there was no fish tissue sampling conducted on the Athabasca or Clearwater rivers given these were last completed in 2008 and 2009, respectively;
- The regional lakes fish tissue program was implemented on Keith, Net, and Brutus lakes in 2010 as compared to Jackson Lake in 2009; and
- A lethal sentinel species monitoring program was conducted in 2010 on the Athabasca River using trout-perch as the target species as compared to a non-lethal tributary sentinel species program in 2009 using slimy sculpin as the target species.

3.1.4.4 Challenges Encountered and Solutions Applied

All monitoring activities implemented under the 2010 Fish Populations component were completed successfully without significant difficulties.

3.1.4.5 Other Information Obtained

A second year of the fish assemblage monitoring study was conducted in 2010. The methods, data analyses, and results of this study are presented in Section 6.

3.1.4.6 Summary of Component Data Now Available

Fish Populations component data collected to date by RAMP are summarized in Table 3.1-15.

Table 3.1-15 Summary of RAMP data available for the Fish Populations component.

WATERBODY AND LOCATION	REACH	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
Athabasca River																													
Poplar Area	0/1		1	1,5	1,5		1,6	1,5	1,3,6														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
Muskeg Area	10/11		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7					1						
Fort-Calumet Area	19[a]																												
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										
Reference site upstream of Ft. McMurray STP	ATR-1																								3				10
Reference site between STP and Suncor	ATR-2												1,3												3				10
Downstream of Suncor's Discharge	ATR-3												1,3												10,3				10
Below Muskeg River	ATR-4												1,3												10,3				10
Downstream of Development (near Firebag River)	ATR-5																												10,6
Athabasca River Tributaries																													
Fort Creek (mouth)															1,8,5,9	1													
Poplar Creek (mouth)	POC-F1																												
Beaver River (upper)	BER-F2																												
Tar River (mouth)	TAR-F1																												
Clearwater River Reach	CR1																										1		1
Clearwater River Reach	CR2																										1		1
Clearwater River Reach	CR3																										1	10	1
Christina River[i]																													
Ells River																													
Upper Ells River[i,h]	ELR-F2												1,3																
Lower Ells River[i,h]	ELR-F1												1,3																
MacKay River																													
Lower reach (85 km section from bridge to mouth)[j]	MAR-F1		1																				1					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				
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1												1,3						4		3		4		4		4		
Reference sites (Steepbank, Horse and Dunkirk rivers)	SR-R/HR-R/DR-R																3				3								
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																												
Jackpine Creek (accessable areas of lower creek)	JAC-F1														8					1				1					
Shelley Creek																													
Muskeg Creek (Canterra road crossing)[e]																							1,4		1,4				
Stanley Creek																													
Wapasu Creek (mouth or Canterra road)[e]																							1,4		1,4				
Steepbank River																													
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																									
Vicinity of Steepbank Mine	SR-E/STR-F1												1,3								3								
Baseline site in vicinity of Bitumin Heights	SR-R												1,3																
Upstream sentinel site[g]	SR-EC												1,3				3				3								
Sentinel baseline sites (Horse and Dunkirk rivers)																	3				3								
Regionally-Important Lakes																													
Various lakes in water/air emissions pathway																													6

WATERBODY AND LOCATION	REACH	2004				2005				2006				2007				2008				2009				2010			
		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		1		1		1		1		1		1		1		1		1	1	1,6		1	1	1		1	1	1
Steepbank Area	4[a]/5[a]/6		1		1		1		1,6		1		1		1		1		1	1	1,6		1	1	1		1	1	1
Muskeg Area	10/11		1		1		1		1,6		1		1		1		1		1	1	1,6		1	1	1		1	1	1
Tar-Ells Area	16/17		1		1		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		1	1	1
CNRL/TrueNorth Area (Fort/Asphalt reaches)																													
Reference Area - about 200 km upstream[b]	5/6																												
Reference Area - upstream of Fort McMurray[c]																													
Radiotelemetry study region[d]																													
Reference site upstream of Ft. McMurray STP	ATR-1															3	3												3
Reference site between STP and Suncor	ATR-2															3	3												3
Downstream of Suncor's Discharge	ATR-3															3	3												3
Below Muskeg River	ATR-4															3	3												3
Downstream of Development (near Firebag River)	ATR-5															3	3												3
Athabasca River Tributaries																													
Fort Creek (mouth)																													
Poplar Creek (mouth)	POC-F1																								10				
Beaver River (upper)	BER-F2																								10				
Tar River (mouth)	TAR-F1																								10				
Clearwater River Reach	CR1		1		1,6		1		1		1		1,6		1		1,6		1		1		1	1	1,6		1	1	1
Clearwater River Reach	CR2		1				1				1		1,6		1		1,6		1		1		1	1	1,6		1	1	1
Clearwater River Reach	CR3		1				1				1		1,6		1		1,6		1		1		1	1	1,6		1	1	1
Christina River[i]					1																								
Ells River																													
Upper Ells River[i,h]	ELR-F2		4		3		4		3							3	3												10
Lower Ells River[i,h]	ELR-F1		4		3		4		3							3	3												10
MacKay River																													
Lower reach (85 km section from bridge to mouth)[j]	MAR-F1		4																						10				
Muskeg River																													
Lower 35 km below Jackpine Creek confluence	MUR-F2			1	6							1	6												10				
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1				3						4	3	3										4	3	3,10				10
Reference sites (Steepbank, Horse and Dunkirk rivers)	SR-R/HR-R/DR-R				3							3	3											3	3,10				
Upper Muskeg River (near Wapasu Creek Confluence)																													
Muskeg River Tributaries																													
Alands Drain																													
Jackpine Creek (upper portion of the creek)	JAC-F2																								10				10
Jackpine Creek (accessable areas of lower creek)	JAC-F1			1																					10				10
Shelley Creek																													
Muskeg Creek (Canterra road crossing)[e]																													
Stanley Creek																													
Wapasu Creek (mouth or Canterra road)[e]																													
Steepbank River																													
Steepbank Mine baseline fisheries reach (1995)[f]	AF014																												
Vicinity of Steepbank Mine	SR-E/STR-F1				3							3	3											3	3,10				10
Baseline site in vicinity of Bitumin Heights	SR-R																												
Upstream sentinel site[g]	SR-EC				3							3	3											3	3				
Sentinel baseline sites (Horse and Dunkirk rivers)					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)
2002-2010: 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 program

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

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.
[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.

3.1.5 Acid-Sensitive Lakes Component

3.1.5.1 Overview of 2010 Monitoring Activities

The 2010 Acid-Sensitive Lakes (ASL) component consisted of monitoring 50 lakes and ponds within and beyond the RAMP study area for water quality variables during August and September, 2010. The location of each lake is presented in Figure 3.1-6. The 50 lakes are located in four physiographic regions:

- Stony Mountains;
- Birch Mountains;
- West of Fort McMurray;
- Northeast of Fort McMurray;
- Canadian Shield; and
- Caribou Mountains.

The date of sampling and the UTM coordinates for each lake are presented in Table 3.1-16. The unique identification number listed in Table 3.1-16 is that ascribed to each lake by the NO_xSO_x Monitoring Working Group (NSMWG) lake sensitivity mapping program (WRS 2004). Also included is the current AENV name of the lake.

The sampling design for the ASL program reflects the natural geographic distribution of lakes within the study region, which limits the ability to apply a more statistically defensible stratified sampling design. The 50 lakes represent a majority of the lakes within the RAMP region that are worth sampling including a large number of little ponds that are less than 0.5 km^2 in area. Beaver ponds were not considered to be permanent lakes. There are very few lakes close to the major oil sands developments (Syncrude and Suncor) that are not clearly influenced by the developments themselves. The closest lakes are those lakes in the Muskeg River uplands and the area NW of Fort McMurray, which are well represented in the ASL program. Low alkalinity lakes are represented in the upland areas (Birch Mountains, Stony Mountains). Lakes to the Northwest and Northeast of the oils sands region in the Caribou Mountains and Canadian Shield are remote from emission sources of NO_xSO_x and were selected as *baseline* lakes.

Timing of Sampling

Sampling was conducted during the fall when chemical conditions were considered to have stabilized and thermal stratification (if it occurred) would have broken down. A fall sampling program is consistent with most of the major lake surveys that have been conducted in Alberta (e.g., Saffron and Trew 1996). In order to address the possibility of a spring pulse in acidity that could be missed with this sampling regime, a seasonal sampling program was conducted for five years by AENV (as recommended in CEMA 2004b) on 10 representative lakes scattered around the oil sands region. The results were summarized in the 2008 RAMP technical report (RAMP 2009a). The CEMA/AENV study showed that much of the water in these shallow lakes (median depth 1.8 m) freezes during the winter and the lake chemistry changes dramatically. Large decreases in pH and increases in Gran alkalinity are observed during the winter accompanied by low oxygen levels and high levels of sulphide (strong sulphide odour). In spring, the lakes recover from the low pH and high alkalinities as the water melts and oxygen is re-introduced. Detecting a subtle decrease in pH or decrease in alkalinity in the spring, when all these events were occurring, was considered difficult if not impossible. A separate corroborative study on the Steepbank, Firebag and Muskeg rivers conducted in 2003 failed to detect a spring acid pulse on these rivers attributable to sulphates and nitrates deposited on the snow during the winter (WRS 2003).

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 station 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 3.1-17.

One blind field blank was collected using de-ionized water from the Limnology Laboratory, University of Alberta. Two field replicates were sampled and assessed by the University of Alberta laboratory. The field and quality control samples were analyzed for the water quality variables listed in Table 3.1-17 (Appendix B). The analytical methods for each water quality variable are described in the RAMP database available on the RAMP website.

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.

Figure 3.1-6 Locations of Acid-Sensitive lakes sampled in 2010.

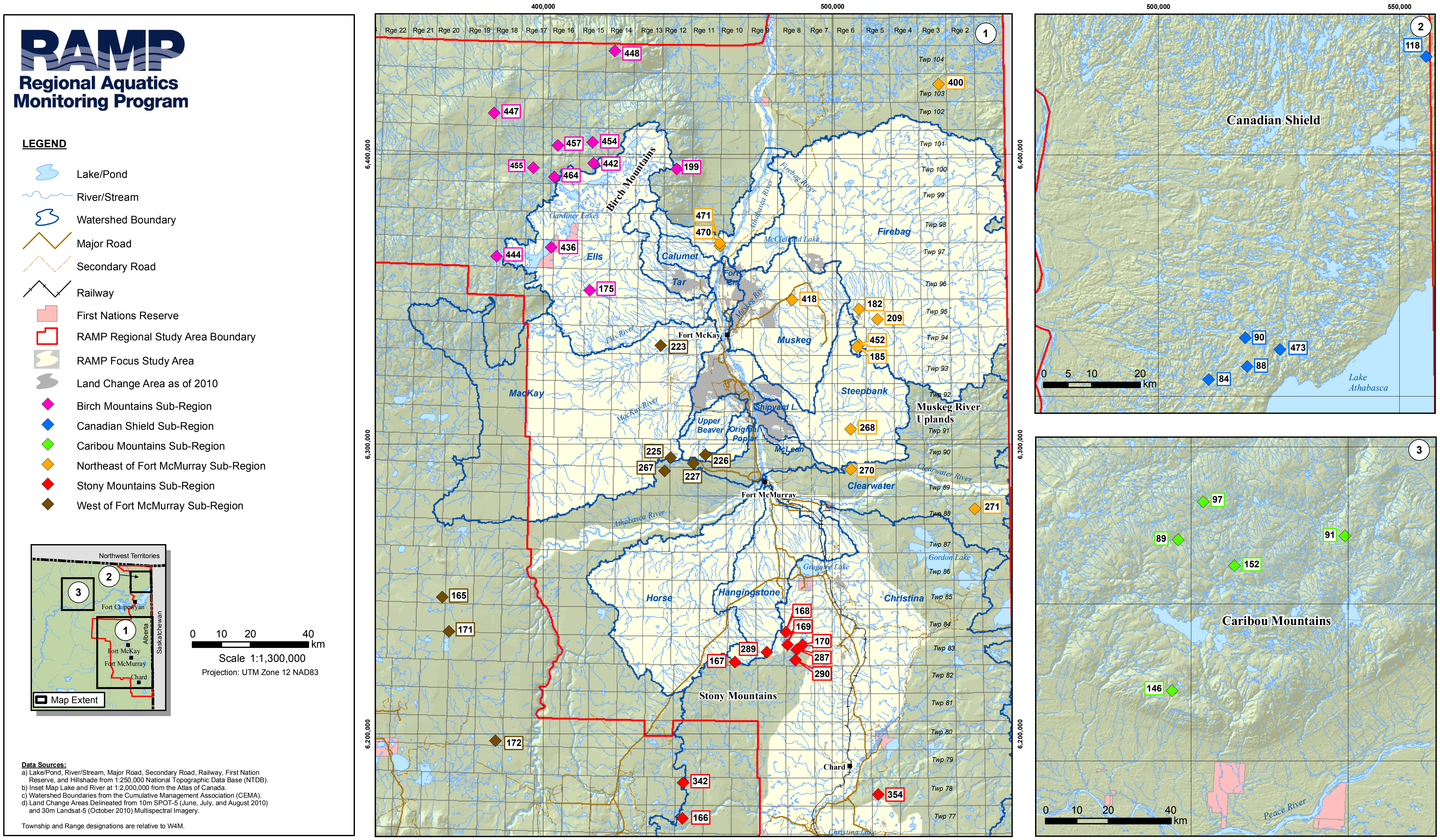


Table 3.1-16 Lakes sampled in 2010 for the Acid-Sensitive Lakes component.

Lake Identification			Lake Area (km^2)	UTM Coordinates (NAD83, Zone12)		Sampling Date month/day/year
Unique ID[1]	Original Name	AENV Designation		Easting	Northing	
Stony Mountains Sub-Region						
168	A21	SM 10	1.38	483819	6235130	09/03/10
169	A24	SM 9	1.45	484387	6230872	09/03/10
170	A26	SM 6	0.71	489502	6230877	09/03/10
167	A29	SM 5	1.05	466180	6224950	09/03/10
166	A86	SM 7	1.44	448014	6170896	09/03/10
287	25	SM 8	2.18	487594	6229281	09/03/10
289	27	SM 3	1.83	477248	6228400	09/03/10
290	28	SM 4	0.54	487068	6225576	09/03/10
342	82	SM 2	1.97	448271	6183205	09/03/10
354	94	SM 1	2.50	515689	6179207	09/03/10
Birch Mountains Sub-Region						
436	L18/Namur	BM 2	43.39	402704	6368016	09/03/10
442	L23/Otasan	BM 9	3.44	417321	6396959	09/03/10
444	L25/Legend	BM 1	16.80	383849	6364923	09/03/10
447	L28	BM 6	1.30	382996	6414339	08/31/10
448	L29/Clayton	BM 7	0.65	424694	6435790	08/31/10
454	L46/Bayard	BM 8	1.20	416941	6404239	09/03/10
455	L47	BM 4	4.37	396500	6395456	09/03/10
457	L49	BM 5	2.61	404995	6403111	09/03/10
464	L60	BM 3	0.91	403796	6392247	09/03/10
175	P13	BM 10	0.38	416003	6353212	09/18/10
199	P49	BM 11	2.61	446002	6394961	09/18/10
Northeast of Fort McMurray Sub-Region						
452	L4 (A-170)	NE 1	0.61	508990	6334305	09/02/10
470	L7	NE 2	0.33	461006	6368512	09/02/10
471	L8	NE 3	0.56	460931	6369481	09/02/10
400	L39/E9/A-150	NE 4	1.12	536495	6424234	09/02/10
268	E15	NE 5	1.87	506092	6305335	09/02/10
182	P23	NE 6	0.28	509000	6346712	09/18/10
185	P27	NE 7	0.09	508300	6333712	09/18/10
209	P7	NE 8	0.15	515399	6343212	09/18/10
270	4	NE 9	3.44	506113	6291421	09/02/10
271	6	NE 10	4.31	549064	6277789	09/02/10
418	Kearl	NE 11	5.34	485939	6349881	09/02/10
West of Fort McMurray Sub-Region						
165	A42	WF 1	3.20	365015	6247322	09/03/10
171	A47	WF 2	0.47	367321	6235430	09/03/10
172	A59	WF 3	2.06	383467	6197733	09/03/10
223	P94	WF 4	0.03	440557	6334112	09/18/10
225	P96	WF 5	0.21	444002	6295513	09/18/10
226	P97	WF 6	0.16	456002	6296463	09/18/10
227	P98	WF 7	0.08	451762	6293513	09/18/10
267	1	WF 8	2.22	441917	6290884	09/03/10
Caribou Mountains Sub-Region						
146	E52/ Fleming	CM 1	1.60	243692	6522556	08/31/10
91	O-1/E55	CM 5	2.70	298955	6571856	08/31/10
97	O-2/E67	CM 4	0.56	253582	6582654	08/31/10
152	E59/Rocky I.	CM 2	9.53	263546	6562225	08/31/10
89	E68 Whitesand	CM 3	2.46	245596	6570610	08/31/10
Canadian Shield Sub-Region						
473	A301	S 4	1.40	525150	6559733	09/02/10
118	L107/Weekes	S 1	3.73	555469	6620456	09/02/10
84	L109/Fletcher	S 2	1.29	510321	6553552	09/02/10
88	O-10	S 5	0.70	518279	6556260	09/02/10
90	R1	S 3	0.55	517889	6562197	09/02/10

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

Table 3.1-17 Water quality variables analyzed in 2010 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	

3.1.5.2 Changes in Monitoring Network from 2009

All 50 lakes were sampled in 2010. There was no change in sampling design or its implementation.

3.1.5.3 Challenges Encountered and Solutions Applied

There were no exceptional challenges encountered in implementing the ASL field program in 2010.

3.1.5.4 Other Information Obtained

AENV collected additional water samples for metals analyses from each ASL component lake surveyed during the 2010 field season (Table 3.1-16). These water samples were sent to Alberta Innovates Technology Futures (AITF), Vegreville, Alberta for analysis of the total and dissolved fractions of the metals listed in Table 3.1-18. The results of the metals analyses are reported in Appendix G.

Table 3.1-18 Metals analyzed in 2010 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

3.1.5.5 Summary of Component Data Now Available

The selection of lakes sampled during the twelve years of the ASL component is summarized in Table 3.1-19.

Table 3.1-19 Summary of lakes sampled for the Acid-Sensitive Lakes component, 1999 to 2010.

NO_xSO_x GIS No.	Original RAMP Designation	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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			+									

3.2 ANALYTICAL APPROACH

A weight-of-evidence approach is used for the analysis of RAMP data by applying multiple analytical methods to interpret results and determine whether any changes have occurred due to oil sands development.

The approach used for analyzing the RAMP data is as follows:

- A description and explanation of the measurement endpoints that were selected;
- 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 temporally and spatially;
- A comparison of the monitoring data to published guidelines to assess whether any exceedances in all variables measured have occurred;
- A comparison of the 2010 monitoring data to regional *baseline* ranges to assess whether any of the selected measurement endpoints fall outside of natural variability; and
- A description and explanation of the criteria that were used to assess whether or not changes in the selected measurement endpoints have occurred.

3.2.1 Climate and Hydrology Component

3.2.1.1 Selection of Measurement Endpoints

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

- Mean open-water season (May 1 to approximately October 31, 2010) discharge;
- Mean winter (November 1, 2009 to March 31, 2010) discharge;
- Annual maximum daily (November 1, 2009 to October 31, 2010) 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 2010 data. Values for each of these four measurement endpoints were calculated for the *test* and *baseline* hydrographs as discussed below. A percent change in the measurement endpoints between the *test* and *baseline* values was also calculated.

3.2.1.2 Water Year Convention

Starting in 2010, the RAMP Climate and Hydrology component analysis, including the calculation of the above measurement endpoints, follows a water year (WY) convention with a water year defined as November 1 through to October 31 of the following calendar year. For example, the 2010 WY is defined as the period from November 1, 2009 to October 31, 2010. This water year approach has become the standard base period for hydrometric analysis for interior northern river systems that typically have a well-defined winter period with several months of precipitation received in the form of snow. Winter flows for these systems are typically low, followed by higher flows (and sometimes annual maximum flows) resulting from snowmelt contributions to the system. The winter flow conditions for these northern river systems straddles two calendar years with the onset of winter conditions beginning typically around the start of November and ending with the spring freshet in the following calendar year. When considering the RAMP FSA, a water year analytical timeframe (relative to a calendar year timeframe previously used by RAMP [RAMP 2009a]):

- provides a basis for analysis and reporting that allows for seasonal connectivity of flow data as representative of the hydrologic regime;
- aligns RAMP hydrologic analyses with analysis protocols for river systems with similar seasonal attributes; and
- provides for statistical independence between winter measurement endpoints by including a single, full winter flow period within the annual analytical time period rather than two partial winter seasons as formerly applied using the calendar-year approach.

The transition to using a water year convention in 2010 will not affect the results of hydrological analyses calculated for the 24 seasonal RAMP stations as the seasonal data for these stations are aligned within the same water year and calendar year. Potential effects on the calculated annual runoff volumes and measurement endpoints for the 11 year-round RAMP stations are discussed below. With the exception of the calculated mean winter discharge, the estimated annual runoff volume and calculated measurement endpoints will not be significantly affected by a transition to a water year convention for the following reasons:

- The annual runoff volume for a watershed will be calculated based on flows recorded from November 1 to October 31 of the following calendar year. The winter flows (regardless of a calendar year or water year basis for calculation) represent a small portion of the annual runoff volume; it is this period of low flows that will be accounted differently with the change to a water year analysis. Changes to a water year convention will; therefore, have little effect on the calculated annual runoff volume since this value is typically dominated by open-season flow conditions;
- The reported annual maximum daily flow statistic will not be affected by the change to water year convention as maximum flows generally occur during spring freshet or summer rainfall events, which will be reported consistently with both water year and calendar year conventions; and
- Open-water season minimum daily discharge values will not be affected by a change to water year convention as the open-water period (defined as May 1 to October 31) is consistent regardless of a water year or calendar year convention.

The mean winter discharge estimates calculated using a water year convention will more appropriately describe the seasonal flow conditions as this measurement endpoint will reflect flow conditions experienced over one connected winter season rather than two partial winter seasons as previously calculated using the calendar year convention.

3.2.1.3 Temporal Comparisons of Climate and Hydrologic Conditions

For each climate and hydrometric station, records for the 2010 WY were assessed in relation to the historical context as available based on past records for the location using an Exploratory Data Analysis (EDA) (Kundzewicz and Robson 2004). Historical values were calculated and represented graphically including daily median, upper quartile, lower quartile, historical maximum and historical minimum values. Observed and calculated *baseline* (described below) hydrographs were plotted and described in the context of historical data. The degree of robustness for this context is dependent on the period of record available for the specific locations and varies from station to station throughout the RAMP FSA. As data continues to be collected this method will provide a more robust analysis of the temporal context and also additional methods, that would incorporate statistical analyses, will become more valid for the region. Whenever possible, hydrometric monitoring locations have been selected to support the development of increasing record length to further support assessment of the climate and hydrologic regime of the region and specific stations within the RAMP FSA. The period of record and record length is provided when describing the temporal context of the 2010 WY observations and calculated *baseline* conditions using the EDA approach.

3.2.1.4 Comparison to *Baseline* Conditions

The 2010 hydrologic data was analyzed using a water balance approach consistent with previous analytical methods from 2004 to 2009. The water balance approach is used to develop a *baseline* and *test* hydrograph for each watershed with focal projects. The *test* hydrographs represent the data developed from recorded water levels and flow measurements, 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 2010 hydrograph. Additional details regarding this analytical approach are found in (RAMP 2008 and Appendix C of this report).

The RAMP 2010 hydrology water balance analysis consisted of:

- establishing observed (*test)* hydrographs for all operating stations in 2010 using water level records, associated stage/discharge relationships, and Aquatic Informatics Aquarius software (Aquarius 2.7, Aquatic Informatics ™);
- estimating the 2010 *baseline* hydrographs (described below);
- calculating hydrologic measurement endpoints (described above) for both the *baseline* and *test* hydrographs; and
- applying criteria to assess the percentage change in the hydrologic measurement endpoints from estimated *baseline* and observed (*test*) scenarios.

Estimation of 2010 Baseline Hydrograph

The 2010 WY *baseline* hydrographs are defined for this analysis as the hydrographs that would have been observed in the 2010 WY had there been no focal projects in the watershed. Additional influences may be incorporated in the 2010 WY *baseline* hydrograph due to development activities from other oil sands developments 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 2010 WY *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 the 2010 WY;

Hyd_O is the *test* hydrograph which was observed in the 2010 WY;

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 the 2010 WY; 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 watershed responsiveness caused by changes in the watershed. In addition, the Climate and Hydrology Component subgroup under the RAMP Technical Program Committee established that this approach would assume that areas of land change not closed-circuited would be estimated to have an increased runoff of 20%. This value is based on the following:

- The Spring Creek study conducted over a 36-year period in the boreal forest area of northern Alberta, which concluded that "The first 4 years after harvesting indicated minor increases in annual runoff from the Rocky Creek watershed" (AENV 2000). Within the RAMP FSA, land cleared for industrial purposes (and still contributing to flow) are slated to become hydrologically closed-circuited as part of the development process and while these areas are classified as "cleared and contributing" they are generally within the four year post-harvesting period. The assumption of increasing flow for these areas is consistent with the Spring Creek study.
- While the use of 20% is a generalized assumption, the effect of clearing in most watersheds, related to oil sands development, is (as discussed above, and unlike forestry) a temporary land classification with cleared areas being slated for near-term development. These areas will be incorporated into the closed-circuited areas of the developments as mining plans unfold. In most cases the percentage of the areas of watersheds that are cleared and contributing is relatively small compared to the overall land-cover of the watershed such that this assumption (whether it be from 15 to 25%) would have a minor impact on the overall calculation results when considering the drainage basin as a whole.
- The RAMP Climate and Hydrology Component subgroup under the RAMP Technical Program Committee will continue to assess the 20% assumption in light of current/available research.

While the water balance approach does not account for changes in runoff timing, watershed responsiveness, or storage properties that could be associated with development activities, this approach provides an evaluative technique that identifies the approximate magnitude of changes in the above measurement endpoints at the mouth of major watercourses in the RAMP FSA. The Climate and Hydrology Component subgroup under the RAMP Technical Program Committee is currently investigating additional hydrologic indicators that could further describe regional hydrologic flow conditions including methods to assess potential changes in timing and frequency of flow conditions. These methods required considerable hydrometric record lengths. This approach is; therefore, being evaluated for locations where the record length is approaching the requirements of the methodologies under investigation. The water balance approach, as described above, is applicable for all stations within the RAMP FSA with 2010 WY flow records and associated land use and industrial flow data. The water balance approach thereby provides a consistent approach for the 2010 WY for all watersheds in the RAMP FSA.

3.2.1.5 Classification of Results

The percent difference between the *test* and *baseline* values of the hydrologic measurement endpoints developed through the water balance analyses 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).

3.2.2 Water Quality Component

The analytical approach used in 2010 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 2010 concentrations of water quality measurement endpoints to historical concentrations of each endpoint at each station, water quality regional *baseline* conditions, and selected criteria for determining change in water quality.

3.2.2.1 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 (2004a);
- water quality variables of interest listed in the RAMP 5-year report (Golder 2003);
- results of correlation analysis of the RAMP 1997 to 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 Communities component and the Fish Populations component; and
  - appropriate analytical strategies for the Water Quality component.

Table 3.2-1 presents the water quality variables listed in these various sources.

The water quality measurement endpoints used in 2010 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 3.2-1). Total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with TSS (Golder 2003). 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 (note that because of current uncertainty related to high-resolution analysis of naphthenic acids, naphthenic acids data are presented and assessed separately in Section 6 of this document, rather than in Section 5 as has been done in previous RAMP Technical Reports); and
- In addition to the above water quality measurement endpoints, overall ionic composition at each station was assessed graphically using Piper diagrams (Section 3.2.2.2).

Table 3.2-1 Potential water quality measurement endpoints.

Group	RAMP (2009b) Variables Listed in EIAs	CEMA Variables of Concern (CEMA 2004a)	RAMP 5-year Report (Golder 2003)	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 Populations components (inferred).

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

3.2.2.2 Assessment of Results

Temporal Trend Analysis

Statistical trend analysis 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 using the program WQStat Plus, with a level of significance of α=0.05. Values were not flow-averaged before trend analysis.

Trend analysis also was undertaken on water quality data for the Athabasca River, at stations, which have been monitored continuously by Alberta Environment since 1976. Seasonal Mann-Kendall analysis was applied to monthly AENV water quality data from the Athabasca River upstream of Fort McMurray (station ATR-UFM, approximately 100 m upstream of the Horse River), and the 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 3.2.2.1), including total suspended solids, total dissolved solids, dissolved phosphorus, total nitrogen, total boron, total strontium, calcium, chloride, magnesium, potassium, sodium, sulphate and total arsenic, from the period of RAMP sampling (1997 to 2010), to assess trends potentially related to development between the two stations during this time period.

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 the ionic composition of water. 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 3.2-1).

Comparison to Water Quality Guidelines and Historical Data

The fall 2010 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 2010 (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 Regional Baseline Concentrations

To allow for a regional comparison, untransformed data for 15 of the 21 water quality measurement endpoints from all *baseline* stations sampled by RAMP from 1997 to 2010 (fall only) were pooled from each cluster of similar stations (Table 3.2-2). Descriptive statistics describing *baseline* water quality characteristics for each group were calculated; for each water quality cluster (Table 3.2-2), 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 3.2-4). The median rather than the mean was used as an indicator of typical conditions; given water quality data are characteristically positively skewed.

Regional *baseline* ranges did not include, and were not applied to lakes sampled by the RAMP Water Quality Component in 2010, to address concerns expressed by the RAMP 2010 Peer Review (AITF 2011) in combining water quality data from streams and lakes in regional *baseline* ranges.

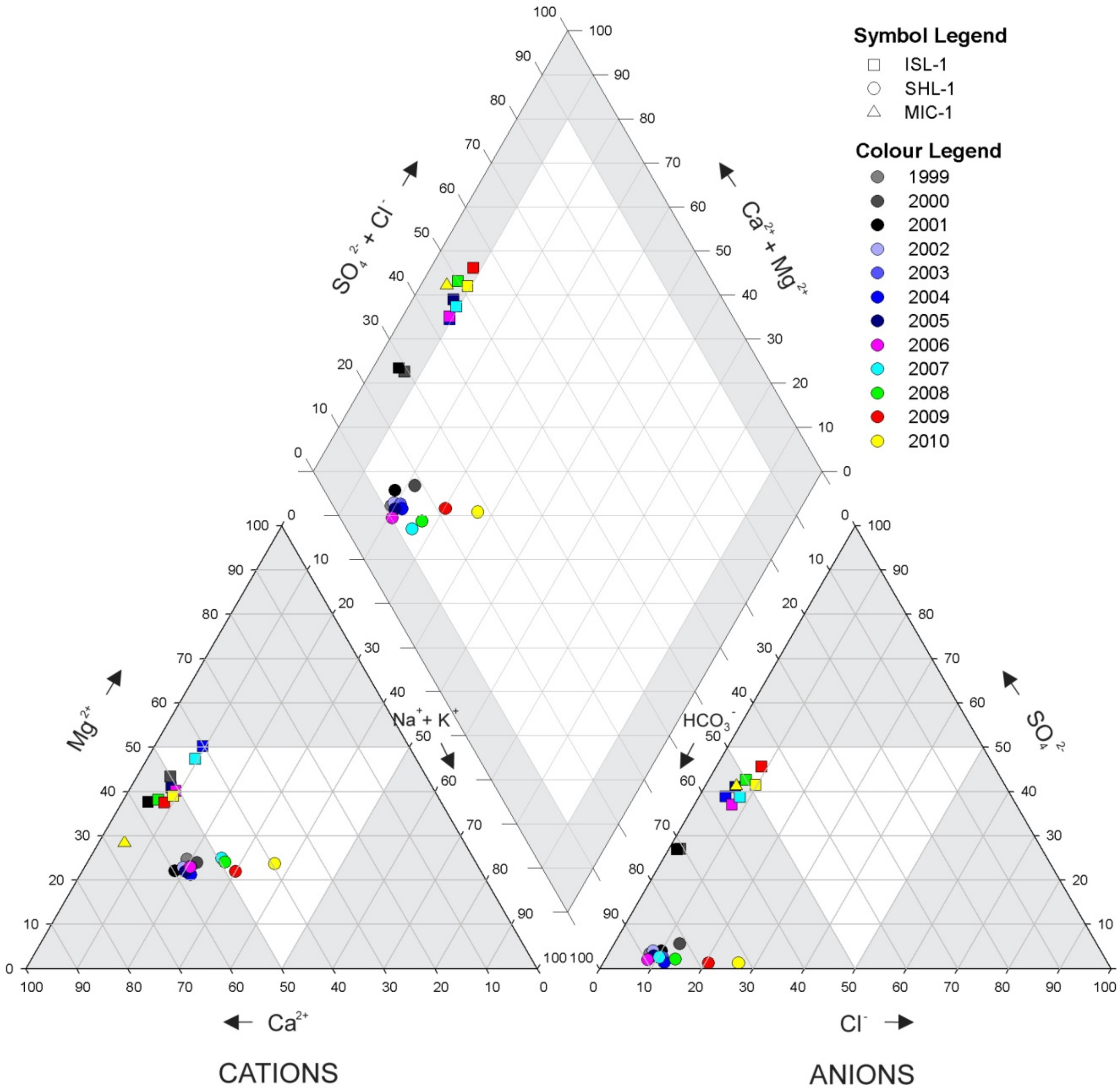
Data for the fifteen selected water quality measurement endpoints were presented graphically in the context of relevant regional variability by presenting data for each station for all years of sampling by RAMP to allow assessment of any temporal trends (Figure 3.2-2). Where possible, stations located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

Development of Regional *Baseline* Concentrations Descriptions of regional *baseline* water quality conditions were developed from existing data collected by RAMP since 1997 from *baseline* locations throughout the study area. These ranges of regional natural variability in water quality were used as one method of screening water quality observed at all stations in fall 2010, to assess whether water quality conditions at the time of sampling were similar to, or differed from, those typically observed in the region.

This analytical approach is similar to that of the Reference Condition Approach to biomonitoring (Bailey *et al.* 2004), also is 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). It also shares similarities with CCME's prescribed approach for developing site-specific water quality objectives (SSWQOs), which uses the 90% percentile of upstream water quality observations to define benchmarks for assessment of water quality in a given waterbody, typically downstream of some kind of development (CCME 2011).

Multivariate data analysis was used to develop descriptions of regional *baseline* water quality that were then applied to water quality measurements from *baseline* and *test* stations. In this approach, water quality data from all RAMP *baseline* water quality stations from 2002 to 2010 were pooled using cluster analysis. Cluster analysis was applied to the RAMP water quality variables. Similar approaches to consolidation and analysis of large water quality datasets are common in the water quality assessment literature (e.g., Boyacioglu and Boyacioglu 2010, Astel *et al.* 2007, Singh *et al.* 2004, Jones and Boyer 2002, Güler *et al.* 2004).

Figure 3.2-1 Example Piper diagram, illustrating relative ion concentrations in waters from Isadore's Lake, Mills Creek and Shipyard Lake, 1999 to 2010.



Data Pre-Treatment Summary There were seven criteria that were used to evaluate the water quality data before they were included in the cluster analysis:

1. Only fall data were included in the analysis, to exclude any confounding effects of seasonality.
2. Data from lakes were excluded from the analysis, in response to uncertainty from the RAMP 2010 Peer Review (AITF 2011) in combining lake and stream data in the development of regional *baseline* descriptions.
3. Total nitrogen concentration was removed, because it is a value calculated from constituent nitrogen-species measurements (i.e., TKN and NO_3+NO_2) that were already included in the model.
4. Water quality data collected prior to 2002 were excluded because total and dissolved metals data from 1997 to 2001 had higher analytical detection limits, which could have confounded clustering. Prior to the 2009 RAMP analysis, earlier data had been included, with method detection limits from 2002-onward adjusted upward to eliminate potential confounding effects of different MDLs. The current approach of using lower-detection-limit data from 2002 onward was adopted in 2009, given seven years of data with low MDLs existed, which better described the variability of trace metals in water.
5. Dissolved and total values for each metal were analyzed for covariance; and total metals that significantly covaried with their dissolved counterpart were removed. Generally, metals that significantly covaried were present predominantly in dissolved form and therefore exhibited similar or identical total and dissolved concentrations. Exclusion of the total measure of these metals ensured that these variables were not overweighted in the model because of their colinearity. Data from 11 total metals were removed from further analysis: barium, boron, calcium, chlorine, lithium, mercury, molybdenum, nickel, strontium, sulphur and uranium.
6. Analytes with 50% or greater non-detect values were excluded from analysis. If analytes were adjusted to the detection limit in the case of a non-detect value, this would introduce artificial variability. This screening step eliminated 24 analytes, or 39% of the data (ammonia, dissolved beryllium, biochemical oxygen demand, dissolved bismuth, total bismuth, total cadmium, carbonate, dissolved chromium, hydroxide, dissolved mercury, total ultra-trace mercury, naphthenic acids, nitrate, nitrite, nitrate+nitrite, dissolved selenium, total selenium, dissolved silver, total silver, dissolved thorium, dissolved tin, total tin and total recoverable hydrocarbons).
7. Analytes missing 15% or more data were removed to avoid excessive blank values, since conventional cluster analysis methods cannot handle missing data. Any remaining blank values were filled in using the mean value for that analyte from that station over the years of data available. Four station-years (CHR-2 2004, BER-1 2006, CAR-1 2006 and FIR-1 2006) and five analytes (chlorophyll *a*, total magnesium, total potassium, total sodium, and dissolved sulphur) were removed from the data following this step.

This resulted in a data set that included data from 2002 to 2010 and 56 stations. In total, 57 analytes in 347 station-year combinations were used in the cluster analysis. This methodology is similar to that of 2009 except for the exclusion of lakes data in the 2010 analysis.

Cluster Analysis helps to identify groups of similar data. In this case, cluster analysis was applied to the data over stations per year to determine if the stations grouped into ecologically significant patterns. Ward's hierarchical clustering using Euclidean distances was used in the cluster analysis.

Prior to cluster analysis, the data were transformed to address differences in measurement units. Many analytes were measured in mg/L; however, pH, true colour and conductivity have their own measurement systems of different scales. In order for data to be comparable, they were ranked by analyte in order to remove differences of scale.

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). Five potential clusters were identified from the resulting dendrogram. 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.

Based on the dendrogram and on ecological knowledge of the area, the most logical grouping structure indicated the presence of three clusters (Table 3.2-2):

- Athabasca River mainstem and Delta;
- Southern and western tributaries, plus McLean Creek and Mills Creek:
  - Christina, Clearwater, Hangingstone and Horse Rivers;
  - Beaver, Calumet, Ells, Dunkirk, MacKay, Tar Rivers, and Poplar Creek;
  - McLean Creek; and
  - Mills Creek;
- Eastern tributaries, including Muskeg River and Steepbank River:
  - Firebag River and Fort Creek;
  - Jackpine, Muskeg, Shelley, Iyinimin, Stanley and Wapasu Creeks and Muskeg River; and
  - North Steepbank and Steepbank rivers.

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 3.2-3 lists the stations from which *baseline* data from 2002 to 2010 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 3.2-2 Classification of groups of RAMP *baseline* water quality monitoring stations with similar water quality, based on 2002 to 2010 data.

Waterbody	Total No. of Station/Year Combinations	Cluster		
		1	2	3
Athabasca River and Delta				
Athabasca River	90	83	7	-
Delta/Embarras River	3	3	-	-
Eastern tributaries				
Firebag River	17	-	2	15
Fort Creek	7	-	3	4
McLean Creek	9	-	9	-
Muskeg River				
Jackpine Creek	12	-	2	10
Muskeg Creek	7	-	2	5
Muskeg River	18	-	3	15
Shelley Creek	3	-	1	2
Iyinimin Creek	3	-	2	1
Stanley Creek	9	-	-	9
Wapasu Creek	7	-	-	7
Southern tributaries				
Christina River	18	1	12	5
Clearwater River	18	1	17	-
Hangingstone River	5	-	5	-
Horse River	1	-	1	-
Steepbank River				
North Steepbank River	9	-	1	8
Steepbank River	25	-	8	17
Western tributaries				
Beaver River	10	-	10	-
Calumet River	14	-	14	-
Ells River	17	-	17	-
Dunkirk River	1	-	1	-
MacKay River	19	-	18	-
Poplar Creek	9	-	9	-
Tar River	16	-	16	-
Mills Creek	1	-	1	-
Total	347	88	161	98

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

Table 3.2-3 Regional *baseline* water quality data groups and station comparisons.

Regional *Baseline* Grouping (Cluster)	*Baseline* Stations Used in Creating Regional Comparison[1]	*Test* Stations (2010) Compared Against Regional *Baseline*
1. Athabasca	ATR-DC-CC, ATR-DC-E, ATR-DC-M, ATR-DC-W, ATR-MR-W	ATR-DC-E, ATR-DC-W, ATR-SR-E, ATR-SR-W, ATR-MR-E, ATR-MR-W, ATR-DD-E, ATR-DD-W, ATR-FR-CC
2. Southern and western tributaries, McLean Creek and Mill's Creek	BER-2, CAR-1, CAR-2, CLR-1, CLR-2, DUR-1, ELR-1, ELR-2, ELR-2A, HAR-1[2], HOR-1, MAR-2, MAR-2A, TAR-1, TAR-2	BER-1, BER-2, CAR-1, CAR-2, CHR-1, CHR-2, CLR-1, CLR-2, ELR-1, ELR-2, ELR-2A, HOR-1, MAR-1, MAR-2, MAR-2A, MCC-1, MIC-1, POC-1, TAR-1, TAR-2
3. Eastern tributaries, Muskeg River and Steepbank River	FIR-2, FIR-2X, FOC-1, IYC-1, JAC-1, JAC-2, MUC-1, MUR-6, NSR-1, SCH-1, STC-1, STR-2, STR-3, WAC-1	FIR-1, FIR-2, FOC-1, MUR-1, MUR-6, NSR-1, STR-1, STR-2, STR-3

[1] See Table 3.1-5 for classification of station status by year. Where station status changed from *baseline* to *test* during 1997 to 2010, 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.

Figure 3.2-2 Example of a comparison of RAMP data from a specific watershed against regional *baseline* concentrations and water quality guidelines, in this case, for the Steepbank River watershed.

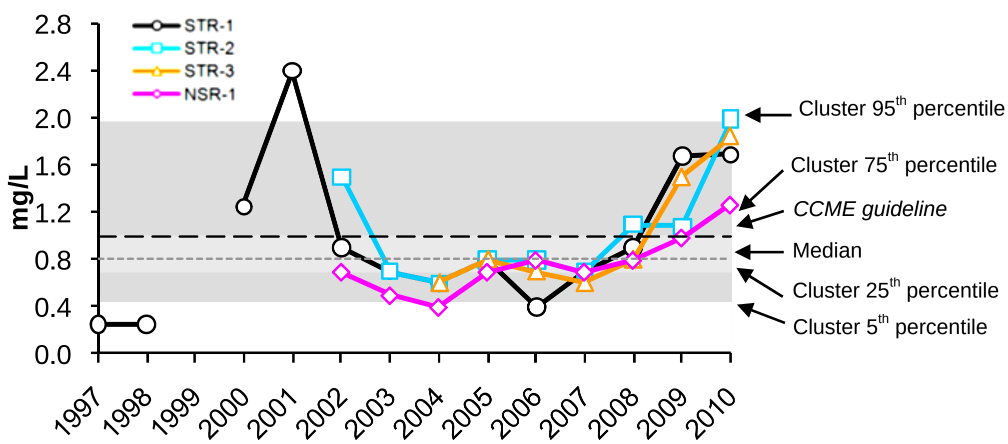


Table 3.2-4 Number of observations available for determining regional *baseline* water quality.

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)	36	56	78
Total Dissolved Solids (TDS)	36	56	78
Dissolved phosphorus	36	56	79
Total nitrogen	36	56	77
Total strontium	36	56	79
Total boron	36	56	79
Total mercury (ultra-trace)	25	46	31
Total arsenic	36	56	48
Calcium	36	56	78
Magnesium	36	56	78
Sodium	36	56	78
Potassium	36	56	78
Chloride	36	56	78
Sulphate	36	56	78

3.2.2.3 Classification of Results

The following criteria were used for assess water quality results:

- **Trend Analysis**: Any significant (α=0.05) trends over time in water quality measurement endpoints.
- **Comparison to Historical Concentrations**: Fall 2010 data for each of the selected water quality measurement endpoints at a given station were assessed all historical observations for that endpoint at that station, with historically high or low observations identified.
- **Comparison to Published Water Quality Guidelines**: All water quality data collected by RAMP in 2010 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 3.2-5). All values that exceeded these guidelines are reported explicitly in Section 5.
- **Comparison to Regional *Baseline* Conditions**: 2010 water quality data for each of the selected water quality measurement endpoints were assessed against a 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 2010 was summarized into a single index value, ranging from 0 to 100, using an approach based on the CCME Water Quality Index. 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. A detailed description of the index and how it is calculated is found at http://www.ccme.ca/ourwork/water.html?category_id=102. Its specific application to RAMP is described below.

Index calculations for RAMP water quality data used regional *baseline* conditions, calculated and described in Section 3.2.2.2, as the benchmark for comparison. Specifically, individual water quality observations were compared to the 95th percentile 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 3.2.2.1) with the exception of 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=423) yielded index values ranging from 76.3 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 a "Negligible-Low" difference from *baseline,* corresponds with CCME guideline-based index classes "Good" and "Excellent"; RAMP classification of a "Moderate" difference from *baseline* generally corresponds with CCME class "Fair"; and RAMP classification of a "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).

Water Quality Index values were not calculated for lakes (i.e., McClelland, Kearl, Isadore's, Shipyard), because of concerns raised by the RAMP Peer Review (AITF 2011) regarding combining lakes and streams in regional *baseline* ranges.

Table 3.2-5 Water quality guidelines used to screen data collected by the RAMP Water Quality Component, 2010.

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	°C	-	-[g]	-	-
Suspended Solids	mg/L	-	> 10 mg/L[l]	-	-
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[k]
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 = $10^{(0.86[\log(\text{hardness})]-3.2)/1000}$

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 $e^{1.6-3.327*\text{median pH}+0.402*pH2}$

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

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

l: Concentration should not be increased by more than 10 mg/L over background value.

3.2.3 Benthic Invertebrate Communities and Sediment Quality

3.2.3.1 Benthic Invertebrate Communities Component

The analytical approach used in 2010 for the Benthic Invertebrate Communities 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;
- detailed data analysis, consisting of:
  - analysis of variance testing for differences between upstream *baseline* and downstream *test* reaches, and/or differences in time trends;
  - calculation of regional *baseline* conditions for 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 regional *baseline* conditions; and
  - control charts to indicate when a reach was shifting from *baseline* conditions;
- developing criteria to be used in detecting changes in benthic invertebrate community measurement endpoints.

Selection of Benthic Invertebrate Community Measurement Endpoints

For each sample, the following benthic invertebrate community measurement endpoints were calculated:

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

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

  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).

In addition to these core benthic invertebrate community measurement 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 Athabasca River 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 measurement endpoints for benthic invertebrate communities were calculated 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.

Temporal Trends and Spatial Comparisons

Possible changes in benthic invertebrate communities were evaluated by comparing 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.

Analysis of variance was used to test for variations over time for reaches or lakes that have been exposed to oil sands development since RAMP started in 1997. The ANOVA used variations within reaches (or lakes) to judge the significance of linear time trends. Linear contrasts were used to carry out the analysis of variance and to test the specific hypothesis:

- H_1: No linear time trend in mean values of measurement endpoints during the period of sampling.

RAMP has produced data for some reaches such as lower Jackpine Creek (JAC-D2) during both the *baseline* period for that reach and now when it is classified as a *test* reach. For those reaches, linear contrasts were developed that test the following null hypotheses:

- H_2: No difference from before to after exposure to oil sands development in mean values of measurement endpoints.

Where a *test* reach can also be compared with a *baseline* reach, evidence of an effect is derived from a change from before to after exposure to oil sands development, in the difference between *test* and *baseline* reaches. Linear contrasts were thus used to test the following specific hypotheses where the data allowed:

- H_3: No change from before to after exposure in difference between *baseline* and *test* reach mean values of measurement endpoint.

- H_4: No difference in linear time trends during the period of exposure to oil sands development.

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 1977, 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 change in the benthic invertebrate community. A decrease in taxa richness, Simpson's Diversity, evenness and percent EPT would each be considered a negative change or difference. An increase or decrease in abundance could be considered a positive or negative change. Excessively high abundances (i.e., on the order of 100's of thousands of organisms per m^2) would be considered a negative change 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).

Comparison to Published Literature

There are no conventional "guidelines" *per se* against which to judge observed differences in measurement endpoints of benthic invertebrate communities given *baseline* ranges of variation tend to depend on local or regional climatic, hydrological, and geological conditions. The RAMP *baseline* reach database and published literature; therefore, provides (*de facto*) the most appropriate set of regional *baseline* conditions and information against which to assess differences observed in *test* reaches.

Determination of Regional Baseline Conditions

Regional *baseline* conditions were defined as the range of variability for measurement endpoints across all *baseline* reaches for each habitat type. The range of variability was used as a benchmark in control charts in the assessment of measurement endpoints for benthic invertebrate communities.

Control charts are conventionally used in the assessment of industrial process using the following general rules of thumb which indicate when a process is "out of control": (i) Any single value falling outside of the range defined by $\bar{x} \pm 3SD$; (ii) two sequential observations falling outside of $\bar{x} \pm 2SD$; (iii) four sequential observations falling outside of $\bar{x} \pm 1SD$; (iv) a trend over time in the last six observations (Westgard *et al.* 1981).

In this assessment, the range of regional *baseline* conditions was estimated using the data obtained from *baseline* reaches not influenced by oil sands developments. Control charts were established separately for erosional and depositional reaches. Exploratory analysis has not identified any variable (apart from habitat class) as explaining substantial variation in temporal or spatial differences in measurement endpoints for benthic invertebrate communities, justifying the development of control charts for erosional and deposition reaches (RAMP 2009b). The lack of influence of other physical stream variables on composition was because *baseline* reaches were generally large tributaries.

Visual inspection of box and normal probability plots indicated that some measurement endpoints (reach means) were non-normally distributed among *baseline* reaches. The conditions for *baseline* reach means was estimated, therefore, using 1st and 99th percentiles as surrogates for $\overline{X} \pm 3SDs$, 5th and 9th percentiles as surrogates for $\overline{X} \pm 2SDs$, and 25th and 75th percentiles as surrogates for $\overline{X} \pm 1SDs$ (e.g., Figure 3.2-3). For the univariate measures (i.e., abundance, richness, Simpson's Diversity, evenness and percent EPT), these ranges were developed for the individual measurement endpoints within both erosional and depositional habitat classes. A monotonic increase or decrease in measurement endpoints over the past six years of data was tested using a Spearman rank correlation (this test was somewhat redundant, for some reaches, with the ANOVA test for time trends, but still considered complimentary). The multivariate CA axis scores were treated somewhat differently. Bi-plots of *baseline* reach scores were generated within SYSTAT , which was also used to generate 1%, 5%, 25%, 50%, 75%, 95% and 99% ellipses (Figure 3.2-4). These ellipses were used to judge whether a reach was "in control" using the "rules of thumb". A test of time trends over the past six years for *test* reaches was computed using the Euclidean distances to the centroid of the *baseline* reach ellipse.

Figure 3.2-3 Example time trend chart for benthic invertebrate community abundance in relation to regional *baseline* conditions, in this case, for erosional reaches.

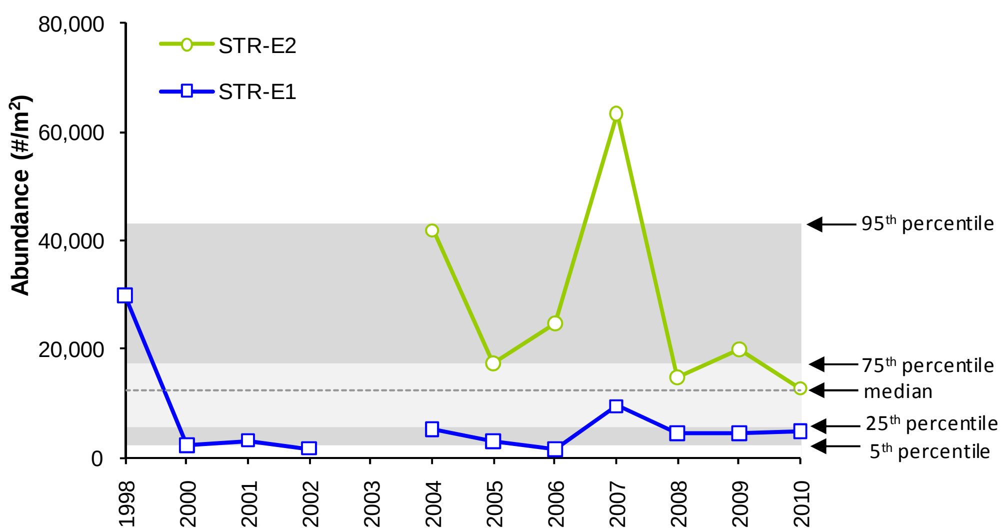
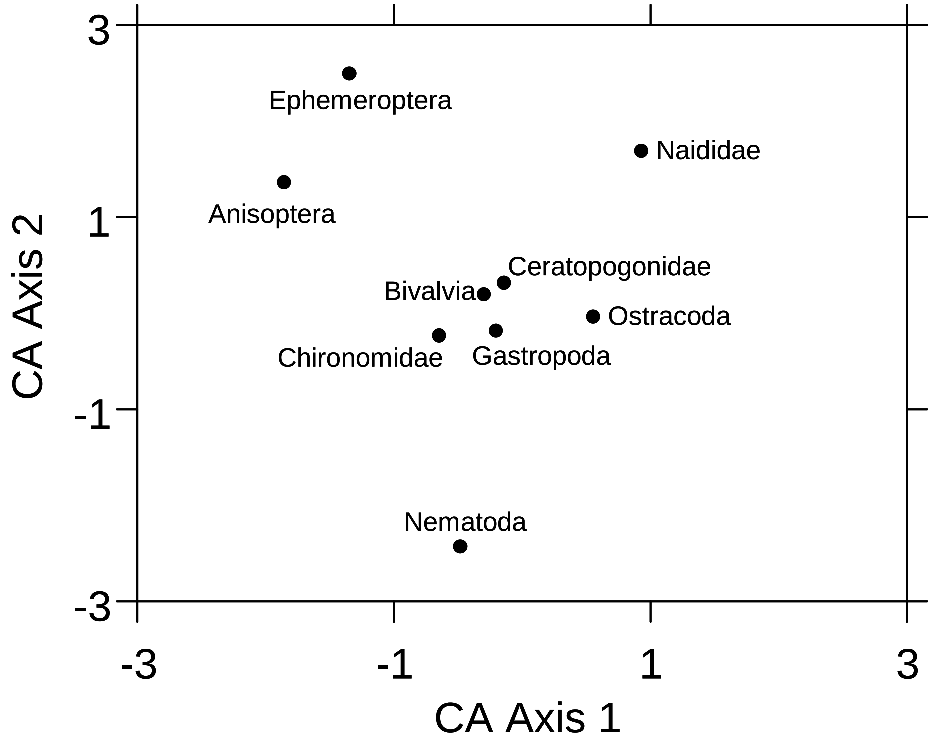
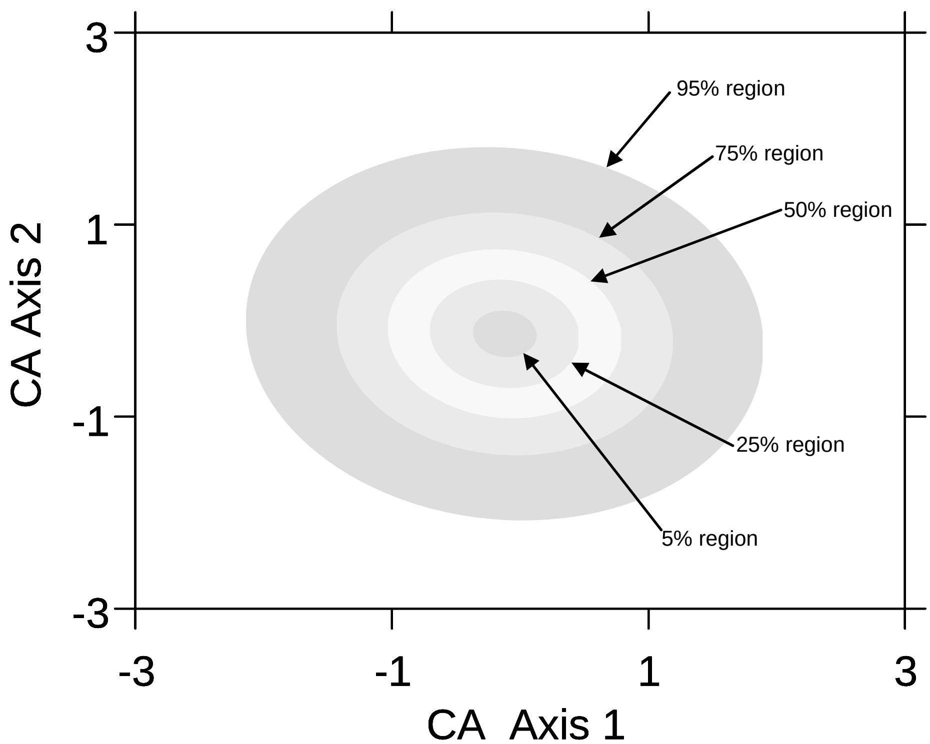


Figure 3.2-4 Example bi-plot showing time trend of benthic invertebrate CA Axis scores in relation to regional *baseline* conditions, in this case, for samples from the Athabasca Delta *test* reaches.





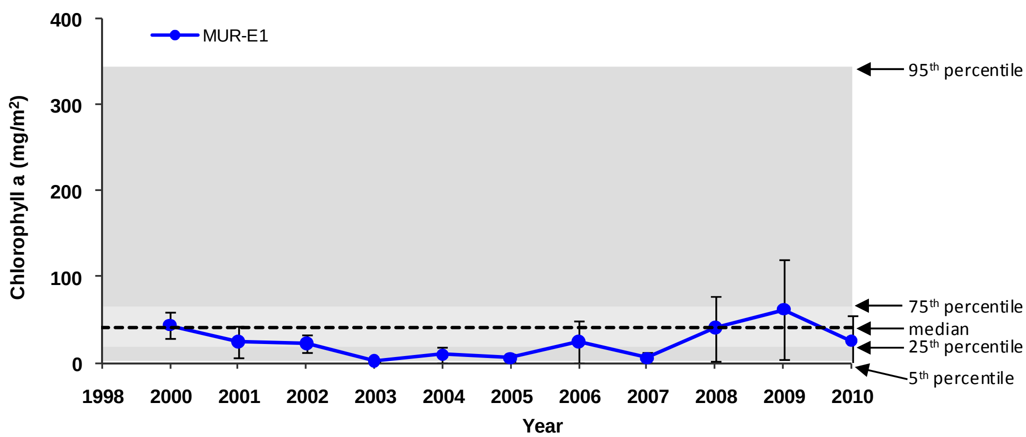
Environmental Variables

A number of environmental variables, including physical substrate condition and water temperature, chemistry, and flow velocities were measured at each reach (Section 3.1.3.2). 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 effect 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 1999). 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 3.2-5 Example of periphyton chlorophyll *a* data against the range of regional *baseline* concentrations, in this case, for the lower Muskeg River.



Classification of Results

The criteria used for classifying results of benthic invertebrate communities was whether or not the core measurement endpoints for benthic invertebrate communities at a given location (i.e., river reach or lake) designated as *test* either exceeds regional *baseline* conditions, has significantly changed from when the reach was designated as *baseline*, or if is significantly different from the upstream *baseline* reach (if applicable).

Measured changes were classified as Negligible-Low, Moderate and High on the basis of the strength of the statistical signal from a reach/lake for changes in core measurement endpoints for benthic invertebrate communities (Table 3.2-6). 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 3.2.3.1 for a discussion of how the "noise" is assessed). There are five core measurement endpoints for benthic invertebrate communities assessed (abundance, taxa richness, Simpson's Diversity, evenness, and percent EPT). If any one of those measurement endpoints produces a strong signal of a change, then this criterion will be considered to have been met. Allowing any one of the five 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 3.2-6) if any measurement endpoint has fallen outside of regional *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 regional *baseline* conditions within the current year. This is particularly relevant for the assessment of waterbodies (reaches or lakes) for which there is at least a three-year data record.

Table 3.2-6 Classification of results for Benthic Invertebrate Communities component.

Criterion	Classification			"Yes"
	Negligible-Low	Moderate	High	
Statistical significance	No	Yes	Yes	Strong statistical signal on any one of five measurement endpoints across time, with difference from *baseline* implying a negative change.
Exceed *baseline* range of variation	No	No	Yes	Any three of five measurement endpoints with values that violate a control charting criterion.

3.2.3.2 Sediment Quality Component

The analytical approach undertaken for the Sediment Quality component in 2010 was expanded relative to previous years and included:

- review and selection of particular sediment quality variables as measurement endpoints including predicted toxicity of sediments due to PAHs (calculated using an equilibrium-partitioning model);
- tabular presentation of 2010 results, comparing 2010 concentrations of the sediment quality measurement endpoints to concentrations previously observed within the reach, where data were available, and sediment quality guidelines;
- graphical presentation of 2010 results describing particle-size distribution, TOC, total metals (both absolute and normalized to percent-fines), total hydrocarbons,

total PAHs (both absolute and normalized to 1% TOC), and predicted PAH toxicity, using an equilibrium-partitioning approach to assessing potential for chronic toxicity from PAH mixtures in sediments described by Neff *et al.* (2005); and

- analysis of the relationship between various sediment quality measurement endpoints and benthic invertebrate community measurement endpoints, using correlation analysis.

Selection of Sediment Quality Measurement Endpoints

The selection of sediment quality measurement endpoints (Table 3.2-7) 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 2003);
- 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:
  - o the importance of various sediment quality variables to interpreting the results of the Benthic Invertebrate Communities component; and
  - o approaches and appropriate analytical strategies for the Sediment Quality component.

Table 3.2-7 Potential sediment quality measurement endpoints.

Variable Group	EIA Review: Variables Listed in EIAs	RAMP 5-Year Report (Golder 2003)	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 (parent+alkylated)	Parent PAHs Alkylated PAHs Naphthalene Dibenzothiophenes Retene Predicted PAH Toxicity
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 potential for chronic toxicity of all PAHs in a sediment sample, following methods described in Neff *et al.* (2005);
- *Metals:* With the exception of total arsenic (see below) and sum of total metals, 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 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).

Tabular Presentation of 2010 Sediment Quality Results

2010 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 2010. Concentrations of any sediment quality measurement endpoint and any metal that exceeded relevant guidelines were also reported.

Classification of Results

Sediment quality in each depositional benthic invertebrate sampling reach in fall 2010 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 3.2.2.3), 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 as benchmarks for comparison. All sediment quality data collected by RAMP since 1997 at all stations classified as *baseline* were used to develop *baseline* ranges of sediment quality. 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.

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 2010 (n=281), sediment quality index values of 82.2 to 100.0 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.

Sediment quality index scores were not calculated for lakes, following concerns expressed by the 2010 RAMP Peer Review (AITF 2011) regarding combining streams and lakes in the determination of regional *baseline* ranges.

3.2.4 Fish Populations Component

The analytical approach used in 2010 for the Fish Populations 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 covariance (ANCOVA) on fish population measurement endpoints to test for differences in time trends, and/or differences between *baseline* and *test* reaches;
- presenting results in tabular and graphical format comparing 2010 fish population measurements endpoints to historical or baseline results for each monitoring activity; and
- selecting and using criteria to assess change in fish population measurement endpoints both spatially and temporally.

3.2.4.1 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).

Temporal Trends and Spatial Comparisons

Temporal comparisons to assess changes over time were conducted by season as well as spatial comparisons between areas of the river for each measurement endpoint. 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, goldeye, and lake whitefish).

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 a measure of relative abundance for each species (catch per unit effort - CPUE). These measurement endpoints were calculated for each area on a river, for each season. Temporal comparisons were graphically presented in order to compare species composition and CPUE between 1987 and 2010 for each of the large-bodied KIR species (and lake whitefish in fall only), for each season.

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 (all seasons combined). Length classes were divided into 25 mm increments for goldeye, and 50 mm increments for walleye, longnose sucker, white sucker, and northern pike.

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

- Fish condition (or “how fat a fish is”) was compared among years (1987 to 2010) for each season using analysis of covariance (ANCOVA; $\alpha = 0.05$), where body weight ($\log_{10}$ transformed) was the dependent variable, year was the independent variable, and fork length ($\log_{10}$ transformed) was the covariate; and

- Fulton’s Condition Factor was calculated as K= (body weight/fork length^3)x100, and used in tabular and graphical presentations showing mean condition for each species, per season, over time (1997 to 2010) compared to the mean condition of fish captured from 1986 to 1996.

In order to be consistent with past analyses, 2010 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 large-bodied KIR species in each area of the river was evaluated over time, with the exception of lake whitefish for which only fall condition was evaluated over time due to insufficient sample sizes in spring and summer.

Incidence of External Health Abnormalities The incidence of external fish health abnormalities were evaluated for all species captured during the Athabasca River and Clearwater River fish inventories. The following metrics were calculated relative to the total number of fish captured:

- Percent of fish of each species in each season with fin erosion and body wounds; and

- Percent of fish of each species with external pathology, including parasites, growths/lesions, and body deformities.

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, as defined by ASRD, were calculated and compared over time (1997 to 2010) 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.

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 2010.

Classification of Results

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.

3.2.4.2 Regional Lakes Fish Tissue Studies

Selection of Measurement Endpoints

Whole-organism metrics (fork length, body weight and age) and mercury burden (both absolute concentration and the concentration standardized to fish weight for regional comparisons) were the measurement endpoints used to analyze fish tissues results from the three regional lakes (i.e., Keith, Net, and Brutus lakes).

Spatial Comparisons

Measurement endpoints calculated from data collected during the fish tissue program on Keith, Net, and Brutus lakes were used to evaluate fish tissue chemical concentrations and risk to human health.

Whole-organism Metrics Whole-organism metrics (i.e., fork length, body weight, age) were reported along with the sex for individual fish collected during the tissue program in the regional lakes.

Mercury Mercury concentrations were reported for fish collected during tissue programs on the three regional lakes. Scatterplots were used to initially assess relationships between mercury concentrations and fork length, weight, and age for each species. An ANCOVA was used to further evaluate significant correlations between length, weight, and age and mercury concentrations. Assumptions of regression models were tested and, if necessary, analyses were performed using log_{10}-transformed data.

Mercury concentrations in tissue samples from Keith, Net, and Brutus lakes were compared to fish tissue mercury concentrations from lakes in the region previously sampled by RAMP to assess spatial differences. Spatial differences in mercury concentrations of fish for each species were compared between lakes using and ANOVA ($\alpha = 0.05$). The size of lake is also a contributing factor to bioavailability of mercury to fish (Beckvar *et al.* 1996, Heyes *et al.* 2000). Therefore, the size of lake sampled was tested using an ANOVA ($\alpha = 0.05$) to see if size was a significant influencing factor on mercury concentrations in fish.

Comparison to Published Guidelines

Mercury measured in fish collected from the regional lakes was used to evaluate potential risk to human health.

Potential Risk to Human Health To assess potential risk to human health due to ingestion of fish tissues, fish tissue mercury data were screened against the Health Canada guidelines for general fish consumption (0.5 mg/kg) (Health Canada 2007, last updated July 2007) and subsistence level fish consumption (0.2 mg/kg) (Health and Welfare Canada 1979, INAC 2003, updated June 2006).

Mercury has a Health Canada consumption guideline, both for general and subsistence consumers, which are risk-based values that take into account the toxicity (including carcinogenicity) of the contaminant, body weight of the consumer, and exposure rate. In addition, the Government of Alberta has released fish consumption guidelines for fish captured within the RAMP FSA, developed through a risk assessment of fish mercury data collected through RAMP (GOA 2009). The consumption limits were established for fish species from specific waterbodies previously sampled by RAMP and ASRD, and given the differences in physical factors between waterbodies, which can influence the production of methylmercury in a system (Beckvar *et al.* 1996, Heyes *et al.* 2000), the guidelines are not directly applicable to the lakes sampled in 2010.

Health Canada's mercury guideline is for total mercury and not methylmercury, which is the form of mercury taken up by fish. The guideline makes 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 (Bloom 1992, Beckvar *et al.* 1996, Health Canada 2007). Guidance accompanying the mercury guideline 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 (0.5 mg/kg) of total mercury in fish (Health Canada 2007) is less conservative than its guideline for subsistence-level consumption (0.2 mg/kg) of total mercury (INAC 2003), which was originally derived from various studies on the toxicity of methylmercury to Aboriginal consumers (Health and Welfare Canada 1979).

Classification of Results

Summary indicators of 2010 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 the size of fish consumed. Table 3.2-8 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 2010. 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.

Table 3.2-8 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 concentrations above the subsistence fisher guideline (0.2 mg/kg)	Average mercury concentration above the general consumer guideline (0.5 mg/kg)

3.2.4.3 Sentinel Species Monitoring

Selection of Measurement Endpoints

Measurement endpoints selected for sentinel species monitoring on the Athabasca River are summarized in Table 3.2-9. These are based on Environment Canada's Environmental Effects Monitoring (EEM) guidelines developed for the metal mining and pulp and paper sectors (Environment Canada 2010).

The measurement endpoints for lethal sentinel species monitoring were calculated as follows:

- Age = mean age;
- Growth = weight-at-age;
- Condition Factor (K) = 100*(body weight/length^3);
- Gonadosomatic index (GSI) = 100*(gonad weight/body weight); and
- Liversomatic index (LSI) = 100*(liver weight/body weight).

Table 3.2-9 Measurement endpoints for sentinel species monitoring on the Athabasca River (EEM 2010).

Response	Measurement Endpoints	Dependent Variable	Covariate
Age	Age	Age	None
Energy Use	Growth	Body weight	Age
	Gonad Size (GSI)	gonad weight	Body weight
Energy Storage	Liver Size (LSI)	Liver weight	Body Weight
	Condition	Body weight	Fork length

Temporal Trends and Spatial Comparisons

The two *baseline* sites are upstream and downstream of the Fort McMurray sewage treatment plant (STP). The influence from the Fort McMurray sewage treatment plant (STP) makes it difficult to determine the most appropriate *baseline* site to compare the three *test* sites. In 2002, Site 2 was used as the *baseline* site because it provided a more similar chemical environment to the *test* sites (i.e., all four sites were downstream of the STP). Similarly in 2010, water quality sampled at RAMP stations in the vicinity of all trout-perch sentinel monitoring sites downstream of the STP have similar water quality characteristics. However, water quality at two RAMP stations near Donald Creek (ATR-DC-E, ATR-DC-W) located between the STP and the sentinel species Site 2 on the Athabasca River exhibited nutrient concentrations and conductivity similar to water quality sampled upstream of Fort McMurray by AENV (ATR-UFM). Therefore, water quality data in 2010 indicated that the STP had very little effect on water quality at *baseline* Site 2, most likely due to dilution (Site 2 is approximately 15 kilometers downstream of the STP). This finding suggests that water quality is not necessarily a suitable criterion to define Site 2 as the more appropriate *baseline* site.

More conclusive evidence that *baseline* Site 2 was a more representative *baseline* site was based on physical habitat characteristics. The Athabasca River upstream of Fort McMurray, where *baseline* Site 1 is located, is comprised predominantly of cobble bars with little fine substrate, whereas habitat downstream of Fort McMurray was predominantly sand and silt with few cobble/boulder areas. Therefore, comparisons were made between *baseline* Site 2 and *test* sites 3, 4, and 5 and between *baseline* Site 1 and *baseline* Site 2 to determine if any differences are observed between *baseline* sites.

Based on the differences between *baseline* Site 1 and *baseline* Site 2, the following spatial comparisons were evaluated for 2010 and between 2002 and 2010:

- Between *baseline* sites (i.e., upstream of Fort McMurray vs. downstream of Fort McMurray to test the impact of the sewage treatment plant and other municipal effects);
- *Baseline* Site 2 versus average of all *test* sites;
- *Baseline* Site 2 versus Site 3 (first *test* site);
- *Baseline* Site 2 versus Site 4 (second *test* site); and
- *Baseline* Site 2 versus Site 5 (third *test* site).

The analyses frequently resulted in significant variations in the slope of the relationship between the dependent variable and the covariate across site-year combinations. Those situations make interpretation of the data challenging because the magnitude of the effect depends on the value of the dependent variable. Barrett *et al.* (2010) recommended retaining the interaction term in ANCOVA only when it improves the overall model fit by more than a few percentage points. Here, we retained the interaction term when it improved the model fit by at least 5%. In addition, Lowell and Kilgour (2008) recommended calculating the effect size at extreme values of the dependent variable and reporting the effect size as being equivalent to the largest observed difference. This was the approach taken here when different slopes was considered to improve overall explained variation.

The effect sizes (i.e., percent difference from the *baseline* site) were calculated as:

$$ES = \frac{100 * (\bar{y}_1 - \bar{y}_2)}{\bar{y}_1}$$

where,

$\bar{y}_1$ is the mean response of treatment combination 1; and

$\bar{y}_2$ is the mean of treatment combination 2.

The effect sizes were calculated for each spatial comparison for each year (1999, 2002, and 2010). The mean $\bar{y}$ values were derived from the least-square means or the predicted means for a common average x.

For testing for possible differences in age of trout-perch between *baseline* Site 2 and *test* sampling sites, mean age was compared among sites over time using ANOVA ($\alpha = 0.05$), where age represented the dependent variable and site the independent variable.

For testing for possible differences in the growth of trout-perch between *baseline* Site 2 and *test* sampling sites, size-at-age was compared among sites over time using ANCOVA ($\alpha = 0.05$), where age represented the dependent variable, site the independent variable, and body weight the covariate.

For testing for possible differences in reproduction of trout-perch between *baseline* Site 2 and *test* sampling sites, relative gonad size was compared among sites over time using an ANCOVA ($\alpha = 0.05$), where gonad size represented the dependent variable, site the independent variable, and weight the covariate. Relative liver size was also compared among reaches, where liver size represented the dependent variable, site the independent variable, and body weight the covariate.

For testing for possible differences in condition of trout-perch between *baseline* Site 2 and *test* sampling sites, condition factor was compared among sites over time using ANCOVA ($\alpha = 0.05$), where body weight represented the dependent variable, site the independent variable, and length the covariate.

Power analysis was used to determine the required sample size to effectively detect the difference in measurement endpoints between *baseline* and *test* sites, assuming a 5% probability of committing a Type I error and a 95% probability of detecting the difference, and the unexplained variability (i.e. the population standard deviation). Power was calculated by re-arranging the following power equation (Green 1989):

$$n = \frac{2(t_\alpha + t_\beta)^2 \sigma^2}{\delta^2}$$

where,

n is the number of fish;

σ is the population standard deviation;

δ is the specified effect size;

t_α is the Students *t* statistic for a two-tailed test with significance level α; and

t_β is the Students *t* statistic for a one-tailed test with significance level β.

The estimated site-year standard deviation was the square-root of the pooled mean squared error term from the ANOVA or ANCOVA from the 2002 and 2010 data. Separate estimates of site-year standard deviation were generated for male and female trout-perch.

Classification of Results

The selected criteria for determining change in a measurement endpoint for sentinel species monitoring was established for the Pulp and Paper Environmental Effects Monitoring (EEM) Program (Environment Canada 2010) as a measure for determining change in a sentinel fish species population. The criteria are as follows:

- ± 25% difference in age of fish collected at a *test* site from age of fish collected at a *baseline* site;
- ± 25% difference in growth (weight-at-age) in fish collected at a *test* site from growth (weight-at-age) of fish collected at a *baseline* site;
- ± 25% difference in GSI in fish collected at a *test* site from GSI of fish collected at a *baseline* site;

- ± 25% difference in LSI in fish collected at a *test* site from LSI of fish collected at a *baseline* site; and

- ± 10% difference in condition in fish collected at a *test* site from condition of fish collected at a *baseline* site.

There are two steps in determining the classification of the effects criterion as Negligible-Low, Moderate, or High (Table 3.2-10):

- an exceedance of the effects criteria on any one of the three responses (age, energy use [weight-at-age, GSI], energy storage [LSI, K]) observed at a *test* site compared to *baseline* Site 2 in the current sampling year; and

- an exceedance at a *test* site in two consecutive years of sampling, including the current year.

Table 3.2-10 Classification of results for the sentinel species monitoring program.

Criteria	Negligible-Low	Moderate	High	"Yes"
Exceedance in current sampling year	No	Yes	Yes	Exceedance of the effects criteria on any one of the three responses at a *test* site compared to the *baseline* site.
Exceedance across sampling years	No	No	Yes	Exceedance of the effects criteria on any one of the three responses in two consecutive sampling years.

3.2.5 Acid-Sensitive Lakes Component

The analytical approach used in 2010 for the ASL component was in accordance with methods outlined in the RAMP Technical Design and Rationale (RAMP 2009b). The analytical approach consisted of:

- selecting ASL measurement endpoints;
- developing criteria to be used in detecting changes in ASL measurement endpoints; and
- detailed data analysis of 2010 results.

Minor changes and additions to the analyses described in the RAMP Technical Design and Rationale document are included in Section 3.2.5.8.

3.2.5.1 Selection of Measurement Endpoints

The measurement endpoints for the ASL component in 2010 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 many 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, and Legge 1988). The poor correlation between sulphate and H^+ in the RAMP ASL component lakes was demonstrated in RAMP (2004).

3.2.5.2 Temporal Trends

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

Among-Year Comparisons of Measurement Endpoints A one-way analysis of variance (ANOVA) was conducted to determine whether there have been any significant changes in the mean concentrations of each ASL measurement endpoint in the 50 RAMP lakes during the nine years of monitoring when all lakes were sampled (2002 to 2010). 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 test for differences 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 (i.e., $\alpha \geq 0.05$). Any observed changes were discussed in relation to acidification, natural variability and other possible causes unrelated to emissions of acidifying substances.

Among-Year Comparisons of Measurement Endpoints using the General Linear Model Analysis of variance using the General Linear Model (GLM) was applied to the data to examine trends in measurement endpoints over time in the ASL component lakes. The model regresses the concentration of a measurement endpoint against time in each individual lake and determines the overall significance of the regressions over the 50 lakes. This test is more powerful than the one-way ANOVA for detecting potential changes in a measurement endpoint over time because potential changes are examined in each individual lake rather than between the mean values over all the lakes. The GLM 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 to be most sensitive to acidification (high potential acid input/low critical load; see below). The sign and significance of the individual regression coefficients for each lake were also examined.

Calculation of Critical Loads of Acidity and Comparison to Modeled Potential Acid Input The critical load (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 2010 were calculated using the Henriksen steady state water chemistry model modified for the effects of organic acids on buffering and acid sensitivity. Details of the model and its assumptions are described below.

3.2.5.3 The Modified Henriksen Model

The original Henriksen model was modified to account for both the buffering of weak organic anions and the lowering of ANC attributable to strong organic acids. The modified model assumed that DOC, with its associated buffering from weak organic acids (ANC_{org}) and reduction of ANC from strong organic acids (A^-_{SA}), was exported from the catchment basin to each lake in the same way that we assume the export of base cations (carbonate alkalinity) to each lake. The modified Henriksen model is:

$$CL= ([BC]^*_0 + ANC_{org} - A^-_{SA} - ANC_{lim}) .Q$$

Where,

$[BC]^*_0$	is the original base cation concentration before acidification;
ANC_{lim}	is the limiting acid-neutralizing capacity of the lake required to maintain a healthy and functional aquatic ecosystem;
ANC_{org}	= 0.00680* DOC exp(0.8833*pH);
A^-_{SA}	= 6.05 *DOC +21.04; and
Q	is the runoff to each lake from the catchment and lake area.

The modifications of the Henriksen model for organic acids and the empirical relationships for developed for ANC_{org} and A_{-SA} are described in WRS (2006) and RAMP (2009b).

3.2.5.4 Calculation of Runoff (Q)

The runoff (Q) to each lake, was calculated from analysis of heavy isotopes of oxygen (^{18}O) and (^{2}H) in each lake conducted and provided by John Gibson (University of Victoria). With this technique, the natural evaporative enrichment of ^{18}O and ^{2}H in each lake 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, and Gibson *et al*. 2010). This technique utilizes a different set of assumptions from traditional hydrometric methods, which extrapolate water yields from one or more gauged catchments to the ungauged lake catchments. Potential inaccuracies in the traditional hydrometric method, especially in low-relief catchments, have previously been recognized in lakes in the Athabasca oil sands region (WRS 2004).

3.2.5.5 Original Base Cation Concentration ($[BC]^*_0$)

During the process of acidification of a catchment, base cations are released from the soils to the lake waters. In applying the Henriksen model, it was assumed that base cations have not increased in these lakes as a result of acidic deposition; that is, the current base cation concentrations are equivalent to the original values. This simplifying assumption was adopted for the following two reasons:

1. The discrepancy between the original and the current base cation concentrations in a lake is normally calculated by an equation presented in Brakke *et al.* (1990) based on increases in sulphur concentrations in a lake resulting from aerial deposition. Calculations of $[BC]^*_0$ using the Brakke *et al.* (1990) equation indicated that there is an insignificant difference between the current and calculated original base cation concentrations in all 50 lakes (See Appendix H).

2. A study by Whitfield *et al.* (2010) in which the Magic Model was applied to the Athabasca oil sands region concluded that, to date, sulphate deposition levels have resulted in only a limited removal of base cations from the soil.

3.2.5.6 Choice of ANC_{lim}

The critical load concept as expressed in the Henriksen model assumes a dose-response relationship between a water quality variable and an aquatic indicator organism. In this case, the water quality variable is the acid-neutralizing capacity (alkalinity) required to maintain a healthy fish population. In applying the Henriksen model in Europe, a critical threshold ANC_{lim} of 20 μeq/L was set to protect brown trout, the most common European salmonid, and to ensure that no toxic acidic episodes occur to this species during the year.

In North America, the effects of acidification on biota have been historically related to pH rather than alkalinity or acid-neutralizing capacity. Research on pH tolerance of a wide range of aquatic organisms has shown that a pH>6 is required to maintain aquatic ecosystem functioning and protect both fish and other organisms (RMCC 1990, Environment Canada 1997, Jeffries and Lam 1993). Within a given region, lake pH has been empirically and theoretically related to alkalinity as an inverse hyberbolic sine function (Small and Sutton 1986) and this relationship has been used to equate the two variables for the purpose of critical load modelling (e.g., Jeffries and Lam 1993). The relationship between pH and alkalinity for the Athabasca oil sands region was derived from a water quality survey conducted on lakes in the ALPAC forest management area (WRS 2000, see Appendix G). Across these lakes, a pH of 6.0 is associated with an alkalinity of ~75 μeq/L. Accordingly, this value was chosen for ANC_{lim} in the Acid Deposition Management Framework for the Athabasca oil sands region (CEMA 2004b) and has been applied in numerous studies (e.g., Gibson *et al.* 2010).

3.2.5.7 Comparisons to Modelled PAI

The critical loads for each lake were compared with levels of the Potential Acid Input (PAI) to each lake basin taken from the Maximum Emissions Scenario summarized in CEMA (2010c). This emissions scenario was based on the emissions database compiled by Alberta Environment. The ability of nitrates to be assimilated and used as a nutrient by plants within the lake catchment was accounted for by applying the approach adopted by CEMA and AENV whereby any nitrogen deposition in excess of 10 kg/ha/y and 25 % of the first 10 kg/ha/y deposited N were considered acidifying (CEMA 2008, AENV 2007b).

Mann Kendell Trend Analysis on Measurement Endpoints in Individual Lakes Potential trends in measurement endpoints were examined in all 50 lakes using Mann-Kendall trend analysis. Significant trends were examined and discussed in relation to previous hydrologic events and the logical consistencies (or inconsistencies) of these observed trends. The program used for the analysis (MAKESENS) 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. 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 were 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 deemed most likely to Acidify. The pH, Gran alkalinity, sulphate, sum of base cations, 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 the ratio of modeled PAI to CL. The higher the ratio in a given lake, the greater is the risk for acidification of this lake. 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, Systat 2004). A trend in the value of a measurement endpoint was determined on the basis of the criteria described below. As there is a low probability (1% or less) that these criteria will be violated in a truly random population of a measurement endpoint, there is a high probability of detecting a true trend in a measurement endpoint over time. The visual presentation of the data in charts permits the detection of trends before significant changes actually occur.

The following criteria were used to identify a trend or potential risk for acidification using Shewhart control plots (from Systat 2004):

- One year where a measurement endpoint is beyond three standard deviations (on either side).
- Nine consecutive years where a measurement endpoint is on one side of central line (mean value).
- Six consecutive years where a measurement endpoint is steadily increasing or decreasing.
- Two out of three consecutive years where a measurement endpoint is outside the two standard deviations limit (on one side). This is a modified version of the first test. This gives an early warning that the measurement endpoints might be going “out-of-control”.
- Four out of five consecutive years where a measurement endpoint is outside the one standard deviation limit (on one side). This test is similar to the previous one; this test may also be considered to be an early warning indicator of a measurement endpoint going “out-of-control”.

3.2.5.8 Supporting Analyses

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

- 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 2010 to the range of chemical characteristics of lakes within the Athabasca oil sands region;
- Classification of the ASL component lakes by water chemistry using piper plots; and
- Analysis of metals in the individual RAMP lakes.

Update of the ASL Database, Summary Statistics and Comparisons of RAMP ASL Chemistry to Regional Lake Chemistry The water quality chemistry data from 2010 and all the monitoring years combined were tabulated and summarized statistically. Lakes with unusual chemical characteristics were identified based on the 5th and 95th percentiles in the values of the 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 NO_xSO_x Management Working Group (NSMWG, WRS 2004). The comparison is used to determine how typical the ASL component lakes are of lakes within the Athabasca oil sands region. Comparisons involved:

- examination of the ranges, medians and mean values of key variables for 2010 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 ASL component lakes and a dataset of lakes in the oil sands region (WRS 2001).

Classification of the ASL Component Lakes in Piper Plots Piper plots were used to characterize the waters in each of the ASL component lakes according to the major chemical constituents. A piper diagram is a multivariate graphical technique that is used to divide the lakes into four water types on the basis of major cations and anions (Güler *et al*. 2002, Freeze and Cherry 1979, and Back and Hanshaw 1965). The four water types are described below:

- Type I Ca^{2+} - Mg^{2+} - HCO_3^-;
- Type II Na^+ - K^- - HCO_3^-;
- Type III Na^+- K^- - Cl^- - SO_4^{2-}; and
- Type IV Ca^{2+} - Mg^{2+} - Cl^- - SO_4^{2-}.

Principal Components Analysis of the RAMP ASL Data Principal Components Analysis (PCA) was applied to the RAMP ASL component lakes in order to group the lakes into specific lake types or categories based on lake chemistry. The PCA concentrated on the conventional variables including the measurement endpoints. The data were examined first for normality and inter-correlation of the water quality variables. Highly correlated variables were determined using a Spearman rank correlation analysis and were eliminated from the analysis. As only a handful of variables appeared to be normally distributed, the data for the PCA were $\log_{10}$-transformed. In order to account for the large differences in scale between chemical variables, the values of each variable were standardized to a mean of zero and divided by the standard deviation (ter Braak and Smilauer 2002 and Güler *et al.* 2004). The final list of variables included pH, Gran alkalinity calcium, sodium, sulphate, nitrates, ammonia, total nitrogen, DOC, conductivity, total phosphorus, dissolved iron and dissolved aluminum. Lake groupings were discussed on the basis of their chemistry and location (physiographic region).

Analysis of Metal Concentrations in the RAMP ASL Lakes The total and dissolved metal fractions from nine years of monitoring by AENV (2001, 2003 to 2010) were tabulated and summarized statistically. Lakes having relatively high metal concentrations were identified as those exceeding the 95^{th} percentile concentration for individual metals. Exceedances of the Alberta and CCME surface water quality guidelines were also identified (CCME 2011, AENV 1999b). The lakes and physiographic regions having the highest metal concentrations were identified and plotted on regional maps. Trend analysis was conducted on selected metals linked with acidification

3.2.5.9 Classification of Results

A summary of the state of the ASL component lakes in 2010 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 monitoring years. The number of lakes in 2010 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% measurement endpoint-lake combinations exceeding ± 2 SD criterion;
- Moderate - subregion has 2% to 10% measurement endpoint-lake combinations exceeding ± 2 SD criterion; and
- High - subregion has > 10% measurement endpoint-lake combinations exceeding ± 2 SD criterion.

4.0 CLIMATIC AND HYDROLOGIC CHARACTERIZATION OF THE ATHABASCA OIL SANDS REGION IN 2010

The following characterization of the 2010 climate and hydrology of the Athabasca oil sands region and comparison with long-term climate and hydrology information provides context for the results of the 2010 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 regional context.

The following discussion is based on the 2010 water year (WY), from November 1, 2009 to October 31, 2010. Use of the 2010 WY provides a more hydrologically-meaningful dataset by containing a single, full winter flow period rather than the two partial winter seasons that would be used with a calendar year approach.

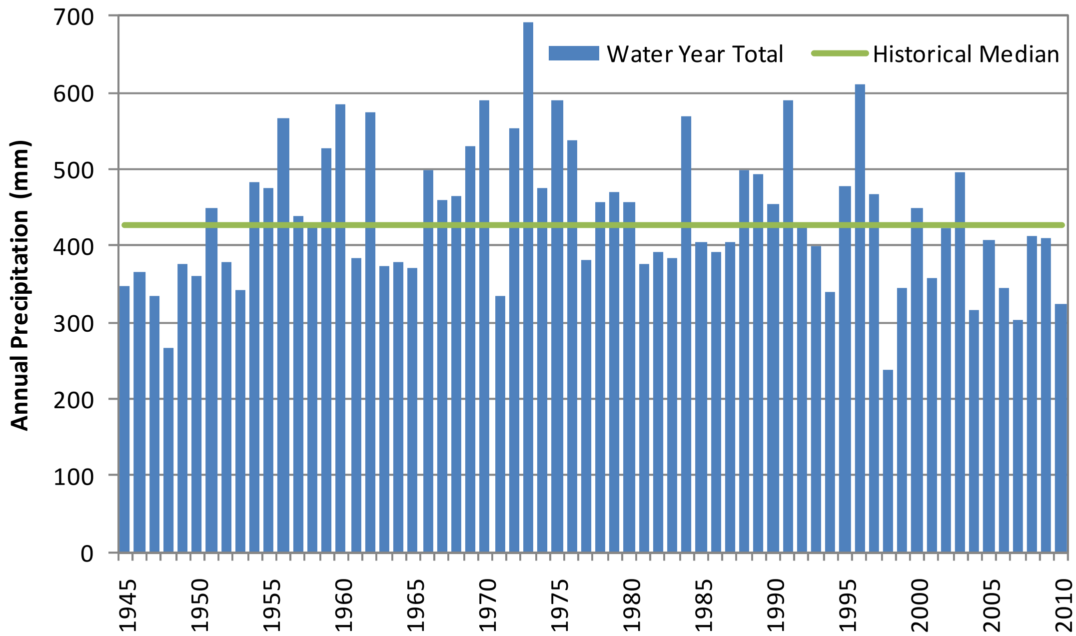
4.1 PRECIPITATION AND SNOWPACK

Long-term precipitation records are available for Fort McMurray from the 1945 WY to the 2010 WY with data collected at Environment Canada (EC) Station 3062693, Fort McMurray A, until July 2008 and EC Station 3062700, Fort McMurray AWOS A, thereafter. Total precipitation measured at this station in the 2010 WY was 326 mm (Figure 4.1-1), which is 25% lower than the long-term annual average for Fort McMurray (from the 1945 WY to the 2009 WY) of 438 mm, and represents the seventh consecutive year in which precipitation measured at Fort McMurray was below average. Monthly total precipitation values were below average in 10 of 12 months in the 2010 WY (November to March, May to July, September, and October) (Figure 4.1-2). Monthly precipitation in April and August exceeded the long-term average for those months by 9% and 8%, respectively. In April, total precipitation was strongly influenced by a substantial snowfall event early in the month with a maximum accumulation of approximately 50 mm over a 24-hour period measured at Mildred Lake and C3-Steepbank Climate Station (Figure 4.1-3).

Precipitation records for EC Mildred Lake Station 3064528 and RAMP stations C1–Aurora Climate Station, C2–Horizon Climate Station, C3-Steepbank Climate Station, L1–McClelland Lake Station, and L2–Kearl Lake Station provide additional characterization of conditions throughout the region in 2010 (Figure 4.1-3). The 2010 WY cumulative precipitation record at all stations was generally below average historical values for the entire year (Figure 4.1-3). For all stations other than EC Mildred Lake Station 3064528, precipitation in the winter period was only half of the historical mean WY precipitation by the end of April. In general, stations to the east of the Athabasca River (Fort McMurray, C1-Aurora Climate Station, L1-McClelland Lake Station, and L2-Kearl Lake Station) received less precipitation than stations to the west (EC Mildred Lake Station, C2-Horizon Climate Station, and C3-Steepbank Climate Station). There was no clear north-south precipitation pattern present in the 2010 WY data.

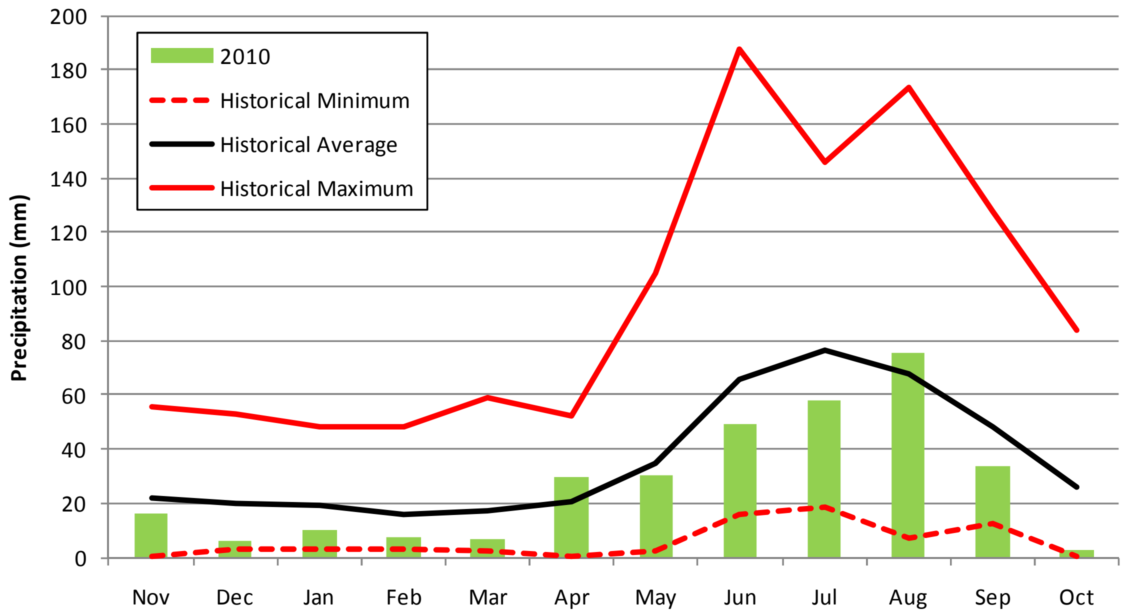
Snowpack amounts (in terms of mm snow water equivalent or SWE) were measured at 16 locations in February, March and April 2010, in each of four land category types (i.e., flat low-lying, mixed deciduous, jackpine, and open land/lake) (Figure 4.1-4). The maximum SWE values recorded for each category are presented in Figure 4.1-4. The six-year (2004 to 2009) average maximum SWE values are included for comparison. Depending on land category, the 2010 maximum SWE amounts were similar to those recorded for 2004 and 2006 and were 21% to 37% lower than the historical average maximum SWE calculated based on the six years of available record. The SWE values in the four land categories differed from the six-year historical averages, with highest SWE values occurring in flat low-lying areas and open land/lake and intermediate amounts occurring in the two sub-canopy categories (mixed deciduous and jackpine stands). The 2010 values do not include SWE input from the snowfall event in early April.

Figure 4.1-1 Historical annual precipitation at Fort McMurray (1945 WY to 2010 WY).



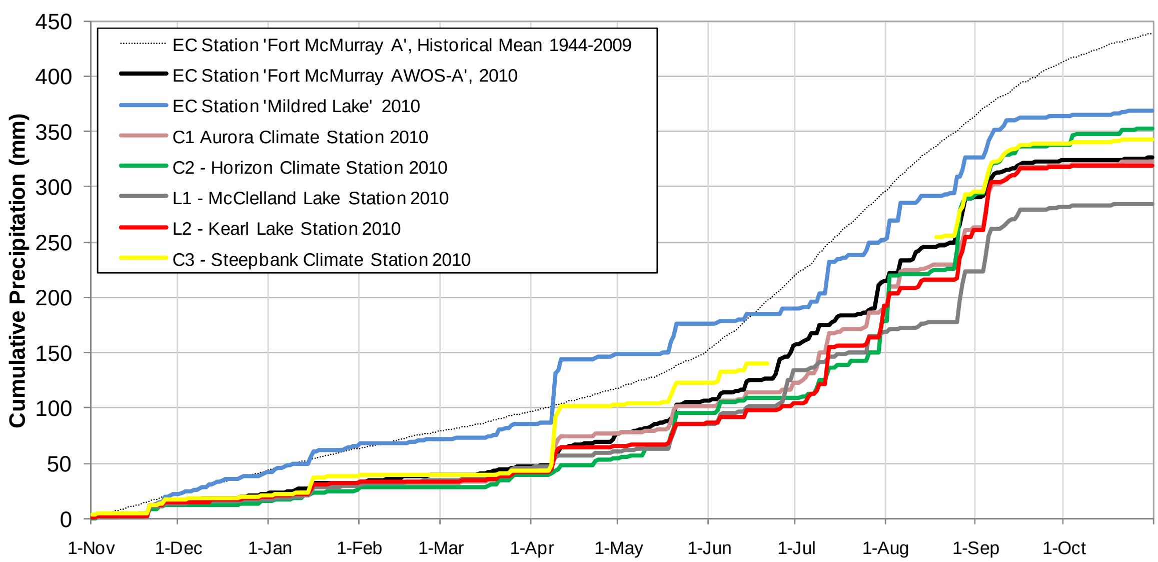
Note: Data recorded at Environment Canada (EC) station 3062693 (Fort McMurray A) from November 1944 until July 2008 and then at EC station 3062700 (Fort McMurray AWOS A) thereafter.

Figure 4.1-2 Monthly precipitation at Fort McMurray in 2010.



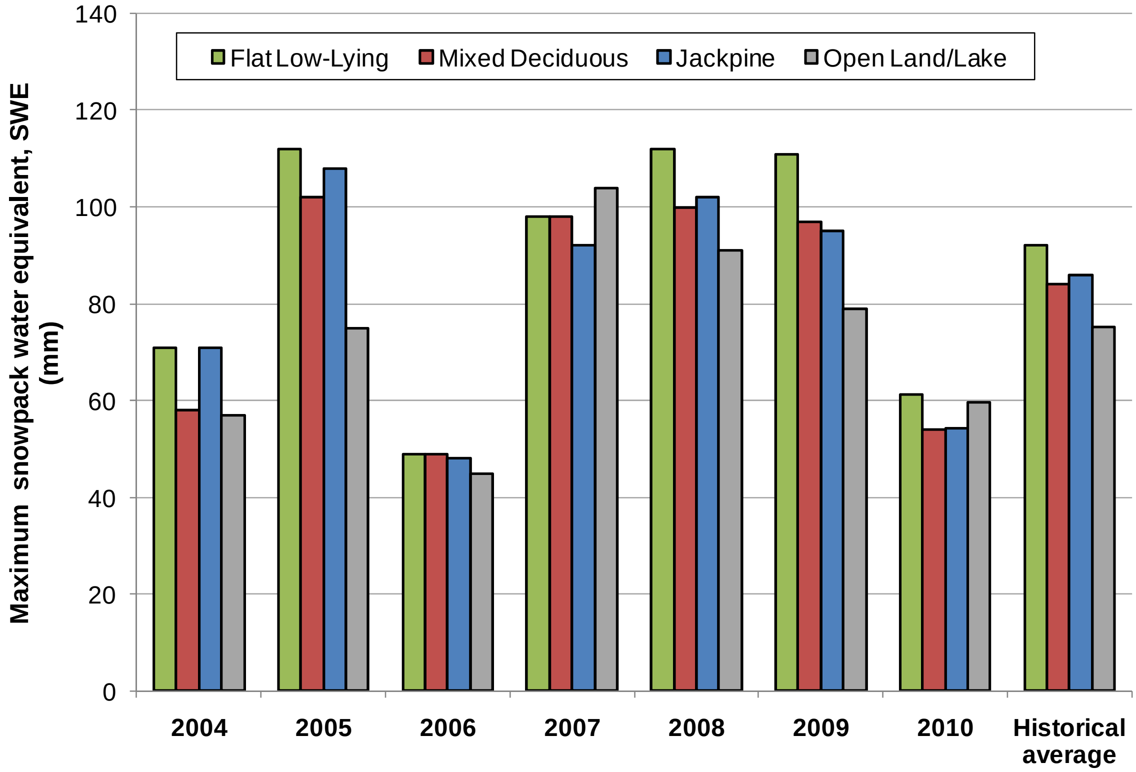
Note: 2010 data recorded at Environment Canada Station 3062700 (Fort McMurray AWOS A); historical values based on data from EC station 3062693 (Fort McMurray A) from November 1945 until July 2008, and at AWOS A thereafter.

Figure 4.1-3 Cumulative total precipitation at climate stations in the Athabasca oil sands region in 2010.



Note: Data at Station C3 is missing from June 26 to August 17. The gap was interpolated by using the cumulative average from three nearby stations (i.e., stations C1 Aurora, EC Mildred Lake, and S40 MacKay River) to complete the cumulative annual record.

Figure 4.1-4 Historical maximum measured snowpack amounts in the Athabasca oil sands region (2004 to 2010).



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

2010 WY provisional hydrographs for four Water Survey of Canada (WSC) stations are presented in the following sections. The WY data are compared to long-term WY flow statistics in order to characterize the 2010 WY 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 River;
- WSC Station 07DB001, MacKay River near Fort McKay, representative of watersheds west of the Athabasca River; and
- WSC station 07CE002, Christina River near Chard, representative of watersheds south of Fort McMurray.

4.2.1 Athabasca River

The total annual flow volume for the Athabasca River measured at WSC Station 07DA001, Athabasca River below McMurray, was 14,050 million m^3 for the 2010 WY (Table 4.2-1). This is 28% less than the long-term WY average flow volume of 19,547 million m^3 over the station's 53-year recording period (1958 to 2010). The 2010 WY flow volume was the fourth-lowest value to occur over the historical record (Figure 4.2-1). Since 1991, all annual flow volumes have been lower than the long-term average with the exception of 1996, 1997 and 2005.

The flow measured at this station was lower than historical median values with the exception of localized peaks in late April, May and early October (Figure 4.2-2). Melting of the snowpack in basins upstream of this station coupled with a significant rain-on-snow event around April 9 (33 mm over three days) likely caused the sharp increase in flow measured in late April. A reduced winter snowpack and freshet period resulted in flow declining to near the historical daily minimum throughout early May. A rainfall event of 20 mm on May 25 resulted in the 2010 WY annual maximum daily discharge of 1,160 m^3/s. This discharge was 54% lower than the historical WY annual daily maximum flow. Thereafter, flow decreased to below the historical WY daily median level again throughout most of June and July. During August, flows gradually increased until September when daily flows were close to the historical WY daily median flow of 655 m^3/s as a result of high rainfall during July and August (Figure 4.1-3). Following rainfall in late August and significant rainfall in early September, flows in the Athabasca River peaked on October 5 at 1,080 m^3/s, an increase of 77% over the historical WY daily median of 609 m^3/s and close to the annual WY daily maximum for that time of the year. This response highlights the impact of increasing antecedent soil moisture conditions (i.e., the increasing relative wetness condition of the soil) during sustained rainfall causing enhanced runoff response to later rainfall events. Flows receded after this event to close to the historical WY daily lower quartile in November. The 2010 open-water period (May 1 to October 31) minimum daily flow of 372 m^3/s recorded on October 31 was 13% lower than the historical mean minimum daily discharge of 429 m^3/s (Table 4.2-1).

4.2.2 Muskeg River

The 2010 seasonal (March to October) runoff volume for the Muskeg River watershed recorded at WSC Station 07DA008, Muskeg River near Fort McKay, was 86 million m^3 (Table 4.2-1). This is 27% lower than the long-term average seasonal runoff volume of 118 million m^3 over the station's 36-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), and the hydrograph in the 2010 WY followed this pattern. During the freshet period, flow peaked at 13 m^3/s on April 29, approximately two weeks earlier than the normal freshet date for this watershed. A secondary peak of 9.4 m^3/s occurred on May 25, reflecting the effect of a major rainfall event at that time (Figure 4.1-3). The freshet peak, also the maximum daily flow of 13 m^3/s was 50% lower than the long-term average maximum daily flow of 26 m^3/s for this location (Table 4.2-1). Streamflow from July to October was close to the historical average minimum daily flow. The 2010 March to October minimum daily flow of 0.42 m^3/s recorded on March 10 was 51% higher than the historical average minimum daily flow of 0.28 m^3/s (Table 4.2-1). Similar to the Athabasca River hydrograph, the Muskeg River also showed a significant response to increased precipitation in late August and early September with a flow of 11.9 m^3/s recorded on September 17 and 18. Although close to the 2010 maximum flow, this storm-driven discharge response was 66% lower than the historical maximum for these dates.

4.2.3 MacKay River

The 2010 seasonal (March to October) runoff volume for the MacKay River watershed recorded at WSC Station 07DB001, MacKay River near Fort McKay, was 308 million m^3 (Table 4.2-1). This is 28% below the long-term average seasonal runoff volume (Figure 4.2-5). The spring freshet hydrograph recorded for the MacKay River was less distinct than for the Muskeg River. The maximum-recorded freshet flow of 22 m^3/s occurred on April 23 (Figure 4.2-6). The MacKay River hydrograph response to the May 25 rainfall event (Figure 4.1-3) resulted in a peak flow of 46.6 m^3/s recorded on May 25. This value was the same as the maximum daily flow of 46.6 m^3/s recorded on September 8 in response to the late August and September rainfall events (Figure 4.1-3). These data further indicate the regional significance of antecedent moisture conditions in determining the hydrological response to rainfall events in producing high flows. Following the early September peak flows, flows in the MacKay River receded to just above the historical median daily flow values and remained at that level until the end of the 2010 WY (Figure 4.2-6). The 2010 March to October minimum daily flow of 0.17 m^3/s recorded on March 1 was 51% lower the historical average minimum daily flow of 0.35 m^3/s (Table 4.2-1).

4.2.4 Christina River

The 2010 seasonal (March to October) runoff volume for the Christina River watershed recorded at WSC station 07CE002, Christina River near Chard, was 503 million m^3 (Table 4.2-1). This value was 19% higher than the long-term average seasonal runoff volume of 422 million m^3 over the 26-year recording period and is the seventh consecutive year of above-average seasonal flow volumes recorded at this station (Figure 4.2-7). Melting of the spring snowpack dominated the hydrograph in this basin during late April and early May with a more sustained response than the other three rivers (Figure 4.2-8). Peak daily flow during this period was 40.4 m^3/s on May 4, which was 123% higher than the historical median daily flow for this date. Following this date, the Christina River hydrograph showed a similar pattern to the other rivers up to late May but continued to increase to a maximum discharge of 80 m^3/s on June 8, almost three times the historical median daily flow of 21 m^3/s for this date. This response suggests a localized, high intensity rainfall event. Rainfall data for this area was not available but the hydrograph from the WSC Pony Creek gauging station (07CE003), located approximately 5 km from the Christina River gauging station exhibited a similar pattern in late May and June. Hydrograph peaks centered on June 8 are also present on the Athabasca River, Muskeg River and MacKay River hydrographs but were recorded as a less significant event in the context of the respective annual hydrographs.

Flows receded through the remainder of June and July and August until the September rainfall event (Figure 4.1-3). A peak discharge of 35.4 m^3/s during this period was recorded on September 10. In contrast to the other stations, flows after this event remained approximately 68% above the historical median daily flow until the end of the 2010 WY. The 2010 seasonal (March to October) minimum daily flow of 4.75 m^3/s recorded on March 1 was 105% higher than the seasonal historical average minimum daily flow of 2.30 m^3/s (Table 4.2-1). These data suggests a wetter than normal year in the Christina River watershed, in contrast to the other three watersheds.

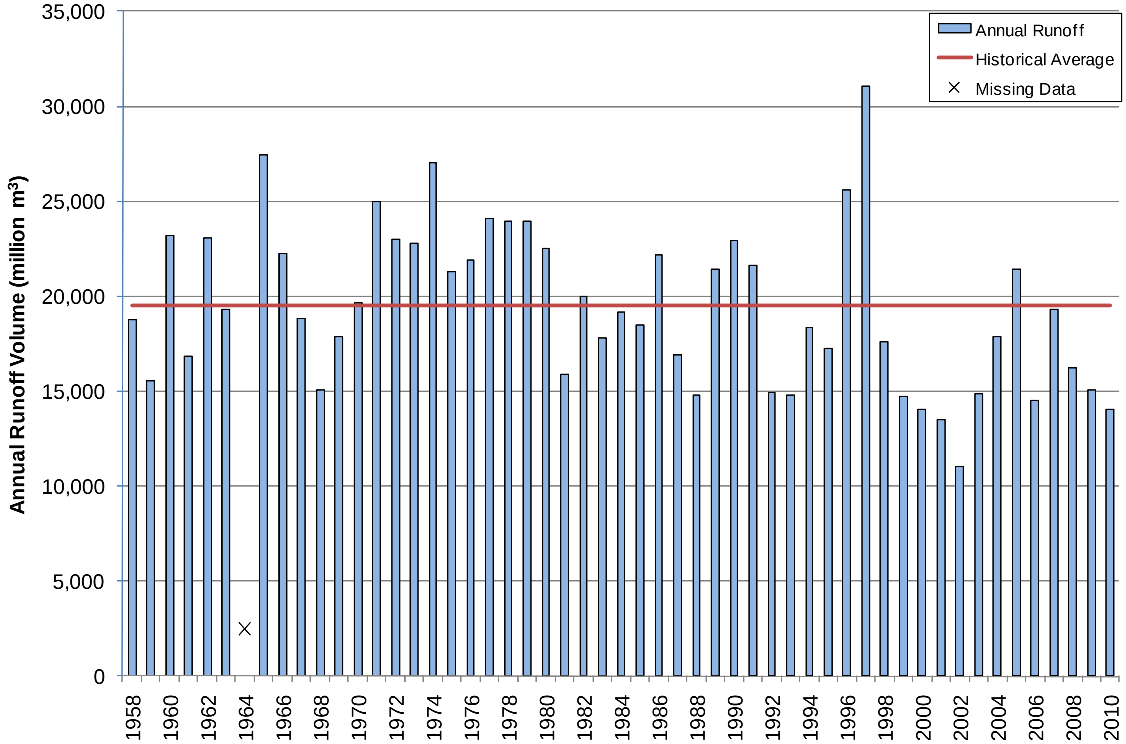
Table 4.2-1 Summary of 2010 streamflow variables compared to historical values measured in the Athabasca oil sands region.

Streamflow Variable	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 - 2010	1974 - 2010	1973 - 2010	1983 - 2010
Runoff Volume[1]				
Historical mean (million m^3)	19,547	118	430	422
2010 (million m^3)	14,050	85.7	308	503
Maximum Daily Discharge[1]				
Historical mean (m^3/s)	2,504	26.0	117	82.4
2010 (m^3/s)	1,160	13.0	47.8	80.0
Minimum Daily Discharge[2]				
Historical mean (m^3/s)	429	0.28	0.35	2.30
2010 (m^3/s)	372	0.42	0.17	4.75

[1] Annual water year (November 1 to October 31) 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.

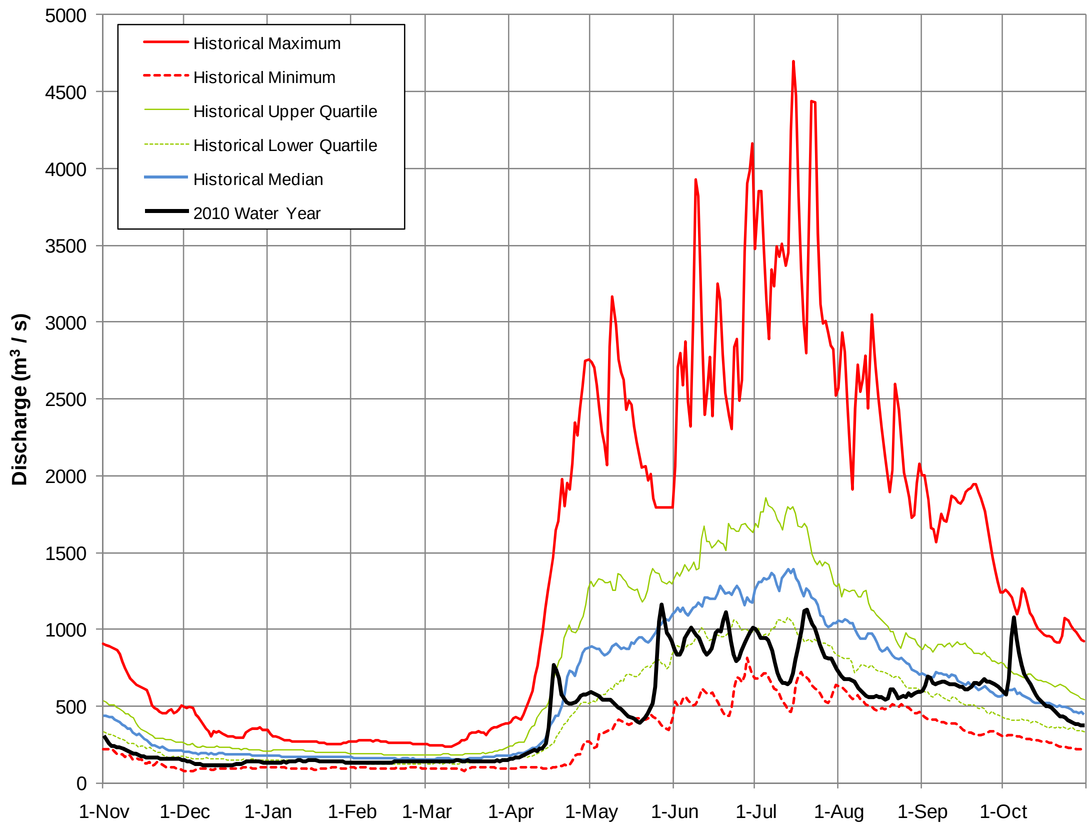
[2] Open-water (May to October) minimum daily discharge provided for the Athabasca River below Fort McMurray (07DA001), while seasonal (March to October) minimum daily discharge are provided for the other three stations.

Figure 4.2-1 Historical annual runoff volume in the Athabasca River basin, 1958 to 2010.



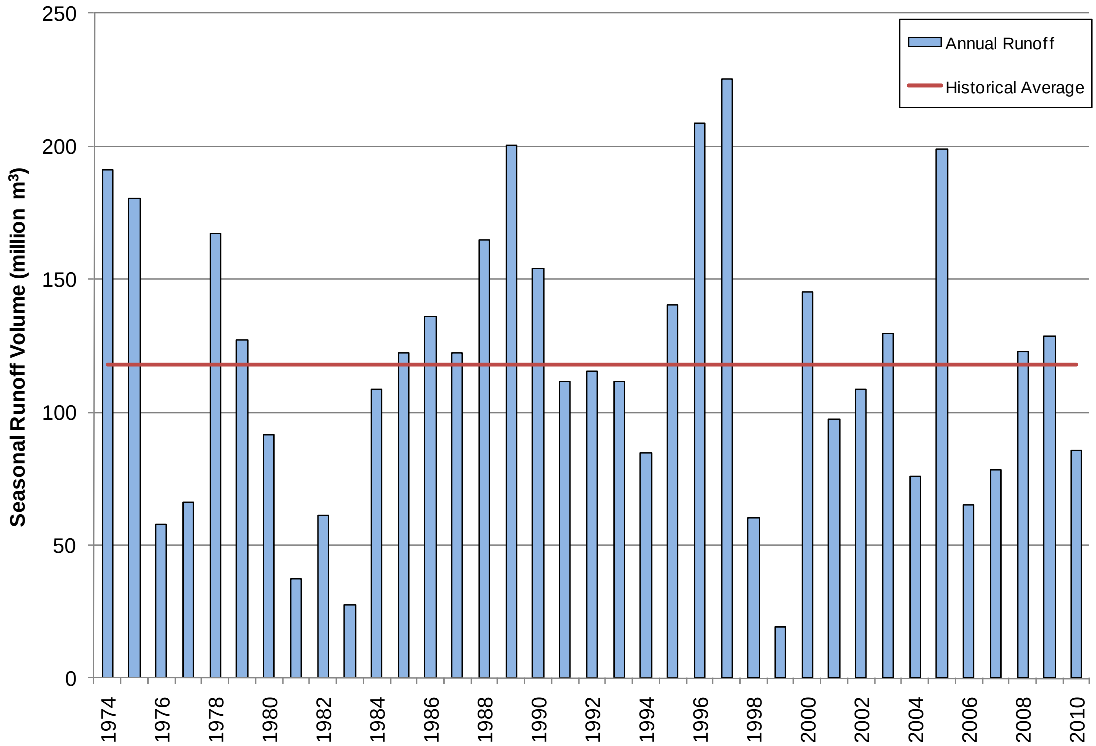
Note: Based on data recorded from 1958 to 2010 at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2.

Figure 4.2-2 The 2010 WY Athabasca River hydrograph compared to historical values.



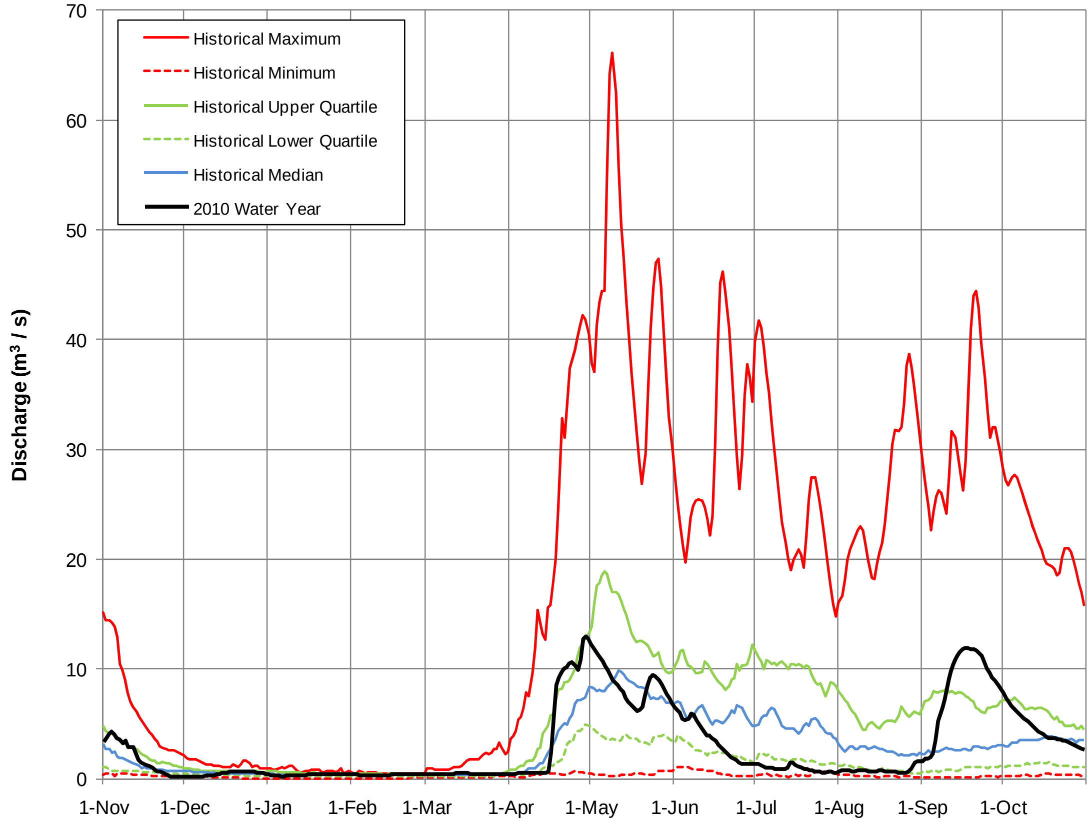
Note: Based on data recorded at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2. Historical values were calculated for the period 1958 to 2009.

Figure 4.2-3 Historical seasonal (March to October) runoff volume in the Muskeg River basin, 1974 to 2010.



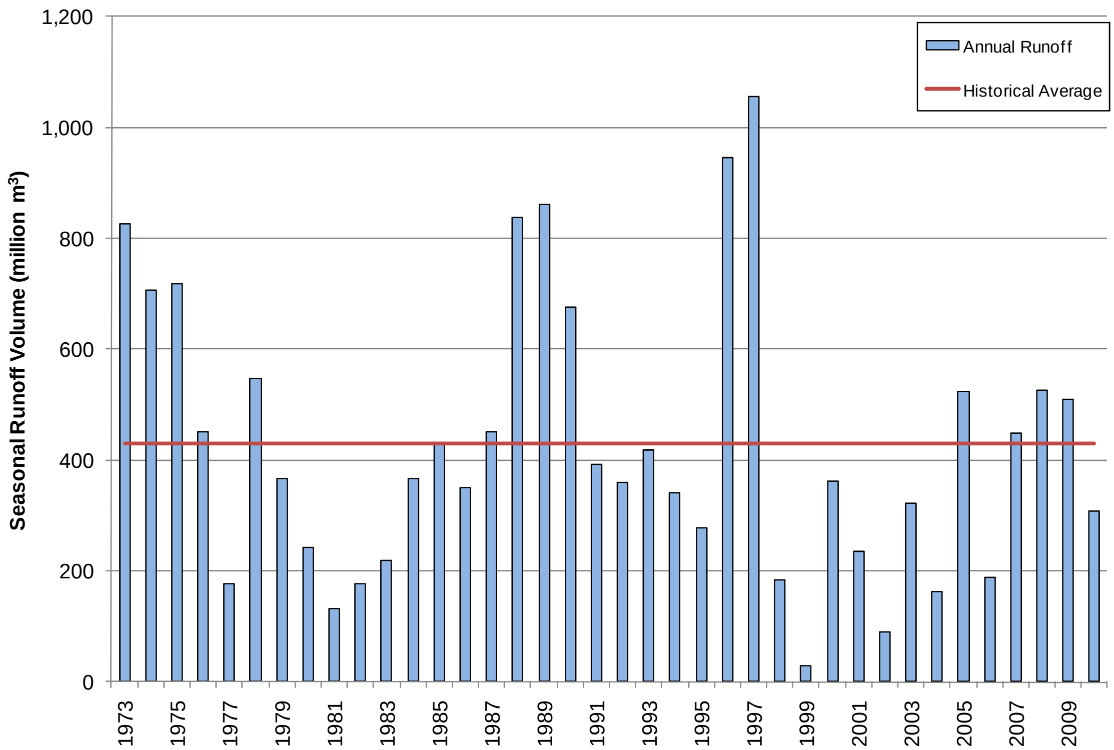
Note: Based on data recorded from 1974 to 2010 at WSC Station 07DA008, Muskeg River near Fort McKay; the upstream drainage area is 1,457 km^2.

Figure 4.2-4 The 2010 WY Muskeg River hydrograph compared to historical values.



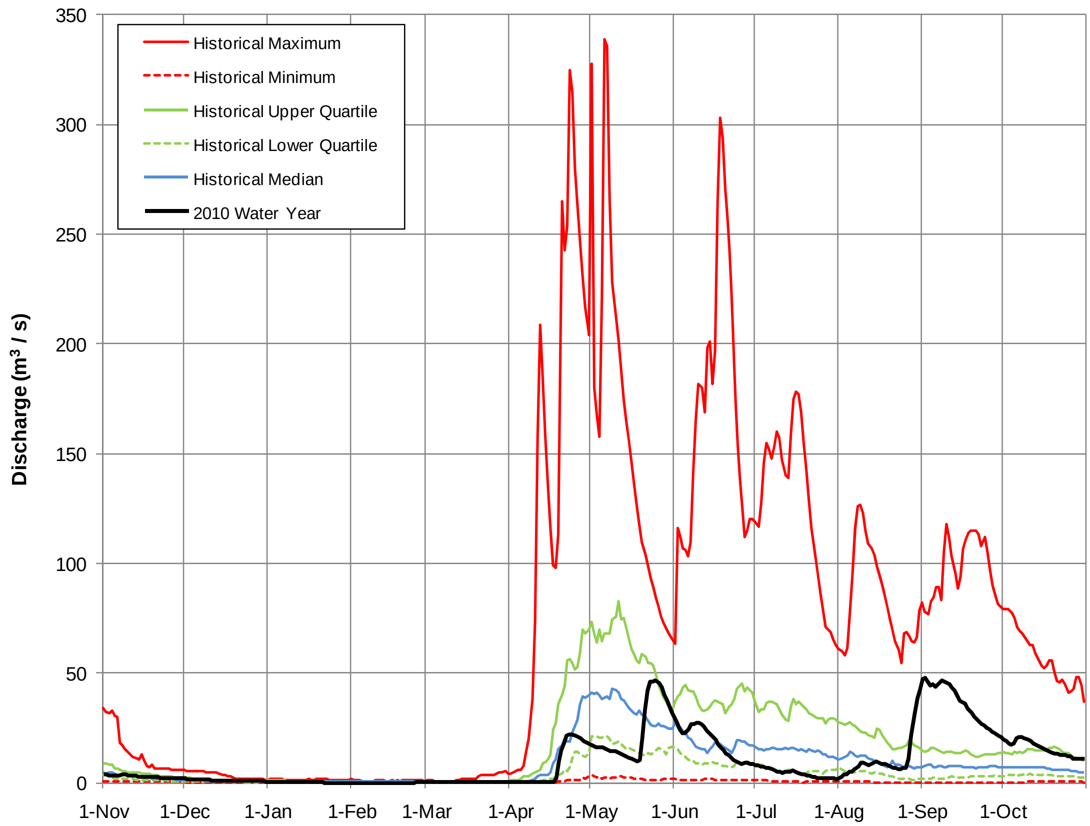
Note: Based on data recorded at WSC Station 07DA008, Muskeg River near Fort McKay; the upstream drainage area 1,460 km^2. Historical values were calculated for the period 1974 to 2009.

Figure 4.2-5 Historical seasonal (March to October) runoff volume in the MacKay River basin, 1973 to 2010.



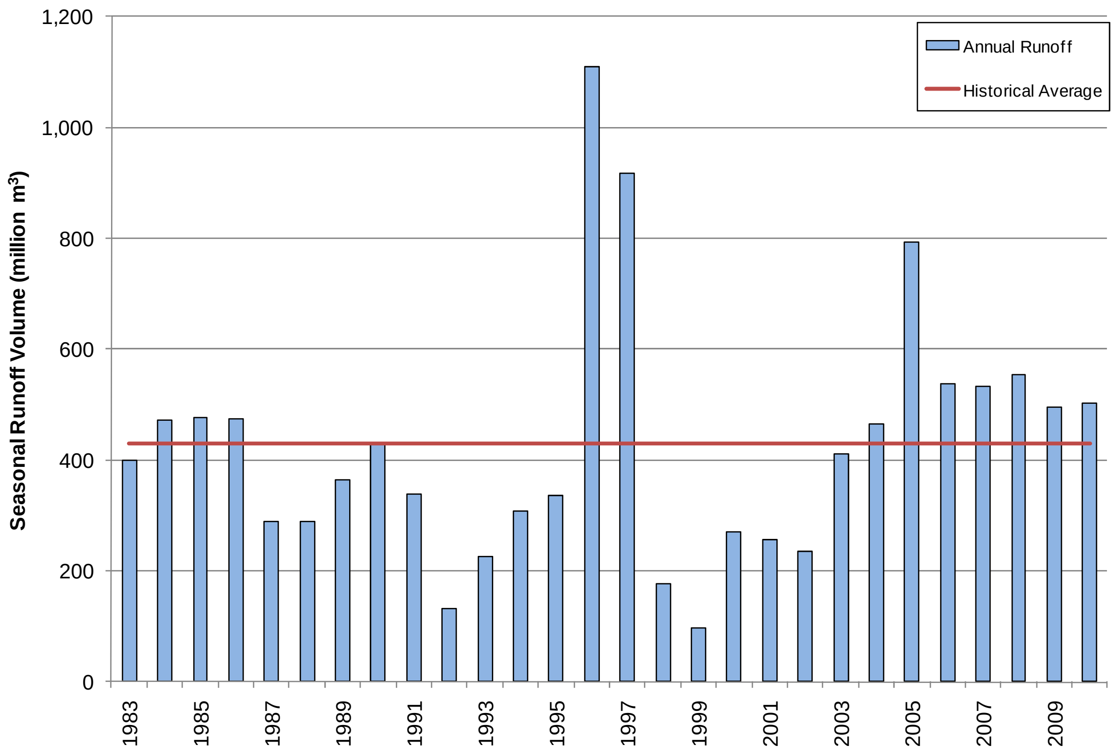
Note: Based on data recorded from 1973 to 2010 at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2.

Figure 4.2-6 The 2010 WY MacKay River hydrograph compared to historical values.



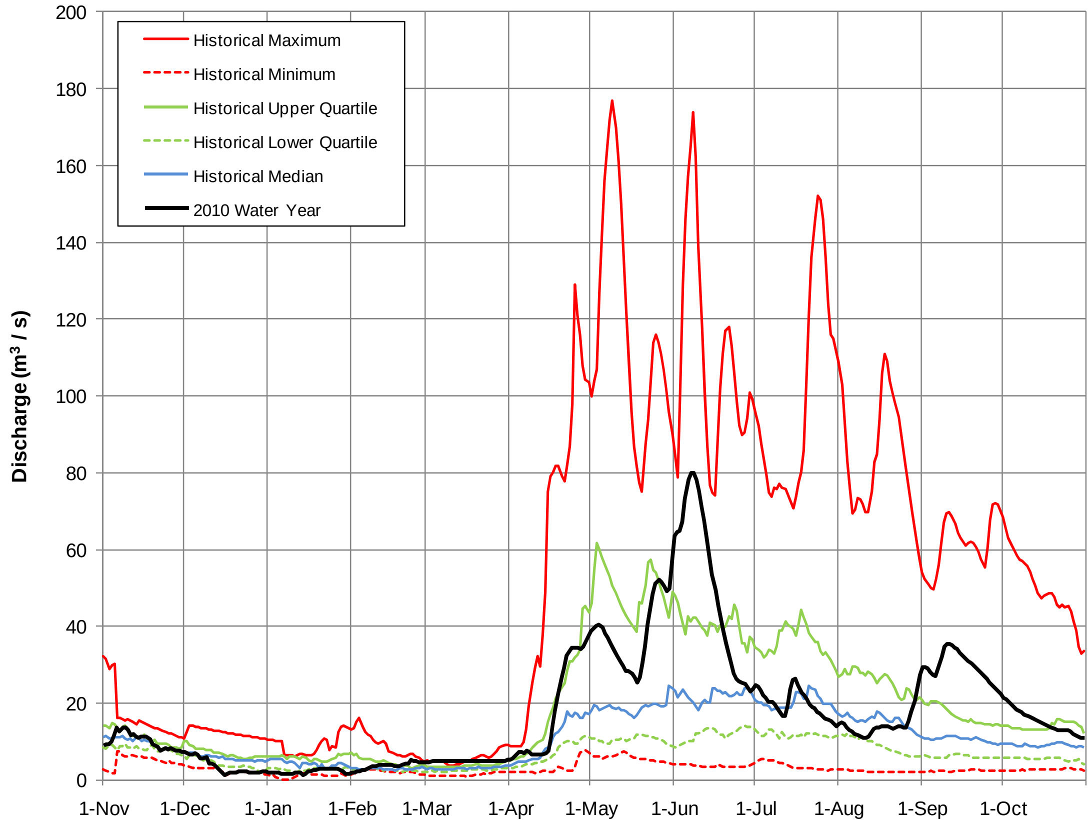
Note: Based on data recorded at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2. Historical values were calculated for the period 1973 to 2009.

Figure 4.2-7 **Historical seasonal (March-October) runoff volume in the Christina River basin, 1983 to 2010.**



Note: Based on data recorded from 1983 to 2010 at WSC Station 07CE002, Christina River near Chard; the upstream drainage area is 4,863 km^2.

Figure 4.2-8 The 2010 WY Christina River hydrograph compared to historical values.



Note: Based on 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 2009.

4.3 SUMMARY

In summary, climate and hydrology in the RAMP FSA in the 2010 WY was characterized by:

1. Annual precipitation measured at Fort McMurray that was 25% lower than the historical average, with monthly total precipitation below the long-term average in ten of 12 months. Winter precipitation was lower than the long-term average at all climate stations with the exception of EC Mildred Lake Station 3064528.

2. The runoff volume for WSC Station 07DA001, Athabasca River below Fort McMurray, was the fourth lowest in the 53-year record period, continuing a trend of below average annual flows for much of the past two decades.

3. Seasonal (March to October) runoff volumes were almost 30% below historical seasonal average values for the Muskeg and MacKay rivers but 19% higher for the Christina River. Annual maximum daily flows were primarily determined by rainfall for all watersheds.

4. Annual minimum and maximum daily flow values recorded at hydrological stations in the Muskeg, MacKay and Christina River basins were more extreme when compared with the corresponding long-term minimum and maximum daily flow.

5.0 2010 RAMP RESULTS

The following chapter consists of two parts. The first part focuses on detailed monitoring results specific to individual watersheds within the RAMP Focus Study Area (FSA). Monitoring in these watersheds includes the collection of data characterizing hydrology, water quality, benthic invertebrate communities and sediment quality, and fish populations. The second part presents data specific to the Acid-Sensitive Lakes component of RAMP and focuses on water quality monitoring at 50 lakes and ponds located throughout the RAMP Regional Study Area (RSA).

For the watershed analyses, Section 5.1 presents 2010 results for the Athabasca River and the Athabasca River Delta (ARD); Sections 5.2 to 5.10 present 2010 watershed results for the major tributaries of the Athabasca River within the RAMP FSA; and Section 5.11 contains the 2010 results for miscellaneous aquatic systems that were monitored in 2010. Table 5.1 provides a guide to assist the reader in finding watershed-specific results. For the Acid-Sensitive Lakes component, all monitoring results are presented in Section 5.12.

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	Miscellaneous Aquatic Systems	Acid-Sensitive Lakes
Climate and Hydrology	5-8	5-117	5-187	5-213	5-237	5-261	5-276	5-311	5-335	5-370	5-378	-
Water Quality	5-10	5-119	5-188	5-214	5-238	5-262	5-277	5-312	5-336	-	5-378	
Benthic Invertebrate Communities	5-13	5-122	5-190	5-215	5-240	5-263	5-279	5-313	5-339	-	5-378	-
Sediment Quality	5-16	5-127	5-190	5-217	5-242	5-263	5-281	5-315	5-339	-	5-378	-
Fish Populations	5-19	5-128	5-192	5-217	5-242	5-263	5-282	5-315	5-339	-	5-378	-

Definitions for Monitoring Status

The RAMP 2010 Technical Report uses the following definitions for monitoring status:

1. ***Test*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches) downstream of one or more focal projects; 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

2. ***Baseline*** is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 2010) or were (prior to 2010) 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 the Athabasca River and Athabasca River Delta.

Athabasca River and Delta	Summary of 2010 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	**EMR-1** Embarras River
Benthic Invertebrate Communities										🟤	🟡	🟡	ns	🟡
Sediment Quality Index										n/a	n/a	n/a	n/a	n/a
Fish Populations														
Criteria	**Site 1** upstream of Fort McMurray (west bank)	**Site 2** upstream of Oil Sands Development (west bank)			**Site 3** upstream of Muskeg River (west bank)	**Site 4** downstream of Muskeg River (east bank)			**Site 5** downstream of Firebag River (east bank)	no sites sampled				
Sentinel Species Monitoring	n/a	n/a			🟠	🟡			🟠					

Legend and Notes

🟡 Negligible-Low

🟠 Moderate

🟤 High

ns – not sampled

n/a – not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches for benthic invertebrate communities. The SQI was not calculated given the limited existing *baseline* data.

baseline (green)

test (blue)

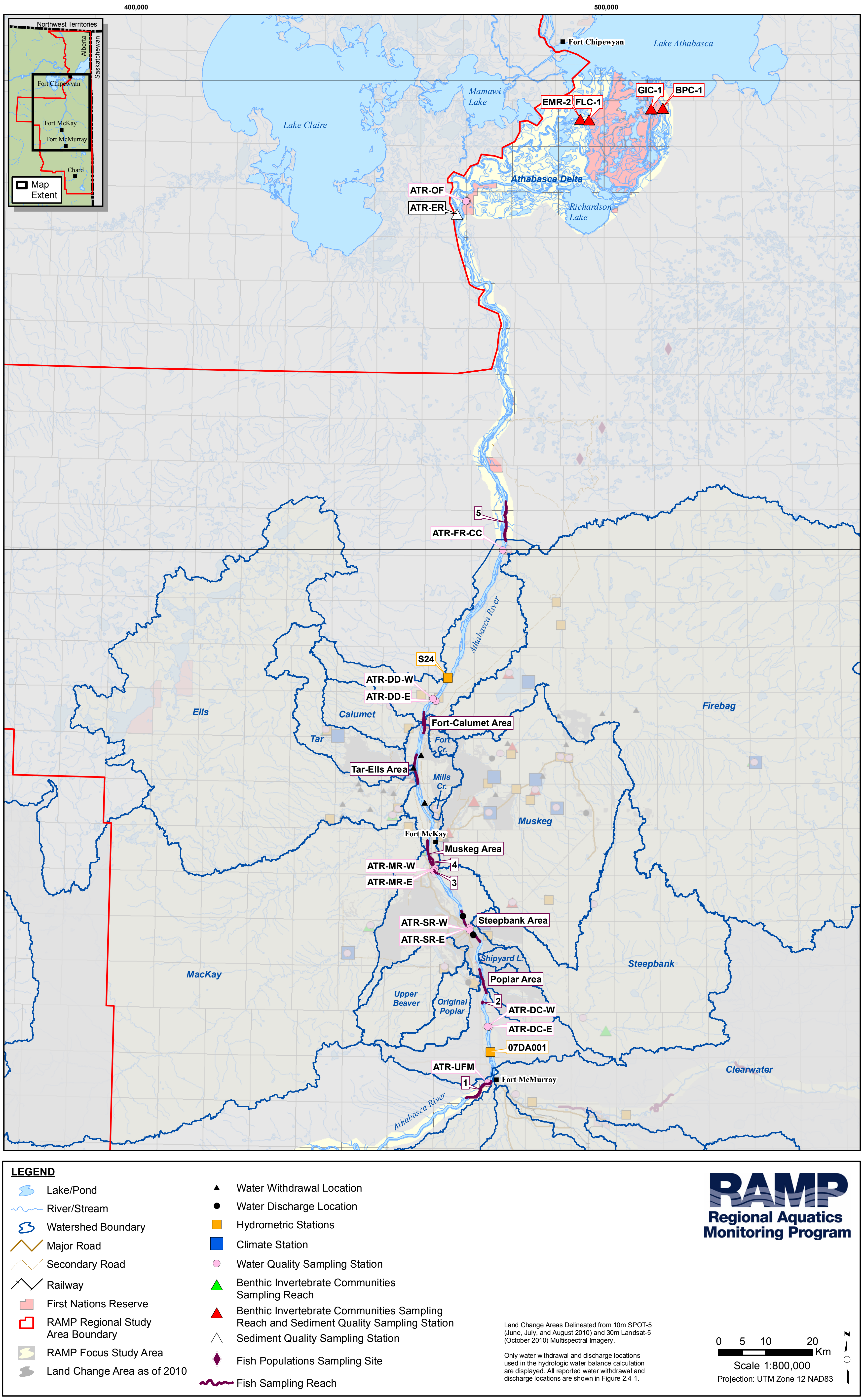
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 for a detailed description of the classification methodology.

Fish Populations: Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2010), see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.1-1 Athabasca River and Athabasca River Delta.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K01_Mainstem_20110318.mxd

Figure 5.1-2 Representative monitoring stations of the Athabasca River and Athabasca River Delta, fall 2010.

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-DD-E: Athabasca River downstream of development

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-FR-CC: Athabasca River upstream of Firebag River

5.1.1 Summary of 2010 Conditions

As of 2010, approximately 2.5% (87,995 ha) of the RAMP FSA had undergone land change from focal projects and other oil sands developments (Table 2.5-2). Approximately 22% (35,800 ha) of the minor Athabasca River tributary watersheds had undergone land change as of 2010 from focal projects and other oil sands developments (Table 2.5-2). For 2010, 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 2010 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, reported focal project water withdrawal and discharge locations, and the land change area for 2010. Figure 5.1-2 contains fall 2010 photos of a number of monitoring stations in the Athabasca River and Athabasca River Delta.

Hydrology 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 0.6%, 1.7%, 0.4% and 0.8% 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 results for the case in which focal projects plus other oil sands developments are considered.

Water Quality Differences in water quality in fall 2010 between all *test* and one of the *baseline* stations in the Athabasca River and regional *baseline* conditions were **Negligible-Low** with the exception of *baseline* station ATR-DC-E which showed **Moderate** differences from regional *baseline* conditions. Concentrations of water quality measurement endpoints at *test* stations were generally similar to those at upstream *baseline* stations (ATR-DC-E and ATR-DC-W) and consistent with regional *baseline* conditions. Concentrations of total mercury exceeded the AENV chronic guideline at all stations and showed a general decrease from upstream (ATR-DC) to downstream (ATR-FR) on the Athabasca River; total aluminum, total nitrogen, chloride, total arsenic, and other metals also exhibited a similar longitudinal trends. Concentrations of these measurement endpoints were also generally higher along the east bank of the river, suggesting an influence of the Clearwater River on water quality in the Athabasca River mainstem. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem was consistent with previous sampling years.

Benthic Invertebrate Communities and Sediment Quality The differences in measurement endpoints for benthic invertebrate communities in the ARD at *test* reach BPC-1 are classified as **Negligible-Low** because there were not significant time trends in any measurement endpoints for benthic invertebrate communities. With the exception of CA Axis 2 scores, all other measurement endpoints were within historical conditions for the ARD reaches and within previously-measured values for *test* reach BPC-1.

Differences in values of measurement endpoints for benthic invertebrate communities at *test* reach FLC-1 are classified as **High** because the statistical decrease in diversity, evenness, and percent EPT is typically associated with a negative change in the benthic invertebrate community. The increase in abundance is potentially indicative of an increase in available nutrients. Differences in values of measurement endpoints for benthic invertebrate communities at *test* reach GIC-1 are classified as **Negligible-Low** because there were no significant time trends in any measurement endpoints for benthic invertebrate communities. The average number of taxa per sample was lower in 2010 than previous years, likely a reflection of lower total abundance. Values of all other measurement endpoints were within previously-measured values for the reach.

Differences in richness, diversity and evenness from historical conditions for the ARD reaches in fall 2010 indicate that the fauna at *test* reach EMR-2 was significantly different from the benthic invertebrate communities of the ARD reaches. The relatively high abundance of mayflies and caddisflies at *test* reach EMR-2 indicates that the community is robust and healthy. Differences in measurement endpoints for benthic invertebrate communities at *test* reach EMR-2 are classified as **Negligible-Low** because the measured differences did not imply a negative difference between the benthic invertebrate community at *test* reach EMR-2 and historical conditions for the other ARD reaches.

Concentrations of sediment quality measurement endpoints at all five stations in the ARD were similar to previously-measured concentrations with generally low hydrocarbon, metals and PAH concentrations. However, since the beginning of RAMP sampling in 1999, an increase in concentrations of total PAHs has been observed at *test* station BPC-1, although this trend is not evident in concentrations of carbon-normalized total PAHs. Percent of total organic carbon has increased at *test* station FLC-1 likely related to the increasing proportion of fines in sediments over time, first observed in 2007 and could be indicative of decreasing water flow in this small channel. The PAH Hazard Index was historically high at *test* stations FLC-1 and EMR-2 and above the potential chronic toxicity threshold value of 1.0. Increased Hazard Index (HI) values at these stations were related to low concentrations of total hydrocarbons rather than high concentrations of total PAH. The increase in HI values suggests greater bioavailability of PAHs in sediments. Acute and chronic toxicity data for these sediments were inconclusive with historically low survival but historically high growth of *Hyalella* and high survival but low growth of *Chironomus* at *test* station FLC-1. The change in sediment quality at *test* station FLC-1 is also reflected in the decrease in diversity, evenness and richness of the benthic invertebrate community that was observed in fall 2010.

Fish Populations (fish inventory) As outlined in RAMP (2009a), 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. A shift in species dominance from white sucker to walleye was observed in spring, from goldeye to northern pike in summer, and from walleye to goldeye in fall, although lake whitefish dominates the catch in fall.

As of 2010, 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 for some of the KIR species. However, the variability of this measurement endpoint among years does not indicate consistent negative or positive changes in the fish populations and likely reflect natural variability over time.

The fish health assessment has indicated that abnormalities observed in 2010 in all species were within the historical range and consistent with studies done prior to major oil sands development in the upper Athabasca River, Athabasca Delta, and Peace and Slave rivers.

Fish Populations (sentinel species) Based on the differences in measurement endpoints in trout-perch at *test* sites 3, 4 and 5 relative to *baseline* Site 2, the following assessments were made:

- Female trout-perch at *test* Site 3 and male and female trout-perch at *test* Site 4 indicated a **Negligible-Low** difference from *baseline* Site 2 because none of the measurement endpoints exceeded the effects criteria;
- Male trout-perch at *test* Site 3 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age exceeded the effects criteria;
- Male trout-perch at *test* Site 5 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age exceeded the effects criteria; and
- Female trout-perch at *test* Site 5 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age, GSI and condition exceeded the effects criteria; however, this response was not observed in previous sentinel programs.

Generally, there is little evidence to suggest that characteristics of trout-perch populations between sites and across years on the Athabasca River have changed due to increasing activities from the focal projects and other oil sands developments given that trout-perch from sites closer to intense mining activity (i.e., *test* sites 3 and 4) do not show substantial differences from *baseline* fish, suggesting that female trout-perch at *test* Site 5 are responding to localized conditions unrelated to oil sands development.

5.1.2 Hydrologic Conditions: 2010 Water Year

Athabasca River below Eymundson Creek (RAMP Station S24) Continuous annual hydrometric data have been collected for RAMP Station S24 since June 2001. The annual runoff volume recorded at this station in the 2010 water year (WY) was 15,310 million m^3. The open-water period (May to October) runoff volume of 11,723 million m^3 was 15% lower than the historical average open-water runoff volume. Flows steadily decreased in November and December 2009 during river freeze-up and remained relatively constant from January to March 2010 (Figure 5.1-3). Flows were near historical median flows from November 2009 to March 2010. Flows increased during the freshet in April 2010, with the freshet peak of 698 m^3/s on April 20, similar to the historical median flow on this date. Flows decreased until May 19, and there were nine days of daily flows below historical minimum values recorded from May 5 to 22. The 2010 WY annual maximum daily discharge of 1,224 m^3/s recorded on May 28 was 41% lower than the historical mean annual maximum daily flow. Flows from June until late August were generally below historical median values. Rainfall throughout August and early September resulted in increased flows in September. Flows at Station S24 reached a late-WY peak of 1,143 m^3/s on October 6. The open-water period minimum daily flow of 416 m^3/s recorded on May 19 was 17% higher than the mean historical open-water minimum daily flow value.

The 2010 WY hydrograph at Station S24 was consistent with the hydrograph observed upstream at WSC Station 07DA001, Athabasca River below Fort McMurray (Section 4.2.1). The 2010 WY annual runoff volume and annual maximum daily flow at WSC Station 07DA001 and at Station S24 were below historical values. The minimum open-water daily flow was below the corresponding historical value at WSC Station 07DA001 but not at Station S24, likely due to the longer period of record at WSC Station 07DA001 (52 years) compared with Station S24 (eight years).

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph
The estimated water balance at Station S24 in the 2010 WY 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 the 2010 WY for all oil sands developments in the Athabasca River watershed upstream of Station S24. In both cases the changes due to oil sands developments in the Firebag River watershed were included even though the confluence of the Firebag River with the Athabasca River is below Station S24.

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 land area from focal projects as of 2010 in the minor Athabasca River tributaries, McLean Creek, Shipyard Lake and upper Beaver River is estimated to be 334 km^2 (Table 2.5-1). The loss of flow to the Athabasca River that would have otherwise occurred from this land area is estimated at 35.3 million m^3.

2. As of 2010, the area of land change from focal projects in the minor Athabasca River tributaries, McLean Creek, Shipyard Lake and upper Beaver River that was not closed-circuited is estimated to be 100 km^2 (Table 2.5-1). The increase in flow to the Athabasca River that would not have otherwise occurred from this land area is estimated at 2.1 million m^3.

3. Water withdrawals directly from the Athabasca River by focal projects in the 2010 WY were 97.8 million m^3.

4. Water discharges directly to the Athabasca River by focal projects in the 2010 WY were 6.8 million m^3.

5. The 2010 WY discharge into the Athabasca River from major tributaries (i.e., 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 0.8 million m^3 more than it would have been in the absence of focal projects in those watersheds.

The estimated cumulative effect is a loss of flow of 123.5 million m^3 at Station S24 from what the estimated *baseline* flow would have been in the absence of focal projects. The estimated observed and *baseline* hydrographs are 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 0.6%, 1.7%, 0.4% and 0.8% lower, respectively, than from the estimated *baseline* hydrograph (Table 5.1-3). These differences are all classified as **Negligible-Low** (Table 5.1-1).

In the second case, inputs from both focal and non-focal oil sands developments were considered. The non-focal oil sands developments occur within the Horse River, Hangingstone River and Christina River watersheds. These are the only three watersheds in the RAMP FSA that contained non-focal oil sands developments under construction or operational as of 2010 (Table 2.5-1).

The estimated cumulative effect of focal plus non-focal oil sands developments is a loss of flow of 123.7 million m^3 at Station S24 from the estimated *baseline* flow that would have occurred in the absence of these projects and developments (Table 5.1-2). This is a 0.2 million m^3 difference as compared to the first case. The values of the hydrologic measurement endpoints are essentially identical for the two cases (Table 5.1-3).

5.1.3 Water Quality

In 2010, water quality samples were taken on the Athabasca River at:

- *baseline* stations ATR-DC-E and ATR-DC-W, east and west banks, upstream of Donald Creek in winter, spring, summer, and fall (data available most years from 1997 to 2010);
- *test* stations ATR-SR-E and ATR-SR-W, east and west banks, upstream of the Steepbank River in fall (data available from 2000 to 2010);
- *test* stations ATR-MR-E and ATR-MR-W, east and west banks, upstream of the Muskeg River in fall (data available most years from 1998 to 2010);
- *test* stations ATR-DD-E and ATR-DD-W, east and west banks, "downstream of development" (near Susan Lake) in winter, spring, summer, and fall (data available from 2002 to 2010); and
- *test* station ATR-FR-CC, cross-channel composite sample, upstream of the Firebag River in fall (data available from 2002 to 2010).

In addition, monthly sampling of Athabasca River water quality is undertaken by AENV, upstream of Fort McMurray (ATR-UFM) and near the ARD at Old Fort (ATR-OF).

Temporal Trends The following significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- Increasing concentrations of total nitrogen at *baseline* station ATR-DC-E and *test* station ATR-MR-E;
- Decreasing concentrations of total strontium, calcium, and sulphate at *baseline* station ATR-DC-E; and
- A decreasing concentration of chloride at *test* station ATR-MR-E.

The following significant trends (α=0.05) in concentrations of water quality measurement endpoints were detected from the monthly AENV data for the Athabasca River mainstem (Figure 5.1-4):

- Increasing concentrations of total nitrogen and sulphate at ATR-OF (upstream of oil sands development); and
- Decreasing concentrations of total phosphorus at both ATR-OF OF (upstream of oil sands development) and ATR-UFM (downstream of oil sands development).

Seasonal water quality data collected by RAMP at ATR-DD (downstream of development) from 2005 to 2010 and by AENV at ATR-UFM and ATR-OF are presented in Figure 5.1-4.

2010 Results Relative to Historical Concentrations Concentrations of a number of water quality measurement endpoints in the Athabasca River mainstem were outside of previously-measured concentrations in fall 2010 (Table 5.1-4). This may be related to river discharges that were above the upper quartile of historical flows in September 2010 (Figure 5.1-3). Concentrations of the following water quality measurement endpoints in fall 2010 exceeded previously-measured maximum concentrations for the fall season:

- Total mercury at all *baseline* and *test* stations;
- Total arsenic at *baseline* station ATR-DC-E, and *test* stations ATR-MR-E, ATR-DD-E, and ATR-DD-W;
- Total suspended solids at *baseline* station ATR-DC-E and *test* station ATR-DD-E;
- Total dissolved solids at *baseline* station ATR-DC-W, and *test* stations ATR-DD-E and ATR-DD-W;
- Total nitrogen at *baseline* station ATR-DC-E and *test* station ATR-DD-W; and
- Total boron at *test* stations ATR-MR-E and ATR-DD-W.

Concentrations of the following water quality measurement endpoints in fall 2010 were below previously-measured minimum concentrations for the fall season:

- Potassium at all stations with the exception of *baseline* station ATR-DC-E;
- Calcium at *test* stations ATR-MR-E, ATR-DD-E, ATR-DD-W, and ATR-FR-CC;
- Strontium at *test* station ATR-MR-E; and
- Chloride at *test* station ATR-DD-W.

Concentrations of most major ions at all stations were lower in fall 2010 than observed in previous RAMP fall sampling years (Table 5.1-4).

Ion Balance The ionic composition of water sampled in fall 2010 at all stations in the Athabasca River was consistent with the ionic composition of the Athabasca River mainstem since 1997 and dominated by calcium and bicarbonate (Figure 5.1-5 to Figure 5.1-8). Water collected near the east bank of the Athabasca River, especially from *baseline* station ATR-DC-E, have a greater proportion of sodium and chloride ions compared to other stations in the Athabasca River, likely related to the incomplete mixing of the Clearwater River into the Athabasca River mainstem upstream of *baseline* station ATR-DC-E (see Section 5.9 for a description of the ionic composition of water from the Clearwater River).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints were below water quality guidelines in fall 2010 (Table 5.1-4) except total aluminum at all stations in the Athabasca River mainstem; and, total mercury that exceeded the AENV guideline for chronic exposure at all stations with the exception of *test* station ATR-DD-W, but were below the AENV guideline for acute exposure. Concentrations of total mercury were highest at *baseline* station ATR-DC-E (12.9 mg/L) and higher on the east bank of the Athabasca River compared to the west bank (Table 5.1-4). The lowest concentration of mercury was observed at *test* station ATR-DD-W, on the west bank of the Athabasca River (5.0 mg/L).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Athabasca River mainsteam in fall 2010 (Table 5.1-5):

- total iron at all stations (dissolved iron was below water quality guidelines at all stations with the exception of *baseline* station ATR-DC-E);
- total phosphorus at all stations with the exception of *baseline* station ATR-DC-W, and *test* stations ATR-SR-W and ATR-FR-CC;
- sulphide and total chromium at all stations with the exception of *baseline* station ATR-DC-W;
- total copper at *baseline* station ATR-DC-E and *test* stations ATR-SR-E, ATR-MR-E, and ATR-DD-E; and
- total phenols at all stations with the exception of *test* station ATR-SR-W and ATR-MR-W.

Concentrations of water quality measurement endpoints that exceeded relevant water quality guidelines in other seasons are listed in Table 5.1-5.

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of the following water quality measurement endpoints exceeded the 95th percentile of regional *baseline* concentrations in fall 2010 (Figure 5.1-9 to Figure 5.1-12):

- total mercury at all stations with the exception of *test* station ATR-DD-W;
- total arsenic at *baseline* station ATR-DC-E and *test* stations ATR-SR-E and ATR-MR-E;
- total dissolved solids at *baseline* station ATR-DC-W and *test* station ATR-DD-W; and
- total suspended solids and total nitrogen at *baseline* station ATR-DC-E.

Concentrations of dissolved potassium were below the 5th percentile of regional *baseline* concentrations in fall 2010 at all stations with the exception of *baseline* station ATR-DC-E and *test* stations ATR-SR-W, ATR-MR-E, and ATR-MR-W.

Water Quality Index The WQI values at all stations in the Athabasca River mainstem in fall 2010 indicated **Negligible-Low** differences from regional *baseline* water quality conditions with the exception of *baseline* station ATR-DC-E (WQI: 76.3), which indicated **Moderate** differences from regional *baseline* conditions (Table 5.1-6). The WQI value for all other stations on the Athabasca River ranged from 83.2 to 97.5 (Table 5.1-6).

Classification of Results Differences in water quality in fall 2010 between all *test* and one of the *baseline* stations in the Athabasca River and regional *baseline* conditions were **Negligible-Low** with the exception of *baseline* station ATR-DC-E which showed **Moderate** differences from regional *baseline* conditions. Concentrations of water quality measurement endpoints at *test* stations were generally similar to those at upstream *baseline* stations (ATR-DC-E and ATR-DC-W) and consistent with regional *baseline* conditions. Concentrations of total mercury exceeded the AENV chronic guideline at all stations and showed a general decrease from upstream (ATR-DC) to downstream (ATR-FR) on the Athabasca River; total aluminum, total nitrogen, chloride, total arsenic, and other metals also exhibited similar longitudinal trends. Concentrations of these measurement endpoints were also generally higher along the east bank of the river, suggesting an influence of the Clearwater River on water quality in the Athabasca River mainstem. The ionic composition of water at all water quality monitoring stations in the Athabasca River mainstem was consistent with previous sampling years.

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 four depositional reaches in the ARD in fall 2010:

- Depositional *test* reach BPC-1 in Big Point Channel, sampled from 2002 to 2005 and 2007 to 2010;
- Depositional *test* reach FLC-1 in Fletcher Channel, sampled from 2002 to 2005 and 2007 to 2010;
- Depositional *test* reach GIC-1 in Goose Island Channel, sampled from 2002 to 2005 and 2007 to 2010; and
- Depositional *test* reach EMR-2 in the Embarras River, sampled for the first time in 2010.

2010 Habitat Conditions Water at *test* reaches BPC-1, GIC-1, FLC-1 and EMR-2 in the ARD was relatively deep (>1 m), slightly alkaline (pH: 8.2 to 8.4) and had moderate conductivity (233 to 265 µS/cm) (Table 5.1-7). Substrate was dominated by sand at *test* reach GIC-1 and by silt at *test* reaches BPC-1, FLC-1 and EMR-2 with a moderate total organic carbon content at all reaches (0.4% to 2.5%) (Table 5.1-7).

Relative Abundance of Benthic Invertebrate Community Taxa in 2010 The benthic invertebrate communities at *test* reaches BPC-1 and FLC-1 in fall 2010 were numerically-dominated by tubificid worms (68% and 81%, respectively) (Table 5.1-11) with subdominant taxa consisting of midges Chironomidae (11% at *test* reach BPC-1 and 4% at *test* reach FLC-1), fingernail clams (4% at *test* reach BPC-1 and 6% at *test* reach FLC-1) and Ostracoda (7% at *test* reach BPC-1 and 3% at *test* reach FLC-1). Similar to previous years the dominant chironomids at *test* reach BPC-1 were *Procladius* and *Cryptotendipes* (Table 5.1-11). The freshwater mussel *Anodonta* and the fingernail clam *Pisidium* were present in some replicates at *test* reach BPC-1. *Amnicola* was the genus representing snails at *test* reach BPC-1. One genus of Plecoptera (stonefly) (*Isoperla*) and two types of Ephemeroptera (*Hexagenia limbata* and members of the Family *Baetidae*) were present at *test* reach BPC-1.

The benthic invertebrate community at *test* reach GIC-1 was less numerically-dominated by tubificid worms (23%) and more dominated by Ostracoda (39%) and Chironomidae (30%) with subdominant taxa consisting of Gastropoda (4%), Bivalvia (2%) and Ceratopogonidae (2%) (Table 5.1-11). The chironomids at *test* reach GIC-1 included *Polypedilum*, *Stempellina*, *Stempellinella* and *Cryptochironomus*. The ceratopogonids (sand flies) were from the genus *Probezzia*. Bivalvia included fingernail clams from the genera *Pisidium* and *Sphaerium*. The Gastropoda (snails) were from the genus *Gyraulus*.

The benthic invertebrate community at *test* reach EMR-2 was dominated numerically by Chironomidae (41%), Bivalvia (29%) and Ostracoda (19%) with subdominant taxa consisting of Ceratopogonidae (4%) and Trichoptera (3%) (Table 5.1-11). Chironomids were dominated by several forms including *Procladius*, *Tanytarsus*, *Polypedilum*, *Pagastiella*, *Cryptotendipes* and *Chironomus*. Bivalves were represented by members of the genera *Pisidium* and *Sphaerium*. Ceratopogonids included *Probezzia* and *Culicoides*. Trichoptera (caddisflies) were dominated by the genus *Oecetis* and included some members of the genera *Polycentropus* and *Mystacides*. Mayflies were present from the genus *Caenis* and the species *Hexagenia limbata*.

Big Point Channel

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested at *test* reach BPC-1 (Hypothesis 1, Section 3.2.3.1). There were no significant differences over time in abundance, richness, diversity, evenness or CA Axis 1 scores (Table 5.1-9). There was a significant increase in CA Axis 2 scores from 2003 to 2010 reflecting an increase in the relative abundance of ostracods and naidid worms over time.

Comparison to Published Literature The relative abundance at *test* reach BPC-1 of tubificid worms was high (68%). Published literature has identified that benthic invertebrate communities with greater than 30% worms are known to be potentially indicative of degraded conditions (Griffiths 1998); communities with greater than 90% worms are known to be indicative of severe organic enrichment and communities with greater than 20% worms and greater than 50% chironomids and isopods are considered potentially indicative of mild organic enrichment (Hynes 1960). Taking this information into account, *test* reach BPC-1 could be classified as reflecting mild organic enrichment. The worms (*Tubificidae*) at *test* reach BPC-1 were not identified below the Family level but the high numbers of tubificids is not uncommon in the shifting-sand environment of the ARD (Barton and Locke 1979).

Other biota found at *test* reach BPC-1 suggested a different interpretation of conditions. The stonefly *Isoperla* and the mayfly *Hexagenia limbata* were present at *test* reach BPC-1 in fall 2010 and both are associated with good water and sediment quality (Hilsenhoff 1987). The freshwater mussel *Anodonta* was also present. Members of the family Unionidae (such as *Anodonta*) tend to be sensitive to changes in their environment, in part because of their long life span (up to 25 years; Clarke 1981). The presence of this genus at *test* reach BPC-1 suggests that water and sediment quality has been good for a long period of time.

2010 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities at *test* reach BPC-1 were within the range of historical conditions, as defined by the range of data from previous sampling years for all ARD reaches up to 2009 (Figure 5.1-13). Total abundance in fall 2010 (52,000 per m^2) was approximately equal to the long-term average and the number of taxa (14) was near the 95^{th} percentile of historical conditions for the ARD reaches. Diversity and evenness were below median historical values for the first time in three years but within historical conditions. The percent of the fauna as EPT taxa in fall 2010 (<1%) was below the previously-measured maximum value (19%) in 2008 but still higher than 2009 (i.e., 0%). The CA Axis 1 and 2 scores suggest that the benthic invertebrate community in 2010 had shifted with scores near the 95^{th} percentile of historical conditions for the ARD reaches.

Classification of Results The differences in measurement endpoints for benthic invertebrate communities at *test* reach BPC-1 are classified as **Negligible-Low** because there were no significant time trends in any measurement endpoints for benthic invertebrate communities. With the exception of CA Axis 2 scores, all other measurement endpoints were within historical conditions for the ARD reaches and within previously-measured values for *test* reach BPC-1.

Fletcher Channel

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested at *test* reach FLC-1 (Hypothesis 1, Section 3.2.3.1). There was a significant increase in abundance and a significant decrease in diversity, evenness, percent EPT, and CA 1 axis scores over time (Table 5.1-10), all of which explained more than 20% of the variation in annual means.

Comparison to Published Literature The percent of the fauna as Tubificidae (81%) was high as was total abundance (>100,000 per m^2) in fall 2010. As discussed for *test* reach BPC-1, *test* reach FLC-1 could be classified as having "mild" to "moderate" organic enrichment (Hynes 1960, Griffith 1998). *Test* reach FLC-1 did not contain mayflies, stoneflies or caddisflies in fall 2010, which have been present in this reach in previous years (Table 5.1-8). The absence of these groups and the low relative abundance of Chironomidae (4%) support the likelihood that the benthic invertebrate community in fall 2010 was different from previous years.

2010 Results Relative to Historical Conditions Total abundance, diversity, and evenness were outside historical conditions for ARD reaches at *test* reach FLC-1 (Figure 5.1-13). The CA axis scores for *test* reach FLC-1 were within historical conditions for ARD reaches (Figure 5.1-14).

Classification of Results Differences in values of measurement endpoints for benthic invertebrate communities at *test* reach FLC-1 are classified as **High** because the significant decrease in diversity, evenness, percent EPT is typically associated with a negative change in the benthic invertebrate community (Kilgour *et al*. 2005). The increase in abundance is potentially indicative of an increase in available nutrients. Interestingly, the percent of total organic carbon has increased over time in the sediment at *test* station FLC-1 (Table 5.1-14).

Goose Island Channel

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested at *test* reach GIC-1 (Hypothesis 1, Section 3.2.3.1). There were no significant time trends in any measurement endpoints for benthic invertebrate communities (Table 5.1-11).

Comparison to Published Literature The percent of the fauna as Tubificidae (23%) and Chironomidae (30%) were generally within the range of values that would be considered appropriate for depositional river reaches. Typically, greater than 20% worms (Tubificidae) can be indicative of mild organic enrichment; however, the dominance of fauna such as chironomids and/or isopods suggests that organic enrichment is not a factor (Hynes 1960, Griffiths 1998). There were no mayflies, caddisflies or stoneflies in fall 2010 at *test* reach GIC-1 but the relative abundance of those groups have been low in previous years (Table 5.1-8). Abundance was generally low (<3,000 per m^2) indicative of low levels of nutrients (Brinkhurst 1974).

2010 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities at *test* reach GIC-1 were within historical conditions for reaches in the ARD with the exception of taxa richness, which was below the 5th percentile of historical conditions (Figure 5.1-13). Total abundance was low in fall 2010 but within previously-measured values at *test* reach GIC-1 (Figure 5.1-13). There were no EPT taxa present in fall 2010, which was also observed in fall 2003.

Classification of Results Differences in values of measurement endpoints for benthic invertebrate communities at *test* reach GIC-1 are classified as **Negligible-Low** because there were significant time trends in any measurement endpoints for benthic invertebrate communities. The average number of taxa per sample was lower in 2010 than previous years, likely a reflection of lower total abundance. Values of all other measurement endpoints were within previously-measured values for the reach.

Embarras River

Temporal and Spatial Comparisons Temporal comparisons could not be conducted for *test* reach EMR-2 because there are no previous data to compare against, while spatial comparisons could not be conducted for *test* reach EMR-2 because there is no upstream *baseline* reach on the Embarras River.

Comparison to Published Literature The benthic invertebrate community at *test* reach EMR-2 was typical for a shifting-sand environment. The relative abundance of tubificid worms was low (~ 1%) and chironomids accounted for just over 40% with fingernail clams accounting for about 30% of the fauna (Table 5.1-11). The relative abundance for chironomids and fingernail clams are typical for rivers in good condition (Hynes 1960, Griffiths 1998).

2010 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities at *test* reach EMR-2 were compared to the historical conditions for the other ARD reaches (Figure 5.1-13). The number of taxa, diversity and evenness exceeded historical conditions for the ARD reaches reflecting a more robust community. Approximately 3% of the fauna were EPT, which is slightly higher than the other ARD reaches in fall 2010 but within historical conditions (Figure 5.1-13).

Classification of Results Differences in richness, diversity and evenness from historical conditions for the ARD reaches in fall 2010 indicate that the fauna at *test* reach EMR-2 was significantly different from the benthic invertebrate communities of the ARD reaches. The relatively high abundance of mayflies and caddisflies at *test* reach EMR-2 indicates that the community is robust and healthy. Differences in measurement endpoints for benthic invertebrate communities at *test* reach EMR-2 are classified as **Negligible-Low** because the measured differences did not imply a negative difference between the benthic invertebrate community at *test* reach EMR-2 and historical conditions for the other ARD reaches.

5.1.4.2 Sediment Quality

In fall 2010, sediment quality was sampled in the ARD at:

- *test* station BPC-1 in Big Point Channel, sampled from 1999 to 2003, 2005 and 2007 to 2010; and
- *test* station FLC-1 in Fletcher Channel, sampled from 2001 to 2003, 2005 and 2007 to 2010;

- *test* station GIC-1 in Goose Island Channel, sampled from 2001 to 2003, 2005 and 2007 to 2010;
- *test* station EMR-2 in the Embarras River, previously sampled in 2005; and
- *test* station ATR-ER, in the Athabasca River mainstem immediately upstream of the Embarras River sampled from 2000 to 2010.

Temporal Trends Sufficient data now exists for all ARD stations, with the exception of *test* station EMR-2, to conduct trend analyses. The following significant (α=0.05) trends in concentrations of sediment quality measurement endpoints were detected:

- An increasing concentration of total organic carbon at *test* station FLC-1;
- An increasing concentration of total PAHs at *test* station BPC-1 (carbon-normalized total PAHs at *test* station BPC-1 did not show a significant increase);
- An increasing PAH Hazard Index at *test* station FLC-1 (primarily due to a high value in 2010 discussed below); and
- Decreasing concentrations of total metals and total arsenic at *test* station ATR-ER.

2010 Results Relative to Historical Concentrations Concentrations of sediment quality measurement endpoints at all five stations in fall 2010 were within previously-measured concentrations (Table 5.1-12 to Table 5.1-16 and Figure 5.1-15 to Figure 5.1-19) with the following exceptions:

1. Sediments at all five stations in fall 2010 were dominated by silt and/or sand. Concentrations of total organic carbon at ARD stations was relatively low (<2.6%) but exceeded the previously-measured maximum concentration at *test* station EMR-2 (Table 5.1-16).
2. Total metals expressed in absolute terms or normalized to %-silt-and-clay were similar to those observed in previous years at all stations (Figure 5.1-15 to Figure 5.1-19).
3. Total hydrocarbon concentrations (CCME F1-F4) were below previously-measured minimum concentrations at all stations with the exception of *test* station BPC-1 (Figure 5.1-18).
4. Concentrations of PAHs, absolute and normalized to organic content, were below and at previously-measured minimum concentrations at *test* stations GIC-1 and ATR-ER, respectively, and absolute PAH concentrations exceeded previously-measured maximum concentrations at *test* stations EMR-2, FLC-1 and BPC-1.
5. Similar to previous years, PAHs at all stations in fall 2010 were dominated by alkylated species indicating a petrogenic origin of these compounds.
6. Potential chronic toxicity of PAHs in sediments at *test* stations EMR-2 and FLC-1 exceeded previously-measured maximum values. Concentrations of total PAHs at these two stations in fall 2010 were similar to previous years but total hydrocarbons, which are used to adjust bioavailability in the equilibrium-partitioning approach used to calculate the potential chronic toxicity, were historically low. Therefore, a decrease in concentrations of

total hydrocarbons rather than an increase in total PAHs caused the increase in Hazard Index values at these stations. Regardless, this suggests greater bioavailability of PAHs in sediment pore waters at these locations in 2010.

7. Direct measures of sediment toxicity to invertebrates indicated good survival (i.e., ≥75%) of the amphipod *Hyalella* at all stations with the exception of *test* station FLC-1, which showed historically-low survival (44%) (Table 5.1-12 to Table 5.1-15). In addition, all stations indicated good survival (≥80%) of the midge *Chironomus* with the exception of *test* station EMR-2 (68%).

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 and GIC-1 where *Chironomus* growth was lower and *Hyalella* growth was higher than previously-measured values.

Comparison with Sediment Quality Guidelines No hydrocarbon fraction, specific PAHs, or total metals measured at all stations exceeded relevant sediment or soil quality guidelines in fall 2010 with the exception of total arsenic at *test* station EMR-2 (Table 5.1-16).

2010 Results Relative to Historical Conditions Absolute and carbon-normalized concentrations of total PAHs, total hydrocarbons (i.e., sum of F1-F4), and total metals are generally low relative to other locations in the Athabasca River mainstem and its tributaries in the RAMP FSA (Figure 5.1-20 to Figure 5.1-24). Concentrations of total PAHs at stations in the ARD are less than 3 mg/kg, relative to concentrations of approximately 30 mg/kg in upstream watersheds. Concentrations of total hydrocarbons (F1-F4) are in the low hundreds of mg/kg compared to approximately 10,000 mg/kg in sediments of upstream watersheds (i.e., Muskeg, Ells, Mackay, Tar rivers and Fort and Poplar creeks). 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) located near a bitumen outcrop.

Summary Concentrations of sediment quality measurement endpoints at all five stations in the ARD were similar to previously-measured concentrations with generally low hydrocarbon, metals and PAH concentrations. However, since the beginning of RAMP sampling in 1999 in the ARD, an increase in concentrations of total PAHs has been observed at test station BPC-1, although this trend is not evident in concentrations of carbon-normalized total PAHs. Percent of total organic carbon has increased at test station FLC-1 likely related to the increasing proportion of fines in sediments over time, which was first observed in 2007 (RAMP 2008) and could be indicative of decreasing water flow in this small channel. The PAH Hazard Index was historically high at test stations FLC-1 and EMR-2 and above the potential chronic toxicity threshold value of 1.0. The increase in the Hazard Index values at these stations were related to low concentrations of total hydrocarbons rather than high concentrations of total PAH; however, the increase in Hazard Index values suggests greater bioavailability of PAHs in sediments. Acute and chronic toxicity data for sediments at *test* station FLC-1 were historically low for survival but historically high for growth of *Hyalella* and high survival but low growth of *Chironomus*. Given that there is no *baseline* sediment quality data for the ARD, SQI values were not calculated for ARD stations.

5.1.5 Fish Populations

Fish populations monitoring in 2010 on the Athabasca River consisted of a spring, summer, and fall fish inventory, a fish tag return assessment, and fall sentinel species monitoring targeting trout-perch.

5.1.5.1 Fish Inventory

Temporal and Spatial Comparisons

Temporal comparisons to assess changes over time and by season, as well as spatial comparisons among areas of the river, were conducted for the following measurement endpoints: species composition; species richness; catch per unit effort; length-frequency distributions; and condition factor.

Species Richness A total of 5,283 fish were captured in the ten standardized reaches (Figure 3.1-5) during the spring, summer, and fall fish inventories on the Athabasca River in 2010 (Table 5.1-17), of which:

- 1,319 fish representing 16 species were caught in the spring;
- 1,586 fish representing 17 species were caught in the summer; and
- 2,378 fish representing 17 species were caught in the fall.

A comparison of total catch and species richness in 2010 by season and area is provided in Table 5.1-18 and Figure 5.1-25.

A temporal comparison of seasonal species richness and total number of fish captured is presented in Figure 5.1-26. A total of 20 species were captured in 2010 compared to 16 species captured in 2009 and 22 species captured in 1997, which represents the highest species richness documented to date during the Athabasca River inventory. Species richness in 2010 was generally higher in all seasons compared to historical years; however, total catch is higher in recent years since the RAMP fish inventories have targeted the whole fish assemblage and not just large-bodied species. In the last five years since sampling reaches and capture efficiency has been standardized, species richness and total catch has been variable but with no evidence of increasing or decreasing trends (Figure 5.1-26).

Species Composition Key features of the species composition of the Athabasca River fish inventory for 2010 and in comparison to previous years are as follows:

1. Similar to 2009, the most abundant large-bodied species captured in 2010 were white sucker and walleye, goldeye and flathead chub, and lake whitefish and goldeye in spring, summer, and fall, respectively (Figure 5.1-27).
2. The most abundant small-bodied fish in each season in 2010 was trout-perch (Table 5.1-17).
3. KIR species composition in spring in more recent years showed a slight shift in dominance from white sucker to walleye and a decrease in goldeye relative to other species (Figure 5.1-27). 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 2010 was similar to 2002 and 2003.

4. KIR species composition in summer showed a shift in dominance from goldeye to northern pike in 2010 compared to the previous two years (Figure 5.1-27). The number of northern pike captured in summer 2010 is greater than in all previous sampling years. The number of walleye captured in summer has also increased in 2010 compared to 2008 and 2009 and reflects numbers of walleye captured in historical years.
5. In fall 2010, goldeye dominated the catch, which was a shift from a dominance of walleye in previous sampling years (Figure 5.1-27). The dominant KIR species captured during the fall survey has varied between walleye and goldeye, however, the dominant species captured in fall is lake whitefish across most years given this species is a fall-spawner.

Catch Per Unit Effort To provide a standardized comparison across time, catch per unit effort (CPUE), as a measure of relative abundance, was calculated only for reaches that are currently sampled by RAMP. Historically, other reaches in the Athabasca River have been sampled; however, these data were not included for comparisons of CPUE. The total CPUE, for all species combined from 1987 to 2010 is presented in Figure 5.1-28. CPUE for large-bodied KIR species combined in spring, summer, and fall 2010 was compared to three sampling periods: 1987 to 1996, designated as pre-RAMP; 1997 to 2004, designated as RAMP prior to standardization of sampling reaches; 2005 to 2009, designated as RAMP post reach standardization (Figure 5.1-29). Spring, summer and fall spatial comparisons of CPUE for each large-bodied KIR species in 2010 are presented in Figure 5.1-30.

Total CPUE for all species combined has shown variability in each season across time. Generally, CPUE has been higher in more recent years (i.e., from 2005 to 2010) since RAMP has focused on targeting the whole fish assemblage (Figure 5.1-28). In previous years and in years prior to RAMP (i.e., 1987 to 1996) more emphasis has been put on capturing large-bodied species; therefore, time trend analysis was conducted on seasonal CPUE for each large-bodied KIR species, which have been consistently targeted over time from 1987 to 2010. The following significant trends (α=0.05) were detected:

- Spring – increasing CPUE of lake whitefish, longnose sucker, walleye and white sucker;
- Summer – increasing CPUE of goldeye and longnose sucker; and
- Fall – increasing CPUE of goldeye, lake whitefish, walleye, and white sucker.

There were no decreasing trends in CPUE of any large-bodied KIR species. The significant increasing trends detected may be due to an improvement in capture success over time; however, trend analysis was conducted on these species specifically because they have been targeted consistently over time and are least affected by increasing method standardization.

Spatial comparisons were conducted to look at changes over time in the use of certain areas of the Athabasca River by large-bodied KIR species (Figure 5.1-29). Across seasons, there has been an increase in CPUE in the Poplar area of the Athabasca River, which is the furthest upstream reach that is sampled; a similar increase in CPUE has also been observed in the area of the river near the mouth of the Muskeg River. CPUE has been variable over time for large-bodied KIR species in the other areas of the river with no decreasing trends observed in any area (Figure 5.1-29).

In spring 2010, walleye dominated the catch in the two most upstream reaches of the river that were sampled (i.e., Poplar and Steepbank) and white sucker dominated the catch in the Muskeg, Tar-Ells, and Fort-Calumet areas of the river (Figure 5.1-30). The relative abundance of each species was similar across areas with the exception of white sucker having variable CPUE between areas.

In summer 2010, with the exception of the most downstream area (Fort-Calumet), goldeye dominated the catch at all sampled areas of the river. Lake whitefish dominated the catch in the Fort-Calumet area (Figure 5.1-30), likely reflecting the beginning of their fall spawning migration upstream in the Athabasca River. The catch of goldeye was much higher in the two most upstream areas compared to the other areas; catch of all other species was generally consistent across areas.

In fall 2010 and historically, with the exception of the Tar-Ells area, lake whitefish was the dominant species captured in all sampled areas of the river (Figure 5.1-29); goldeye dominated the catch in the Tar-Ells area. The relative abundance of all other species was generally consistent across areas.

Length-Frequency Distributions Length-frequency distributions for large-bodied KIR fish species for all seasons combined are presented in Figure 5.1-31 to Figure 5.1-35. The average relative length-frequency distributions for 1997-2009 (RAMP sampling period) and 1987 to 1996 (pre-RAMP) were compared to the 2010 length-frequency distributions for each species. The species-specific results are as follows:

1. The length-frequency distribution of goldeye in 2010 showed a shift to a larger dominant length-class (351-400 mm) and a smaller amount of individuals from smaller length-classes compared to previous years (Figure 5.1-31).

2. The length-frequency distribution of longnose sucker in 2010 showed a shift in dominance to smaller length classes compared to previous years (Figure 5.1-32). The dominant length class in 2010 was 51-100 mm compared to a dominant length class of 401 to 450 mm in 2007, 2008, and 2009. The increase of catch in the smaller length-class is likely attributed to juvenile fish capture in summer and very low capture success of adults in fall 2010.

3. The length-frequency distribution of northern pike was similar to previous sampling years with consistent dominance in the 401-500 mm and 501-600 mm length-classes across years (Figure 5.1-33). There was a smaller number of juvenile fish captured in 2010 compared to historical years but a slight increase in larger northern pike (i.e., >700 mm).

4. The length-frequency distribution of walleye in 2010 showed a shift in dominance to smaller length classes compared to previous years (Figure 5.1-34); however, similar to previous sampling years, two distinct modes were apparent in the 2010 distribution (i.e., co-dominance of 51-100 mm and 401-450 mm). These two modes are likely age-related and become more obvious when examining the seasonal data from 2010. Longer fish captured in spring are likely from the spawning adult population with juveniles captured in summer and fall.

5. The length-frequency distribution of white sucker showed a slight shift in dominance to larger length-classes with a dominant length-class in 2010

between 451 and 500 mm compared to previous years when the 351-400 mm and 401-451 mm length-classes were dominant (Figure 5.1-35).

Condition Factor Mean condition factor for large-bodied KIR fish species captured in the Athabasca River from 1997 to 2010 in spring and fall compared to the mean condition from 1987 to 1996 (pre-RAMP) are presented in Figure 5.1-36 to Figure 5.1-40. Statistical differences between 2010 and all previous sampling years for summer and fall were tested using analysis of covariance (ANCOVA). Given that large-bodied fish captured in spring are in their spawning period, the variability in condition of fish captured in spring could also be related to an increase in reproductive tissue and; therefore, any differences in condition between years in spring is not necessarily reflective of differences in energy storage. Species-specific results are as follows:

1. Similar to 2009 results, condition in goldeye in summer 2010 was significantly higher compared to 2000 and 2008 ($p \leq 0.001$) and condition of goldeye in fall 2010 was significantly higher than 1996 and lower than 2005 ($p \leq 0.001$) (Figure 5.1-36);
2. Similar to 2009 results, there were no significant differences in longnose sucker condition among years in summer and fall ($p \geq 0.05$) (Figure 5.1-37);
3. Condition of northern pike in summer 2010 was significantly lower compared to 2008 ($p<0.001$) and condition of northern pike in fall 2010 was significantly lower compared to 2006 ($p=0.009$) (Figure 5.1-38);
4. Similar to 2009 results, condition of walleye in summer 2010 was significantly higher compared to 2008 ($p<0.001$). There were no significant differences in condition of walleye among years during the fall inventory ($p=0.1$) (Figure 5.1-39); and
5. There were no significant differences in condition of white sucker between 2010 and all previous years in summer and fall ($p>0.05$) (Figure 5.1-40).

Recruitment to the Sport Fishery

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 1.5 in 2010, meaning that there are 1.5 undersize walleye for every legal-sized fish (Figure 5.1-41). The average ratio from 1987 to 1996 (i.e., prior to any major development) was 1.8 and the average from 1997 to 2009 was 1.6, indicating a slight decrease in the number of undersize to legal-sized fish in 2010, although still within the historical range (0.7 to 2.1).

The ratio of undersize (i.e., <600 mm) to legal size (i.e., >600 mm) northern pike was 1.8 in 2010 (Figure 5.1-42). The average ratio from 1987 to 1996 (i.e., prior to any major development) was 3.3 and the average from 1997 to 2009 was 3.1, indicating a decrease in the number of undersize to legal-sized fish in 2010, although still within the historical range (1.6 to 4.5).

From 1987 to 2010, the human population in the lower Athabasca region has increased substantially with industrial development. As a result, it is likely that the sportfish populations have experienced increased fishing pressure over time, resulting in a decrease in recruitment to the population.

External Health Assessment

Observed abnormalities were primarily associated with minor skin aberrations or wounds, scars, and fin erosion, but infrequent cases of parasites, growths, lesions and body deformities are also observed. In 2010, 10.0%, 1.7%, and 2.8% of fish captured in spring, summer, and fall, respectively, were found to have some type of external abnormality. The 2010 incidence of external abnormalities was lower in all seasons compared to 2009 (RAMP 2010).

A total of 118 of 5,284 (2.2%) fish captured exhibited some form of external pathological abnormality such as parasites, growths, lesions (open sores) or body deformities. A summary of the percentage of fish by year and species for all seasons combined exhibiting some form of pathology is presented in Table 5.1-19. For each type of external pathology, there has been no increasing trend over time (Figure 5.1-43). Northern pike, walleye, white sucker, goldeye, lake whitefish and longnose sucker were the main species for which pathological abnormalities were recorded mostly due to their higher catch frequency and relative abundance compared to other species in the river and the selectiveness of boat electrofishing for large-bodied species. External pathology is primarily observed in walleye and white sucker compared to other species with 5.2% and 5.1% of fish with some type of external pathology in 2010, respectively; the percent of external pathology was higher than the historical range (1987 to 2009) for walleye (1.3% to 4.2%) and within the historical range for white sucker (1.7% to 26.4%) (Table 5.1-19). One of eleven burbot captured had parasites on the surface of the body, leading to a high percent of external pathology (9.1%) given the low capture success.

Similar levels of fish abnormalities have been documented in previous studies of the Athabasca River and other regional waterbodies. A Northern River Basins Study completed fish health assessments from 1992 to 1994 on reaches of the Athabasca River, upstream of Fort McMurray (Mill *et al.* 1996). Abnormalities recorded included tumours, lesions, scars or injuries, skin discolouration, deformities, and parasites. Similar to what has been observed during RAMP fish inventories, mountain whitefish, lake whitefish, northern pike, burbot, longnose sucker and white sucker were the primary species that exhibited some type of external pathology. In another study of the Athabasca River conducted in 1992 external abnormalities were found in northern pike, longnose sucker and white sucker accounting for 8.7, 45.6, and 50% of the total fish captured of each species, respectively (Barton *et al.* 1993). In a separate study in 1993, 0.8% of mountain whitefish and 76.7% of lake whitefish had some type of external abnormality (Mill *et al*. 1996). For comparison, other studies were conducted on the Wapiti, Smoky and Peace rivers documented 33% of burbot captured with some type of external abnormality (Hvenegaard and Boag 1993). In the Peace-Athabasca Delta, a study in 1993 documented 0.95% of lake whitefish captured with some type of external abnormality (Balagus *et al.* 1993). Other studies have documented no external abnormalities in any fish in the upper portion of the Athabasca River (R.L. & L. 1994) while other studies in the upper portion of the Athabasca River have documented a range between 0% and 15.7% of the total number of fish captured with some type of external abnormality (Mill *et al.* 1996).

The range of external pathology in fish from all studies, upstream and downstream of oil sands development is variable indicating no consistent pattern in observations of fish abnormalities that could be related to oil sands development.

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. A shift in species dominance from white sucker to walleye was observed in spring, from goldeye to northern pike in summer, and from walleye to goldeye in fall, although lake whitefish dominates the catch in fall.

As of 2010, 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 for some of the large-bodied KIR species. However, the variability of this measurement endpoint among years does not indicate consistent negative or positive changes in the fish populations and likely reflect natural variability over time.

The fish health assessment has indicated that abnormalities observed in 2010 in all species were within the historical range and consistent with studies done prior to major oil sands development in the upper Athabasca River, the ARD, and the Peace and Slave rivers.

5.1.5.2 Fish Tag Return Assessment

Angler Returns

A total of four RAMP Floy tags were submitted to the Alberta Sustainable Resource Development (ASRD), Fort McMurray office by anglers in 2010. The 2010 tag returns were for two walleye and two northern pike; however, three of the four tag returns did not provide enough information to map the distance between the initial capture and the recapture location. A summary of RAMP tag returns in 2010 during the RAMP fish inventories and from anglers is provided in Table 5.1-20 and a cumulative summary of RAMP tags returned to date is presented in Table 5.1-21 for comparison by species. Figure 5.1-44 shows the location of first capture and tagging by RAMP and the location of recapture by angler, as well as the most direct travel route, for the one walleye with complete information.

Fish Inventory Returns

Walleye and northern pike are tagged during the RAMP fish inventory programs. During the 2010 Athabasca River fish inventory, nine walleye, three northern pike and one white sucker were recaptured that had been previously tagged:

- All walleye with the exception of two were recaptured in the same river reach where they were originally tagged;
- One walleye was recaptured further upstream relative to its original capture location and one walleye was recaptured on the other side of the river to the original capture reach;
- One walleye was originally captured in 2005 (previously recaptured in 2006), one in 2007, three in 2008, and four in 2009;
- Two northern pike were recaptured in the same river reach where they were originally tagged and one was recaptured further downstream relative to the original capture reach;

- One northern pike was originally captured in 2008, 2009, and 2010 (in the same season but in a different location), respectively; and
- The white sucker was originally tagged during the Muskeg River fish fence in 2006 (RAMP 2007) and was recaptured near the mouth of the Muskeg River.

During the Clearwater River 2009 fish inventory, ten fish were captured that had been previously tagged during Clearwater inventories. Of these ten fish, there were seven northern pike, one walleye, and two white sucker:

- One northern pike was originally captured in 2003, downstream of the mouth of the Christina River and recaptured in 2010 at the furthest upstream reach on the Clearwater River;
- One northern pike was originally captured in 2005 in the middle reach and recaptured in 2010 in the upstream reach;
- Two northern pike were originally captured in 2007 and recaptured in the same reach in 2010;
- Two northern pike were originally captured in 2009 and recaptured in the same reach in 2010;
- One northern pike was captured and recaptured in 2010 in the same season but in different reaches;
- One walleye was originally captured in 2009 in the same reach as where it was recaptured; and
- The two white sucker were tagged and recaptured within the same area of the river in 2010 but in different seasons.

5.1.5.3 Sentinel Species Monitoring

Lethal sentinel species monitoring, using trout-perch, was conducted at five sites on the Athabasca River in fall (October) 2010 (Figure 3.1-5). Based on their location with respect to the location of focal project activities in 2010, sites 1 and 2 are designated as *baseline* and sites 3, 4, and 5 are designated as *test*.

Previous lethal trout-perch sentinel programs were conducted in 1999 and 2002; a non-lethal program was conducted in 2007. In 2002, all five sites were sampled, similar to 2010. Only three of the five sites were sampled in 1999; therefore, direct comparisons to 2010 were done with data from 2002. However, data from 1999 have been included in summary charts and figures to visually interpret temporal comparisons.

The non-lethal program conducted in 2007 was not used in the analysis given the trout-perch captured during that program could not be sexed.

Field Sampling Results

In situ water quality measurements (dissolved oxygen greater than 10 mg/L, conductivity from 184 to 283 µS/cm, and pH from 7.84 to 8.17) indicated suitable conditions at all sites. Sampling was primarily conducted in the morning with water temperatures ranging from 6.8 to 8.8°C.

Sampling was conducted in river sections comprised mainly of slow glides, with wetted widths ranging from 100 to 400 m. Sampling at *baseline* Site 1 took place in a river reach dominated by large cobble with very little fine substrate; sampling at all other sites took place in reaches with substrate dominated by sand and silt with few cobbles and boulders. The bank slope at all sites was gradual with little cover.

The average flow velocity across all sites was 0.3 m/s and the sampling depth across all sites ranged from 0.3 m to 0.5 m.

Target numbers of trout-perch (40 adult fish of each sex) were collected at four of five sites (Table 5.1-23). *Test* Site 5 had fewer adult fish and the target number was not obtained for either sex. *Post hoc* power analyses results indicated that the sample size from each site was adequate to detect differences in weight-at-age, GSI, LSI, and condition; however, greater sample sizes were required to evaluate a ±25% difference in mean age (Table 5.1-22).

Age

In 2010, the mean age of adult female trout-perch ranged from two years (*baseline* Site 1 and *test* Site 5) to five years (*test* Site 3) and the mean age of male adult trout-perch ranged from two years (*test* Site 5) to four years (*test* Site 4) (Table 5.1-23). The average age across all sampling years (1999, 2002, and 2010) was generally the same, although a higher mean age of female trout-perch was observed in 2010 at *baseline* Site 2 and *test* sites 3, and 4 relative to previous sampling years (Figure 5.1-45).

An ANOVA was used to compare age of male and female trout-perch between *baseline* and *test* sites in the Athabasca River and between 2002 and 2010 (i.e., when all five sites were sampled). Generally, there were no significant differences in the mean age between *baseline* and *test* sites ($p>0.1$) in 2010, with the exception of female trout-perch from *baseline* Site 1 and *test* Site 5, which had a lower mean age (mean age: two years) relative to female trout-perch from *baseline* Site 2 (mean age: > four years) ($p<0.05$) (Table 5.1-24). However, as noted above, statistical power was low for comparisons in mean age between *baseline* and *test* sites, with the exception of *baseline* Site 2 versus *test* Site 5 (Table 5.1-22). In 2002, female trout-perch from these two sites had approximately equal mean ages.

Growth (Weight-at-Age)

An ANCOVA was used to compare the relationship between body weight and age of male and female trout-perch between *baseline* and *test* sites in the Athabasca River in 2010 and between 2002 and 2010. For male trout-perch, the slopes of the relationship of weight-at-age at *test* Site 3 and *test* Site 5 were higher than at the *baseline* Site 2 (Table 5.1-25 and Figure 5.1-46). In both cases, the weight of trout-perch was greater at the *test* sites at any given age after the fish reached an approximate age of 2 years. The difference in weight at the oldest age class between the *baseline* and *test* sites 3 and 5 was 50 to 62%, respectively, exceeding the effects criterion of ±25%. The effects criterion was also exceeded in female trout-perch from *test* Site 5, with approximately 25% slower growth than female trout-perch from *baseline* Site 2 and male trout-perch from *test* Site 4, with approximately 50% faster growth than male trout-perch from *baseline* Site 2; these differences were not statistically significant given the high degree of within-reach variation in body weight.

Gonadosomatic Index (GSI)

The Gonadosomatic index (GSI) is a measurement endpoint that is calculated for each fish as a ratio of gonad weight to body weight, and provides a measure of gonad development and reproductive success for a fish. In 2010, the mean GSI of adult female trout-perch ranged from 2.7 (*test* Site 5) to 6.6 (*test* Site 3) and the mean GSI of male adult trout-perch was approximately 1.1 at all sites (Table 5.1-23). With the exception of *test* Site 5, GSI was similar in female trout-perch across years, whereas GSI of male trout-perch in 2010 was generally higher than previous sampling years indicating heavier gonad weights in relation to body size (Figure 5.1-47).

An ANCOVA was used to compare the relationship between body weight and gonad weight of male and female trout-perch between *baseline* and *test* sites in the Athabasca River in 2010 and between 2002 and 2010 (Figure 5.1-48). Differences in gonad size were generally small for female trout-perch with the exception of female trout-perch at *test* Site 5 in 2010 that had ovaries that were approximately 39% lighter than ovaries of female trout-perch at *baseline* Site 2 ($p<0.05$) (Table 5.1-26). This result is in contrast to what was observed in 2002 when female trout-perch from *test* Site 5 had ovaries that were approximately 10% heavier than ovaries in female trout-perch from *baseline* Site 2 (Table 5.1-26).

Gonad weight in male trout-perch was more variable between sites in 2010 ($p<0.05$). However, the differences in gonad size between male trout-perch from the *baseline* and *test* sites did not exceed the effects criterion (±25%) as observed in 2002 when trout-perch from all three *test* sites had heavier gonads than male trout-perch from *baseline* Site 2 (~30 to 70% heavier) (Table 5.1-26).

Liver Somatic Index (LSI)

The liver somatic index (LSI) is a measurement endpoint that is calculated for each fish as a ratio of liver weight to body weight, and provides a measure of energy storage. In 2010, the mean LSI of adult female trout-perch ranged from 1.8 (*test* Site 5) to 2.6 (*baseline* Site 2) and the mean LSI of male adult trout-perch ranged from 1.6 (*test* Site 3) to 2.0 (*baseline* Site 2) (Table 5.1-23). LSI was generally higher across sites in female and male trout-perch in 2010 compared to previous sampling years (Figure 5.1-49).

An ANCOVA was used to compare the relationship between body weight and liver weight of male and female trout-perch between *baseline* and *test* sites in the Athabasca River in 2010 and between 2002 and 2010 (Figure 5.1-50). There was a significant decrease in liver size in relation to body weight for female and male trout-perch for *test* sites 3 and 4 and for females at *test* Site 5 compared to *baseline* Site 2 ($p>0.05$) in 2010 and across years. However, these differences did not exceed the effects criterion (Table 5.1-27).

Condition

Condition factor is a standard measurement endpoint that is calculated for each fish as a ratio of fish length and weight (i.e., how "fat" a fish is), and provides a measure of energy storage. In 2010, the mean condition of female and male trout-perch was approximately 1.1 at all sites (Table 5.1-23). Condition of male and female trout-perch in 2010 was similar to trout-perch in 1999 and lower than 2002 across all sites (Figure 5.1-51).

An ANCOVA was used to compare condition of male and female adult trout-perch between *baseline* and *test* sites in the Athabasca River in 2010 and between 2002 and 2010 (Figure 5.1-52). Differences in condition among site-year combinations were insignificant for both female and male trout-perch ($p>0.05$) with the exception of female trout-perch at *test* Site 5 compared to female trout-perch at *baseline* Site 2 in 2010 and across years. Female trout-perch at *test* Site 5 were 12% lighter than female trout-perch at *baseline* Site 2 compared to a 5% difference in condition of female trout-perch between *test* Site 5 and *baseline* Site 2 in 2002. The difference in condition observed between trout-perch at *test* Site 5 and *baseline* Site 2 exceeded the effects criterion.

Interpretation of 2010 Responses

As outlined in RAMP (2009b), the Athabasca River sentinel species program was developed to evaluate spatial differences in measurement endpoints between *baseline* and *test* sites. In addition, results from the 2010 study can be compared to past sentinel programs to assess possible trends over time. A summary of 2010 response patterns at each *test* site for male and female trout-perch is provided in Table 5.1-29.

Female and male trout-perch from *test* sites 3 and 4 exhibited few differences in measurement endpoints relative to fish from *baseline* Site 2. There was a tendency for weight-at-age and LSI to be lower in females at these *test* sites, which suggests a possible limitation in food resources (i.e., lower energy use and storage; Gibbons and Munkittrick 1994), but the differences in weight-at-age were not statistically significant. Interestingly, male fish at *test* sites 3 and 4 and at *test* Site 5 as well exhibited greater growth relative to *baseline* Site 2 suggesting greater availability of food resources; however, there was no concomitant increase in GSI, LSI or condition. It is likely that the response of female trout-perch at *test* sites 3 and 4 and male trout-perch at *test* sites 3, 4, and 5 are not substantially different to what is observed at *baseline* Site 2 and, with the exception of male weight at age at *test* sites 3 and 5, none of the measurement endpoints exceeded the effects criteria.

Female trout-perch at *test* Site 5 exhibited the greatest differences in measurement endpoints relative to *baseline* Site 2. Overall, there was a decrease in mean age, energy storage and energy use. A decrease in mean age of adult fish is commonly the result of an increase in adult mortality or an increase in recruitment (Gibbons and Munkittrick 1994). Increased recruitment seems unlikely because there is little evidence of increased reproductive effort (i.e., lower GSI at *test* Site 5), although reproductive effort for trout-perch is difficult to assess with a single sampling event given they spawn multiple times during the growing season. In addition, as suggested in Gibbons *et al.* (1998), there are other factors that could influence recruitment, including number and quality of eggs, number of spawning events, number of successful spawning individuals, availability and quality of spawning habitat and survival and growth of juveniles. The loss of older age classes would also result in a decline in mean age; however, energy use and storage typically increase under these circumstances as competition for food resources decreases (Gibbons and Munkittrick 1994) and both were lower in females from *test* Site 5. From the data collected during this study, it is difficult to interpret the response of female trout-perch at *test* Site 5. In 2002, the mean age of females was also lower than *baseline* fish; however, there were no differences in energy use or storage. It appears further information is required regarding the age structure and food resources at *test* Site 5 to facilitate interpretation of the response. However, it is important to note that trout-perch from sites closer to intense mining activity do not show substantial differences from *baseline* fish, suggesting that female trout-perch at *test* Site 5 are responding to localized conditions unrelated to oil sands development.

Classification of Results

The effects criteria for age, weight-at-age, GSI, and LSI defined by Environment Canada (2010) is a ± 25% difference between *test* and *baseline* sites and a ± 10% difference for condition. Differences greater than the effects criteria between *baseline* and *test* sites suggest an ecologically relevant change in the trout-perch population at the *test* sites.

Differences in measurement endpoints that exceeded the Environment Canada effects criteria are as follows:

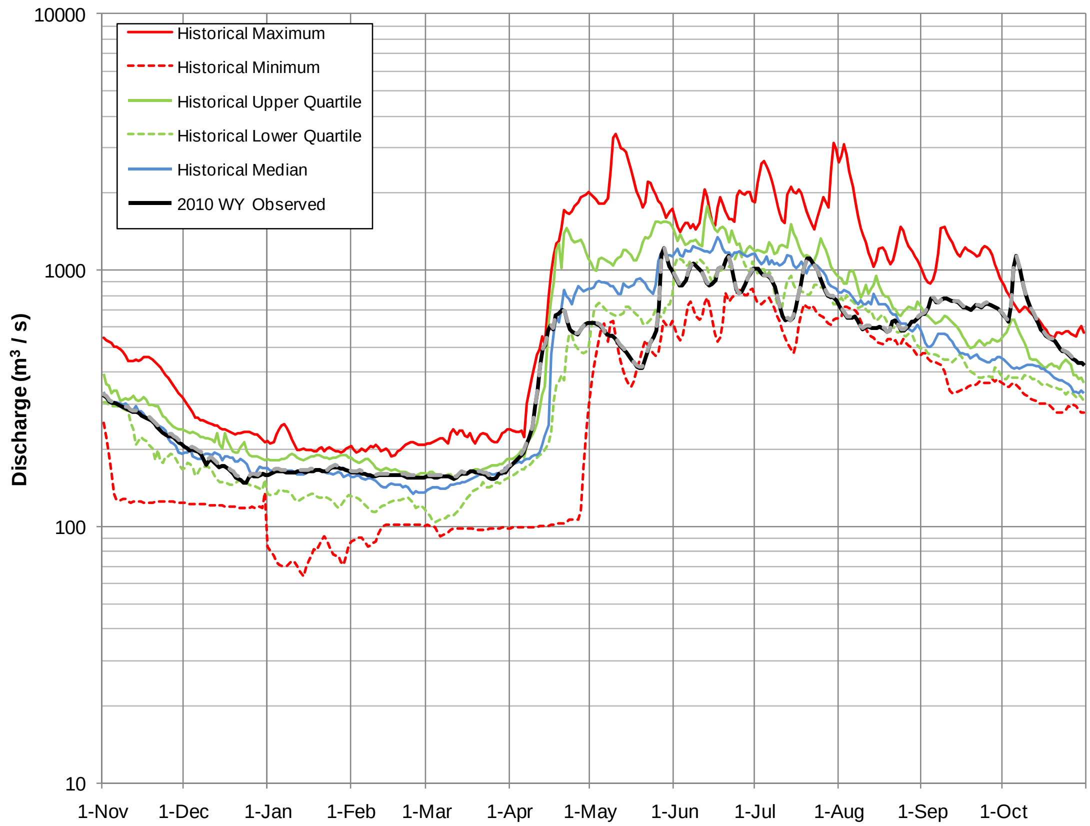
- Age of female trout-perch at *test* Site 5 was 38% lower compared to *baseline* Site 2;
- Weight-at-age in female trout-perch at *test* Site 5 was 34% lower compared to *baseline* Site 2;
- GSI of female trout-perch at *test* Site 5 was 39.0% lower compared to *baseline* Site 2;
- Condition of female trout-perch at *test* Site 5 was 12% lower compared to *baseline* Site 2; and
- Weight-at-age in male trout-perch at *test* sites 3, 4, and 5 was >50% higher compared to *baseline* Site 2.

In 2007, a non-lethal trout-perch sampling program was conducted on the Athabasca River in summer and fall. Given it is difficult to sex trout-perch externally; fish were not separated by sex for statistical analyses. Similar to results in 2010, condition of adult trout-perch at *test* Site 5, in summer 2007, was 12% lower than adult trout-perch at *baseline* Site 2; this effect was not observed during the fall sampling program in 2007 (RAMP 2008). Condition of adult trout-perch at *test* Site 3 in fall 2007 was 28% higher than adult trout-perch at *baseline* Site 2; this effect was not observed in 2010.

Based on the differences in measurement endpoints in trout-perch at *test* sites 3, 4 and 5 relative to *baseline* Site 2, the following assessments were made:

- Female trout-perch at *test* Site 3 and male and female trout-perch at *test* Site 4 indicated a **Negligible-Low** difference from *baseline* Site 2 because none of the measurement endpoints exceeded the effects criteria;
- Male trout-perch at *test* Site 3 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age exceeded the effects criteria;
- Male trout-perch at *test* Site 5 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age exceeded the effects criteria; and
- Female trout-perch at *test* Site 5 indicated a **Moderate** difference from *baseline* Site 2 because weight-at-age, GSI and condition exceeded the effects criteria; however, this response was not observed in previous sentinel programs.

Figure 5.1-3 Athabasca River: 2010 WY hydrograph and historical context.



Note: Based on 2010 WY provisional data from Station S24, Athabasca River below Eymundson Creek. The upstream drainage area is 146,000 km^2. Historical data are calculated from nine years of record (June 21, 2001 to October 31, 2009).

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, 2010 WY.

<table>
<tr><th rowspan="2">Component</th><th colspan="2">Volume (million m^3)</th><th rowspan="2">Basis and Data Source</th></tr>
<tr><th>Focal Projects</th><th>Focal Projects Plus Other Oil Sands Developments</th></tr>
<tr><td>Observed test hydrograph (total discharge)</td><td colspan="2">15,310.3</td><td>Sum of observed daily discharges obtained from RAMP Station S24, Athabasca River below Eymundson Creek.</td></tr>
<tr><td>Closed-circuited area water loss from the observed hydrograph</td><td>-35.3</td><td>-35.4</td><td>335 km^2 (334 km^2 focal projects only) of land estimated to have been closed-circuited as of 2010 (Table 2.5-1), in the cumulative area upstream of S24, including (from Table 2.4-1): minor Athabasca River tributaries, McLean Creek, Upper Beaver River, Shipyard Lake and Horse River.</td></tr>
<tr><td>Incremental runoff form land clearing (not closed-circuited area)</td><td>+2.1</td><td>+2.2</td><td>103 km^2 (100 km^2 focal projects only) of land estimated to have undergone land change by focal projects as of 2010 but are not closed-circuited (Table 2.5-1), in the cumulative area upstream of S24, including (from Table 2.4-1): minor Athabasca River tributaries, McLean Creek, upper Beaver River, Shipyard Lake and Horse River.</td></tr>
<tr><td rowspan="5">Water withdrawals from the Athabasca River watershed from focal projects</td><td colspan="2">-34.8</td><td>Withdrawals by Suncor (daily values provided).</td></tr>
<tr><td colspan="2">-34.1</td><td>Withdrawals by Syncrude (monthly totals provided; constant daily values assumed).</td></tr>
<tr><td colspan="2">-13.6</td><td>Withdrawals by Shell (daily values provided).</td></tr>
<tr><td colspan="2">-15.2</td><td>Withdrawals by Canadian Natural (daily values provided).</td></tr>
<tr><td colspan="2">-0.1</td><td>Withdrawals by Imperial (daily values provided).</td></tr>
<tr><td rowspan="2">Water releases in the Athabasca River watershed from focal projects</td><td colspan="2">+0.3</td><td>Releases by Syncrude (daily values provided).</td></tr>
<tr><td colspan="2">+6.5</td><td>Releases by Suncor (daily values provided).</td></tr>
<tr><td>The difference between test and baseline hydrographs on tributary streams</td><td>+0.4</td><td>+0.3</td><td>Net sum of incremental volume results from the major tributaries as listed in Section 5.2 to Section 5.11[1].</td></tr>
<tr><td>Estimated baseline hydrograph (total discharge)</td><td>15,433.8</td><td>15,433.9</td><td>Estimated baseline discharge at RAMP Station S24, Athabasca River below Eymundson Creek.</td></tr>
<tr><td>Incremental flow (change in total discharge)</td><td>-123.5</td><td>-123.7</td><td>Total discharge from observed test hydrograph less total discharge from estimated baseline hydrograph.</td></tr>
<tr><td>Incremental flow (% of total discharge)</td><td>-0.80%</td><td>-0.80%</td><td>Incremental flow as a percentage of total discharge of estimated baseline hydrograph.</td></tr>
</table>

Note: Data and assumptions are discussed in Section 3.2.1.4.

Note: Based on the provisional 2010 WY 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 2010 (Table 2.5-1).

Table 5.1-3 Calculated change in hydrologic measurement endpoints for the Athabasca River in the 2010 WY, 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	742	737	-0.6%
Mean winter discharge	187	184	-1.7%
Annual maximum daily discharge	1,230	1,224	-0.4%
Open-water season minimum daily discharge	419	416	-0.8%

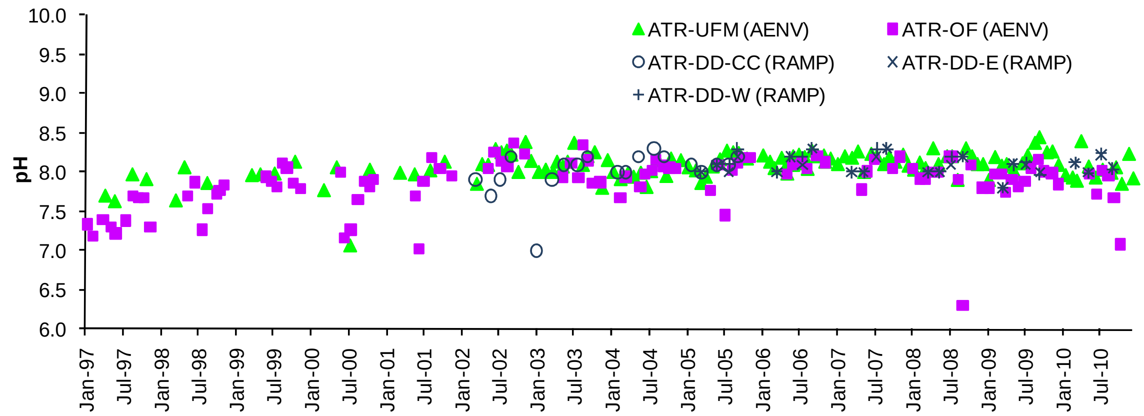
Note: Based on the provisional 2010 WY data for Station S24, Athabasca River below Eymundson Creek.

[1] Differences in results between the focal project and focal project plus other oil sands developments, only exist when presented at two decimal places both for *baseline* values and relative change values.

Figure 5.1-4 Water quality measurement endpoints, 1997 to 2010 AENV and RAMP data for the Athabasca River mainstem.

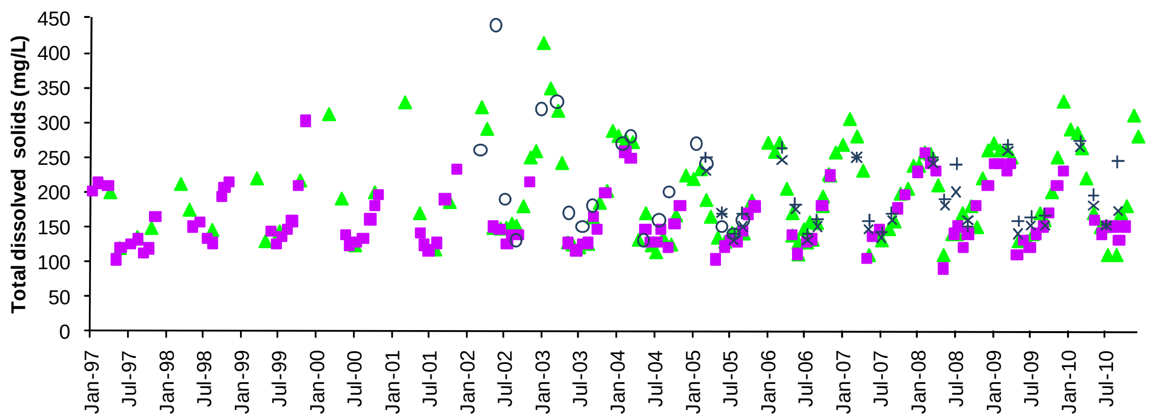
pH

Trend at ATR-UFM: up   Trend at ATR-OF: up



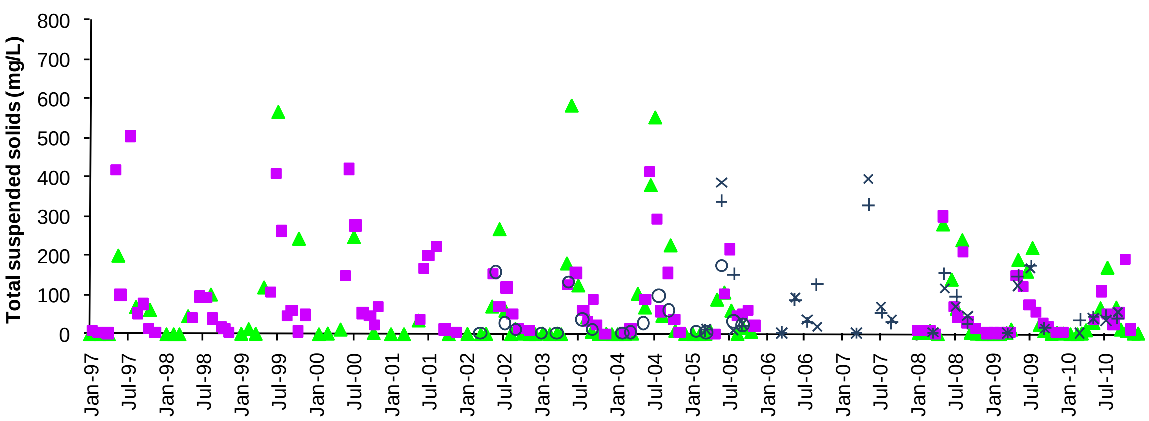
Total dissolved solids

Trend at ATR-UFM: none   Trend at ATR-OF: none



Total suspended solids

Trend at ATR-UFM: none   Trend at ATR-OF: none

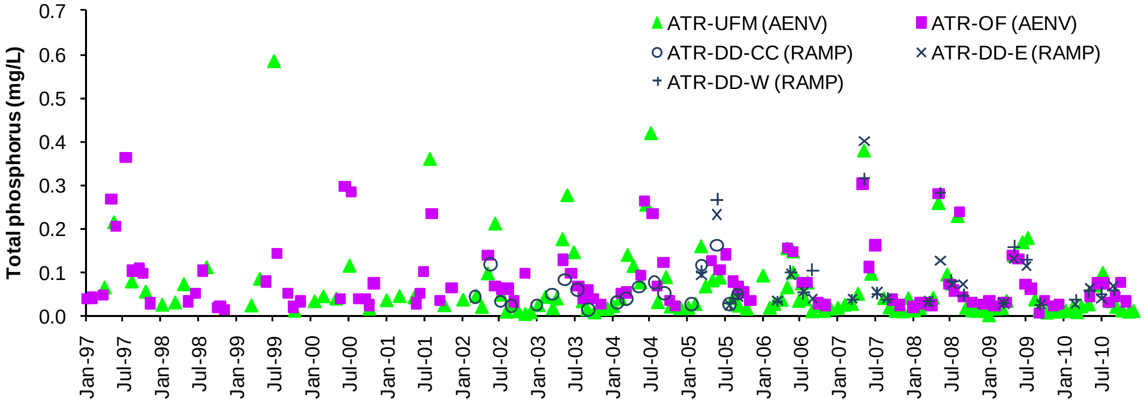


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

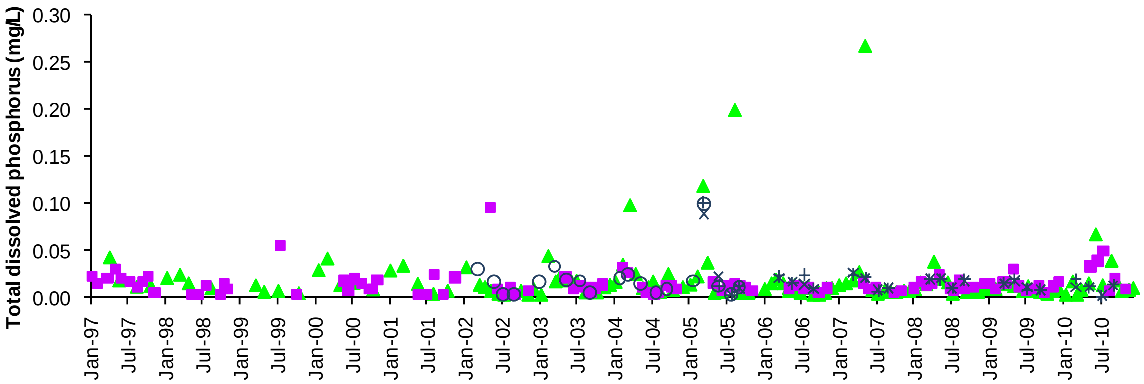
Total phosphorus

Trend at ATR-UFM: down Trend at ATR-OF: down



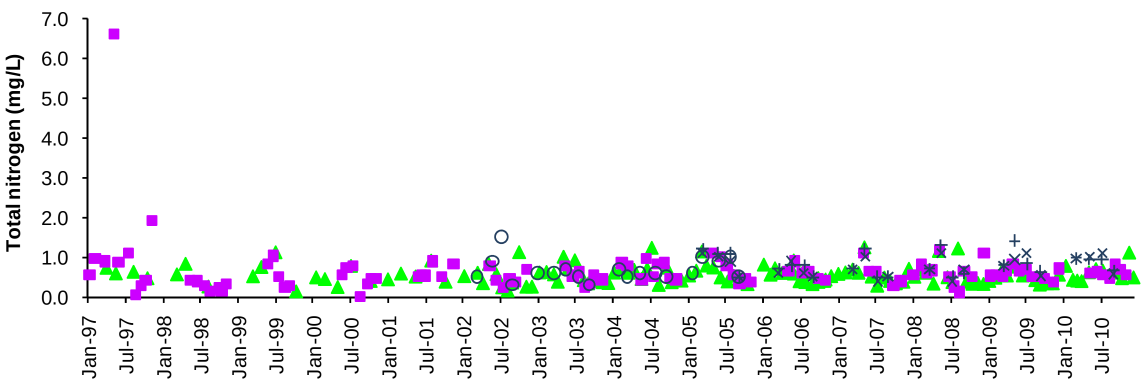
Total dissolved phosphorus

Trend at ATR-UFM: none Trend at ATR-OF: up



Total nitrogen

Trend at ATR-UFM: none Trend at ATR-OF: up

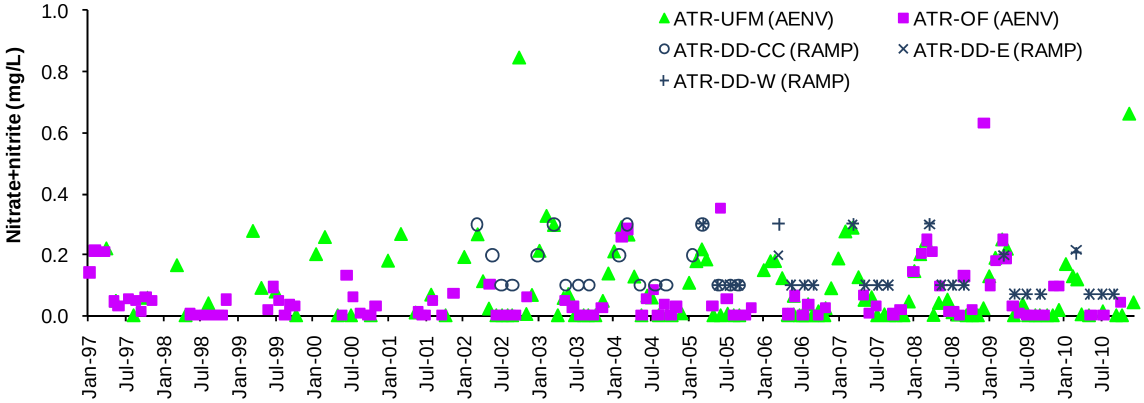


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

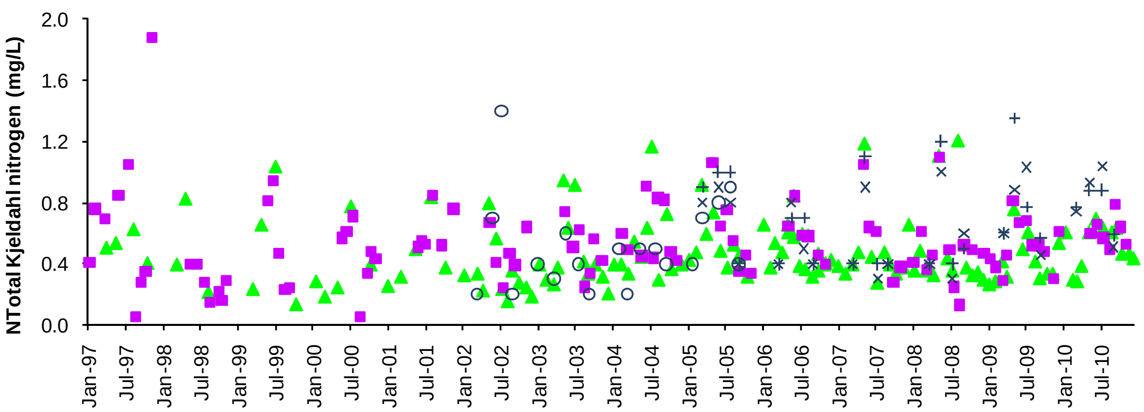
Nitrate + Nitrite

Trend at ATR-UFM: down Trend at ATR-OF: none



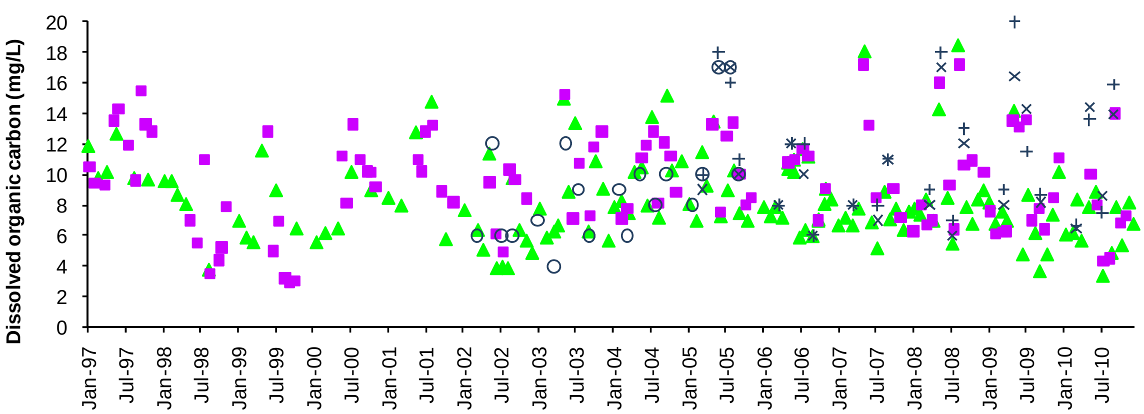
Total Kjeldahl nitrogen

Trend at ATR-UFM: none Trend at ATR-OF: up



Dissolved organic carbon

Trend at ATR-UFM: none Trend at ATR-OF: none

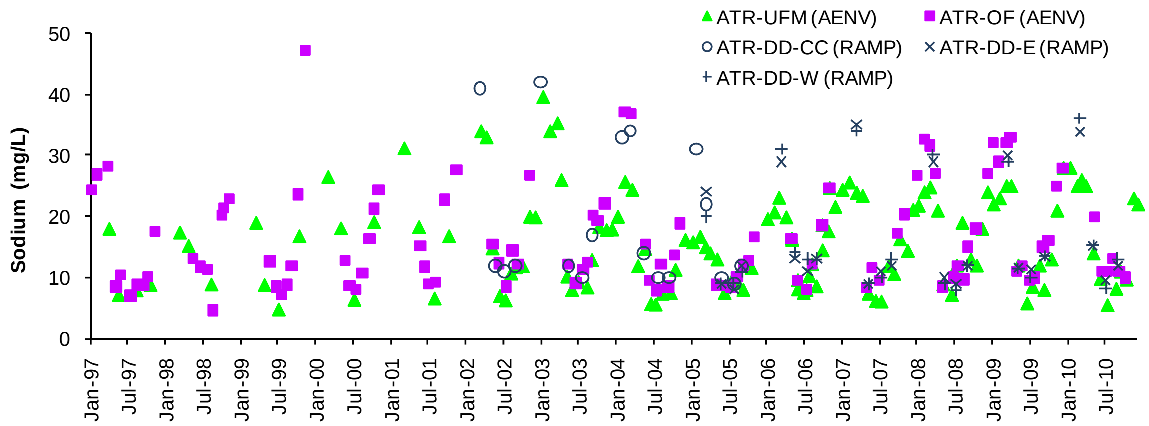


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

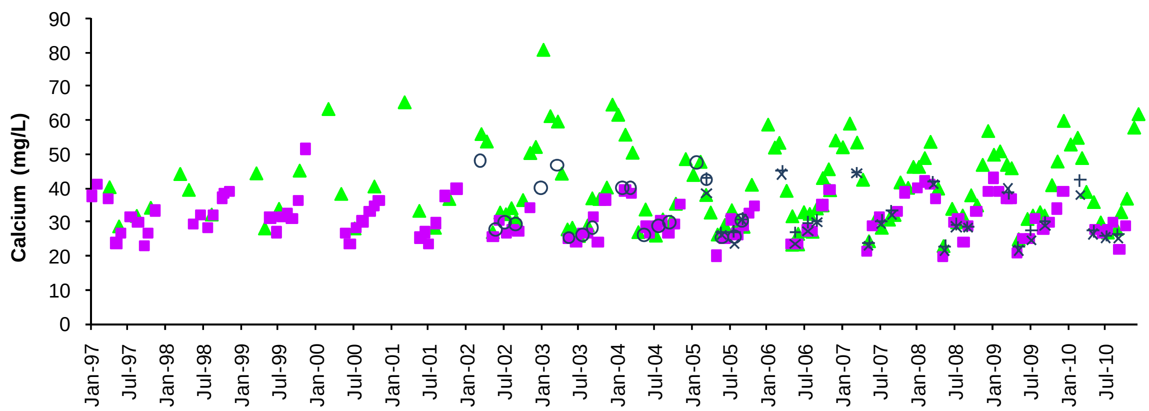
Sodium

Trend at ATR-UFM: none Trend at ATR-OF: none



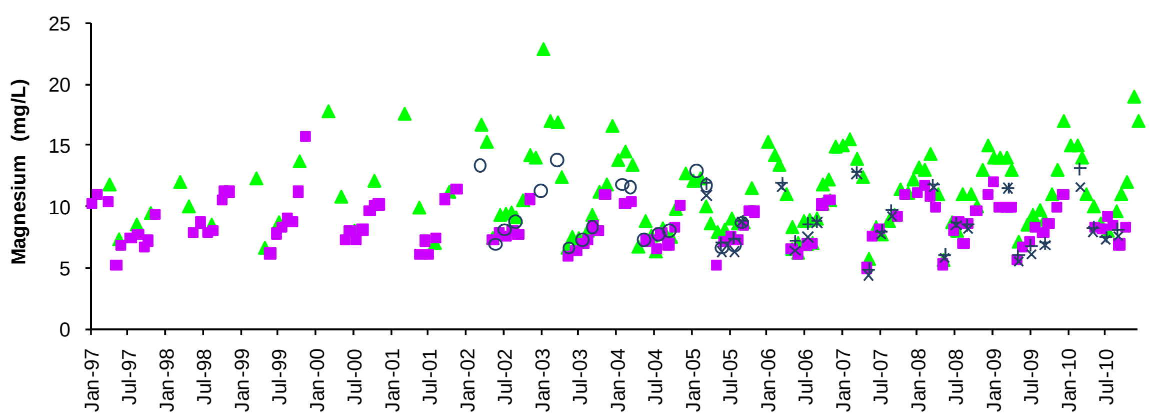
Calcium

Trend at ATR-UFM: none Trend at ATR-OF: none



Magnesium

Trend at ATR-UFM: none Trend at ATR-OF: none

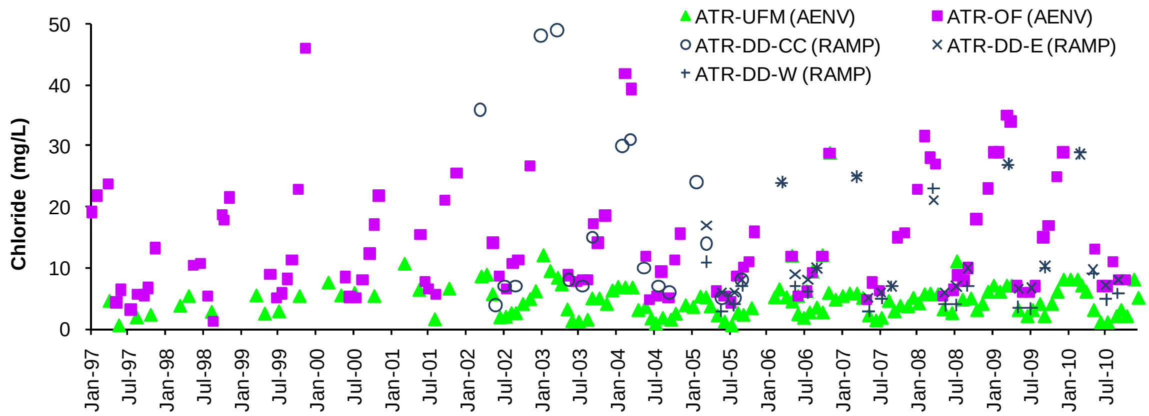


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

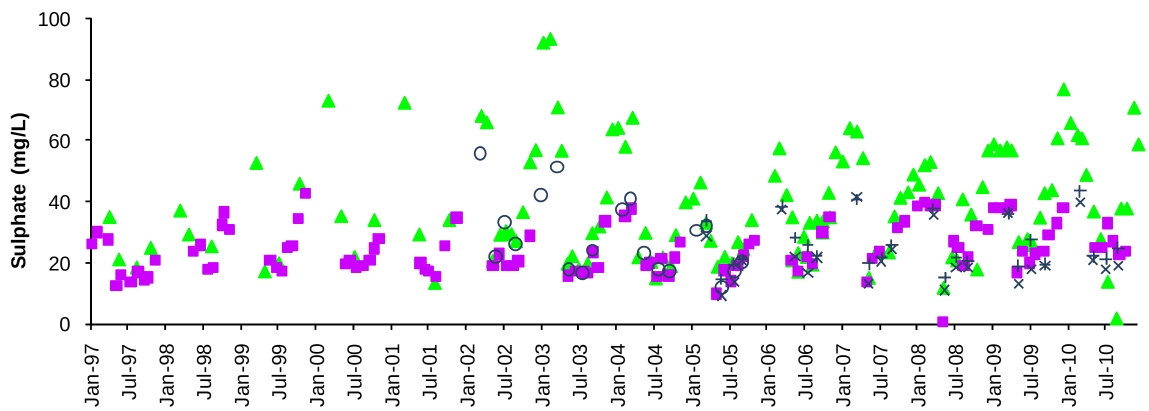
Chloride

Trend at ATR-UFM: none   Trend at ATR-OF: none



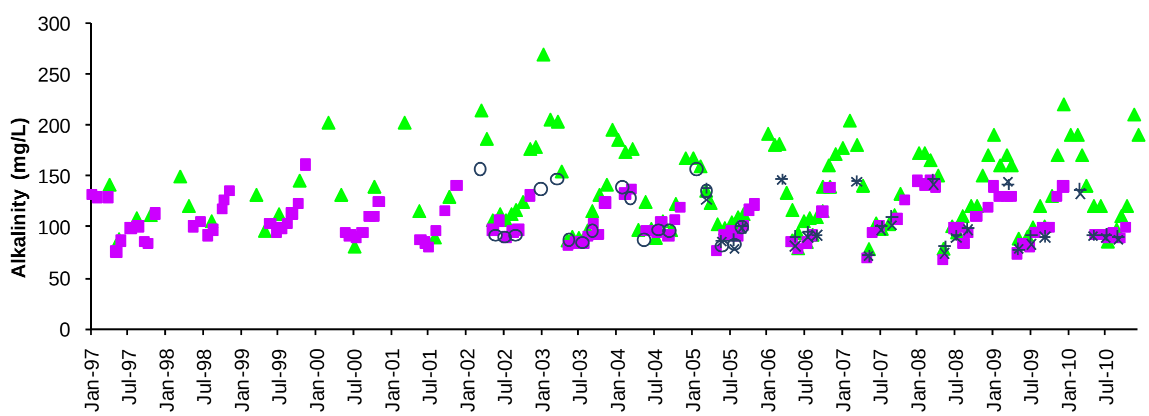
Sulphate

Trend at ATR-UFM: none   Trend at ATR-OF: up



Alkalinity (as $CaCO_3$)

Trend at ATR-UFM: none   Trend at ATR-OF: none

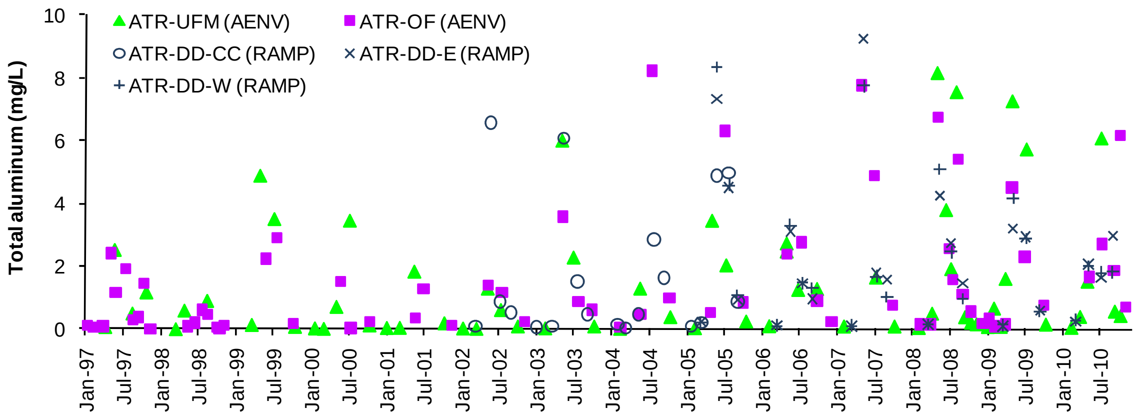


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

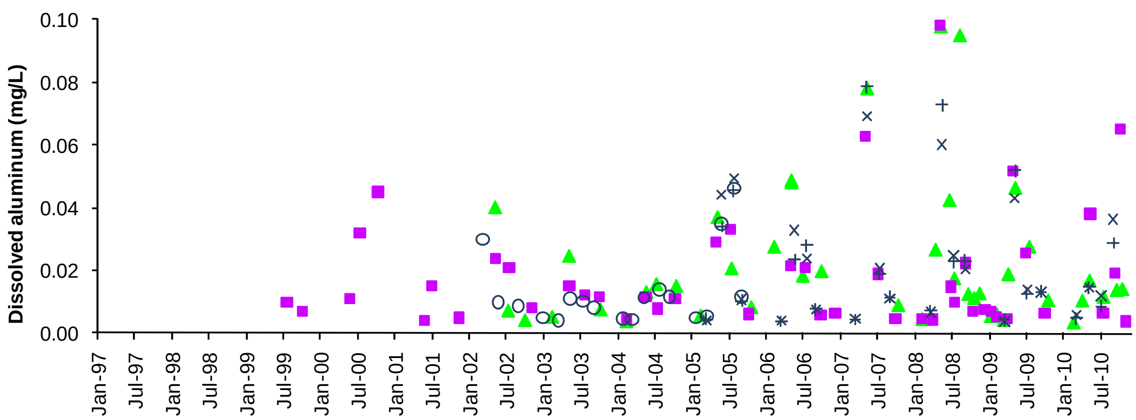
Total aluminum

Trend at ATR-UFM: up Trend at ATR-OF: up



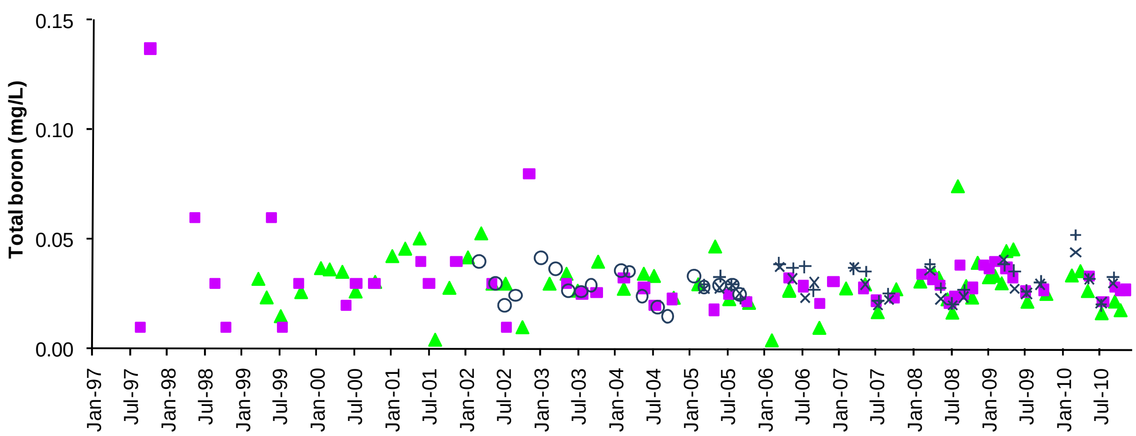
Dissolved aluminum

Trend at ATR-UFM: up Trend at ATR-OF: none



Total boron

Trend at ATR-UFM: none Trend at ATR-OF: none

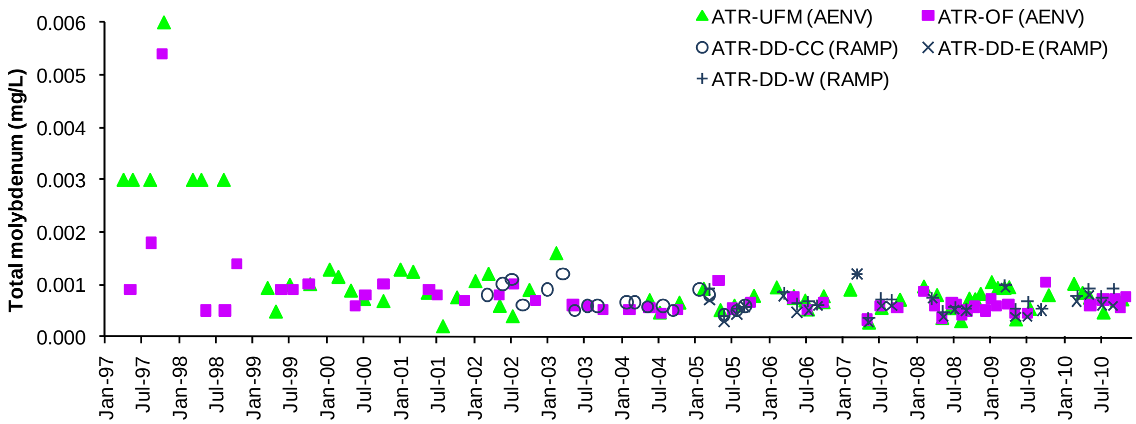


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

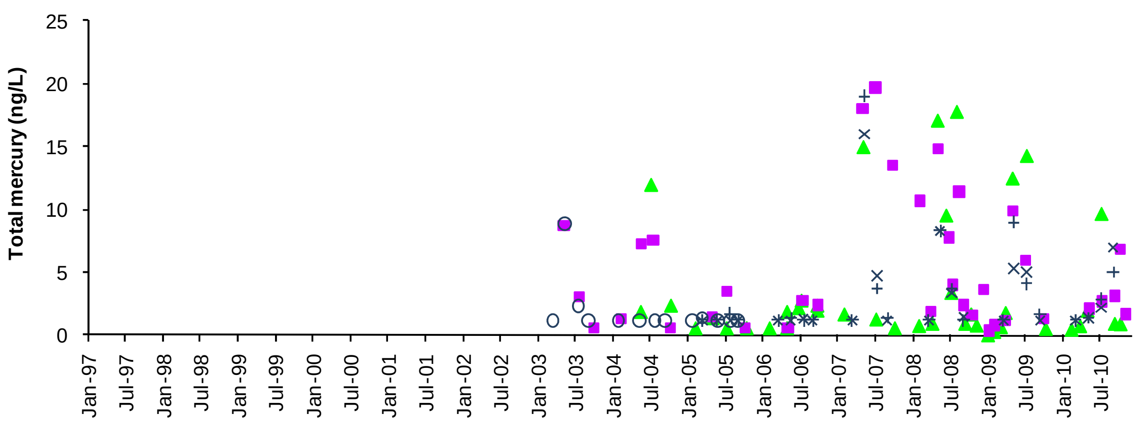
Total molybdenum

Trend at ATR-UFM: none   Trend at ATR-OF: down



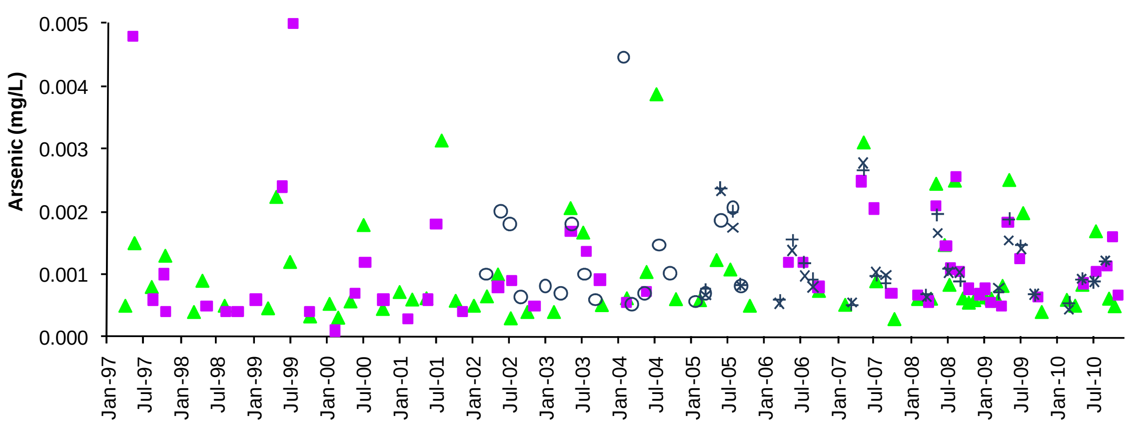
Total mercury (ultra-trace)

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 5.1-4 Concentrations of water quality measurement endpoints, Athabasca River mainstem, fall 2010.

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	55	7.3	8.1	8.4	8.03	8.19	8.14	8.21	8.10	8.21	8.06	8.04	8.19
Total suspended solids	mg/L	-	51	1	7	344	136	18	21	17	35	5	57	39	28
Conductivity	µS/cm	-	52	150	288	446	217	264	232	256	225	252	236	247	238
Nutrients															
Total dissolved phosphorus	mg/L	0.05[2]	38	0.003	0.006	0.025	0.018	0.0072	0.0132	0.0065	0.0131	0.0075	0.0129	0.0136	0.0134
Total nitrogen*	mg/L	1.0	50	0.133	0.373	**1.903**	0.831	0.471	0.701	0.421	0.661	0.501	0.581	0.661	0.621
Nitrate+nitrite	mg/L	1.3	56	0.001	<0.003	0.843	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071
Dissolved organic carbon	mg/L	-	51	2.5	7.6	25.0	17.1	9.5	24.2	22.2	15.4	22.3	13.9	15.9	14.2
Ions															
Sodium	mg/L	-	53	4	11	21	17.8	10.7	12.2	10.3	13.2	10.6	12	13	12.9
Calcium	mg/L	-	56	19.4	35.8	50.5	19.5	31.7	23.8	29.6	24.5	28.8	25.2	26.5	26.1
Magnesium	mg/L	-	54	5.4	9.6	14.2	6.58	9.44	7.37	8.65	7.51	8.57	7.54	8.13	7.76
Chloride	mg/L	230, 860[3]	56	1.0	2.9	7.2	16.9	2.97	9.09	3.99	9.37	4.44	8.02	5.83	8.25
Sulphate	mg/L	100[4]	55	13	30	61	7.3	28.7	18.2	27.6	16	26.6	19.2	24.9	19.6
Total dissolved solids	mg/L	-	47	109	172	270	168	282	162	173	167	174	172	244	179
Total alkalinity	mg/L		56	64	120	176	74.3	101	83.8	95.4	82.0	93.3	87.7	90.9	87.5
Selected metals															
Total aluminum	mg/L	0.1	17	0.07	**0.20**	**1.29**	**3.76**	**1.38**	**2.80**	**1.51**	**3.13**	**1.52**	**2.97**	**1.81**	**1.47**
Total arsenic	mg/L	0.005	19	0.0003	0.0006	0.0019	0.0017	0.000892	0.00136	0.000977	0.00143	0.000941	0.00122	0.00121	0.00104
Dissolved aluminum	mg/L	0.1[2]	10	0.004	0.011	0.020	0.0587	0.0233	0.0433	0.0232	0.0491	0.0245	0.0364	0.0287	0.0298
Total boron	mg/L	1.2[5]	13	0.01	0.03	0.04	0.0364	0.0287	0.0301	0.0241	0.0322	0.0258	0.0300	0.0326	0.028
Total molybdenum	mg/L	0.073	19	0.0007	0.0008	0.0180	0.000206	0.000615	0.000426	0.00539	0.00039	0.0019	0.000595	0.000929	0.000702
Total mercury (ultra-trace)	ng/L	5, 13[6]	8	0.55	0.71	2.40	**12.9**	**5.7**	**11.2**	**6.0**	**11.0**	**5.8**	**7.0**	5.0	**5.2**
Total strontium	mg/L	-	13	0.220	0.291	0.355	0.0992	0.232	0.162	0.222	0.15	0.215	0.168	0.181	0.176
Other variables that exceeded CCME/AENV guidelines in 2010															
Total Phosphorus	mg/L	0.05	54	0.006	0.021	0.350	**0.131**	-	**0.15**	-	**0.0823**	**0.0591**	**0.0700**	**0.0579**	-
Sulphide	mg/L	0.002[7]	12	<0.001	<0.005	**0.040**	**0.0059**	-	**0.0043**	**0.0026**	**0.0045**	**0.0028**	**0.0036**	**0.0057**	**0.0034**
Total Chromium	mg/L	0.001	21	0.0002	0.001	**0.007**	**0.00524**	-	**0.00338**	**0.00185**	**0.00374**	**0.00191**	**0.00316**	**0.00250**	**0.00212**
Total Copper	mg/L	[8]	23	0.0007	0.001	0.004	**0.00277**	-	**0.00204**	-	**0.00218**	-	**0.00214**	-	-
Dissolved iron	mg/L	0.3[2]	21	0.01	0.08	0.19	**0.378**	-	-	-	-	-	-	-	-
Total iron	mg/L	0.3	17	0.14	**0.33**	**3.29**	**1.04**	**0.44**	**2.48**	**1.28**	**2.65**	**1.27**	**2.10**	**1.73**	**1.49**
Total Phenolics	mg/L	0.004	5	<1	<1	<1	**0.0079**	**0.0102**	**0.0191**	-	**0.0074**	-	**0.0262**	**0.0495**	**0.0196**

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 H_2S (B.C. 2006).

8 Guideline is hardness-dependent: 0.002 mg/L at hardness = 0 to 120 mg/L; 0.003 mg/L at hardness = 120 to 180 mg/L; 0.004 mg/L at hardness > 120 mg/L (CCME 2007).

Figure 5.1-5 Piper diagram of ion concentrations in Athabasca River mainstem (*test* stations ATR-SR versus *baseline* stations ATR-DC), fall 1997 to 2010.

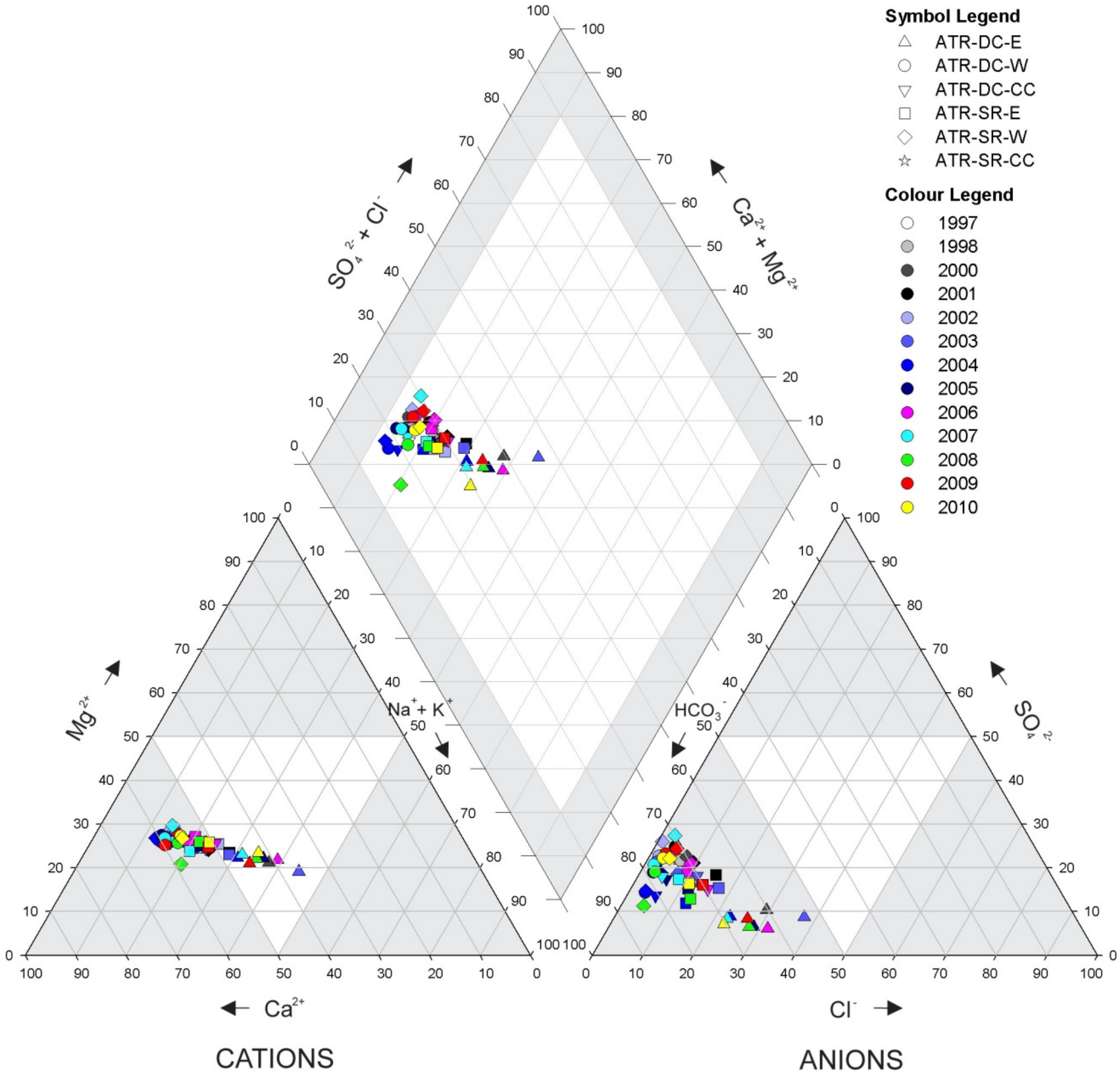


Figure 5.1-6 Piper diagram of ion concentrations in Athabasca River mainstem (*test* stations ATR-MR versus *baseline* stations ATR-DC), fall 1997 to 2010.

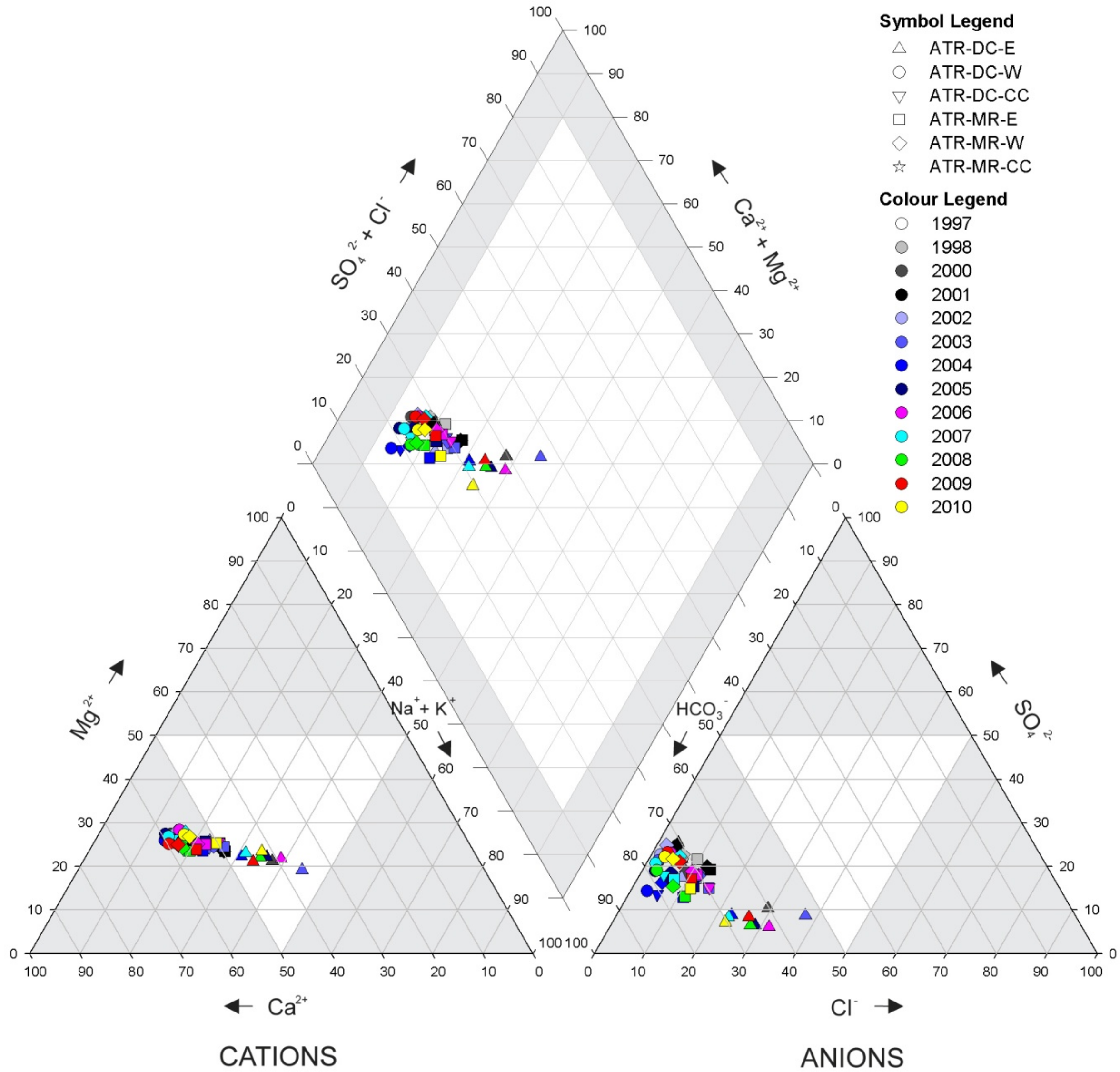


Figure 5.1-7 Piper diagram of ion concentrations in Athabasca River mainstem (*test* stations ATR-FR versus *baseline* stations ATR-DC), fall 1997 to 2010.

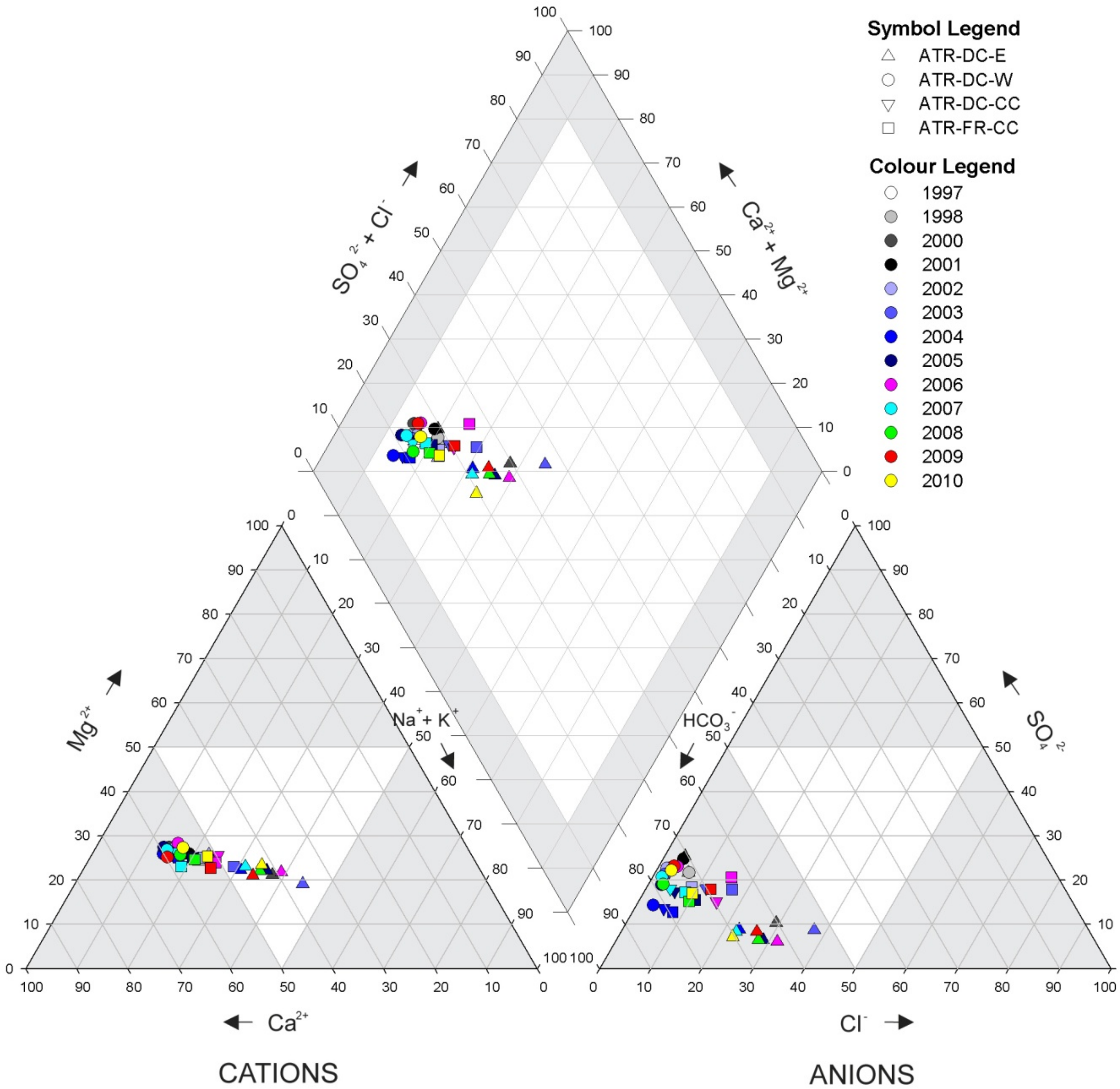


Figure 5.1-8 Piper diagram of ion concentrations in Athabasca River mainstem *test* stations ATR-DD versus *baseline* stations ATR-DC), fall 1997 to 2010.

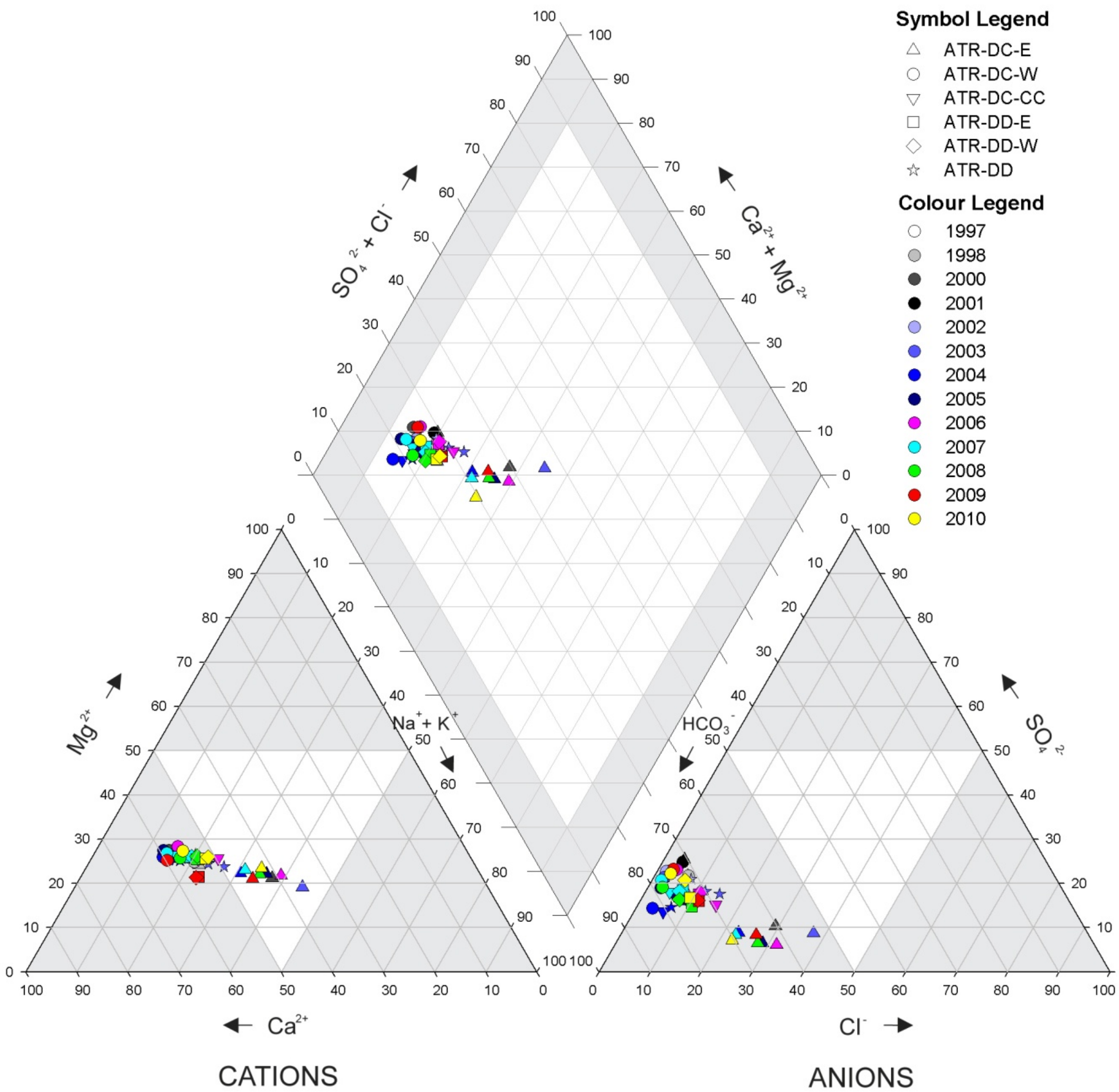


Table 5.1-5 Water quality guideline exceedances in the Athabasca River mainstem, downstream of development (ATR-DD), 2010.

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											
Sulphide	mg/L	0.002[4]	-	0.0023	ns	ns	ns	ns	-	0.0034	ns
Total phenolics	mg/L	0.004	-	0.0041	ns	ns	ns	ns	-	-	ns
Total nitrogen*	mg/L	1.0	1.211	1.075	ns	ns	ns	ns	-	-	ns
Dissolved cadmium	mg/L	[3]	0.000028	0.000030	ns	ns	ns	ns	0.000014	0.000016	ns
Total cadmium	mg/L	[3]	0.000038	0.000041	ns	ns	ns	ns	0.000020	0.000024	ns
Total aluminum	mg/L	0.1	0.110	0.123	ns	ns	ns	ns	0.223	0.289	ns
Total iron	mg/L	0.3	-	-	ns	ns	ns	ns	0.485	0.621	ns
Spring											
Sulphide	mg/L	0.002[4]	0.0059	0.0040	ns	ns	ns	ns	0.0024	0.0035	ns
Total phenolics	mg/L	0.004	-	-	ns	ns	ns	ns	0.0073	0.0045	ns
Total phosphorus	mg/L	0.05	0.127	-	ns	ns	ns	ns	0.065	0.057	ns
Dissolved cadmium	mg/L	[3]	-	0.000022	ns	ns	ns	ns	0.000009	0.000011	ns
Total nitrogen*	mg/L	1.0	-	-	ns	ns	ns	ns	1.001	-	ns
Total aluminum	mg/L	0.1	5.36	0.77	ns	ns	ns	ns	2.06	2.00	ns
Total cadmium	mg/L	[3]	0.000027	0.000037	ns	ns	ns	ns	0.000022	0.000022	ns
Total chromium	mg/L	0.001	0.0042	-	ns	ns	ns	ns	0.0017	0.0016	ns
Total copper	mg/L	[3]	0.00254	-	ns	ns	ns	ns	-	-	ns
Total iron	mg/L	0.3	3.39	0.53	ns	ns	ns	ns	1.44	1.36	ns
Total lead	mg/L	[3]	0.0015	-	ns	ns	ns	ns	-	-	ns

ns = not sampled

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] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[3] Guideline is hardness dependant.

[4] B.C. Working Water Quality Guideline (2001).

[5] Guideline is for total nitrogen.

Table 5.1-5 (Cont'd.)

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
Summer											
Total phenolics	mg/L	0.004	0.0045	-	ns	ns	ns	ns	-	-	ns
Sulphide	mg/L	0.002[4]	0.0032	-	ns	ns	ns	ns	-	-	ns
Total Kjeldahl nitrogen	mg/L	1.0[5]	1.48	-	ns	ns	ns	ns	1.04	-	ns
Total nitrogen*	mg/L	1.0	1.551	-	ns	ns	ns	ns	1.111	-	ns
Dissolved cadmium	mg/L	[3]	-	0.000013	ns	ns	ns	ns	0.000008	0.000007	ns
Total cadmium	mg/L	[3]	0.000017	0.000029	ns	ns	ns	ns	0.000025	0.000028	ns
Total aluminum	mg/L	0.1	2.11	1.85	ns	ns	ns	ns	1.62	1.79	ns
Total chromium	mg/L	0.001	0.0020	0.0016	ns	ns	ns	ns	0.0015	0.0017	ns
Total iron	mg/L	0.3	1.76	1.01	ns	ns	ns	ns	1.14	1.16	ns
Total phosphorus	mg/L	0.05	0.071	-	ns	ns	ns	ns	-	0.051	ns
Fall											
Total phenolics	mg/L	0.004	0.0079	0.0102	0.0191	-	0.0074	-	0.0262	0.0495	0.0196
Dissolved iron	mg/L	0.3[2]	0.378	-	-	-	-	-	-	-	-
Total phosphorus	mg/L	0.05	0.131	-	0.150	-	0.082	0.059	0.070	0.058	-
Sulphide	mg/L	0.002[4]	0.0059	-	0.0043	0.0026	0.0045	0.0028	0.0036	0.0057	0.0034
Total mercury (ultra-trace)	mg/L	5, 13[2]	12.9	5.7	11.2	6.0	11.0	5.8	7.0	-	5.2
Total aluminum	mg/L	0.1	3.76	1.38	2.80	1.51	3.13	1.52	2.97	1.81	1.47
Total chromium	mg/L	0.001	0.0052	0.0018	0.0034	0.0019	0.0037	0.0019	0.0032	0.0025	0.0021
Total copper	mg/L	[3]	0.0028	-	0.0020	-	0.0022	-	0.0021	-	-
Total iron	mg/L	0.3	3.37	1.16	2.48	1.28	2.65	1.27	2.10	1.73	1.49

ns = not sampled

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.

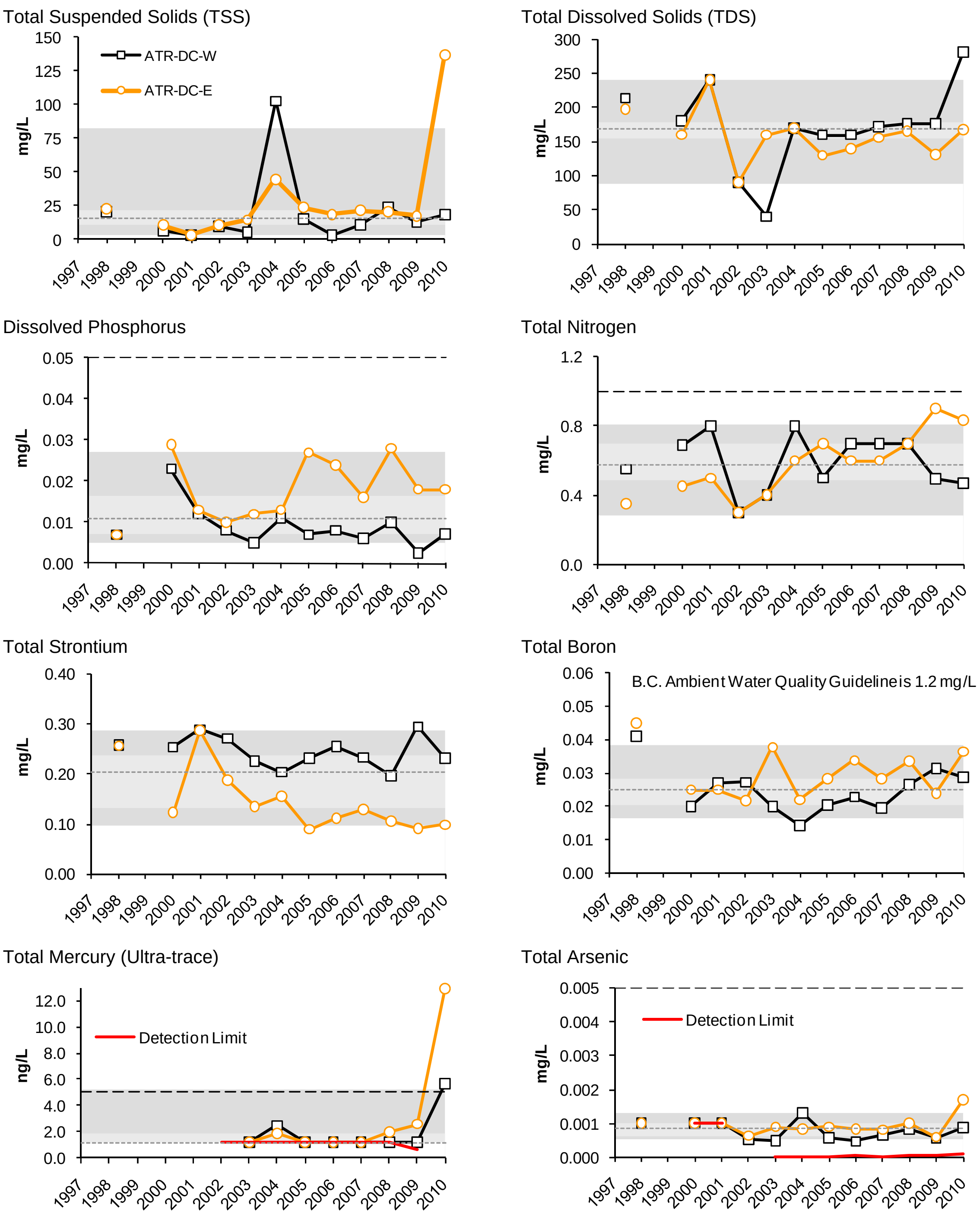
[2] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999b).

[3] Guideline is hardness dependant.

[4] B.C. Working Water Quality Guideline (2001).

[5] Guideline is for total nitrogen.

Figure 5.1-9 Concentrations of selected water quality measurement endpoints (fall data) relative to historical concentrations and regional *baseline* fall concentrations, Athabasca River mainstem, upstream of Donald Creek (ATR-DC).



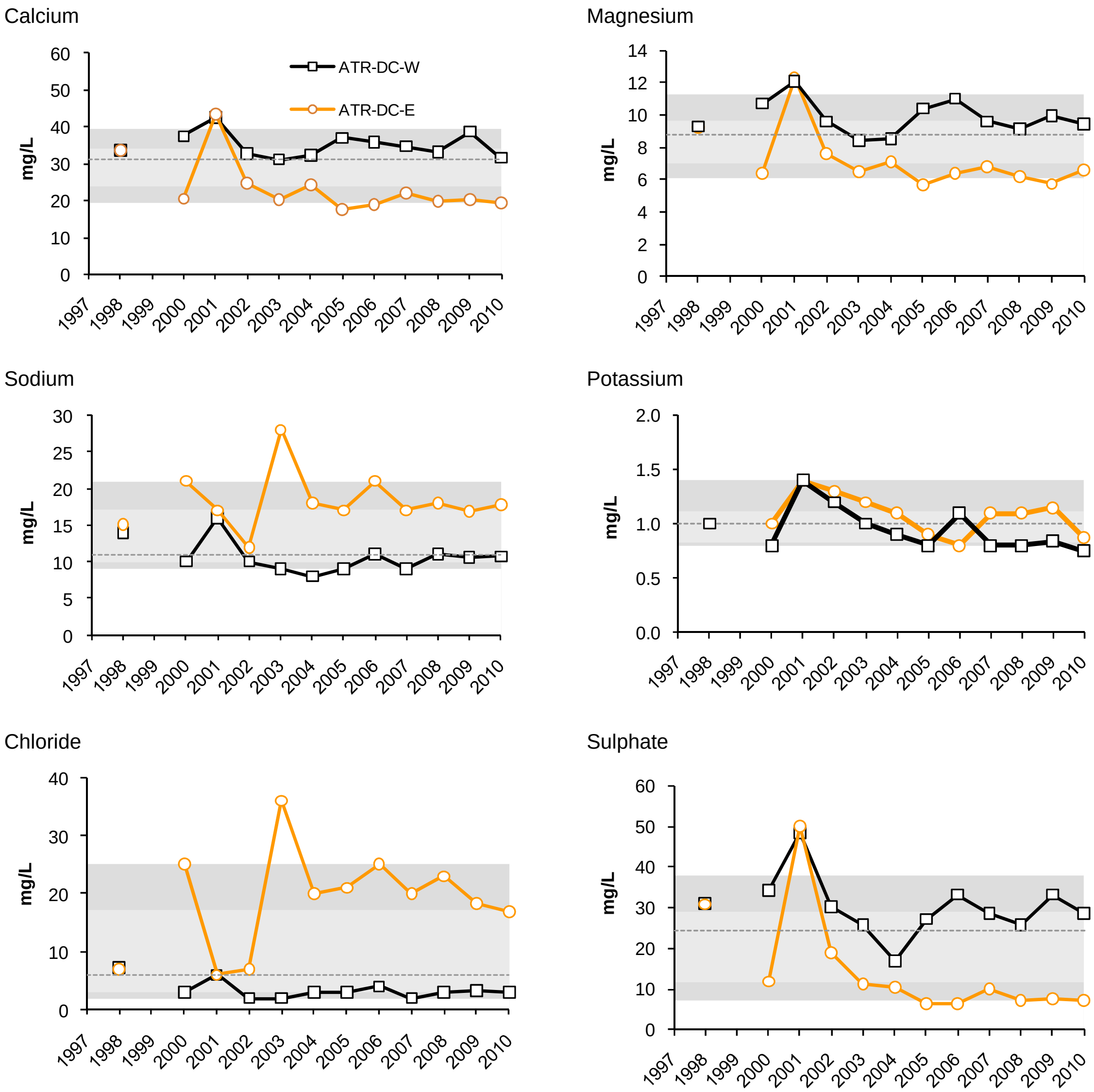
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-9 (Cont'd.)



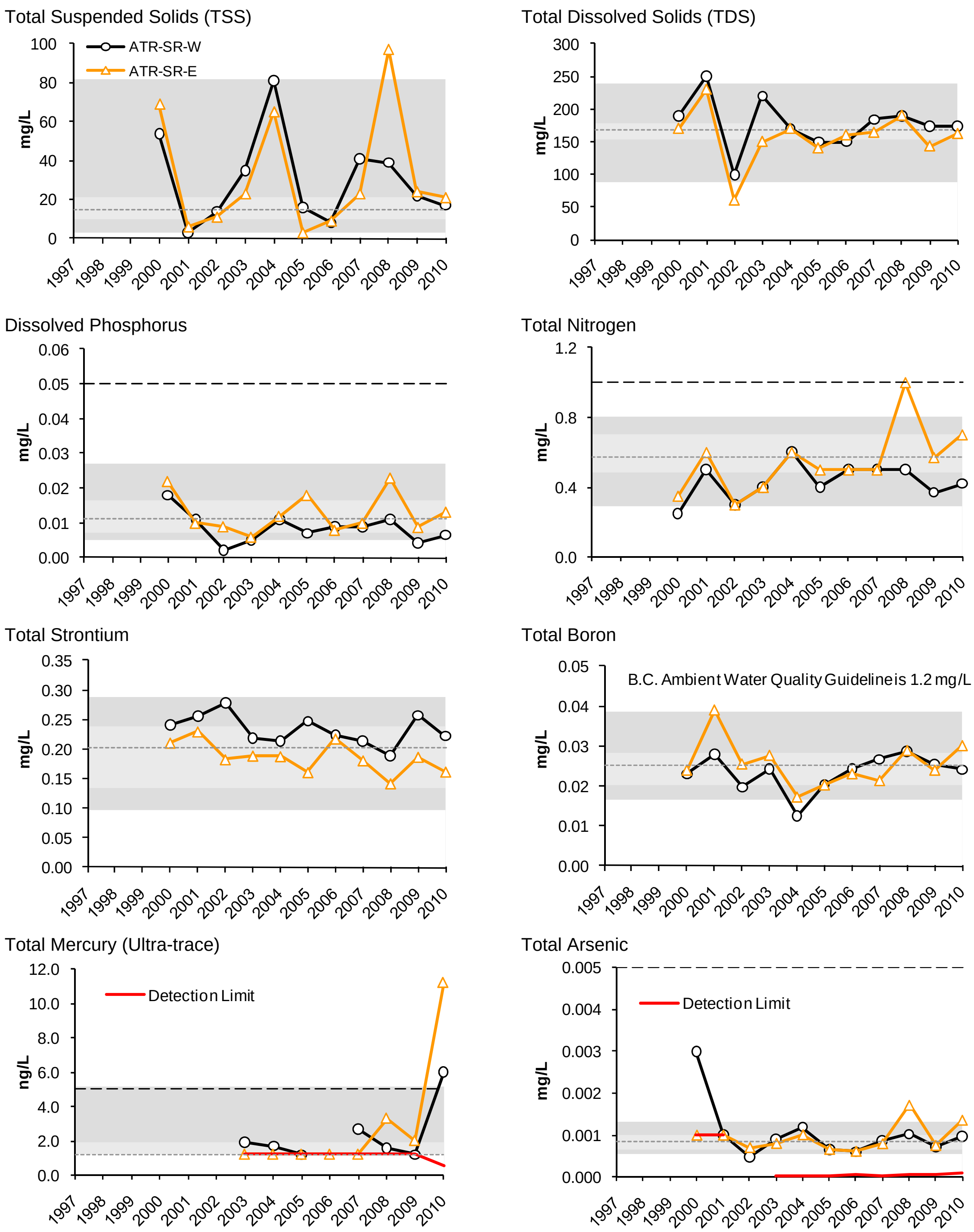
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-10 Concentrations of selected water quality measurement endpoints (fall data) relative to historical concentrations and regional *baseline* fall concentrations, Athabasca River mainstem, upstream of the Steepbank River (ATR-SR).



Non-detectable values are shown at the detection limit.

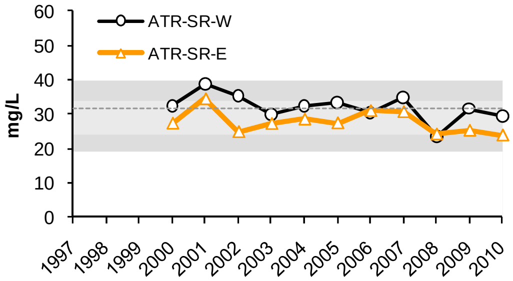
– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

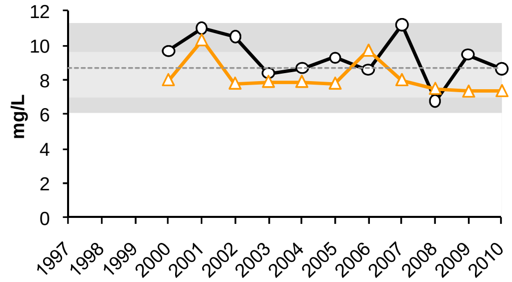
See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-10 (Cont'd.)

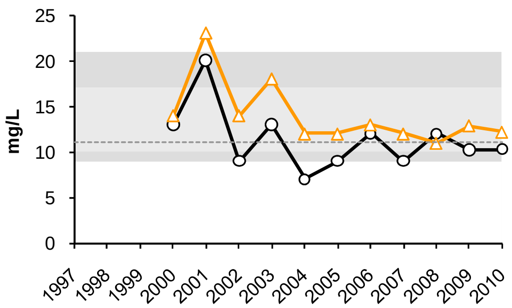
Calcium



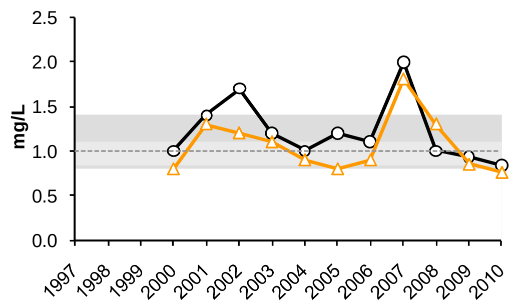
Magnesium



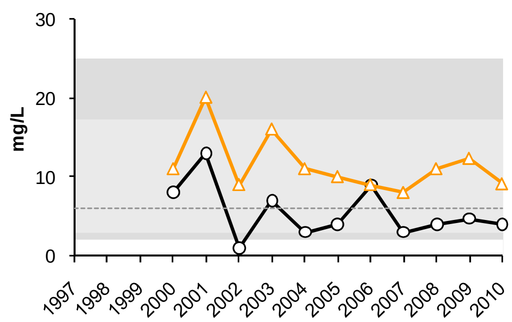
Sodium



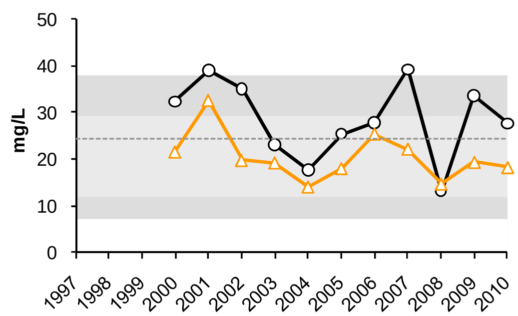
Potassium



Chloride



Sulphate



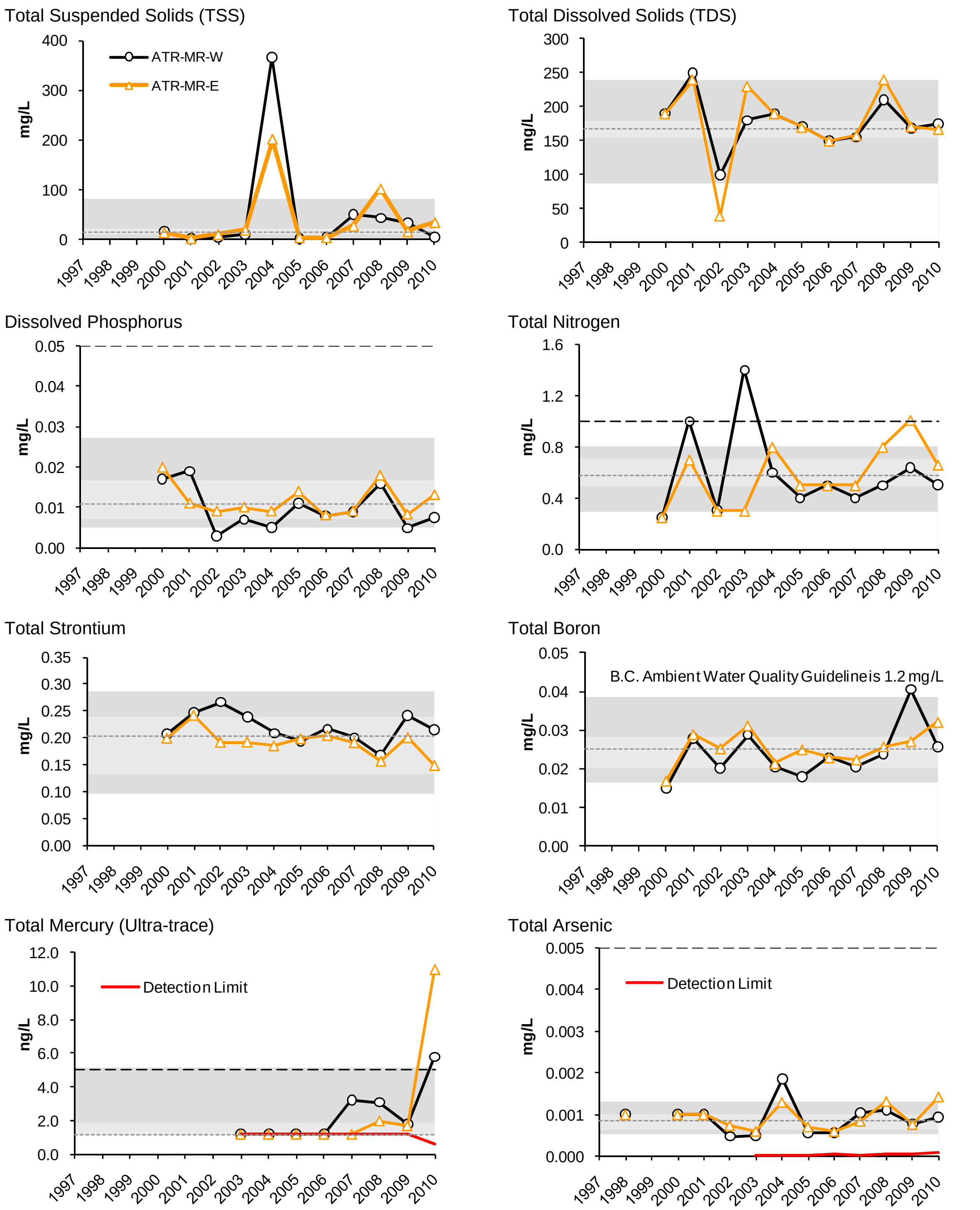
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-11 Concentrations of selected water quality measurement endpoints (fall data) relative to historical concentrations and regional *baseline* fall concentrations, Athabasca River mainstem, upstream of the Muskeg River (ATR-MR).



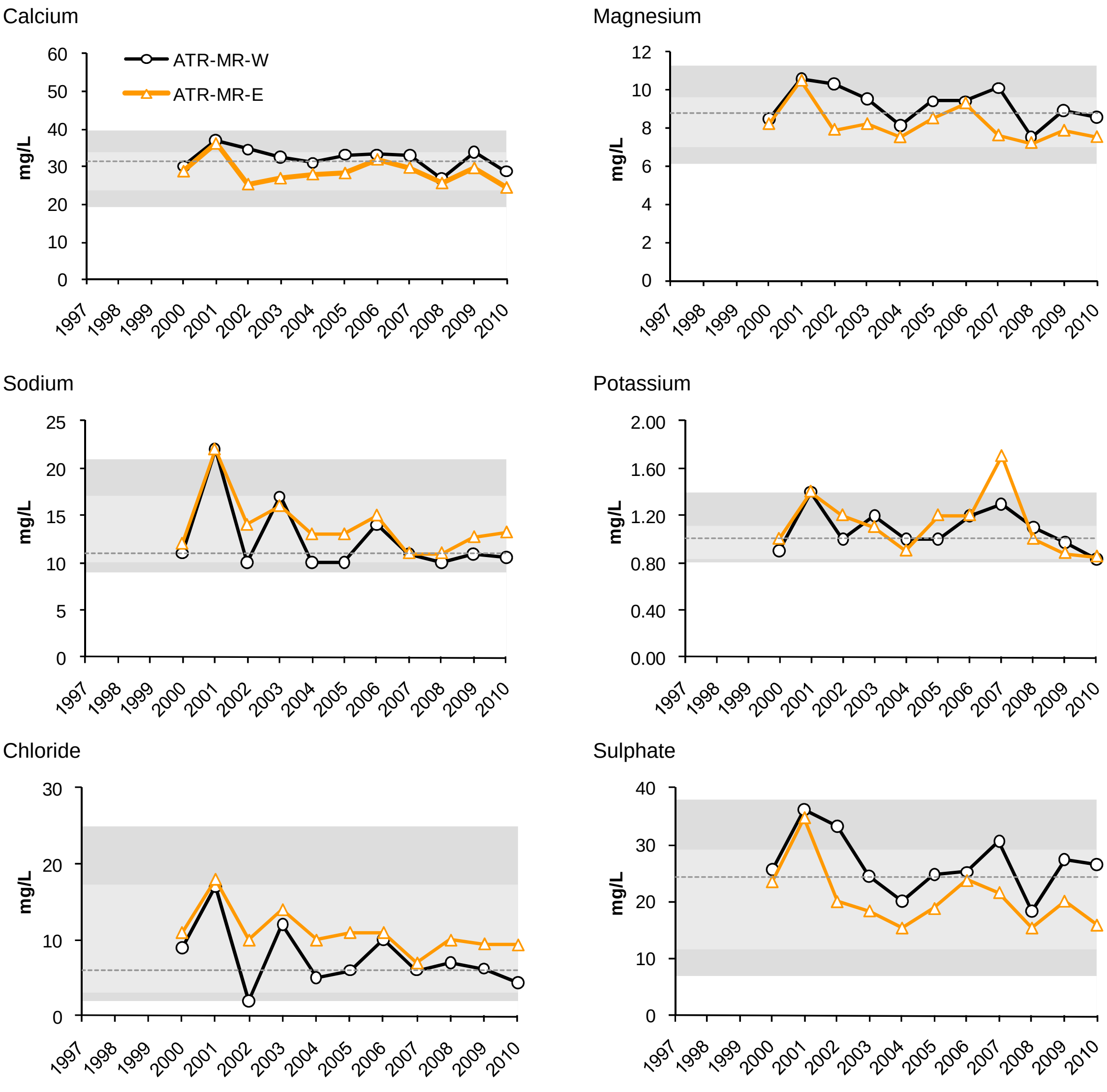
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-11 (Cont'd.)



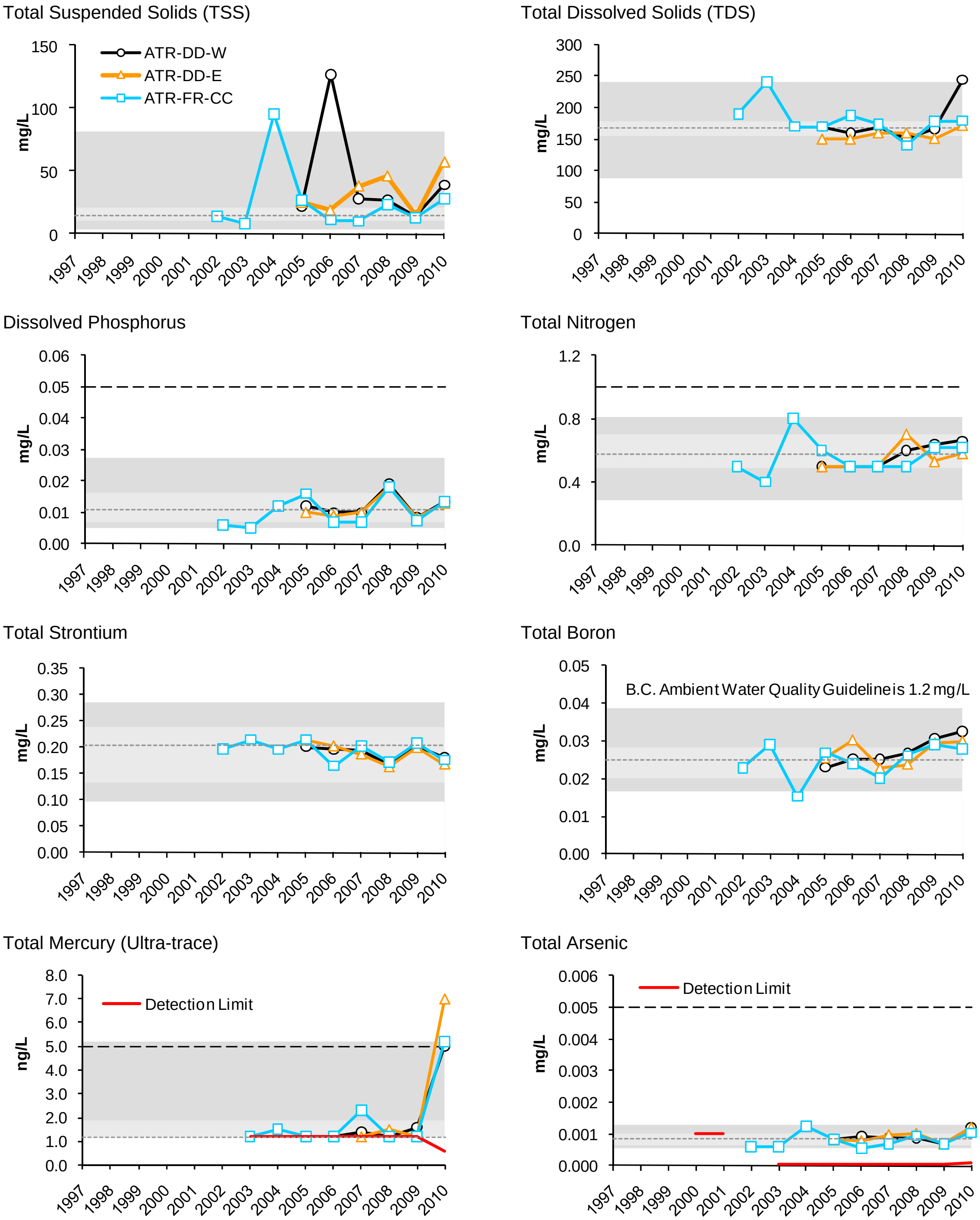
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-12 Concentrations of selected water quality measurement endpoints (fall data) relative to historical concentrations and 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.

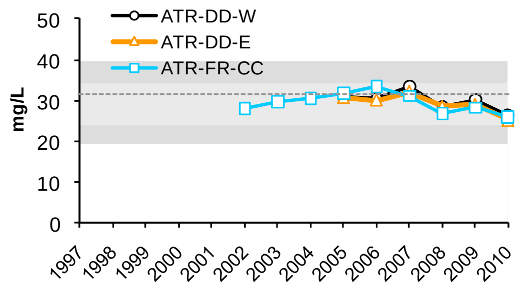
– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

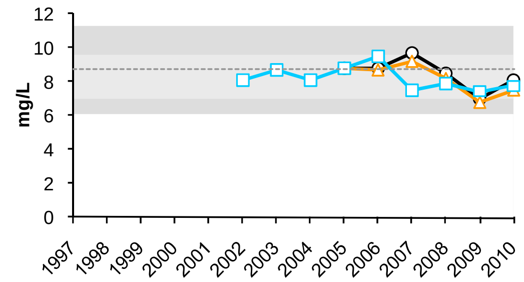
See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.1-12 (Cont'd.)

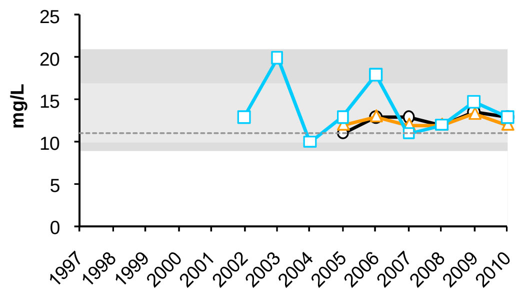
Calcium



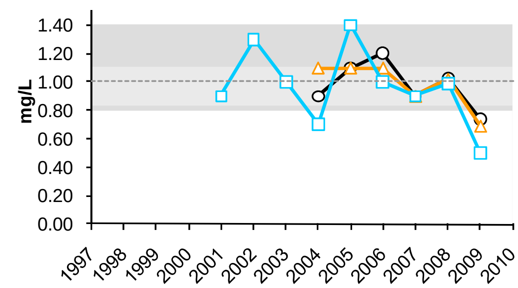
Magnesium



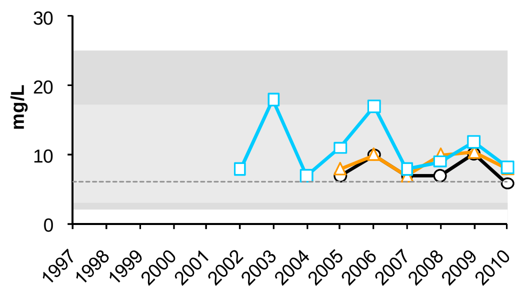
Sodium



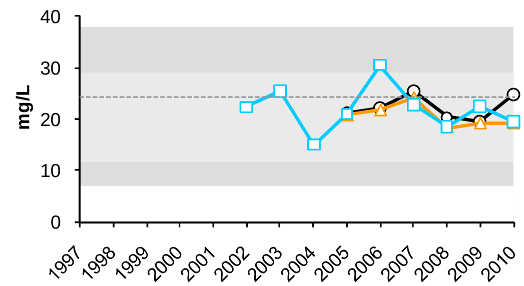
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.1-6 Water quality index (fall 2010) for Athabasca River mainstem stations.

Station Identifier	Location	2010 Designation	Water Quality Index	Classification
ATR-DC-E	Upstream of Donald Creek, East Bank	*baseline*	76.3	Moderate
ATR-DC-W	Upstream of Donald Creek, West Bank	*baseline*	97.5	Negligible-Low
ATR-SR-E	Upstream of the Steepbank River, East Bank	*test*	83.2	Negligible-Low
ATR-SR-W	Upstream of the Steepbank River, West Bank	*test*	86.3	Negligible-Low
ATR-MR-E	Upstream of the Muskeg River, East Bank	*test*	87.1	Negligible-Low
ATR-MR-W	Upstream of the Muskeg River, West Bank	*test*	92.0	Negligible-Low
ATR-DD-E	Downstream of all development, East Bank	*test*	92.2	Negligible-Low
ATR-DD-W	Downstream of all development, West Bank	*test*	90.7	Negligible-Low
ATR-FR-CC	Upstream of the Firebag River, Cross-Channel	*test*	97.4	Negligible-Low

Note: see Figure 5.1-1 for the locations of these water quality stations.

Note: see Section 3.2.2.3 for a description of the Water Quality Index.

Table 5.1-7 Average habitat characteristics of benthic invertebrate community sampling locations of the Athabasca River Delta.

Variable	Units	Big Point Channel	Fletcher Channel	Goose Island Channel	Embarras River
Sample date	-	Sept. 4, 2010	Sept. 4, 2010	Sept. 4, 2010	Sept. 4, 2010
Habitat	-	Depositional	Depositional	Depositional	Depositional
Water depth	m	2.5	1.0	1.5	1.5
Field Water Quality					
Dissolved oxygen	mg/L		9.2	9.1	9.0
Conductivity	µS/cm	233	234	239	265
pH	pH units	8.2	8.4	8.2	8.4
Water temperature	°C	15.2	16	15	16.3
Sediment Composition					
Sand	%	28	15	89	6
Silt	%	52	63	9	62
Clay	%	20.2	22	2.0	33
Total Organic Carbon	%	2.5	2.4	0.4	2.4

Table 5.1-8 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								Embarras River
	2003	2004	2005	2007	2008	2009	2010	2002	2003	2004	2005	2007	2008	2009	2010	2002	2003	2004	2005	2007	2008	2009	2010	2010
Amphipoda		<1	2				<1																	
Anisoptera	<1	<1	<1	<1	<1		<1		<1	<1	<1	<1				<1	<1	<1		<1	<1			
Bivalvia	10	1	8	37	12	8	4	1	13	3	3	2	1	2	6	13	4	2	3	2	4	2	2	29
Ceratopogonidae	1	<1	7	1	1	2	1	2	10	5	2	8	6	<1	5	1	17	3	2	2	3	1	2	4
Chironomidae	6	40	31	3	11	23	11	86	13	27	4	18	52	11	4	74	28	64	13	24	27	55	30	41
Copepoda				<1		1	1							<1	<1	<1			1		<1	2		<1
Empididae					<1	4		<1														<1		
Ephemeroptera	<1	<1	1	<1			<1	<1	1	<1	<1	<1	<1					<1	<1		1	<1		<1
Erpobdellidae		<1																						
Gastropoda	4	<1	1	2	12	<1	<1	1	14	<1	2	1	1	2	<1	5	11	<1	<1	1	24	1	4	<1
Heteroptera	<1	<1							<1	<1							<1							
Hydracarina	<1				<1		<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		<1
Nematoda	<1	<1	1	1	7	<1	<1	5	5	<1	<1	1	22	<1	<1	5		<1	2	2	1	<1	<1	1
Ostracoda	<1	2	2	<1	<1	5	7	3	2	4	4	1	7	4	3	1	9	3	8	9	2	13	39	19
Plecoptera				<1	<1		<1				<1													
Tabanidae									<1															
Tipulidae	<1																					<1		
Trichoptera	1	2	1	1	4				<1	<1	2	1				<1				1	2			3
Tubificidae	75	52	46	54	52	49	68	2	26	58	81	66	10	72	81	<1	27	27	62	57	36	24	23	1
	Benthic Invertebrate Community Measurement Endpoints																							
Total Abundance (No./m^2)	11,552	103,983	4,757	64,933	32,419	22,905	51,967	11,897	8,328	27,207	10,843	13,055	20,696	27,801	118,413	36,000	2,914	35,776	12,243	15,348	8,270	12,374	2,922	56,463
Richness	11	12	10	15	12	11	14	12	11	9	10	11	12	10	12	14	10	11	11	12	11	15	8	23
Simpson's Diversity	0.42	0.59	0.63	0.54	0.73	0.68	0.53	0.53	0.78	0.56	0.33	0.52	0.66	0.47	0.35	0.54	0.79	0.66	0.61	0.61	0.73	0.79	0.69	0.86
Evenness	0.46	0.64	0.77	0.57	0.81	0.79	0.58	0.58	0.86	0.63	0.37	0.57	0.74	0.53	0.38	0.58	0.89	0.73	0.67	0.67	0.84	0.85	0.79	0.90
% EPT	1	2	1	1	19	0	<1	1	1	<1	3	<1	<1	0	0	<1	0	<1	<1	1	2	<1	0	3

Table 5.1-9 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Big Point Channel of the Athabasca River Delta.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Time Trend	Time Trend	
Abundance	0.606	1	No change
Richness	0.517	7	No change
Simpson's Diversity	0.058	22	No change
Evenness	0.060	15	No change
EPT	0.411	2	No change
CA Axis 1	0.063	6	No change
CA Axis 2	**0.015**	49	Increase over time

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Table 5.1-10 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Fletcher Channel of the Athabasca River Delta.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Time Trend	Time Trend	
Abundance	**0.011**	36	Increase over time
Richness	0.576	10	No change
Simpson's Diversity	**0.005**	31	Decrease over time
Evenness	**0.003**	31	Decrease over time
EPT	**0.023**	30	Absent in last two years
CA Axis 1	**0.003**	37	Increase over time
CA Axis 2	0.793	2	No change

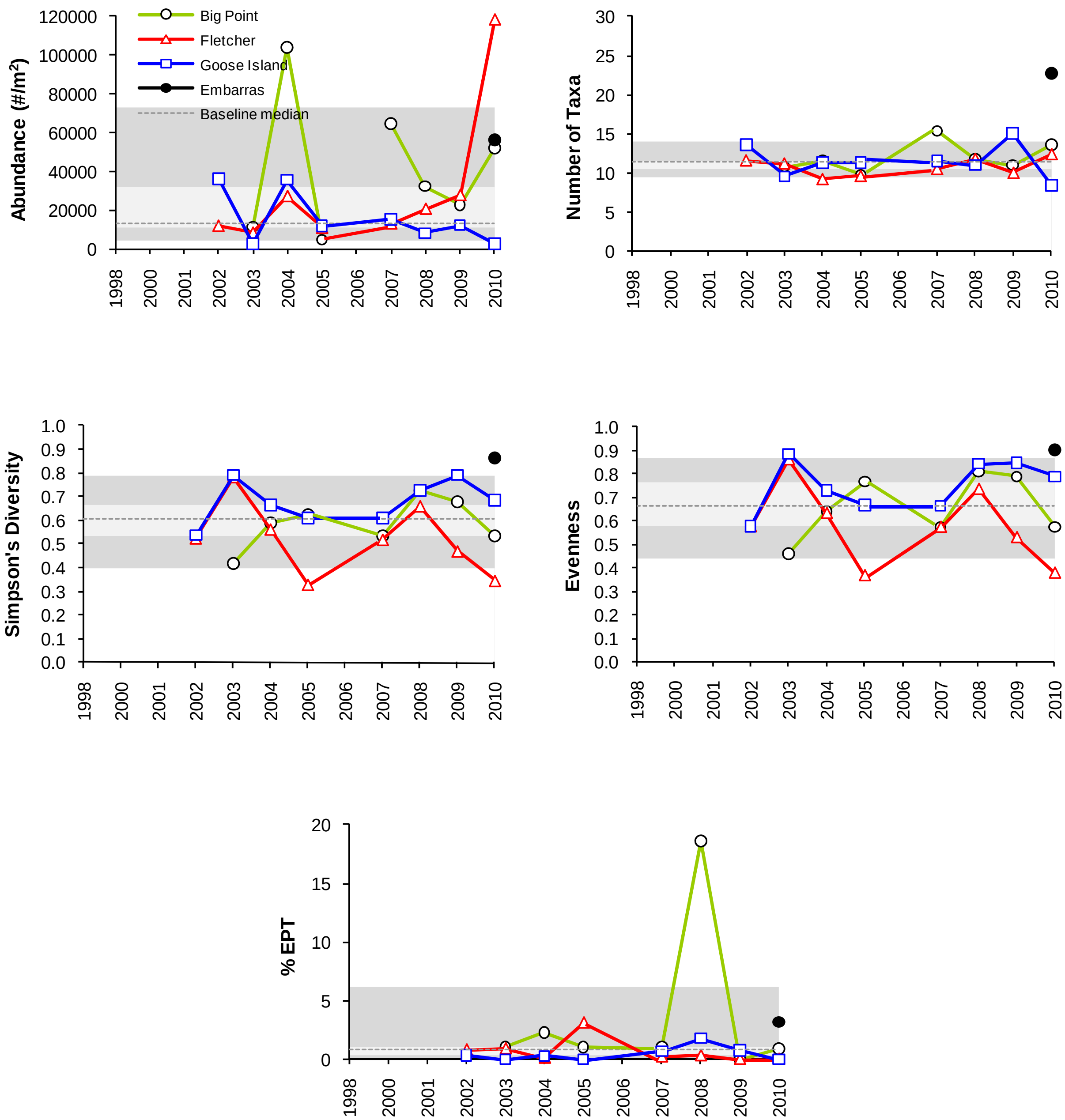
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Table 5.1-11 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Goose Island Channel of the Athabasca River Delta.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Time Trend	Time Trend	
Abundance	0.061	13	No change
Richness	0.878	0	No change
Simpson's Diversity	0.852	0	No change
Evenness	0.682	1	No change
EPT	0.389	12	No change
CA Axis 1	0.495	7	No change
CA Axis 2	0.826	0	No change

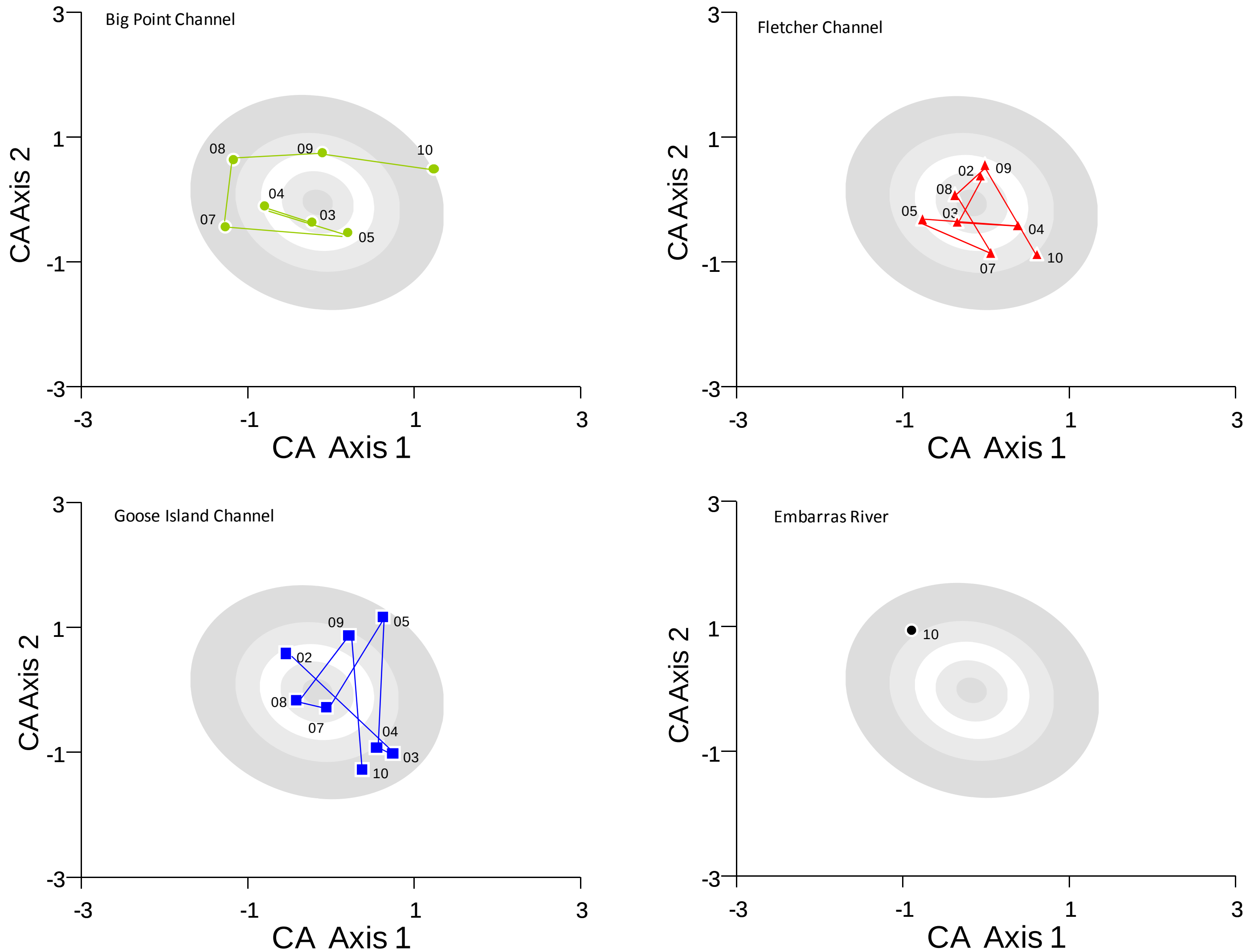
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.1-13 Variation in benthic invertebrate community measurement endpoints in the Athabasca River Delta, 2002 to 2010.



Note: Historical *baseline* values reflect pooled results for all ARD reaches prior to 2010.

Figure 5.1-14 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 2009 and serves as a range of values against which to compare the 2010 data.

Table 5.1-12 Concentrations of sediment quality measurement endpoints, Athabasca River mainstem upstream of Embarras River (ATR-ER).

Measurement Endpoints	Units	Guideline	September 2010	2000-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	7.9	9	8.4	13	22
Silt	%	-	7.9	9	28	32	42
Sand	%	-	84.1	9	36	56	64
Total organic carbon	%	-	0.6	9	0.8	1.1	1.7
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]	<20	5	11	24	39
Fraction 3 (C16-C34)	mg/kg	300[1]	76	5	161	260	**570**
Fraction 4 (C34-C50)	mg/kg	2800[1]	72	5	141	190	340
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.006	9	0.005	0.008	0.037
Retene	mg/kg	-	0.017	9	0.031	0.051	0.081
Total dibenzothiophenes	mg/kg	-	0.239	9	0.092	0.234	0.749
Total PAHs	mg/kg	-	1.175	9	0.816	1.175	2.482
Total Parent PAHs	mg/kg	-	0.042	9	0.073	0.110	0.156
Total Alkylated PAHs	mg/kg	-	1.102	9	0.660	1.102	2.355
Predicted PAH toxicity[3]	H.I.	-	1.027	9	0.397	1.050	1.500
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.2	5	3.4	7.4	8.6
Chironomus growth - 10d	mg/organism	-	2.088	5	1.154	2.100	3.500
Hyalella survival - 14d[4]	# surviving	-	9.8	5	7.0	9.2	10.0
Hyalella growth - 14d[4]	mg/organism	-	0.248	5	0.050	0.200	0.288

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 5.1-13 Concentrations of sediment quality measurement endpoints, Goose Island Channel (GIC-1).

Measurement Endpoints	Units	Guideline	September 2010	1997-2009 (fall data only GIC-1)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	2.2	7	12	20	28
Silt	%	-	8.8	7	34	51	58
Sand	%	-	89.0	7	17	30	53
Total organic carbon	%	-	0.5	7	1.1	1.7	2.4
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[2]	<10	4	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[2]	<20	4	<5	13	20
Fraction 3 (C16-C34)	mg/kg	300[2]	39	4	180	248	**360**
Fraction 4 (C34-C50)	mg/kg	2800[2]	46	4	88	143	200
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.004	7	0.005	0.009	0.015
Retene	mg/kg	-	0.006	7	0.027	0.044	0.078
Total dibenzothiophenes	mg/kg	-	0.043	7	0.202	0.238	0.412
Total PAHs	mg/kg	-	0.294	7	1.016	1.239	2.161
Total Parent PAHs	mg/kg	-	0.021	7	0.077	0.121	0.177
Total Alkylated PAHs	mg/kg	-	0.273	7	0.935	1.126	1.984
Predicted PAH toxicity[4]	H.I.	-	0.800	7	0.810	1.101	1.263
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	9.4	5	4.0	7.0	8.4
Chironomus growth - 10d	mg/organism	-	0.174	5	1.336	2.600	4.200
Hyalella survival - 14d[1]	# surviving	-	8.4	5	7.0	9.0	10.0
Hyalella growth - 14d[1]	mg/organism	-	1.658	5	0.100	0.110	0.304

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 5.1-14 Concentrations of sediment quality measurement endpoints, Fletcher Channel (FLC-1).

Measurement Endpoints	Units	Guideline	September 2010	2001-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	22.8	7	10	14	18
Silt	%	-	60.8	7	18	38	72
Sand	%	-	16.4	7	11	47	70
Total organic carbon	%	-	2.2	7	0.6	1.3	1.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	13	30
Fraction 1 (C6-C10)	mg/kg	30[2]	<10	4	<5	13	30
Fraction 2 (C10-C16)	mg/kg	150[2]	<30	4	<5	21	30
Fraction 3 (C16-C34)	mg/kg	300[2]	68	4	110	**340**	**430**
Fraction 4 (C34-C50)	mg/kg	2800[2]	49	4	53	206	280
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.014	7	0.003	0.009	0.016
Retene	mg/kg	-	0.072	7	0.020	0.044	0.105
Total dibenzothiophenes	mg/kg	-	0.590	7	0.132	0.185	0.591
Total PAHs	mg/kg	-	2.758	7	0.594	1.213	2.703
Total Parent PAHs	mg/kg	-	0.144	7	0.048	0.100	0.160
Total Alkylated PAHs	mg/kg	-	2.615	7	0.546	1.113	2.543
Predicted PAH toxicity[4]	H.I.	-	5.357	7	0.488	0.798	1.168
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.8	5	3.4	6.0	9.4
Chironomus growth - 10d	mg/organism	-	0.230	5	1.652	2.600	3.600
Hyalella survival - 14d[1]	# surviving	-	4.4	5	8.0	9.0	9.6
Hyalella growth - 14d[1]	mg/organism	-	1.294	5	0.100	0.110	0.290

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 5.1-15 Concentrations of sediment quality measurement endpoints, Big Point Channel (BPC-1).

Measurement Endpoints	Units	Guideline	September 2010	1999-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	21.8	9	10	20	32
Silt	%	-	49.8	9	26	51	64
Sand	%	-	28.4	9	10	36	64
Total organic carbon	%	-	2.2	9	0.1	1.2	2.2
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<5	<21
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	<5	<21
Fraction 2 (C10-C16)	mg/kg	150[1]	29	4	<5	13	23
Fraction 3 (C16-C34)	mg/kg	300[1]	122	4	110	200	**307**
Fraction 4 (C34-C50)	mg/kg	2800[1]	78	4	33	110	199
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.013	9	0.005	0.009	0.024
Retene	mg/kg	-	0.078	8	0.041	0.052	0.096
Total dibenzothiophenes	mg/kg	-	0.279	9	0.150	0.236	0.358
Total PAHs	mg/kg	-	2.028	9	1.045	1.358	1.821
Total Parent PAHs	mg/kg	-	0.148	9	0.096	0.107	0.209
Total Alkylated PAHs	mg/kg	-	1.879	9	0.945	1.251	1.702
Predicted PAH toxicity[3]	H.I.	-	2.484	9	0.830	1.160	2.590
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.2	7	3.2	7.0	9.0
Chironomus growth - 10d	mg/organism	-	0.942	7	0.890	1.822	3.600
Hyalella survival - 14d[4]	# surviving	-	7.6	7	6.6	8.0	9.0
Hyalella growth - 14d[4]	mg/organism	-	0.208	7	0.048	0.100	0.214

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.

Table 5.1-16 Concentrations of sediment quality measurement endpoints, Embarras River (EMR-2).

Measurement Endpoint	Units	Guideline	September 2010	September 2005
			Value	Value
Physical variables				
Clay	%	-	32.4	43
Silt	%	-	57.4	53
Sand	%	-	10.2	4
Total organic carbon	%	-	2.6	2.6
Total hydrocarbons				
BTEX	mg/kg	-	<10	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	33	<5
Fraction 3 (C16-C34)	mg/kg	300[1]	54	390
Fraction 4 (C34-C50)	mg/kg	2800[1]	36	190
Polycyclic Aromatic Hydrocarbons (PAHs)				
Naphthalene	mg/kg	0.0346[2]	0.025	0.018
Retene	mg/kg	-	0.072	0.130
Total dibenzothiophenes	mg/kg	-	0.483	0.331
Total PAHs	mg/kg	-	2.620	1.563
Total Parent PAHs	mg/kg	-	0.174	0.126
Total Alkylated PAHs	mg/kg	-	2.447	1.437
Predicted PAH toxicity[3]	H.I.	-	5.962	0.726
Metals that exceed CCME guidelines in 2009				
Arsenic	mg/kg	5.9	**7.02**	**8.20**
Chronic toxicity				
Chironomus survival - 10d	# surviving	-	6.8	ns
Chironomus growth - 10d	mg/organism	-	1.624	ns
Hyalella survival - 14d	# surviving	-	8.8	ns
Hyalella growth - 14d	mg/organism	-	0.214	ns

Values in **bold** indicate concentrations exceeding guidelines.

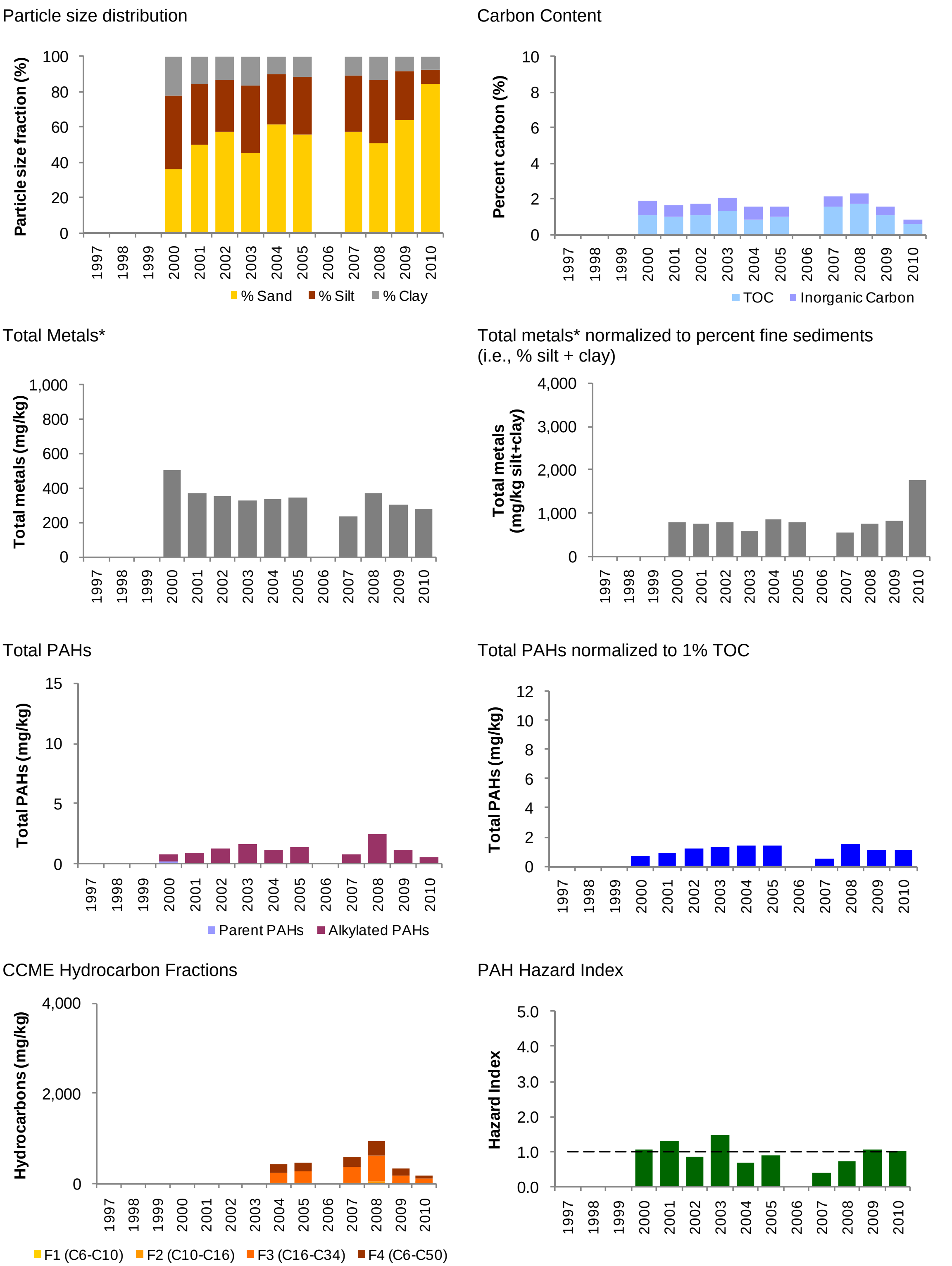
ns = not sampled

[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.

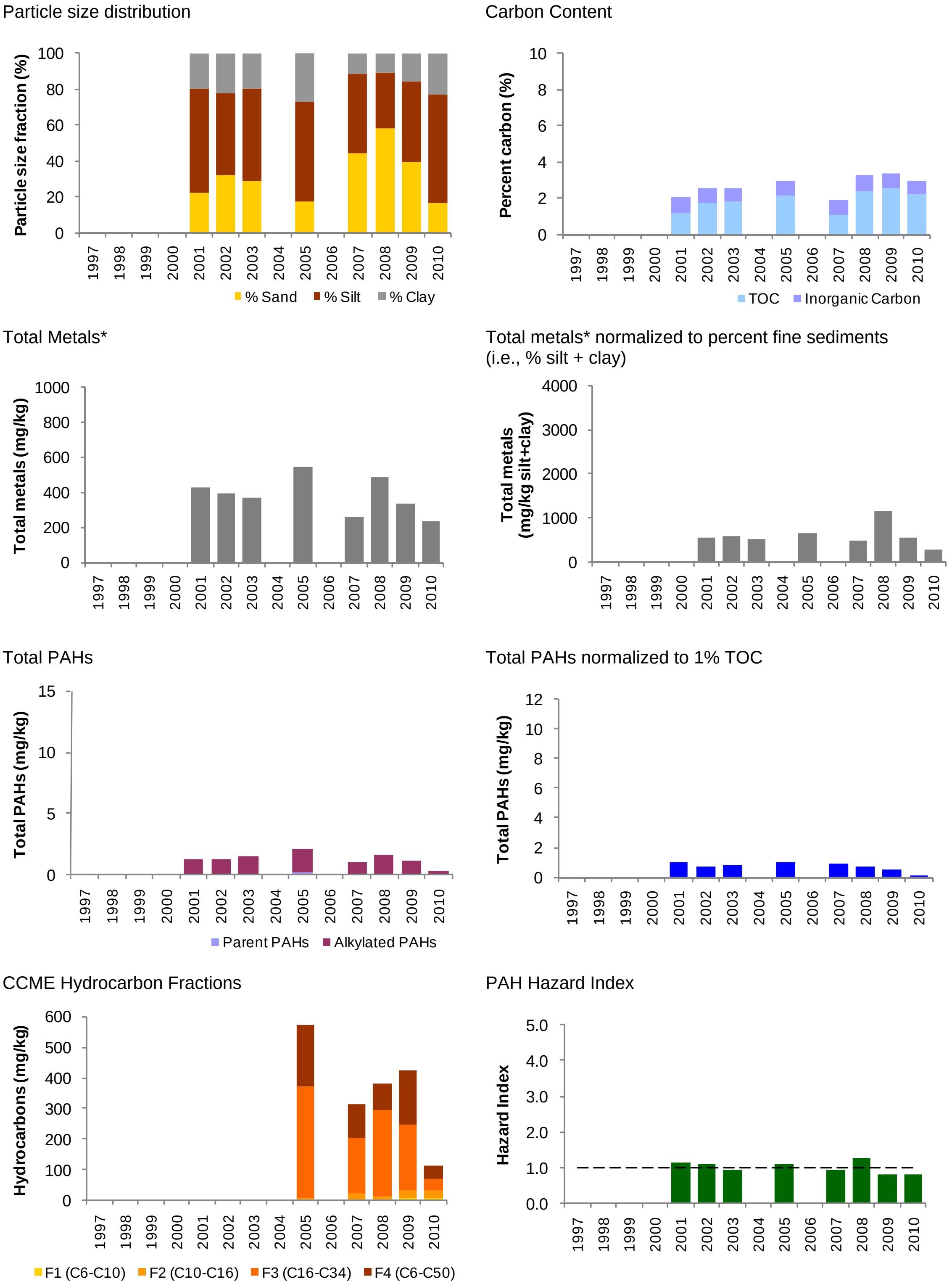
Figure 5.1-15 Characteristics of sediment collected in the Athabasca River upstream of Embarras River (ATR-ER), 2000 to 2010 (fall data only).



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.1-16 Characteristics of sediment collected in Goose Island Channel (GIC-1), 2001 to 2010 (fall data only).

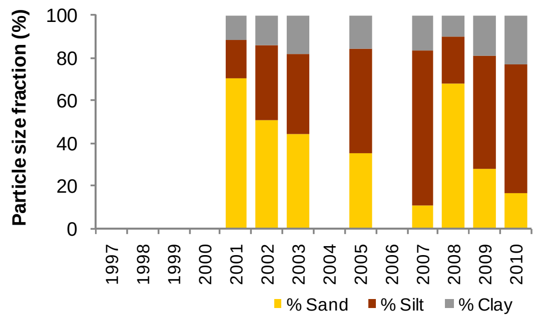


* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

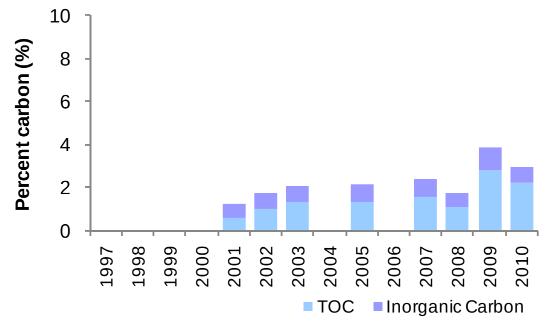
** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.1-17 Characteristics of sediment collected in Fletcher Channel (FLC-1), 2001 to 2010 (fall data only).

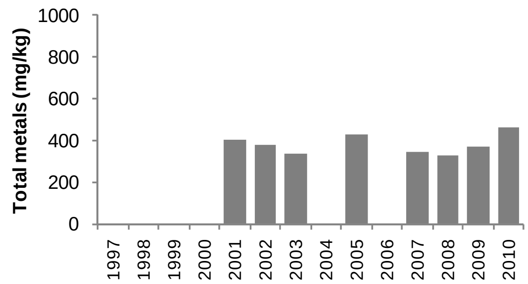
Particle size distribution



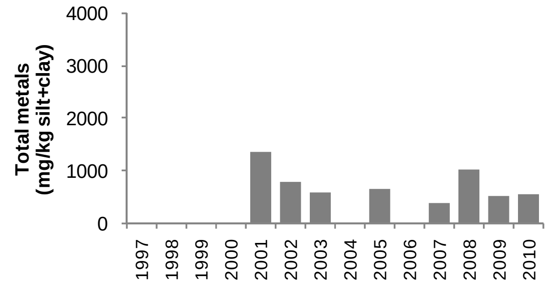
Carbon Content



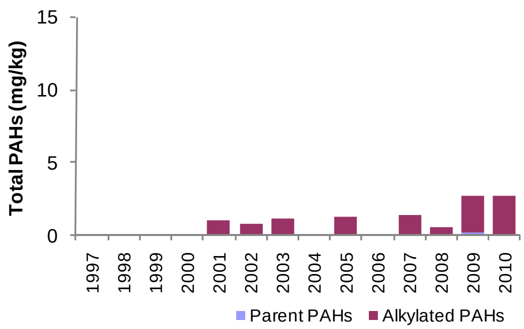
Total Metals*



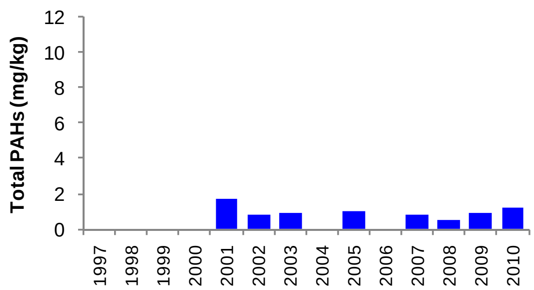
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



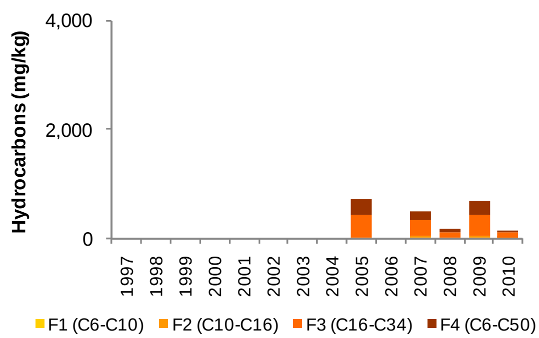
Total PAHs



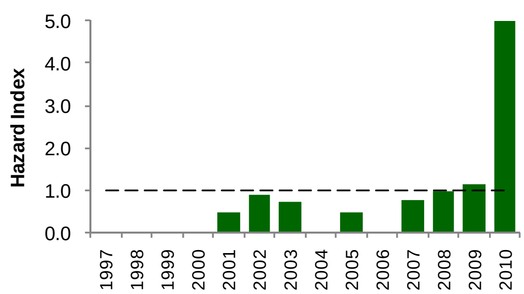
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



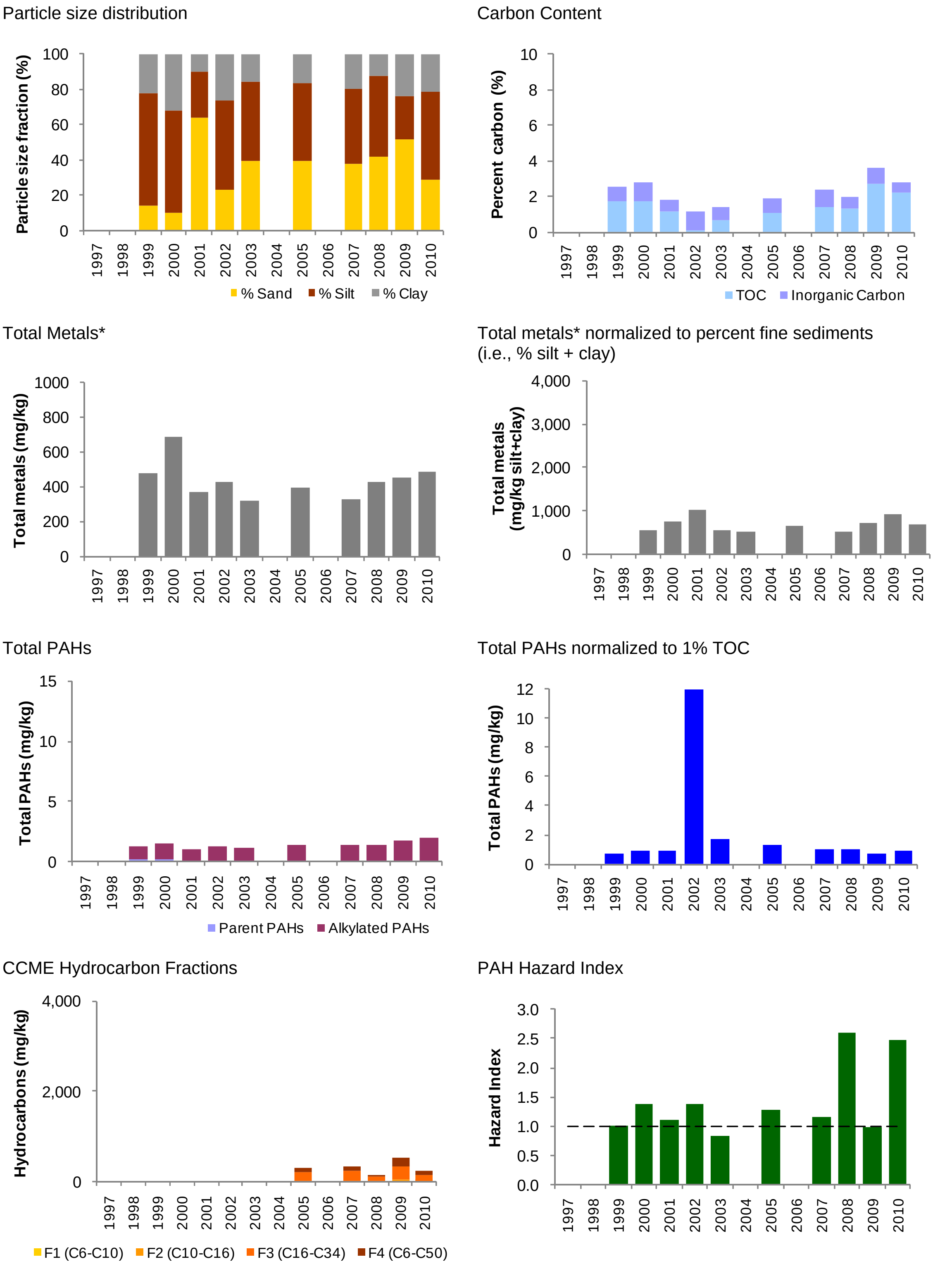
PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

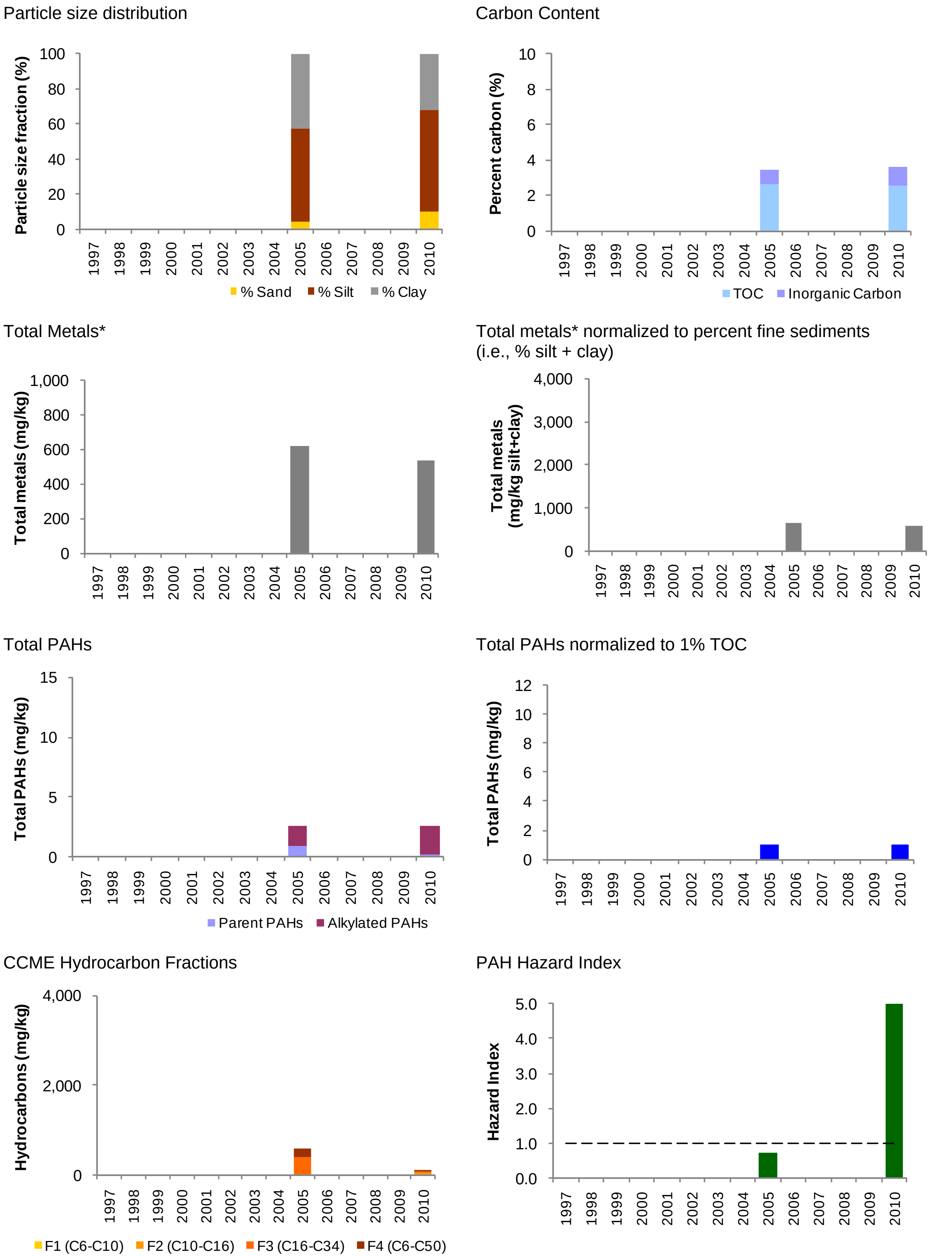
Figure 5.1-18 Characteristics of sediment collected in Big Point Channel (BPC-1), 1999-2010 (fall data only).



* 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%).

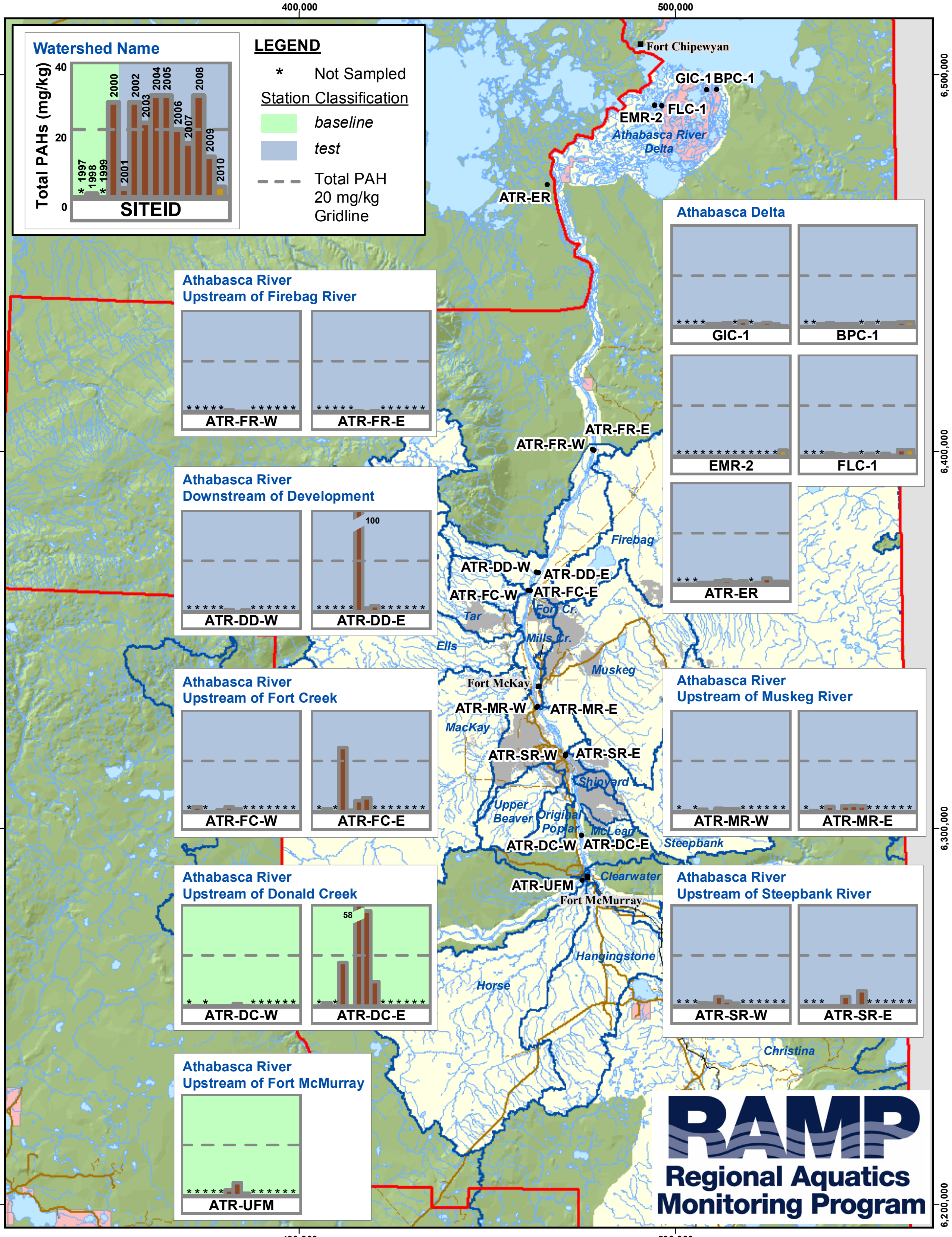
Figure 5.1-19 Characteristics of sediment collected in the Embarras River (EMR-2), 2005 and 2010 (fall data only).



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

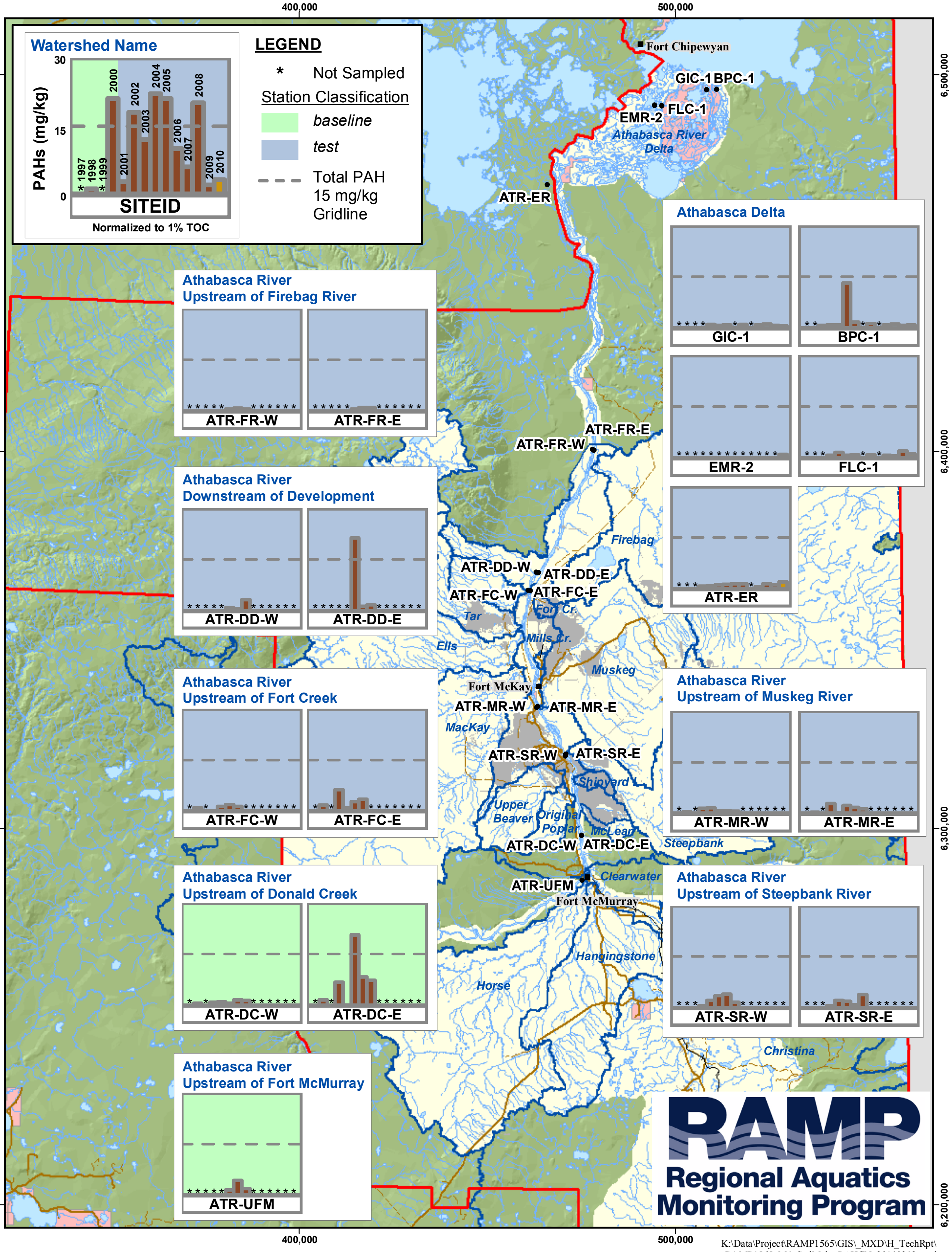
** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.1-20 Concentrations of total PAHs in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2010.



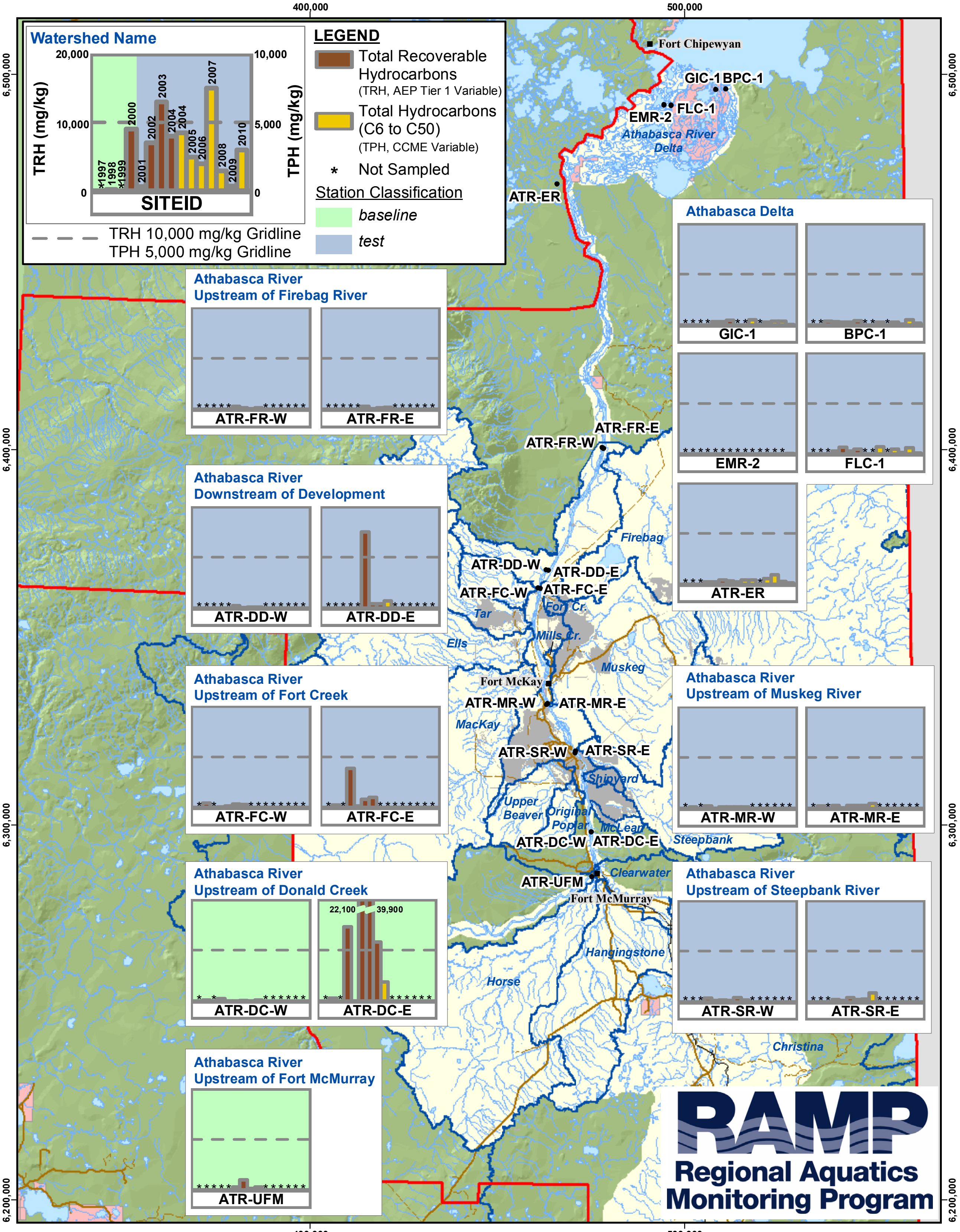
K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_M3_SedMain_PAH_20110318.mxd

Figure 5.1-21 Carbon-normalized concentrations of total PAHs in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2010.



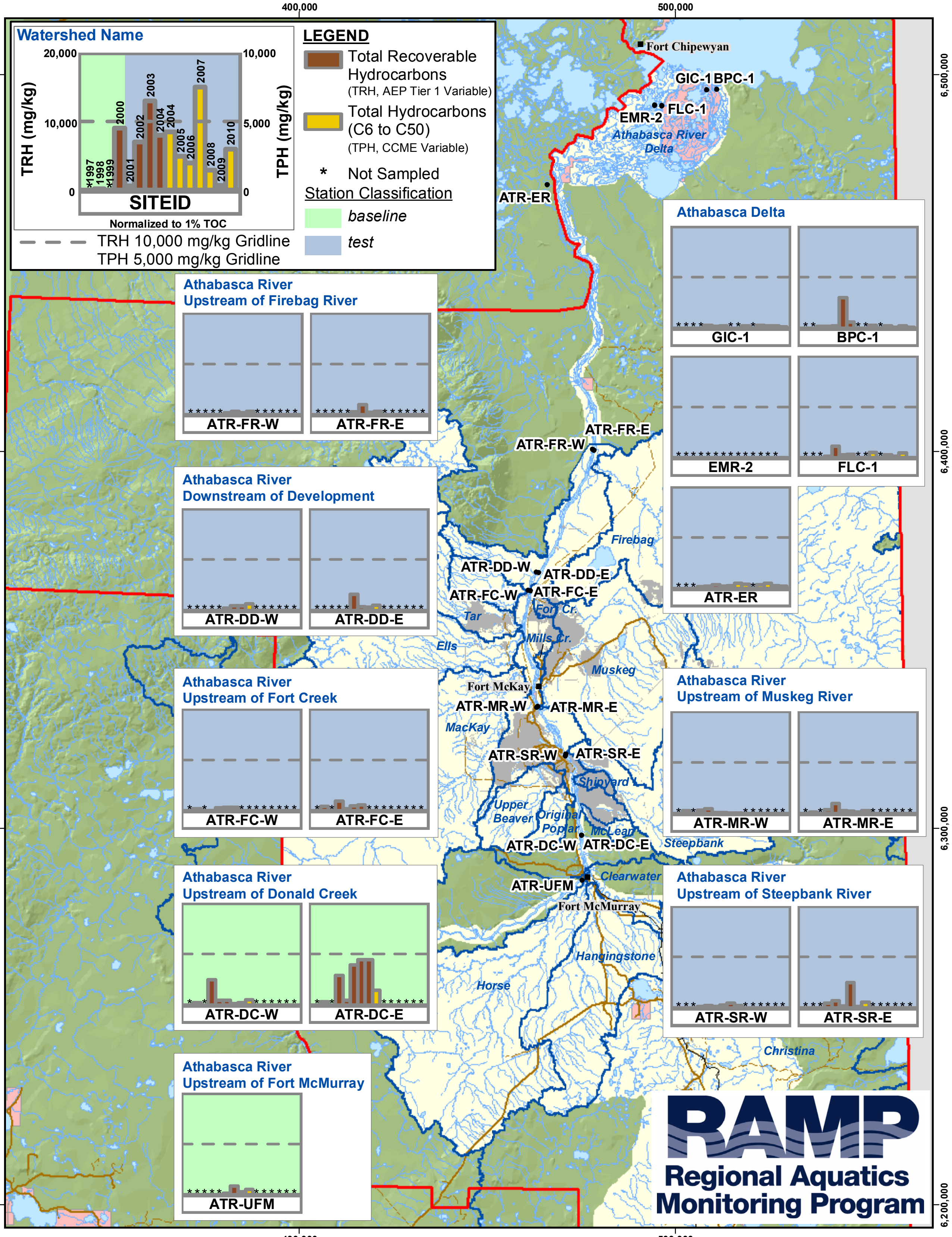
K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_M4_SedMain_PAHCN_20110318.mxd

Figure 5.1-22 Concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2010.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_M1_SedMain_TH_20110318.mxd

Figure 5.1-23 Carbon-normalized concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2010.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_M2_SedMain_THCN_20110318.mxd

Figure 5.1-24 Concentrations of total arsenic in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2010.

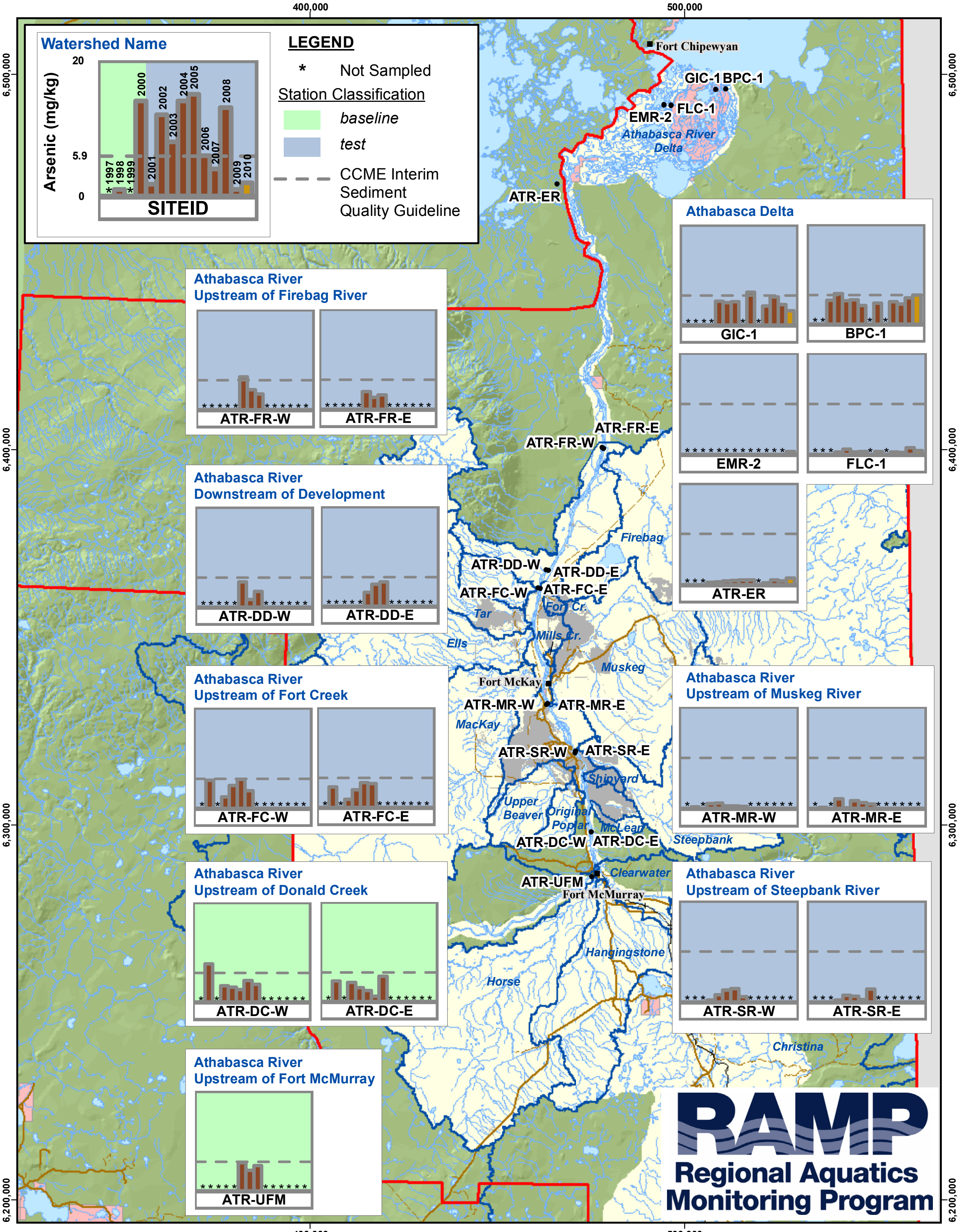


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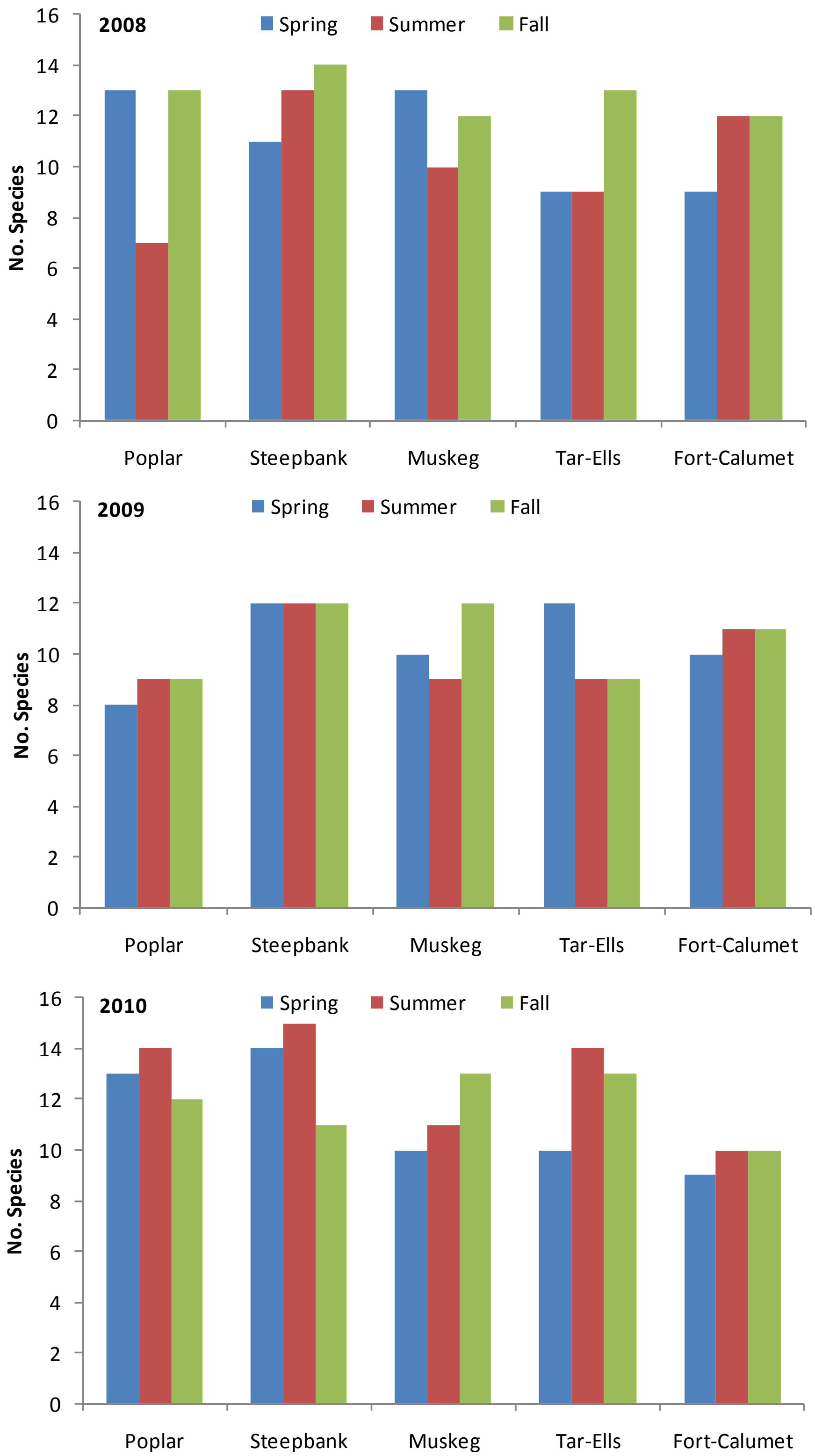
Table 5.1-17 Percent composition of species in the Athabasca River during spring, summer, and fall, 2010.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
Arctic grayling	-	-	-	-	17	0.71
brook stickleback	-	-	2	0.13	-	-
burbot	5	0.38	5	0.32	1	0.04
emerald shiner	109	8.26	80	5.04	17	0.71
flathead chub	53	4.02	495	31.21	39	1.64
finescale dace	1	0.08	-	-	-	-
goldeye	76	5.76	63	3.97	159	6.69
lake chub	10	0.76	95	5.99	13	0.55
lake whitefish	18	1.36	3	0.19	412	17.33
longnose sucker	63	4.78	50	3.15	4	0.17
mountain whitefish	1	0.08	1	0.06	9	0.38
northern pike	21	1.59	28	1.77	37	1.56
pearl dace	1	0.08	-	-	2	0.08
slimy sculpin	-	-	3	0.19	-	-
spoonhead sculpin	-	-	1	0.06	3	0.13
spottail shiner	15	1.14	14	0.88	2	0.08
trout-perch	464	35.18	516	32.53	1,486	62.49
walleye	288	21.83	185	11.66	99	4.16
white sucker	193	14.63	2	0.13	40	1.68
yellow perch	1	0.08	43	2.71	38	1.60
Total	**1,319**	**100**	**1,586**	**100**	**2,378**	**100**

Table 5.1-18 Percent composition of species in the Athabasca River in each area during spring, summer, and fall, 2010.

Species	Spring (% of Total Catch)					Summer (% of Total Catch)					Fall (% of Total Catch)				
	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet
Arctic grayling	-	-	-	-	-	-	-	-	-	-	0.87	1.56	-	-	-
brook stickleback	-	-	-	-	-	0.46	-	-	-	-	-	-	-	-	-
burbot	0.65	0.62	-	-	-	0.46	-	0.65	-	-	-	-	-	0.47	-
emerald shiner	2.28	12.11	6.43	1.49	20.72	0.46	10.79	6.91	4.26	4.69	0.44	0.24	0.99	2.35	0.75
flathead chub	6.19	3.08	0.36	9.70	4.50	29.91	20.33	24.41	30.85	56.25	1.31	1.68	1.65	4.23	-
finescale dace	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
goldeye	5.54	6.57	5.71	3.73	5.41	1.14	7.05	3.02	4.79	7.03	4.58	7.07	7.41	9.86	4.91
lake chub	-	1.03	1.43	0.75	-	8.22	0.41	3.46	15.43	5.08	0.22	0.96	-	0.47	1.13
lake whitefish	0.65	2.46	0.71	0.00	1.80	-	1.24	-	-	-	18.52	15.83	10.87	10.80	40.00
longnose sucker	8.14	4.93	1.79	5.22	1.80	3.20	2.07	5.40	2.13	0.78	0.65	0.12	0.00	-	-
mountain whitefish	-	0.21	-	-	-	-	-	-	0.53	-	0.22	0.48	0.33	0.94	-
northern pike	0.65	1.03	2.14	2.99	3.60	1.60	3.32	2.38	1.06	-	1.31	2.28	1.15	0.94	1.13
pearl dace	0.33	-	-	-	-	-	-	-	-	-	0.22	-	0.16	-	-
slimy sculpin	-	-	-	-	-	-	-	0.22	1.06	-	-	-	-	-	-
spoonhead sculpin	-	-	-	-	-	-	-	-	-	0.39	-	0.12	-	0.47	0.38
spottail shiner	1.30	2.05	-	0.75	-	1.14	0.41	0.65	1.60	0.78	-	0.12	-	0.47	-
trout-perch	43.97	41.07	28.57	18.66	21.62	33.79	35.68	41.04	25.00	17.58	61.44	61.87	71.50	58.69	48.68
walleye	24.43	15.20	15.36	44.78	32.43	15.53	16.18	9.50	10.11	5.86	6.54	4.08	3.29	6.10	0.75
white sucker	5.54	9.45	37.50	11.94	8.11	-	-	0.22	0.53	-	1.96	1.68	1.65	2.35	0.75
yellow perch	-	0.21	-	-	-	4.11	2.49	2.16	2.66	1.56	1.74	1.92	0.99	1.88	1.51
Total # of Species	**13**	**14**	**10**	**11**	**9**	**12**	**11**	**13**	**13**	**10**	**14**	**15**	**12**	**14**	**10**
Total # of Fish Captured	**307**	**487**	**280**	**134**	**111**	**438**	**241**	**463**	**188**	**256**	**459**	**834**	**607**	**213**	**265**

Figure 5.1-25 Species richness in each sampled area of the Athabasca River during spring, summer and fall, 2008 to 2010.



Note: Spatial comparisons were made from 2008 to 2010 when all areas were consistently sampled in each season.

Figure 5.1-26 Species richness and total catch in the Athabasca River during spring summer and fall, 1987 to 2010.

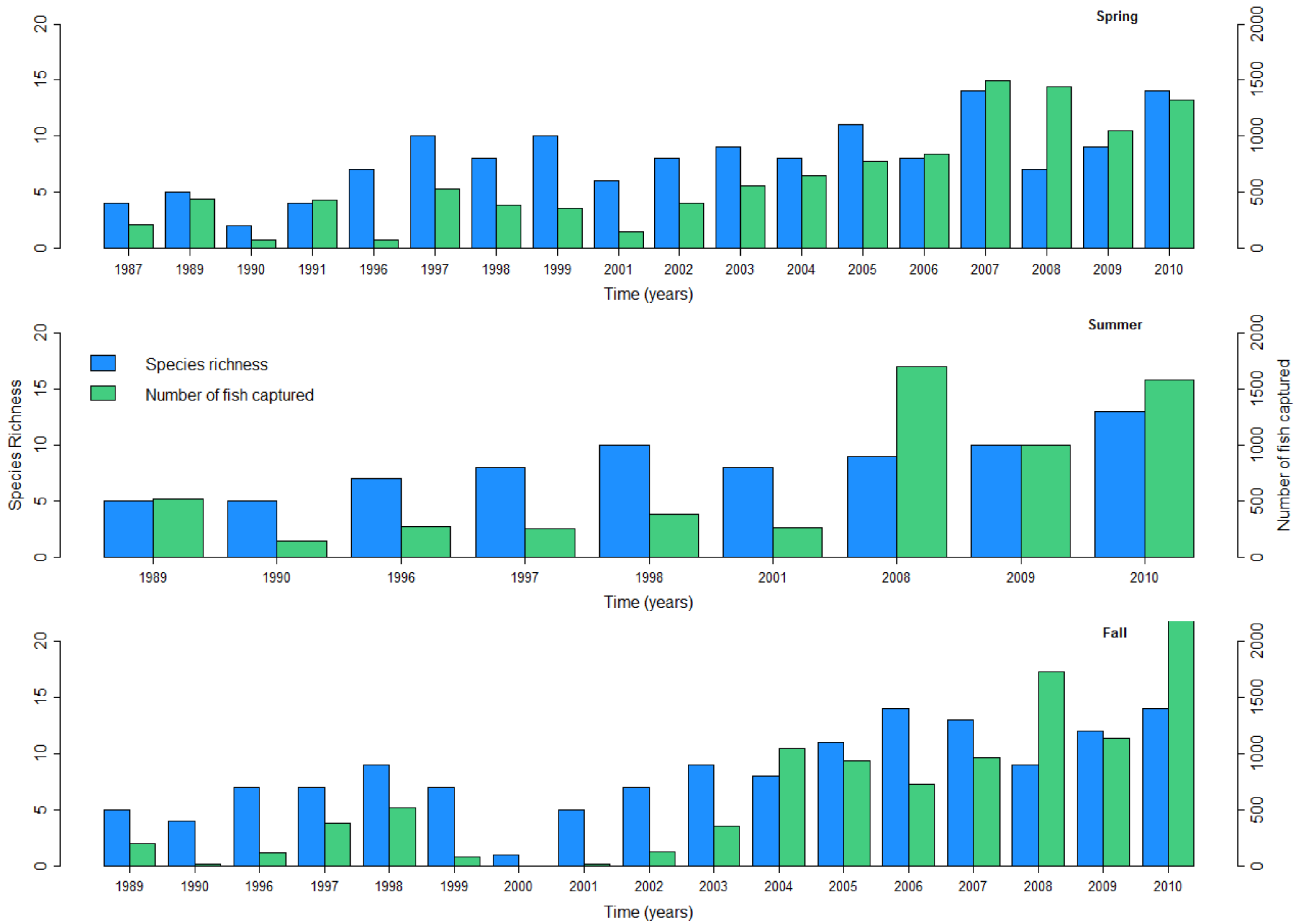


Figure 5.1-27 Percent composition of large-bodied KIR species caught during the Athabasca River spring, summer, and fall inventories, 1987 to 2010.

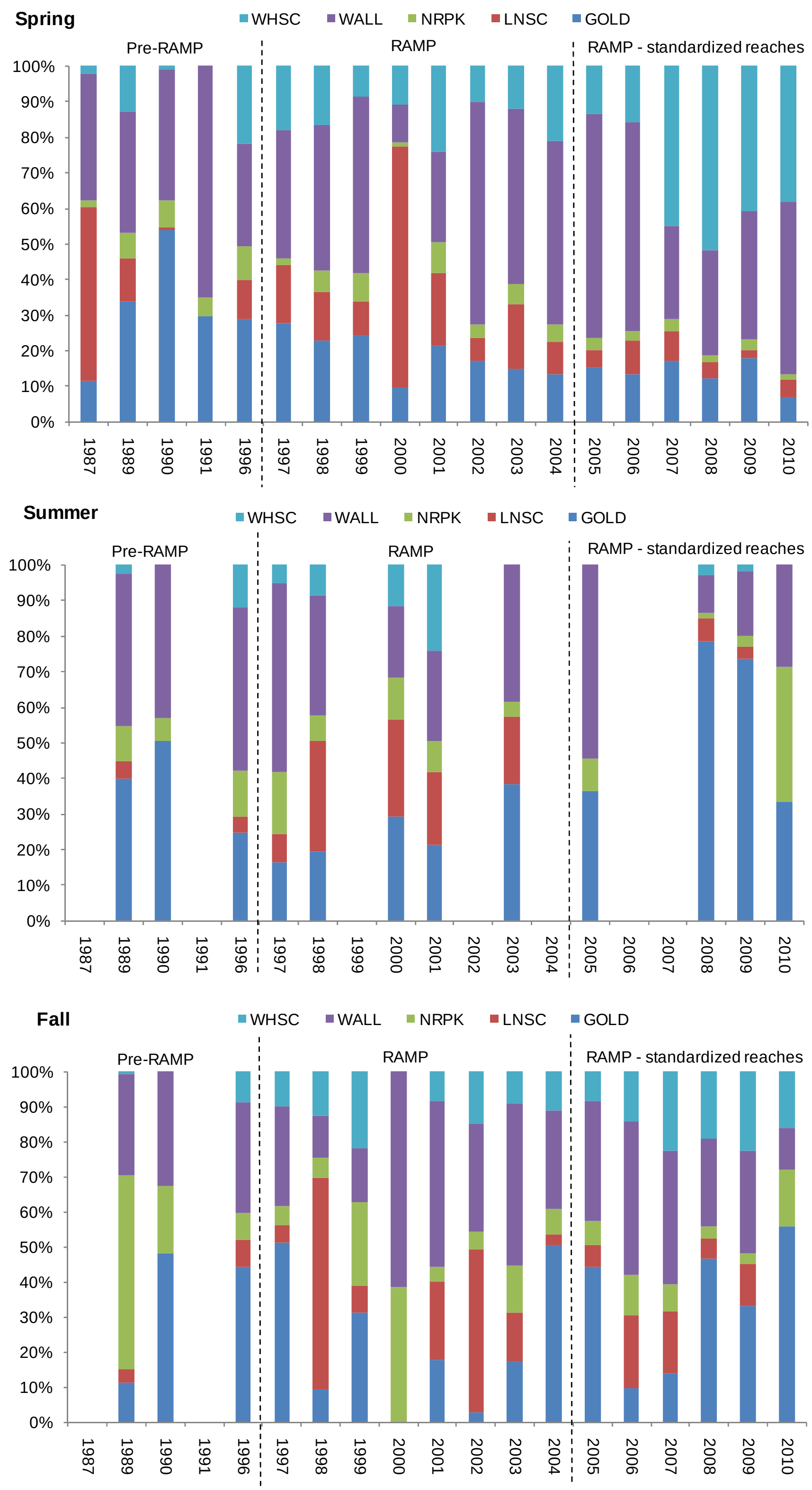


Figure 5.1-28 Total CPUE (± 1SD) of all species combined from 1987 to 2010 in spring, summer and fall in the Athabasca River.

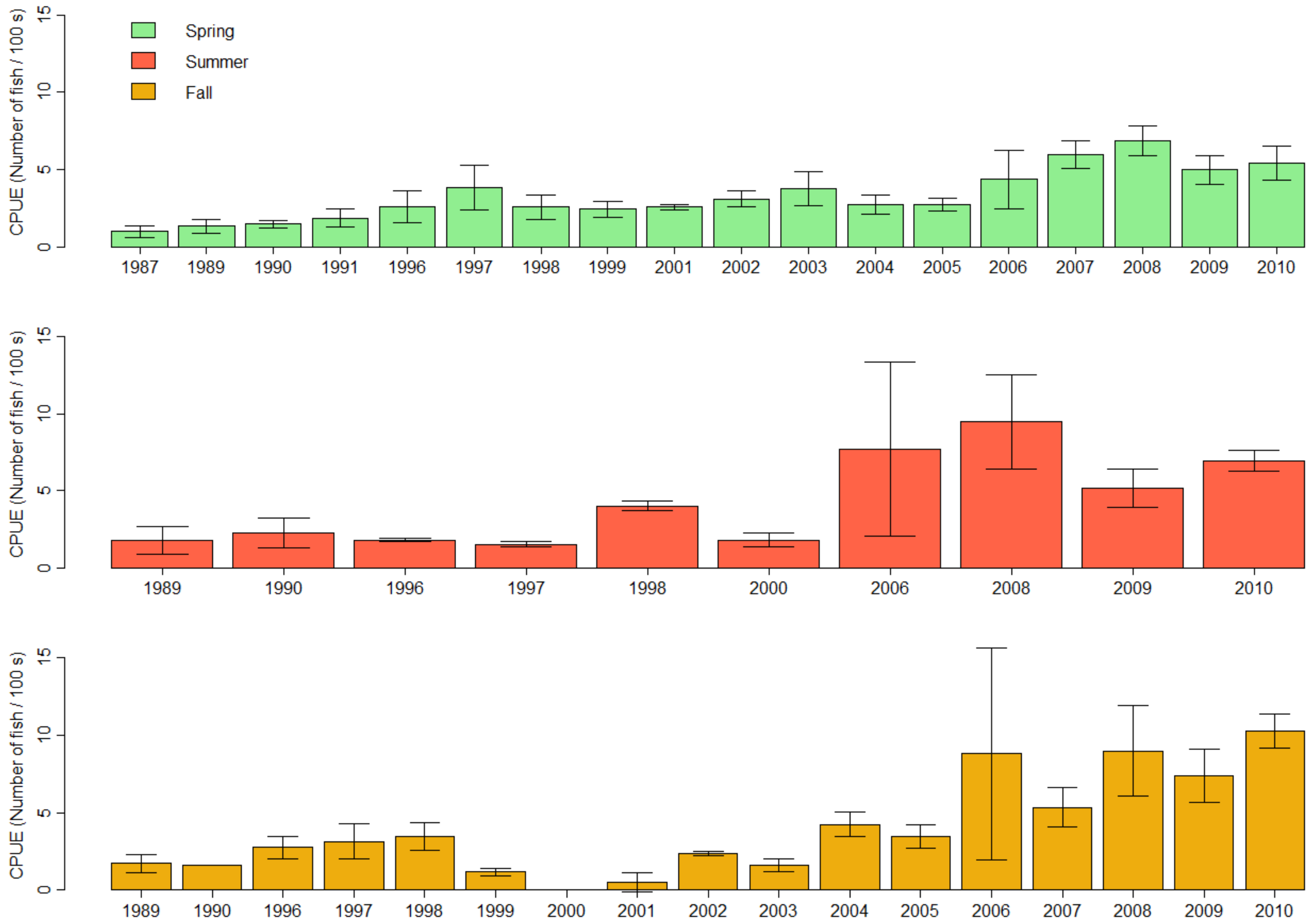


Figure 5.1-29 Mean CPUE (± 1SD) of large-bodied KIR fish species combined in spring, summer and fall from 1987 to 2010.

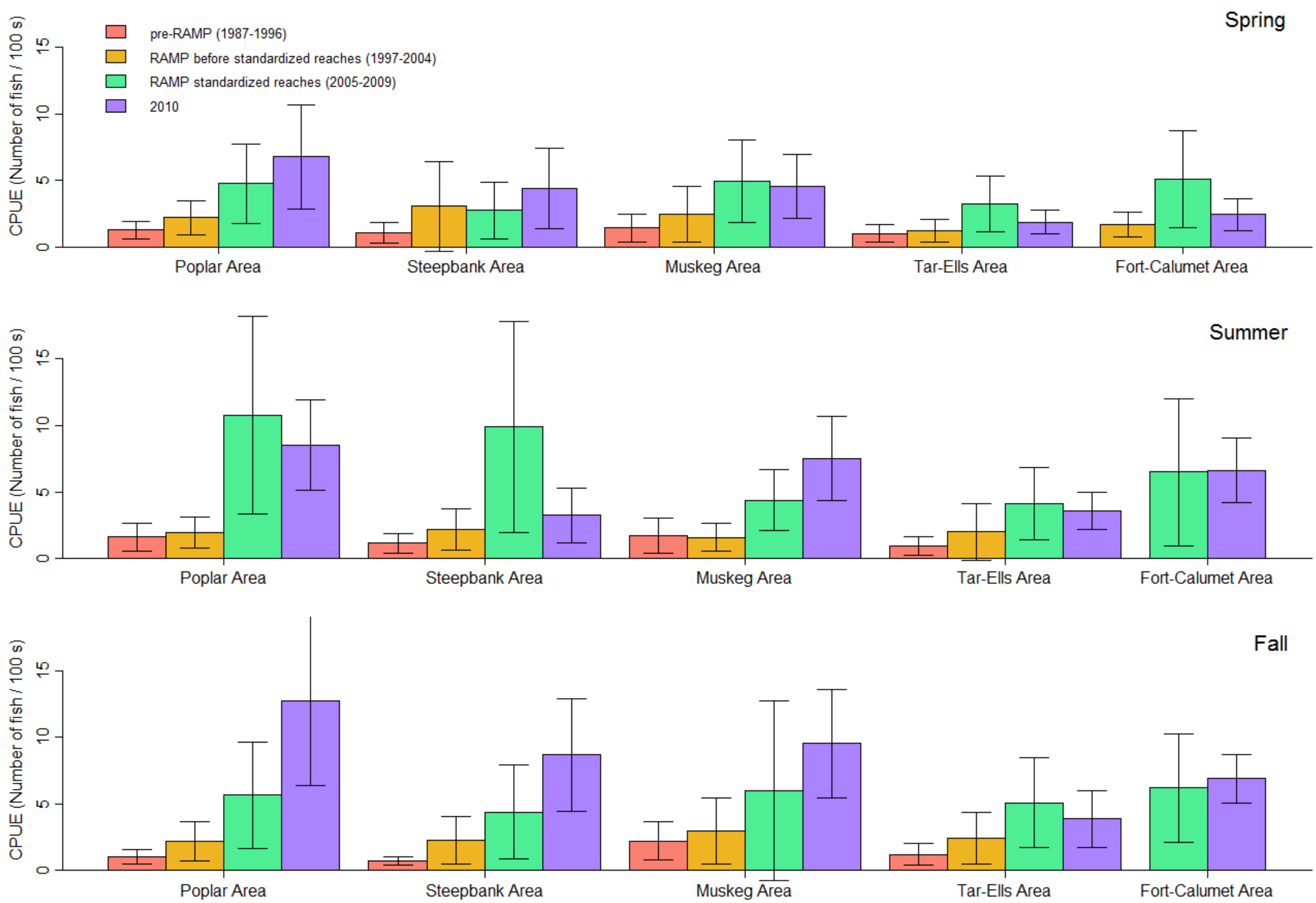


Figure 5.1-30 Spatial comparisons of mean CPUE (± 1SD) of large-bodied KIR fish species in spring, summer and fall 2010 in the Athabasca River.

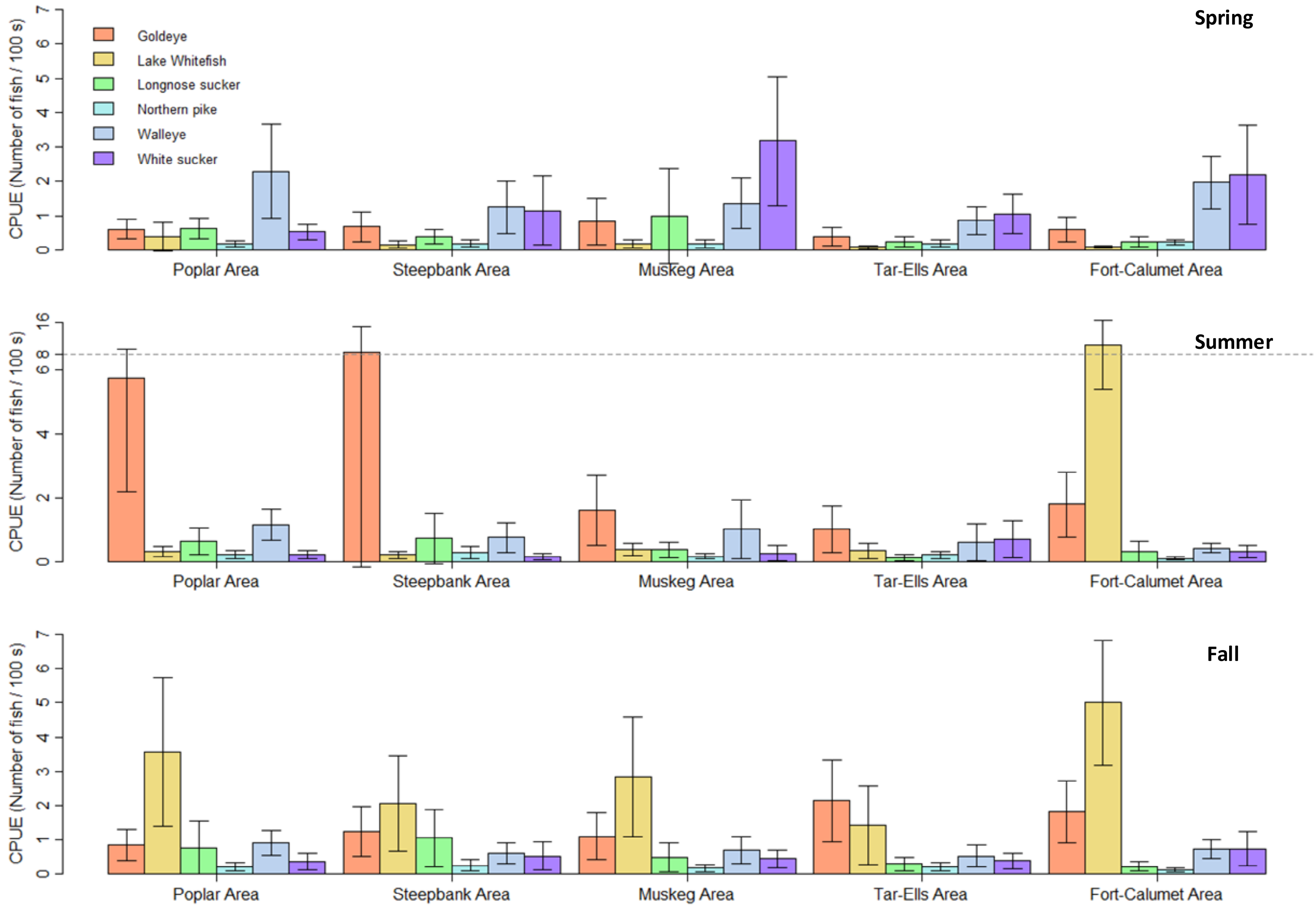


Figure 5.1-31 Relative length-frequency distributions for goldeye captured in the Athabasca River in 2010 (n=298) compared to the average from 1997 to 2009 (period of RAMP sampling sands), and the average from 1987 to 1996 (pre-RAMP); 50 mm length classes.

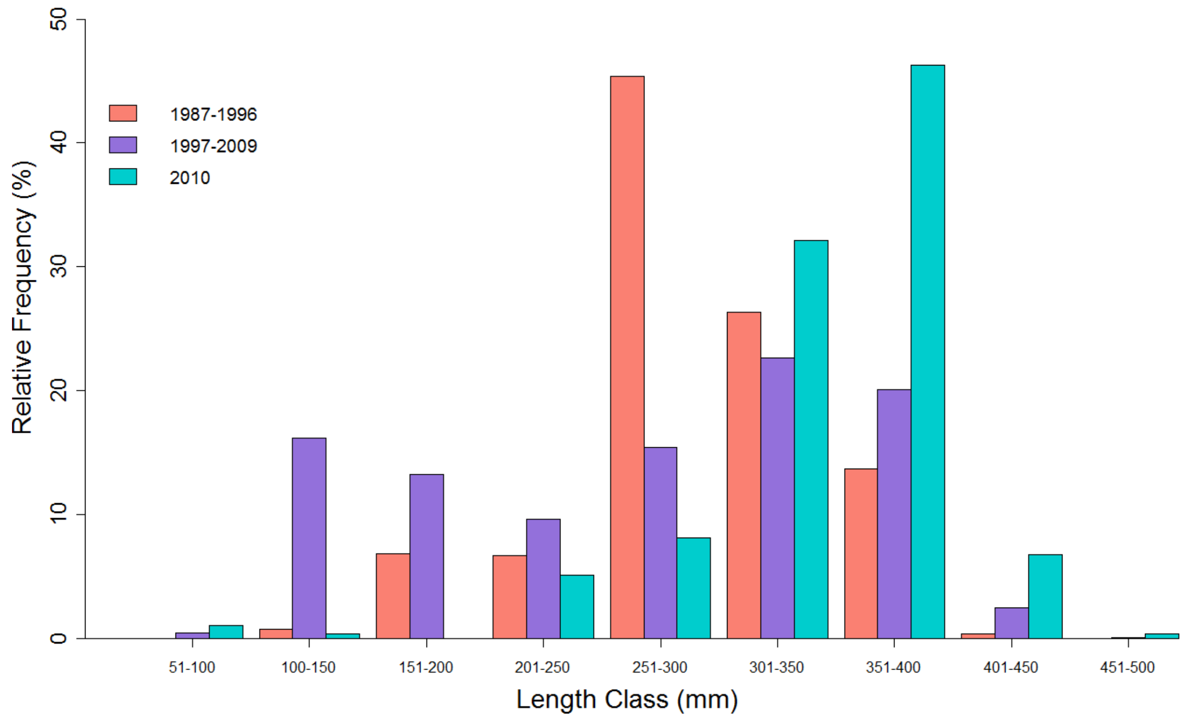


Figure 5.1-32 Relative length-frequency distributions for longnose sucker captured in the Athabasca River in 2010 (n=117) compared to the average from 1997 to 2009 (RAMP sampling period) and from 1987 to 1996 (pre-RAMP); 50 mm length classes.

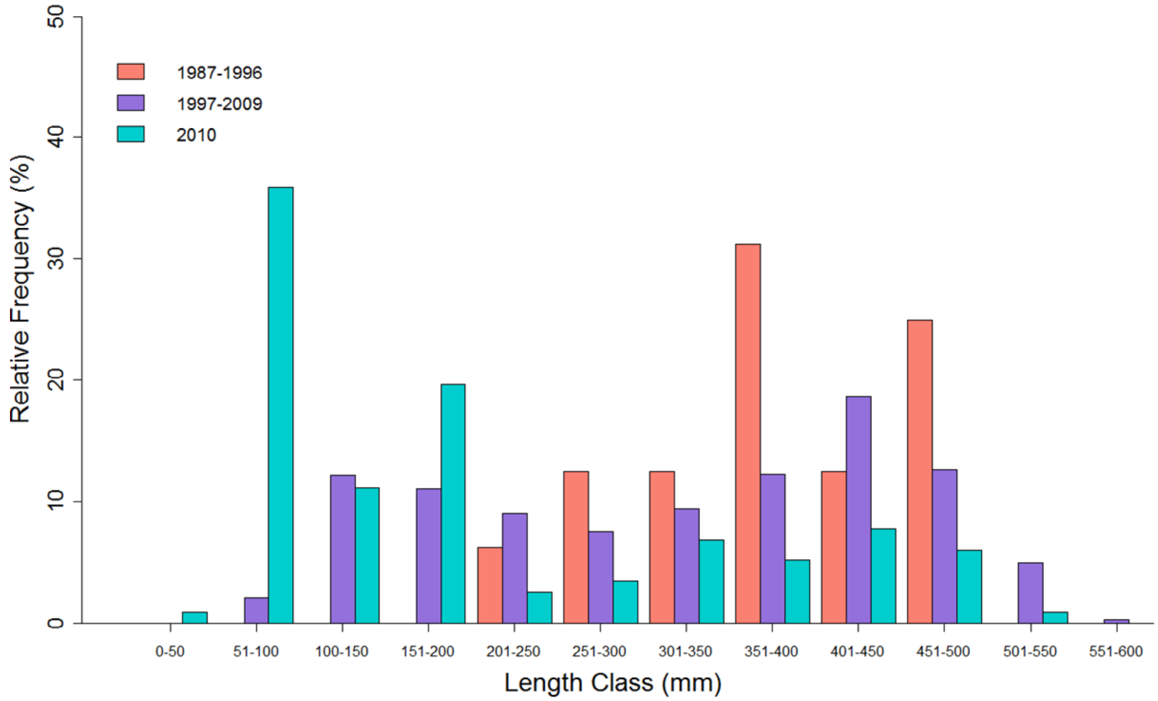


Figure 5.1-33 Relative length-frequency distributions for northern pike captured in the Athabasca River in 2010 (n=86) compared to the average from 1997 to 2009 (RAMP sampling period), and the average from 1987 to 1996 (pre-RAMP); 50 mm length classes.

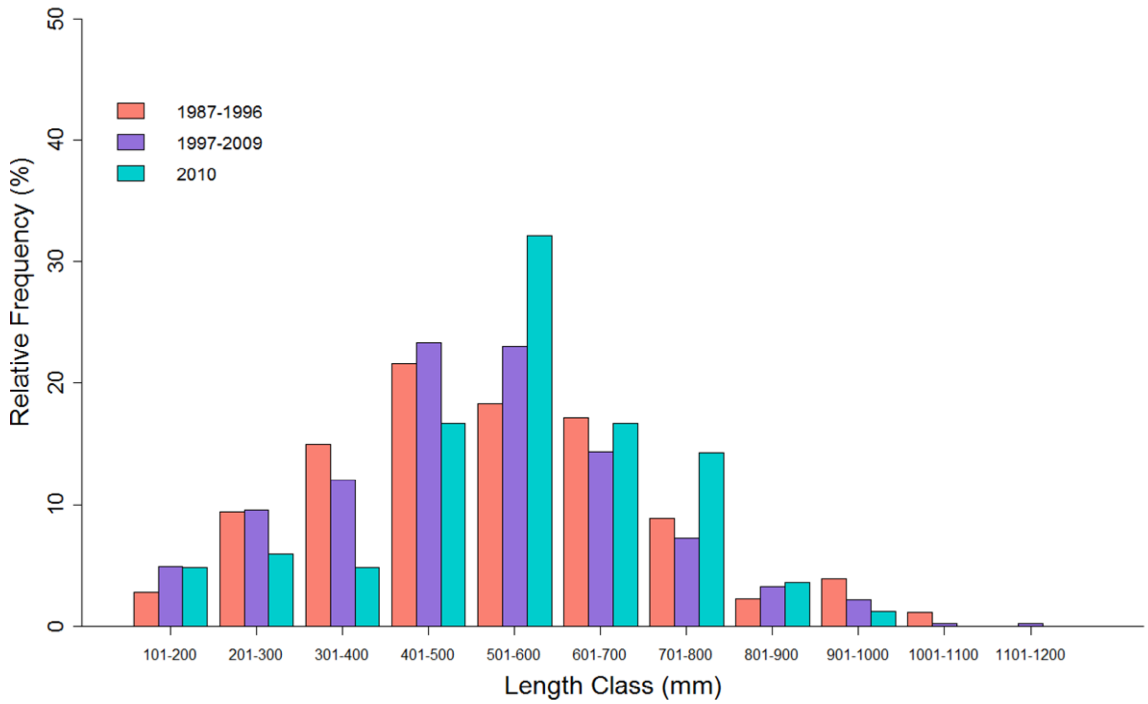


Figure 5.1-34 Relative length-frequency distributions for walleye captured in the Athabasca River in 2010 (n=572) compared to the average from 1997 to 2009 (RAMP sampling period), and the average from 1987 to 1996 (pre-RAMP); 50 mm length classes.

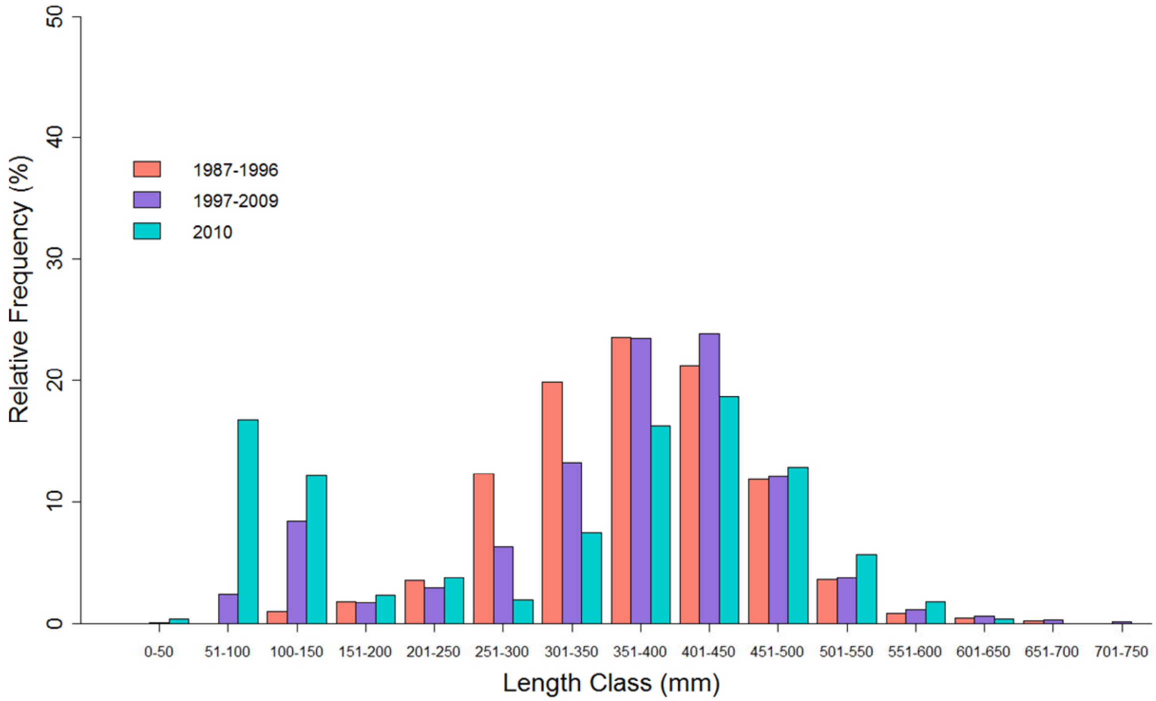


Figure 5.1-35 Relative length-frequency distributions for white sucker captured in the Athabasca River in 2010 (n=235) compared to the average from 1997 to 2009 (RAMP sampling period), and the average from 1987 to 1996 (pre-RAMP); 50 mm length classes.

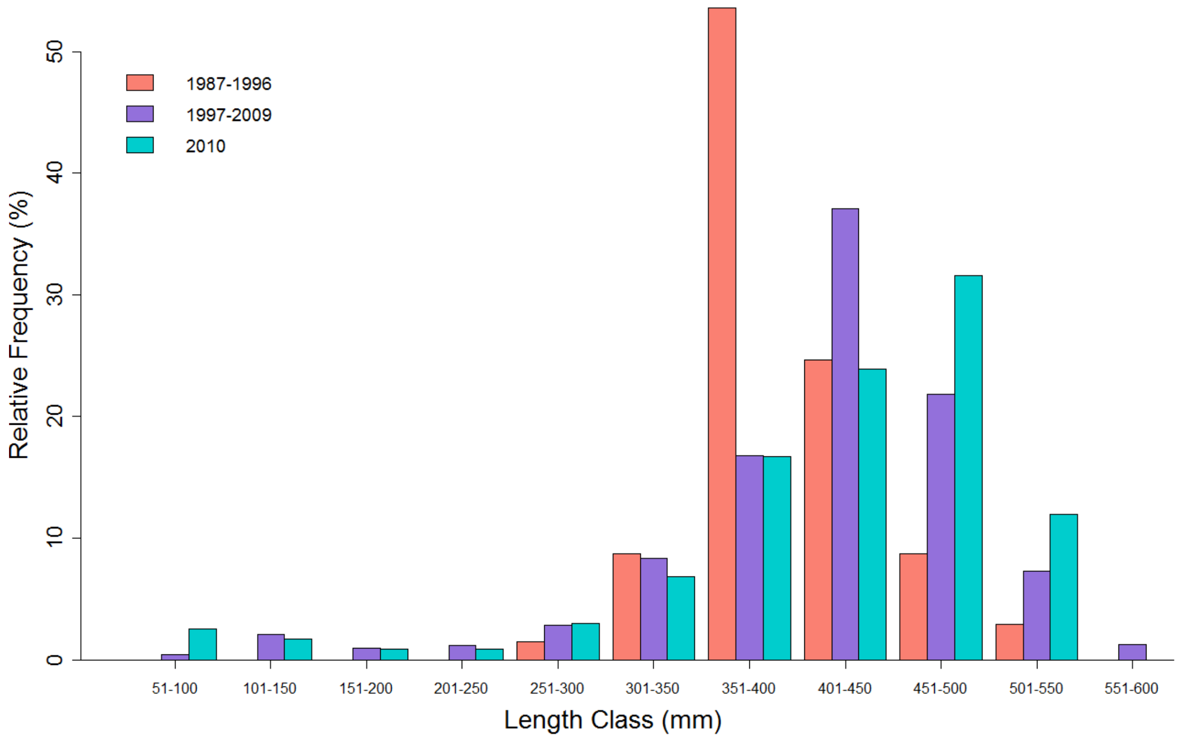


Figure 5.1-36 Mean condition (± 1SE) of goldeye captured during the spring, summer, and fall inventories from 1997 to 2010 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

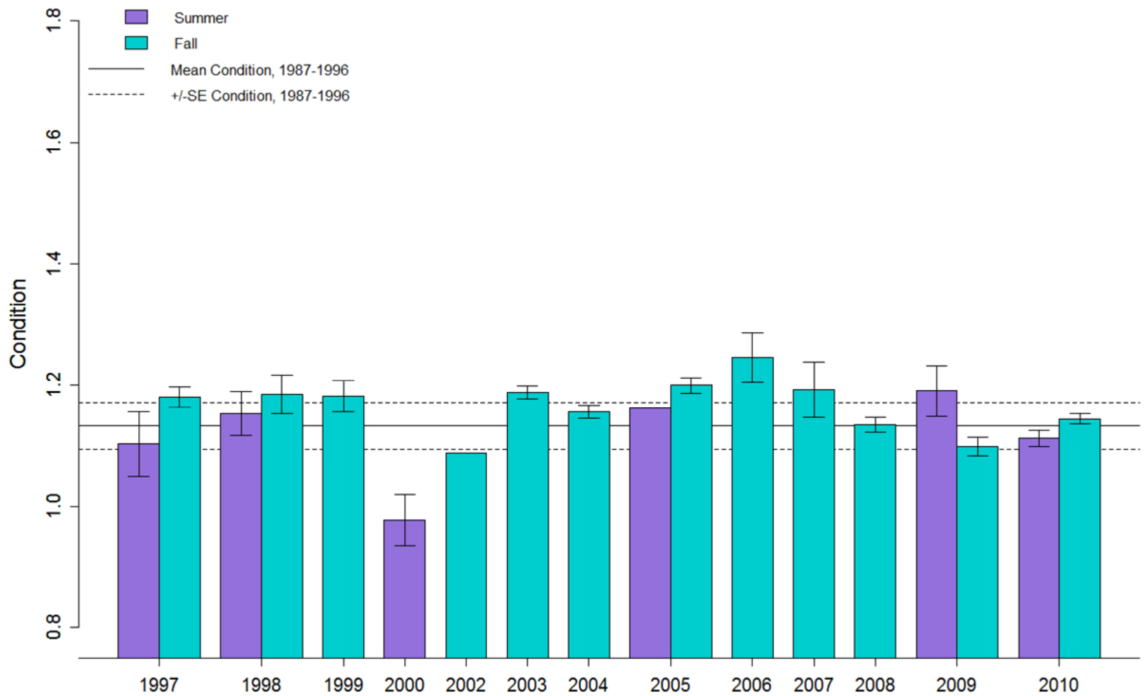


Figure 5.1-37 Mean condition (± 1SE) of longnose sucker captured during the spring, summer, and fall inventories from 1997 to 2010 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

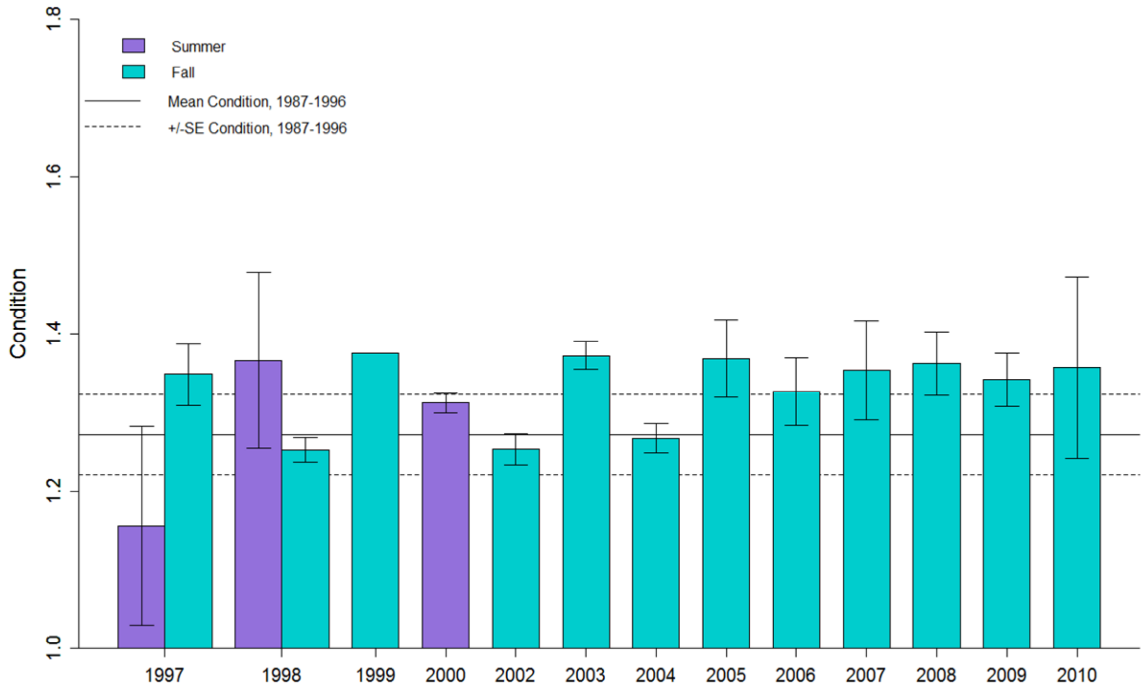


Figure 5.1-38 Mean condition (± 1SE) of northern pike captured during the spring, summer, and fall inventories from 1997 to 2010 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

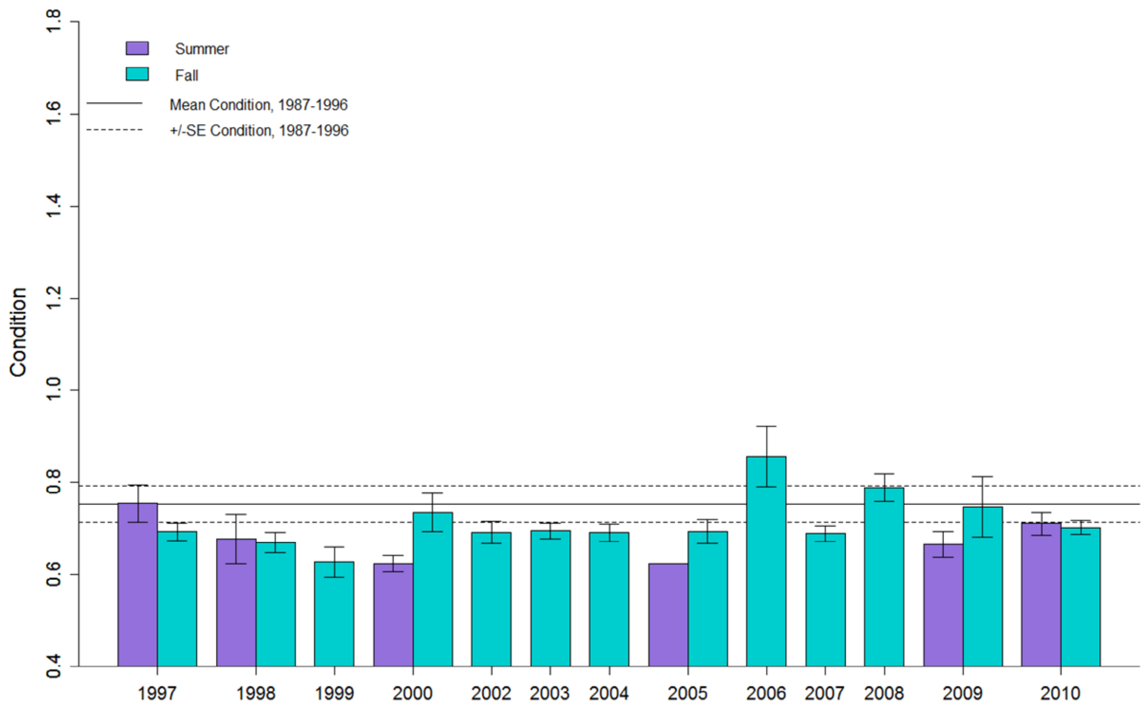


Figure 5.1-39 Mean condition (± 1SE) of walleye captured during the spring, summer, and fall inventories from 1997 to 2010 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

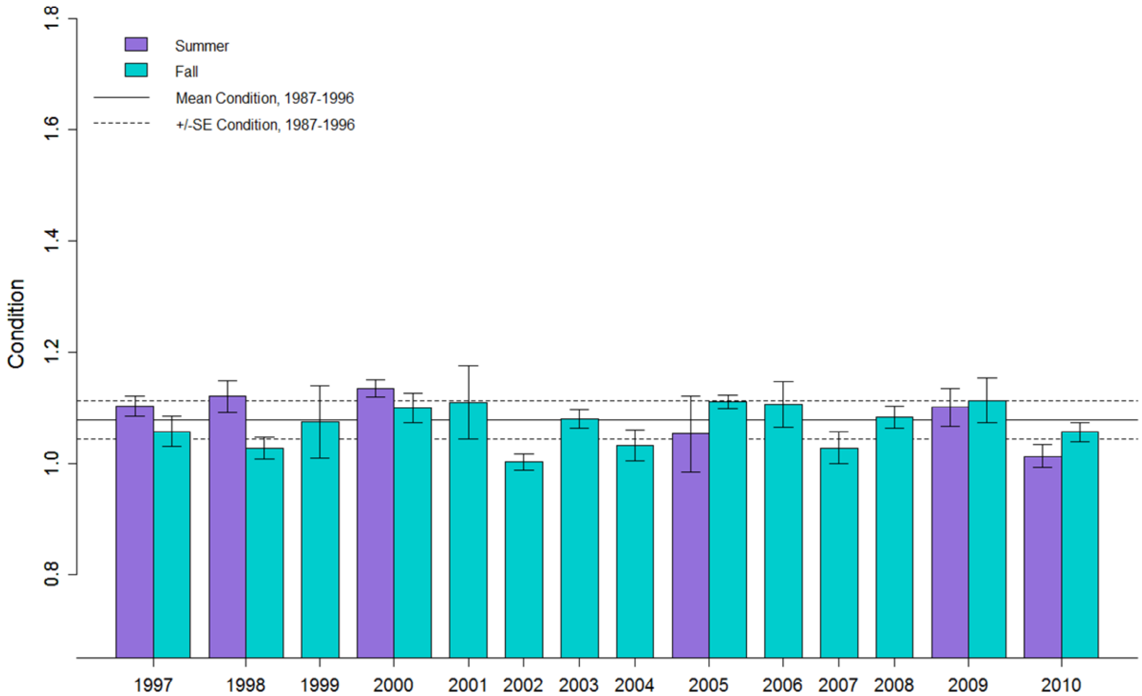


Figure 5.1-40 Mean condition (± 1SE) of white sucker captured during the spring, summer, and fall inventories from 1997 to 2010 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

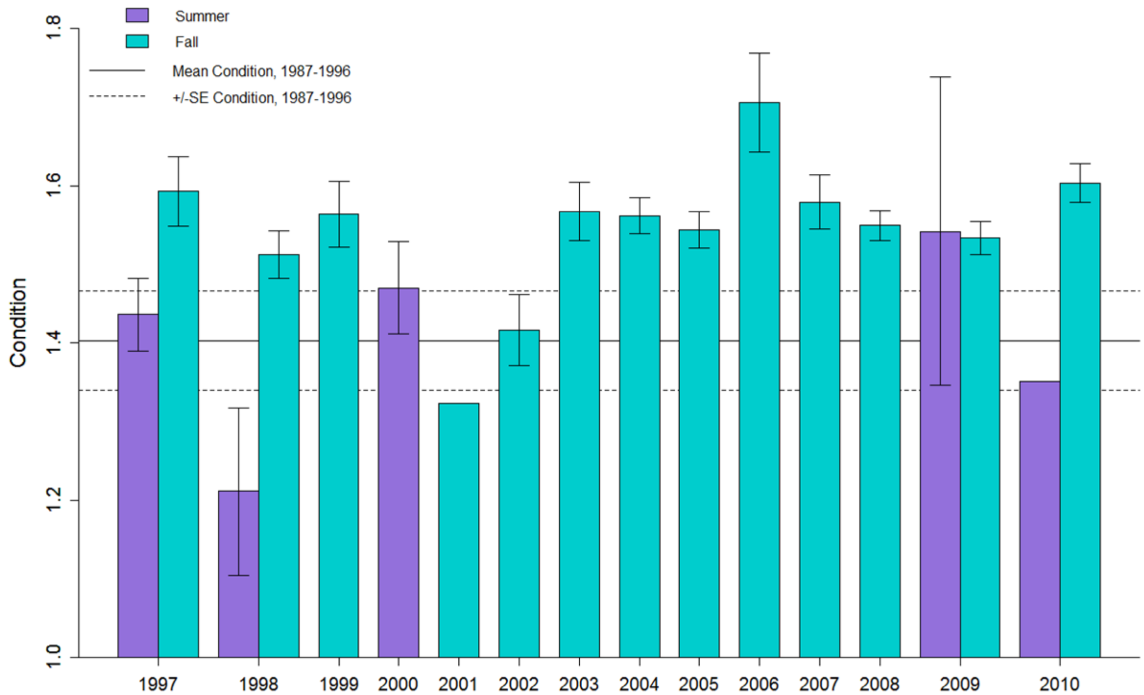


Figure 5.1-41 Recruitment of walleye to the sport fishery estimated using data collected during the Athabasca River inventories, 1987 to 2010.

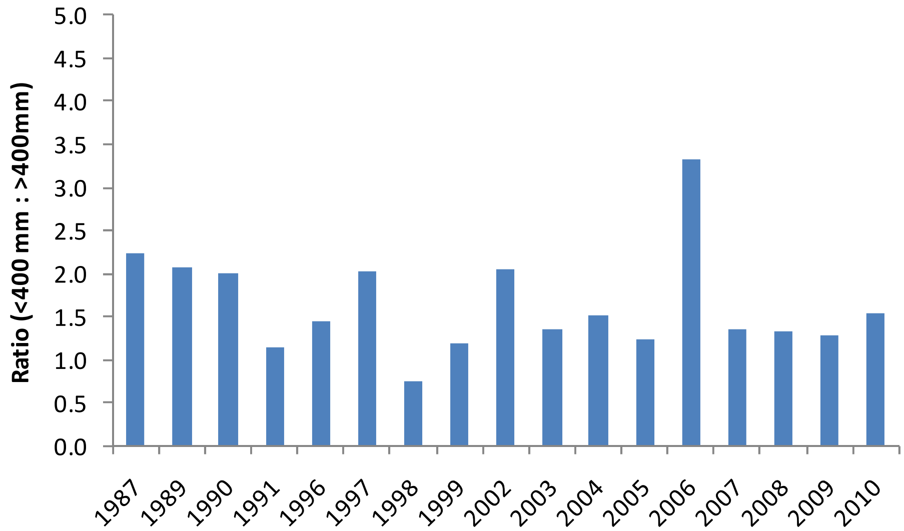


Figure 5.1-42 Recruitment of northern pike to the sport fishery estimated using data collected during the Athabasca River inventories, 1987 to 2010.

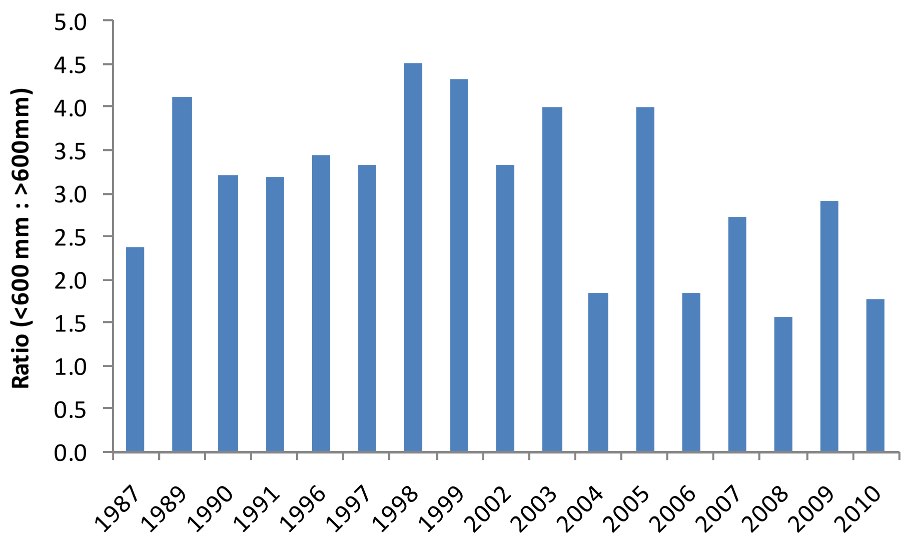


Table 5.1-19 Percent of total fish captured by species with external pathology (growth/lesion, deformity, parasite), 1987 to 2010.

Year	Arctic Grayling	Burbot	Flathead Chub	Northern Pike	Walleye	Goldeye	Mountain Whitefish	White Sucker	Longnose Sucker	Spottail Shiner	Lake Whitefish	Yellow Perch	Lake Chub	Trout-Perch	Cisco	Bull Trout
1987	-	-	-	0.98	-	-	-	-	-	-	-	-	-	-	-	-
1989	1.11	3.23	-	2.24	2.26	1.45	5.56	1.91	2.30	-	10.08	-	-	-	-	-
1990	-	-	-	1.59	1.28	1.70	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	1.43	2.40	2.89	-	-	-	-	20.00	-	-	-	-	-
1996	-	-	2.75	9.77	4.12	1.91	50.00	26.40	9.62	-	6.88	20.00	-	-	-	-
1997	-	-	0.37	10.23	2.87	2.77	12.50	12.22	11.28	10.53	3.66	-	1.85	-	-	-
1998	-	3.70	0.91	5.75	1.94	1.82	-	8.52	2.55	-	10.14	-	-	-	-	-
1999	-	-	-	11.86	2.13	2.40	-	8.47	9.30	-	14.08	-	-	-	-	-
2000	-	-	-	2.78	1.32	1.54	-	10.53	4.24	-	19.05	-	-	-	-	-
2001	-	-	-	-	1.85	-	-	5.88	-	-	-	-	-	6.25	-	-
2002	-	-	-	-	2.22	-	-	1.92	1.08	-	3.45	-	-	-	-	-
2003	-	-	0.60	4.69	1.68	-	-	3.95	1.60	-	4.26	-	-	0.26	33.33	-
2004	-	-	-	-	2.84	-	-	5.10	1.61	-	-	-	-	0.22	-	-
2005	-	-	-	-	1.97	0.29	-	2.76	1.47	-	0.68	-	-	0.44	-	100.00
2006	-	-	0.85	1.85	3.15	1.08	-	1.68	-	-	1.56	-	-	-	-	-
2007	-	-	-	-	2.55	0.49	-	2.99	1.59	-	3.75	-	-	0.28	-	-
2008	-	-	0.26	5.08	2.90	0.43	-	8.63	5.00	-	2.94	-	-	0.10	-	-
2009	-	-	1.11	4.26	4.18	0.96	25.00	7.20	6.58	-	3.33	-	-	0.26	-	-
2010	-	9.09	-	2.33	5.24	2.35	-	5.11	0.85	-	1.39	-	-	-	-	-

Figure 5.1-43 Percent of total fish captured in the Athabasca River with some type of external pathology, 1987 to 2010.

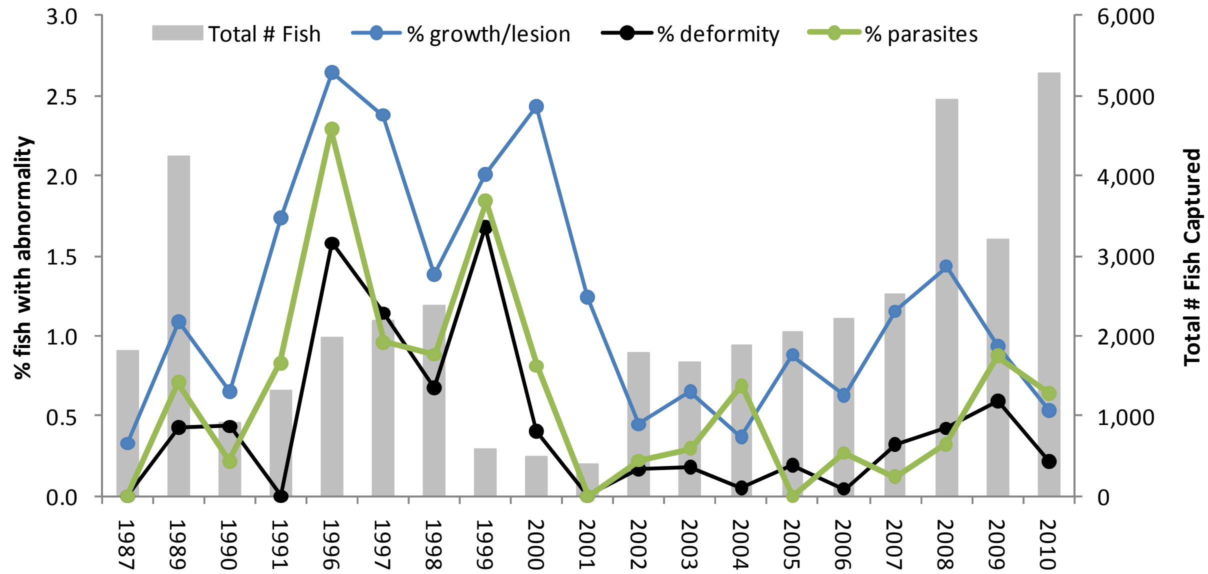


Table 5.1-20 Results of RAMP fish tag return by anglers and during the Athabasca River and Clearwater River fish inventories, 2010.

Variable	Fish Species		
	Walleye	Northern pike	White sucker
No. of Fish Recaptured	11	12	3
Minimum Distance Travelled (km)	0	0	1
Maximum Distance Travelled (km)	14	52	<1

Table 5.1-21 Results of RAMP fish tag returns by anglers, Athabasca and Clearwater rivers (1999 to 2010).

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

Figure 5.1-44 Walleye and northern pike tag recovery locations by anglers, 2010.

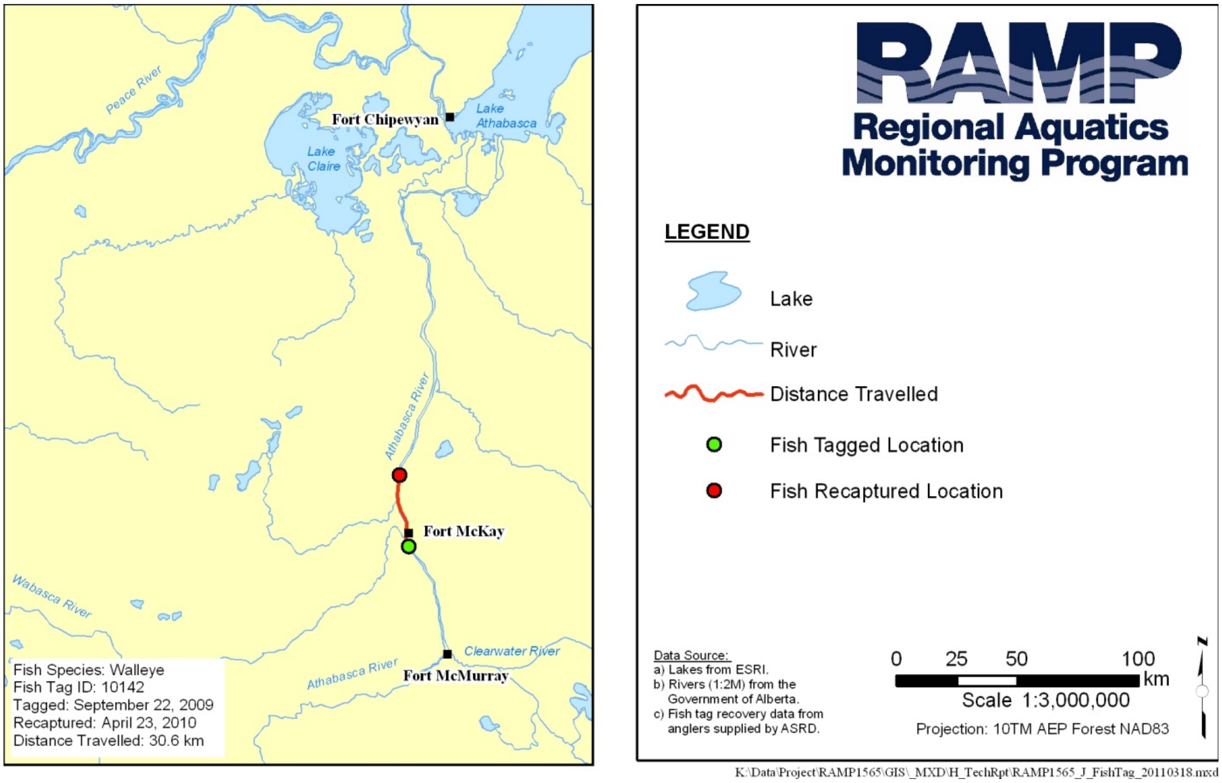


Table 5.1-22 *Post-hoc* power analyses for comparisons of age, weight-at-age, GSI, LSI, and condition between *baseline* and *test* sites for the trout-perch sentinel species program.

Response Variable	Covariate	Critical Effect Size (% Difference)	Gender	Pooled MSE	Required Sample Size per Site/Year
Age	none	25	F	0.0190	28
			M	0.0210	33
Body Weight	Age	25	F	0.0110	17
			M	0.0080	13
Gonad Weight	Body Weight	25	F	0.0060	10
			M	0.0130	20
Liver Weight	Body Weight	25	F	0.0072	12
			M	0.0068	11
Body Weight	Body Length	10	F	0.0016	14
			M	0.0015	13

Table 5.1-23 Summary of morphometric data (mean ± 1SE) for trout-perch on the Athabasca River, 2010.

Site	N	Sex	Age (years)	Length (mm)	Weight (g)	K	GSI	LSI
1	20	Female	2.2±0.23	64.20±0.27	3.04±1.95	1.11±0.13	4.60±0.10	2.18±0.02
	20	Male	2.8±0.11	66.79±0.20	3.27±1.41	1.07±0.17	2.48±0.07	1.65±0.02
2	20	Female	4.1±0.37	79.14±0.50	5.79±2.44	1.08±0.14	6.18±0.11	2.57±0.02
	20	Male	3.2±0.11	64.95±0.24	3.09±1.54	1.10±0.17	2.08±0.08	2.00±0.01
3	20	Female	4.6±0.25	79.36±0.50	5.90±2.27	1.11±0.20	6.57±0.14	2.21±0.01
	20	Male	3.3±4.34	66.67±0.32	3.33±2.05	1.07±0.16	6.51±0.08	1.57±0.01
4	20	Female	4.0±0.28	80.75±0.40	5.92±1.98	1.09±0.16	5.92±0.10	2.16±0.01
	20	Male	3.6±0.14	74.08±0.26	4.39±1.71	1.05±0.18	2.59±0.06	1.68±0.01
5	9	Female	2.3±1.06	59.44±0.34	2.27±2.64	1.04±0.24	2.66±0.07	1.81±0.01
	14	Male	2.4±0.19	57.36±0.29	2.12±2.03	1.07±0.17	1.34±0.08	1.67±0.02

Condition factor (K) = (weight)/length^3) * 10^5

GSI = (gonad weight)/body weight) * 100

LSI = (liver weight)/body weight) * 100

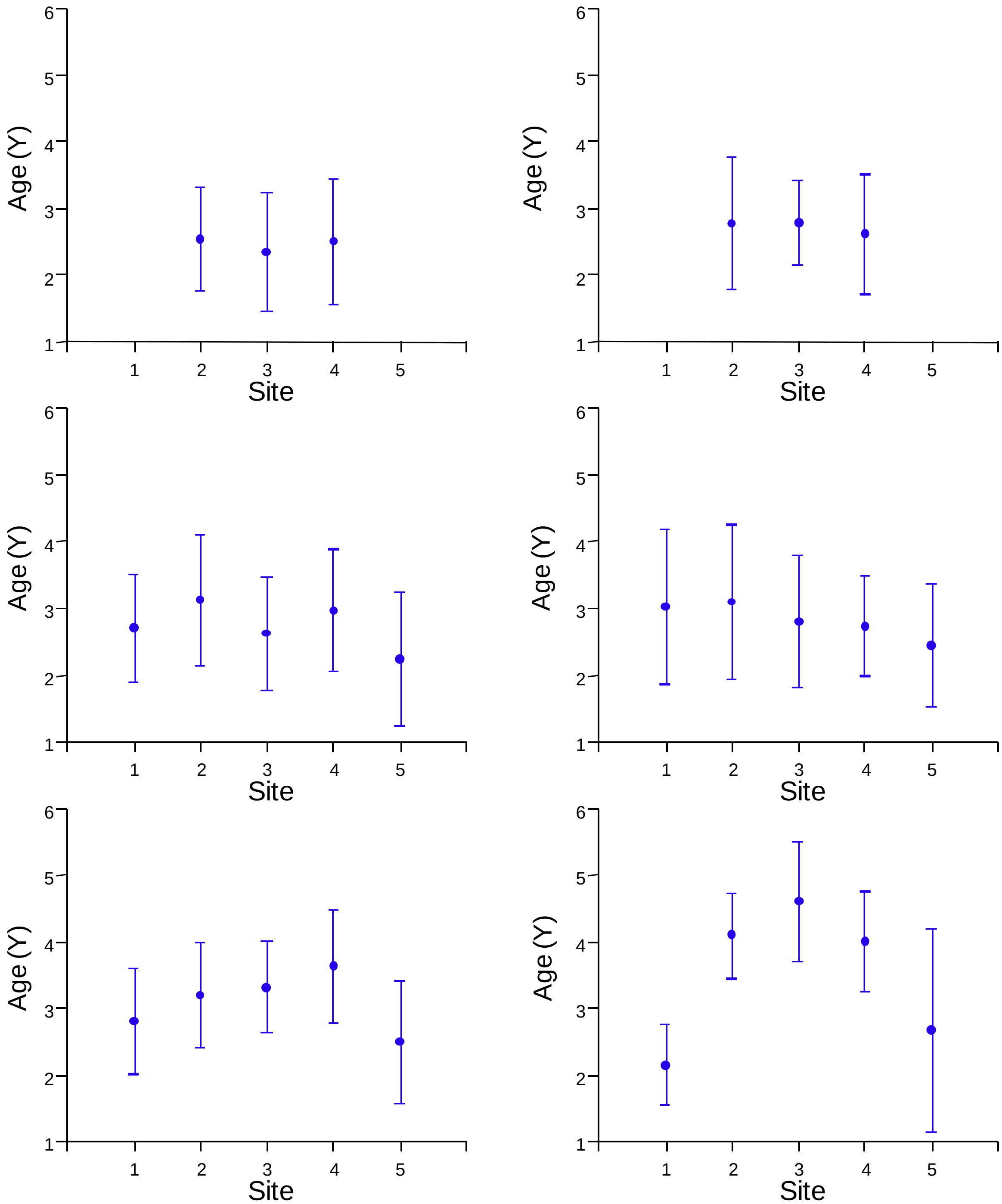
Table 5.1-24 Summary of ANOVA and effects criterion for age of trout-perch from the *test* sites compared to *baseline* sites in the Athabasca River, 1999, 2002, 2010.

Sex	Comparison	P-value *Baseline* vs. *Test* (2010)	P-value Difference Between 2002 and 2010	P-value Change Over Time	Percent Difference		
					1999	2002	2010
Female	Site 1 vs. Site 2	**<0.001**	**0.000**	**0.000**	-	3.2	**48.9**
	Site 2 vs. Avg. *test* sites	0.197	0.849	0.159	-1.4	-14.2	-9.5
	Site 2 vs. Site 3	0.272	0.090	0.934	3.9	-9.6	11.7
	Site 2 vs. Site 4	0.799	0.557	0.318	-6.8	-10.0	-2.5
	Site 2 vs. Site 5	**0.018**	0.306	**0.001**	-	-14.8	**-37.6**
Male	Site 1 vs. Site 2	0.184	0.986	0.029	-	13.0	13.2
	Site 2 vs. Avg. *test* sites	0.749	0.849	0.017	-6.9	-17.5	-1.7
	Site 2 vs. Site 3	0.698	0.090	0.934	-9.4	-16.7	4.3
	Site 2 vs. Site 4	0.243	0.557	0.318	-4.5	-4.3	13.4
	Site 2 vs. Site 5	0.099	0.306	**0.001**	-	**-31.7**	-22.8

Note: p-values tests for variations in least square means between sites (i.e., test of intercepts).

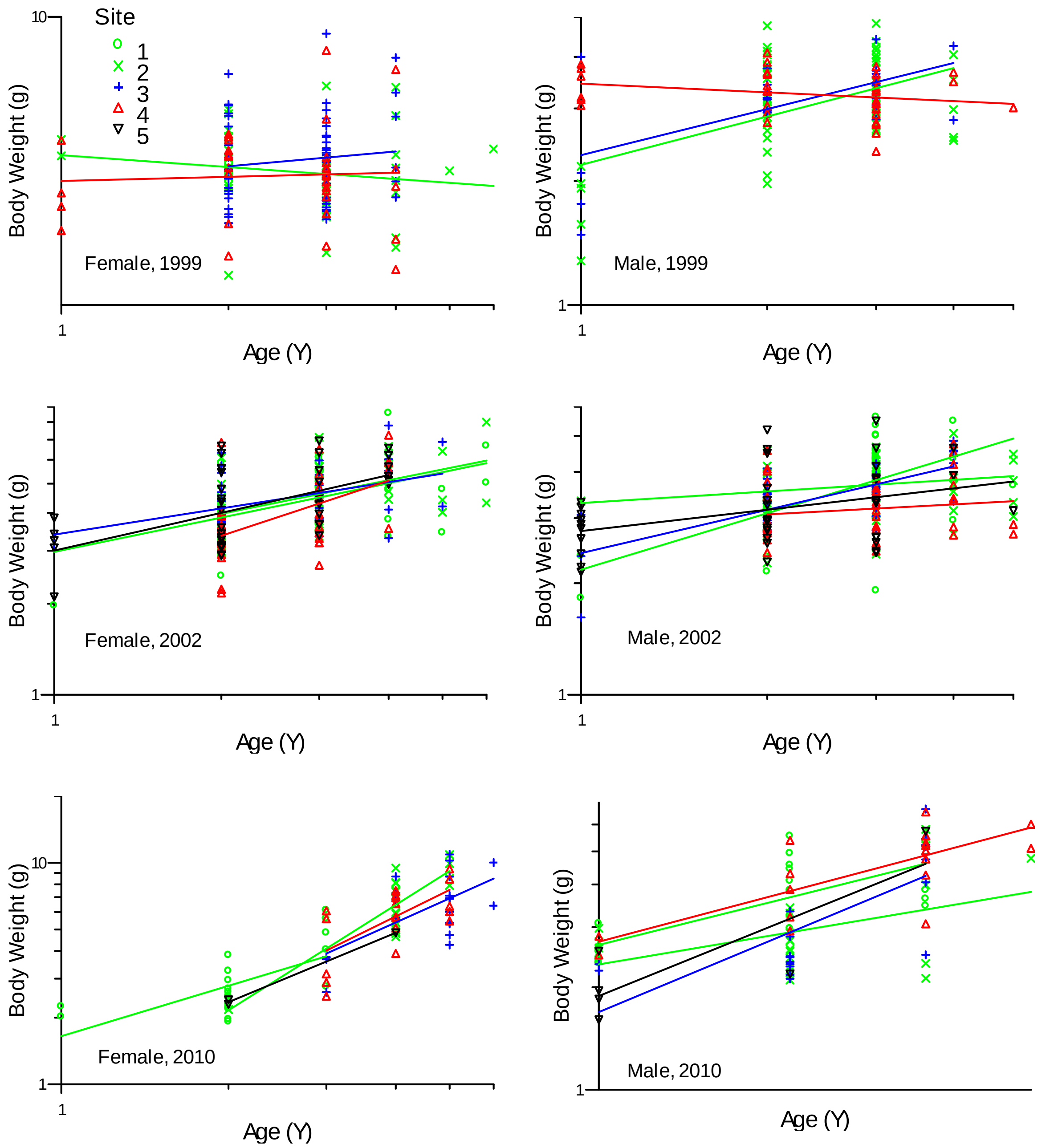
Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-45 Mean age ±1SE of female and male trout-perch in *baseline* sites 1 and 2 and *test* sites 3, 4, and 5 in the Athabasca River, 1999, 2002, and 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-46 Relationship between body weight (g) and age (years) of male and female trout-perch in *baseline* and *test* sites in the Athabasca River, 1999, 2002, 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

Table 5.1-25 Summary of ANCOVA and effects criterion for the relationship between body weight and age of trout-perch from the *test* sites compared to *baseline* sites in the Athabasca River, 1999, 2002, 2010.

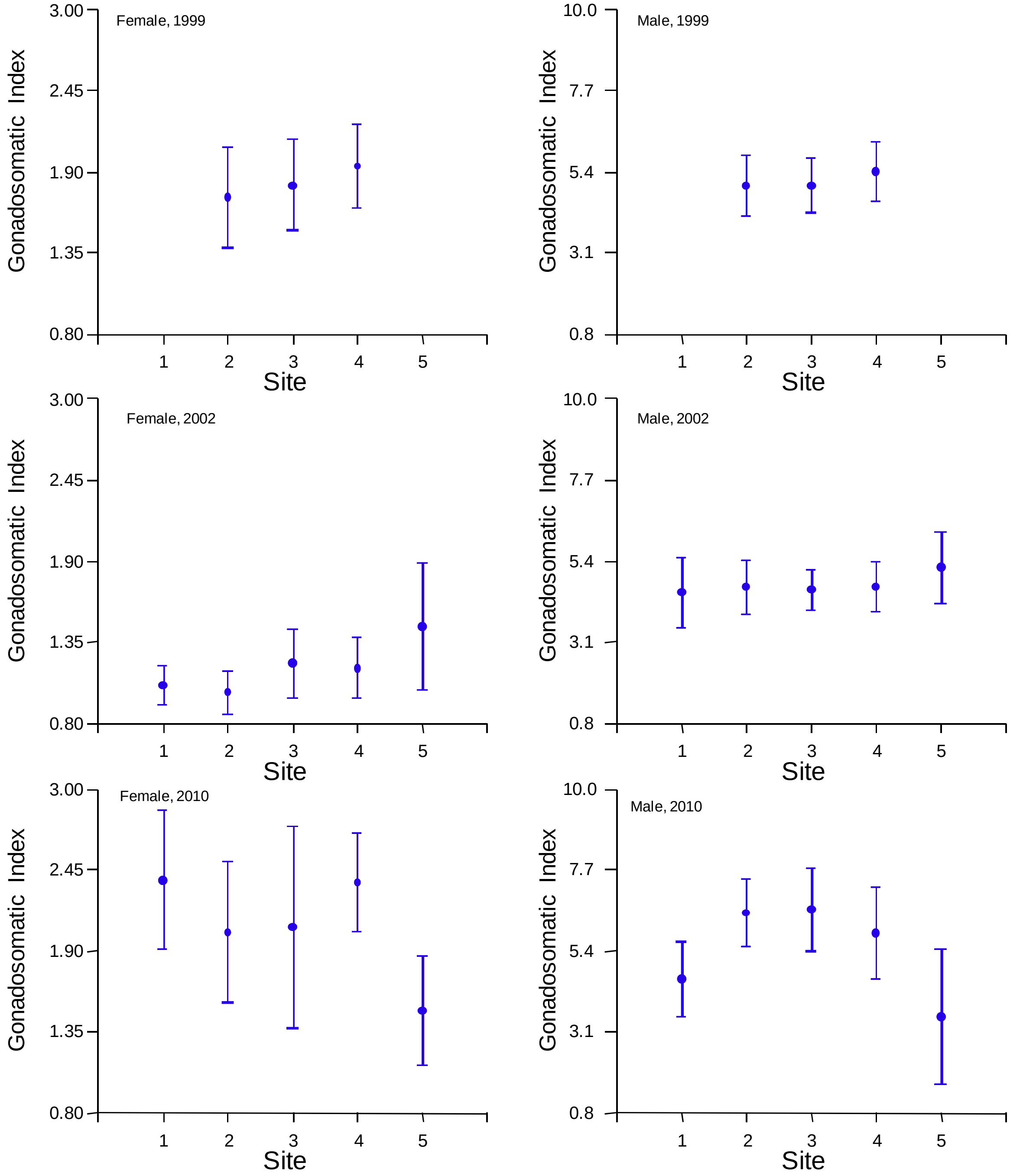
Sex	Comparison	P-value *Baseline* vs. *Test* (2010)	P-value Difference Between 2002 and 2010	P-value Change Over Time	Percent Difference		
					1999	2002	2010
Female	Site 1 vs. Site 2	**0.016**	**0.000**	**0.000**	-	11.9	**39.6**
	Site 2 vs. Avg. *test* sites	0.199	0.166	0.300	14.5	-3.6	**-25.5**
	Site 2 vs. Site 3	0.243	0.371	0.551	22.4	4.1	-24.8
	Site 2 vs. Site 4	0.404	0.198	0.256	6.6	-15.6	-18.0
	Site 2 vs. Site 5	0.291	0.270	0.419	-	5.1	**-33.8**
Male	Site 1 vs. Site 2	0.316	0.000		-	**-103.2**	**-44.6**
	Site 2 vs. Avg. *test* sites	**0.010**	0.056	0.233	-11.3	-11.7	**55.5**
	Site 2 vs. Site 3	**0.007***	0.111	0.130	4.2	15.8	**50.1**
	Site 2 vs. Site 4	0.252	0.289	0.847	-25.0	-14.5	**54.7**
	Site 2 vs. Site 5	**0.038***	0.080	0.138	-	-10.8	**61.6**

Note: p-values provided tests for variations in least square means between sites (i.e., test of intercepts)

* p-values for comparisons between Site 2 vs. 3 and Site 2 vs. 5 for male trout-perch in 2010 refer to the test of slopes (i.e., the test of intercepts was not conducted due to unequal slopes)

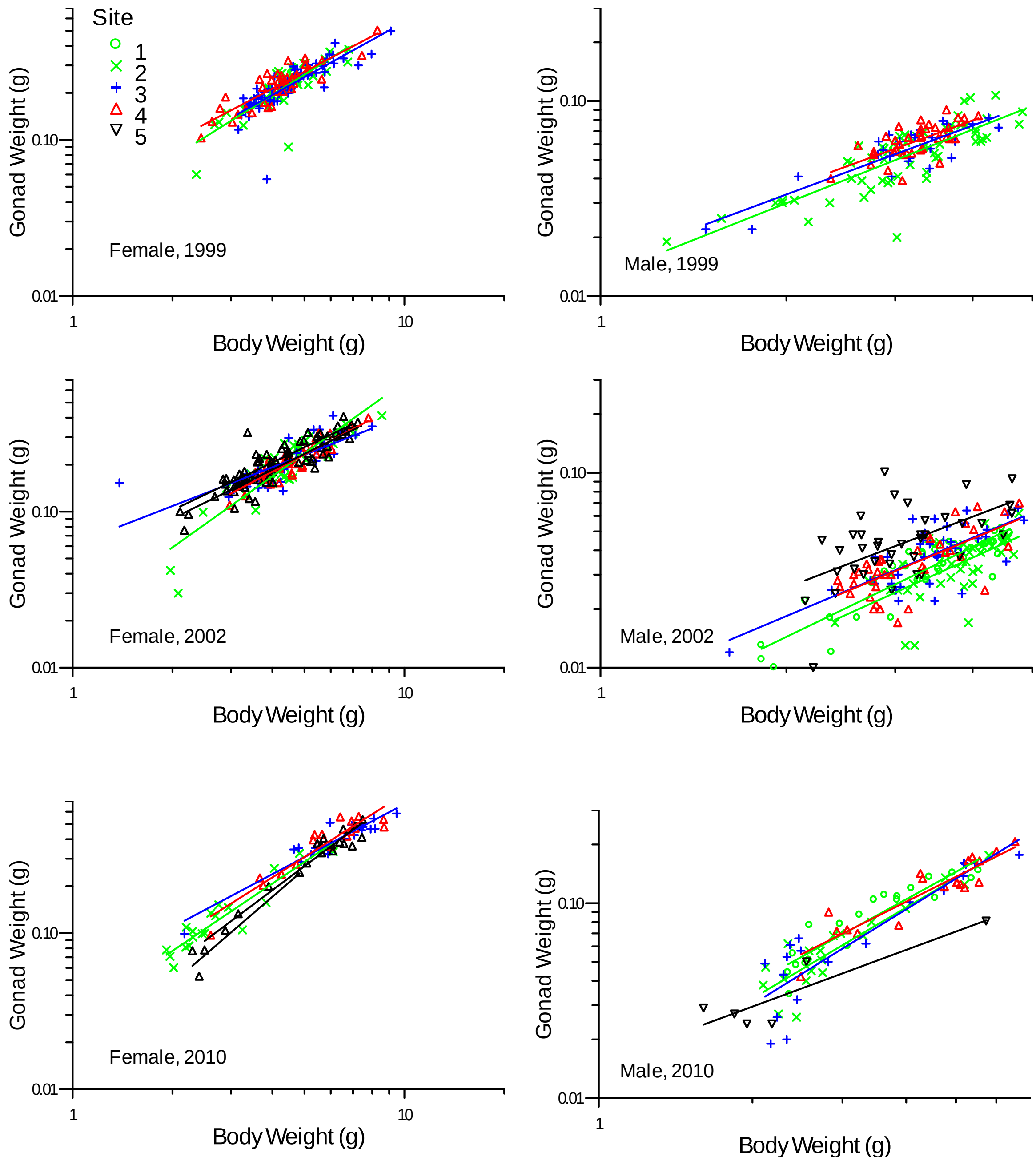
Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-47 Mean gonadosomatic index (GSI ±1SE) of female and male trout-perch in *baseline* sites 1 and 2 and *test* sites 3, 4, and 5 in the Athabasca River, 1999, 2002, and 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-48 Relationship between body weight (g) and gonad weight (g) of male and female trout-perch in *baseline* and *test* sites in the Athabasca River, 1999, 2002, 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

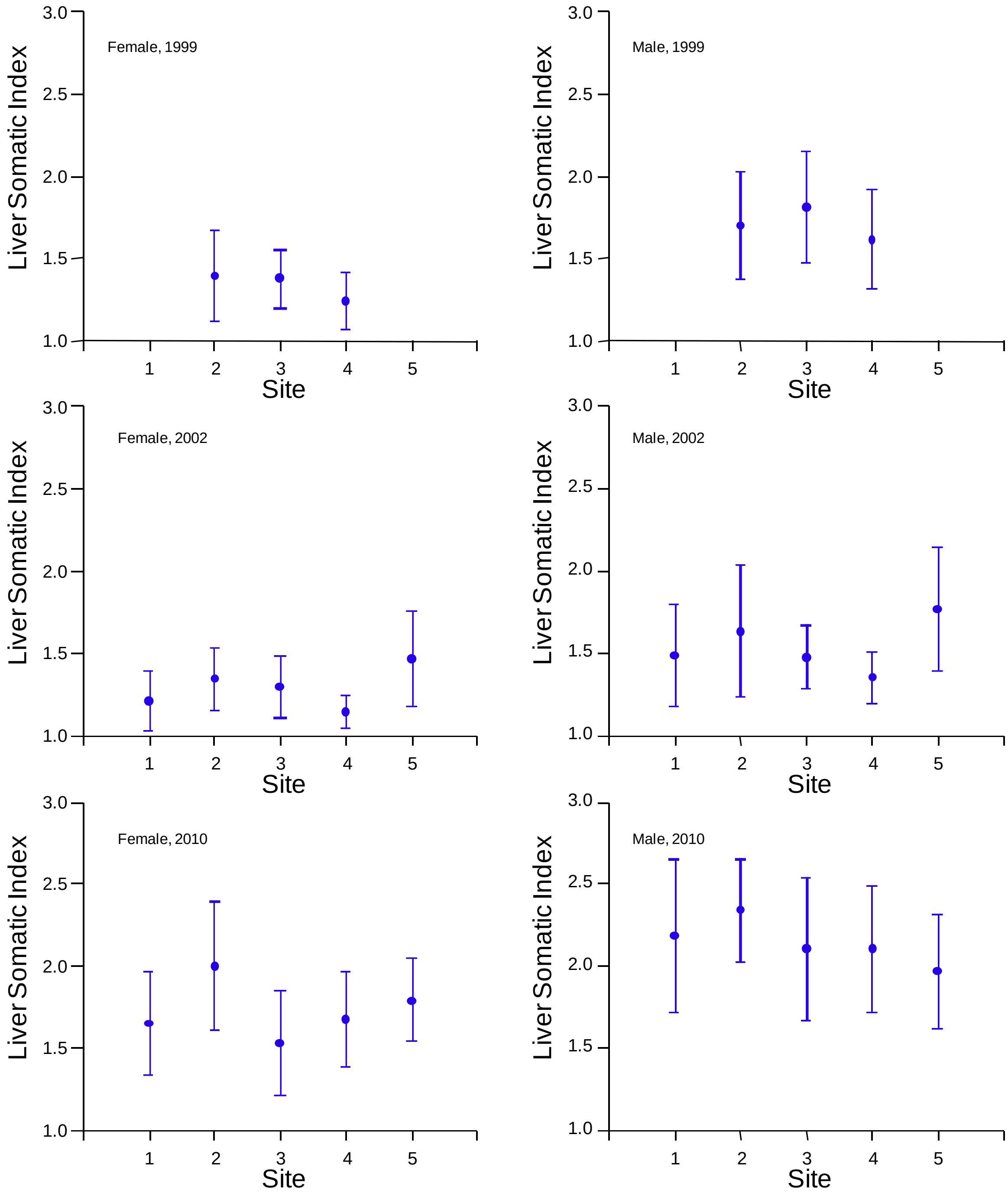
Table 5.1-26 Summary of ANCOVA and effects criterion for the relationship between body weight and gonad weight of trout-perch from *test* sites 3, 4, and 5 compared to *baseline* site 2 in the Athabasca River, 1999, 2002, 2010.

Sex	Comparison	P-value *Baseline* vs. *Test* (2010)	P-value Difference Between 2002 and 2010	P-value Change Over Time	Percent Difference		
					1999	2002	2010
Female	Site 1 vs. Site 2	**0.005**	0.120	**0.001**	-	-7.1	-21.1
	Site 2 vs. Avg. *test* sites	**0.002**	**0.003**	**0.020**	3.6	2.5	-15.1
	Site 2 vs. Site 3	0.799	0.494	0.787	-1.1	-3.4	1.5
	Site 2 vs. Site 4	0.182	0.246	0.310	8.3	0.5	-7.7
	Site 2 vs. Site 5	**<0.001**	**0.000**	**0.002**	-	10.4	**-39.0**
Male	Site 1 vs. Site 2	0.108	0.764	**0.017**	-	10.0	12.7
	Site 2 vs. Avg. *test* sites	0.507	**0.000**	**0.001**	10.4	**42.4**	-3.9
	Site 2 vs. Site 3	0.772	**0.006**	**0.023**	7.0	**29.3**	-2.4
	Site 2 vs. Site 4	0.228	0.169	**0.001**	13.7	**28.9**	11.2
	Site 2 vs. Site 5	0.062	**0.000**	**0.033**	-	**69.0**	-20.6

Note: p-values tests for variations in least square means between sites.

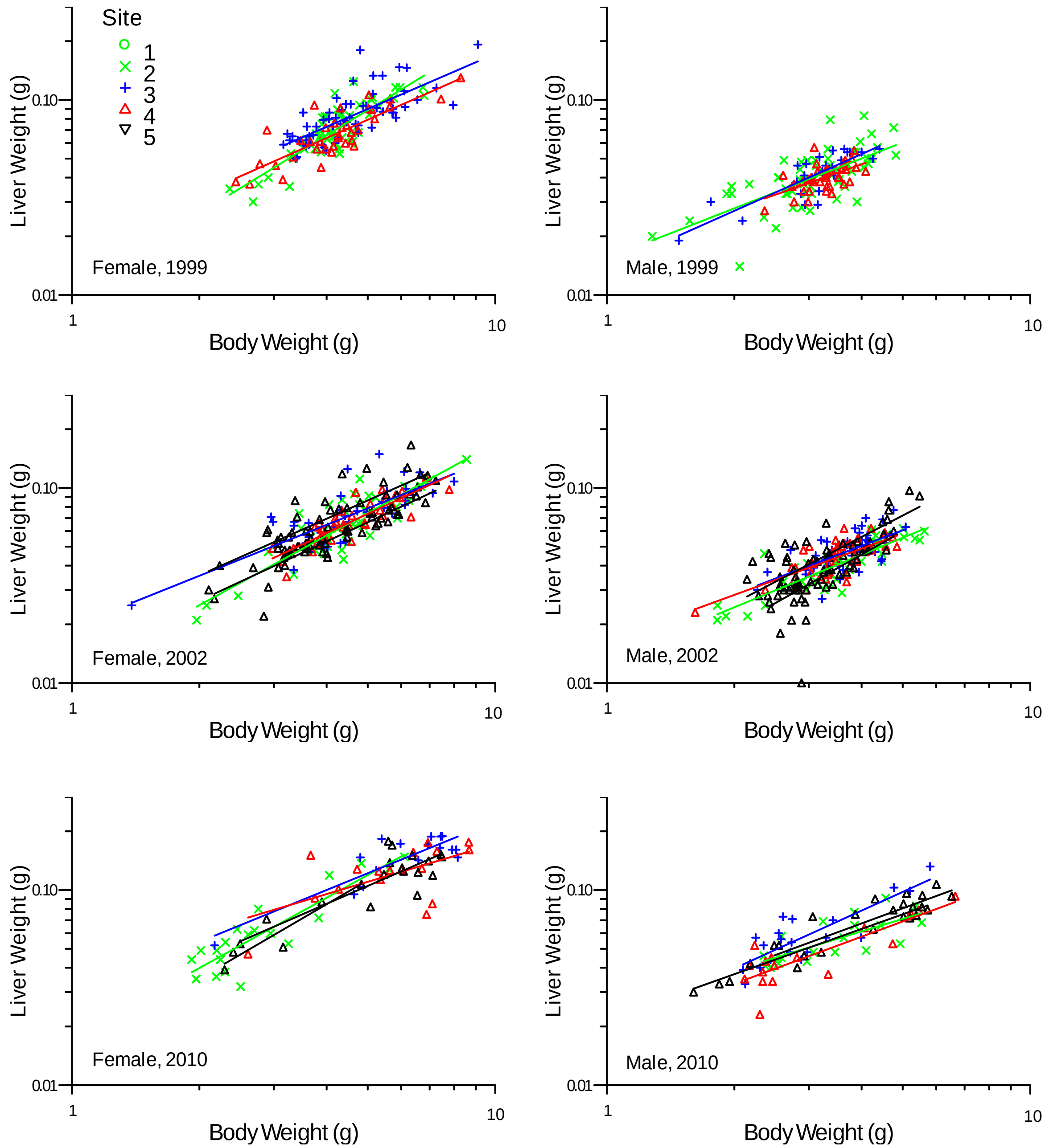
Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-49 Mean liver somatic index (LSI ±1SE) of female and male trout-perch in *baseline* sites 1 and 2 and *test* sites 3, 4, and 5 in the Athabasca River, 1999, 2002, and 2010.



Note: Site 1 and Site 5 were not sampled in 1999

Figure 5.1-50 Relationship between body weight (g) and liver weight (g) of male and female trout-perch in *baseline* and *test* sites in the Athabasca River, 1999, 2002, 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

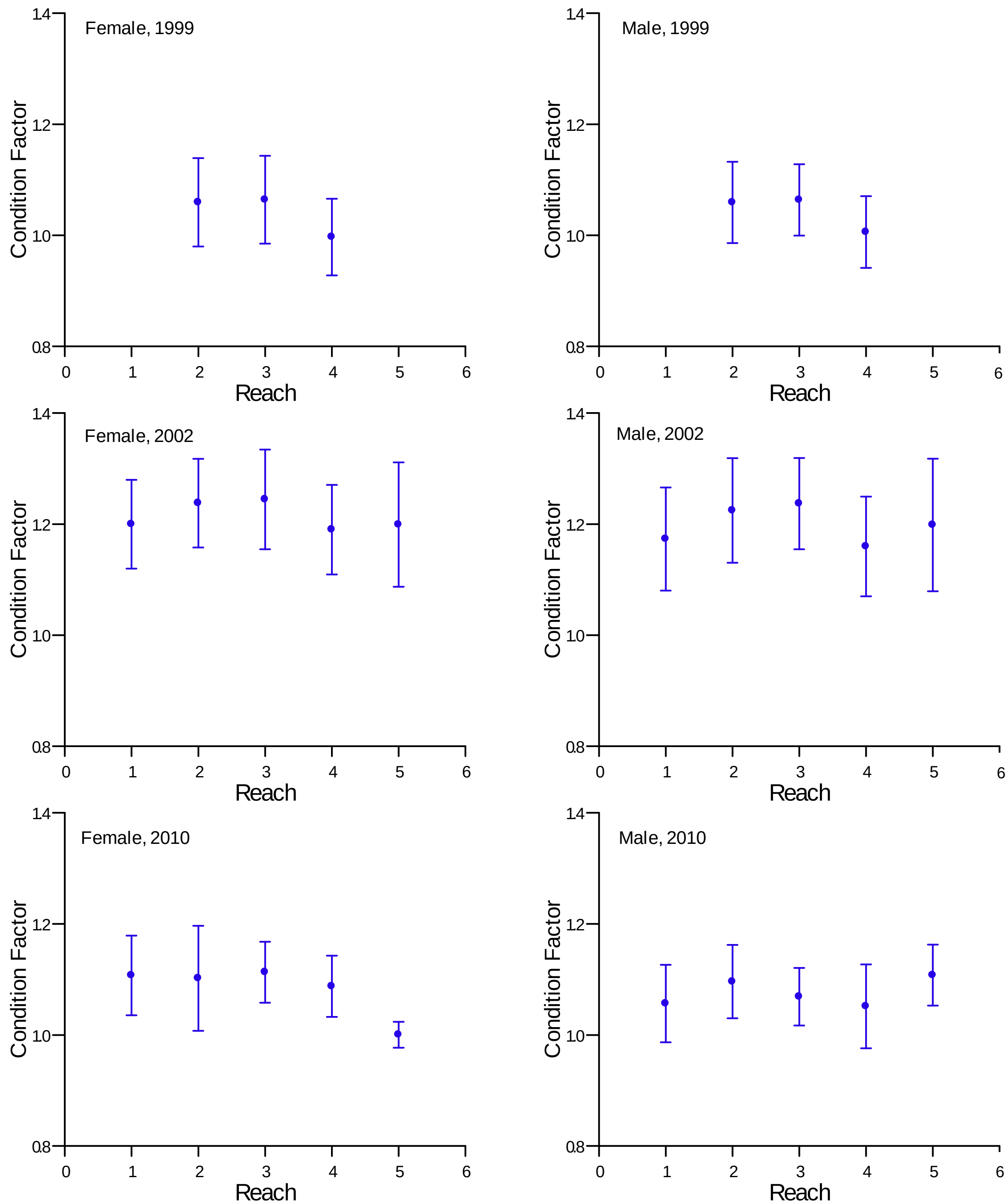
Table 5.1-27 Summary of ANCOVA and effects criterion for the relationship between body weight and liver weight of male and female trout-perch from *test* sites 3, 4, and 5 compared to *baseline* site 2 in the Athabasca River, 1999, 2002, 2010.

Sex	Comparison	P-value *Baseline* vs. *Test* (2010)	P-value Difference Between 2002 and 2010	P-value Change Over Time	Percent Difference		
					1999	2002	2010
Female	Site 1 vs. Site 2	**0.021**	0.079	**0.002**	-	-10.3	-17.4
	Site 2 vs. Avg. *test* sites	**0.002**	0.055	**0.000**	2.3	-5.2	-17.8
	Site 2 vs. Site 3	**0.006**	0.252	**0.001**	7.9	-8.0	-15.6
	Site 2 vs. Site 4	**0.005**	0.914	**0.000**	-3.4	-16.6	-15.9
	Site 2 vs. Site 5	**0.005**	**0.012**	0.219		8.9	-22.0
Male	Site 1 vs. Site 2	**0.004**	0.368	**0.000**	-	-11.9	-19.5
	Site 2 vs. Avg. *test* sites	**0.002**	0.070	**0.000**	-1.5	-4.9	-15.6
	Site 2 vs. Site 3	**<0.001**	**0.000**	**0.000**	2.1	-2.2	-22.8
	Site 2 vs. Site 4	**0.040**	0.480	**0.000**	-5.1	-16.9	-12.3
	Site 2 vs. Site 5	0.162	0.080	0.410	-	4.5	-11.8

Note: p-values tests for variations in least square means between sites.

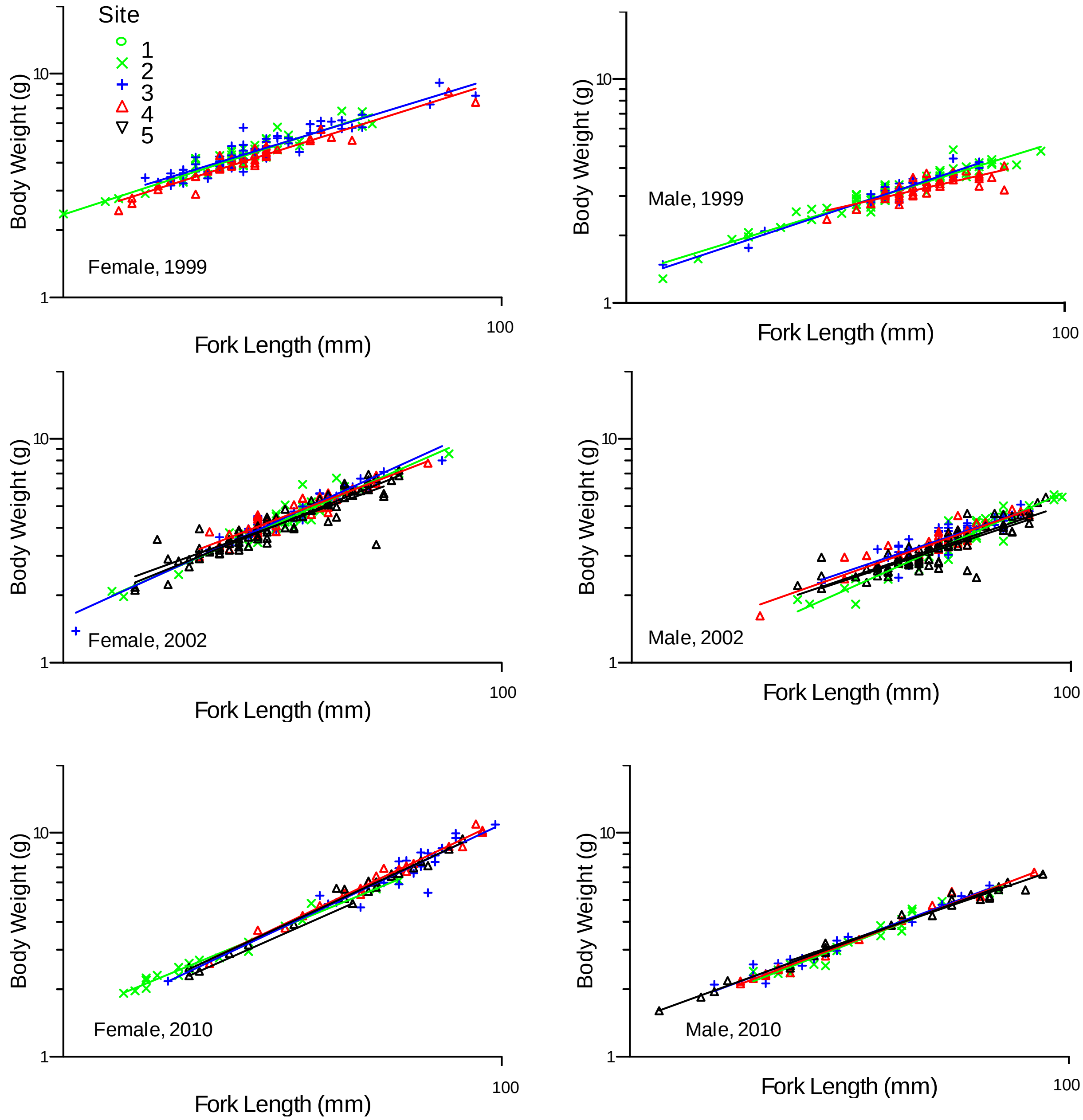
Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-51 Mean condition factor ±1SE of female and male trout-perch in *baseline* sites 1 and 2 and *test* sites 3, 4, and 5 in the Athabasca River, 1999, 2002, and 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

Figure 5.1-52 Relationship between body weight (g) and fork length (mm) of male and female trout-perch in *baseline* and *test* sites in the Athabasca River, 1999, 2002, 2010.



Note: Site 1 and Site 5 were not sampled in 1999.

Table 5.1-28 Summary of ANCOVA and effects criterion for condition of male and female trout-perch from *test* sites 3, 4, and 5 compared to *baseline* site 2 in the Athabasca River, 1999, 2002, 2010.

Sex	Comparison	P-value *Baseline* vs. *Test* (2010)	P-value Difference Between 2002 and 2010	P-value Change Over Time	Percent Difference 1999	2002	2010
Female	Site 1 vs. Site 2	0.171	0.574	0.079		-2.3	-4.5
	Site 2 vs. Avg. *test* sites	0.179	0.059	0.666	-2.1	-2.4	-3.6
	Site 2 vs. Site 3	0.478	0.305	0.813	1.4	1.4	2.2
	Site 2 vs. Site 4	0.825	0.180	0.321	-5.5	-4.0	-0.6
	Site 2 vs. Site 5	**0.023**	**0.004**	0.160		-4.5	**-12.4**
Male	Site 1 vs. Site 2	0.646	0.115	0.020		-7.0	-1.3
	Site 2 vs. Avg. *test* sites	0.891	0.078	0.129	-2.5	-4.8	-0.3
	Site 2 vs. Site 3	0.743	0.691	0.883	0.5	-0.4	-0.9
	Site 2 vs. Site 4	0.524	0.067	**0.005**	-5.4	-8.1	1.9
	Site 2 vs. Site 5	0.632	0.089	0.398		-5.8	-2.0

Note: p-values tests for variations in least square means between sites.

Note: Site 1 and Site 5 were not sampled in 1999.

Table 5.1-29 Summary of response patterns in trout-perch at *test* sites compared to *baseline* Site 2 in the Athabasca River, 2010.

Sex	Site	Age	Energy Use		Energy Storage		Significant Difference from *Baseline*			Response Pattern Based on Effects Criteria[1]		
			Weight-at-age	GSI	LSI	K	Age	Energy Use	Energy Storage	Age	Energy Use	Energy Storage
Female	3	11.7	**-25**	1.5	-16	2	0	0	-	0	0	0
	4	-2.5	-18	-8	-16	1	0	0	-	0	0	0
	5	**-37.6**	**-34**	**-39**	-22	**-12**	-	-	-	-	-	-
Male	3	4.3	**50**	-2.4	-23	-1	0	+	-	0	+	0
	4	13.4	**55**	11	-12	2	0	0	-	0	0	0
	5	-22.8	**62**	-21	-12	-2	0	+	0	0	+	0

[1] + denotes a significant increase in the measurement endpoint compared to results at *baseline* Site 2; - denotes a significant decrease in the measurement endpoint compared to results at *baseline* Site 2; 0 denotes no difference from results at *baseline* Site 2.

5.2 MUSKEG RIVER WATERSHED

Table 5.2-1 Summary of results for the Muskeg River watershed.

Muskeg River Watershed	Summary of 2010 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	**WAC-1** Wapasu Creek at Canterra Road	**IYC-1** Iyinimin Creek	**KEL-1** Kearl Lake	no station sampled
Water Quality Index	🟡		🟡	🟡	🟡	🟡	🟡	🟡	n/a	
Benthic Invertebrate Communities and Sediment Quality										
Criteria	**MUR-E1** lower reach	**MUR-D2** middle reach	**MUR-D3** upper reach	**JAC-D1** lower reach	**JAC-D2** 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	🟡	🟡	🟡	🟡				n/a	
Fish Populations										
Fish Populations component activities are included in the Fish Assemblage Monitoring Pilot Study (Section 6.0)										

Legend and Notes

🟡 Negligible-Low — *baseline* (green shading)
🟠 Moderate — *test* (blue shading)
🟤 High

n/a - not applicable, summary indicators for *test* reaches/stations were designated based on comparisons with *baseline* reaches/station. The WQI/SQI was not calculated given the limited existing *baseline* data.

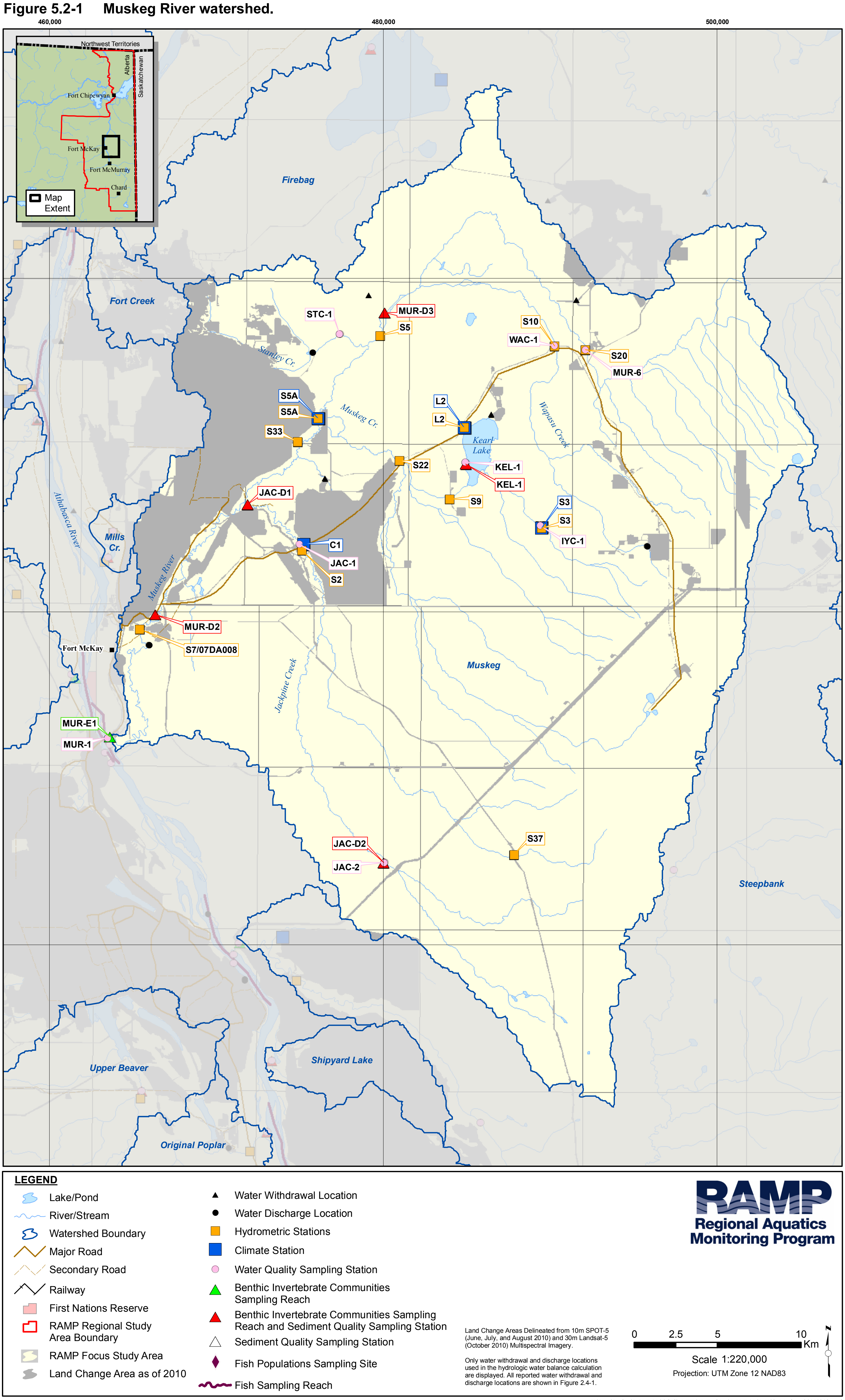
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology.

Figure 5.2-1 Muskeg River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K02_Muskeg_20110318.mxd

Figure 5.2-2 Representative monitoring stations of the Muskeg River watershed, 2010.

Water Quality Station MUR-1 (Muskeg River): Left Downstream Bank

Water Quality Station IYC-1 (Iyinimin Creek): Centre of Channel, facing downstream

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): Left Downstream Bank

Water Quality Station STC-1 (Stanley 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 2010 Conditions

As of 2010, approximately 12% (17,200 ha) of the Muskeg River watershed had undergone land change from focal projects (Table 2.5-2). The designations of specific areas of the watershed are as follows:

1. 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 Muskeg River Mine and Shell Jackpine Mine leases are designated as *test*.

2. The remainder of the watershed, including Iyinimin Creek and the upper portion of Jackpine Creek, 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 Muskeg River watershed in 2010. The Fish Populations component did not conduct regular monitoring activities in the Muskeg River watershed in 2010. However, the pilot study of fish assemblage monitoring in 2010 included a reach on the lower Muskeg River; Section 6 contains the results of this study. Table 5.2-1 is a summary of the 2010 assessment of the Muskeg River watershed, and Figure 5.2-1 denotes the location of the monitoring stations for each RAMP component, reported focal project water withdrawal and discharge locations, and the area of land change for 2010 in the Muskeg River watershed. Figure 5.2-2 contains fall 2010 photos of the water quality monitoring stations in the watershed.

Hydrology The calculated mean open-water discharge and the annual maximum daily flow at WSC Station 07DA008 (RAMP Station S7) are 1.7% and 3.0% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph for the station, respectively (Table 5.2-3). These differences are classified as **Negligible-Low**. The calculated mean winter discharge and the open-water period minimum daily discharge are 52.1% and 64.1% higher in the observed *test* hydrograph at WSC Station 07DA008 (RAMP Station S7) than in the estimated *baseline* hydrograph, respectively. These differences are classified as **High**.

Water Quality While concentrations of a number of water quality measurement endpoints in the Muskeg River watershed in fall 2010 were outside the range of previously-measured minimum and maximum concentrations, including total mercury, total nitrogen and total aluminum, water quality at most stations in the Muskeg River watershed were generally consistent with regional *baseline* conditions, and differences in water quality in fall 2010 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions are **Negligible-Low**.

Benthic Invertebrate Communities and Sediment Quality Differences in the benthic invertebrate community at *test* reach MUR-E1 as of fall 2010 are classified as **Negligible-Low** because there were no significant differences over time in the values of all measurement endpoints in fall 2010 and all measurement endpoints were within the range of regional *baseline* erosional reaches. There was however, a significant trend in CA Axis 1 scores over time reflecting a modest increase in percent of the fauna as tubificid worms and decrease in the percent of the fauna as chironomids, mayflies, stoneflies and caddisflies.

Differences in the benthic invertebrate community at *test* reach MUR-D2 as of fall 2010 are classified as **Negligible-Low** because, although there was a significant decrease in total abundance over time, the statistical signal explained less than 20% of the variation in annual means. In addition, all measurement endpoints for benthic invertebrate communities were within the range of regional *baseline* depositional reaches with the exception of taxa richness, which exceeded the range of regional *baseline* conditions, implying an improvement in the benthic invertebrate community at *test* reach MUR-D2.

Differences in the benthic invertebrate community at *test* reach MUR-D3 as of fall 2010 are classified as **Moderate** because taxa richness was significantly lower in the period when reach MUR-D3 was *test* compared to the *baseline* period. There was also a significant decrease in CA Axis 1 scores over time in the *test* period, reflecting a shift to higher relative abundance of chironomids and bivalves at *test* reach MUR-D3 over time.

Differences in the benthic invertebrate community at *test* reach JAC-D1 as of fall 2010 are classified as **Negligible-Low** because the significant increases over time in taxa richness, diversity, evenness and percent EPT at reach JAC-D1 once the reach became *test* do not imply a negative change in the benthic invertebrate community, and values of all measurement endpoints in fall 2010 for benthic invertebrate communities at both *test* reach JAC-D1 and *baseline* reach JAC-D2 were within the range of regional *baseline* conditions.

Differences in the benthic invertebrate community at *test* station KEL-1 in Kearl Lake as of fall 2010 from *baseline* benthic invertebrate communities are classified as **Moderate** because of a significant decrease in the percent EPT in the period that *test* station KEL-1 has been designated as *test* explaining more than 20% of the variation in annual means.

Sediment quality at all Muskeg River watershed stations sampled in fall 2010 was generally consistent with that of previous years and regional *baseline* conditions with the exception of predicted PAH toxicity, which was higher than historical values at several stations, particularly *test* station MUR-D2. Concentrations of total PAH at these stations were within previously-measured concentrations. Differences in sediment quality in fall 2010 at all five stations in the Muskeg River watershed were assessed as **Negligible-Low** compared to regional *baseline* conditions.

5.2.2 Hydrologic Conditions: 2010 Water Year

Muskeg River

WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay Continuous annual hydrometric data have been collected for the WSC Station 07DA008 (RAMP Station S7) from 1974 to 1986 and from 1999 to 2010. Seasonal data from March to October has been collected every year since 1974. The 2010 water year (WY) open-water runoff volume of 71.2 million m^3 was 32% lower than the historical mean open-water runoff volume of 104.6 million m^3. Flows decreased during river freeze-up in November 2009 and values from November 26 to December 7, 2009 were below historical minimum values (Figure 5.2-3). Winter flows remained similar to historical median values until March 2010 and increased during the spring freshet to a peak of 13 m^3/s on April 29. This peak flow was the maximum daily flow recorded in the 2010 WY and was 43% lower than the historical mean annual maximum daily flow of 23 m^3/s. After the freshet, flows decreased until late August; flows were below the historical minimum values recorded on July 26 and 27. Precipitation in late August and September resulted in flows exceeding the historical median level, with flow reaching 11.9 m^3/s on September 17 and 18. Following this peak, flows then decreased to the end of the 2010 WY. The minimum daily flow during the open-water period (May to October) on August 25 of 0.55 m^3/s was 50% lower than the historical mean minimum daily flow.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DA008 for the 2010 WY is presented in Table 5.2-2 and described below:

1. The closed-circuited land area from focal projects in the Muskeg River watershed as of 2010 is estimated to be 120.7 km^2 (Table 2.5-1). The loss of flow to the Muskeg River that would have otherwise occurred from this land area is estimated at approximately 7.58 million m^3.
2. As of 2010, the area of land change in the Muskeg River watershed from focal projects that was not closed-circuited is estimated to be 51.5 km^2 (Table 2.5-1). The increase in flow to the Muskeg River that would not have otherwise occurred from this land area is estimated at 0.65 million m^3.
3. Syncrude discharged 9.3 million m^3 of water into Stanley Creek via the Aurora Clean Water Diversion (CWD). As in previous water balance calculations involving the CWD (RAMP 2009a, RAMP 2010), 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. 0.18 million m^3 of water was released by Hammerstone from its quarry operations.
5. 0.37 million m^3 of water was released by Husky from its Sunshine project treatment plant and well-pads.
6. Imperial withdrew 0.53 million m^3 of water from two site ponds from for use in construction/compaction activities, dust suppression, and ice road construction associated with the Kearl project.
7. The Shell Jackpine Mine withdrew 0.12 million m^3 of water to support drilling and dust suppression activities.

The estimated cumulative effect of land change, water withdrawals, and water releases is an increase in flow of 2.28 million m^3 to the Muskeg River. The observed and estimated *baseline* hydrographs for WSC Station 07DA008 (RAMP Station S7) are presented in Figure 5.2-3. The calculated mean open-water discharge and the annual maximum daily flow are 1.7% and 3.0% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph, respectively (Table 5.2-3). These differences are classified as **Negligible-Low** (Table 5.2-1). The calculated mean winter discharge and the open-water period minimum daily discharge are 52.1% and 64.1% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph, respectively (Table 5.2-3). These differences are classified as **High** (Table 5.2-1).

Kearl Lake

Station L2, Kearl Lake Continuous lake level data have been collected at Station L2 since 1999, with partial records for 1999 to 2001 and 2008. Within the 2010 WY, lake levels decreased from November 2009 to March 2010 with values similar to the historical median values recorded during this period (Figure 5.2-4). Lake levels increased during the spring freshet followed by a decrease to near historical lower quartile values for most of June, July and August. The minimum lake level in the 2010 WY was 331.79 m on August 24, while the maximum lake level in the 2010 WY of 331.98 m on September 28 occurred as a result of heavy rainfall in late August and early September. Lake levels decreased during October to near historical median levels for this month.

5.2.3 Water Quality

In fall 2010, water quality samples were taken from:

- the Muskeg River near its mouth (*test* station MUR-1, sampled from 1997 to 2010);
- the Muskeg River upstream of Wapasu Creek (*test* station MUR-6, designated as *baseline* from 1998 to 2007 and *test* from 2008 to 2010);
- Jackpine Creek near its mouth (*test* station JAC-1, designated as *baseline* from 1998 to 2005 and *test* from 2006 to 2010);
- upper Jackpine Creek (*baseline* station JAC-2, sampled from 2008 to 2010);
- Stanley Creek near its mouth (*test* station STC-1, designated as *baseline* from 2001 to 2002 and *test* from 2003 to 2010);
- Wapasu Creek near its mouth (*test* station WAC-1, sampled intermittently from 1998 to 2010, designated as *baseline* from 1998 to 2006 and *test* from 2007 to 2010);
- Kearl Lake (*test* station KEL-1, designated as *baseline* from 1998 to 2008 and *test* from 2009 to 2010); and
- Iyinimin Creek near its mouth (*baseline* station IYC-1, sampled in 2007, 2008, and 2010).

Temporal Trends The following statistically significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- A decreasing concentration of sulphate at *test* station MUR-6 (1998 to 2010) and *test* station JAC-1 (1999 to 2010);
- An increasing concentration of total nitrogen and decreasing concentrations of total strontium, magnesium, sulphate, and calcium at *test* station WAC-1 (1998, 1999, 2004 to 2010);
- Decreasing concentrations of total dissolved phosphorus, potassium, and total arsenic at *test* station KEL-1 (1998, 2000 to 2010), although the trend in total arsenic is likely related to an improvement in the analytical detection limit over the sampling period; and
- A decreasing concentration of total arsenic at *test* station STC-1 (1999, 2001 to 2010), although the trend in total arsenic is likely related to an improvement in the analytical detection limit over the sampling period.

No trends were detected at *test* station MUR-1, and trend analyses could not be completed for *baseline* stations JAC-2 or IYC-1 due to an insufficient number of sampling years.

2010 Results Relative to Historical Concentrations Concentrations of water quality measurement endpoints were within historical ranges in fall 2010 with the exception of (Table 5.2-4 to Table 5.2-11):

- total mercury, with a concentration that exceeded its previously-measured maximum concentrations at *test* station MUR-1 (Figure 5.2-7);

- total nitrogen and total Kjeldahl nitrogen, with concentrations that exceeded their previously-measured maximum concentrations at *test* station MUR-6 (Figure 5.2-7);
- total aluminum, with a concentration that exceeded its previously-measured maximum concentration and total suspended solids, with a concentration that was equal to its previously-measured maximum concentration at *test* station JAC-1 (Figure 5.2-8);
- concentrations of all water quality measurement endpoints represented minimum or maximum concentrations at *baseline* station JAC-2 with the exception of sulphate and total dissolved solids (Figure 5.2-8);
- total phenols, with a concentration that exceeded its previously-measured maximum concentration and conductivity, calcium, total alkalinity, and total strontium, with concentrations that were below their previously-measured minimum concentrations at *test* station WAC-1(Figure 5.2-8);
- concentrations of all water quality measurement endpoints represented historical minimum or maximum concentrations at *baseline* station IYC-1 with the exception of total dissolved solids, dissolved aluminum, total molybdenum, total chromium, and total iron (Figure 5.2-8); and
- total nitrogen and total Kjeldahl nitrogen, with concentrations that exceeded their previously-measured maximum concentrations, and sulphate and total aluminum, with concentrations that were below previously-measured minimum concentrations at *test* station KEL-1 (Figure 5.2-9).

In previous sampling years, the concentration of total mercury was below analytical detection limits at most stations. In summer 2010, the analytical detection limit for total mercury was reduced resulting in concentrations of total mercury in fall 2010 that were lower than previously-measured minimum concentrations at *test* stations MUR-6, JAC-1, STC-1, WAC-1, and KEL-1 and *baseline* station JAC-2 (Table 5.2-5, Table 5.2-6, Table 5.2-7, Table 5.2-8, Table 5.2-9, and Table 5.2-11).

Ion Balance The ionic composition of water in the Muskeg River watershed in fall 2010 was similar to that measured in previous years (Figure 5.2-5). The ionic composition of water in Stanley Creek (*test* station STC-1) has historically had the greatest variability, indicating influence of site-drainage waters from Syncrude Aurora North’s CWD. However, for the last three years the ionic balance at *test* station STC-1 has been consistently dominated by calcium and bicarbonate with low concentrations of sulphate and chloride. The ionic composition of water in Kearl Lake (*test* station KEL-1) was consistent with that of previous years of sampling with anions dominated by calcium bicarbonate and low concentrations of sodium and potassium chloride (Figure 5.2-5).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines In fall 2010, concentrations of water quality measurement endpoints at stations in the Muskeg River watershed were below water quality guidelines with the exception of:

- total nitrogen at all stations with the exception of *test* station STC-1 (Table 5.2-8); and
- total aluminum at *test* stations MUR-1 and JAC-1, and *baseline* stations JAC-2 and IYC-1 (Table 5.2-4, Table 5.2-6, Table 5.2-7, and Table 5.2-10).

Other Water Quality Guideline Exceedances The following other water quality measurement endpoints exceeded water quality guidelines in the Muskeg River watershed in fall 2010 (Table 5.2-12):

- total phenols at all stations;
- sulphide and total Kjeldahl nitrogen at all stations with the exception of *test* station STC-1;
- total iron at *test* stations JAC-1 and MUR-1 and *baseline* stations JAC-2 and IYC-1;
- dissolved iron at *test* station MUR-1; and
- total chromium at *baseline* station IYC-1.

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2010 at *test* stations MUR-1, MUR-6, JAC-1, STC-1, and WAC-1, and *baseline* stations JAC-2 and IYC-1 were within regional *baseline* concentrations with the exception of (Figure 5.2-7 and Figure 5.2-8):

- total mercury, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *test* station MUR-1;
- total nitrogen and total mercury, with concentrations that exceeded the 95th percentile of their regional *baseline* concentrations at *baseline* station JAC-2;
- dissolved phosphorus, with a concentration that was below the 5th percentile of its regional *baseline* concentrations at *test* station WAC-1; and
- total strontium, with a concentration that was below the 5th percentile of its regional *baseline* concentrations, and total mercury, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *baseline* station IYC-1.

Due to the decrease in the analytical detection limit for total mercury, fall concentrations were below the 5th percentile of its regional *baseline* concentrations for *test* stations MUR-6, JAC-1, STC-1, and WAC-1.

Concentrations of water quality measurement endpoints in Kearl Lake were not compared to regional *baseline* concentrations because lakes were not included in the calculation of regional *baseline* conditions given the ecological differences between lakes and rivers.

Water Quality Index The WQI values for all stations in the Muskeg River watershed in fall 2010 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.2-13). Water quality index values were generally higher in fall 2010 than in the previous two years of sampling.

Classifications of Results Concentrations of several water quality measurement endpoints in the Muskeg River watershed in fall 2010 were outside the range of previously-measured minimum and maximum concentrations, including total mercury, total nitrogen and total aluminum; however, water quality at most stations in the Muskeg River watershed were generally consistent with regional *baseline* conditions. Differences in water quality in fall 2010 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions are **Negligible-Low**.

5.2.4 Benthic Invertebrate Communities and Sediment Quality

5.2.4.1 Benthic Invertebrate Communities

Muskeg River Mainstem

Benthic invertebrate community samples were sampled in fall 2010 at:

- erosional *test* reach MUR-E1, near the mouth of the Muskeg River, sampled since 2000;
- depositional *test* reach MUR-D2, near the Canterra Road crossing, sampled since 2000; and
- depositional *test* reach MUR-D3, upstream of the Shell Muskeg River and Syncrude Aurora North developments, designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2010.

2009 Habitat Conditions Water at *test* reach MUR-E1 in fall 2010 was shallow (0.3 m), fast flowing (1.9 m/s), alkaline (pH: 8.3) and had high conductivity (309 µS/cm) (Table 5.2-14). The substrate was dominated by large gravel (33%), small gravel (31%), and small cobble (29%). Periphyton biomass averaged 25.4 mg/m^2, which was within regional *baseline* conditions (Figure 5.2-10).

Water at *test* reach MUR-D2 in fall 2010 was relatively deep (2.1 m) slow-flowing (0.4 m/s), alkaline (pH: 7.8) and had moderate conductivity (220 µS/cm) (Table 5.2-15). The substrate was dominated by sand (85%) with a moderate amount of silt (12%) and low percent of organic carbon (2%).

Water at *test* reach MUR-D3 in fall 2010 was relatively deep (1.9 m), slow-flowing (0.3 m/s), alkaline (pH: 7.6) and had moderate conductivity of 253 µS/cm, and low dissolved oxygen concentrations (6.2 mg/L) (Table 5.2-16). The substrate was dominated by sand (90%) with small amounts of silt and clay and moderate level of organic carbon (12%).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach MUR-E1 in fall 2010 was dominated by tubificid worms (26%), chironomids (15%), and ostracods (15%) with subdominant taxa consisting of Ephemeroptera (10%) and Hydracarina (10%) (Table 5.2-17). Chironomids were diverse, consisting of many common forms including *Ablabesmyia*, *Thienemannimyia gr*., *Polypedilum*, *Stempellina* and *Corynoneura*. Species of mayfly included the common forms such as *Baetis*, *Acerpenna*, and *Caenis,* as well as taxa that require good water quality such as *Heptagenia*. Caddisflies (Trichoptera; *Lepidostoma* and *Hydropsyche*) and stoneflies (Plecoptera; *Isoperla* and *Skwala*) were present in low relative abundance.

The benthic invertebrate community of *test* reach MUR-D2 in fall 2010 was dominated by chironomids (53%) and tubificid worms (11%) with subdominant taxa consisting of Ceratopogonids (5%) (Table 5.2-18). Chironomids were diverse including *Larsia*, *Micropsectra*, *Stempillina, Stempellinella* and *Procladius.* Speices of mayfly (Ephemeroptera) included *Caenis*, *Baetis, and Ephemeralle*; caddisfly (Trichoptera; *Triaenodes* and *Lepidostoma*) were present in lower relative abundance (Table 5.2-18).

The benthic invertebrate community of *test* reach MUR-D3 was dominated by chironomids (70%) with subdominant taxa consisting of fingernail clams (10%), ostracods (7%), and tubificid worms (7%) (Table 5.2-19). Dominant chironomids included the common forms *Micropsectra, Polypedilum, Paratendipes,* and *Tribelos*. Mayflies (Ephemeroptera; *Leptophlebia*) and caddisflies (Trichoptera; *Nemotaulius*) were present in low relative abundance.

Temporal Comparisons Changes in time trends of the values of measurement endpoints for benthic invertebrate communities were tested for *test* reach MUR-E1 (Hypothesis 1, Section 3.2.3.1; spatial comparisons were not conducted because there is no upstream *baseline* erosional reach in the Muskeg River). There were no significant differences in the values of measurement endpoints for benthic invertebrate communities over time with the exception of CA Axis 1 scores, which increased over time (Table 5.2-20). The time trend for CA Axis 1 scores explained only 5% of the variation in the annual means for *test* reach MUR-E1 (Table 5.2-20). Variations in CA Axis 1 scores have been observed in *test* reach MUR-E1 over time (Figure 5.2-11) with scores in 2010 near the 95th percentile of regional *baseline* erosional reaches, reflecting higher relative abundance of tubificid worms and lower relative abundance of chironomids, mayflies, stoneflies and caddisflies compared to previous years (Table 5.2-17).

Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* reach MUR-D2 (Hypothesis 1, Section 3.2.3.1; spatial comparisons were not conducted because the upstream reach MUR-D3 of the Muskeg River is also designated as *test*). There was a significant decrease in abundance and CA Axis 1 scores over time (Table 5.2-21), however, these time trends explained less than 20% of the variation in annual means for both measurement endpoints (Table 5.2-21).

Two temporal comparisons were conducted for *test* reach MUR-D3 (spatial comparisons were not conducted because there is no *baseline* reach on the Muskeg River).

First, changes in mean values of measurement endpoints for benthic invertebrate communities were tested at *test* reach MUR-D3 between the years before and after the reach were designated as *test* (Hypothesis 2, Section 3.2.3.1). There was a significant decrease in taxa richness in the *test* period compared to the *baseline* period and the variation in the annual means was greater than 20% (Table 5.2-22).

Second, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that *test* reach MUR-D3 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). There was a significant decrease in CA Axis 1 scores over time in the *test* period explaining more than 20% of the variation in annual mean CA 1 Axis scores (Table 5.2-22). This reflects a shift to higher relative abundances of chironomids and bivalves over time (Table 5.2-19).

Comparison to Published Literature The benthic invertebrate community of *test* reach MUR-E1 in fall 2010 was comprised of less than 30% tubificid worms and contained a variety of other groups such as sphaeriid fingernail clams, mayflies, caddisflies and stoneflies that require good water and sediment quality (Hynes 1960, Griffiths 1998).

The benthic invertebrate community of *test* reach MUR-D2 was diverse with an average of more than 25 taxa per sample. In addition to mayflies and caddisflies, the reach contained amphipods, and sphaeriid fingernail clams. The percent of the fauna as tubificid worms was less than 30% and the percent of fauna as chironomids was moderate (approximately 50%) reflecting good water and sediment quality (Hynes 1960, Griffiths 1998).

While the benthic invertebrate community at *test* reach MUR-D3 in fall 2010 was comprised of less than 10% as tubificid worms, the percent as chironomids was approximately 70% (Table 5.2-19) which could indicate some disturbance (Hynes 1960, Griffiths 1998). The presence of other groups such as sphaeriid bivalve clams, amphipods, mayflies and caddisflies in fall 2010 indicate good water and sediment quality.

2010 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints for benthic invertebrate communities in fall 2010 at *test* reach MUR-E1 were within the range of regional *baseline* erosional reaches (Figure 5.2-12). Values of all measurement endpoints were within previously-measured ranges with the exception of the CA Axis 1 scores, which were higher in 2010 than in previous years reflecting higher relative abundance of tubificid worms and lower relative abundances of chironomids compared to previous years. The percent abundance of mayflies (10% in 2010), caddisflies (1% in 2010) and stoneflies (2% in 2010) were lower than in previous years as well (Table 5.2-17).

Values of all measurement endpoints for benthic invertebrate communities in fall 2010 at *test* reach MUR-D2 were within the range of regional *baseline* depositional reaches with the exception of taxa richness (Figure 5.2-13). Taxa richness exceeded the range of regional *baseline* ranges but was within previously-measured values for this reach (Figure 5.2-13). CA Axis 1 scores have shifted over time towards regional *baseline* conditions (Figure 5.2-14).

Values of all measurement endpoints for benthic invertebrate communities in fall 2010 at *test* reach MUR-D3 were within the range of regional *baseline* conditions for depositional reaches (Figure 5.2-15).

Classification of Results The differences in the benthic invertebrate community at *test* reach MUR-E1 as of fall 2010 are classified as **Negligible-Low** because there were no significant differences over time in the values of all measurement endpoints in fall 2010 and all measurement endpoints were within the range of regional *baseline* erosional reaches. There was however, a significant trend in CA Axis 1 scores over time reflecting a modest increase in percent of the fauna as tubificid worms and decrease in the percent of the fauna as chironomids, mayflies, stoneflies and caddisflies.

The differences in the benthic invertebrate community at *test* reach MUR-D2 as of fall 2010 are classified as **Negligible-Low** because, although there was a significant decrease in total abundance over time, the statistical signal explained less than 20% of the variation in annual means. In addition, all measurement endpoints for benthic invertebrate communities were within the range of regional *baseline* depositional reaches with the exception of taxa richness, which exceeded the range of regional *baseline* conditions, implying an improvement in the benthic invertebrate community at *test* reach MUR-D2.

The differences in the benthic invertebrate community at *test* reach MUR-D3 as of fall 2010 from *baseline* benthic invertebrate communities are classified as **Moderate** because taxa richness was significantly lower in the period when reach MUR-D3 was *test* compared to the *baseline* period. There was also a significant decrease in CA Axis 1 scores over time in the *test* period and this decrease, reflecting a shift to higher relative abundance of chironomids and bivalves at *test* reach MUR-D3 over time.

Jackpine Creek

Benthic invertebrate community samples were sampled in fall 2010 at:

- depositional *test* reach JAC-D1, near the mouth of Jackpine Creek (designated as *baseline* from 2002 to 2005 and *test* from 2006 to 2010); and
- depositional *baseline* reach JAC-D2 (designated as *baseline* from 2006 to 2010).

2010 Habitat Conditions Water at *test* reach JAC-D1 in fall 2010 was deep (0.9 m), slow-flowing (0.4 m/s), alkaline (pH: 8.2) and had moderate conductivity (191 µS/cm) (Table 5.2-23). The substrate was dominated by sand (86%) with moderate amounts of silt (11%) (Table 5.2-23). Water at *baseline* reach JAC-D2 was also relatively deep (0.8 m), slow-flowing (0.6 m/s), and alkaline (pH: 8.2) with substrate dominated by sand (75%) and silt (11%) (Table 5.2-23).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach JAC-D1 was dominated by chironomids (53%) and Ceratopogonidae (13%) with subdominant taxa consisting of Naididae worms (8%), gastropod snails (4%) and Ephemeroptera (3%) (Table 5.2-24). Dominant chironomids were of the genera *Procladius*, *Stempellinella*, *Paratanytarus*, *Polypedilum*, *Paralauterbourniella*. Mayflies (Ephemeroptera) were present in low abundance represented by the genera *Caenis* and *Callibaetis*.

The benthic invertebrate community at *baseline* reach JAC-D2 was dominated by chironomids (59%) consisting principally of *Tanytarsus*, *Micropsectra/Tanytarsus*, *Paratendipes* and *Paralauterbourniella* (Table 5.2-24) with subdominant taxa consisting of ceratopogonids (12%), Ephemeroptera (6%, *Caenis*), Coleoptera (5%, *Dubiraphia*), and Naididae worms (5%) (Table 5.2-24). Caddisflies (Trichoptera; *Ptilostomis* and *Oecetis*) were present in low abundance.

Temporal and Spatial Comparisons Temporal comparisons were conducted by testing for changes in time trends of measurement endpoints for benthic invertebrate communities for the period that *test* reach JAC-D1 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). For spatial comparisons, changes in mean values of benthic invertebrate communities measurement endpoints were tested between t*est* reach JAC-D1 and *baseline* reach JAC-D2 from before to after *test* reach JAC-D1 was designated as *test* (2006) (Hypothesis 3, Section 3.2.3.1).

There was a significant increase over time in taxa richness, diversity, evenness and percent EPT at *test* reach JAC-D1 once the reach became *test* (Table 5.2-25); none of these significant changes in measurement endpoints are negative trends. In addition, there were no significant differences in the values of any of the benthic invertebrate community measurement endpoints between *test* reach JAC-D1 and *baseline* reach JAC-D2 from before to after reach JAC-D1 was designated as *test* (Table 5.2-25).

Comparison to Published Literature *Test* reach JAC-D1 had a benthic invertebrate community indicative of healthy robust conditions reflected by a variety of fauna including mayflies that comprised 3% of the fauna and caddisflies that were present in lower relative abundance. The percent of the community as tubificid worms was low (7%) and consistent with a robust benthic invertebrate community (Hynes 1960, Griffiths 1998).

2010 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints for benthic invertebrate communities in fall 2010 at both *test* reach JAC-D1 and *baseline* reach JAC-D2 were within the range of values for regional *baseline* depositional reaches (Figure 5.2-17). The CA axis scores in 2010 in *test* reach JAC-D1 were within the range of regional *baseline* conditions and within the range of values previously-measured at *baseline* reach JAC-D2 or during the *baseline* period for reach JAC-D1 (Figure 5.2-18).

Classification of Results The differences in the benthic invertebrate community at *test* reach JAC-D1 as of fall 2010 are classified as **Negligible-Low** because the significant increases over time in taxa richness, diversity, evenness and percent EPT at reach JAC-D1 once the reach became *test* do not imply a negative change in the benthic invertebrate community, and values of all measurement endpoints in fall 2010 for benthic invertebrate communities at both *test* reach JAC-D1 and *baseline* reach JAC-D2 were within the range of regional *baseline* conditions.

Kearl Lake

Benthic invertebrate community samples were sampled in fall 2010 at depositional *test* station KEL-1 in Kearl Lake (designated as *baseline* from 2001 to 2008 and as *test* from 2009 to 2010).

2010 Habitat Conditions Water in Kearl Lake was slightly alkaline (pH: 7.5) with moderate conductivity (154 µS/cm) (Table 5.2-26). The substrate was dominated by sand (59%) and silt (36%), with high levels of total organic carbon (35%); organic materials are a major component of the substrate of Kearl Lake as a result of the natural accumulation of decaying aquatic vegetation.

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of Kearl Lake in fall 2010 was dominated by copepods (30%), naidid worms (20%), and chironomids (13%), with subdominant taxa consisting of bivalve clams (7%), amphipods (7%) and nematodes (3%) (Table 5.2-27). Dominant chironomids included common forms such as *Dicrotendipes*, *Endochironomus*, *Polypedilum*, *Tanytarsus*, and *Procladius*. Species of bivalve clams were principally of the genus *Pisidium*. Amphipods were dominated by *Hyalella azteca* and *Gammarus lacustris*. Gastropoda (snails) included *Physa*, *Gyraulus* and *Valvata sincera*.

Temporal Comparisons Changes in values of measurement endpoints for benthic invertebrate communities were tested for *test* station KEL-1 between the years before and after the reach was designated as *test* (Hypothesis 2, Section 3.2.3.1). There was a significant decrease in percent EPT in the *test* period, explaining 36% of the variation in annual mean percent EPT (Table 5.2-28). There was also a significant decrease in CA Axis 1 scores but this decrease explained only 5% of the variation in the annual mean values (Table 5.2-28).

Comparison to Published Literature The benthic invertebrate community of Kearl Lake in fall 2010 contained fauna that would be considered typical of benthos from a shallow lake. The percent of the fauna as worms was low (tubificid worms were not found in 2010 and naidid worms accounted for 20% of the fauna) as was the percent of the fauna as chironomids (13%). The benthic invertebrate community also contained a mixture of permanent aquatic forms such as amphipods, bivalves and gastropods and flying insects (chironomids, Ephemeroptera, Trichoptera), typical of lake systems.

2010 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities were within the range of previously-measured values for Kearl Lake during the *baseline* period.

Classification of Results The differences in the benthic invertebrate community at *test* station KEL-1 as of fall 2010 are classified as **Moderate** because of a significant decrease in the percent EPT in the period that station KEL-1 has been designated as *test*, explaining more than 20% of the variation in annual mean percent EPT.

5.2.4.2 Sediment Quality

Sediment quality was sampled in fall 2010 in depositional reaches and lakes of the Muskeg River watershed in the same locations as benthic invertebrate communities were sampled in fall 2010:

- *test* station MUR-D2 on the Muskeg River (sampled from 2000 to 2010);
- *test* station MUR-D3 on the Muskeg River (designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2010);
- *test* station JAC-D1 on Jackpine Creek near its mouth (designated as *baseline* in 1997 and *test* from 2006 to 2010);
- *baseline* station JAC-D2 on Jackpine Creek (sampled from 2006 to 2010); and
- *test* station KEL-1 in Kearl Lake (designated as *baseline* from 2001 to 2008 and as *test* from 2009 to 2010).

2010 Results Relative to Historical Concentrations Sediments sampled in 2010 from all stations in the Muskeg River watershed were taken from the same locations as those reaches sampled from 2006 to 2009. Prior to the integration of the Sediment Quality component with the Benthic Invertebrate Communities component in 2006, benthic invertebrate communities *test* reaches MUR-D2 and MUR-D3 correspond to pre-2006 sediment-quality *test* stations MUR-2 and MUR-D2, respectively, and *test* reach JAC-D1 corresponds with pre-2006 sediment quality station JAC-1; *baseline* reach JAC-D2 was established in 2006 (Table 3.1-10).

Concentrations of sediment quality measurement endpoints were similar to previously-measured concentrations at each station (Table 5.2-29 to Table 5.2-33 and Figure 5.2-21 to Figure 5.2-25). Concentrations of volatile, low-molecular-weight hydrocarbons (i.e., CCME fraction 1 and BTEX – benzene, toluene, ethylene and xylene) were undetectable at all stations in fall 2010. Concentrations of heavier hydrocarbon fractions in fall 2010 were within previously-measured concentrations. The concentrations of absolute (non-normalized) total PAHs exceeded the previously-measured maximum concentrations at *test* station MUR-D3 (Table 5.2-30 and Figure 5.2-22), but carbon-normalized concentrations of total PAHs were within previously-measured concentrations at all stations. Similar to previous years, concentrations of total PAHs in sediments generally increased from upstream to downstream in tributaries, with lowest concentrations in *test* station KEL-1 in Kearl Lake (Table 5.2-33 and Figure 5.2-25) and *baseline* station JAC-D2 (Table 5.2-32 and Figure 5.2-24) and highest concentrations at *test* station MUR-D2 (Table 5.2-29 and Figure 5.2-21).

Although concentrations of total PAHs were generally lower than previously-measured maximum concentrations, the potential PAH toxicity in sediments was higher than previously calculated at all stations with the exception of *baseline* station JAC-D2 and *test* station KEL-1. The PAH toxicity index was nearly 4.0 at *test* station MUR-D2 (Table 5.2-29). The apparent incongruity of this high PAH Hazard Index with historically-average PAH concentrations in this reach is explained by the relatively low total hydrocarbons measured from this reach in fall 2010, which is used in the Hazard Index value calculation as a contributing factor of predicting bioavailability.

Survival of the midge *Chironomus* at *test* station JAC-D1 and *baseline* station JAC-D2 were within the range of previously-measured survival rates, and growth of *Chironomus* at both stations was higher than previously-measured maximum growth rates (Table 5.2-31 and Table 5.2-32). *Hyalella* survival at *baseline* station JAC-D2 was within the range of previously-measured survival rates and growth was lower than previously-measured minimum growth rates. *Hyalella* survival at *test* station JAC-D1 was higher than previously-measured maximum survival rates and growth was within previously-measured growth rates.

Spatial Comparisons The following comparisons of sediment quality measurement endpoints among stations in the Muskeg River watershed in fall 2010 are noted:

1. Percent sand and total organic carbon were higher at *test* station MUR-D3 (85.1% and 23.9%, respectively) than *test* station MUR-D2 (64.0% and 5.5%, respectively).

2. Concentrations of hydrocarbons (including PAHs) were higher at *test* stations MUR-D2, MUR-D3, and JAC-D1 than *baseline* station JAC-D2.

3. Survival and growth of *Chironomus* and *Hyalella* were similar between *test* station JAC-D1 and *baseline* station JAC-D2.

Comparison of Fall Sediment Quality Measurement Endpoints to Published Guidelines Concentrations of Fraction-3 hydrocarbons exceeded relevant CCME soil-quality guidelines at all stations with the exception of *baseline* station JAC-D2 and *test* station JAC-D1 (Table 5.2-31 and Table 5.2-32). The concentration of Fraction-2 hydrocarbons exceeded the CCME soil-quality guideline at *test* station KEL-1 (Table 5.2-33).

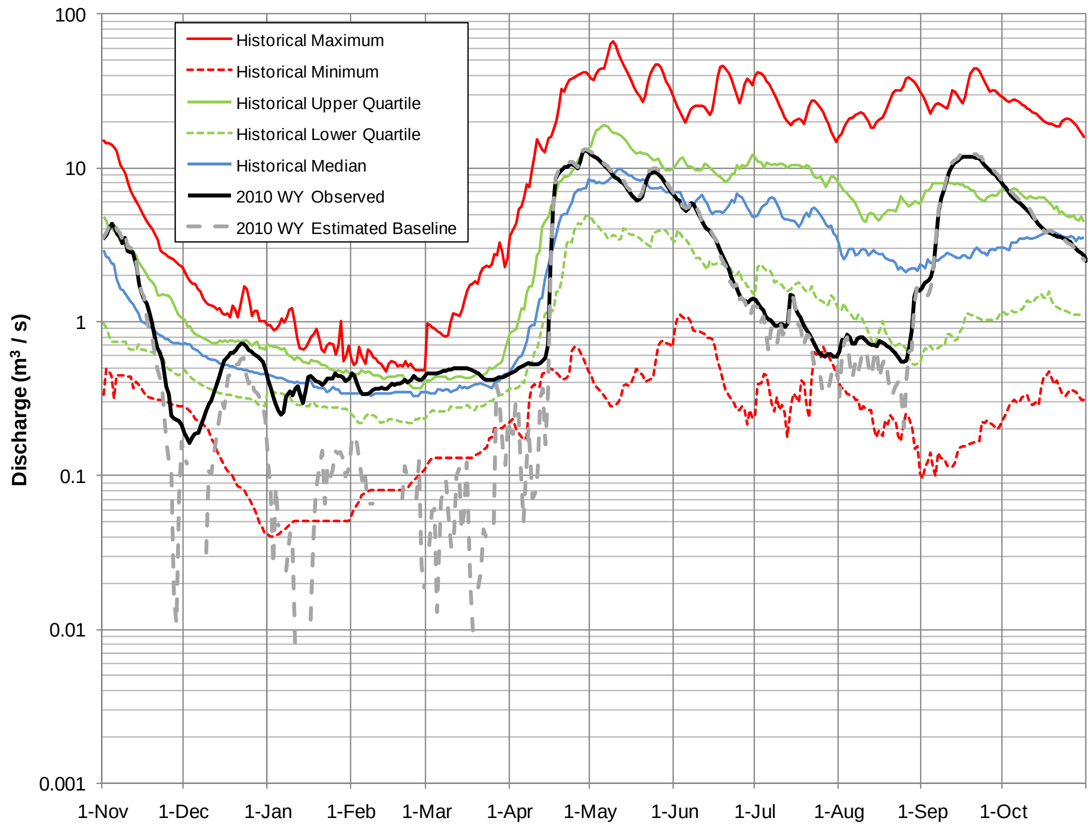
Sediment Quality Index The SQI values for all stations in the Muskeg River watershed in fall 2010 indicated **Negligible-Low** differences in sediment quality conditions from regional *baseline* conditions (Table 5.2-34).

Classification of Results Sediment quality at all Muskeg River watershed stations sampled in fall 2010 was generally consistent with that of previous years and regional *baseline* conditions with the exception of predicted PAH toxicity, which was higher than historical values at several stations, particularly *test* station MUR-D2. Concentrations of total PAHs at these stations were within previously-measured concentrations. Differences in sediment quality in fall 2010 at all five stations in the Muskeg River watershed were assessed as **Negligible-Low** compared to regional *baseline* conditions.

5.2.5 Fish Populations

The Fish Populations component did not conduct regular monitoring activities in the Muskeg River watershed in 2010. However, the pilot study of fish assemblage monitoring in 2010 included a reach on the lower Muskeg River; Section 6 contains the results of this study.

Figure 5.2-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Muskeg River in the 2010 WY, compared to historical values.



Note: Based on provisional 2010 WY 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 2009, and values for other months calculated from data collected from 1974 to 1986 and 1999 to 2009.

Note: Minor differences (within expected measurement error) were calculated between observed flows at WSC Station 07DA008 (RAMP Station S7) and the net flow releases from focal projects that led estimated *baseline* values to be slightly negative for a number of days during the winter. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a), and 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, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**93.85**	**Observed discharge at WSC Station 07DA008 (RAMP Station S7), Muskeg River near Fort McKay**
Closed-circuited area water loss from the observed *test* hydrograph	-7.58	Estimated 120.7 km^2 of the Muskeg River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.65	Estimated 51.5 km^2 of the Muskeg River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Muskeg River watershed from focal projects	-0.65	Water withdrawn by Imperial Kearl and Shell Jackpine (all values provided daily)
Water releases into the Muskeg River watershed from focal projects	9.86	Syncrude Aurora Clean Water Diversion discharges to Stanley Creek, and other releases by Hammerstone Muskeg Valley and Husky Sunshine (all values provided daily)
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**96.13**	**Estimated *baseline* discharge at RAMP Station S7 (WSC Station 07DA008), Muskeg River near Fort McKay**
Incremental flow (change in total discharge)	+2.28	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+2.3%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on provisional 2010 WY 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.

Note: Minor differences (within expected measurement error) were calculated between observed flows at WSC Station 07DA008 (RAMP Station S7) and the net flow releases from focal projects that led estimated *baseline* values to be slightly negative for a number of days during the winter. Baseline values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a).

Table 5.2-3 Calculated changes in hydrologic measurement endpoints for the Muskeg River watershed, 2010 WY.

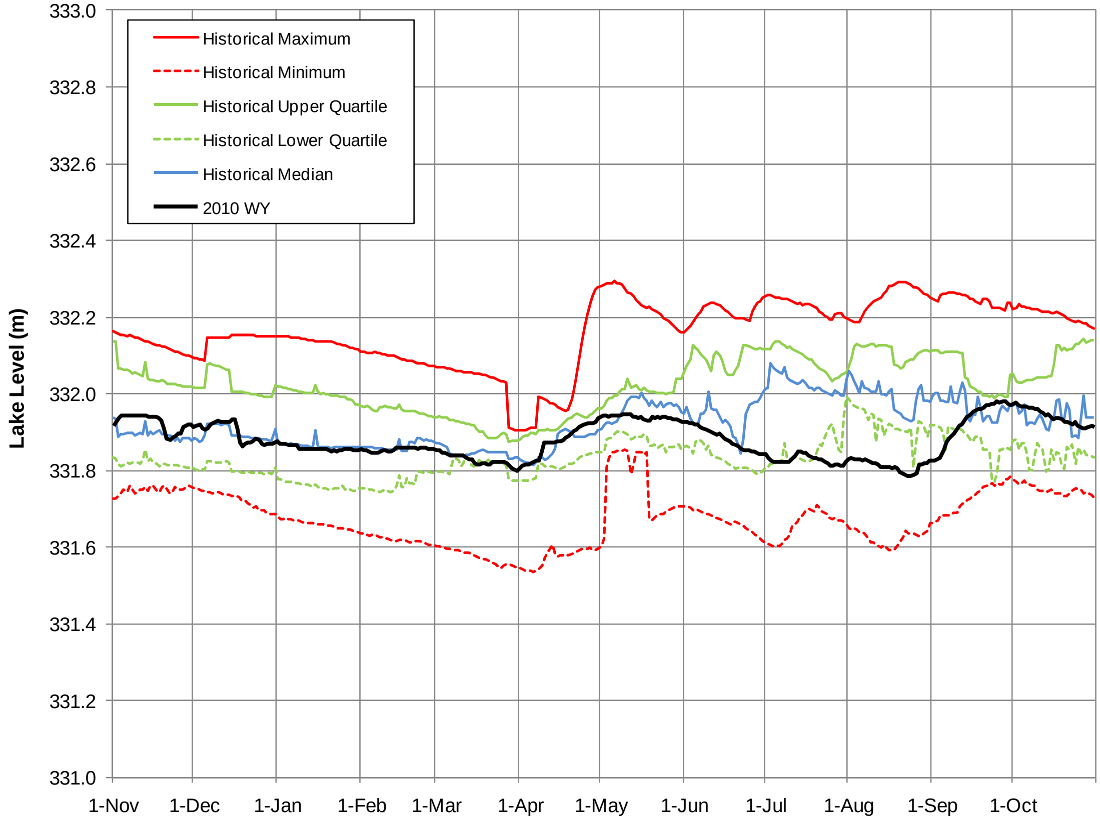
Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	4.55	4.48	-1.7%
Mean winter discharge	0.47	0.72	52.1%
Annual maximum daily discharge	13.41	13.00	-3.0%
Open-water season minimum daily discharge	0.33	0.55	64.1%

Note: Based on provisional the 2010 WY 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.

Note: Minor differences (within expected measurement error) were calculated between observed flows at WSC Station 07DA008 (RAMP Station S7) and the net flow releases from focal projects that led estimated *baseline* values to be slightly negative for a number of days during the winter. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a).

Figure 5.2-4 Observed lake levels for Kearl Lake in the 2010 WY, compared to historical values.



Note: Observed 2010 WY lake levels based on the 2010 WY provisional data for Station L2, Kearl Lake. Historical values calculated from 1999 to October 2009, with periods of missing data present in most years.

Table 5.2-4 Concentrations of selected water quality measurement endpoints, mouth of Muskeg River (*test* station MUR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	13	7.4	8.2	8.4
Total suspended solids	mg/L	-[1]	13	13	<3	3	70
Conductivity	µS/cm	-	330	13	220	324	671
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.016	13	0.004	0.013	0.030
Total nitrogen*	mg/L	1.0	**1.38**	13	0.40	0.90	**1.62**
Nitrate+nitrite	mg/L	1.3	<0.071	13	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	25	13	15	21	29
Ions							
Sodium	mg/L	-	11	13	8	13	64
Calcium	mg/L	-	46.8	13	28.8	44.5	108
Magnesium	mg/L	-	12.6	13	7.1	12.0	18.9
Chloride	mg/L	230, 860[3]	2.9	13	1.0	3.0	36.0
Sulphate	mg/L	100[4]	3.9	13	0.6	5.4	91
Total dissolved solids	mg/L	-	238	13	170	280	405
Total alkalinity	mg/L		167	13	105	166	313
Selected metals							
Total aluminum	mg/L	0.1	**0.257**	13	0.026	0.067	**1.20**
Dissolved aluminum	mg/L	0.1[2]	0.0031	13	0.0019	0.0061	0.0300
Total arsenic	mg/L	0.005	0.0005	13	0.0003	0.0004	<0.001
Total boron	mg/L	1.2[5]	0.039	13	0.032	0.044	0.150
Total molybdenum	mg/L	0.073	0.00010	13	0.00007	0.00009	0.00030
Total mercury (ultra-trace)	ng/L	5, 13[6]	3	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.12	13	0.09	0.12	0.30
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.006**	13	<0.002	**0.005**	**0.022**
Dissolved iron	mg/L	0.3[2]	**0.381**	13	0.140	**0.351**	**1.020**
Total iron	mg/L	0.3	**1.33**	13	0.29	**0.66**	**1.81**
Total Phenols	mg/L	0.004	**0.008**	13	0.001	0.002	**0.011**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.31**	13	0.30	0.80	**1.55**

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 5.2-5 Concentrations of selected water quality measurement endpoints, Muskeg River upstream of Wapasu Creek (*test* station MUR-6), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	12	7.2	8.1	8.4
Total suspended solids	mg/L	-[1]	<3	12	<3	<3	25
Conductivity	µS/cm	-	255	12	233	312	441
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.012	12	0.011	0.014	0.029
Total nitrogen*	mg/L	1.0	**1.93**	12	0.30	0.85	**1.92**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	26.8	12	13.0	18.5	31.9
Ions							
Sodium	mg/L	-	3	12	3	4	7
Calcium	mg/L	-	35.0	12	31.3	44.3	67.4
Magnesium	mg/L	-	12.6	12	11.6	15.9	21.4
Chloride	mg/L	230, 860[3]	0.7	12	<0.5	1.0	3.0
Sulphate	mg/L	100[4]	2.4	12	1.5	3.7	6.3
Total dissolved solids	mg/L	-	204	12	180	233	320
Total alkalinity	mg/L		131	12	120	175	235
Selected metals							
Total aluminum	mg/L	0.1	0.0251	12	0.0091	0.0202	**0.110**
Dissolved aluminum	mg/L	0.1[2]	0.0048	12	0.0017	0.0053	<0.01
Total arsenic	mg/L	0.005	0.00037	12	0.00026	0.00038	0.00100
Total boron	mg/L	1.2[5]	0.0116	12	0.0060	0.0113	0.0159
Total molybdenum	mg/L	0.073	0.00010	12	0.00007	0.00009	0.00030
Total mercury (ultra-trace)	ng/L	5, 13[6]	0.80	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.066	12	0.058	0.085	0.164
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phenolics	mg/L	0.004	**0.031**	12	0.001	0.005	0.010
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.860**	12	0.200	0.750	**1.850**
Sulphide	mg/L	0.002[7]	**0.006**	12	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).

8 Guideline is for total nitrogen.

Table 5.2-6 Concentrations of selected water quality measurement endpoints, Jackpine Creek (*test* station JAC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1999-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	11	7.8	8.1	8.3
Total suspended solids	mg/L	-[1]	8	11	<3	<3	8
Conductivity	µS/cm	-	217	11	183	237	413
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.013	11	0.006	0.014	0.026
Total nitrogen*	mg/L	1.0	**1.54**	11	0.70	0.90	**1.62**
Nitrate+nitrite	mg/L	1.3	<0.071	11	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	28.8	11	18.6	23.0	30.0
Ions							
Sodium	mg/L	-	15	11	10	12	18
Calcium	mg/L	-	25.6	11	22.2	29.2	56.6
Magnesium	mg/L	-	8.0	11	6.6	8.5	14.2
Chloride	mg/L	230, 860[3]	1.3	11	0.9	2.0	5.6
Sulphate	mg/L	100[4]	2.2	11	<0.5	2.7	4.3
Total dissolved solids	mg/L	-	186	11	110	206	234
Total alkalinity	mg/L		109	11	93	122	227
Selected metals							
Total aluminum	mg/L	0.1	**0.197**	11	0.018	0.062	**0.120**
Dissolved aluminum	mg/L	0.1[2]	0.0073	11	0.0033	0.0087	**0.170**
Total arsenic	mg/L	0.005	0.0006	11	0.0003	0.0005	<0.001
Total boron	mg/L	1.2[5]	0.048	11	0.033	0.042	0.066
Total molybdenum	mg/L	0.073	0.0001	11	0.0001	0.0001	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	7	<1.2	<1.2	1.5
Total strontium	mg/L	-	0.096	11	0.085	0.108	0.171
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.008**	11	**0.006**	**0.009**	**0.103**
Total iron	mg/L	0.3	**0.584**	11	**0.380**	**0.591**	**1.570**
Total phenols	mg/L	0.004	**0.018**	11	0.001	**0.006**	**0.019**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.47**	11	0.60	0.80	**1.55**

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 5.2-7 Concentrations of selected water quality measurement endpoints, upper Jackpine Creek (*baseline* station JAC-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (Fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.18	2	7.98	7.99	8.00
Total suspended solids	mg/L	-[1]	13	2	3	5	6
Conductivity	µS/cm	-	202	2	213	215	216
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.012	2	0.014	0.016	0.017
Total nitrogen*	mg/L	1.0	**2.63**	2	0.90	0.98	1.06
Nitrate+nitrite	mg/L	1.3	<0.071	2	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	29.1	2	22.6	23.8	25.0
Ions							
Sodium	mg/L	-	10	2	10	11	11
Calcium	mg/L	-	22.1	2	26.9	28.7	30.5
Magnesium	mg/L	-	7.2	2	8.6	8.6	8.6
Chloride	mg/L	230, 860[3]	0.5	2	<0.5	0.8	1.0
Sulphate	mg/L	100[4]	1.95	2	0.67	1.34	2.00
Total dissolved solids	mg/L	-	160	2	150	162	173
Total alkalinity	mg/L		103	2	110	112	113
Selected metals							
Total aluminum	mg/L	0.1	**0.70**	2	0.14	0.17	0.20
Dissolved aluminum	mg/L	0.1[2]	0.0137	2	0.0088	0.0096	0.0104
Total arsenic	mg/L	0.005	0.00076	2	0.00068	**0.00069**	0.00070
Total boron	mg/L	1.2[5]	0.0609	2	**0.0448**	0.0510	0.0571
Total molybdenum	mg/L	0.073	0.00014	2	0.00011	0.00012	0.00014
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.9	2	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.104	2	0.104	0.113	0.121
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0047**	2	**0.007**	**0.0076**	**0.0081**
Total iron	mg/L	0.3	**0.816**	2	**0.689**	**0.694**	**0.698**
Total phenols	mg/L	0.004	**0.012**	2	**0.006**	**0.009**	**0.012**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.56**	2	0.80	0.90	0.99

JAC-2 has only been sampled in 2008, 2009, and 2010.

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 5.2-8 Concentrations of selected water quality measurement endpoints, Stanley Creek (*test* station STC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1999-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.17	9	7.60	8.00	8.20
Total suspended solids	mg/L	-[1]	<3	9	<3	<3	6
Conductivity	µS/cm	-	353	9	271	392	760
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.019	10	0.010	0.019	0.033
Total nitrogen*	mg/L	1.0	0.61	10	0.30	0.40	**2.10**
Nitrate+nitrite	mg/L	1.3	<0.071	10	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	11.1	9	6.0	8.0	12.2
Ions							
Sodium	mg/L	-	6	9	2	3	26
Calcium	mg/L	-	52.7	9	45.4	62.5	112
Magnesium	mg/L	-	12.1	9	11.1	12.9	20.5
Chloride	mg/L	230, 860[3]	2.0	9	<0.5	<1.0	14
Sulphate	mg/L	100[4]	2.2	9	<0.5	5.3	**126**
Total dissolved solids	mg/L	-	242	9	200	264	480
Total alkalinity	mg/L		182	9	157	206	260
Selected metals							
Total aluminum	mg/L	0.1	0.0073	10	0.0010	0.0070	0.0200
Dissolved aluminum	mg/L	0.1[2]	<0.001	10	0.0004	<0.0010	<0.020
Total arsenic	mg/L	0.005	<0.0001	10	<0.0001	0.00014	<0.0010
Total boron	mg/L	1.2[5]	0.032	10	0.018	0.025	0.087
Total molybdenum	mg/L	0.073	<0.0001	10	<0.00001	0.00006	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.114	10	0.075	0.141	0.248
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phenols	mg/L	**0.004**	**0.004**	10	0.001	0.003	**0.052**

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 5.2-9 Concentrations of selected water quality measurement endpoints, Wapasu Creek (*test* station WAC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	8	7.4	8.0	8.2
Total suspended solids	mg/L	-[1]	<3	8	<3	<3	3
Conductivity	µS/cm	-	207	8	209	266	600
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0093	8	0.0090	0.0140	0.0220
Total nitrogen*	mg/L	1.0	**1.35**	8	0.50	1.00	**1.84**
Nitrate+nitrite	mg/L	1.3	<0.071	8	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	31.2	8	11.0	17.5	33.2
Ions							
Sodium	mg/L	-	7	8	6	7	9
Calcium	mg/L	-	26.7	8	29.1	38.6	78.2
Magnesium	mg/L	-	9.3	8	8.6	13.3	28.2
Chloride	mg/L	230, 860[3]	2.7	8	0.8	2.0	3.0
Sulphate	mg/L	100[4]	2.2	8	1.6	2.8	7.7
Total dissolved solids	mg/L	-	199	8	160	210	350
Total alkalinity	mg/L		99	8	103	146	327
Selected metals							
Total aluminum	mg/L	0.1	0.024	8	0.014	0.015	0.074
Dissolved aluminum	mg/L	0.1[2]	0.009	8	0.004	0.017	0.050
Total arsenic	mg/L	0.005	0.00037	8	0.00025	0.00033	0.00100
Total boron	mg/L	1.2[5]	0.021	8	0.019	0.027	0.081
Total molybdenum	mg/L	0.073	<0.0001	8	0.00003	0.00005	0.00040
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	6	<1.2	<1.2	3.3
Total strontium	mg/L	-	0.063	8	0.067	0.089	0.130
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.011**	8	**0.003**	**0.009**	**0.019**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.280**	8	0.40	0.90	**1.77**
Total phenols	mg/L	0.004	**0.015**	8	0.006	**0.007**	**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).

[8] Guideline is for total nitrogen.

Table 5.2-10 Concentrations of selected water quality measurement endpoints, Iyinimin Creek (*baseline* station IYC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.9	2	8.0	8.1	8.2
Total suspended solids	mg/L	-[1]	29	2	<3	10	17
Conductivity	µS/cm	-	134	2	143	173	202
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.017	2	0.018	0.025	0.031
Total nitrogen*	mg/L	1.0	**1.93**	2	0.90	0.90	0.90
Nitrate+nitrite	mg/L	1.3	<0.071	2	<0.10	<0.10	<0.10
Dissolved organic carbon	mg/L	-	34	2	27	30	33
Ions							
Sodium	mg/L	-	5	2	7	8	9
Calcium	mg/L	-	18.0	2	18.8	21.4	24.0
Magnesium	mg/L	-	6.2	2	6.5	7.4	8.3
Chloride	mg/L	230, 860[3]	<0.5	2	1.0	1.5	2.0
Sulphate	mg/L	100[4]	2.2	2	2.7	3.3	3.9
Total dissolved solids	mg/L	-	141	2	134	153	172
Total alkalinity	mg/L		64	2	72	88	104
Selected metals							
Total aluminum	mg/L	0.1	**0.902**	2	0.115	0.502	**0.889**
Dissolved aluminum	mg/L	0.1[2]	0.035	2	0.022	0.033	0.044
Total arsenic	mg/L	0.005	0.0008	2	0.0007	0.0008	<0.0008
Total boron	mg/L	1.2[5]	0.0247	2	0.0254	0.0371	0.0487
Total molybdenum	mg/L	0.073	0.00013	2	0.00011	0.00015	0.00019
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.8	2	<1.2	1.8	2.4
Total strontium	mg/L	-	0.046	2	0.050	0.062	0.073
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.007**	2	**0.007**	**0.01**	**0.013**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.86**	2	0.8	0.8	0.8
Total phenols	mg/L	0.004	**0.009**	2	**0.009**	**0.0125**	**0.016**
Total chromium	mg/L	0.001	**0.0011**	2	<0.0003	0.0008	**0.0013**
Total iron	mg/L	0.3	**1.05**	2	**0.96**	**1.06**	**1.15**

Guidelines are CCME (2007) or AENV (1999) 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 1999).

[7] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[8] Guideline is for total nitrogen.

Table 5.2-11 Concentrations of selected water quality measurement endpoints, Kearl Lake (*test* station KEL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	11	7.6	8.0	8.3
Total suspended solids	mg/L	-[1]	<3	11	<3	4	19
Conductivity	µS/cm	-	165	11	133	174	183
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.005	11	0.002	0.008	0.013
Total nitrogen*	mg/L	1.0	**1.92**	11	0.45	**1.40**	**1.80**
Nitrate+nitrite	mg/L	1.3	<0.071	11	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	21.9	11	9.8	21.0	24.0
Ions							
Sodium	mg/L	-	9.4	11	8.0	10.0	11.3
Calcium	mg/L	-	16.6	11	16.5	19.6	20.6
Magnesium	mg/L	-	6.7	11	5.7	6.8	7.6
Chloride	mg/L	230, 860[3]	<0.5	11	<0.5	<1.0	3.0
Sulphate	mg/L	100[4]	2.2	11	2.4	4.7	5.7
Total dissolved solids	mg/L	-	142	11	94	154	220
Total alkalinity	mg/L		81	11	72	88	93
Selected metals							
Total aluminum	mg/L	0.1	0.007	11	0.011	0.023	**0.130**
Dissolved aluminum	mg/L	0.1[2]	<0.0010	11	0.0008	0.0021	0.0300
Total arsenic	mg/L	0.005	0.0003	11	0.0003	0.0004	<0.0010
Total boron	mg/L	1.2[5]	0.044	11	0.012	0.047	0.052
Total molybdenum	mg/L	0.073	<0.0001	11	0.00003	0.00010	0.00090
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	7	<1.2	<1.2	1.3
Total strontium	mg/L	-	0.067	11	0.056	0.066	0.215
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.002**	11	<0.002	**0.005**	**0.010**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.85**	11	0.40	**1.30**	**1.70**
Total phenols	mg/L	0.004	**0.010**	11	<0.001	0.005	**0.012**

Guidelines are CCME (2007) or AENV (1999) 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 1999).

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 Piper diagram of fall ion concentrations in the Muskeg River.

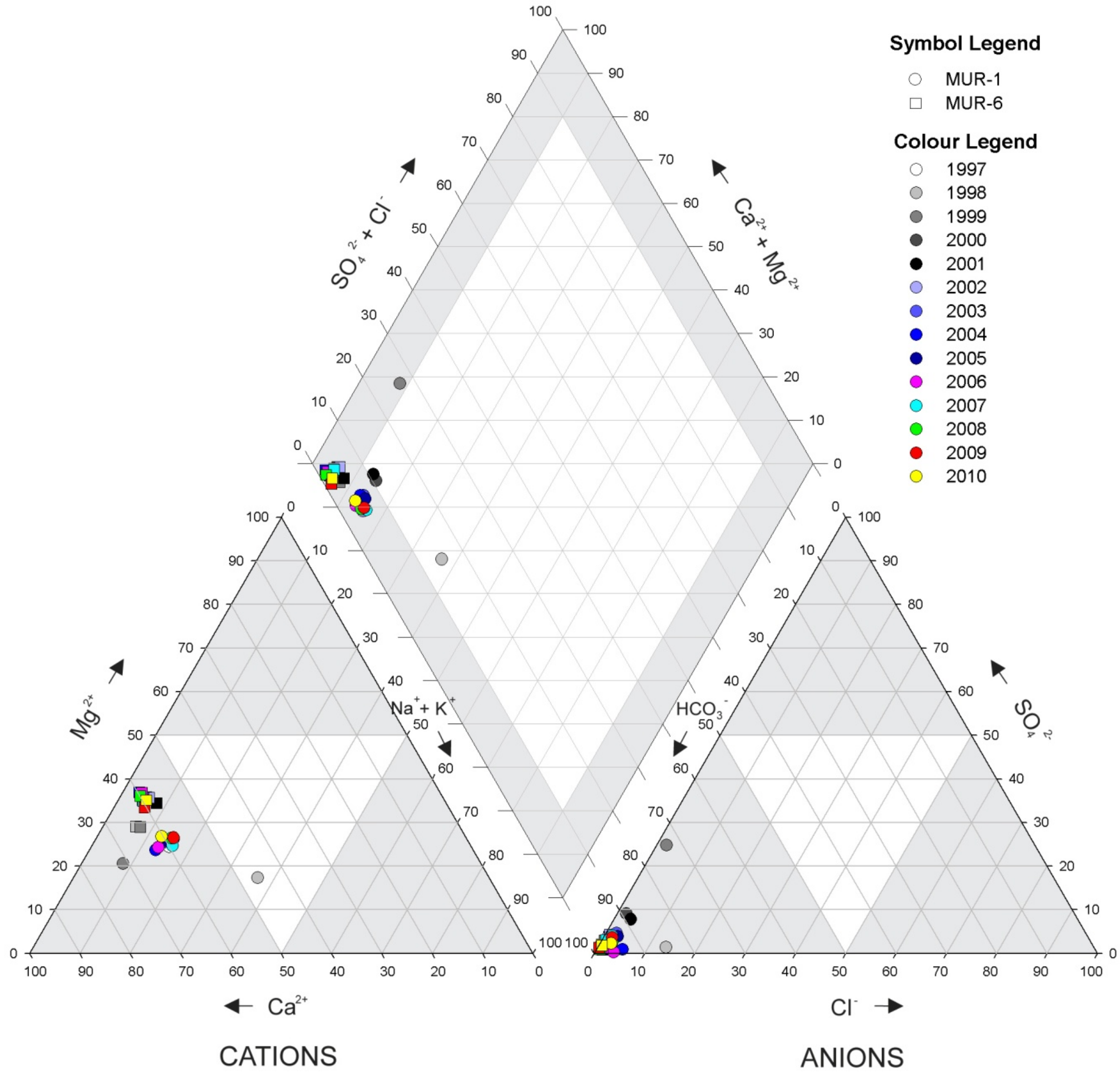


Figure 5.2-6 Piper diagram of fall ion concentrations in tributaries to the Muskeg River and Kearl Lake.

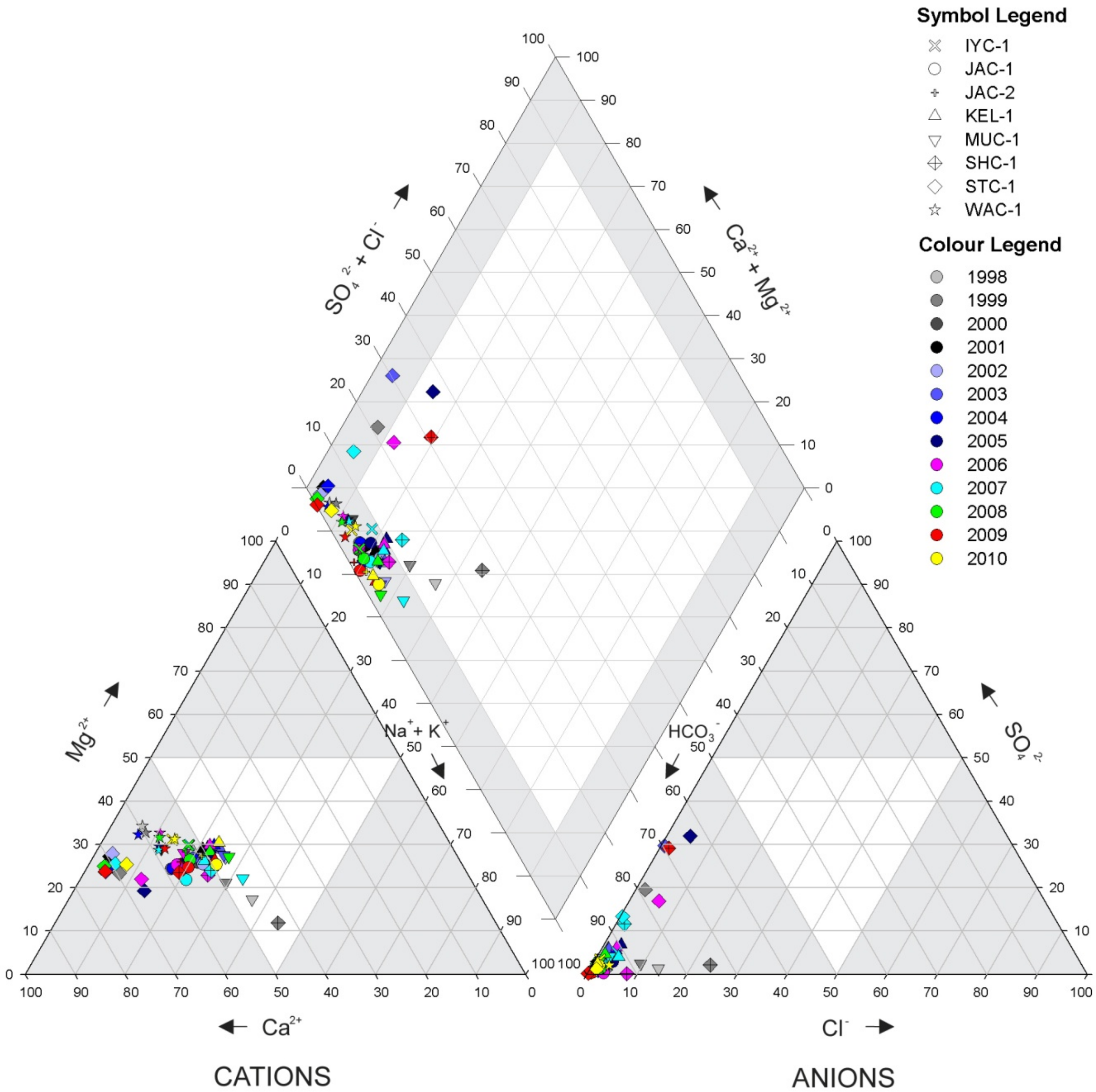


Table 5.2-12 Water quality guideline exceedances, Muskeg River watershed, fall 2010.

Variable	Units	Guideline	JAC-1	JAC-2	MUR-1	MUR-6	STC-1	WAC-1	IYC-1	KEL-1
Sulphide	mg/L	0.002[1]	0.0083	0.0047	0.0057	0.0059	-	0.0114	0.0066	0.0021
Total aluminum	mg/L	0.10	0.20	0.70	0.26	-	-	-	0.90	-
Dissolved iron	mg/L	0.3[3]	-	-	0.38	-	-	-		
Total iron	mg/L	0.3	0.58	0.82	1.33	-	-	-	1.05	-
Total chromium	mg/L	0.001	-	-	-	-	-	-	0.0011	-
Total phenols	mg/L	0.004	0.018	0.012	0.008	0.031	0.004	0.015	0.009	0.010
Total Kjeldahl nitrogen	mg/L	1.0[4]	1.47	2.56	1.31	1.86	-	1.28	1.86	1.85
Total nitrogen*	mg/L	1.0	1.541	2.631	1.381	1.931	-	1.351	1.931	1.921

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

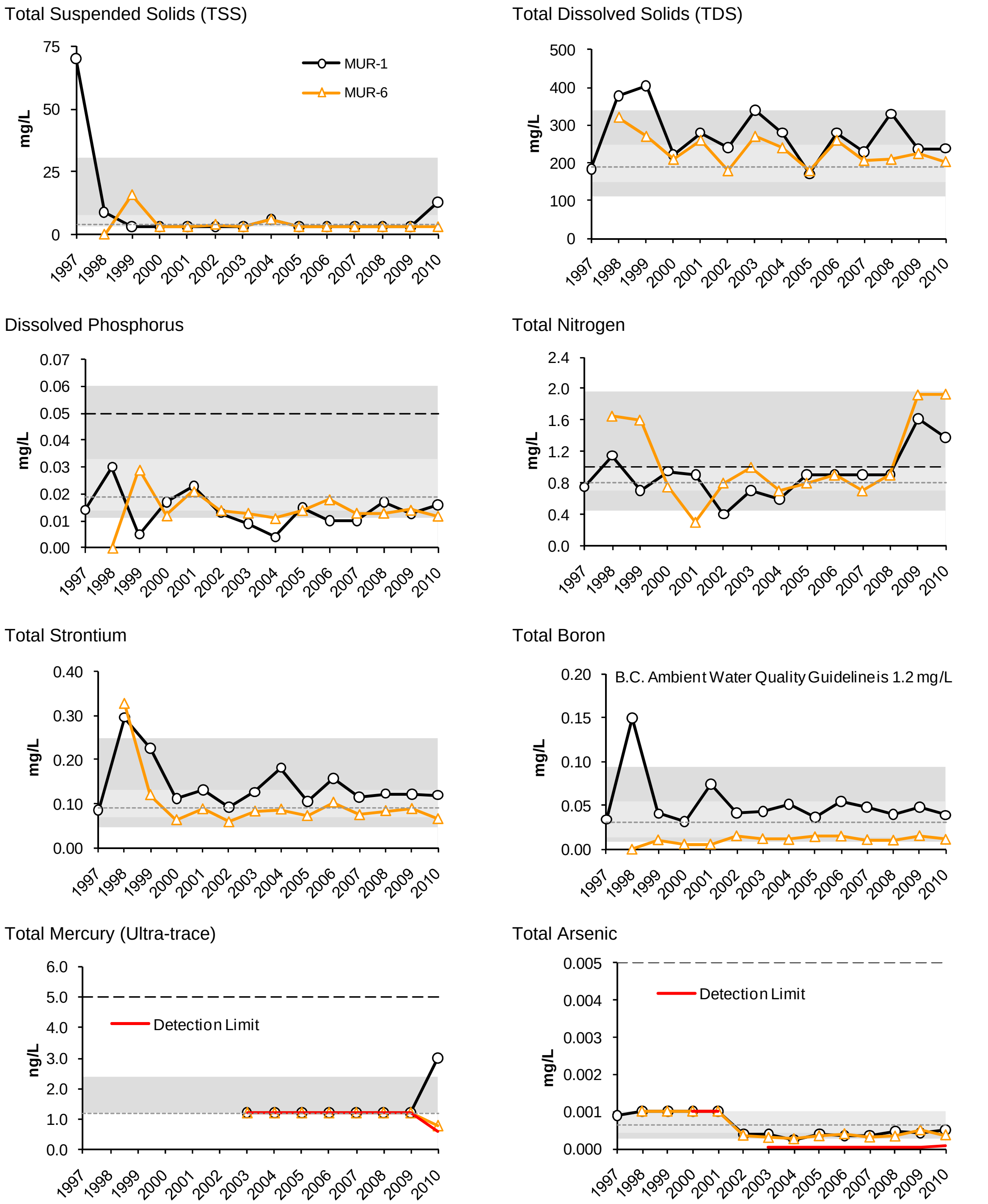
[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[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.

Figure 5.2-7 Selected water quality measurement endpoints in the Muskeg River at the mouth (*test* station MUR-1) and upstream of Wapasu Creek (*test* station MUR-6) (fall 2010) relative to historical concentrations and regional *baseline* fall concentrations.



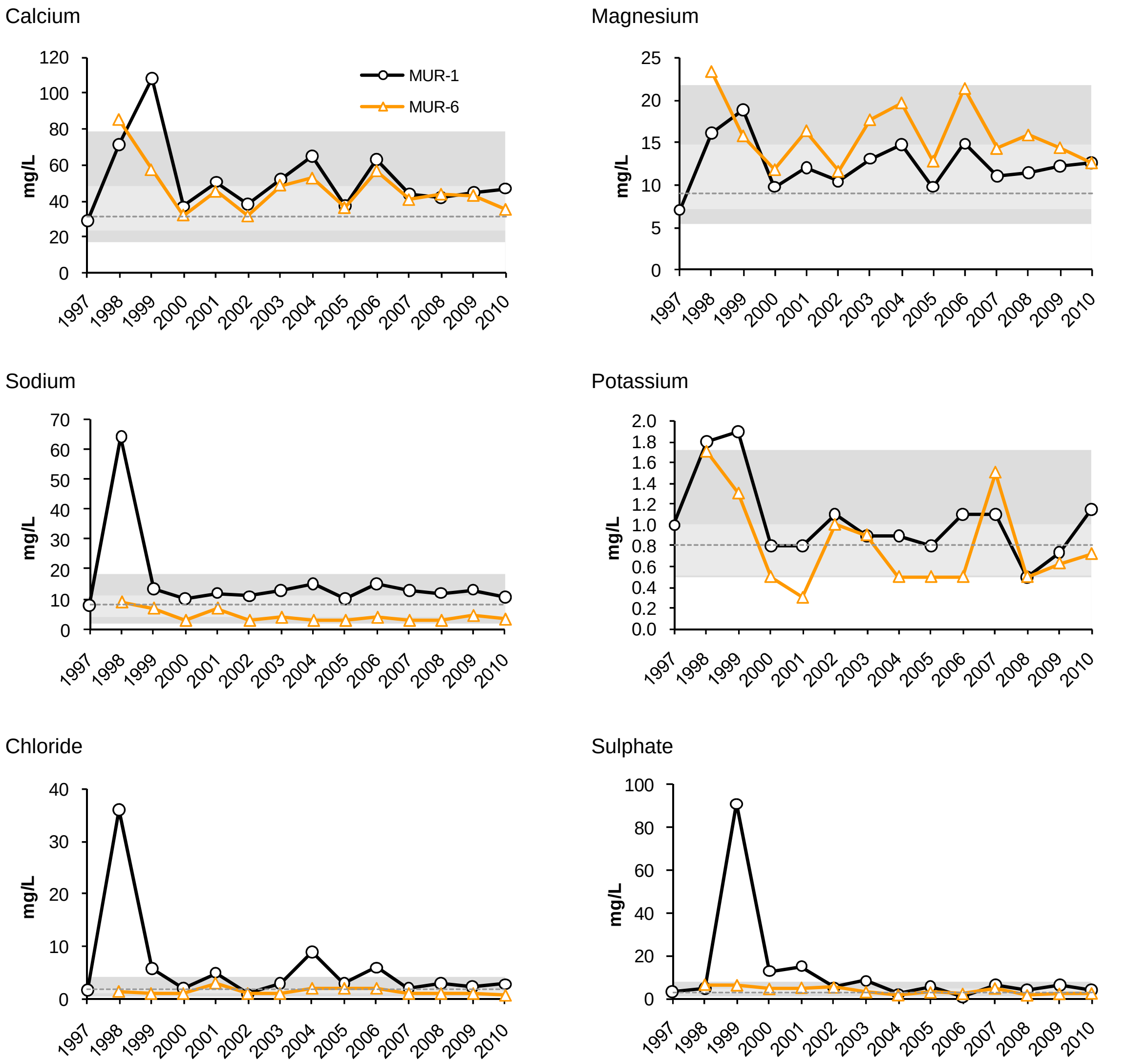
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.2-7 (Cont'd.)

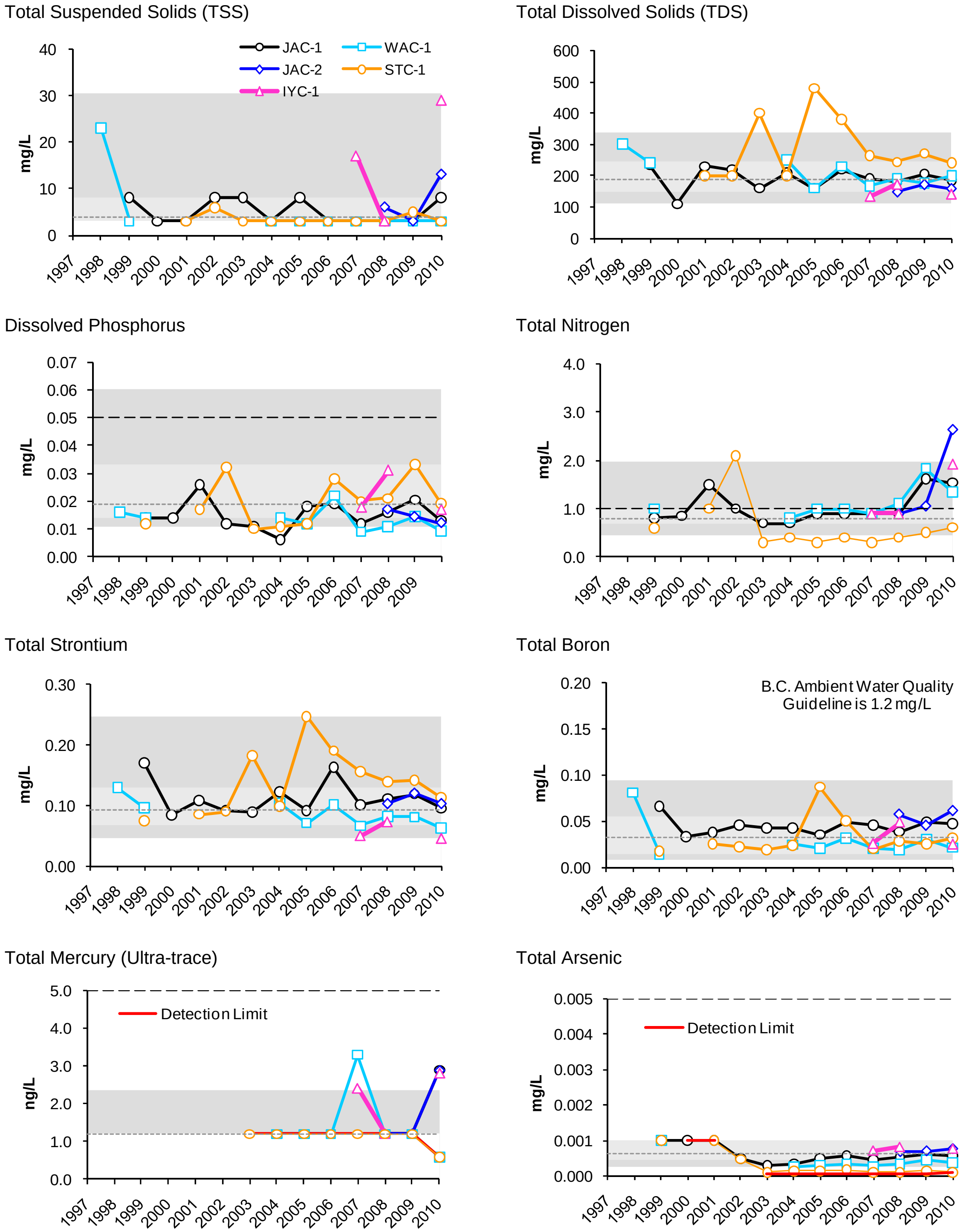


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.2-8 Selected water quality measurement endpoints in Muskeg River tributaries (fall 2010) relative to historical concentrations and regional *baseline* fall concentrations.

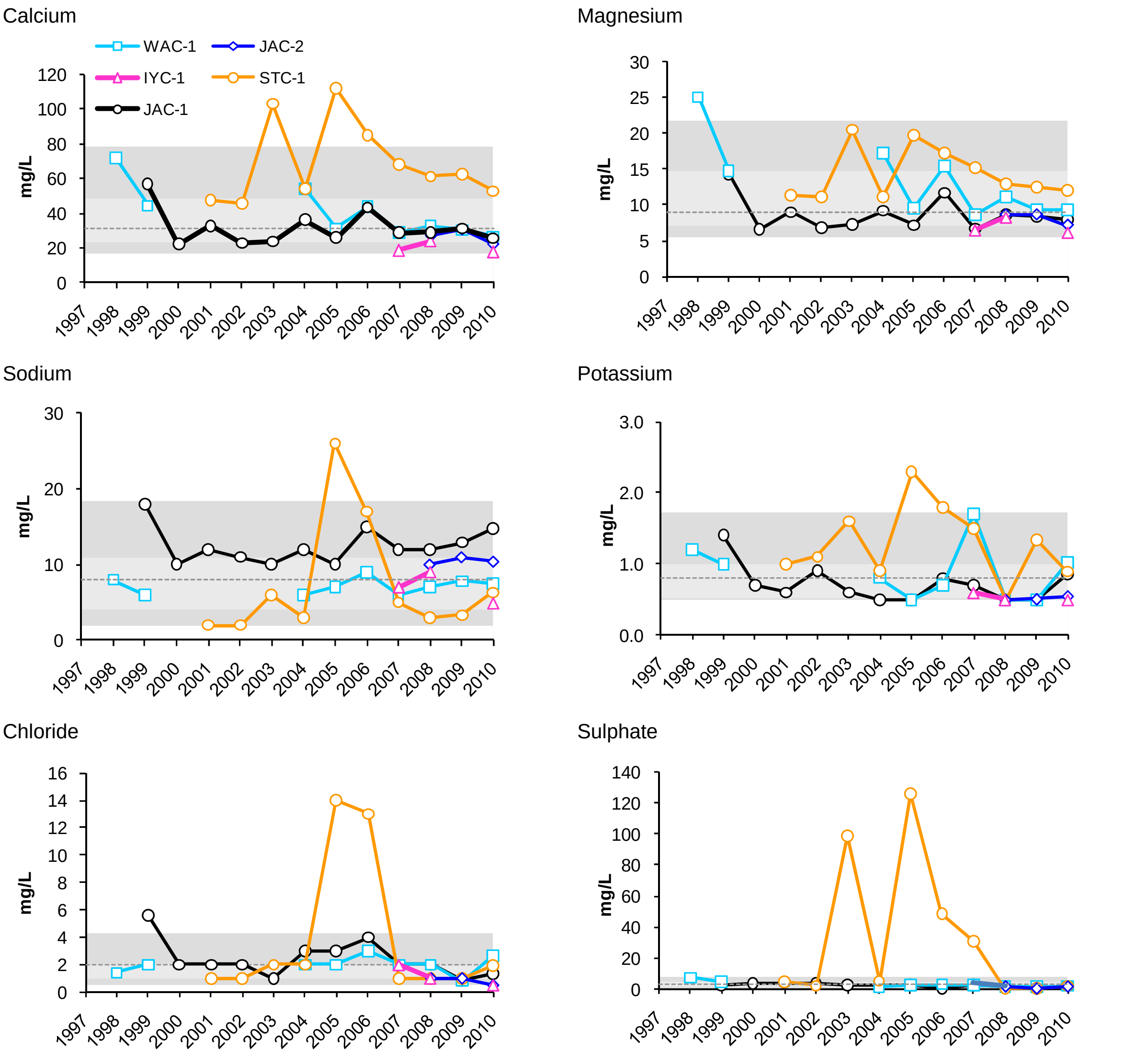


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.2-8 (Cont'd.)



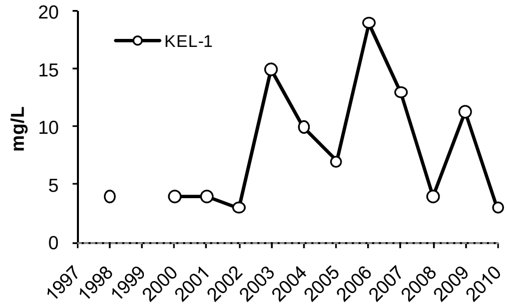
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

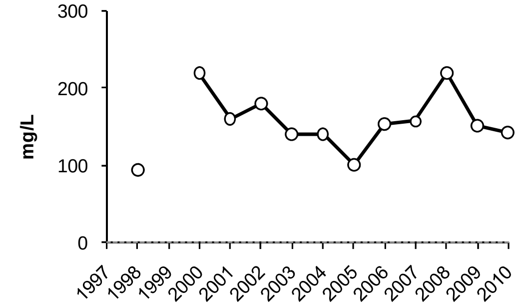
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.2-9 Selected water quality measurement endpoints in Kearl Lake (fall 2010) relative to historical concentrations.

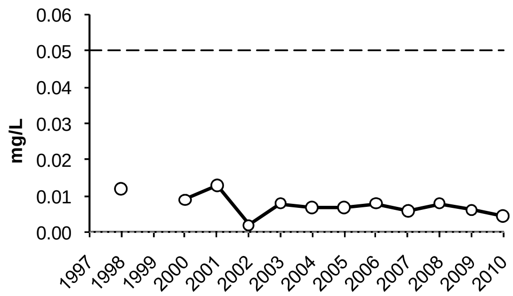
Total Suspended Solids (TSS)



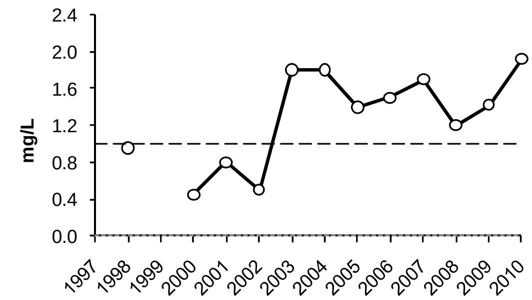
Total Dissolved Solids (TDS)



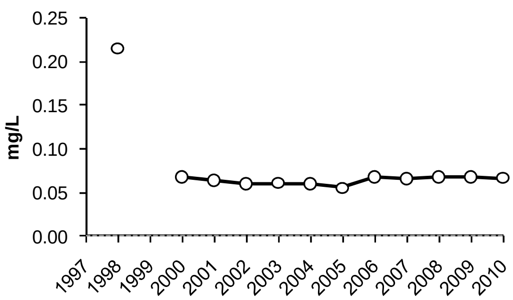
Dissolved Phosphorus



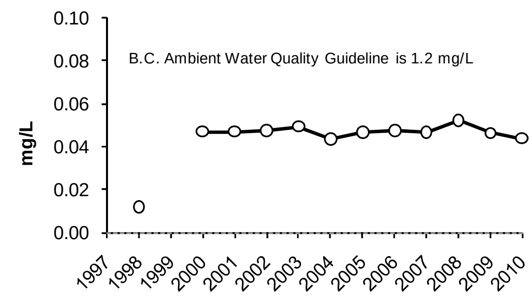
Total Nitrogen



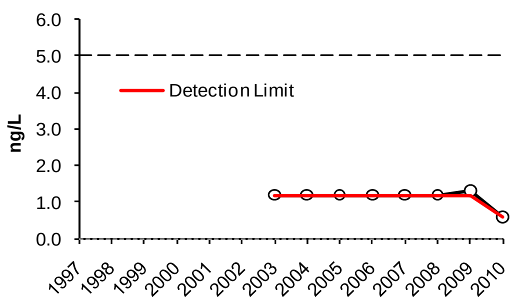
Total Strontium



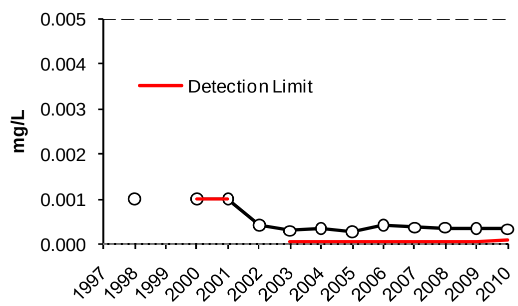
Total Boron



Total Mercury (Ultra-trace)



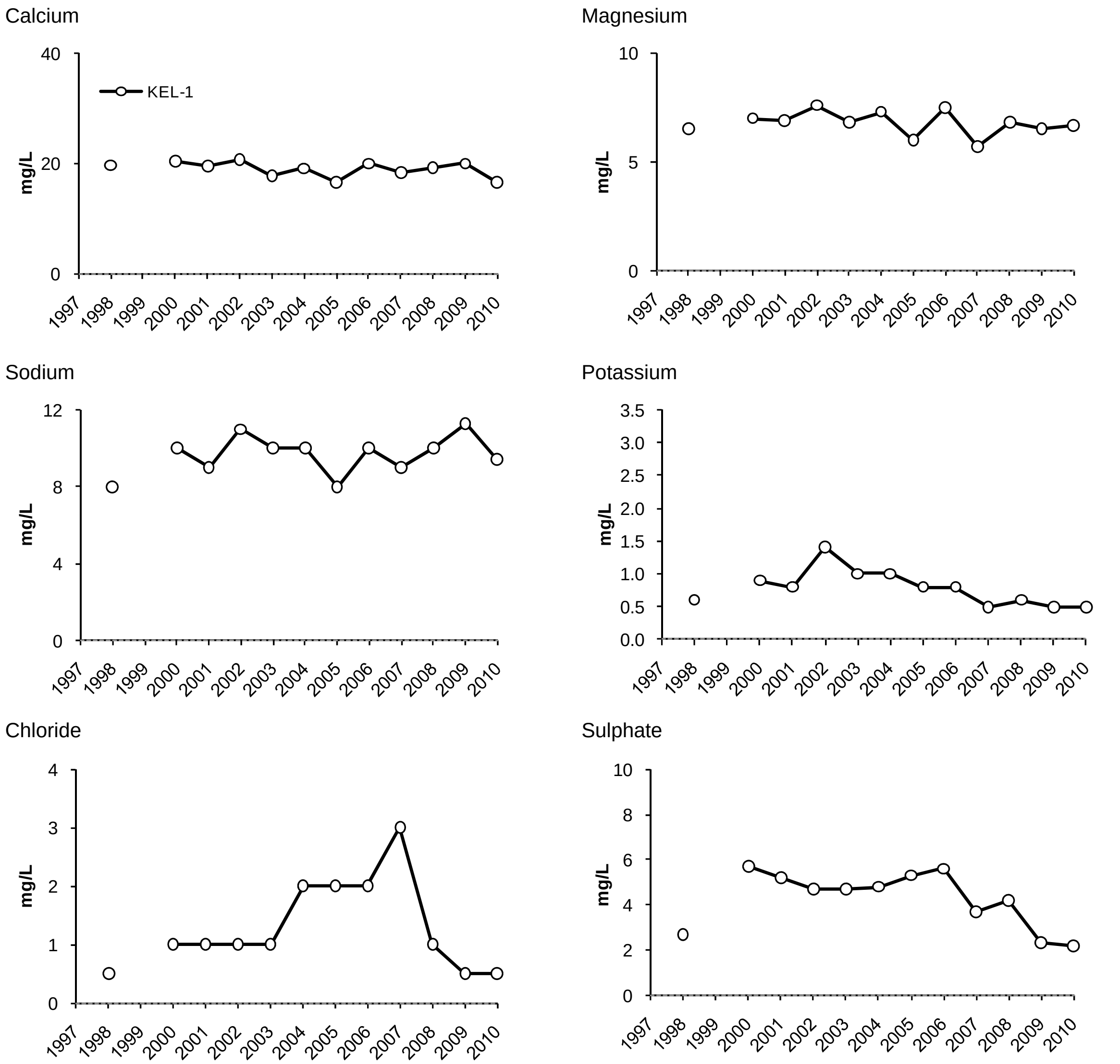
Total Arsenic



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Figure 5.2-9 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Table 5.2-13 Water quality index (fall 2010) for Muskeg River watershed stations.

Station Identifier	Location	2010 Designation	Water Quality Index	Classification
MUR-1	Lower Muskeg River	*test*	98.7	Negligible-Low
MUR-6	Upstream of Wapasu Creek	*test*	98.5	Negligible-Low
JAC-1	Near mouth of Jackpine Creek	*test*	98.7	Negligible-Low
JAC-2	Upper Jackpine Creek	*baseline*	93.6	Negligible-Low
STC-1	Near mouth of Stanley Creek	*test*	100.0	Negligible-Low
IYC-1	Near mouth of Iyinimin Creek	*baseline*	92.2	Negligible-Low
WAC-1	Near mouth of Wapasu Creek	*test*	98.7	Negligible-Low

Note: see Figure 5.2-1 for the locations of these water quality stations.
Note: see Section 3.2.2.3 for a description of the Water Quality Index.

Table 5.2-14 Average habitat characteristics of benthic invertebrate community in *test* reach MUR-E1 of the Muskeg River, fall 2010.

Variable	Units	MUR-E1 Lower *Test* Reach of the Muskeg River
Sample date	-	Sept. 8, 2010
Habitat	-	Erosional
Water depth	m	0.3
Current velocity	m/s	1.9
Field Water Quality		
Dissolved oxygen	mg/L	9.8
Conductivity	µS/cm	309
pH	pH units	8.3
Water temperature	°C	13.6
Sediment Composition		
Sand/Silt/Clay	%	3
Small Gravel	%	30.5
Large Gravel	%	33
Small Cobble	%	29.5
Large Cobble	%	4
Boulder	%	0
Bedrock	%	0

Figure 5.2-10 Periphyton chlorophyll *a* biomass in *test* reach MUR-E1 of the Muskeg River.

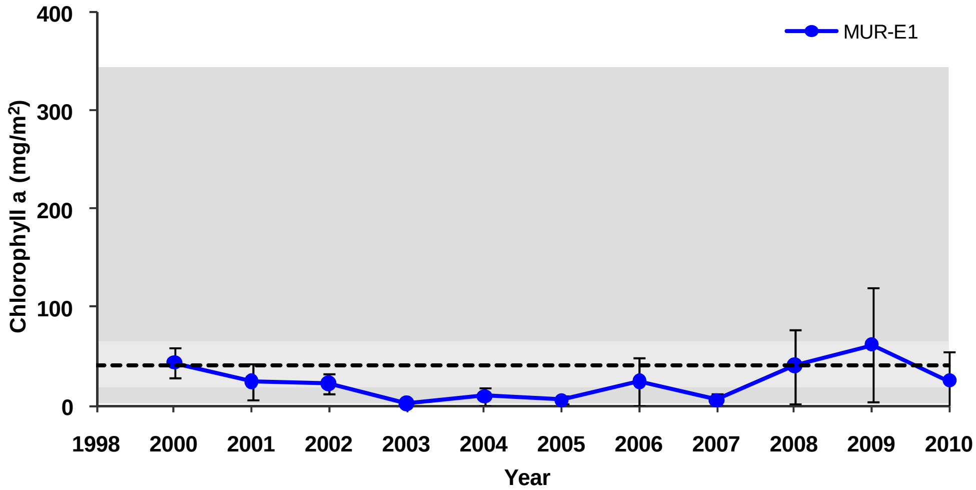


Table 5.2-15 Average habitat characteristics of benthic invertebrate sampling location in *test* reach MUR-D2 of the Muskeg River.

Variable	Units	MUR-D2 Middle *Test* Reach of the Muskeg River
Sample date	-	Sept. 15, 2010
Habitat	-	Depositional
Water depth	m	2.1
Current velocity	m/s	0.4
Field Water Quality		
Dissolved oxygen	mg/L	8.2
Conductivity	µS/cm	220
pH	pH units	7.8
Water temperature	°C	10.1
Sediment Composition		
Sand	%	85
Silt	%	12
Clay	%	4
Total Organic Carbon	%	2

Table 5.2-16 Average habitat characteristics of benthic invertebrate sampling location in *test* reach MUR-D3 of the Muskeg River.

Variable	Units	MUR-D3 Upper *Test* Reach of the Muskeg River
Sample date	-	Sept. 11, 2010
Habitat	-	Depositional
Water depth	m	1.9
Current velocity	m/s	0.3
Field Water Quality		
Dissolved oxygen	mg/L	6.2
Conductivity	µS/cm	253
pH	pH units	7.6
Water temperature	°C	10.5
Sediment Composition		
Sand	%	90
Silt	%	7
Clay	%	3
Total Organic Carbon	%	12

Table 5.2-17 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the lower Muskeg River (*test* reach MUR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year											
	Reach MUR-E1											
	1998	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Amphipoda		<1		<1	<1							
Anisoptera	<1	<1	2	1	1	2	<1	<1	1	2	<1	<1
Bivalvia	6	1	3	5	1	3	2		5	4	1	4
Ceratopogonidae	1	<1	<1	1		<1	<1	1	2	<1	<1	1
Chironomidae	32	31	23	37	58	37	20	31	25	15	52	15
Coleoptera	5	1	2	1	3	10	5	3	2	1	1	1
Copepoda	<1	<1	<1	2	<1	<1	1		<1	<1	2	1
Empididae	4	<1	2	2	3	6	22	1	<1	<1	1	<1
Enchytraeidae	<1	<1	1	<1	<1	1	1	<1		1	<1	<1
Ephemeroptera	12	50	28	5	5	9	21	24	20	25	29	10
Erpobdellidae				<1								
Gastropoda	3	<1	<1	<1	<1				7	2		5
Glossiphoniidae				<1								
Hydra		<1	<1	<1								
Hydracarina	14	6	15	13	13		10	11	17	8	3	10
Lumbriculidae				<1	<1	<1				<1		
Naididae	5	1	6	14	3	3	1	4	3	30	3	4
Nematoda	2	<1	4	2	3	5	2	1	1	<1	1	1
Ostracoda	3	1	<1	3	<1			<1	2	1	<1	15
Plecoptera	4	6	5	5	3	8	8	5	3	2	2	2
Simuliidae	<1							<1	<1			
Tabanidae	0	<1	<1			<1						
Tipulidae	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1	<1
Trichoptera	2	1	8	5	4	4	2	16	3	2	4	1
Tubificidae	5	<1	<1	1	1	13	5		7	7	<1	26
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	20,987
Richness	60	32	29	39	32	31	32	30	36	39	43	40
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	0.83
Evenness	0.95	0.75	0.89	0.92	0.92	0.94	0.89	0.86	0.86	0.89	0.89	0.85
% EPT	18	57	39	16	14	21	31	44	25	30	34	17

Table 5.2-18 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the middle Muskeg River (*test* reach MUR-D2).

Taxon	Percent Major Taxa Enumerated in Each Year										
	Reach MUR-D2										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Amphipoda		<1	<1	1	<1	<1	<1	2			<1
Anisoptera	<1	<1	<1	<1		<1		<1	<1	<1	<1
Bivalvia	4	1	3	1	1	<1		2	4	5	3
Ceratopogonidae	1	1	2	3	7	4	2	28	11	3	5
Chironomidae	75	84	69	81	74	44	55	32	56	48	53
Coleoptera	<1	<1	<1		<1	1	<1	<1		<1	<1
Copepoda	<1	1	<1	<1	1	<1	<1	2	<1	3	2
Empididae	<1	<1	<1	<1	1	1	1		4		<1
Enchytraeidae	<1	1	2	2	3	3	<1	6	1		1
Ephemeroptera	<1	1	2	1	<1	6	1	2	1	1	3
Erpobdellidae	<1	<1	<1	<1		<1		<1			
Gastropoda	<1	3	1	<1		<1	1	2	4	1	4
Glossiphoniidae	<1	<1	<1	<1			<1	<1	<1	<1	1
Hydra	<1	<1				<1	<1	1	<1		4
Hydracarina	1	1	2	1	<1	<1	2	<1	3	1	<1
Lumbriculidae	1	<1	<1	1		<1	<1	<1		7	
Naididae	2	1	<1	2	1	11	1	4	4	6	4
Nematoda	2	1	6	3	3	6	1	6	5	2	3
Ostracoda	1	2	5		<1	10	<1	3	<1	1	1
Plecoptera	<1	<1	<1	<1		<1	<1		<1		
Simuliidae						1					
Tabanidae	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1
Tipulidae	1	<1			<1		<1	<1	1		<1
Trichoptera	<1	<1	<1	<1	<1	1	<1	<1	<1		<1
Tubificidae	10	<1	3	2	8	10	31	5	3	21	11
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	26,218
Richness	26	30	21	14	10	17	24	20	23	23	27
Simpson's Diversity	0.75	0.84	0.86	0.7	0.68	0.78	0.69	0.85	0.87	0.76	0.82
Evenness	0.78	0.87	0.91	0.77	0.77	0.83	0.69	0.90	0.95	0.81	0.86
% EPT	<1	1	2	2	<1	5	1	2	1	1	2

Table 5.2-19 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the upper Muskeg River (*test* reach MUR-D3).

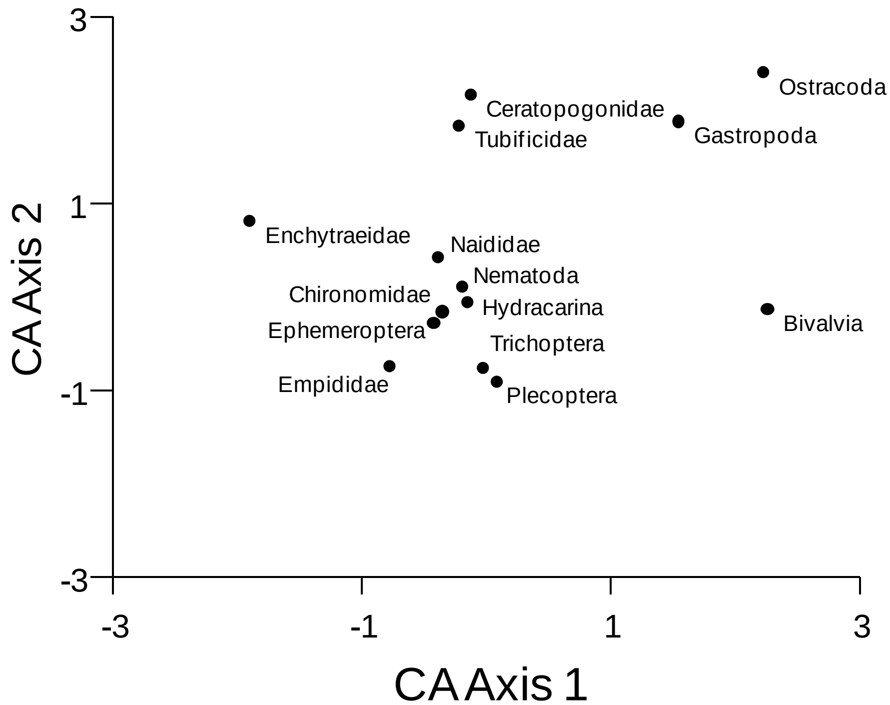
Taxon	Percent Major Taxa Enumerated in Each Year								
	Reach MUR-D3								
	2002	2003	2004	2005	2006	2007	2008	2009	2010
Amphipoda	<1	1	5	<1	1	<1	<1	1	<1
Anisoptera		<1	<1				<1		
Bivalvia	28	17	18	8		5	7	12	10
Ceratopogonidae	<1	2	2	1	1	1	1		<1
Chironomidae	66	65	27	79	54	60	48	42	70
Coleoptera		<1	<1			1	1		<1
Copepoda		1	3	1		<1	2	3	1
Empididae									
Enchytraeidae		<1	1	<1		<1	<1		1
Ephemeroptera		5	5	2	3	3	7	<1	<1
Erpobdellidae	<1	<1	<1	<1	<1	<1		<1	
Gastropoda	<1	1	2	<1	<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	<1
Nematoda	1	2	6	3	4	5	2	<1	
Ostracoda	4	1	7	1		2	3	2	7
Plecoptera						1			
Simuliidae				<1					
Tabanidae	<1	<1	<1	<1	<1	1	<1		
Tipulidae								2	
Trichoptera	<1	<1	<1	1		<1	<1	<1	1
Tubificidae	<1	2	15	2	15	16	9	23	7
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	13,479
Richness	12	17	9	11	15	16	14	10	12
Simpson's Diversity	0.64	0.78	0.71	0.75	0.84	0.82	0.77	0.68	0.67
Evenness	0.71	0.85	0.81	0.83	0.86	0.89	0.85	0.78	0.78
% EPT	<1	6	5	2	3	4	9	<1	2

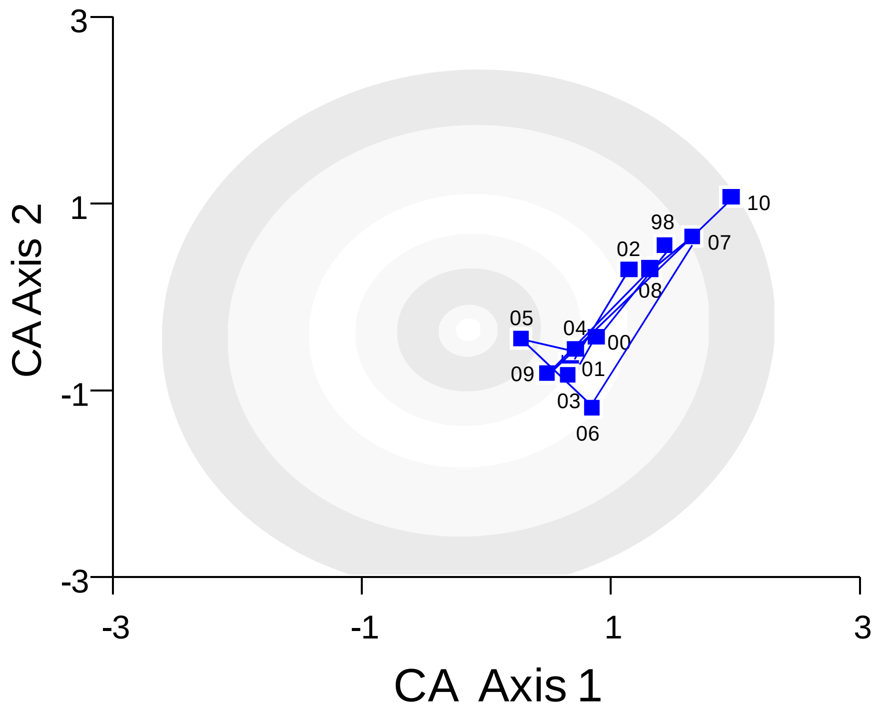
Table 5.2-20 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, *test* reach MUR-E1.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Linear Time Trend	Linear Time Trend	
Abundance	0.662	0	No change
Richness	0.844	0	No change
Simpson's Diversity	0.808	0	No change
Evenness	0.706	0	No change
EPT	0.430	0	No change
CA Axis 1	**0.023**	5	Increase over time
CA Axis 2	0.060	2	No change

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.2-11 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River (*test* reach MUR-E1).





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 5.2-21 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, *test* reach MUR-D2.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Linear Time Trend	Linear Time Trend	
Abundance	**0.000**	19	Decreasing over time
Richness	0.820	0	No change
Simpson's Diversity	0.289	2	No change
Evenness	0.341	2	No change
EPT	0.212	4	No change
CA Axis 1	**0.021**	16	Decreasing over time
CA Axis 2	0.318	2	No change

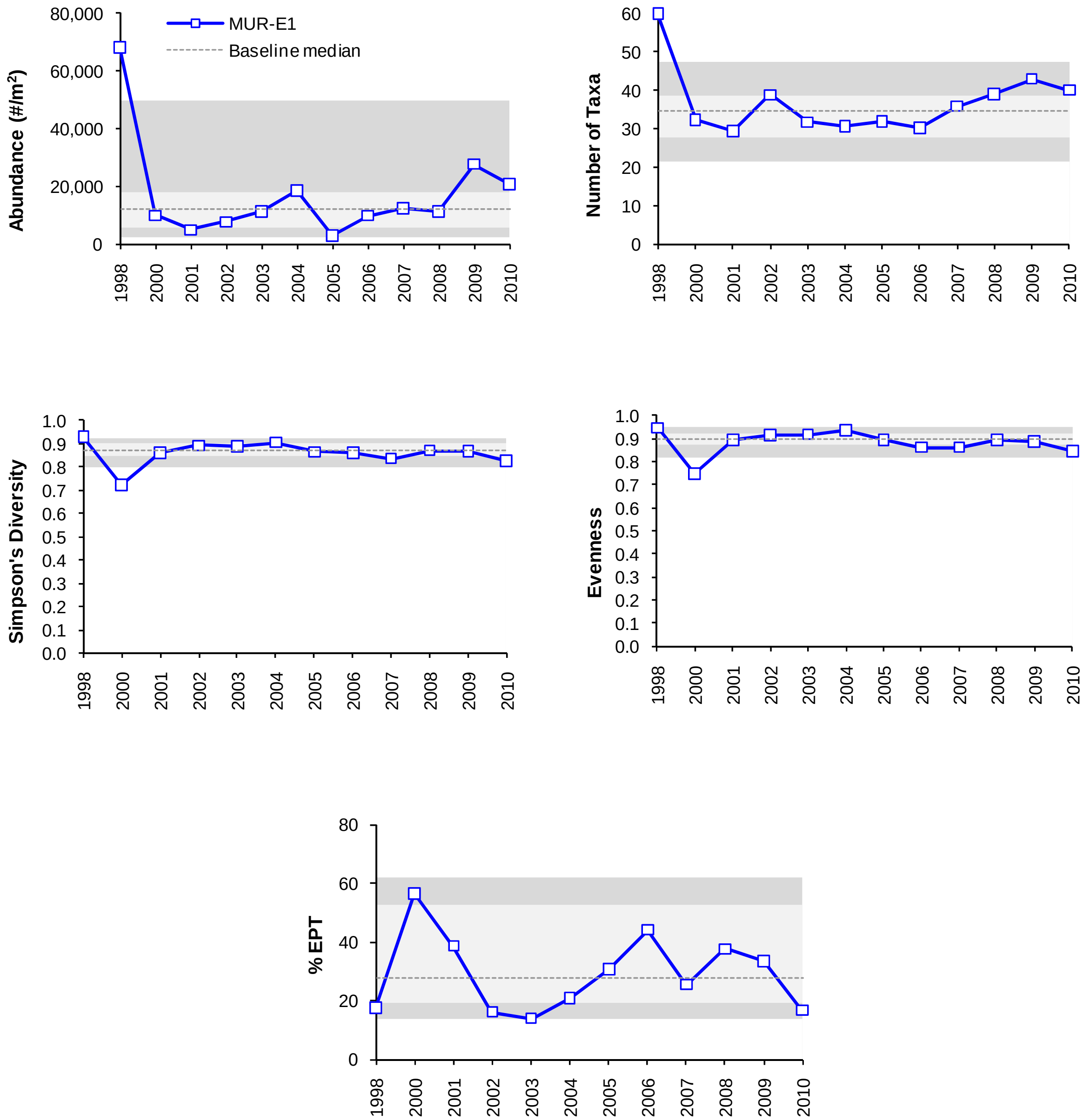
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Table 5.2-22 Analysis of variance (ANOVA) testing differences in benthic invertebrate community measurement endpoints from before to after development in the Muskeg River, *test* reach MUR-D3.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Difference between *Baseline* and *Test* from Before to After	Time Trend (*Test* Period)	Difference between *Baseline* and *Test* from Before to After	Time Trend (*Test* Period)	
Abundance	0.334	0.449	10	6	No difference from *baseline* to *test* period, or time trends in *test* period
Richness	**0.028**	0.222	25	8	Lower in *test* period
Simpson's Diversity	0.044	0.168	20	9	No difference from *baseline* to *test* period, or time trends in *test* period
Evenness	0.174	0.315	11	6	No difference from *baseline* to *test* period, or time trends in *test* period
EPT	0.463	0.083	2	14	No difference from *baseline* to *test* period, or time trends in *test* period
CA Axis 1	0.824	**0.005**	0	22	Decreasing during *test* period
CA Axis 2	0.293	0.526	8	3	No difference from *baseline* to *test* period, or time trends in *test* period

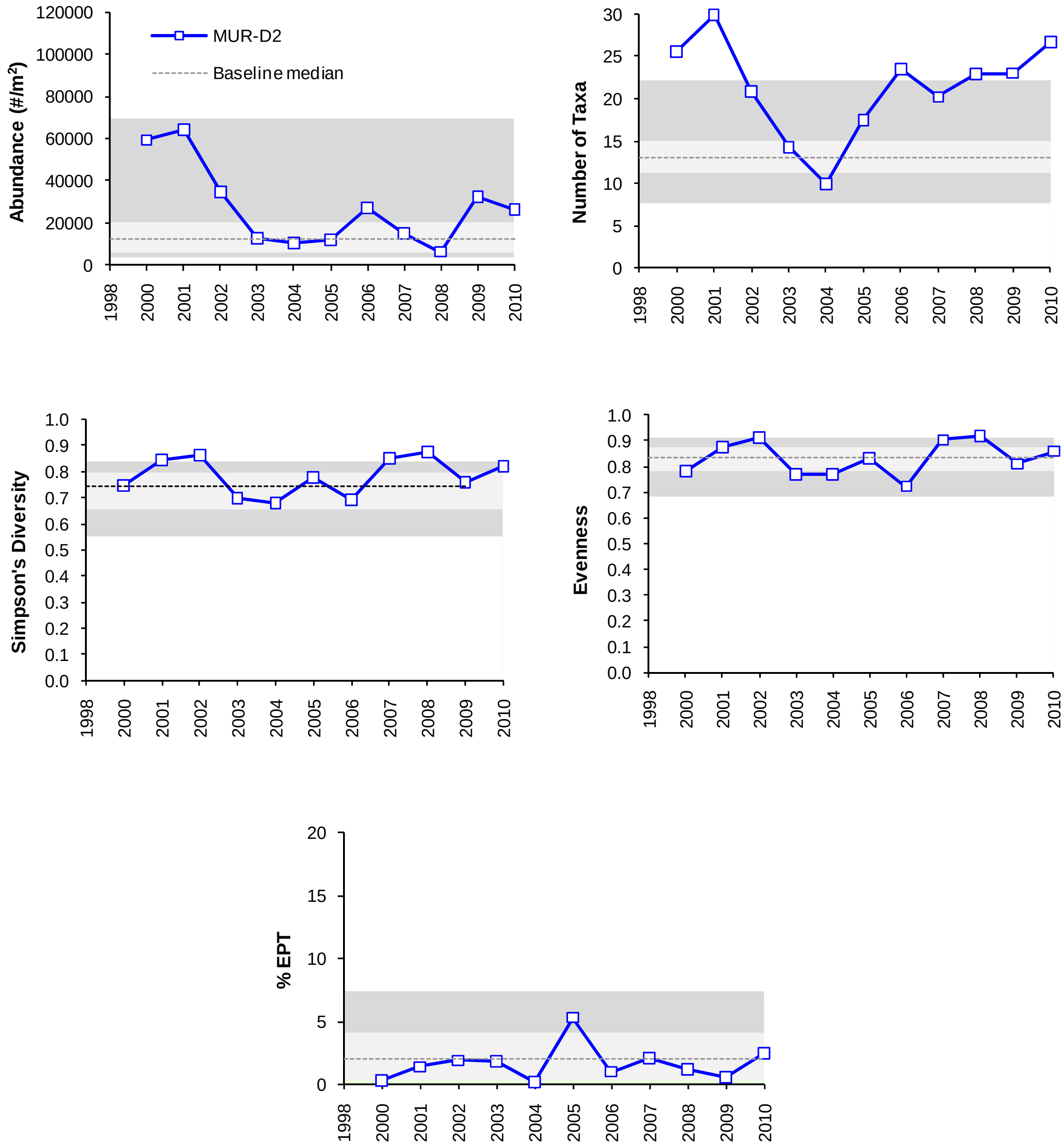
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.2-12 Variation in benthic invertebrate community measurement endpoints in the Muskeg River (*test* reach MUR-E1).



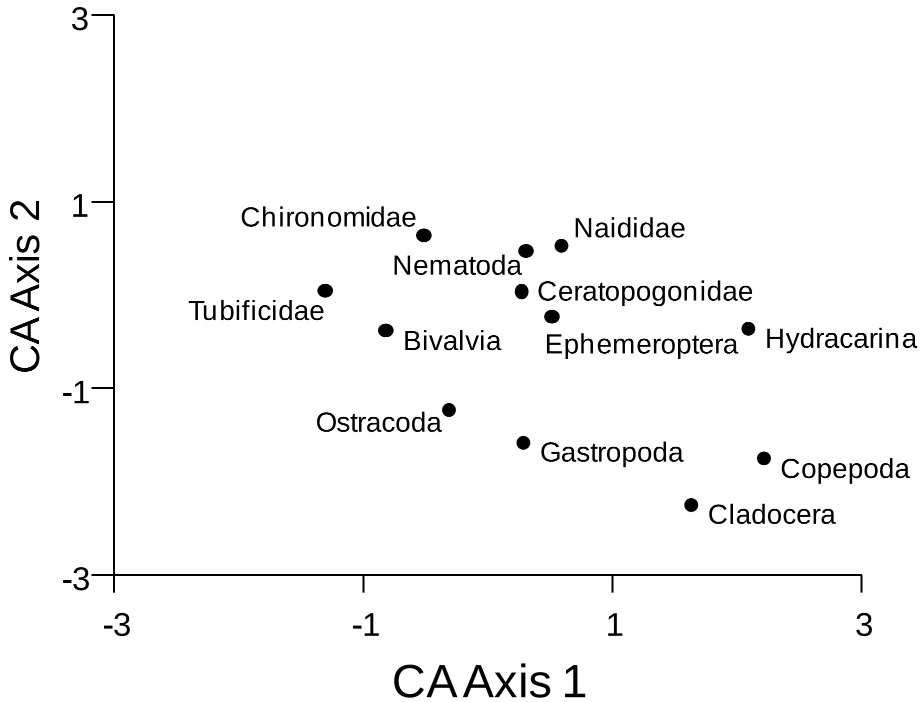
Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

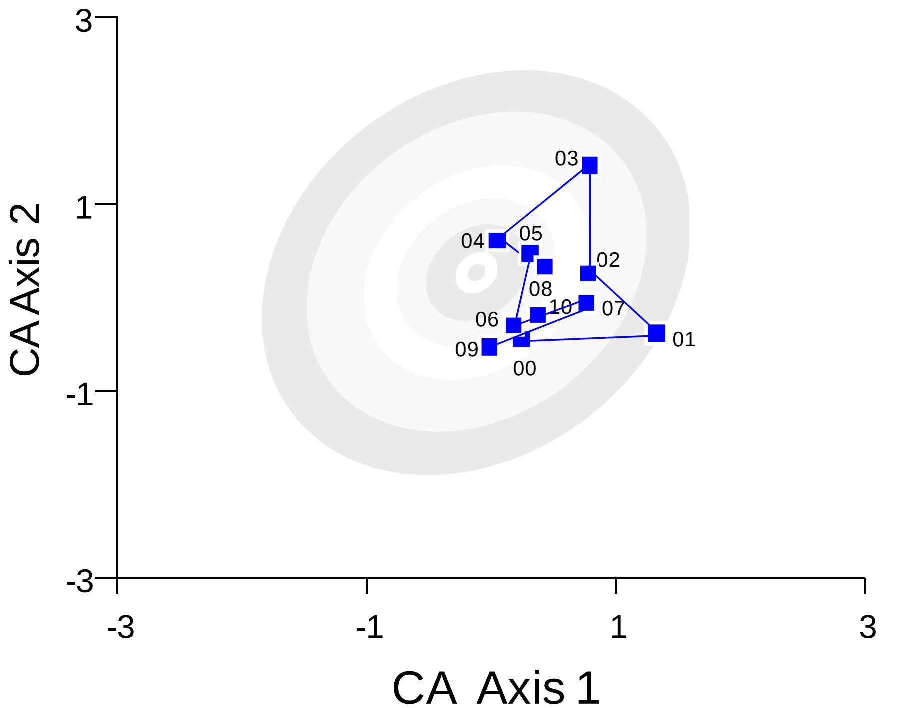
Figure 5.2-13 Variation in benthic invertebrate community measurement endpoints in the Muskeg River (*test* reach MUR-D2).



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

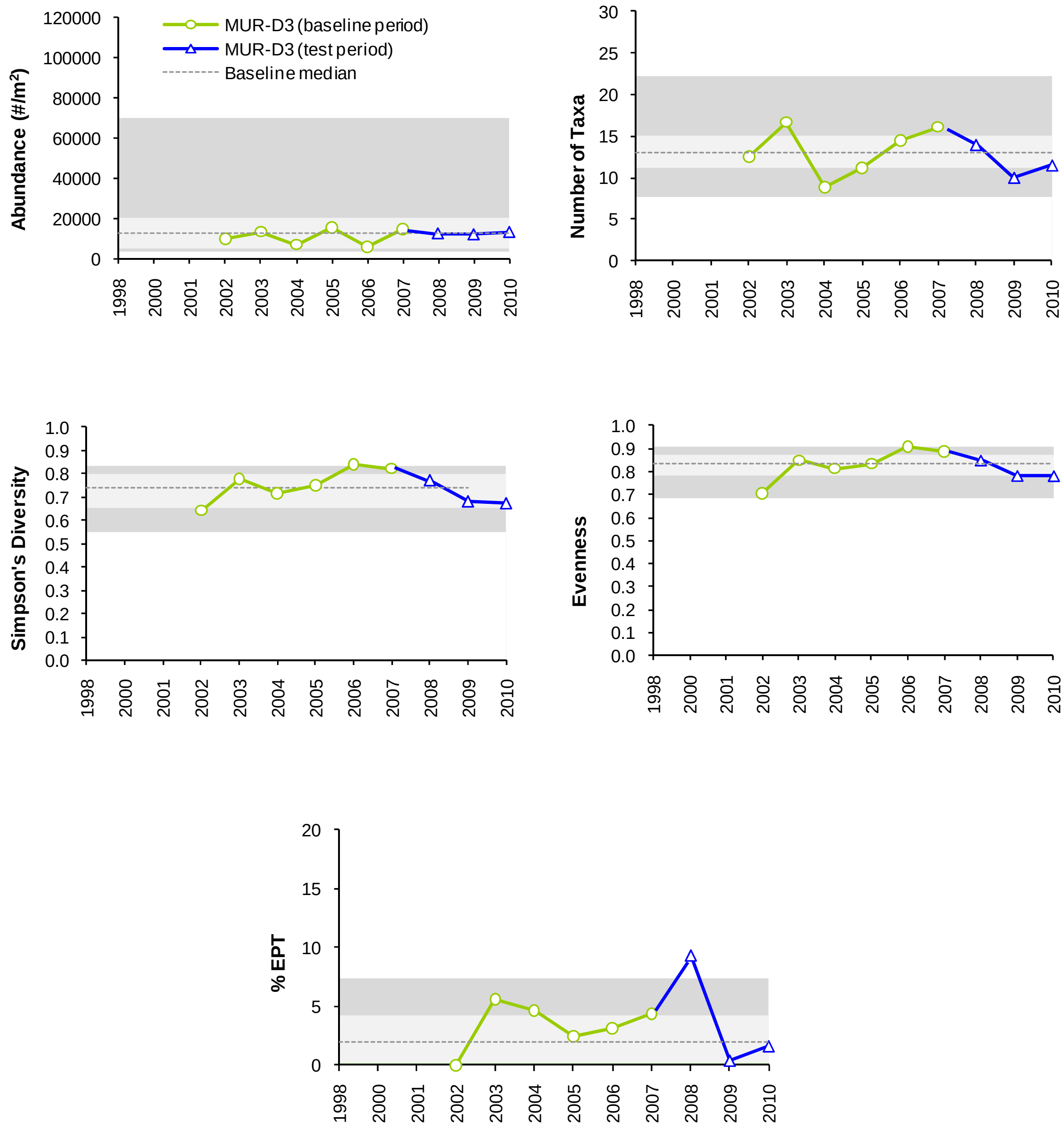
Figure 5.2-14 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River, *test* reach MUR-D2.





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.

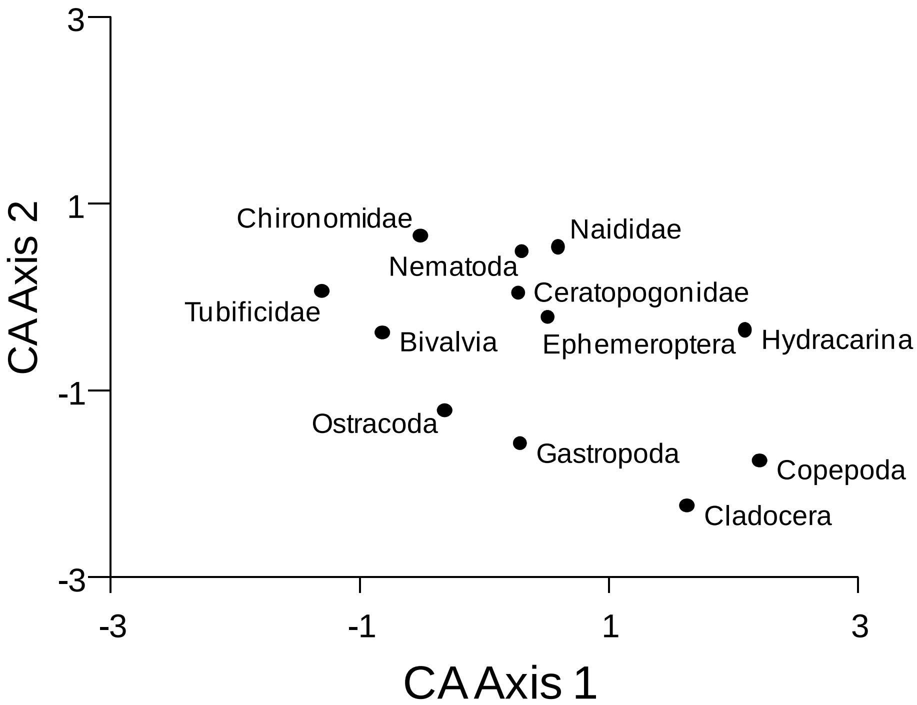
Figure 5.2-15 Variation in benthic invertebrate community measurement endpoints in the upper Muskeg River (MUR-D3).

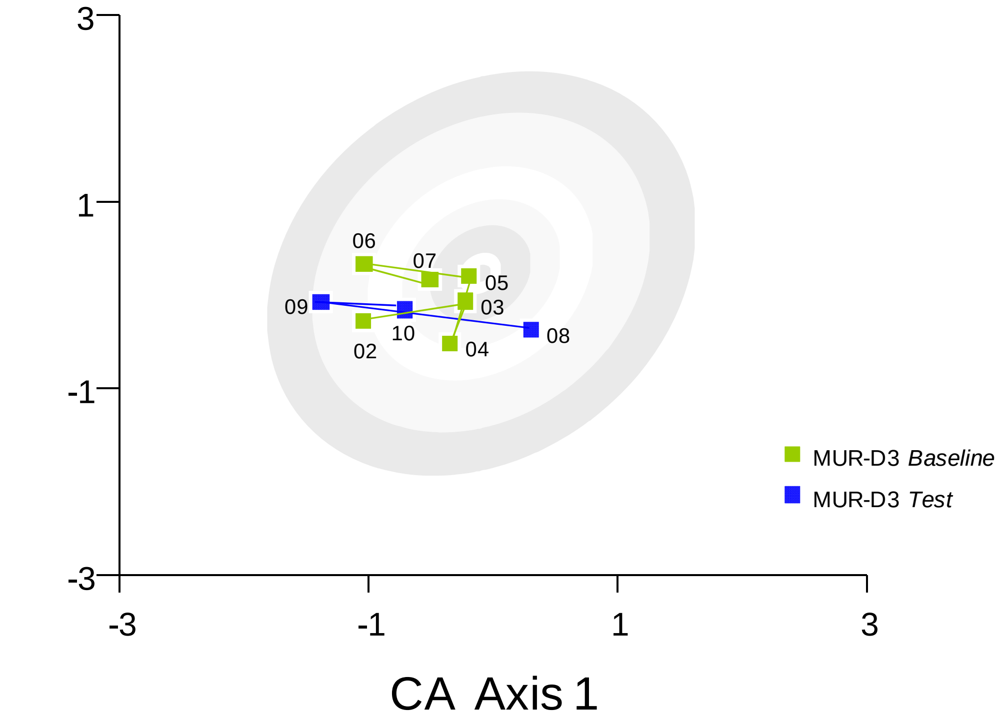


Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Note: *Test* reach MUR-D-3 was designated as *baseline* from 2002 to 2007.

Figure 5.2-16 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River, *test* reach MUR-D3.





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 5.2-23 Average habitat characteristics of benthic invertebrate community sampling locations in Jackpine Creek.

Variable	Units	JAC-D1 *Test* Reach of Jackpine Creek	JAC-D2 *Baseline* Reach of Jackpine Creek
Sample date	-	Sept. 13, 2010	Sept. 12, 2010
Habitat	-	Depositional	Depositional
Water depth	m	0.9	0.8
Current velocity	m/s	0.4	0.6
Field Water Quality			
Dissolved oxygen	mg/L	10.2	9.3
Conductivity	µS/cm	191	185
pH	pH units	8.2	8.2
Water temperature	°C	10.3	10.4
Sediment Composition			
Sand	%	86	75
Silt	%	11	11
Clay	%	3	5
Total Organic Carbon	%	1.4	1.4

Table 5.2-24 Summary of major taxon abundances and benthic invertebrate community measurement endpoints composition in Jackpine Creek.

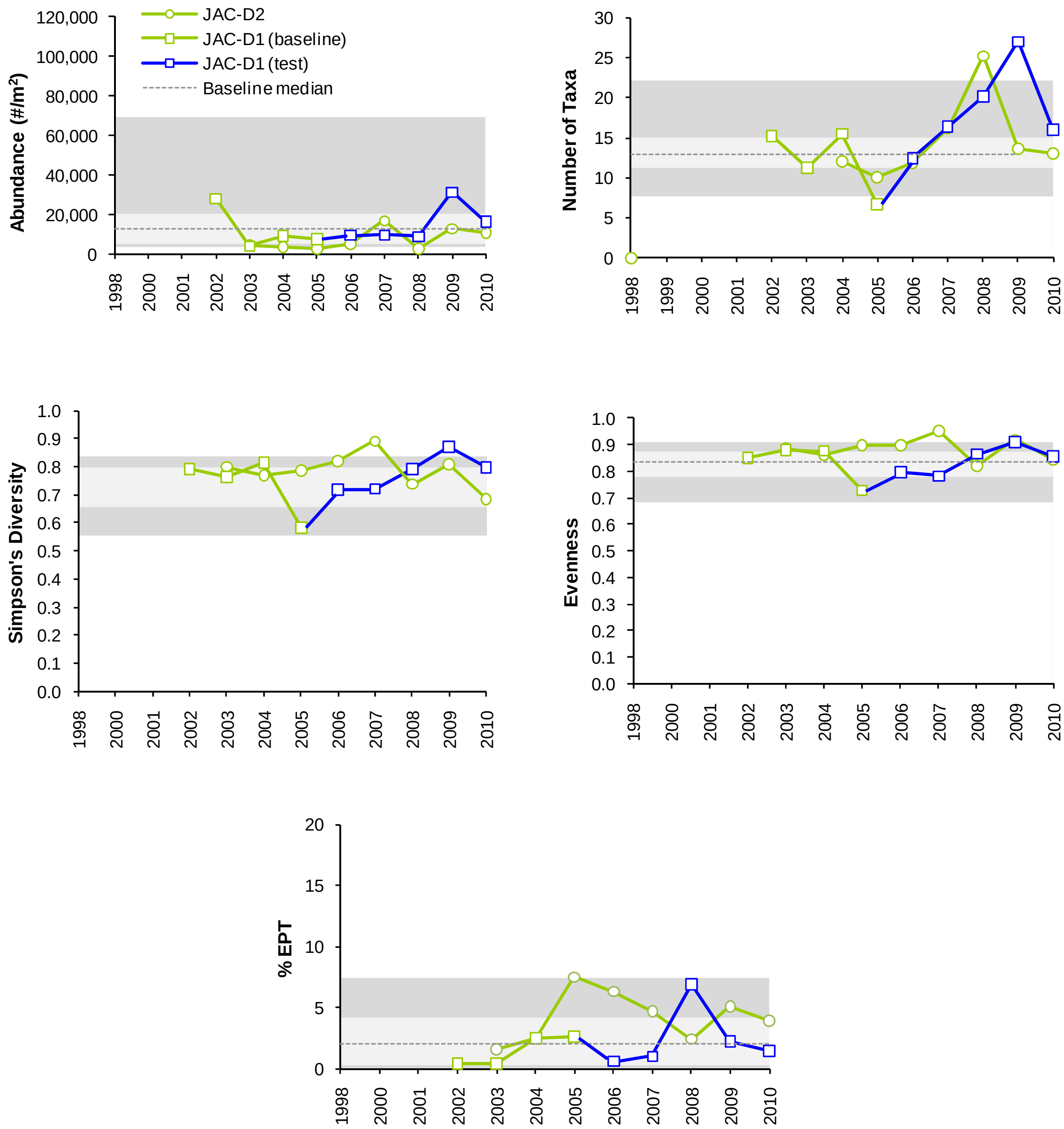
Taxon	Percent Major Taxa Enumerated in Each Year																
	Reach JAC-D1									Reach JAC-D2							
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Amphipoda		<1	<1														
Anisoptera	<1	<1	<1		1	<1	<1	<1	<1			<1				<1	
Bivalvia	1	3	<1	<1		<1	1	<1	<1	<1	<1	<1		<1	2	1	<1
Ceratopogonidae	2	2	4		5	2	9	4	13	1	31	4	2	5	19	11	12
Chironomidae	88	66	69	69	86	66	57	80	53	67	3	44	63	66	60	69	59
Cladocera			8		<1	2	<1	<1	4		<1			<1			
Coleoptera		<1	<1				<1		<1	6	3	6	1	2	3	6	5
Copepoda	<1	1	6	1		1		4	1		2	3		<1	<1		2
Empididae	<1	2	2	4	2	1	1	2	1	1	<1	3	3	1		<1	1
Enchytraeidae	<1	4	<1			<1	1		<1	1	1	1	2	<1	<1	<1	1
Ephemeroptera	<1		2	1	1	1	7	1	3	<1	2	1	6	4	3	7	6
Gastropoda	<1		<1			2	1	<1	4			<1	<1	<1	<1	1	1
Glossiphoniidae		<1													<1		
Hydra			<1						1					<1			
Hydracarina	1	1	1	8	1	5	4	3	1	<1	<1	18	1	2	<1		1
Naididae	<1	2	2		1	<1	1	1	8	3	1	1	2	8	2		5
Nematoda	5	6	1	4	2	2	6	1	2	6	4	2	4	5	3	<1	2
Ostracoda	<1		2	4		1	<1	<1	1	<1	1	3	1	<1	<1		1
Plecoptera					1		<1			<1					<1	<1	
Tabanidae	<1	<1	<1	<1	<1	<1	1	<1	1	1	2	<1	<1	<1	<1	<1	<1
Tipulidae	<1	2	1	1	1	<1	<1		<1	1	13	4	2	<1	<1	2	1
Trichoptera	<1	<1	<1	3	<1	<1	2	1	<1	<1	1	7	1	2	1	1	<1
Tubificidae	<1	<1	1	5	<1	17	8	1	7	2	5	1	2	5	2	1	2
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	16,427	4,787	3,448	2,957	5,174	16,966	2,752	12,952	10,879
Richness	15	11	15	7	12	16	20	27	16	12	10	12	16	25	14	13	14
Simpson's Diversity	0.79	0.76	0.81	0.58	0.72	0.72	0.79	0.87	0.80	0.8	0.77	0.78	0.82	0.89	0.74	0.81	0.68
Evenness	0.85	0.88	0.88	0.73	0.73	0.78	0.82	0.91	0.86	0.89	0.86	0.9	0.86	0.95	0.87	0.92	0
% EPT	<1	<1	2	3	<1	1	2	2	1	2	2	7	6	5	6	5	4

Table 5.2-25 Analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints between *test* reach JAC-D1 and *baseline* reach JAC-D2 of Jackpine Creek.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Difference between *Baseline* and *Test* from Before to After	Time Trend (*test* period)	Difference between *Baseline* and *Test* from Before to After	Time Trend (*test* period)	
Abundance	0.135	0.444	4	1	No differences between *test* and *baseline* reaches or across time
Richness	0.151	**0.004**	4	16	Increasing in *test* reach and decreasing in *baseline* reach
Simpson's Diversity	0.293	**0.007**	4	26	Increasing in *test* reach and decreasing in *baseline* reach
Evenness	0.977	**0.043**	0	17	Increasing in *test* reach and decreasing in *baseline* reach
EPT	0.872	**0.029**	0	12	Increasing in *test* reach and decreasing in *baseline* reach
CA Axis 1	0.620	0.106	1	10	No differences between *test* and *baseline* reaches or across time
CA Axis 2	0.703	0.257	0	1	No differences between *test* and *baseline* reaches or across time

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

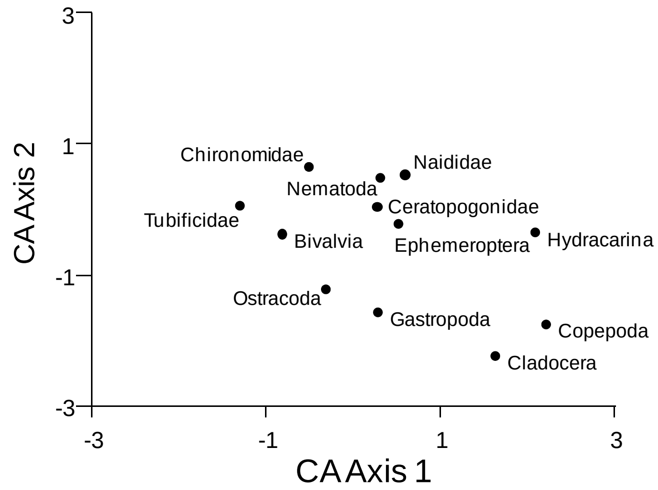
Figure 5.2-17 Variations in benthic invertebrate community measurement endpoints in *test* reach JAC-D1 and *baseline* reach JAC-D2 of Jackpine Creek.

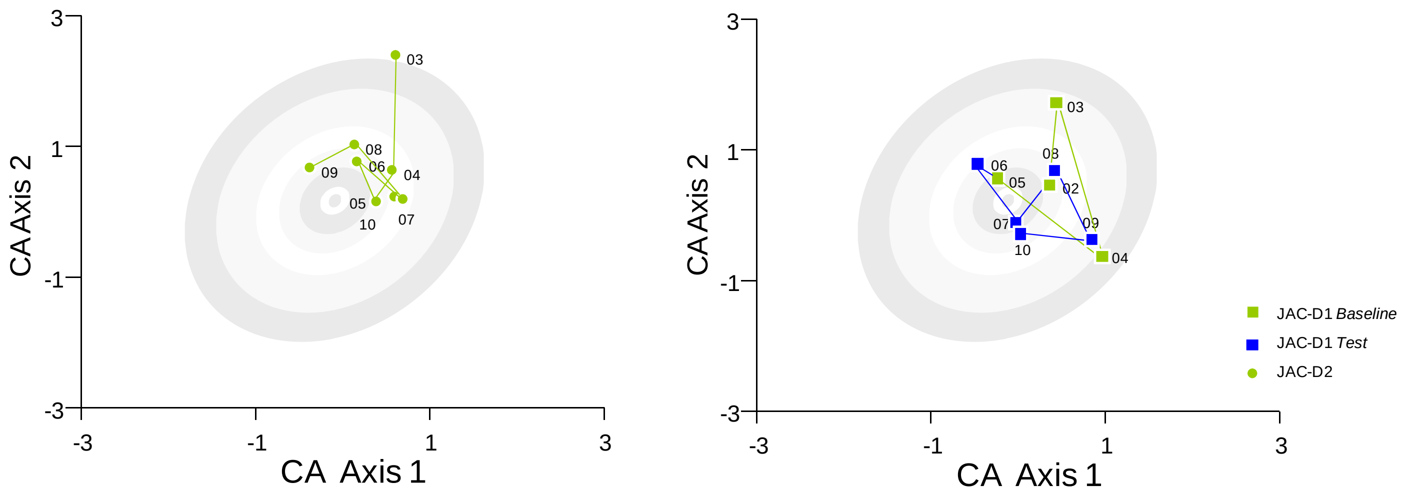


Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Note: *Test* reach JAC-D-1 was designated as *baseline* from 2002 to 2005.

Figure 5.2-18 Ordination (Correspondence Analysis) of benthic invertebrate community composition in *test* reach JAC-D1 and *baseline* reach JAC-D2 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 5.2-26 Average habitat characteristics of benthic invertebrate community sampling locations in Kearl Lake (*test* station KEL-1).

Variable	Units	Kearl Lake
Sample date	-	Sept. 10, 2010
Habitat	-	Depositional
Water depth	m	2.3
Current velocity	m/s	-
Field Water Quality		
Dissolved oxygen	mg/L	7.5
Conductivity	µS/cm	154
pH	pH units	8.2
Water temperature	°C	13.5
Sediment Composition		
Sand	%	59
Silt	%	36
Clay	%	6
Total Organic Carbon	%	35

Table 5.2-27 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Kearl Lake (*test* station KEL-1).

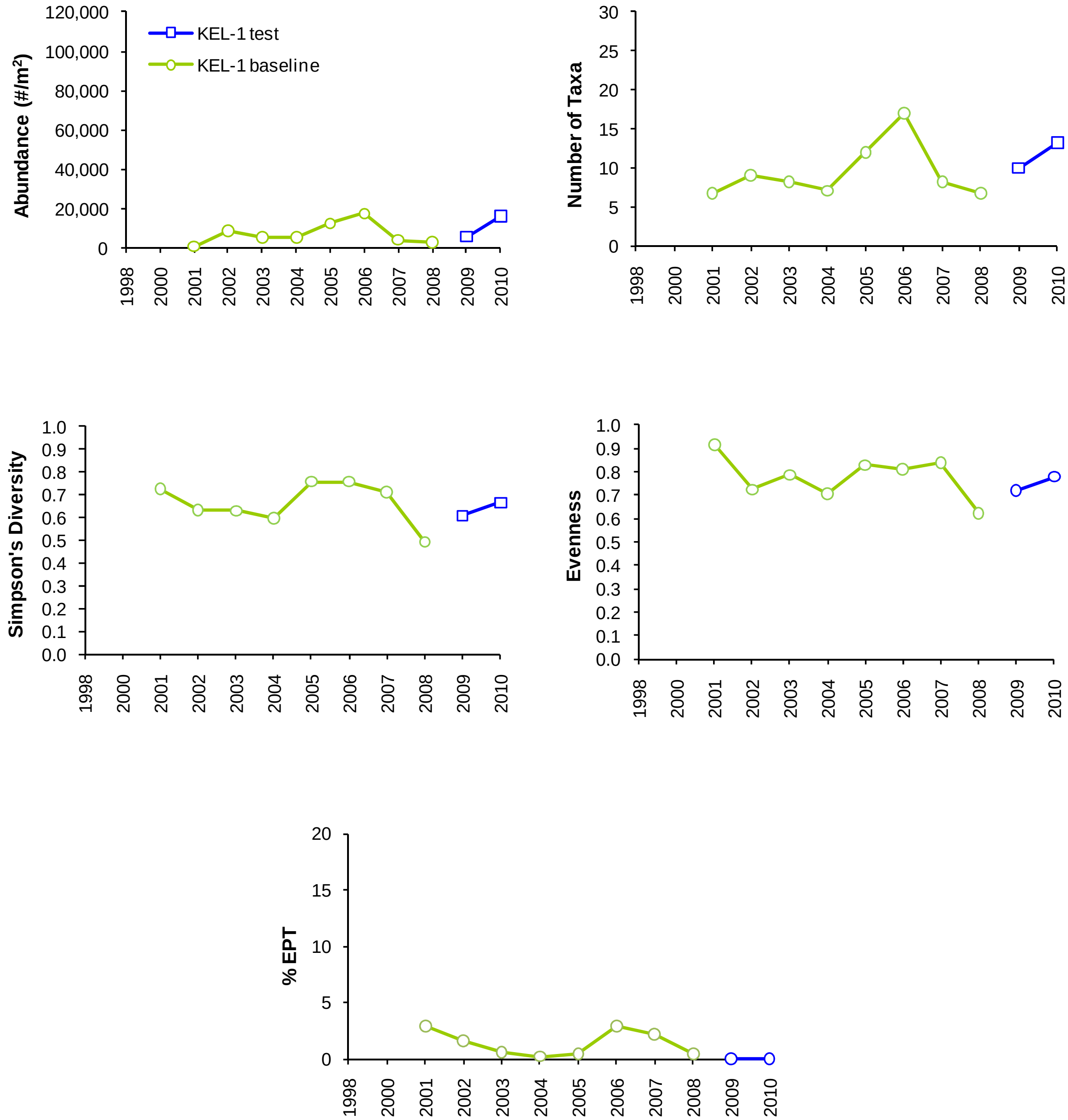
Taxon	Percent Major Taxa Enumerated in Each Year									
	KEL-1									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Amphipoda	13	46	36	58	25	23	27	2	8	7
Anisoptera						<1				<1
Bivalvia	4	4	6	9	4	23	7	11	6	7
Ceratopogonidae		1	1			<1		<1	<1	<1
Chaoboridae	1						<1	<1	<1	<1
Chironomidae	6	42	46	20	45	42	24	28	21	13
Cladocera	1		<1	1	7	<1		1	<1	14
Copepoda	<1	<1		2	15	<1	31	38	56	30
Ephemeroptera	<1	1				2	1			<1
Erpobdellidae					<1	<1		<1	<1	<1
Gastropoda	1	<1				<1		1	<1	<1
Glossiphoniidae	<1	1	1	<1				<1		
Hydracarina	<1		<1				2	7		1
Lumbriculidae						<1				
Naididae		<1	6	5	1	3	2	5	5	20
Nematoda					1	1	3	5		3
Ostracoda	7	7	4	4	1	<1	1		<1	2
Trichoptera	2	1	1	<1	<1	1	2	1		<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	16,370
Richness	7	9	8	7	12	17	8	7	10	1
Simpson's Diversity	0.73	0.64	0.63	0.6	0.76	0.76	0.71	0.49	0.61	0.67
Evenness	0.92	0.72	0.79	0.71	0.83	0.76	0.84	0.62	0.72	0.78
% EPT	3	2	1	<1	<1	2	2	<1	0	<1

Table 5.2-28 Results of analysis of variance (ANOVA) *test*ing for differences in benthic invertebrate community measurement endpoints in Kearl Lake.

Variable	P-value Difference between *Baseline* and *Test* from Before to After	Variance Explained (%) Difference between *Baseline* and *Test* from Before to After	Nature of Changes
Abundance	0.295	2	No difference between *baseline* and *test* period
Richness	0.443	2	No difference between *baseline* and *test* period
Simpson's Diversity	0.497	2	No difference between *baseline* and *test* period
Evenness	0.531	2	No difference between *baseline* and *test* period
EPT	**0.002**	36	Lower in *test* period
CA Axis 1	**0.024**	8	Lower in *test* period
CA Axis 2	0.113	5	No difference between *baseline* and *test* period

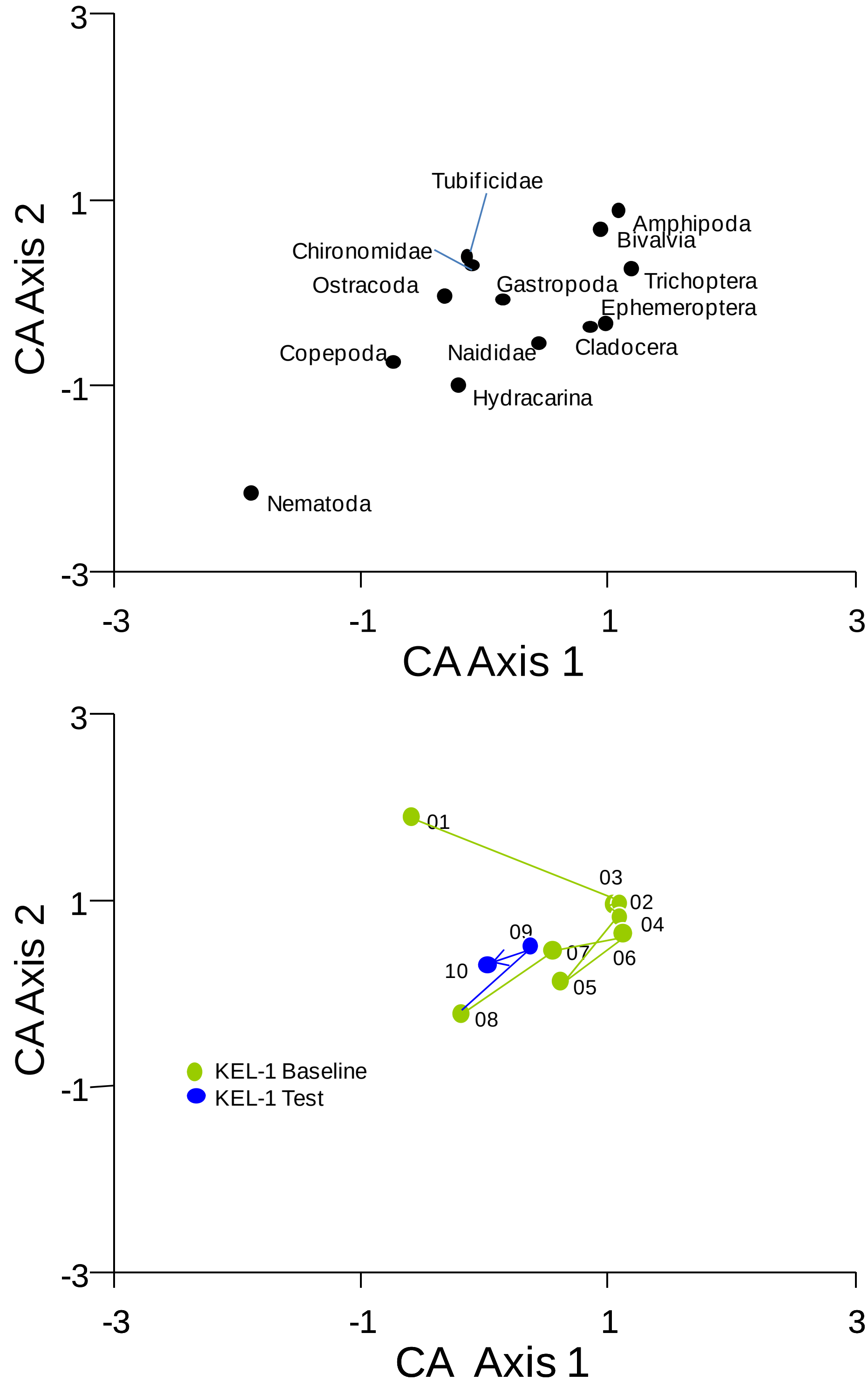
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.2-19 Variations in benthic invertebrate community measurement endpoints in Kearl Lake (KEL-1).



Note: Kearl Lake was designated as *baseline* from 2001 to 2008, shown in green up to 2009.

Figure 5.2-20 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.

Table 5.2-29 Concentrations of selected sediment quality measurement endpoints in the Muskeg River (*test* station MUR-D2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2000-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	9.3	7	<1	4	12
Silt	%	-	26.7	7	<1	16	32
Sand	%	-	64.0	7	60	79	100
Total organic carbon	%	-	5.5	8	0.2	2.8	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	6	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	6	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	71	6	<5	89	**180**
Fraction 3 (C16-C34)	mg/kg	300[1]	**829**	6	110	**1500**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	647	6	62	1250	2100
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0025	8	0.0013	0.0029	0.0200
Retene	mg/kg	-	0.184	8	0.0116	0.1645	0.314
Total dibenzothiophenes	mg/kg	-	7.865	8	0.287	4.306	11.040
Total PAHs	mg/kg	-	20.876	8	0.904	14.799	30.440
Total Parent PAHs	mg/kg	-	0.364	8	0.029	0.359	1.295
Total Alkylated PAHs	mg/kg	-	20.512	8	0.875	14.439	29.764
Predicted PAH toxicity[3]	H.I.	-	3.997	8	0.931	1.455	1.733
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	7	2.6	7.0	8.6
Chironomus growth - 10d	mg/organism	-	ns	7	0.680	2.114	2.500
Hyalella survival - 14d	# surviving	-	ns	7	8.0	8.0	9.2
Hyalella growth - 14d	mg/organism	-	ns	7	0.110	0.246	0.350

Values in **bold** indicate concentrations exceeding guidelines.

ns = not sampled

[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 Muskeg River (*test* station MUR-D3), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2003-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay[4]	%	-	5.3	7	1	7	47
Silt[4]	%	-	9.6	7	1	14	29
Sand[4]	%	-	85.1	7	26	79	98
Total organic carbon	%	-	23.9	7	1.7	22.2	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	6	<5	<5	<73
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	6	<5	<5	<73
Fraction 2 (C10-C16)	mg/kg	150[1]	<90	6	<5	17	130
Fraction 3 (C16-C34)	mg/kg	300[1]	**867**	6	52	**726**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	305	6	71	478	1800
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.010	7	0.003	0.007	0.015
Retene	mg/kg	-	2.330	7	0.131	0.349	0.522
Total dibenzothiophenes	mg/kg	-	0.149	7	0.048	0.123	0.190
Total PAHs	mg/kg	-	0.041	7	0.379	1.124	1.392
Total Parent PAHs	mg/kg	-	0.041	7	0.030	0.050	0.340
Total Alkylated PAHs	mg/kg	-	3.054	7	0.349	0.968	1.188
Predicted PAH toxicity[3]	H.I.	-	0.791	7	0.025	0.284	0.541
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	6	3.0	6.5	8.8
Chironomus growth - 10d	mg/organism	-	ns	6	1.3	1.6	2.2
Hyalella survival - 14d	# surviving	-	ns	6	7.0	8.2	9.2
Hyalella growth - 14d	mg/organism	-	ns	6	0.1	0.2	0.3

Values in **bold** indicate concentrations exceeding guidelines.

ns = not sampled

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 5.2-31 Concentrations of selected sediment quality measurement endpoints in Jackpine Creek (*test* station JAC-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	1.4	6	<1	5	19
Silt	%	-	4.6	6	<1	11	13
Sand	%	-	94.0	6	81	84	99
Total organic carbon	%	-	1.1	6	0.2	1.2	2.7
Total hydrocarbons							
BTEX	mg/kg	-	<10	6	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	6	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	5	13	25	71
Fraction 3 (C16-C34)	mg/kg	300[1]	242	5	150	**510**	**790**
Fraction 4 (C34-C50)	mg/kg	2800[1]	312	5	210	734	820
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0028	6	0.0007	0.0012	0.0030
Retene	mg/kg	-	0.0229	5	0.0072	0.0422	0.9510
Total dibenzothiophenes	mg/kg	-	0.2474	6	0.1047	0.6029	1.6392
Total PAHs	mg/kg	-	1.1963	6	0.4129	1.8356	4.4924
Total Parent PAHs	mg/kg	-	0.0429	6	0.0218	0.1049	0.1360
Total Alkylated PAHs	mg/kg	-	1.1534	6	0.3911	1.7517	4.3754
Predicted PAH toxicity[4]	H.I.	-	0.5972	6	0.2138	0.3102	1.1099
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.8	4	5.6	7.1	8.6
Chironomus growth - 10d	mg/organism	-	3.396	4	1.148	2.767	3.200
Hyalella survival - 14d	# surviving	-	9.8	4	7.0	9.3	9.6
Hyalella growth - 14d	mg/organism	-	0.268	4	0.140	0.270	0.314

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 Jackpine Creek (*baseline* station JAC-D2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2006-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	8.2	4	1	10	13
Silt	%	-	21.8	4	<1	18	23
Sand	%	-	70.1	4	66	72	98
Total organic carbon	%	-	1.7	4	0.1	1.2	1.9
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	8	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	8	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	<27	4	<5	7	20
Fraction 3 (C16-C34)	mg/kg	300[1]	74	4	10	107	190
Fraction 4 (C34-C50)	mg/kg	2800[1]	53	4	<5	69	160
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0041	3	0.0008	0.0012	0.0022
Retene	mg/kg	-	0.0153	3	0.0010	0.0286	0.0331
Total dibenzothiophenes	mg/kg	-	0.0266	3	0.0019	0.0050	0.0069
Total PAHs	mg/kg	-	0.2002	3	0.0143	0.0973	0.1200
Total Parent PAHs	mg/kg	-	0.0199	3	0.0037	0.0074	0.0203
Total Alkylated PAHs	mg/kg	-	0.1803	3	0.0106	0.0899	0.0996
Predicted PAH toxicity[3]	H.I.	-	0.3539	3	0.1351	0.1924	0.2261
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.6	3	4.6	9.2	9.6
Chironomus growth - 10d	mg/organism	-	3.054	3	0.796	2.262	2.360
Hyalella survival - 14d	# surviving	-	8.6	3	8.0	8.8	9.8
Hyalella growth - 14d	mg/organism	-	0.290	3	0.304	0.326	0.338

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 5.2-33 Concentrations of selected sediment quality measurement endpoints in Kearl Lake (*test* station KEL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2001-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay[4]	%	-	16.3	6	1	17	58
Silt[4]	%	-	28.1	6	4	12	62
Sand[4]	%	-	55.7	6	9	61	93
Total organic carbon	%	-	33.4	6	31.1	34.4	38.1
Total hydrocarbons							
BTEX	mg/kg	-	<10	5	<5	8	<220
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	5	<5	8	<220
Fraction 2 (C10-C16)	mg/kg	150[1]	**410**	5	<5	13	**530**
Fraction 3 (C16-C34)	mg/kg	300[1]	**822**	5	230	**334**	**3600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	452	5	81	258	2500
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	ns	3	0.012	0.020	0.036
Retene	mg/kg	-	0.016	6	0.030	0.054	0.113
Total dibenzothiophenes	mg/kg	-	0.058	6	0.028	0.038	0.084
Total PAHs	mg/kg	-	0.723	6	0.793	0.984	1.432
Total Parent PAHs	mg/kg	-	0.080	6	0.078	0.136	0.345
Total Alkylated PAHs	mg/kg	-	0.642	6	0.668	0.781	1.291
Predicted PAH toxicity[3]	H.I.	-	0.117	6	0.031	0.425	0.924
Metals that exceed CCME guidelines in 2010							
none	mg/kg						
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	3	8.8	8.8	9.0
Chironomus growth - 10d	mg/organism	-	ns	3	1.2	1.3	1.5
Hyalella survival - 14d	# surviving	-	ns	3	7.6	9.0	9.0
Hyalella growth - 14d	mg/organism	-	ns	3	0.1	0.2	0.3

Values in **bold** indicate concentrations exceeding guidelines.

ns = not sampled

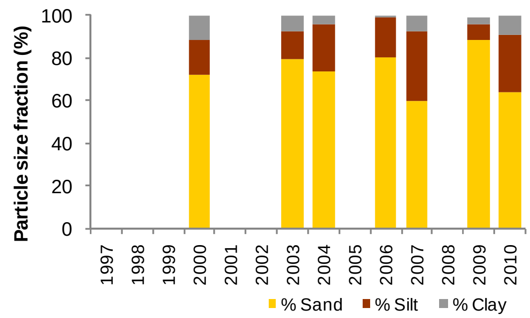
[1] Guideline is for residential/parkland coarse (median grain size > 75 µm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

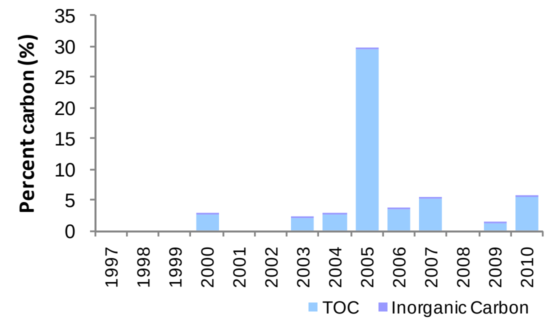
[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Figure 5.2-21 Variation in sediment quality measurement endpoints in the Muskeg River, *test* station MUR-D2.

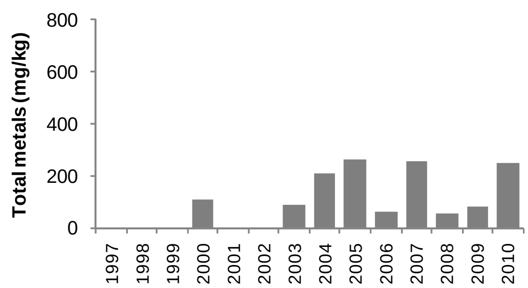
Particle size distribution



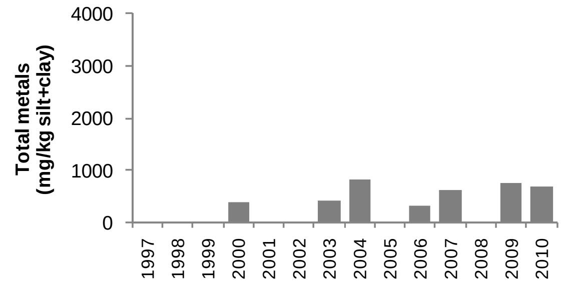
Carbon Content



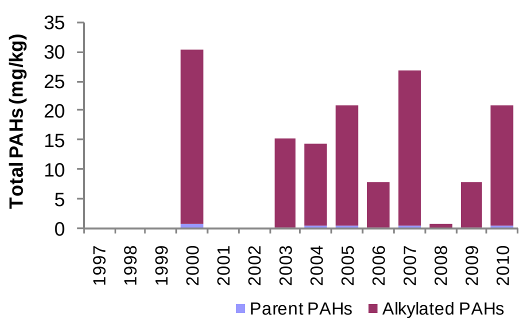
Total Metals*



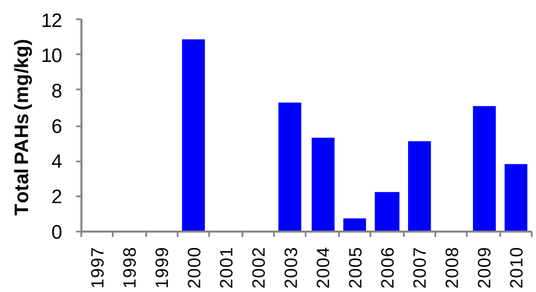
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



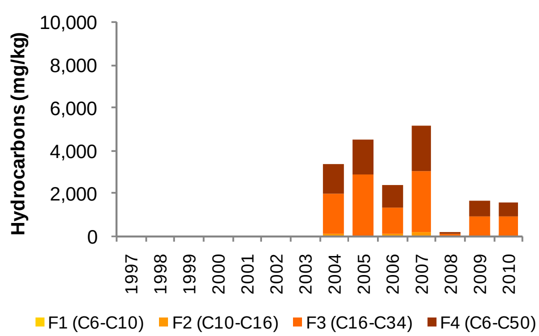
Total PAHs



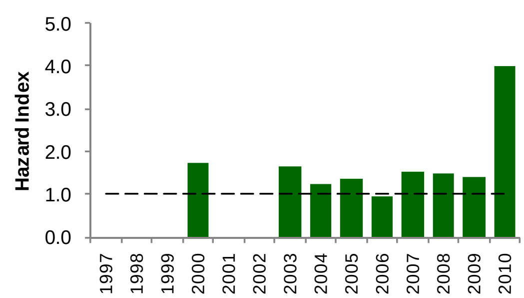
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



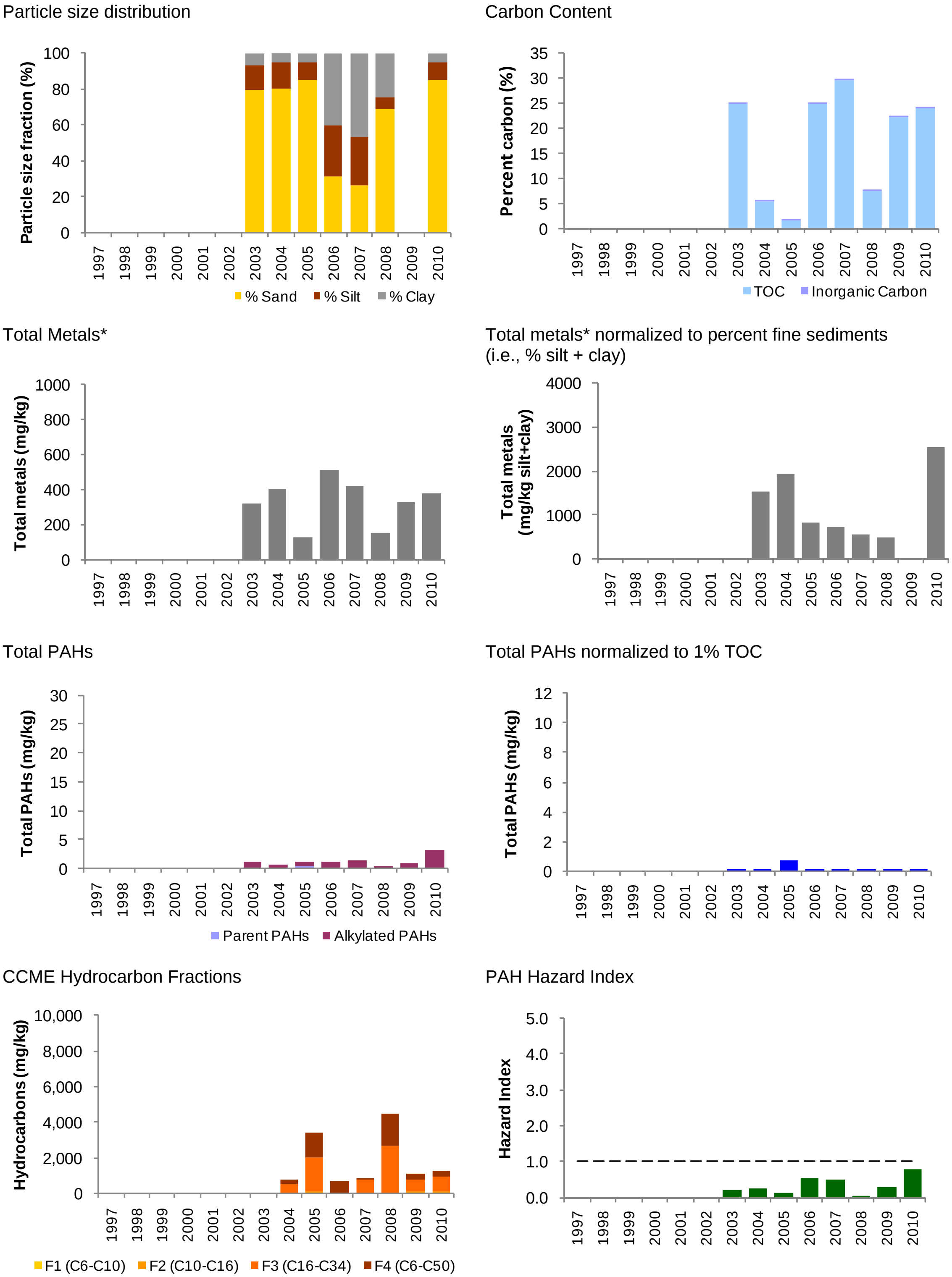
PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.2-22 Variation in sediment quality measurement endpoints in the Muskeg River, *test* station MUR-D3.

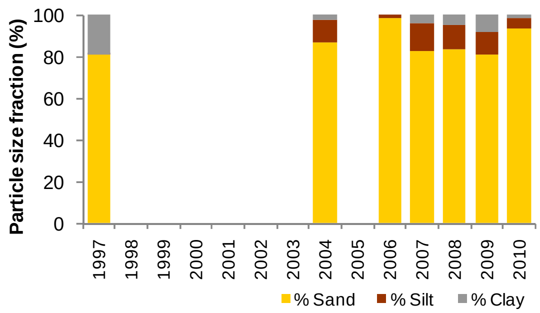


* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

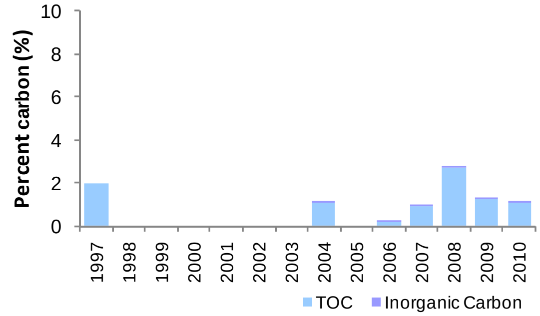
** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.2-23 Variation in sediment quality measurement endpoints in Jackpine Creek, *test* station JAC-D1.

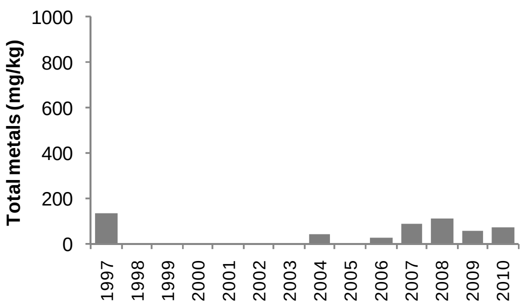
Particle size distribution



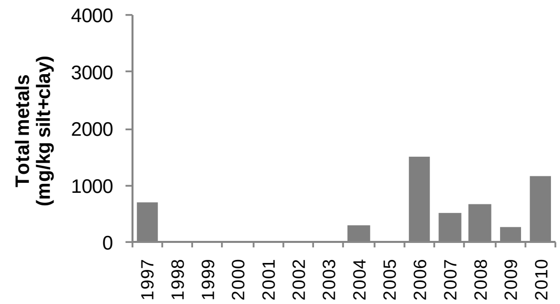
Carbon Content



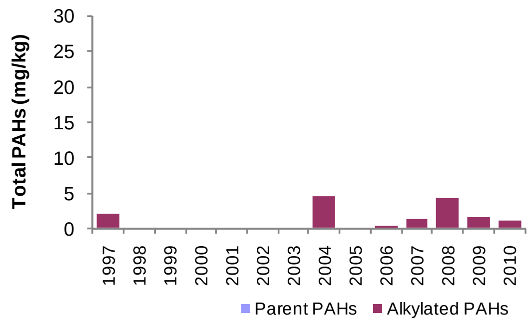
Total Metals*



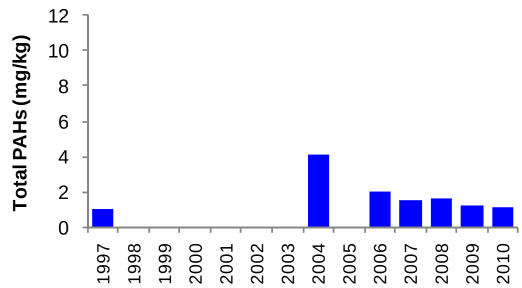
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



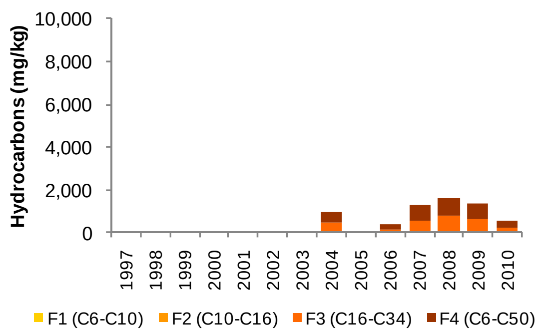
Total PAHs



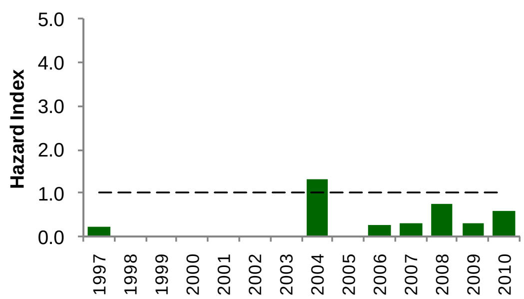
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



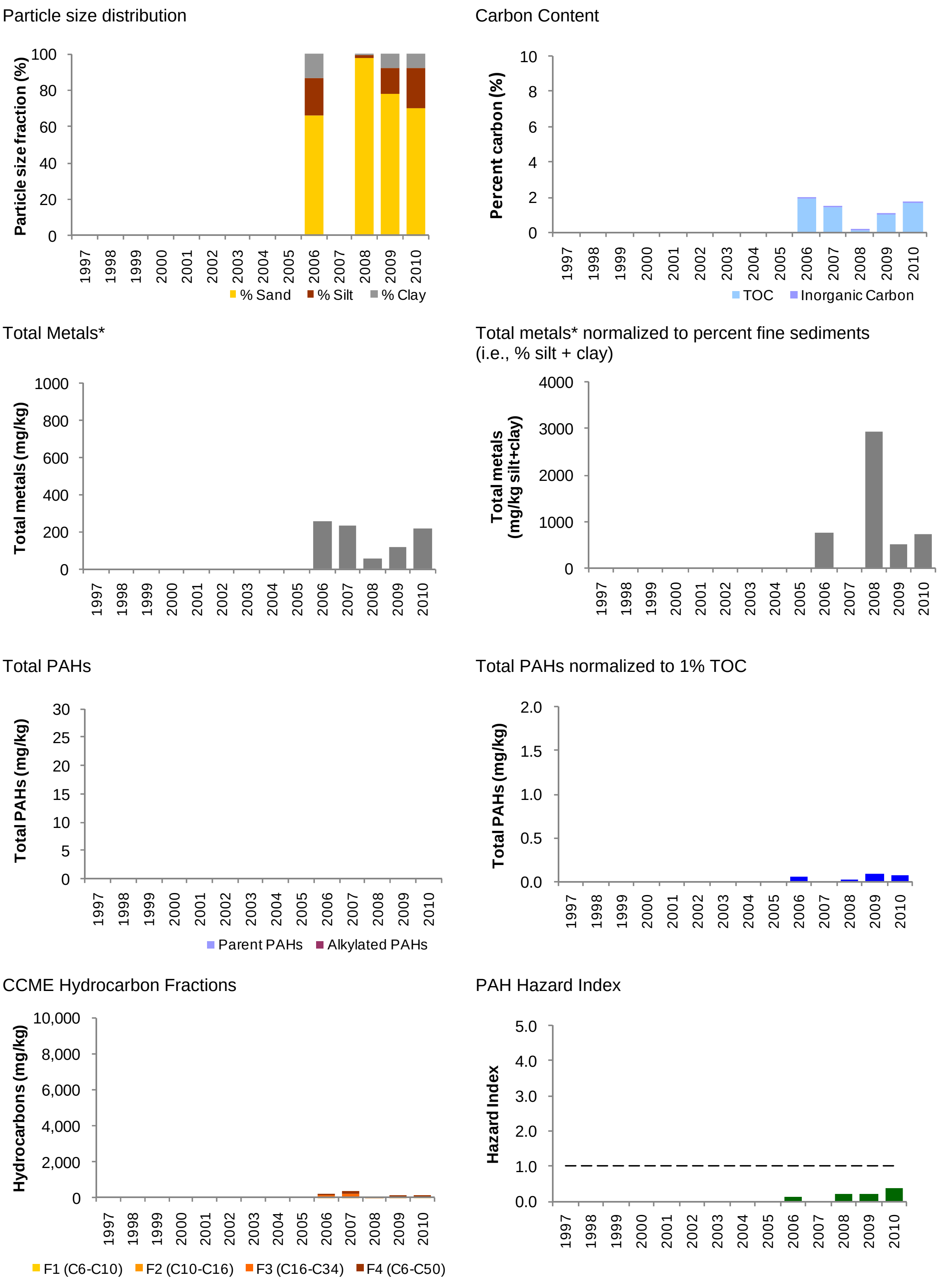
PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

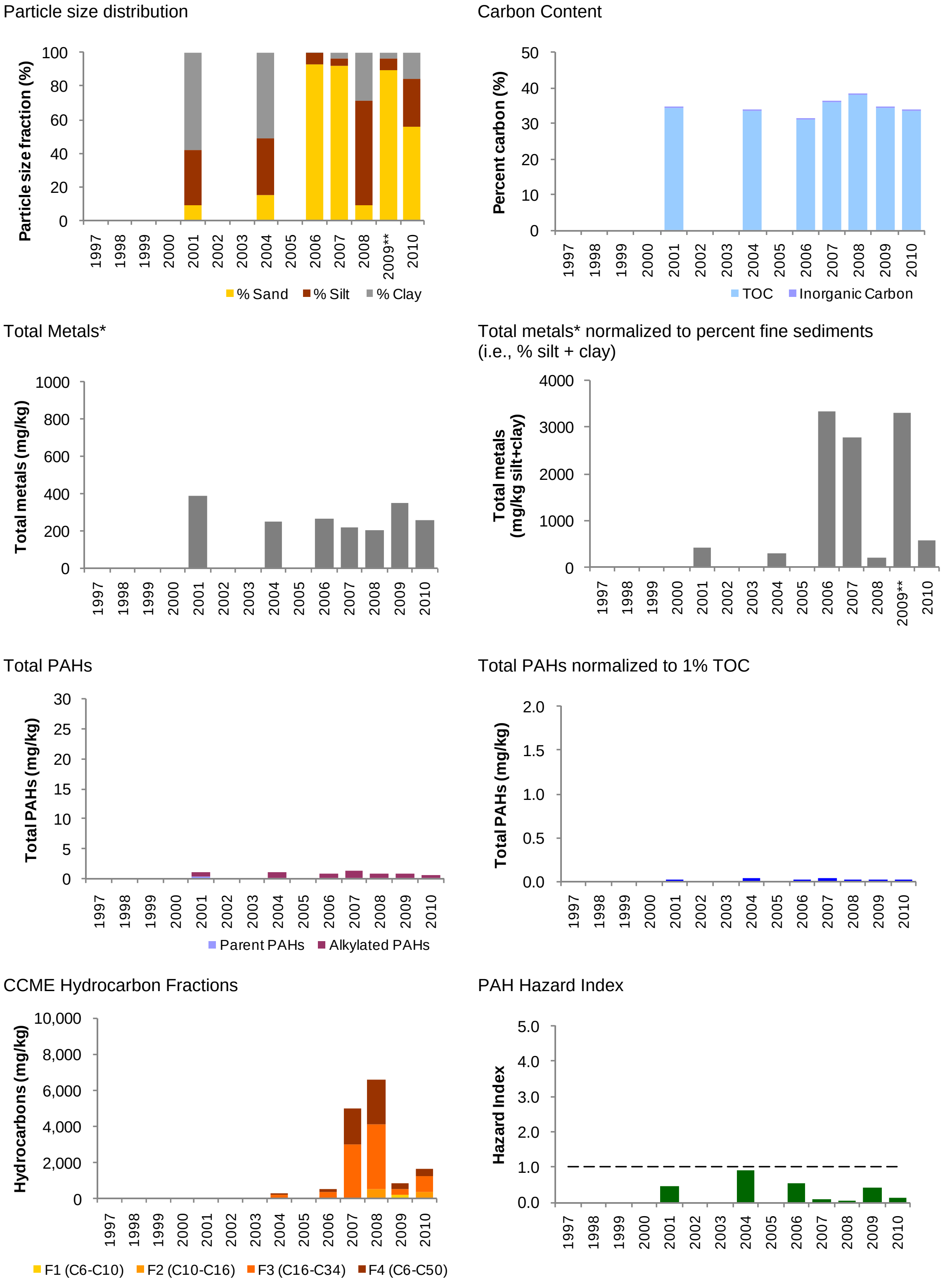
Figure 5.2-24 Variation in sediment quality measurement endpoints in Jackpine Creek, *baseline* station JAC-D2.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.2-25 Variation in sediment quality measurement endpoints in Kearl Lake, *test* station KEL-1.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Table 5.2-34 Sediment quality index (fall 2010) for Muskeg River watershed stations.

Station Identifier	Location	2010 Designation	Sediment Quality Index	Classification
JAC-D1	Mouth of Jackpine Creek	*test*	98.9	Negligible-Low
JAC-D2	Upper Jackpine Creek	*baseline*	98.9	Negligible-Low
MUR-D2	Muskeg River at Canterra Road	*test*	86.1	Negligible-Low
MUR-D3	Upper Muskeg River	*test*	93.6	Negligible-Low

Note: see Figure 5.2-1 for the locations of these sediment quality stations.
Note: see Section 3.2.3.2 for a description of the Sediment Quality Index.

5.3 STEEPBANK RIVER WATERSHED

Table 5.3-1 Summary of results for the Steepbank River watershed.

Steepbank River Watershed	Summary of 2010 Conditions			
	Steepbank River			*North Steepbank River*
Climate and Hydrology				
Criteria	**S38** near Fort McMurray			no station
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-E1** lower reach	no reach sampled	**STR-E2** upper reach	no reach sampled
Benthic Invertebrate Communities	🟠		n/a	
No Sediment Quality component activities conducted in 2010				
Fish Populations				
Fish Populations component activities are included in the Fish Assemblage Monitoring Pilot Study (Section 6.0)				

Legend and Notes

🟡 Negligible - Low	*baseline*
🟠 Moderate	*test*
🟤 High	

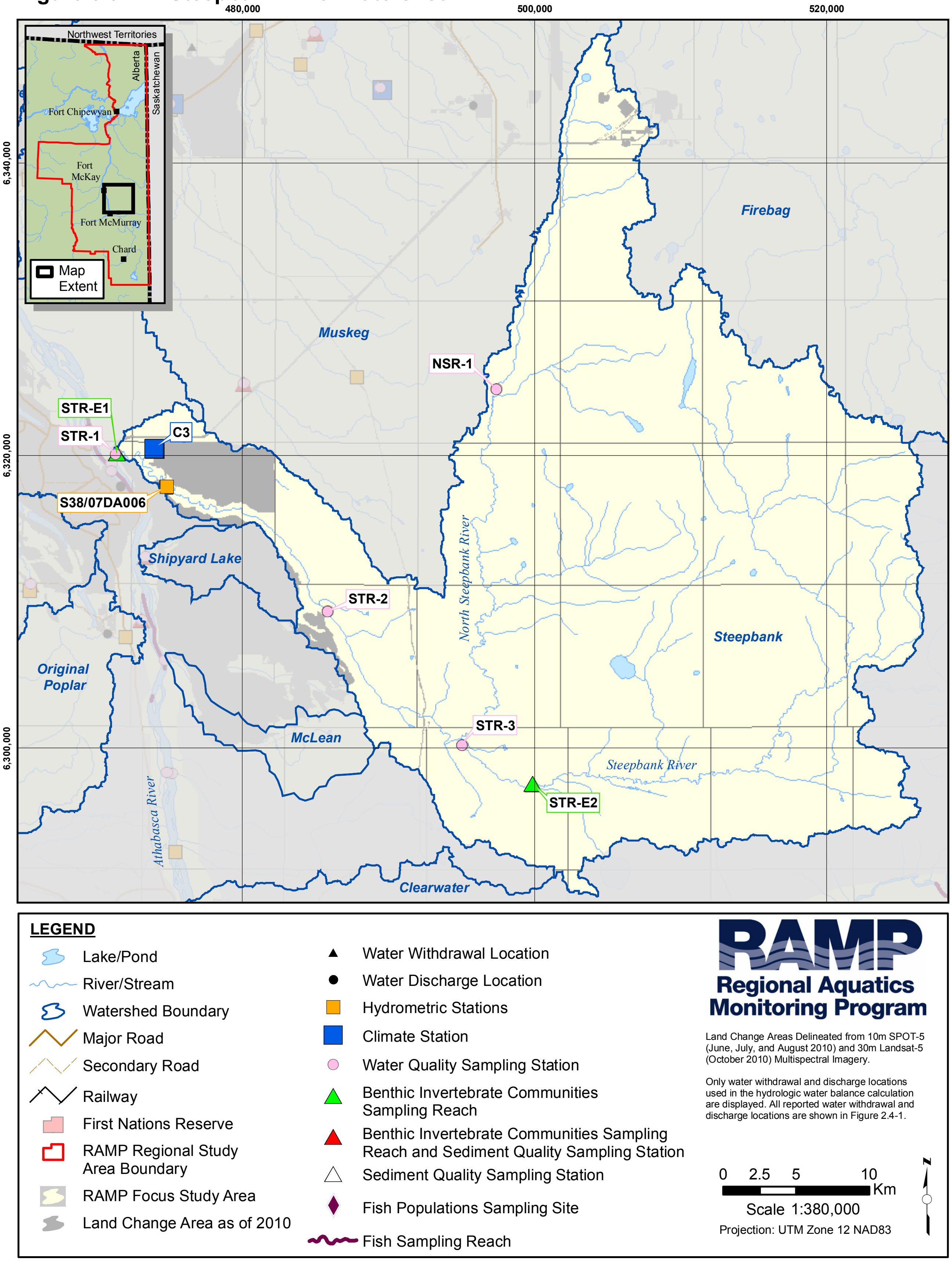
n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between baseline and test areas as well as comparison to regional baselines; see Section 3.2.3.1 for a detailed description of the classification methodology.

Figure 5.3-1 Steepbank River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K03_Steepbank_20110318.mxd

Figure 5.3-2 Representative monitoring stations of the Steepbank River, fall 2010.

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 2010 Conditions

Approximately 3.3% (4,500 ha) of the Steepbank River watershed had undergone land change as of 2010 from focal projects (Table 2.5-2); much but not all of this land change is concentrated in the lower portion of the watershed. The designations of specific areas of the watershed for 2010 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*.

The Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities components of RAMP conducted monitoring activities in the Steepbank River watershed in 2010. The Fish Populations component did not conduct regular monitoring activities in the Steepbank River watershed in 2010. However, the pilot study of fish assemblage monitoring in 2010 included a reach on the lower Steepbank River; Section 6 contains the results of this study. Table 5.3-1 is a summary of the 2010 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, reported focal project water withdrawal and discharge locations, and the area of land change for 2010. Figure 5.3-2 contains photos of water quality monitoring stations in the watershed taken in fall 2010.

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.28% greater in the observed (*test*) hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low.**

Water Quality Concentrations of several water quality measurement endpoints in the Steepbank River watershed in fall 2010 were outside the range of previously-measured values. However, water quality conditions at stations in the Steepbank River watershed in fall 2010 were generally consistent with regional *baseline* fall conditions. The ionic composition of water at all water quality monitoring stations in the Steepbank River watershed in fall 2010 was consistent with previous years. Differences in water quality in fall 2010 at all four water quality monitoring stations compared to regional *baseline* water quality conditions are assessed as **Negligible-Low**.

Benthic Invertebrate Communities The values of measurement endpoints of the benthic invertebrate community at *test* reach STR-E1 have remained generally stable across time and consistent to those for *baseline* reach STR-E2, with a presence of fauna typically associated with a robust healthy community including a high relative abundance of EPT taxa. Lower abundance and richness compared to the median *baseline* conditions have been evident since 2000 at *test* reach STR-E1 but were not significant. The differences in abundance and richness in *test* reach STR-E1 indicate a **Moderate** difference from *baseline* reach STR-E2 because the statistical signal in time trends between the two reaches was strong, explaining more than 20% of the variance in annual means. There were no exceedances of values of measurement endpoints outside of the range of *baseline* conditions.

5.3.2 Hydrologic Conditions: 2010 Water Year

WSC Station 070A006 (RAMP Station S38), Steepbank River near Fort McMurray Continuous annual hydrometric data have been collected for WSC Station 070A006 (RAMP Station S38) from 1974 to 1986 and more recently from 2009 to 2010, with some partial records in 1972 and 1973. Seasonal data from March to October have been collected every year since 1974. The open-water runoff volume in the 2010 water year (WY) was 106 million m^3. This value is 22% lower than the historical mean open-water runoff volume of 137 million m^3 based on the period of record. In the 2010 WY, flows recorded from November 2009 to January 2010 often exceeded historical maximum values recorded from November to January (Figure 5.3-3), and were generally between upper and lower quartile values from January to mid-March. Flows peaked on April 21 at 15.9 m^3/s during the freshet, before decreasing until the beginning of August. Flows throughout mid-June and July fell within the lower quartile of historical values recorded during this period. Flows increased in response to rainfall events in late August and early September, to a maximum daily value of 25.4 m^3/s on September 9. Flows steadily declined to the end of the 2010 WY. The 2010 WY maximum annual daily flow value was 26% lower than the historical mean annual maximum daily flow. The minimum open-water daily flow of 1.3 m^3/s on July 24 was 24% lower than the mean historical minimum open-water daily flow.

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 2010 is estimated to be 4.3 km² (Table 2.5-1). The loss of flow to the Steepbank River that would have otherwise occurred from this land area is estimated at 0.47 million m³.

2. As of 2010, the area of land change in the Steepbank watershed that was not closed-circuited is estimated to be 40.4 km² (Table 2.5-1). The increase in flow to the Steepbank River that would not have otherwise occurred from this land area is estimated at 0.87 million m³.

Classification of Results The estimated cumulative effect of land change is an increase in flow of 0.41 million m³ in the 2010 WY for WSC Station 07DA006 (RAMP Station S38). The observed and estimated *baseline* hydrographs at WSC Station 07DA006 (RAMP Station S38) are 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 0.28% 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 2010, water quality samples were collected from:

- the Steepbank River near its mouth (*test* station STR-1, sampled from 1997 to 2010);

- the Steepbank River upstream of Suncor's oil sands developments (*test* station STR-2, designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2010);

- the Steepbank River upstream of the confluence with the North Steepbank River (*baseline* station STR-3, sampled from 2004 to 2009); and

- the North Steepbank River (*test* station NSR-1, designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2010).

All stations were sampled in fall 2010. Winter water quality sampling was also conducted at *test* station STR-1 in 2010.

Temporal Trends The following significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- A decreasing concentration of sulphate at *test* station STR-1 (1997 to 2010) and *test* station STR-2 (2002 to 2010);

- Decreasing concentrations of chloride and sulphate and an increasing concentration of arsenic at *baseline* station STR-3 (2004 to 2010); and

- An increasing concentration of total nitrogen at *test* station NSR-1 (2002 to 2010).

2010 Results Relative to Historical Concentrations Concentrations of water quality measurement endpoints in fall 2010 at *test* stations STR-1, STR-2, and NSR-1 were within the range of previously-measured concentrations (Table 5.3-4, Table 5.3-5, Table 5.3-7) with the exception of:

- total aluminum, total arsenic, total mercury, and total phosphorus with concentrations that exceeded previously-measured maximum concentrations, and chloride, sulphate, and total strontium with concentrations that were lower than previously-measured minimum concentrations at *test* station STR-1;

- total nitrogen, dissolved organic carbon, total mercury, total phenols, and total Kjeldahl nitrogen with concentrations that were higher than previously-measured maximum concentrations, and total dissolved solids with a concentration that was lower than its previously-measured minimum concentrations at *test* station STR-2; and

- total nitrogen and total Kjeldahl nitrogen with concentrations that were higher than previously-measured maximum concentrations at *test* station NSR-1. In previous years, the concentration of total mercury has been below analytical detection limits. The detection limit of total mercury was reduced in summer 2010 by half relative to previous years, resulting in an observed concentration that was lower than the historical minimum concentration.

Concentrations of several water quality measurement endpoints were outside the range of previously-measured concentrations at *baseline* station STR-3 in fall 2010 (Table 5.3-6). This may be related to river discharges that were higher than the upper quartile (Figure 5.3-3) and greater water depths in fall 2010. Concentrations of water quality measurement endpoints that were outside historical ranges in fall 2010 at *baseline* station STR-3 were:

- total suspended solids, total nitrogen, dissolved organic carbon, total aluminum, dissolved aluminum, total mercury (ultra-trace), and total Kjeldahl nitrogen with concentrations that exceeded previously-measured maximum concentrations;

- conductivity, pH, total dissolved phosphorus, sodium, calcium, magnesium, total alkalinity, total boron, total molybdenum, total strontium, and dissolved iron with concentrations that were below previously-measured minimum concentrations; and

- total dissolved solids with a concentration that was equal to the previously-measured historical minimum concentration.

Ion Balance In fall 2010 the ionic composition of water of all stations in the Steepbank River watershed was dominated by calcium and bicarbonate ions (Figure 5.3-4). The ionic composition at all stations in the Steepbank River watershed has remained consistent since 1997.

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints measured in the Steepbank River in fall 2010 were below water quality guidelines with the exception of total nitrogen and total aluminum at *test* stations STR-1, STR-2, and NSR-1, and *baseline* station STR-3 (Table 5.3-4 to Table 5.3-7).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Steepbank River watershed in 2010 (Table 5.3-8):

- sulphide, total iron, total phenols, and total Kjeldahl nitrogen at *test* stations STR-1, STR-2 and NSR-1, and *baseline* station STR-3 in fall 2010;
- total phosphorus and total chromium at *test* station STR-1 in fall 2010;
- dissolved iron at *baseline* station STR-3 in fall 2010; and
- total nitrogen, total aluminum, and total iron at *test* station STR-1 in winter 2010.

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2010 at *test* stations STR-1, STR-2, and NSR-1 were within regional *baseline* concentrations with the following exceptions (Figure 5.3-5):

- Total suspended solids, total mercury, and total arsenic with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-1 in fall 2010;
- Total nitrogen and total mercury with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-2 in fall 2010; and
- total mercury with a concentration that was lower than the 5th percentile of regional *baseline* concentration at *test* station NSR-1 in fall 2010 due to the detection limit of total mercury being reduced by half in summer 2010.

Water Quality Index The WQI values for all stations in the Steepbank River watershed indicate **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.3-9).

Classification of Results Concentrations of several water quality measurement endpoints in the Steepbank River watershed in fall 2010 were outside the range of previously-measured concentrations. However, water quality conditions at stations in the Steepbank River watershed in fall 2010 were generally consistent with regional *baseline* fall conditions. The ionic composition at all water quality monitoring stations in the Steepbank River watershed in fall 2010 was consistent with previous years. Differences in water quality in fall 2010 at all four water quality monitoring stations 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 2010 in the upper and lower erosional reaches of the Steepbank River. The lower *test* reach STR-E1 has been sampled since 1998; the upper *baseline* reach STR-E2 has been sampled since 2004.

2010 Habitat Conditions Water at *test* reach STR-E1 in fall 2010 was shallow (0.3 m), fast flowing (1.1 m/s), alkaline (pH: 8.3), and had moderate conductivity (135 µS/cm) (Table 5.3-10). Periphyton biomass averaged 22 mg/m^2, which is within the range of regional *baseline* conditions (Figure 5.3-6).

Water at *baseline* reach STR-E2 was shallow (0.3 m), fast flowing (1.3 m/s), alkaline (pH: 8.3), and had moderate conductivity (117 µS/cm). Periphyton biomass averaged 69 mg/m², which is within the range of regional *baseline* conditions but lower than the concentration of periphyton in 2009 (Figure 5.3-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach STR-E1 was dominated by Ephemeroptera (mayflies; 26%) and chironomids (22%) with subdominant taxa consisting of Hydracarina (10%) and Naidid worms (10%) (Table 5.3-11). The chironomids were diverse, consisting of common forms such as *Rheotanytarsus* and *Polypedilum* as well as those more typically associated with clean cold water such as *Tvetenia*. The mayfly assemblage was also diverse and included the widely-distributed *Baetis*, as well as those more typically associated with 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-E2 was dominated by Trichoptera (34%) and chironomids (29%) with subdominant taxa consisting of Ephemeroptera (14%), Empididae (8%) and Hydracarina (6%) (Table 5.3-11). Similar to *test* reach STR-E1, the chironomids at *baseline* reach STR-E2 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 *Lopescladius*. Other sensitive taxa included mayflies such as *Baetis*, *Ephemerella*, and *Drunella grandis*, stoneflies *Zapada*, and caddisflies *Brachycentrus, Lepidostoma, Hydroptilla*, and *Micrasema*.

Values of measurement endpoints (i.e., abundance, richness, diversity, and evenness) of benthic invertebrate communities in fall 2010 in both reaches were similar to 2008 and 2009. *Test* reach STR-E1 had approximately 4,800 individuals per m², an average of 28 taxa per sample, a diversity of approximately 0.9 and an average of 35% EPT taxa per sample. *Baseline* reach STR-E2 had 13,000 individuals per m², an average of 35 taxa per sample, a diversity close to 0.9, and an average of more than 50% EPT per sample.

Temporal and Spatial Comparisons For spatial comparisons, changes in mean values of measurement endpoints for benthic invertebrate communities were tested between t*est* reach STR-E1 and *baseline* reach STR-E2 (Hypothesis 3, Section 3.2.3.1). There were significant decreases in abundance and taxa richness and a significant increase in evenness in *test* reach STR-E1 compared to *baseline* reach STR-E2 over time (2002 to 2010) (Table 5.3-13 and Figure 5.3-7). The statistical signal in the differences between the *baseline* and *test* reaches explained 74% and 63% of the variance in the annual means of abundance and taxa richness, respectively (Table 5.3-13). The Correspondence Analysis results (Figure 5.3-8) indicated a difference in benthic invertebrate communities between *test* reach STR-E1 and *baseline* reach STR-E2 with *baseline* reach STR-E2 having a higher abundance of caddisflies (Trichoptera) and stoneflies (Plecoptera) and both reaches containing high relative proportions of mayflies (Ephemeroptera) relative to other taxa. *Test* reach STR-E1, although consistently different in the composition of the benthic invertebrate community relative to *baseline* reach STR-E2 reach, is still within the range of *baseline* conditions for erosional reaches in the RAMP FSA.

For temporal comparisons within a reach, differences in linear time trends of measurement endpoints during the sampling period (Hypothesis 1, Section 3.2.3.1) were tested for t*est* reach STR-E1 and *baseline* reach STR-E2. There were no differences in time trends of all measurement endpoints with the exception of a decrease in total abundance at *baseline* reach STR-E2 over time (2004 to 2010) while abundance was relatively stable in *test* reach STR-E1 over the same time period (Table 5.3-13 and Figure 5.3-7). However, the statistical signal explaining this difference was low (2%, Table 5.3-13).

Comparison to Published Literature The benthic invertebrate community of *test* reach STR-E1 was diverse with high proportions of chironomids and EPT taxa. This generally indicates the presence of a robust community, reflecting good water and sediment quality (Hynes 1960, Griffiths 1998).

2010 Results Relative to Regional *Baseline* Range Conditions The values of measurement endpoints for the benthic invertebrate community at *test* reach STR-E1, including CA Axis scores, were within the range of *baseline* conditions as defined by *baseline* erosional river reaches in the RAMP FSA (Figure 5.3-7, Figure 5.3-8).

Classification of Results The values of measurement endpoints of the benthic invertebrate community at *test* reach STR-E1 have remained generally stable across time and consistent to those for *baseline* reach STR-E2, with a presence of fauna typically associated with a robust healthy community including a high relative abundance of EPT taxa. Lower abundance and richness compared to the median *baseline* conditions have been evident since 2000 at *test* reach STR-E1 but are not significant. The differences in abundance and richness in *test* reach STR-E1 indicate a **Moderate** difference from *baseline* reach STR-E2 because the statistical signal in time trends between the two reaches was strong, explaining more than 20% of the variance (Table 5.3-13). There were no exceedances of values of measurement endpoints outside of the range of *baseline* conditions.

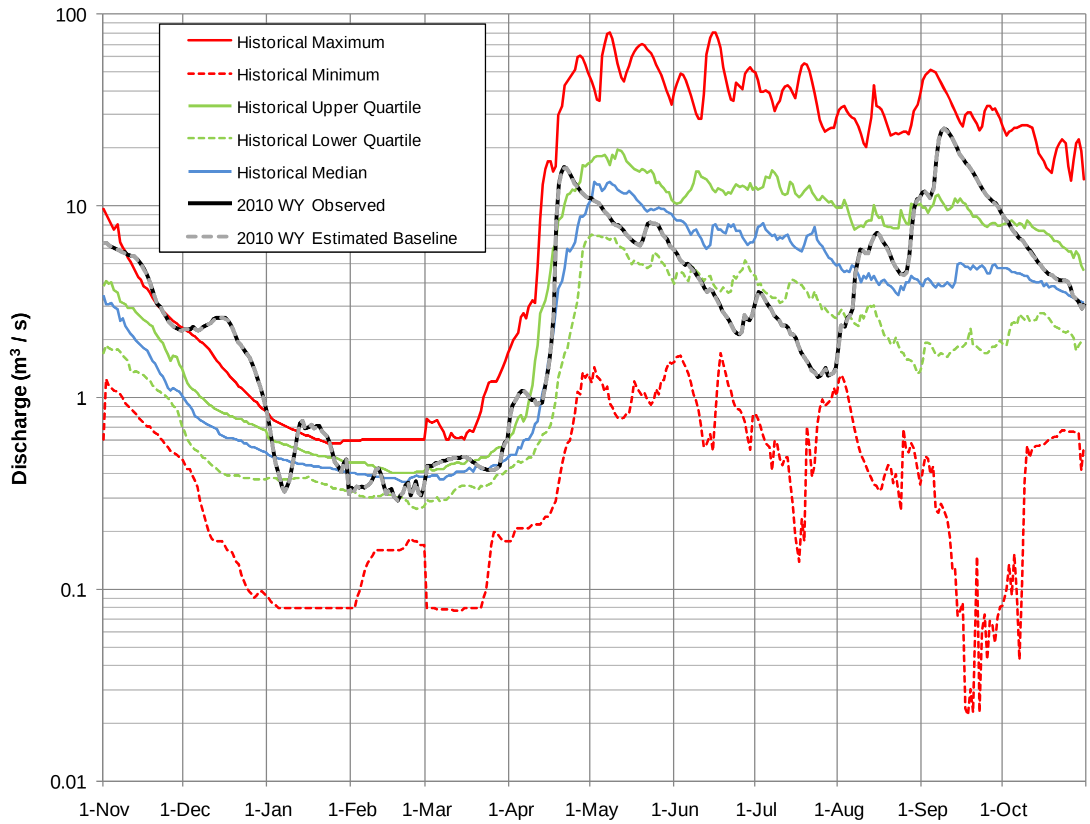
5.3.4.2 Sediment Quality

No sediment quality sampling was conducted in the Steepbank River in 2010 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

The Fish Populations component did not conduct regular monitoring activities in the Steepbank River watershed in 2010. However, the pilot study of fish assemblage monitoring in 2010 included a reach on the lower Steepbank River; Section 6 contains the results of this study.

Figure 5.3-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Steepbank River in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph based on WSC Station 07DA006, Steepbank River near Fort McMurray, provisional data from March 1 to October 31, 2010 and RAMP Station S38 from November 1, 2009 to February 28, 2010. The upstream drainage area is 1,320 km^2. Historical daily values from March 1 to October 31 calculated from data collected from 1972 to 2009, and historical daily values from November 1 to February 28 calculated from data collected from 1972 to 1986.

Table 5.3-2 Estimated water balance at WSC Station 07DA006 (RAMP Station S38), Steepbank River near Fort McMurray, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**143.35**	**Observed discharge from WSC Station 07DA006, Steepbank River near Fort McMurray**
Closed-circuited area water loss from the observed *test* hydrograph	-0.47	Estimated 4.3 km^2 of the Steepbank River watershed is closed-circuited as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.87	Estimated 40.4 km^2 of the Steepbank River watershed with land change as of 2010 that is not closed-circuited (Table 2.5-1)
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**142.94**	**Estimated *baseline* discharge at WSC Station 07DA006, Steepbank River near Fort McMurray**
Incremental flow (change in total discharge)	+0.41	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+0.28%**	**Incremental flow as a percentage of total annual discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on WSC Station 07DA006, Steepbank River near Fort McMurray, provisional data from March 1 to October 31, 2010 and RAMP Station S38 from November 1, 2009 to February 28, 2010. The upstream drainage area of WSC Station 07DA006 is 1,320 km^2, which is slightly smaller than the size of the entire Steepbank River watershed (1,355 km^2, Table 2.5-1).

Table 5.3-3 Calculated change in hydrologic measurement endpoints for the Steepbank River watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	6.68	6.70	0.28%
Mean winter discharge	1.57	1.58	0.28%
Annual maximum daily discharge	25.33	25.40	0.28%
Open-water period minimum daily discharge	1.276	1.280	0.28%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on WSC Station 07DA006, Steepbank River near Fort McMurray, provisional data from March 1 to October 31, 2010 and RAMP Station S38 from November 1, 2009 to February 28, 2010.

Table 5.3-4 Concentrations of water quality measurement endpoints in the Steepbank River (*test* station STR-1), fall 2010.

Measurement Endpoint	Unit	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	12	7.7	8.2	8.5
Total Suspended Solids	mg/L	-[1]	56	12	<3	7	60
Conductivity	µS/cm	-	143	12	141	222	516
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.019	12	0.006	0.020	0.032
Total nitrogen*	mg/L	1.0	**1.69**	12	0.25	0.75	**2.40**
Nitrate+Nitrite	mg/L	1.3	<0.071	12	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	29.6	12	10.0	19.5	30.0
Ions							
Sodium	mg/L	-	7	12	6	11	38
Calcium	mg/L	-	18.3	12	17.2	28.8	50.3
Magnesium	mg/L	-	5.6	12	5.4	8.5	16.2
Chloride	mg/L	230, 860[3]	0.7	12	0.9	2.0	8.4
Sulphate	mg/L	100[4]	2.5	12	2.8	4.7	12.3
Total Dissolved Solids	mg/L	-	144	12	120	181	320
Total Alkalinity	mg/L		69	12	55	94	141
Selected metals							
Total aluminum	mg/L	0.1	**2.79**	12	0.04	**0.14**	**2.73**
Dissolved aluminum	mg/L	0.1[2]	0.028	12	0.004	0.014	0.099
Total arsenic	mg/L	0.005	0.0013	12	0.0005	0.0008	0.0010
Total boron	mg/L	1.2[5]	0.031	12	0.025	0.053	0.200
Total molybdenum	mg/L	0.073	0.000151	12	0.000150	0.000200	0.000500
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.9	7	<1.2	<1.2	1.6
Total strontium	mg/L	-	0.063	12	0.064	0.108	0.252
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.006**	12	**0.003**	**0.006**	**0.041**
Total iron	mg/L	0.3	**2.24**	12	**0.47**	**0.82**	**2.28**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.62**	12	0.03	0.60	**2.30**
Total phenols	mg/L	0.004	**0.012**	12	<0.001	0.004	**0.013**
Phosphorus Total	mg/L	0.05	**0.070**	12	0.008	0.038	**0.054**
Chromium, Total	mg/L	0.001	**0.0029**	12	0.0004	0.0007	**0.948**

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 2010.

Measurement Endpoint	Unit	Guideline	September 2010	2002-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	8	7.8	8.1	8.3
Total Suspended Solids	mg/L	-[1]	14	8	<3	4	28
Conductivity	µS/cm	-	130	8	121	196	274
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.021	8	0.014	0.023	0.038
Total nitrogen*	mg/L	1.0	**1.99**	8	0.60	0.80	**1.50**
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	29.9	8	14.0	24.0	29.7
Ions							
Sodium	mg/L	-	6	8	5	9	16
Calcium	mg/L	-	17.1	8	16.8	26.0	35.9
Magnesium	mg/L	-	5.4	8	5.3	7.8	10.8
Chloride	mg/L	230, 860[3]	<0.5	8	<0.5	2	3
Sulphate	mg/L	100[4]	1.6	8	<0.5	3.1	5.5
Total Dissolved Solids	mg/L	-	139	8	140	166	200
Total Alkalinity	mg/L		65	8	61	101	155
Selected metals							
Total aluminum	mg/L	0.1	**0.427**	8	0.018	**0.123**	**0.536**
Dissolved aluminum	mg/L	0.1[2]	0.0238	8	0.0023	0.0137	0.0294
Total arsenic	mg/L	0.005	0.00073	8	0.00050	0.00067	0.00075
Total boron	mg/L	1.2[5]	0.0251	8	0.0227	0.0512	0.0969
Total molybdenum	mg/L	0.073	0.00013	8	0.00010	0.00016	0.00030
Total mercury (ultra-trace)	ng/L	5, 13[6]	3.4	7	<1.2	<1.2	2.3
Total strontium	mg/L	-	0.057	8	0.053	0.098	0.167
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.006**	8	**<0.003**	**0.007**	**0.012**
Total iron	mg/L	0.3	**0.74**	8	**0.73**	**0.82**	**1.07**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.92**	8	0.50	0.70	**1.40**
Total phenols	mg/L	0.004	**0.0111**	8	**<0.0010**	**0.0065**	**0.0110**

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 2010.

Measurement Endpoint	Unit	Guideline	September 2010	2004-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.9	6	8.0	8.2	8.3
Total Suspended Solids	mg/L	-[1]	7	6	<3	<3	4
Conductivity	µS/cm	-	128	6	195	253	317
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.024	6	0.027	0.038	0.042
Total nitrogen*	mg/L	1.0	**1.85**	6	0.60	0.75	**1.50**
Nitrate+Nitrite	mg/L	1.3	<0.071	6	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	32.4	6	14.0	22.5	29.3
Ions							
Sodium	mg/L	-	5	6	8	13	17
Calcium	mg/L	-	17.1	6	23.1	34.0	40.7
Magnesium	mg/L	-	5.4	6	6.5	10.1	12.4
Chloride	mg/L	230, 860[3]	<0.5	6	<0.5	1.5	2
Sulphate	mg/L	100[4]	1.53	6	0.83	3.05	3.4
Total Dissolved Solids	mg/L	-	140	6	140	193	220
Total Alkalinity	mg/L		64	6	100	143	170
Selected metals							
Total aluminum	mg/L	0.1	**0.233**	6	0.021	0.040	0.089
Dissolved aluminum	mg/L	0.1[2]	0.0301	6	0.0040	0.0099	0.0175
Total arsenic	mg/L	0.005	0.00067	6	0.00046	0.00066	0.00075
Total boron	mg/L	1.2[5]	0.025	6	0.049	0.065	0.114
Total molybdenum	mg/L	0.073	0.00014	6	0.00015	0.00019	0.00028
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.1	6	<1.2	<1.2	1.3
Total strontium	mg/L	-	0.057	6	0.095	0.108	0.150
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.008**	6	**0.004**	**0.006**	**0.011**
Total phenols	mg/L	0.004	**0.011**	6	<0.001	**0.005**	**0.019**
Dissolved iron	mg/L	0.3[2]	**0.336**	6	**0.405**	**0.638**	**0.751**
Total iron	mg/L	0.3	**0.736**	6	**0.698**	**0.934**	**1.040**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.78**	6	0.50	0.65	**1.43**

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 2010.

Measurement Endpoint	Unit	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.9	8	7.5	8.0	8.1
Total Suspended Solids	mg/L	-[1]	<3	8	<3	4	8
Conductivity	µS/cm	-	132	8	110	154	191
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.018	8	0.015	0.022	0.042
Total nitrogen*	mg/L	1.0	1.27	8	0.4	0.7	1.0
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	21.4	8	13	19	23
Ions							
Sodium	mg/L	-	2.4	8	2.0	3.0	4.0
Calcium	mg/L	-	18.7	8	16.5	23.2	31.0
Magnesium	mg/L	-	5.7	8	4.9	6.6	8.8
Chloride	mg/L	230, 860[3]	0.6	8	<0.5	1	2
Sulphate	mg/L	100[4]	0.9	8	<0.5	1.5	5.2
Total Dissolved Solids	mg/L	-	116	8	109	145	160
Total Alkalinity	mg/L		64	8	55	80	106
Selected metals							
Total aluminum	mg/L	0.1	**0.110**	8	0.028	0.052	**0.129**
Dissolved aluminum	mg/L	0.1[2]	0.012	8	0.005	0.011	0.015
Total arsenic	mg/L	0.005	0.0007	8	0.0005	0.0008	0.0013
Total boron	mg/L	1.2[5]	0.011	8	0.010	0.014	0.020
Total molybdenum	mg/L	0.073	0.00014	8	0.00013	0.00020	0.00036
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.055	8	0.049	0.079	0.111
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0038**	8	**0.0028**	**0.0055**	**0.0080**
Dissolved iron	mg/L	0.3[2]	**0.544**	8	**0.507**	**0.844**	**1.290**
Total phenols	mg/L	0.004	**0.006**	8	<0.001	**0.007**	**0.010**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.20**	8	0.30	0.60	0.92

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 5.3-4 Piper diagram of fall ion concentrations in the Steepbank River, fall 2010.

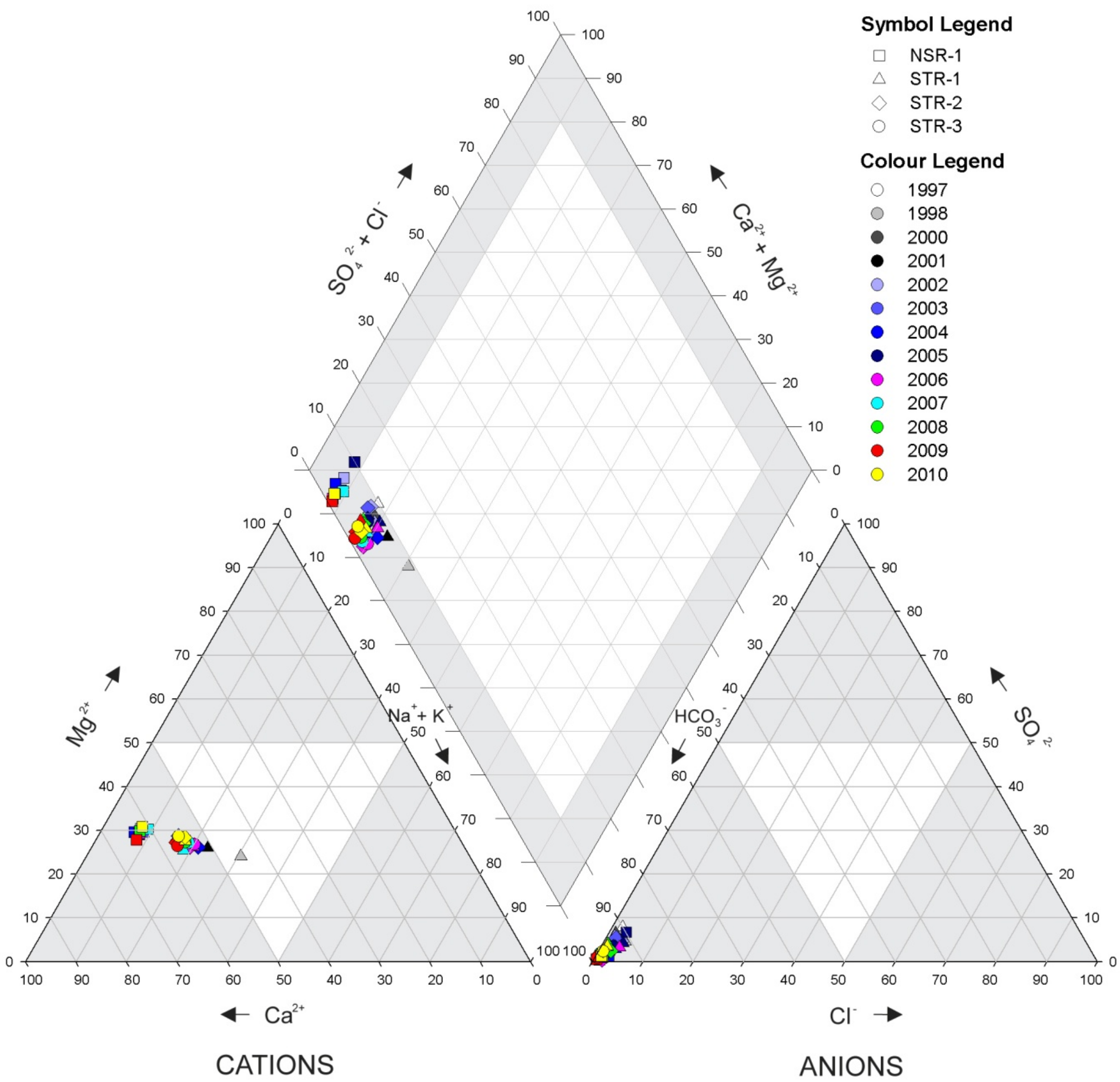


Table 5.3-8 Water quality guideline exceedances, Steepbank River watershed, 2010.

Variable	Unit	Guideline	STR-1	STR-2	STR-3	NSR-1
Winter						
Total nitrogen*	mg/L	1.0	1.135	ns	ns	ns
Total aluminum	mg/L	0.1	0.212	ns	ns	ns
Total iron	mg/L	0.3	0.757	ns	ns	ns
Fall						
Sulphide	mg/L	0.002[1]	0.0060	0.0055	0.0075	0.0038
Total phosphorus	mg/L	0.05	0.0696	-	-	-
Dissolved iron	mg/L	0.3[2]	-	-	0.336	-
Total iron	mg/L	0.3	2.240	0.738	0.736	0.544
Total chromium	mg/L	0.001	0.00292	-	-	-
Total phenols	mg/L	0.004	0.0116	0.0111	0.0112	0.0062
Total nitrogen*	mg/L	1.0	1.691	1.991	1.851	1.271
Total Kjeldahl nitrogen	mg/L	1.0[3]	1.62	1.92	1.78	1.20
Total aluminum	mg/L	0.1	2.790	0.427	0.233	0.011

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

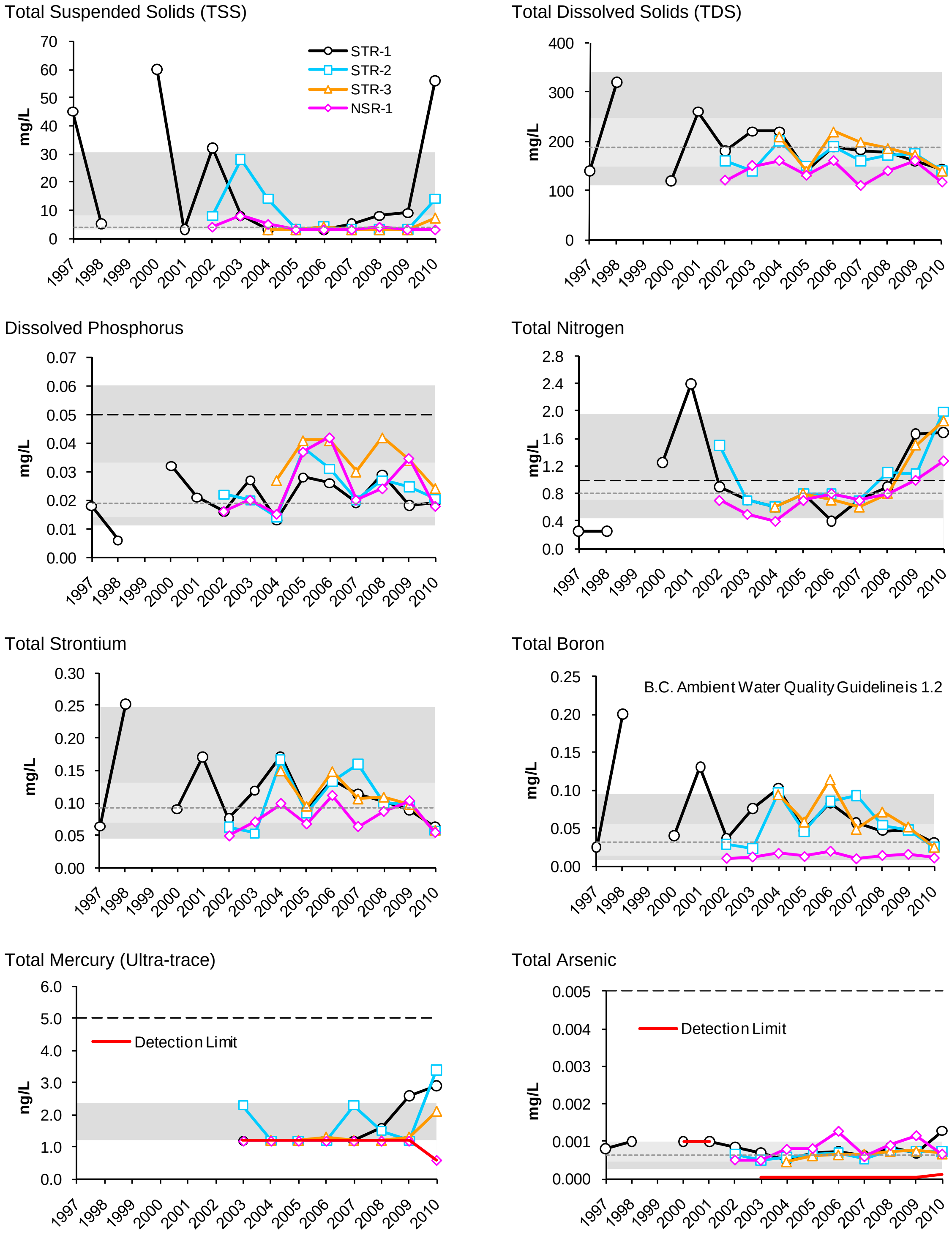
[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] Guideline is for total metal (no guideline for dissolved species).

[3] Guideline is for total nitrogen.

ns = not sampled

Figure 5.3-5 Concentrations of selected water quality measurement endpoints in the Steepbank River (fall data) relative to historical data and regional *baseline* fall concentrations.

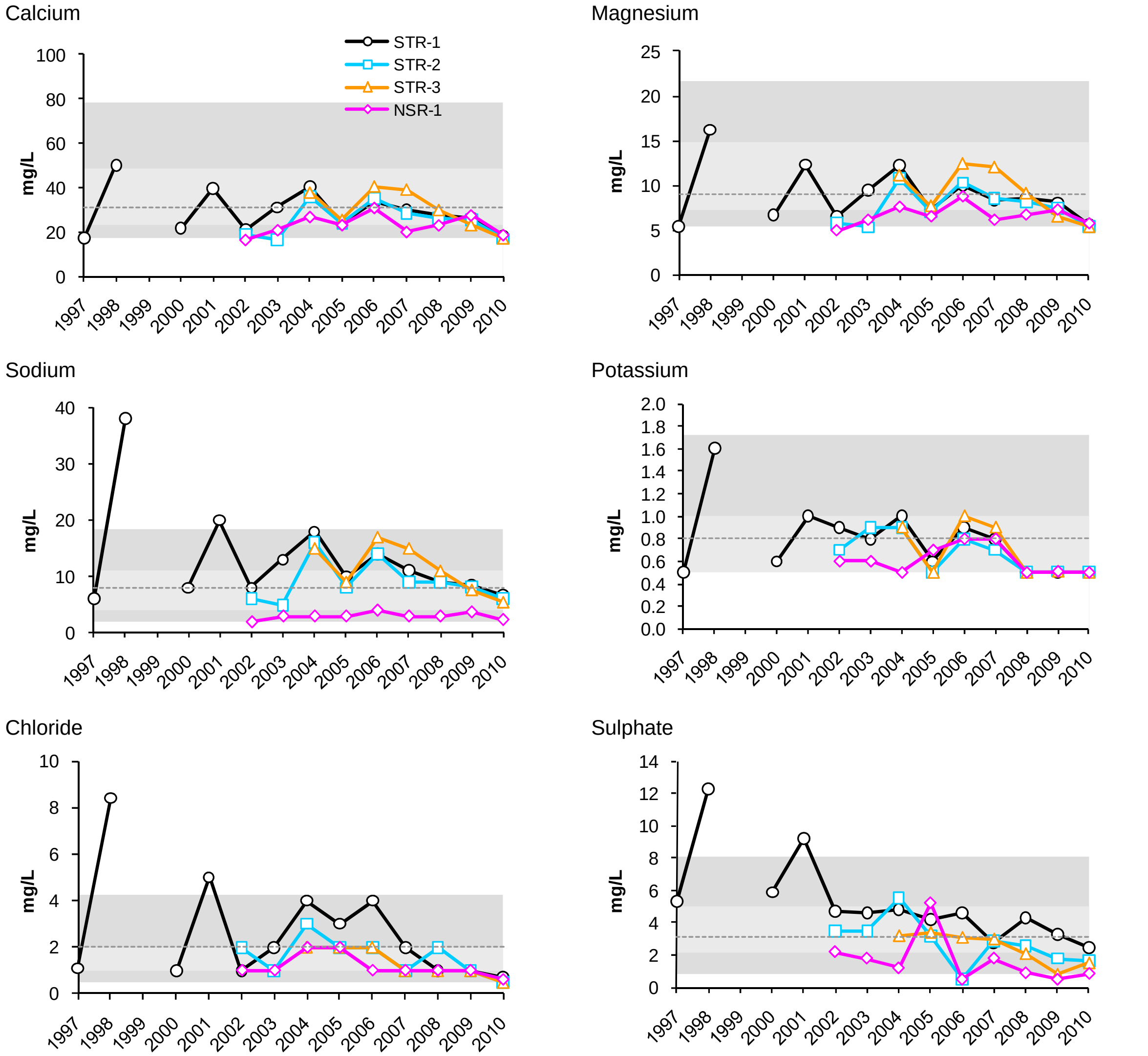


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.3-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.3-9 Water quality index (fall 2010) for Steepbank River watershed stations.

Station Identifier	Location	2010 Designation	Water Quality Index	Classification
STR-1	Lower Steepbank River	*test*	82.9	Negligible-Low
STR-2	Upstream of Suncor Millennium Project	*test*	97.5	Negligible-Low
STR-3	Upstream of North Steepbank River	*baseline*	97.5	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 3.2.2.3 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	STR-E1 Lower *Test* Reach of Steepbank River	STR-E2 Upper *Baseline* Reach of Steepbank River
Sample date	-	Sept. 24, 2010	Sept. 25, 2010
Habitat	-	Erosional	Erosional
Water depth	m	0.3	0.3
Current velocity	m/s	1.1	1.3
Field Water Quality			
Dissolved oxygen	mg/L	11.3	-
Conductivity	µS/cm	135	117
pH	pH units	8.3	8.3
Water temperature	°C	6.3	7.8
Substrate Composition			
Sand/Silt/Clay	%	1	1
Small Gravel	%	15	6
Large Gravel	%	27	8
Small Cobble	%	29	20
Large Cobble	%	2	29
Boulder	%	2	38
Bedrock	%	0	0

Figure 5.3-6 Periphyton chlorophyll *a* biomass in the Steepbank River.

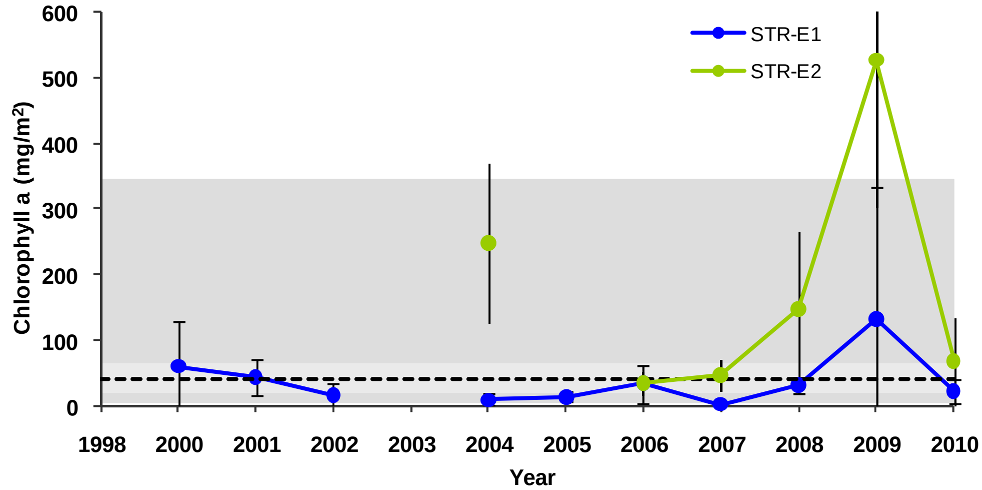


Table 5.3-11 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the lower Steepbank River (*test* reach STR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year										
	Reach STR-E1										
	1998	**2000**	**2001**	**2002**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Anisoptera	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1
Athericidae		<1	<1	<1	<1	<1	<1	1	1	<1	<1
Bivalvia				<1				<1	<1		<1
Ceratopogonidae	<1		<1	<1	<1		<1	3	1	<1	1
Chironomidae	31	15	25	43	38	25	29	36	17	41	22
Cladocera	1	<1								<1	1
Collembola	<1	<1						1	<1		
Copepoda	<1	<1	<1	<1		<1		1	<1	<1	<1
Empididae	2	1	2	6	4	9	7	<1	1	2	2
Enchytraeidae	1	11	1	9	6	9	15	6	9	3	4
Ephemeroptera	51	42	51	19	23	38	15	1	11	30	26
Gastropoda	<1	<1	<1	<1	<1		1	6	2		<1
Hydracarina	6	3	6	4	4	9	15	14	20	11	10
Naididae	2	21	2	2	21	5	13	4	17	7	10
Nematoda	1	2	2	2	1	<1	1	1	1	2	<1
Ostracoda	1	<1	<1	<1			<1	5			
Plecoptera	<1	1	<1	1	1	<1	<1	1	<1	<1	<1
Simuliidae	3	<1	<1	1	<1	3	1	<1	<1	1	<1
Tabanidae	<1	<1			<1			<1			
Tipulidae	<1	<1						<1			<1
Trichoptera	1	<1	<1	1	1	1	<1	2	1	2	2
Tubificidae	2	1	<1	1	<1	1	1	10	19	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	4,810
Richness	41	23	21	17	20	17	23	31	21	28	28
Simpson's Diversity	0.76	0.83	0.79	0.84	0.85	0.81	0.88	0.88	0.75	0.87	0.87
Evenness	0.78	0.87	0.83	0.9	0.9	0.87	0.89	0.91	0.80	0.90	0.90
% EPT	47	39	47	23	24	34	15	13	10	33	35

Table 5.3-12 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the upper Steepbank River (*baseline* reach STR-E2).

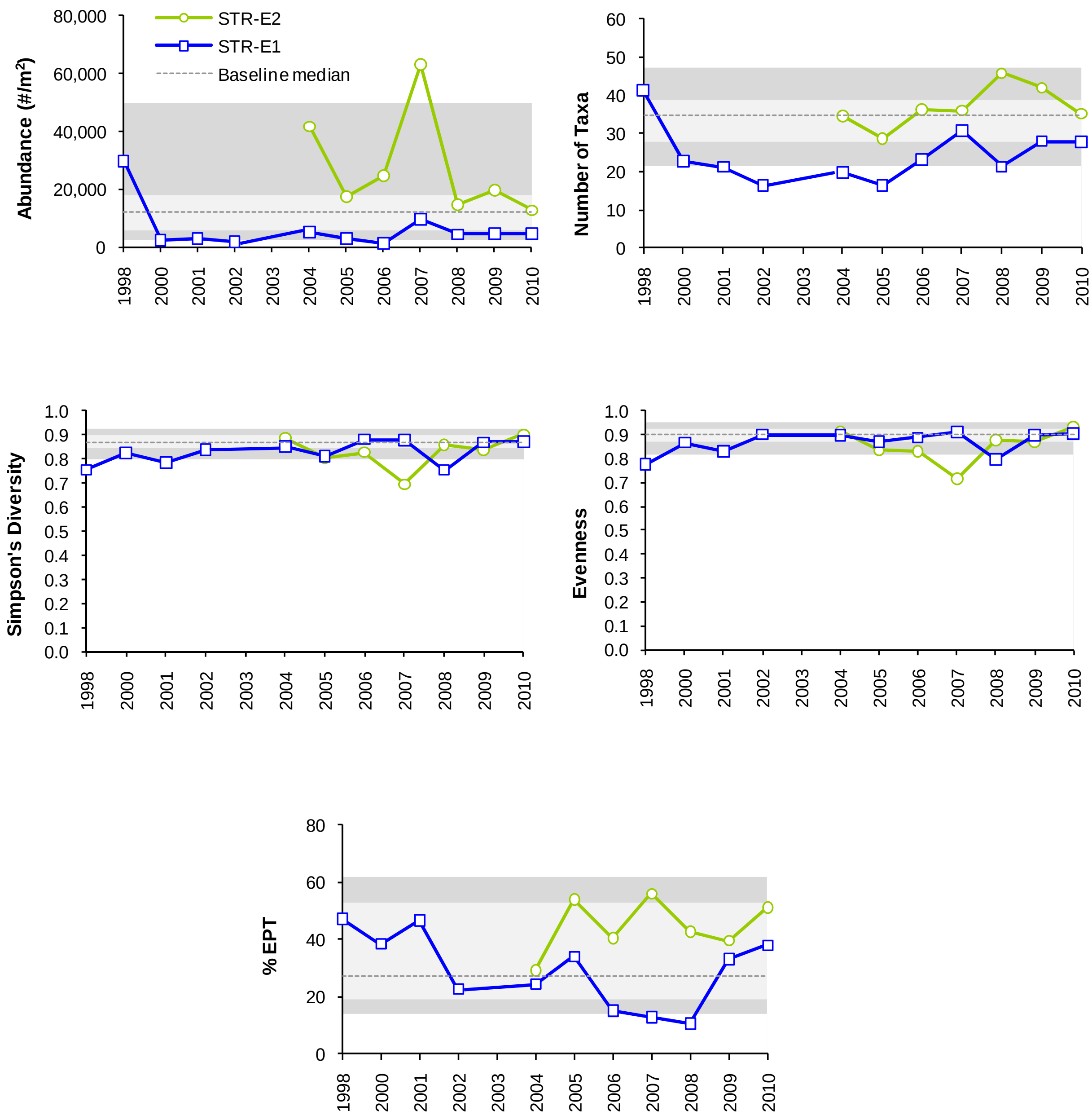
Taxon	Percent Major Taxa Enumerated in Each Year						
	Reach STR-E2						
	2004	2005	2006	2007	2008	2009	2010
Anisoptera	<1	<1	0.3	<1	<1		<1
Athericidae	<1	3	1	1	2	<1	<1
Bivalvia		<1		1	4	2	1
Ceratopogonidae				7	<1		<1
Chironomidae	46	32	24	52	24	41	29
Cladocera	4		<1	1		<1	
Collembola	<1				<1		
Copepoda	4	<1	1		<1	<1	<1
Empididae	2	6	2	<1	3	3	8
Enchytraeidae	<1	1			1	1	
Ephemeroptera	18	23	17	6	35	30	14
Gastropoda			<1	<1	<1	<1	<1
Hydracarina	7	3	5	8	12	6	6
Naididae	2	2	24	16	2	1	3
Nematoda	3	1	1	1	3	2	<1
Ostracoda	1			18	<1	<1	<1
Plecoptera	2	4	2	1	2	2	1
Simuliidae	<1	1	1	<1		1	<1
Tabanidae	<1	<1	0	<1	<1		<1
Tipulidae	1	1	1	<1	1	<1	<1
Trichoptera	9	24	22	6	10	9	34
Tubificidae	<1		1	1	<1	<1	<1
Benthic Invertebrate Community Measurement Endpoints							
Total Abundance (No./m^2)	41,844	17,317	26,123	63,294	14,725	19,878	12,758
Richness	34	29	36	36	46	42	35
Simpson's Diversity	0.89	0.81	0.83	0.70	0.86	0.84	0.90
Evenness	0.92	0.83	0.83	0.72	0.88	0.87	0.93
% EPT	29	54	40	56	31	40	51

Table 5.3-13 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Steepbank River.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Baseline* vs. *Test	**Difference in Time Trend**	***Baseline* vs. *Test***	**Difference in Time Trend**	
Abundance	**0.000**	**0.003**	74	2	Decreasing in *baseline* reach and stable in *test* reach.
Richness	**0.000**	0.075	63	1	Higher in *baseline* reach. No difference in time trends
Simpson's Diversity	0.280	0.565	2	0	No change
Evenness	**0.026**	0.388	7	1	Higher in *test* reach. No difference in time trends
EPT	0.000	0.817	49	0	Higher in *baseline* reach. No difference in time trends
CA Axis 1	**0.000**	0.565	64	0	Higher in *baseline* reach. No difference in time trends.
CA Axis 2	**0.000**	0.552	73	0	Lower in baseline reach. No difference in time trends.

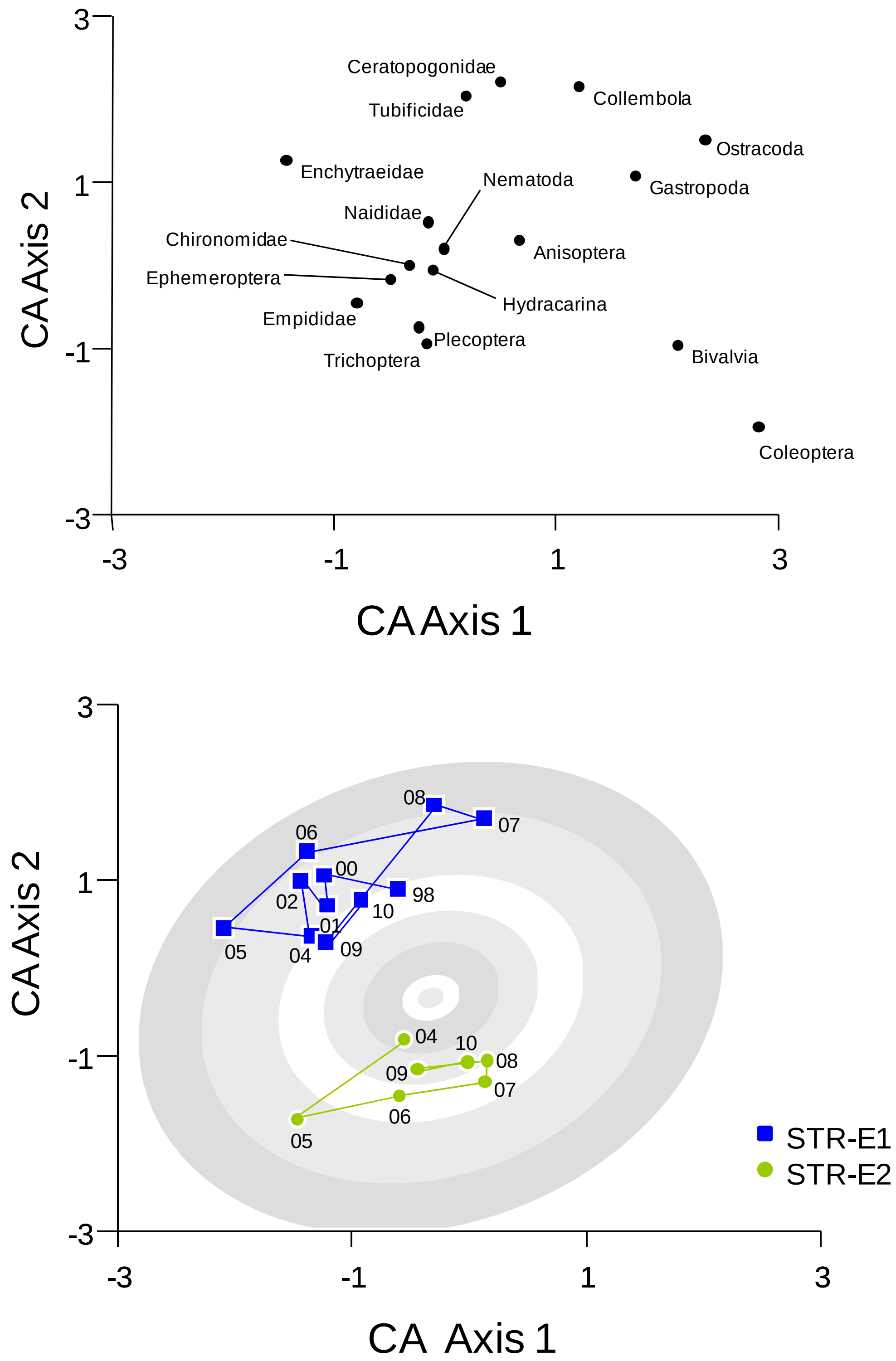
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low;, Moderate or High (Table 3.2-6).

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 3.2.3.1 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.

5.4 TAR RIVER WATERSHED

Table 5.4-1 Summary of results for the Tar River watershed.

Tar River Watershed	Summary of 2010 Conditions	
Climate and Hydrology		
Criteria	**S15A** near the mouth	
Mean open-water season discharge	🟤	
Mean winter discharge	not measured	
Annual maximum daily discharge	🟤	
Minimum open-water season discharge	🟤	
Water Quality		
Criteria	**TAR-1** at the mouth	**TAR-2** upstream of Canadian Natural Horizon
Water Quality	🟡	🟡
Benthic Invertebrate Communities and Sediment Quality		
Criteria	**TAR-D1** lower reach	**TAR-E2** upstream of Canadian Natural Horizon
Benthic Invertebrate Communities	🟠	n/a
Sediment Quality	🟡	n/a
Fish Populations		
No Fish Populations component activities conducted in 2010		

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.

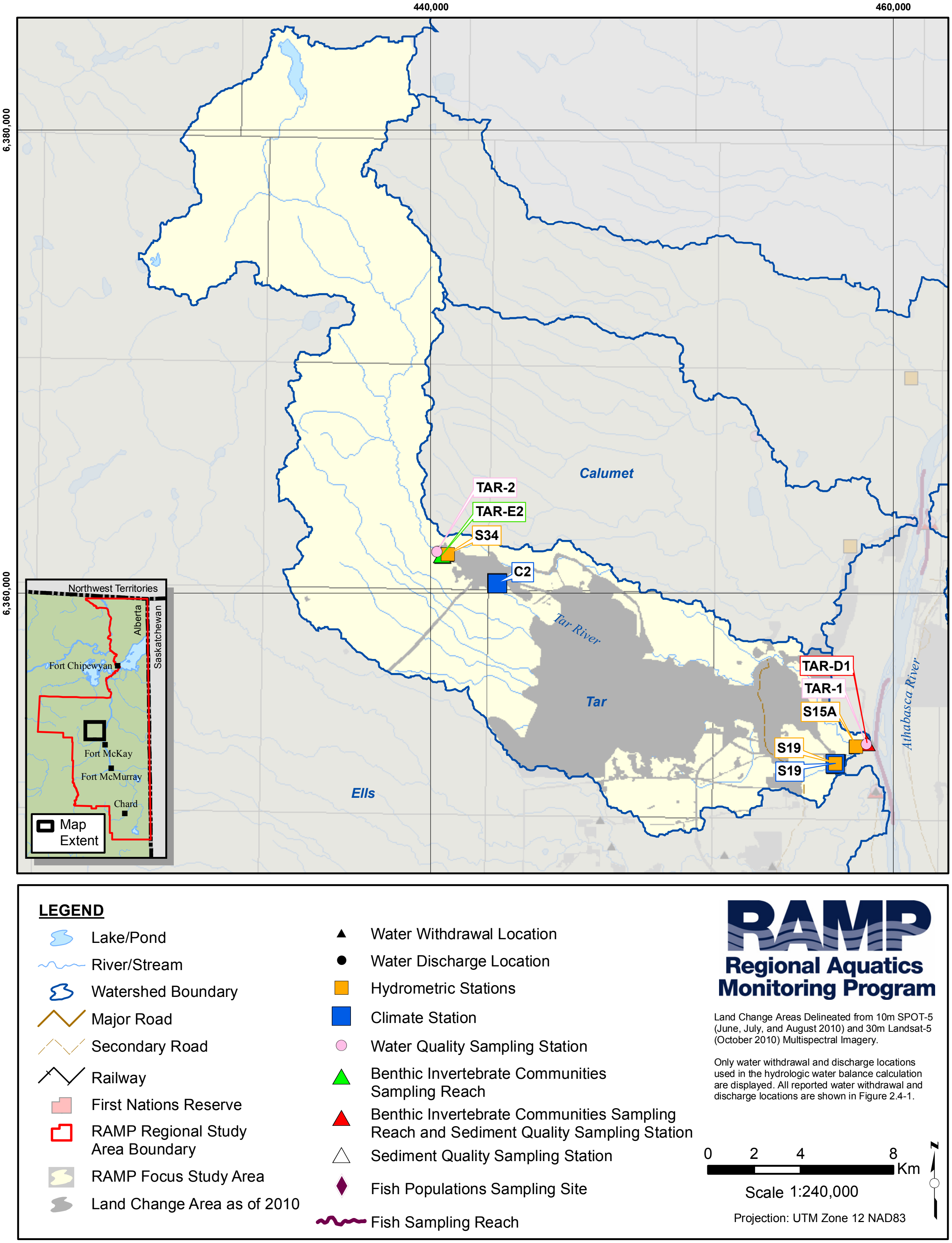
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology.

Figure 5.4-1 Tar River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K04_Tar_20110318.mxd

Figure 5.4-2 Representative monitoring stations of the Tar River, fall 2010.

**Benthic Invertebrate Reach TAR-D1:
Left Downstream Bank**

**Hydrology Station S15A:
Left Downstream Bank**

**Benthic Invertebrate Reach TAR-E2:
Centre of Channel, facing upstream**

**Water Quality Station TAR-2:
Right Downstream Bank**

5.4.1 Summary of 2010 Conditions

As of 2010, approximately 22% (7,350 ha) of the Tar River watershed had undergone land change from focal projects (Table 2.5-2). 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 2010. The Fish Populations component did not conduct regular monitoring activities in the Tar River watershed in 2010. Table 5.4-1 is a summary of the 2010 assessment for the Tar River watershed, while Figure 5.4-1 denotes the location of the monitoring stations for each RAMP component, reported focal project water withdrawal and discharge locations, and the areas of land change for 2010. Figure 5.4-2 contains fall 2010 photos of representative monitoring stations in the watershed.

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 16.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **High**.

Water Quality Differences in water quality observed in fall 2010 between the Tar River and regional *baseline* fall conditions were **Negligible-Low,** which is verified by the continued improvement in water quality conditions at *test* station TAR-1 since 2008, when water quality was assessed as being measurably different from regional *baseline* conditions. Most water quality measurement endpoints at *test* station TAR-1 in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* concentrations.

Benthic Invertebrate Communities and Sediment Quality Differences in measurement endpoints for benthic invertebrate communities at *test* reach TAR-D1 are classified as **Moderate** because significant differences were observed for total abundance, taxa richness, diversity and evenness from before to after the reach was designated as *test.* In addition, the statistical signal in these differences explained more than 20% of the variance in the values of these measurement endpoints. Values of measurement endpoints in fall 2010 at *test* reach TAR-D1 were within the range of regional *baseline* conditions for depositional reaches. Differences in sediment quality observed in fall 2010 between *test* station TAR-D1 and regional *baseline* conditions were **Negligible-Low**. Concentrations of sediment quality measurement endpoints were within historical ranges in fall 2010, including total PAHs and predicted PAH toxicity, although the concentration of carbon-normalized PAHs in fall 2010 represented a historical maximum concentration for *test* station TAR-D1.

5.4.2 Hydrologic Conditions: 2010 Water Year

Tar River near the mouth (RAMP Station S15A) Continuous hydrometric data have been collected during the open-water runoff period (May to October) for Station S15A since 2001. The 2010 water year (WY) open-water runoff volume was 9.2 million m^3, which is 25% lower than the historical mean open-water runoff volume of 12.4 million m^3. In early May flows were below the lower quartile of historical flows (Figure 5.4-3). On four days in late May daily flows were higher than the historical maximum daily flow for the same period in response to a period of heavy rainfall. Flows were below historical minimum flows for the period of June 22 to July 12 and remained below the historical median flow until August 26. Rainfall events in late August and early September increased flows to above the historical median value and exceeded the historical maximum daily flow for September 16. Flows decreased during October to a level similar to historical minimum flow values. The 2010 WY open-water period maximum daily flow of 3.0 m^3/s on May 23 was 58% lower than the historical mean maximum daily flow and the open-water minimum daily flow of 0.10 m^3/s on October 21 was 48% lower than the historical mean minimum daily flow (Figure 5.4-3).

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at RAMP Station S15A is presented in Table 5.4-2 and described as follows:

1. The closed-circuited land area from focal projects as of 2010 is estimated to be 58.7 km^2 (Table 2.5-1). The loss of flow to the Tar River that would have otherwise occurred from this land area is estimated at 2.25 million m^3.
2. As of 2010, the area of land change in the Tar River watershed from focal projects that was not closed-circuited is estimated to be 14.8 km^2 (Table 2.5-1). The increase in flow to the Tar River that would not have otherwise occurred from this land area is estimated at 0.11 million m^3.

The estimated cumulative effect of this land change is a decrease in flow of 2.14 million m^3 to the Tar River. The resulting observed and estimated *baseline* hydrographs are presented in Figure 5.4-3. The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 16.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.4-3). This difference is classified as **High** (Table 5.4-1).

5.4.3 Water Quality

In 2010, water quality samples were taken in fall from:

- the Tar River near its mouth (*test* station TAR-1, designated as *baseline* from 1998 to 2003, and *test* from summer 2004 to 2010); and
- the upper Tar River (*baseline* station TAR-2, sampled since 2004).

Temporal Trends The following significant (α = 0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- Increasing concentrations of chloride and sulphate and a decreasing concentration of total suspended solids at *test* station TAR-1 (1998, 2002 to 2010); and
- A decreasing concentration of chloride at *baseline* station TAR-2 (2004 to 2010).

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within previously-measured concentrations in fall 2010 at *test* station TAR-1, with the exception of dissolved aluminum and total phenols, with concentrations exceeding previously-measured maximum concentrations, and total boron, with a concentration below previously-measured minimum concentrations (Table 5.4-4). Concentrations of several water quality measurement endpoints at *baseline* station TAR-2 in fall 2010 exceeded previously-measured maximum concentrations including total nitrogen, dissolved organic carbon, total mercury, total Kjeldahl nitrogen, and total phenols (Table 5.4-5).

Ion Balance In fall 2010, the ionic composition of water at *baseline* station TAR-2 was consistent with the ionic composition measured since 2004 (Figure 5.4-4). *Test* station TAR-1 has shown much greater variability since sampling was initiated in 1998. In fall 2010, the ionic composition of water at *test* station TAR-1 showed calcium-bicarbonate composition similar to conditions observed in 2006 and earlier and different from the ionic composition of water at *test* station TAR-1 in 2007 and 2008 (Figure 5.4-4).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of total aluminum exceeded water quality guidelines at *test* station TAR-1 and *baseline* station TAR-2 and the concentration of total nitrogen exceeded the water quality guideline at *baseline* station TAR-2 in fall 2010 (Table 5.4-4 and Table 5.4-5).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Tar River in fall 2010 (Table 5.4-6):

- concentrations of sulphide, total phosphorus, total chromium, total iron, and total phenols at *test* station TAR-1; and
- concentrations of total phosphorus, total iron, dissolved iron, total phenols, and total Kjeldahl nitrogen at *baseline* station TAR-2.

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints at *test* station TAR-1 in fall 2010 were within regional *baseline* concentrations in fall 2010 with the exception of total mercury and sulphate with concentrations that exceeded the 95th percentile of regional *baseline* concentrations (Figure 5.4-5). Concentrations of all water quality measurement endpoints at *baseline* station TAR-2 were within the range of regional *baseline* concentrations (Figure 5.4-5).

Water Quality Index The WQI values for both stations in the Tar River watershed (i.e., *test* station TAR-1: 95.0, *baseline* station TAR-2: 98.7) indicated **Negligible-Low** differences from regional *baseline* fall conditions. The calculated WQI value for *test* station TAR-1 showed continued improvement in 2010 from a low WQI value of 59.8 in 2008.

Classification of Results Differences in water quality observed in fall 2010 between the Tar River and regional *baseline* fall conditions were **Negligible-Low,** which is verified by the continued improvement in water quality conditions at *test* station TAR-1 since 2008, when water quality was assessed as being measurably different from regional *baseline* conditions. Most water quality measurement endpoints at *test* station TAR-1 in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* concentrations.

5.4.4 Benthic Invertebrate Communities and Sediment Quality

5.4.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at:

- depositional *test* reach TAR-D1, designated as *baseline* from 2002 to 2003 and as *test* from 2004 to 2010 (not sampled in 2007 and 2008); and
- erosional *baseline* reach TAR-E2, sampled since 2009. Prior to 2009 when reach TAR-E2 was established, *baseline* reach TAR-E1 was sampled from 2003 to 2006. The reach was moved further upstream due to increased focal project development in the watershed.

2010 Habitat Conditions Water at *test* reach TAR-D1 in fall 2010 was shallow (0.5 m), slow flowing (0.5 m/s), alkaline (pH: 8.3) and had high conductivity (367 µS/cm) (Table 5.4-7). The substrate was dominated by sand (91%) with little silt or clay. Water at *baseline* reach TAR-E2 in fall 2010 was shallow (0.3 m), slightly faster flowing (0.7 m/s), alkaline (pH: 8.3), and had lower conductivity (263 µS/cm) (Table 5.4-7). Periphyton biomass in *baseline* reach TAR-E2 averaged 41.9 mg/m^2, which is within the range of regional *baseline* conditions (Figure 5.4-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach TAR-D1 was dominated by tubificid worms (32%), chironomids (31%), and ostracods (22%) with subdominant taxa consisting of ceratopogonids, naidid worms, and Hydracarina (Table 5.4-8). Dominant chironomids included *Procladius, Polypedilum,* and *Saetheria*. Species of mayfly (Ephemeroptera; *Caenis*) and stonefly (Plecoptera; *Nemoura*) were present in low relative abundance.

The benthic invertebrate community of *baseline* reach TAR-E2 was dominated by chironomids (26%), stoneflies (Plecoptera; 21%), and mayflies (Ephemeroptera; 18%) with subdominant taxa consisting of water mites (Hydracarina) and Siamulidae fly larvae (Table 5.4-8). A variety of worms (nadids, nematodes, tubificids) were present in low relative abundance (≤ 1%). Dominant chironomid taxa included *Cricotopus, Parakiefferiella* and taxa that are suitable to clean, fast-flowing water (i.e., *Tvetenia*). Plecoptera included taxa from the families *Capniidae* and *Chloroperlidae* and the genus *Zapada*. Mayflies included taxa from Heptageneiidae and Baetidae, while trichopterans were represented by *Glossosoma*, and the common *Hydropsyche*.

Temporal and Spatial Comparisons Two temporal comparisons were conducted (spatial comparisons were not conducted because *test* reach TAR-D1 is depositional and *baseline* reach TAR-E2 is erosional).

First, changes in mean values of measurement endpoints for benthic invertebrate communities at *test* reach TAR-D1 were tested between the years before and after the reach were designated as *test* (Hypothesis 2, Section 3.2.3.1). Total abundance, taxa richness, diversity, and evenness were significantly lower at *test* reach TAR-D1 in the period it has been designated as *test* as compared to the period it was designated as *baseline*, while there was no significant difference in percent EPT or the CA Axis scores between the two periods (Table 5.4-9). In addition, greater than 20% of the variance in the values of total abundance, taxa richness, diversity, and evenness is accounted for by the differences between the two time periods (Table 5.4-9).

Second, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that *test* reach TAR-D1 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). There was a significant increase in total abundance and taxa richness at *test* reach TAR-D1 over the *test* period (Table 5.4-9). However, these differences accounted for less than 20% of the variance in the annual mean values of these two measurement endpoints (Table 5.4-9). Time trends in the other five measurement endpoints at *test* reach TAR-D1 during the period the reach has been designated as *test* were not significant (Table 5.4-9).

Comparison to Published Literature The percent of the benthic invertebrate community as Tubificidae in *test* reach TAR-D1 during the period it has been designated as *test* was higher compared to the period it was designated as *baseline*; this is indicative of potential nutrient enrichment (Hynes 1960, Griffiths 1998). *Test* reach TAR-D1 in fall 2010 contained a high diversity of benthic invertebrate fauna including sphaeriid bivalves, gastropods, stoneflies (Plecoptera) and Ephemeroptera, all of which indicated a relatively robust benthic invertebrate community.

2010 Results Relative to Regional *Baseline* Conditions The values of the benthic invertebrate community measurement endpoints at *test* reach TAR-D1 in fall 2010 were within the range of variation for regional depositional *baseline* reaches and within the range of previously-measured values for this reach during the years it has been designated as *test* (Figure 5.4-7). While abundance, taxa richness, diversity and evenness in fall 2010 were lower than during the period when the reach was designated as *baselin*e, taxa richness, diversity and evenness in fall 2010 were at values more consistent with values recorded during the period the reach was designated as *baseline* and are greater than values in 2005 and 2006 when they were below the range for *baseline* depositional reaches (Figure 5.4-7). This is reflected as well in the results of the Correspondence Analysis (Figure 5.4-8), which also indicates that the ordination of the benthic invertebrate community at *test* reach TAR-D1 in fall 2010 was similar to that for regional *baseline* depositional reaches.

Classification of Results Differences in measurement endpoints of the benthic invertebrate communities at *test* reach TAR-D1 of the Tar River are classified as **Moderate** because significant differences were observed for total abundance, taxa richness, diversity and evenness from before to after the reach was designated as test. In addition, the statistical signal in these differences explained more than 20% of the variance in the values of these measurement endpoints. Values of measurement endpoints in fall 2010 at test reach TAR-D1 were within the range of regional baseline conditions for depositional reaches.

5.4.4.2 Sediment Quality

Sediment quality was sampled in fall 2010 in the Tar River near its mouth at *test* station TAR-D1 in the same location as the benthic invertebrate communities *test* reach TAR-D1. This station was designated as *baseline* from 1998 to 2003 and as *test* from 2004 to 2010.

2010 Results Relative to Historical Concentrations 2010 sediment quality data from *test* reach TAR-D1 were compared directly to the data collected at this reach in 2009 and in 2006. Prior to integration of the Sediment Quality component with the Benthic Invertebrate Communities component of RAMP in 2006, *test* reach TAR-D1 corresponds to pre-2006 sediment quality station TAR-1.

Sediments at *test* station TAR-D1 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 2010, concentrations of all sediment quality measurement endpoints were within historical ranges at *test* station TAR-D1 with the exception of retene, which had a concentration that exceeded its previously-measured maximum concentration (Table 5.4-10). Concentrations of Fraction-1 hydrocarbons and BTEX (benzene, toluene, ethylene and xylene) were not detectable (Table 5.4-10). Concentrations of hydrocarbons in the sediments at *test* station TAR-D1 in fall 2010 were dominated by Fraction 3 and Fraction 4, which likely indicates the presence of bitumen in the sediments. The concentration of total PAHs in sediment was within previously-measured concentrations, but the concentration of carbon-normalized total PAHs was higher than the previously-measured maximum concentration (Figure 5.4-9). The predicted PAH toxicity in fall 2010 was within the historical range of values (Table 5.4-10) and the PAH Hazard Index for sediments at *test* station TAR-D1 in fall 2010 exceeded the potential chronic toxicity threshold of 1.0 as it has for most of the sampling record at this station (Figure 5.4-9).

Direct tests of sediment toxicity to invertebrates at *test* station TAR-D1 showed 78% survival in test organisms of the amphipod *Hyalella* and 66% survival of test organisms of the midge *Chironomus*. Ten-day growth of *Chironomus* and 14-day growth of *Hyalella* were both within historical ranges (Table 5.4-10).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines No sediment quality measurement endpoints in fall 2010 had concentrations that exceeded the relevant CCME sediment quality guidelines at *test* station TAR-D1, with the exception of Fraction 3 (C16-C34) hydrocarbons and arsenic (Table 5.4-10).

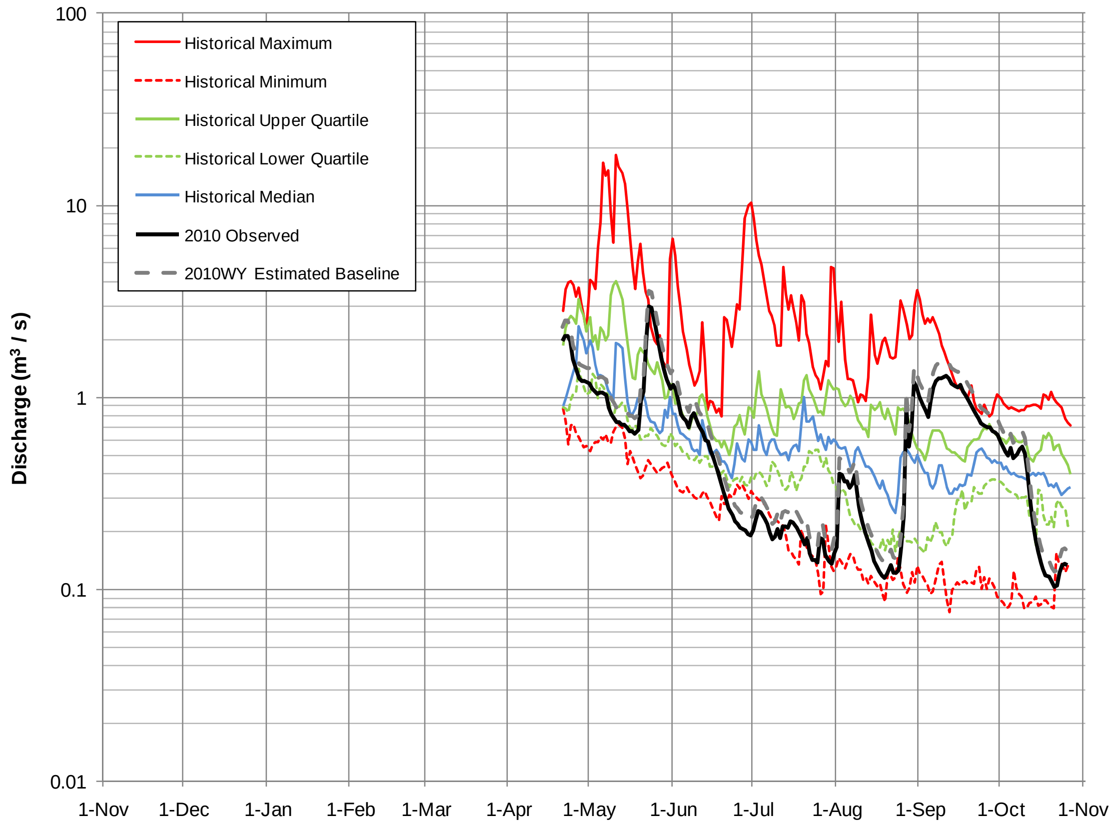
Sediment Quality Index A SQI of 95.4 was calculated for *test* station TAR-D1 for fall 2010, indicating a **Negligible-Low** difference from regional *baseline* conditions. Since 1998, this station has had an SQI value that has shown **Negligible-Low** differences from regional *baseline* conditions, with the exception of 2004 when sediment quality at this station indicated a **Moderate** difference from regional *baseline* conditions.

Classification of Results Differences in sediment quality observed in fall 2010 between *test* station TAR-D1 and regional *baseline* conditions were **Negligible-Low**. Concentrations of sediment quality measurement endpoints were within historical ranges in fall 2010, including total PAHs and predicted PAH toxicity, although the concentration of carbon-normalized PAHs in fall 2010 represented a historical maximum concentration for *test* station TAR-D1.

5.4.5 Fish Populations

The Fish Population component did not conduct regular monitoring activities in the Tar River watershed in 2010.

Figure 5.4-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Tar River in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph based on Station S15A, Tar River near the mouth, provisional data for April 21 to October 26, 2010. The upstream drainage area is 333 km^2. Historical values from May 1 to October 31 calculated from data collected from 2001 to 2009.

Table 5.4-2 Estimated water balance at RAMP Station S15A, Tar River near the mouth, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**10.61**	**Observed discharge, obtained from Station S15A, Tar River near the mouth**
Closed-circuited area water loss from the observed *test* hydrograph	-2.25	Estimated 58.7 km^2 of the Tar River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.11	Estimated 14.8 km^2 of the Tar River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Tar River watershed from focal projects	0	None reported
Water releases into the Tar 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 Tar River not accounted for by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**12.75**	**Estimated *baseline* discharge at RAMP Station S15A, Tar River near the mouth**
Incremental flow (change in total discharge)	-2.14	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**-16.8%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for April 21 to October 26, 2010 for RAMP Station S15A, Tar River near the mouth.

Note: Volumes presented to two decimal places.

Table 5.4-3 Calculated change in hydrologic measurement endpoints for the Tar River watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	0.72	0.60	-16.8%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	3.56	2.96	-16.8%
Open-water period minimum daily discharge	0.12	0.10	-16.8%

Note: Values are calculated from provisional data for April 21 to October 26, 2010 for RAMP Station S15A, Tar River near the mouth.

Table 5.4-4 Concentrations of water quality measurement endpoints, mouth of the Tar River (*test* station TAR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	9	8.1	8.2	8.5
Total Suspended Solids	mg/L	-[1]	13	9	6	15	214
Conductivity	µS/cm	-	392	9	302	493	875
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.015	9	0.012	0.017	**0.125**
Total nitrogen*	mg/L	1.0	0.64	9	0.50	**1.01**	**4.30**
Nitrate+Nitrite	mg/L	1.3	<0.071	9	<0.05	<0.10	**3.50**
Dissolved organic carbon	mg/L	-	17	9	12	17	23
Ions							
Sodium	mg/L	-	20	9	15	32	50
Calcium	mg/L	-	44.3	9	38.0	52.3	88.5
Magnesium	mg/L	-	13.0	9	11.3	16.5	24.3
Chloride	mg/L	230, 860[3]	4.0	9	1.7	5.0	50.0
Sulphate	mg/L	100[4]	64	9	20	42	173
Total Dissolved Solids	mg/L	-	282	9	170	330	590
Total Alkalinity	mg/L		133	9	121	179	221
Selected metals							
Total aluminum	mg/L	0.1	**1.05**	9	**0.17**	**0.51**	**3.95**
Dissolved aluminum	mg/L	0.1[2]	0.0263	9	0.005	0.008	0.026
Total arsenic	mg/L	0.005	0.0019	9	0.0009	0.0016	0.0022
Total boron	mg/L	1.2[5]	0.0532	9	0.054	0.099	0.145
Total molybdenum	mg/L	0.073	0.0010	9	0.0004	0.0011	0.0020
Total mercury (ultra-trace)	ng/L	5, 13[6]	4.4	7	<1.2	<1.2	**5.6**
Total strontium	mg/L	-	0.177	9	0.143	0.227	0.442
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0028**	9	<0.002	**0.007**	**0.023**
Total chromium	mg/L	0.001	**0.0014**	9	0.0006	0.0009	**0.0059**
Total phosphorus	mg/L	0.05	**0.059**	9	0.028	**0.085**	**0.232**
Total iron	mg/L	0.3	**1.57**	9	0.22	**2.04**	**7.03**
Total phenols	mg/L	0.004	**0.020**	9	<0.001	**0.005**	**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 (*baseline* station TAR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	6	8.0	8.3	8.4
Total Suspended Solids	mg/L	-[1]	7	6	<3	5	7
Conductivity	µS/cm	-	281	6	233	351	393
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.039	6	0.022	**0.040**	**0.058**
Total nitrogen*	mg/L	1.0	1.43	6	0.40	0.50	0.60
Nitrate+Nitrite	mg/L	1.0	<0.071	6	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	15	6	8	12	14
Ions							
Sodium	mg/L	-	8	6	6	13	16
Calcium	mg/L	-	38	6	31	46	53
Magnesium	mg/L	-	11.0	6	8.8	13.6	14.3
Chloride	mg/L	230, 860[3]	<0.5	6	<0.5	1.5	2.0
Sulphate	mg/L	100[4]	24	6	20	37	49
Total Dissolved Solids	mg/L	-	201	6	160	241	280
Total Alkalinity	mg/L		122	6	100	158	162
Selected metals							
Total aluminum	mg/L	0.1	**0.383**	6	0.073	**0.146**	**0.708**
Dissolved aluminum	mg/L	0.1[2]	0.037	6	0.008	0.021	0.052
Total arsenic	mg/L	0.005	0.0013	6	0.0008	0.0011	0.0014
Total boron	mg/L	1.2[5]	0.038	6	0.035	0.061	0.074
Total molybdenum	mg/L	0.073	0.0011	6	0.0008	0.0014	0.0015
Total mercury (ultra-trace)	ng/L	5, 13[6]	3.4	6	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.132	6	0.101	0.164	0.185
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phosphorus	mg/L	0.05	**0.057**	6	**0.045**	**0.070**	**0.100**
Dissolved iron	mg/L	0.3[2]	**0.535**	6	**0.108**	**0.321**	**0.816**
Total iron	mg/L	0.3	**1.07**	6	**0.72**	**1.03**	**1.59**
Total Kjeldahl nitrogen	mg/L	1.0[7]	**1.36**	6	**0.30**	**0.40**	**0.50**
Total phenols	mg/L	0.004	**0.021**	6	**0.002**	**0.004**	**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 Guideline is for total nitrogen.

Figure 5.4-4 Piper diagram of fall ion concentrations, Tar River.

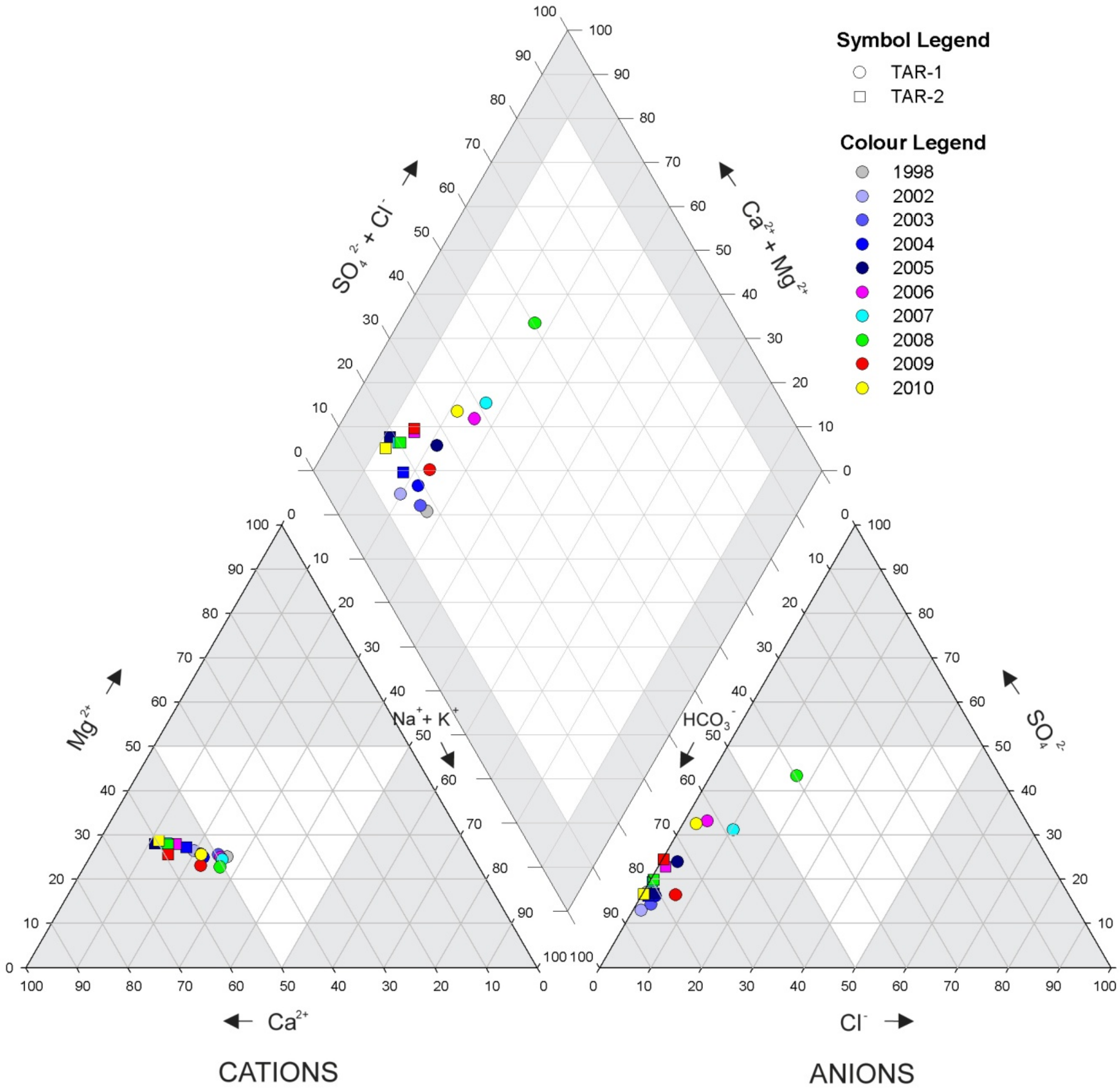


Table 5.4-6 Water quality guideline exceedances, Tar River, 2010.

Variable	Units	Guideline	TAR-1	TAR-2
Fall				
Sulphide	mg/L	0.002[1]	0.0028	-
Total phosphorus	mg/L	0.05	0.059	0.057
Total aluminum	mg/L	0.1	1.05	0.38
Total chromium	mg/L	0.001	0.0014	-
Total iron	mg/L	0.3	1.57	1.07
Dissolved iron	mg/L	0.3[2]	-	0.535
Total phenols	mg/L	0.004	0.020	0.021
Total Kjeldahl nitrogen	mg/L	1.0[3]	-	1.36
Total nitrogen	mg/L	1.0	-	1.431

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

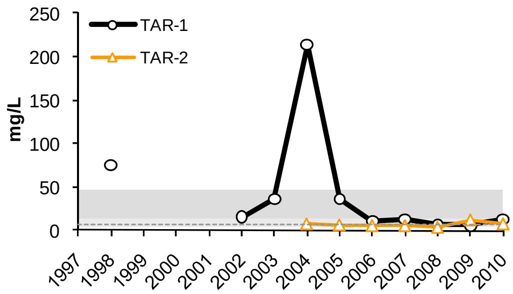
[1] B.C. Working Water Quality Guideline for sulphide as H_2S (B.C. 2006).

[2] Guideline is for total species (no guideline for dissolved species).

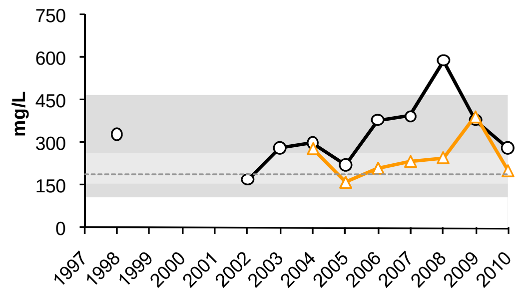
[3] Guideline is for total nitrogen.

Figure 5.4-5 Concentrations of selected water quality measurement endpoints in the Tar River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

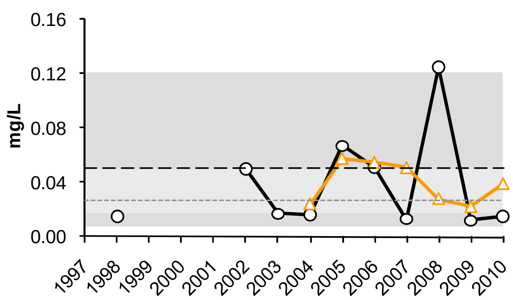
Total Suspended Solids (TSS)



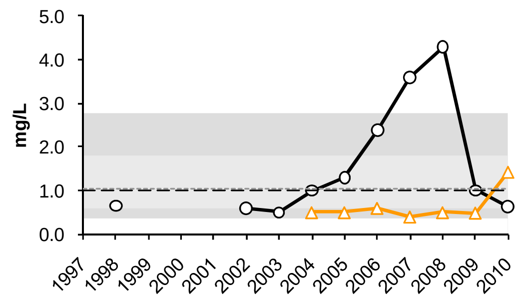
Total Dissolved Solids (TDS)



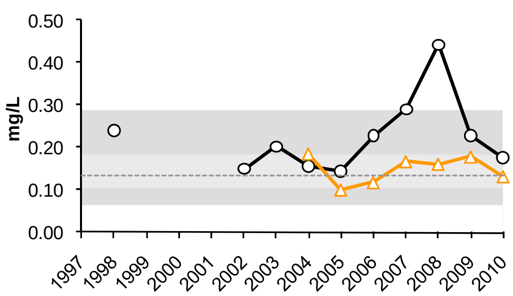
Dissolved Phosphorus



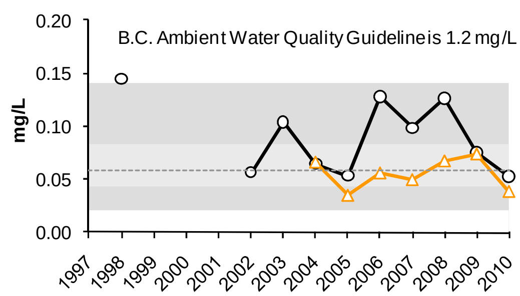
Total Nitrogen



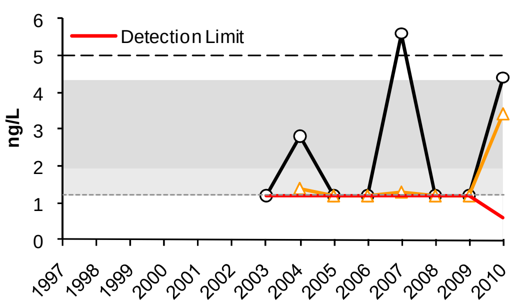
Total Strontium



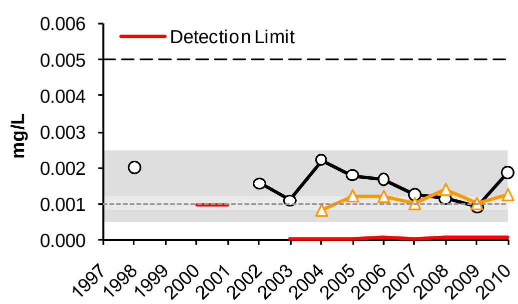
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



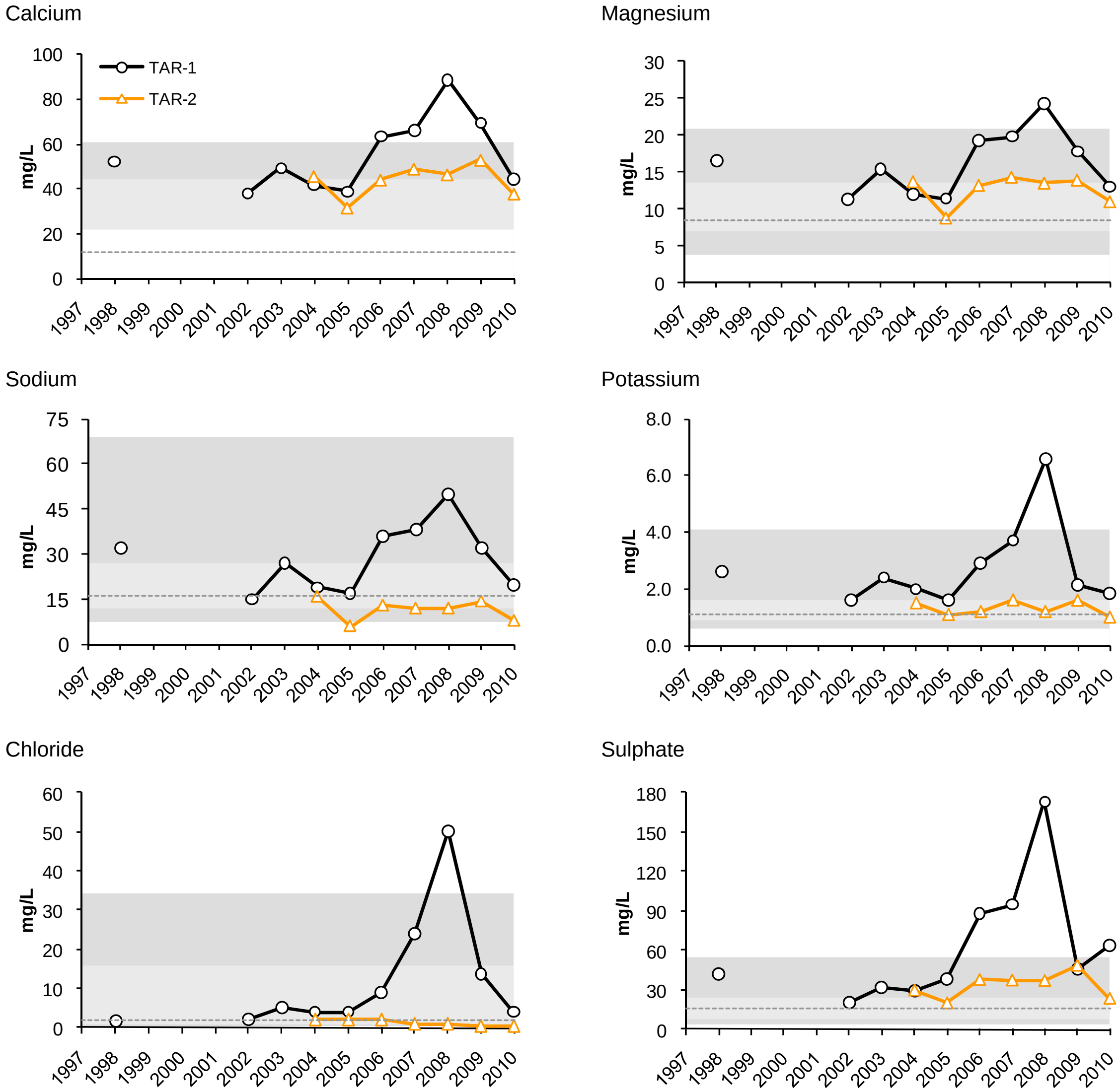
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.4-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling.

See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.4-7 Average habitat characteristics of benthic invertebrate community sampling locations in the Tar River.

Variable	Units	TAR-D1 Lower *Test* Reach of Tar River	TAR-E2 Upper *Baseline* Reach of the Tar River
Sample date	-	Sept. 9, 2010	Sept. 9, 2010
Habitat	-	Depositional	Erosional
Water depth	m	0.5	0.3
Current velocity	m/s	0.5	0.7
Field Water Quality			
Dissolved oxygen	mg/L	8.0	10.2
Conductivity	µS/cm	367	244
pH	pH units	8.3	8.3
Water temperature	°C	13.2	9.2
Sediment Composition			
Sand/Silt/Clay	%		12.5
Small Gravel	%		1.5
Large Gravel	%		14
Small Cobble	%		31
Large Cobble	%		37
Boulder	%		3
Bedrock	%		0
Sand	%	91	
Silt	%	6	
Clay	%	4	
Total Organic Carbon	%	0.62	

Figure 5.4-6 Periphyton chlorophyll *a* biomass in *baseline* reach TAR-E2 of the Tar River.

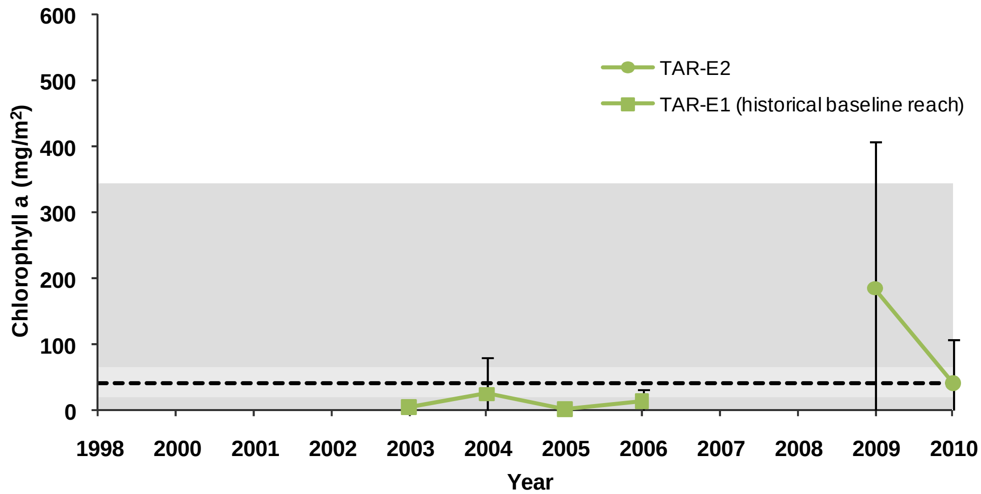


Table 5.4-8 Summary of major taxa abundances and benthic invertebrate community measurement endpoints in the Tar River.

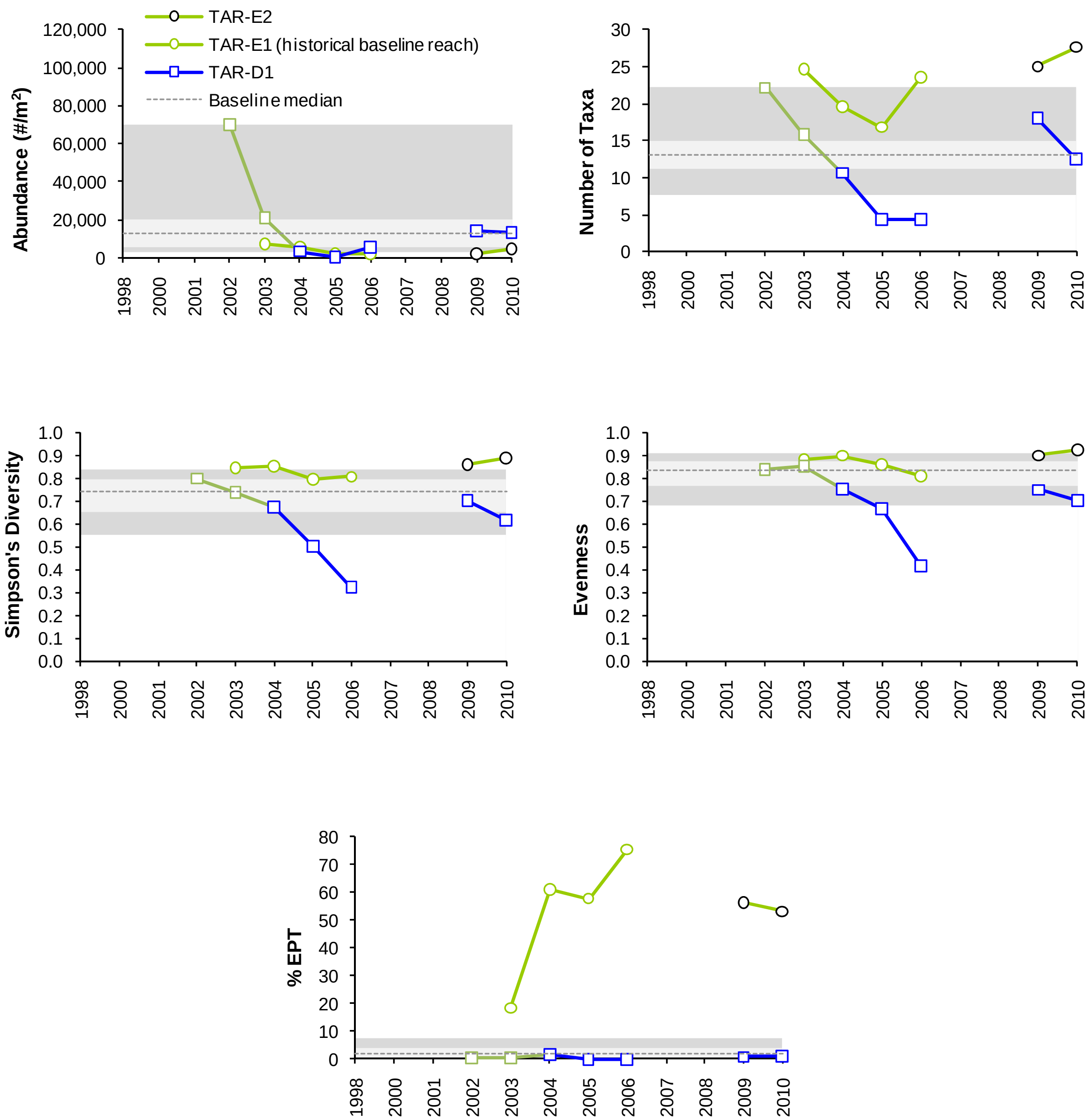
Taxon	Percent Major Taxa Enumerated in Each Year												
	Reach TAR-D1							Reach TAR-E1				Reach TAR-E2	
	2002	2003	2004	2005	2006	2009	2010	2003	2004	2005	2006	2009	2010
Amphipoda	<1												
Anisoptera	<1												
Bivalvia	1	<1	<1	1		<1	<1						
Ceratopogonidae	1	1	16	8		5	4	<1	<1				<1
Chironomidae	86	90	33	20	<1	43	31	67	21	33	8	28	26
Chydoridae	<1	<1	<1										
Coleoptera	<1		<1			<1	<1		<1		<1		
Collembola		<1											
Copepoda	<1	<1	2			11	1	1		<1		<1	<1
Dolichopodidae			1						<1				
Empididae	1	1	1		<1	<1	<1	2	1	2	8		1
Enchytraeidae			5	2				2	<1	<1	2	6	1
Ephemeroptera	<1	<1	1			1	1	5	38	45	48	1	18
Ephydridae								<1				26	
Erpobdellidae	<1	<1	<1						<1				
Gastropoda	<1		1				<1						
Heteroptera								<1					
Hydracarina	<1	1	1			<1	2	1	2	<1	2	4	9
Naididae	<1	4	2			2	3	6	<1	<1	1	<1	<1
Nematoda	2	<1	4	1	<1	1	1	2	<1	<1	<1	<1	<1
Ostracoda	2	<1	25	37		5	22					<1	1
Plecoptera	<1	<1	<1				<1	8	13	12	8	15	21
Simuliidae									13	2	1	<1	2
Tabanidae	<1	<1	<1	1		<1	1						<1
Tipulidae	<1	<1	<1	3	<1	<1	<1	1	<1	<1	1	1	1
Trichoptera	<1	<1	<1			<1		2	10	3	19	16	17
Tubificidae	7	1	6	28	1	28	32	1	1	1	0.3	<1	1
Benthic Invertebrate Community Measurement Endpoints													
Total Abundance (No./m^2)	69,759	20,805	3,489	657	5,534	14,218	13,387	7,166	5,781	2,263	2,155	2037	4,512
Richness	22	16	11	4	4	18	13	25	20	17	24	25	28
Simpson's Diversity	0.80	0.74	0.67	0.50	0.33	0.70	0.62	0.85	0.85	0.8	0.8	0.86	0.89
Evenness	0.84	0.85	0.75	0.87	0.33	0.75	0.70	0.88	0.9	0.86	0.8	0.9	0.92
% EPT	<1	<1	2	0	0	1	<1	18	61	58	7	56	53

Table 5.4-9 Results of analysis of variance (ANOVA) *test*ing for differences in benthic invertebrate community measurement endpoints in *test* reach TAR-D1.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Before vs. After	Time Trend (*test* period)	Before vs. After	Time Trend (*test* period)	
Abundance	**0.000**	**0.000**	45	17	Higher in *baseline* period and increasing during the *test* period
Richness	**0.000**	**0.005**	21	8	Higher in *baseline* period and increasing during the *test* period
Simpson's Diversity	**0.000**	0.658	46	0	Higher in *baseline* period
Evenness	**0.000**	0.892	48	0	Higher in *baseline* period
EPT	0.614	0.935	2	0	No change
CA Axis 1	0.721	0.372	1	7	No change
CA Axis 2	0.294	0.065	10	32	No change

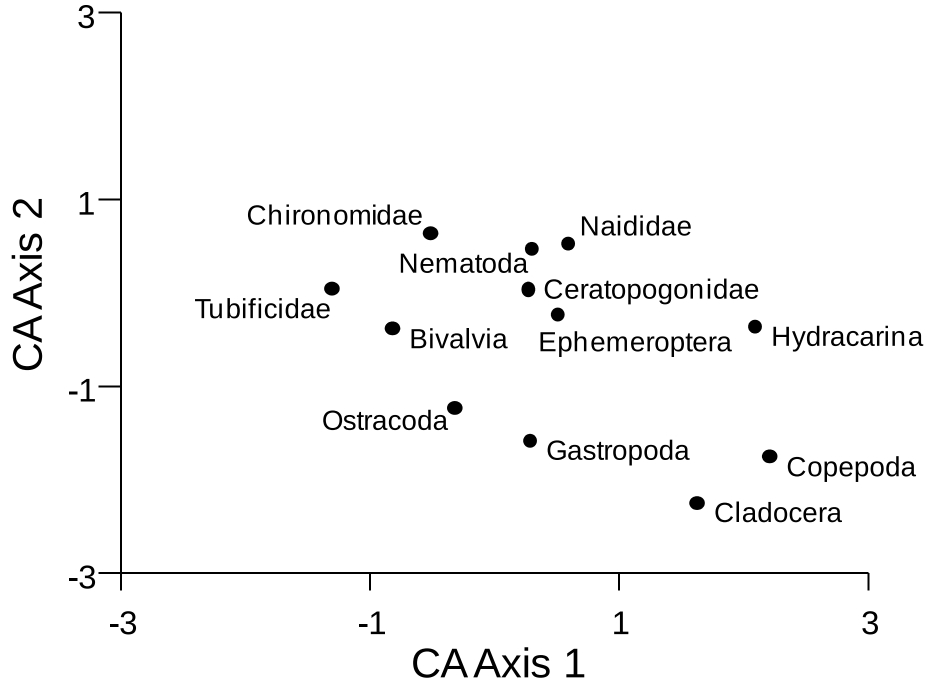
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

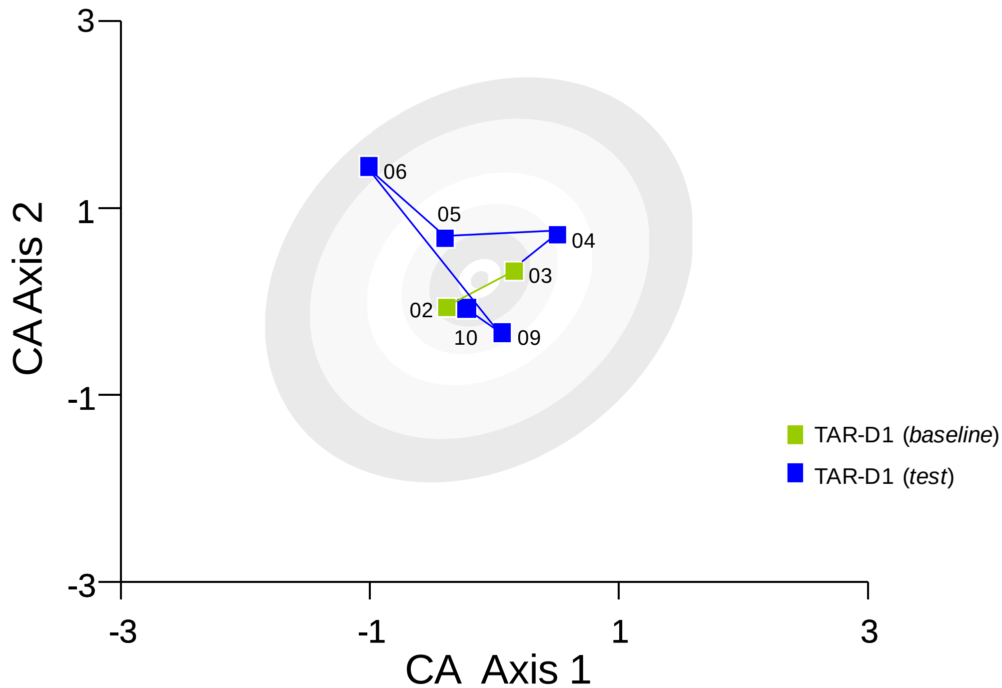
Figure 5.4-7 Variation in benthic invertebrate community measurement endpoints in the Tar River.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.4-8 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Tar River (*test* reach TAR-D1).





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 5.4-10 Concentrations of selected sediment measurement endpoints, Tar River (*test* station TAR-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1998-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	8.6	7	3	12	26
Silt	%	-	10.8	7	3	13	50
Sand	%	-	80.6	7	24	75	94
Total organic carbon	%	-	1.5	7	0.3	1.0	6.3
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	43	4	13	40	100
Fraction 3 (C16-C34)	mg/kg	300[1]	**667**	4	220	**539**	**860**
Fraction 4 (C34-C50)	mg/kg	2800[1]	434	4	170	288	460
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.004	7	0.001	0.004	0.015
Retene	mg/kg	-	2.190	6	0.012	0.037	0.379
Total dibenzothiophenes	mg/kg	-	4.496	7	0.152	0.723	6.256
Total PAHs	mg/kg	-	14.139	7	0.490	2.142	17.014
Total Parent PAHs	mg/kg	-	0.275	7	0.047	0.077	0.449
Total Alkylated PAHs	mg/kg	-	13.864	7	0.398	2.085	16.566
Predicted PAH toxicity[3]	H.I.	-	3.719	7	0.206	1.389	5.308
Metals that exceed CCME guidelines in 2010							
Arsenic	mg/kg	5.9	6.51				
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.6	4	5.0	6.3	8.6
Chironomus growth - 10d	mg/organism	-	2.666	4	0.898	1.937	4.000
Hyalella survival - 14d[4]	# surviving	-	7.8	4	6.6	8.9	10.0
Hyalella growth - 14d[4]	mg/organism	-	0.210	4	0.100	0.144	0.258

Values in **bold** indicate concentrations exceeding guidelines.

1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

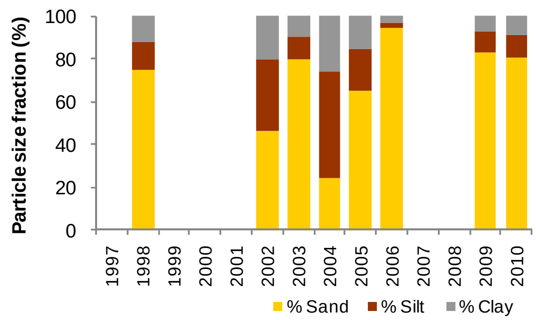
2 Interim sediment quality guideline (ISQG) (CCME 2002).

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.

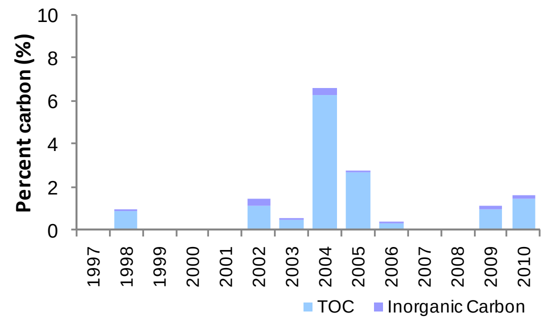
4 2002 *Hyalella* test based on 10-day test period.

Figure 5.4-9 Variation in sediment quality measurement endpoints in the Tar River, *test* station TAR-D1.

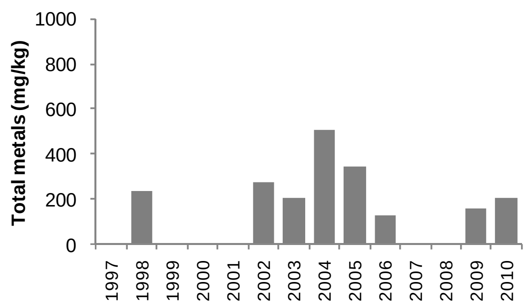
Particle size distribution



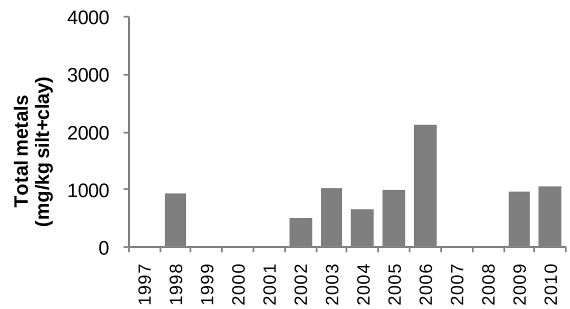
Carbon Content



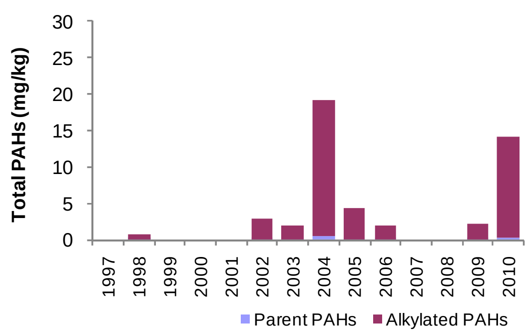
Total Metals*



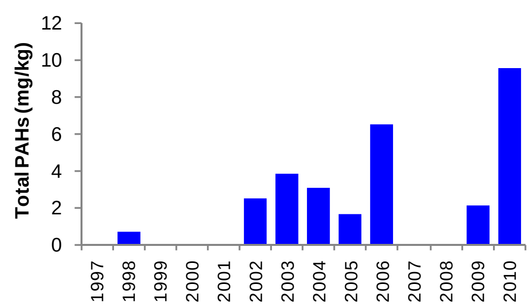
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



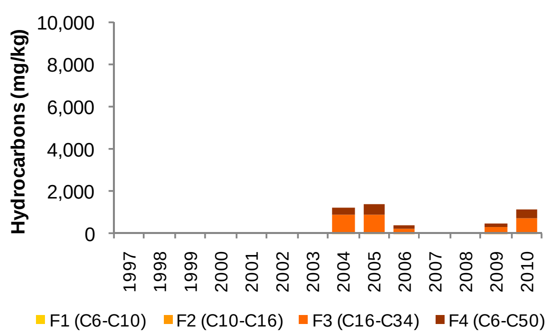
Total PAHs



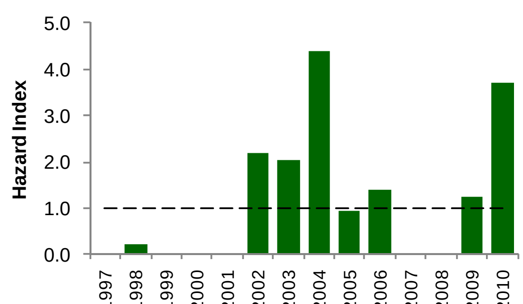
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

5.5 MACKAY RIVER WATERSHED

Table 5.5-1 Summary of results for the MacKay River watershed.

MacKay River Watershed	Summary of 2010 Conditions		
Climate and Hydrology			
Criteria	**S26** near Fort McKay	no stations 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-2A** upstream of Suncor MacKay	**MAR-2** upstream of Suncor Dover
Water Quality Index	🟡	ns	🟡
Benthic Invertebrate Communities and Sediment Quality			
Criteria	**MAR-E1** at the mouth	**MAR-E2** upstream of Suncor MacKay	**MAR-E3** upstream of Suncor Dover
Benthic Invertebrate Communities	🟡	🟠	n/a
No Sediment Quality component activities conducted in 2010			
Fish Populations			
No Fish Populations component activities conducted in 2010			

Legend and Notes

🟡 Negligible-Low
🟠 Moderate
🟤 High

baseline
test

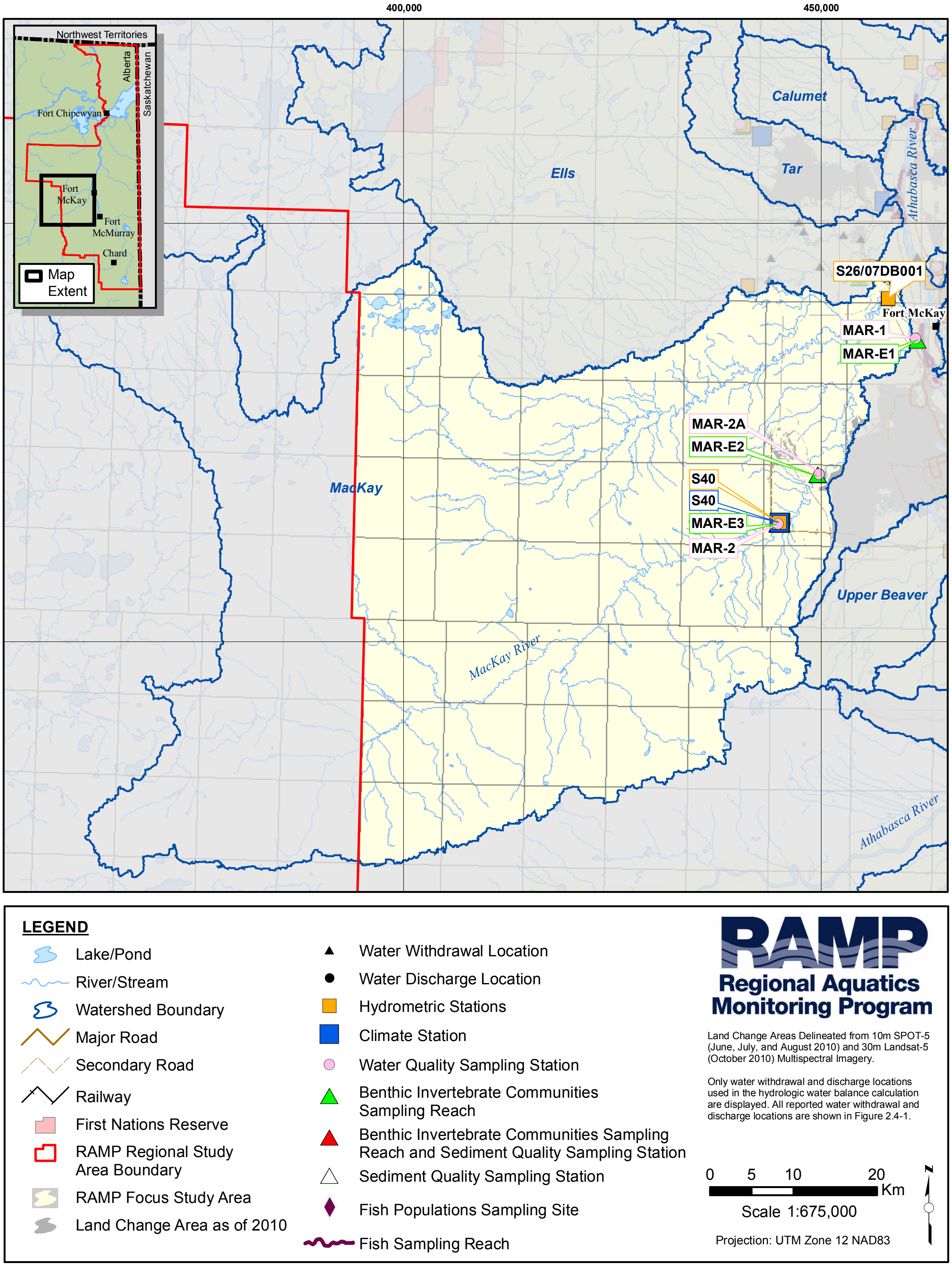
n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 for a detailed description of the classification methodology.

Figure 5.5-1 MacKay River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K05_MacKay_20110318.mxd

Figure 5.5-2 Representative monitoring stations of the MacKay River watershed, fall 2010.

Water Quality Station MAR-1:
Right Downstream Bank

Water Quality Station MAR-1:
Right Downstream Bank

Water Quality Station MAR-2:
Right Downstream Bank

Benthic Invertebrate Reach MAR-E3:
Left Downstream Bank

5.5.1 Summary of 2010 Conditions

As of 2010, less than 1% (1,800 ha) of the MacKay River watershed had undergone land change as a result of focal projects (Table 2.5-2). 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, and Benthic Invertebrate Communities components of RAMP conducted monitoring activities in the MacKay River watershed in 2010. Table 5.5-1 is a summary of the 2010 assessment of the MacKay River watershed, while Figure 5.5-1 denotes the location of the monitoring stations for each RAMP component, locations of reported focal project water withdrawal and discharge locations, and the area of land change for 2010. Figure 5.5-2 contains fall 2010 photos of monitoring stations in the watershed.

Hydrology The 2010 mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are 0.03% lower than from the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low**.

Water Quality Concentrations of several water quality measurement endpoints in the MacKay River watershed in fall 2010 were outside the range of previously-measured concentrations, possibly due to increased water levels and flows than typical of fall conditions. Water quality was generally consistent with regional *baseline* conditions and the ionic composition of water at both stations in fall 2010 was consistent with previous years, and continued to show little year-to-year variation. Differences in water quality in fall 2010 at both *test* and *baseline* stations relative to regional *baseline* water quality conditions were assessed as **Negligible-Low**.

Benthic Invertebrate Communities Differences in measurement endpoints of the benthic invertebrate community at *test* reach MAR-E1 of the MacKay River are classified as **Negligible-Low** because, although there were significant decreases in abundance and richness in the *test* period compared to the *baseline* period and a decrease in abundance during the *test* period, the statistical signal in the differences over time explained less than 10% of the variance in total abundance. It should be noted; however, that there was also a relatively strong time trend in CA Axis 2 scores suggesting a decrease in the percent of the community as mayflies, stoneflies, and caddisflies. Differences in measurement endpoints for the benthic invertebrate community at *test* reach MAR-E2 are classified as **Moderate** because the significant decrease in abundance over time explained more than 20% of the variance in annual means and was lower in 2010 than all previous sampling years at this reach. Significant increases were observed in richness, diversity, evenness and percent of the fauna as EPT taxa but an increase in these measurement endpoints does not imply a negative change in the benthic invertebrate community.

5.5.2 Hydrologic Conditions: 2010 Water Year

WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay Continuous annual hydrometric data have been collected for the WSC Station 07DB001 (RAMP Station S26) from 1973 to 1986 and more recently from 2002 to 2009, with some partial records in 1972. Seasonal data from March to October have been collected every year since 1973. The annual runoff volume in the 2010 water year (WY) was 320 million m^3. This value is 21% below the mean historical annual runoff volume based on the period of record. Flows steadily decreased during freeze-up in November and December 2009 to within the lower quartile of historical flows from mid-January 2010 until decreasing below the historical minimum daily flows from April 11 to 16 (Figure 5.5-3). Flows increased to 22.2 m^3/s on April 23 as a result of snowmelt and continued to increase to 46.6 m^3/s on May 25 as a result of rainfall in May. Flows decreased through most of June and July. The annual maximum daily flow of 47.8 m^3/s on September 2 in response to rainfall during late August was 58% lower than the historical mean annual maximum daily flow of 122 m^3/s. Flows steadily decreased to the end of the 2010 WY. The minimum open-water daily flow of 1.87 m^3/s on July 31 was 49% lower than the historical mean open-water minimum daily flow of 3.70 m^3/s.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DB001 (RAMP Station S26) is presented in Table 5.5-2 and described below:

1. The closed-circuited land area from focal projects as of 2010 is estimated to be 4.4 km^2 (Table 2.5-1). The loss of flow to the MacKay River that would have otherwise occurred from this land area is estimated at 0.25 million m^3.

2. As of 2010, the area of land change in the Mackay watershed that was not closed-circuited is estimated to be 13.4 km^2 (Table 2.5-1). The increase in flow to the MacKay River that would not have otherwise occurred from this land area is estimated at 0.15 million m^3.

The estimated cumulative effect of land change is a loss of flow of 0.1 million m^3 in the 2010 WY at WSC Station 07DB001 (RAMP Station S26). The observed *test* and estimated *baseline* hydrographs are presented in Figure 5.5-3.

The 2010 WY mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph are 0.03% 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 2010, water quality samples were collected from:

- the MacKay River near its mouth (*test* station MAR-1, first sampled in 1998, fall sampling every year from 2000 to 2010); and
- the MacKay River upstream of the Suncor MacKay River Dover *in situ* developments (*baseline* station MAR-2, sampled from 2002 to 2010).

Test station MAR-2A, upstream of the Suncor Dover developments, (initiated as a new RAMP station in 2009) was sampled in winter, spring, and summer 2010. Fall sampling of this station was scheduled for 2010 but was not completed (see Section 3.1.2.5).

Temporal Trends Significant (α=0.05) decreasing trends in concentrations of total boron and sulphate were observed in fall over time (1998 to 2010) at *test* station MAR-1. No significant trends were observed in water quality measurement endpoints at *baseline* station MAR-2.

2010 Results Relative to Historical Concentrations In fall 2010, river discharges exceeded the upper quartile (Figure 5.5-3), which may have contributed to concentrations of water quality measurement endpoints falling outside of previously-measured maximum and minimum concentrations at *test* station MAR-1 and *baseline* station MAR-2 (Table 5.5-4). These included:

- total suspended solids, total aluminum, dissolved aluminum, total arsenic, total mercury, total phosphorus, total chromium, and total phenols, with concentrations that exceeded previously-measured maximum concentrations at *test* station MAR-1;
- calcium, magnesium, chloride, total alkalinity, total boron, and total strontium, with concentrations below previously-measured minimum concentrations at *test* station MAR-1;
- total suspended solids, total dissolved phosphorus, total aluminum, dissolved aluminum, total iron, and total mercury, with concentrations that exceeded previously-measured maximum concentrations at *baseline* station MAR-2; and
- conductivity, calcium, magnesium, sulphate, total alkalinity, and total strontium, with concentrations that were below previously-measured minimum concentrations at *baseline* station MAR-2. The concentration of chloride was below analytical detection limits for the first time during fall sampling at this station.

Ion Balance In fall 2010, the ionic composition of water at both stations in the MacKay River was dominated by bicarbonate and calcium, and was similar to the ionic composition measured in this watershed since 1998 (Figure 5.5-4).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality variables at both stations were within water quality guidelines (Table 5.5-4 and Table 5.5-5) with the exception of:

- total nitrogen and total aluminum at *test* station MAR-1;
- total mercury, which exceeded the AENV guideline for chronic exposure at *test* station MAR-1 but was below the guideline for acute exposure;
- total nitrogen and total aluminum at *baseline* station MAR-2; and
- total mercury, which was equal to the guideline for chronic exposure at *baseline* station MAR-2.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in the MacKay River in 2010 (Table 5.5-6).

- **Winter -** Dissolved species: arsenic, boron, iron, copper, chromium, manganese, selenium, uranium, cadmium, and phosphorus; total species: nitrogen, Kjeldahl nitrogen, phosphorus, arsenic, boron, chromium, copper, manganese, selenium, uranium, iron, phenols, sulphate, sulphide, and ammonia at *test* station MAR-2A;
- **Spring -** Dissolved iron, total phenols, sulphide, total cadmium, total Kjeldahl nitrogen, total nitrogen, total aluminum, and total iron at *test* station MAR-2A;
- **Summer -** Dissolved iron, dissolved cadmium, total cadmium, total phenols, sulphide, total phosphorus, total Kjeldahl nitrogen, total nitrogen, total aluminum, and total iron at *test* station MAR-2A; and
- **Fall -** Sulphide, total Kjeldahl nitrogen, total iron, total chromium, total phenols, and dissolved iron at *test* station MAR-1 and *baseline* station MAR-2.

Concentrations of several dissolved water quality variables (e.g., dissolved iron and manganese, sulphate, boron) and nutrients (nitrogen and phosphorus) were very high in winter at *test* station MAR-2A relative to concentrations measured at this station in other seasons or in winter in other watersheds.

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, concentrations of water quality measurement endpoints were within the range of regional *baseline* concentrations with the exception of total mercury, which exceeded the 95th percentile of regional *baseline* concentrations at *test* station MAR-1 and *baseline* station MAR-2 (Figure 5.5-5).

Water Quality Index The WQI for *test* station MAR-1 (89.8) and *baseline* station MAR-2 (97.5) in fall 2010 indicated **Negligible-Low** differences from regional *baseline* water quality conditions. Water quality index values were similar to the previous two years.

Classification of Results Concentrations of several water quality measurement endpoints in the MacKay River watershed in fall 2010 were outside the range of previously-measured concentrations, possibly due to increased water levels and flows than typical of fall conditions. Water quality was generally consistent with regional *baseline* conditions and the ionic composition of water at both stations in fall 2010 was consistent with previous years, and continued to show little year-to-year variation. Differences in water quality in fall 2010 at both *test* and *baseline* stations relative to regional *baseline* water quality conditions were assessed as **Negligible-Low**.

5.5.4 Benthic Invertebrate Communities and Sediment Quality

5.5.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at:

- erosional *test* reach MAR-E1 near the mouth of the river, sampled since 1998;
- erosional *test* reach MAR-E2 located upstream of the Suncor Dover development, sampled since 2002 and designated as *test* since 2005; and
- erosional *baseline* reach MAR-E3 located upstream of all Suncor *in situ* developments, sampled for the first time in 2010.

2010 Habitat Conditions Water at *test* reach MAR-E1 in fall 2010 was shallow (0.4 m), moderate flowing (0.6 m/s), alkaline (pH: 8.2), and had moderate conductivity (156 µS/cm) and high dissolved oxygen (9.5 mg/L) (Table 5.5-7). The substrate was dominated by large (38%) and small (25%) gravel (Table 5.5-7). *Test* reach MAR-E2 and *baseline* reach MAR-E3 were similar in depth (0.3 to 0.4 m) to *test* reach MAR-E1, but faster flowing (1.0 m/s), had alkaline water with lower conductivity (140 µS/cm and 126 µS/cm, respectively) and higher dissolved oxygen (10.1 mg/L and 10.5 mg/L, respectively) (Table 5.5-7). The substrate at *test* reach MAR-E2 was dominated by large cobble (43%) and small cobble (20%), while the substrate at *baseline* reach MAR-E3 was dominated by small cobble (39%), large gravel (29%), and large cobble (22%) (Table 5.5-7). Periphyton chlorophyll *a* biomass in all reaches in fall 2010 was within the range of variation of periphyton chlorophyll *a* biomass in erosional reaches in the RAMP FSA (Figure 5.5-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach MAR-E1 in fall 2010 was dominated by chironomids (36%) and *Naididae* worms (30%) with subdominant taxa of Ephemeroptera (mayflies; 11%), *Hydracarina* (8%), and tubificid worms (5%) (Table 5.5-8). Dominant chironomid species included those typically associated with running water environments such as *Rheotanytaarsus* and *Synorthocladius*. Mayflies (Ephemeroptera) comprised 11% of the fauna, and included *Acerpenna*, *Baetis*, and *Heptagenia*. Stoneflies (Plecoptera) were present, reflecting that *test* reach MAR-E1 is a cold water environment. Common stoneflies included *Isoperla* and *Taeniopteryx*.

The benthic invertebrate community at *test* reach MAR-E2 in fall 2010 was dominated by chironomids (34%), including those typically associated with cool, running-water environments (e.g., *Tvetenia*). Mayflies (17%; Ephemeroptera, including *Baetis*, *Acerpenna, Acentrella,* and *Hetagenia*) and *Hydracarina* (12%) were present in smaller proportions. Stoneflies (Plecoptera) were also present, reflecting that *test* reach MAR-E2 is a cold water environment. Trichoptera (*Hydropsyche, and Cheumatopsych*e) were present in low relative abundance (Table 5.5-9).

The benthic invertebrate community at *baseline* reach MAR-E3 in fall 2010 was dominated by *Naididae* worms (41%) and chironomids (25%). Mayflies (9%; Ephemeroptera, including *Baetis*, *Acerpenna, Acentrella,* and *Hetagenia*) and Trichoptera (*Hydropsyche, and Cheumatopsych*e) (8%) were present in relatively equal proportions. Stoneflies (Plecoptera) were present in similar numbers to *test* reach MAR-E2 (Table 5.5-9).

Temporal and Spatial Comparisons Two temporal comparisons were conducted for *test* reach MAR-E1 and one temporal comparison was conducted for *test* reach MAR-E2 (spatial comparisons were not conducted because *baseline* reach MAR-E3 was sampled for the first time in 2010 and there was not enough years of data for spatial comparisons between *test* and *baseline* reaches for fall 2010 in the MacKay River watershed).

Changes in mean values of measurement endpoints for benthic invertebrate communities at *test* reach MAR-E1 were tested between the years before (1998, 2000, 2001) and after (2002 to present) the reach was designated as *test* (Hypothesis 2, Section 3.2.3.1). Total abundance, taxa richness, and CA Axis 1 scores were significantly lower in the *test* period compared to the *baseline* period (Table 5.5-10). In all cases, less than 10% of the total variation in the values of these benthic invertebrate community measurement endpoints was explained by these differences. There were no differences in diversity, evenness percent EPT, or CA Axis 2 scores between *baseline* and *tests* periods. The higher CA Axis 1 scores in the *test* period indicate a shift towards higher relative abundance of gastropods and ostracods in the *test* period (Table 5.5-10).

Changes in time trends in the values of the measurement endpoints for benthic invertebrate communities were tested for the period that reach MAR-E1 has been designated as *test* (i.e., since 2002, Hypothesis 1, Section 3.2.3.1). There was a significant decrease in total abundance and a significant increase in CA Axis 2 scores during the *test* period (Table 5.5-10). The decrease in abundance over time explained a small proportion of the total variation (< 10%) in annual means (Table 5.5-10), while the increase in CA Axis 2 scores explained more than 20% of the total variation in annual mean scores and suggests a decrease over time in the relative abundance of Trichoptera, Plecoptera, Ephemeroptera, Empididae, and Bivalvia during the *test* period.

Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that *test* reach MAR-E2 (Hypothesis 1, Section 3.2.3.1) There was a significant decrease in total abundance and a significant increase in values of all six other measurement endpoints over time, with the change in values of total abundance, percent EPT, and CA Axis 1 and 2 scores explaining more than 20% of the variation in annual means for these measurement endpoints (Table 5.5-11).

Comparison to Published Literature The benthic invertebrate communities in *test* reaches MAR-E1 and MAR-E2 reflect healthy robust conditions. The community at *test* reach MAR-E1 contained a relatively high proportion of EPT taxa, despite being lower than previous years. The percent of naidid worms (30%) was higher than previously measured but lower than what has been observed in *baseline* reach MAR-E3. The community at *test* reach MAR-E2 contained a relatively high percentage of EPT taxa (i.e., > 20%) while the percentage of the benthic invertebrate community as naidid worms (8%) and tubificid worms (8%) were both low. The percent of chironomids (36% at *test* reach MAR-E1 and 34% at *test* reach MAR-E2) is what would be expected in a healthy robust benthic invertebrate community (Hynes 1960, Griffiths 1998).

2010 Results Relative to Regional *Baseline* Conditions Values of benthic invertebrate community measurement endpoints were all within regional *baseline* conditions at *test* reach MAR-E1 in fall 2010, with the exception of percent EPT taxa (13%), which was below the 5th percentile of regional *baseline* conditions (Figure 5.5-7). Percent EPT at *test* reach MAR-E1 was lower than previously measured but lower percent EPT (8%) have been observed at *test* reach MAR-E2 in 2002 (8%).

Values of benthic invertebrate community measurement endpoints were all within regional *baseline* conditions at *test* reach MAR-E2 in fall 2010 (Figure 5.5-7). Total abundance was low (~ 2700 per m^2) and near the 5^{th} percentile of regional *baseline* conditions for erosional reaches and lower than observed in this reach in previous years (Table 5.5-9).

Values of benthic invertebrate community measurement endpoints were all within regional *baseline* conditions at *baseline* reach MAR-E3 in fall 2010 (Figure 5.5-7).

Classification of Results Differences in measurement endpoints for benthic invertebrate communities at *test* reach MAR-E1 are classified as **Negligible-Low** because, although there were significant decreases in abundance and richness in the *test* period compared to the *baseline* period and a decrease in abundance during the *test* period, the statistical signal in the differences over time explained less than 10% of the variance in total abundance. It should be noted; however, that there was also a relatively strong time trend in CA Axis 2 scores suggesting a decrease in the percent of the community and mayflies, stoneflies, and caddisflies.

Differences in measurement endpoints for benthic invertebrate community at *test* reach MAR-E2 are classified as **Moderate** because the significant decrease in abundance over time explained more than 20% of the variance in annual means and was lower in 2010 than all previous sampling years at this reach. Significant increases were observed in richness, diversity, evenness and percent of the fauna as EPT taxa but an increase in these measurement endpoints does not imply a negative change in the benthic invertebrate community.

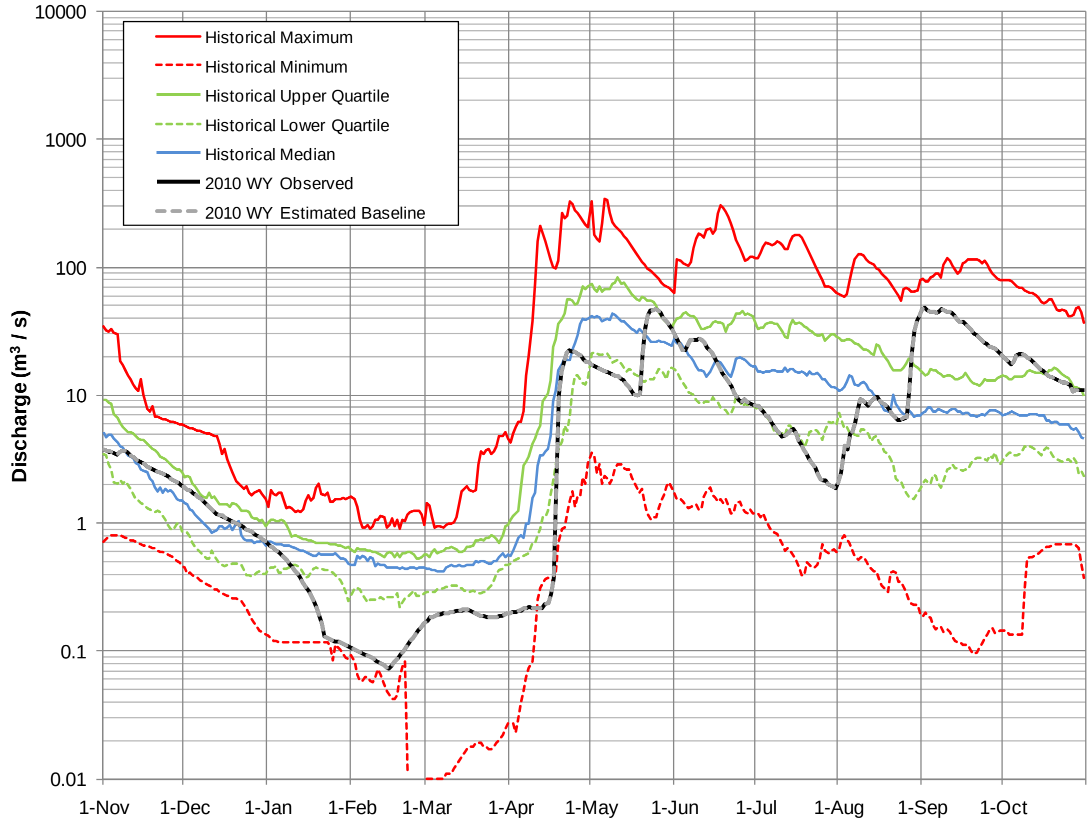
5.5.4.2 Sediment Quality

No sediment quality sampling was conducted in the MacKay River in 2010 because sediment quality is only sampled in the depositional reaches in which benthic invertebrate communities were sampled and the reaches of the MacKay River where benthic invertebrate communities were sampled are erosional.

5.5.5 Fish Populations

The Fish Populations component did not conduct regular monitoring activities in the MacKay River watershed in 2010.

Figure 5.5-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the MacKay River in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph are based on provisional data for WSC Station 07DB001, MacKay River near Fort McKay, from March 1 to October 31, 2010, and RAMP Station S26 for other months in 2010. The upstream drainage area is 5,569 km^2. Historical values from March 1 to October 31 calculated for the period from 1972 to 2009, and historical values for other months calculated for the period from 1972 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, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**319.69**	**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	-0.25	Estimated 4.4 km^2 of the MacKay River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.15	Estimated 13.4 km^2 of the MacKay River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the MacKay River watershed from focal projects	0	None reported
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**319.79**	**Estimated *baseline* discharge at WSC Station 07DB001 (RAMP Station S26), MacKay River near Fort McKay**
Incremental flow (change in total annual discharge)	-0.10	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-0.03%**	**Incremental flow as a percentage of total annual discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2010 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, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	18.07	18.06	-0.03%
Mean winter discharge	0.95	0.95	-0.03%
Annual maximum daily discharge	47.81	47.80	-0.03%
Open-water period minimum daily discharge	1.87	1.87	-0.03%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2010 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 (*test* station MAR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.9	11	7.6	8.2	8.6
Total Suspended Solids	mg/L	-[1]	41	11	<2	6	26
Conductivity	µS/cm	-	183	11	196	268	576
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.027	11	0.004	0.022	0.047
Total nitrogen*	mg/L	1.0	**2.12**	11	0.40	**1.20**	**3.20**
Nitrate+Nitrite	mg/L	1.3	<0.071	11	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	39.7	11	20.0	28.0	40.0
Ions							
Sodium	mg/L	-	15.4	11	15.0	20.0	60.0
Calcium	mg/L	-	20.8	11	24.7	28.5	44.7
Magnesium	mg/L	-	7.3	11	8.1	9.3	15.9
Chloride	mg/L	230, 860[3]	1.2	11	3.0	6.0	41.2
Sulphate	mg/L	100[4]	9.6	11	9.3	18.0	35.5
Total Dissolved Solids	mg/L	-	178	11	170	238	342
Total Alkalinity	mg/L		80	11	96	124	202
Selected metals							
Total aluminum	mg/L	0.1	**1.74**	11	0.05	**0.20**	**0.50**
Dissolved aluminum	mg/L	0.1[2]	0.046	11	0.007	0.020	0.030
Total arsenic	mg/L	0.005	0.0013	11	0.0007	0.0009	0.0010
Total boron	mg/L	1.2[5]	0.051	11	0.057	0.084	0.140
Total molybdenum	mg/L	0.073	0.00016	11	0.00015	0.00040	0.00060
Total mercury (ultra-trace)	ng/L	5, 13[6]	**6.3**	7	<1.2	<1.2	2.9
Total strontium	mg/L	-	0.108	11	0.133	0.158	0.287
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.019**	11	**0.003**	**0.011**	**0.032**
Total phosphorus	mg/L	0.05	**0.072**	11	**0.011**	**0.038**	**0.059**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.05**	11	0.30	**1.05**	**3.10**
Total iron	mg/L	0.3	**2.08**	11	**0.31**	**0.88**	**23.3**
Dissolved iron	mg/L	0.3[2]	**0.429**	11	0.230	**0.469**	**0.787**
Total chromium	mg/L	0.001	**0.0026**	11	0.0003	0.00068	**0.018**
Total phenols	mg/L	0.004	**0.0203**	11	<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).

8 Guideline is for total nitrogen.

Table 5.5-5 Concentrations of water quality measurement endpoints, upper MacKay River (*baseline* station MAR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	8	7.8	8.2	8.3
Total Suspended Solids	mg/L	-[1]	23	8	<3	<3	10
Conductivity	µS/cm	-	164	8	180	228	264
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.026	8	0.008	0.033	0.043
Total nitrogen*	mg/L	1.0	**2.25**	8	0.8	**1.3**	**3.1**
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.071	0.10	0.10
Dissolved organic carbon	mg/L	-	40	8	22	32	41
Ions							
Sodium	mg/L	-	11	8	11	17	19
Calcium	mg/L	-	17.8	8	21.3	25.2	34.5
Magnesium	mg/L	-	6.6	8	6.9	8.5	11.0
Chloride	mg/L	230, 860[3]	<0.5	8	0.8	2.0	3.0
Sulphate	mg/L	100[4]	6.8	8	7.0	13.2	23.7
Total Dissolved Solids	mg/L	-	190	8	160	195	240
Total Alkalinity	mg/L	-	75	8	81	106	128
Selected metals							
Total aluminum	mg/L	0.1	**1.080**	8	0.020	**0.151**	**0.468**
Dissolved aluminum	mg/L	0.1[2]	0.0439	8	<0.0002	0.0241	0.0268
Total arsenic	mg/L	0.005	0.0010	8	0.0006	0.0009	0.0010
Total boron	mg/L	1.2[5]	0.0516	8	0.0430	0.0589	0.1050
Total molybdenum	mg/L	0.073	0.00014	8	0.00013	0.00033	0.00055
Total mercury (ultra-trace)	ng/L	5, 13[6]	5.0	7	<1.2	<1.2	1.8
Total strontium	mg/L	-	0.105	8	0.114	0.134	0.197
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.018**	8	**0.008**	**0.020**	**0.030**
Total phosphorus	mg/L	0.05	**0.059**	8	0.014	0.047	**0.074**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.18**	8	0.7	**1.2**	**3.0**
Total chromium	mg/L	0.001	**0.0014**	8	0.0003	0.00044	0.00086
Total iron	mg/L	0.3	**1.34**	8	**0.386**	**0.919**	**1.277**
Dissolved iron	mg/L	0.3[2]	**0.407**	8	0.289	**0.564**	**0.760**
Total phenols	mg/L	0.004	**0.012**	8	<0.001	**0.009**	**0.020**

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 Water quality guideline exceedances, MacKay River watershed, 2010.

Variable	Units	Guideline	MAR-1	MAR-2	MAR-2A
Winter					
Dissolved arsenic	mg/L	0.005[2]	ns	ns	0.011
Dissolved boron	mg/L	1.2[2]	ns	ns	1.703
Dissolved iron	mg/L	0.3[2]	ns	ns	2.17
Dissolved copper	mg/L	[3]	ns	ns	0.0077
Dissolved chromium	mg/L	0.001[2]	ns	ns	0.0056
Dissolved manganese	mg/L	[3]	ns	ns	10.8
Dissolved selenium	mg/L	0.001[2]	ns	ns	0.0059
Dissolved uranium	mg/L	0.02[2]	ns	ns	0.0204
Dissolved cadmium	mg/L	[3]	ns	ns	0.000037
Total phenols	mg/L	0.004	ns	ns	0.106
Sulphate	mg/L	50, 100[6]	ns	ns	1450
Sulphide	mg/L	0.002[1]	ns	ns	0.037
Ammonia	mg/L	1.37	ns	ns	3.17
Total phosphorus	mg/L	0.05	ns	ns	0.27
Dissolved phosphorus	mg/L		ns	ns	0.10
Total Kjeldahl nitrogen	mg/L	1.0[5]	ns	ns	15.1
Total nitrogen*	mg/L	1.0	ns	ns	15.81
Total arsenic	mg/L	0.005	ns	ns	0.013
Total boron	mg/L	1.2	ns	ns	1.72
Total chromium	mg/L	0.001	ns	ns	0.0060
Total copper	mg/L	[3]	ns	ns	0.0082
Total manganese	mg/L	[3]	ns	ns	12.2
Total selenium	mg/L	0.001	ns	ns	0.0063
Total uranium	mg/L	0.02	ns	ns	0.024
Total iron	mg/L	0.3	ns	ns	9.18
Spring					
Dissolved iron	mg/L	0.3[2]	ns	ns	0.543
Total phenols	mg/L	0.004	ns	ns	0.0089
Sulphide	mg/L	0.002[1]	ns	ns	0.0075
Total cadmium	mg/L	[3]	ns	ns	0.0000074
Total Kjeldahl nitrogen	mg/L	1.0[5]	ns	ns	1.85
Total nitrogen*	mg/L	1.0	ns	ns	1.921
Total Aluminum	mg/L	0.1	ns	ns	0.50
Total iron	mg/L	0.3	ns	ns	1.04

MAR-1 and MAR-2 were sampled in fall 2010 only.

MAR-2A was sampled in winter, spring, and summer 2010 only.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

ns = not sampled

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (2006).

[2] Guideline is for total species (no guideline for dissolved species).

[3] Guideline is hardness dependent.

[4] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999).

[5] Guideline is for total nitrogen.

[6] BC maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, BC. 2006).

Table 5.5-6 (Cont'd.)

Variable	Units	Guideline	MAR-1	MAR-2	MAR-2A
Summer					
Dissolved iron	mg/L	0.3[2]	ns	ns	0.543
Dissolved cadmium	mg/L	[3]	ns	ns	0.0000061
Total cadmium	mg/L	[3]	ns	ns	0.0000084
Total phenols	mg/L	0.004	ns	ns	0.012
Sulphide	mg/L	0.002[1]	ns	ns	0.012
Total phosphorus	mg/L	0.05	ns	ns	0.050
Total Kjeldahl nitrogen	mg/L	1.0[5]	ns	ns	1.64
Total nitrogen*	mg/L	1.0	ns	ns	1.711
Total Aluminum	mg/L	0.1	ns	ns	0.217
Total iron	mg/L	0.3	ns	ns	0.884
Fall					
Sulphide	mg/L	0.002[1]	0.0191	0.0178	ns
Total mercury (ultra-trace)	mg/L	5,13 [4]	6.3	-	ns
Total Phosphorus	mg/L	0.05	-	0.0594	ns
Total Kjeldahl nitrogen	mg/L	1.0[5]	2.05	2.18	ns
Total nitrogen*	mg/L	1.0	2.121	2.251	ns
Total iron	mg/L	0.3	2.08	1.34	ns
Total Aluminum	mg/L	0.1	1.74	1.08	ns
Total Chromium	mg/L	0.001	0.0026	0.0014	ns
Dissolved iron	mg/L	0.3[2]	0.429	0.407	ns
Total phenols	mg/L	0.004	0.0203	0.0118	Ns

MAR-1 and MAR-2 were sampled in fall 2010 only.

MAR-2A was sampled in winter, spring, and summer 2010 only.

Guidelines are CCME (2007) or AENV (1999b) unless otherwise noted.

ns = not sampled

* Total nitrogen calculated as the sum of nitrate+nitrite and total Kjeldahl nitrogen (TKN).

[1] B.C. Working Water Quality Guideline for sulphide as H_2S (2006).

[2] Guideline is for total species (no guideline for dissolved species).

[3] Guideline is hardness dependent.

[4] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999).

[5] Guideline is for total nitrogen.

[6] BC maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, BC. 2006).

Figure 5.5-4 Piper diagram of fall ion concentrations in the MacKay River watershed.

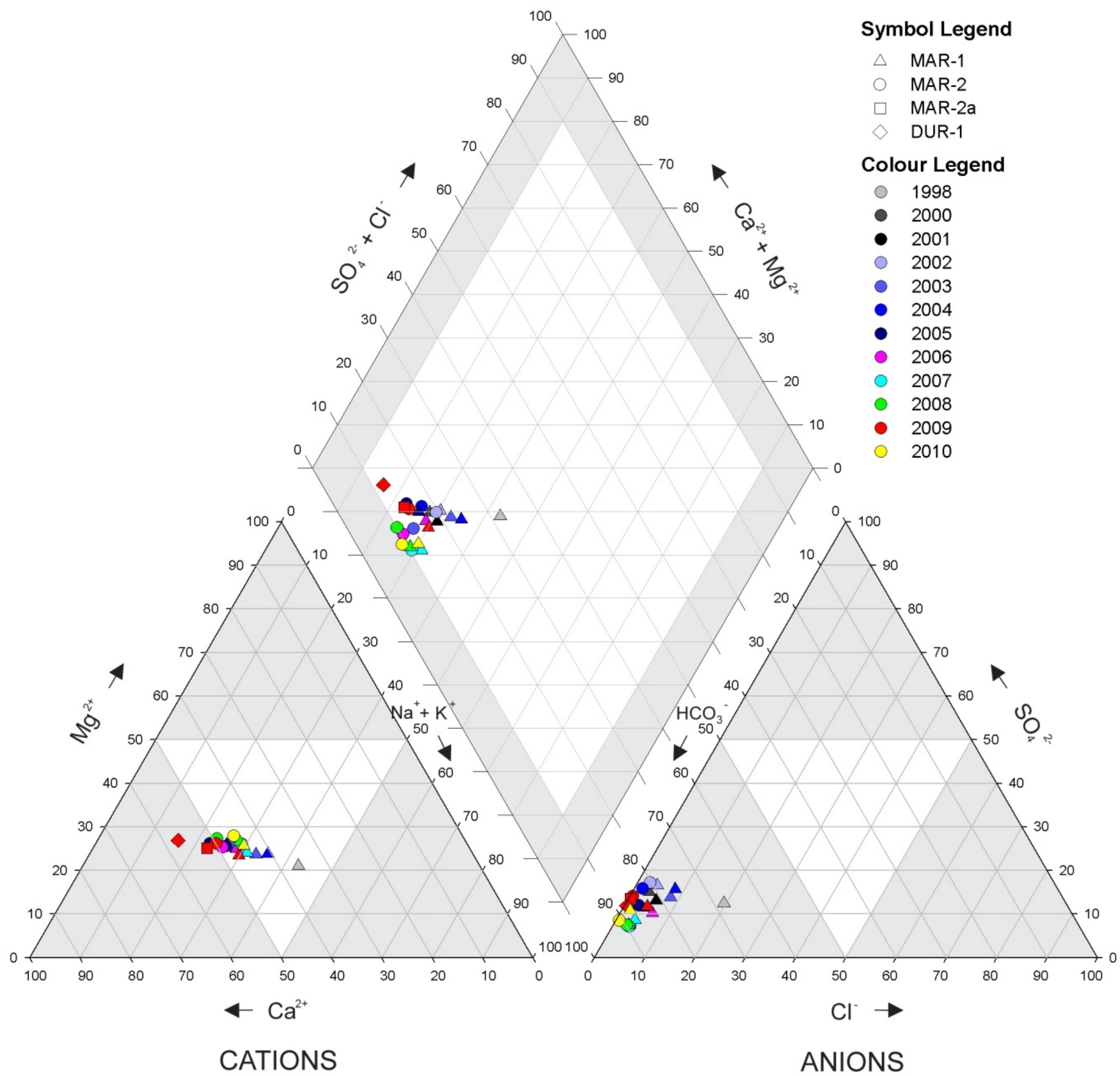
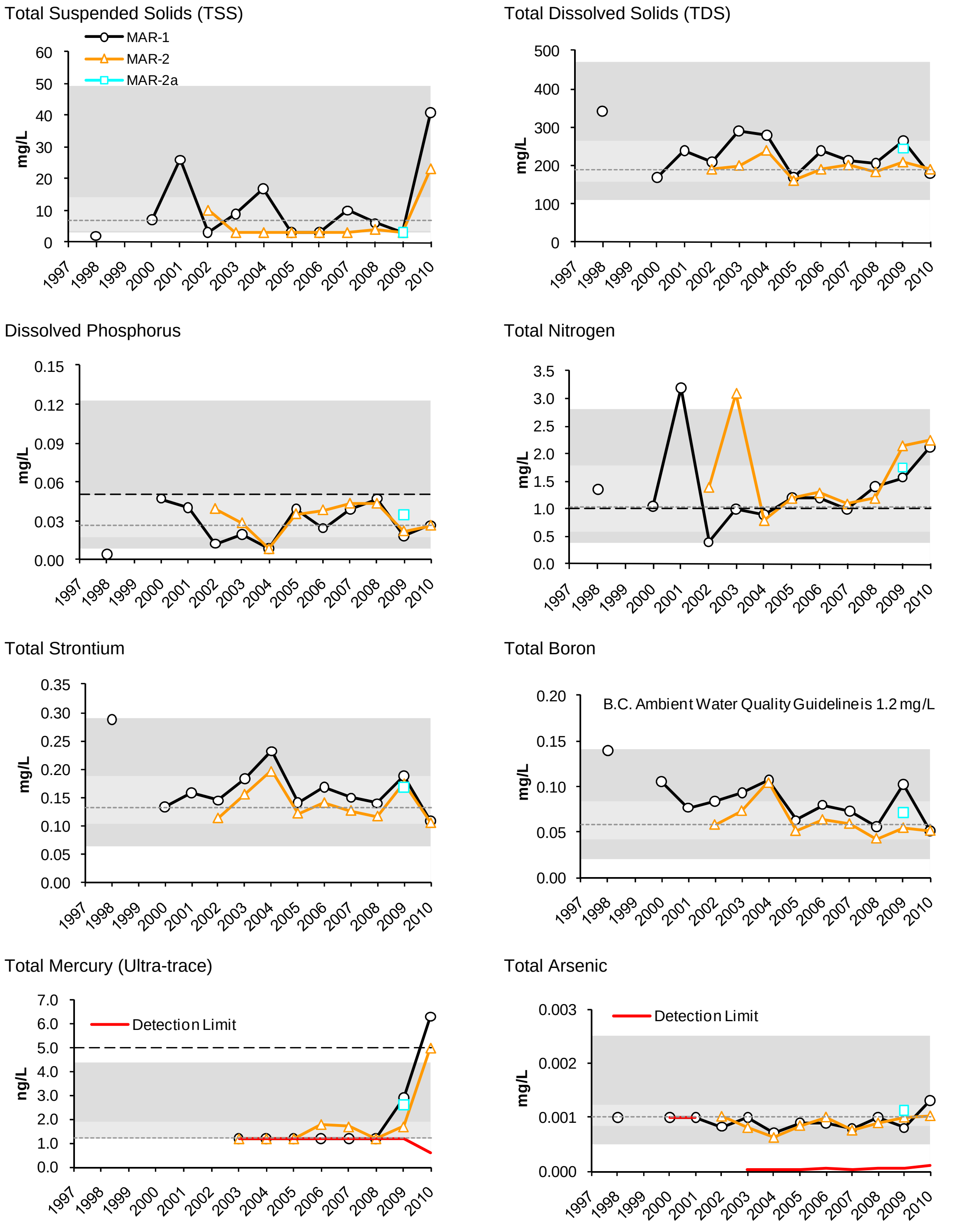


Figure 5.5-5 Concentrations of selected water quality measurement endpoints in the MacKay River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

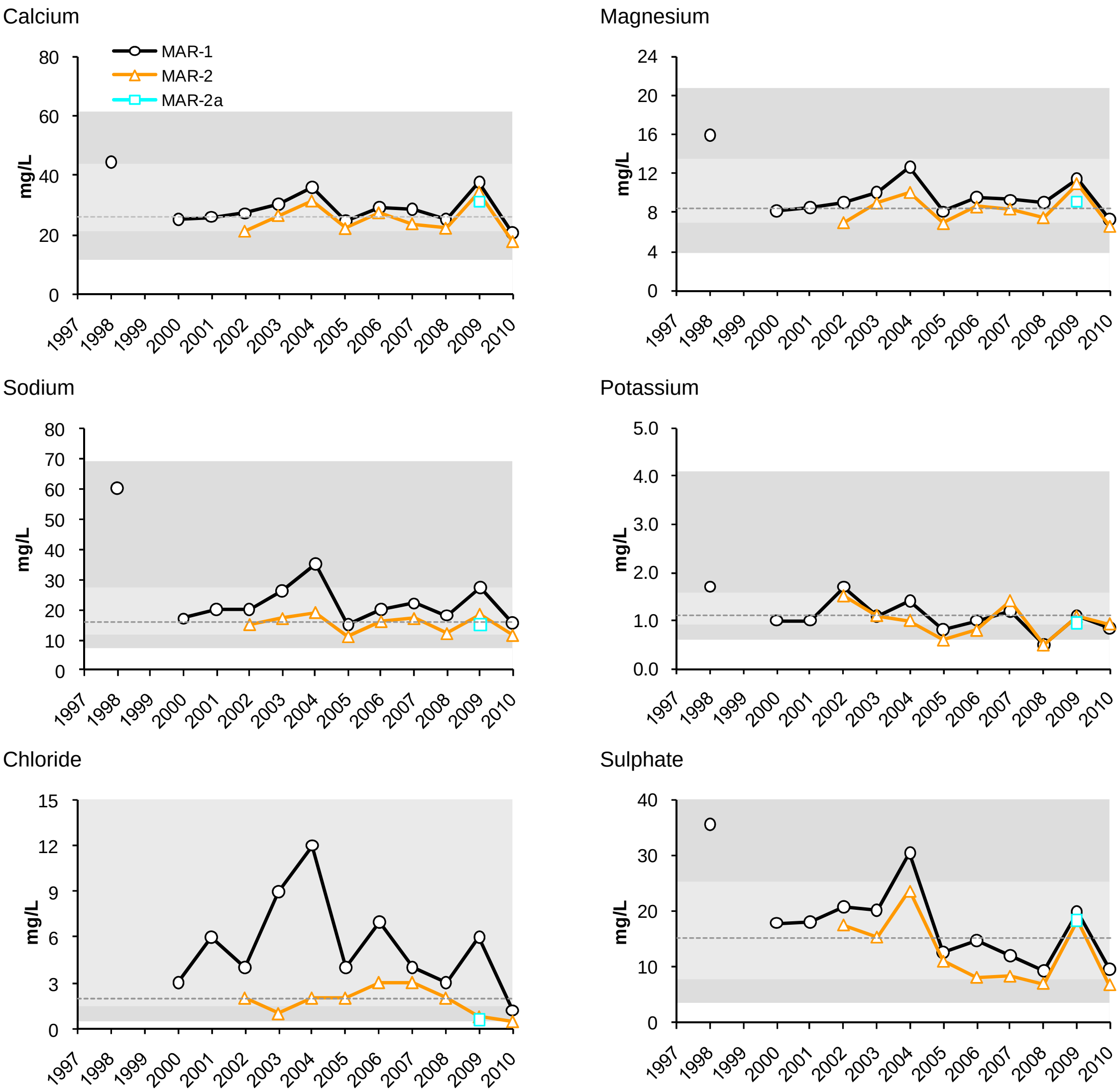


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.5-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.5-7 Average habitat characteristics of benthic invertebrate sampling locations in the MacKay River.

Variable	Units	MAR-E1 Lower *Test* Reach of the MacKay River	MAR-E2 Middle *Test* Reach of the MacKay River	MAR-E3 Upper *Baseline* Reach of the MacKay River
Sample date	-	Sept. 26, 2010	Sept. 26, 2010	Sept. 26, 2010
Habitat	-	Erosional	Erosional	Erosional
Water Depth	m	0.4	0.3	0.4
Current Velocity	m/s	0.6	1.0	1.0
Field Water Quality				
Dissolved Oxygen	mg/L	9.5	10.1	10.5
Conductivity	µS/cm	156	140	126
pH	pH units	8.2	8.2	8.3
Water temperature	°C	11.6	9.1	11.1
Substrate Composition				
Sand/Silt/Clay	%	17	6	0
Small Gravel	%	25	3	3
Large Gravel	%	38	9	29
Small Cobble	%	7	20	34
Large Cobble	%	6	43	22
Boulder	%	<1	8	12
Bedrock	%	8	12	0

Figure 5.5-6 Periphyton chlorophyll *a* biomass in the *test* (MAR-E1 and MAR-E2) and *baseline* (MAR-E3) reaches of the MacKay River.

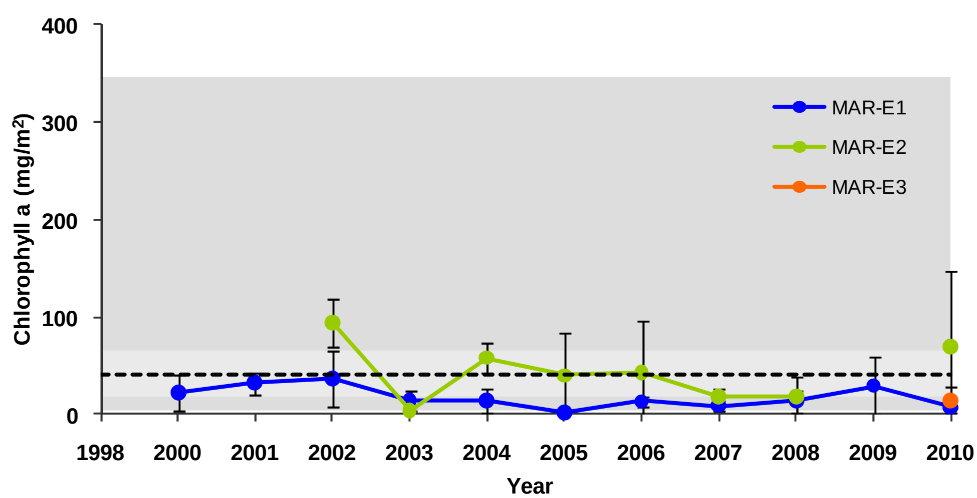


Table 5.5-8 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the MacKay River (*test* reach MAR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year											
	Reach MAR-E1											
	1998	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Anisoptera	1	1	2	1	1	3	2	2	1	5	1	<1
Bivalvia		<1	<1	1	2	2	1		<1	1	<1	<1
Ceratopogonidae	1	1	<1	1	<1	1	5	3	1	1	2	<1
Chironomidae	57	34	4	31	4	57	2	3	40	34	69	36
Coleoptera	<1	<1			<1	<1		<1		<1		<1
Copepoda	<1	<1	<1	<1				<1	1	<1	<1	
Empididae	1	1	4	3	2	2	12	6	1	1	1	
Enchytraeidae	4	12	1	5	5	1	1	1	1	3	1	1
Ephemeroptera	26	21	18	12	19	13	25	29	13	21	16	11
Erpobdellidae						<1						
Gastropoda	<1	<1	1	2	<1	1		1	1	3		3
Heteroptera	<1		<1									
Hydra	<1			1	<1					<1		
Hydracarina	1	4	6	3	18	6	1	2	15	14	<1	8
Lumbriculidae					<1							
Macrothricidae		<1		1								
Naididae	2	17	2	24	8	3	11	8	9	6	3	30
Nematoda	2	2	8	6	1	3	1	1	3	2	2	2
Ostracoda	<1	1	1	6		<1		<1	1	1	<1	1
Plecoptera	2	5	5	<1	1	3	3	8	2	3	1	1
Simuliidae	1	<1	<1	<1	<1		2	<1	1	<1	<1	<1
Tabanidae					<1		1		1			<1
Tipulidae	<1	<1			<1				1			
Trichoptera	<1	<1	3	3	2	5	<1	5	1	<1	<1	1
Tubificidae	2	<1	1	2	<1	1	6	2	1	3	2	5
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	7,972
Richness	49	29	26	37	24	27	23	30	32	38	33	34
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	0.86
Evenness	0.89	0.91	0.93	0.90	0.89	0.88	0.94	0.89	0.92	0.85	0.9	0.89
% EPT	26	25	24	16	23	20	28	42	15	26	23	13

Table 5.5-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the MacKay River (*test* reach MAR-E2 and *baseline* reach MAR-E3).

Taxon	Percent Major Taxa Enumerated in Each Year									
	Reach MAR-E2									Reach MAR-E3
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2010
Anisoptera	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Bivalvia	<1	4	1	<1		<1	1		2	1
Ceratopogonidae	<1	<1	1	1	1	1	2	1	3	1
Chironomidae	31	3	59	49	63	39	43	51	34	25
Coleoptera		<1	<1	<1		<1	<1		<1	<1
Copepoda	<1		<1				<1		<1	<1
Empididae	1	2	1	5	<1	<1	<1	1	<1	<1
Enchytraeidae	1	4	3	3	1	1	2	<1	3	2
Ephemeroptera	2	14	11	1	12	16	8	20	17	9
Erpobdellidae		<1								
Gastropoda	<1	<1	<1	<1		1	1	<1	2	1
Hydra	<1									
Hydracarina	7	21	4	9	5	17	10	5	12	5
Lumbriculidae		<1		<1		1				
Naididae	48	15	4	15	2	9	11	5	8	41
Nematoda	3	1	3	1	3	3	3	3	1	1
Ostracoda	<1	<1	<1			1	<1	1	2	2
Plecoptera	<1	3	3	1	2	3	2	1	3	3
Simuliidae		<1		<1	<1	1		<1	<1	<1
Tabanidae		<1							<1	<1
Tipulidae	<1	<1	<1		1	<1	<1	<1	<1	
Trichoptera	6	4	3	5	1	10	12	12	4	8
Tubificidae	<1	<1	8	1	1	2	4	2	8	<1
Benthic Invertebrate Community Measurement Endpoints										
Total Abundance (No./m^2)	28,222	5,568	15,733	12,332	9,409	12,130	5,257	12,415	2,703	4,300
Richness	40	27	32	30	27	41	39	37	35	35
Simpson's Diversity	0.74	0.87	0.91	0.86	0.65	0.87	0.83	0.90	0.91	0.81
Evenness	0.76	0.91	0.94	0.89	0.65	0.89	0.87	0.93	0.94	0.83
% EPT	8	25	17	16	24	28	26	32	24	22

Table 5.5-10 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints for *test* reach MAR-E1 of the MacKay River.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Baseline* vs. *Test	**Time Trend (*test* period)**	***Baseline* vs. *Test***	**Time Trend (*test* period)**	
Abundance	**0.001**	**0.000**	7	8	High in 1998 and decreasing time trend in *test* period
Richness	**0.003**	0.058	8	3	Lower in *test* period and no time trend in *test* period
Simpson's Diversity	0.508	0.953	4	0	No difference between *baseline* and *test* periods and no time trend in *test* period
Evenness	0.520	0.903	4	0	No difference between *baseline* and *test* periods and no time trend in *test* period
EPT	0.114	0.169	6	5	No difference between *baseline* and *test* periods and no time trend in *test* period
CA Axis 1	**0.011**	0.092	12	5	Slight positive shift from *baseline* to *test* period
CA Axis 2	0.957	**0.000**	0	26	Increasing time trend in *test* period suggesting decrease in relative abundance of Trichoptera, Plecoptera, Empididae, Bivalvia.

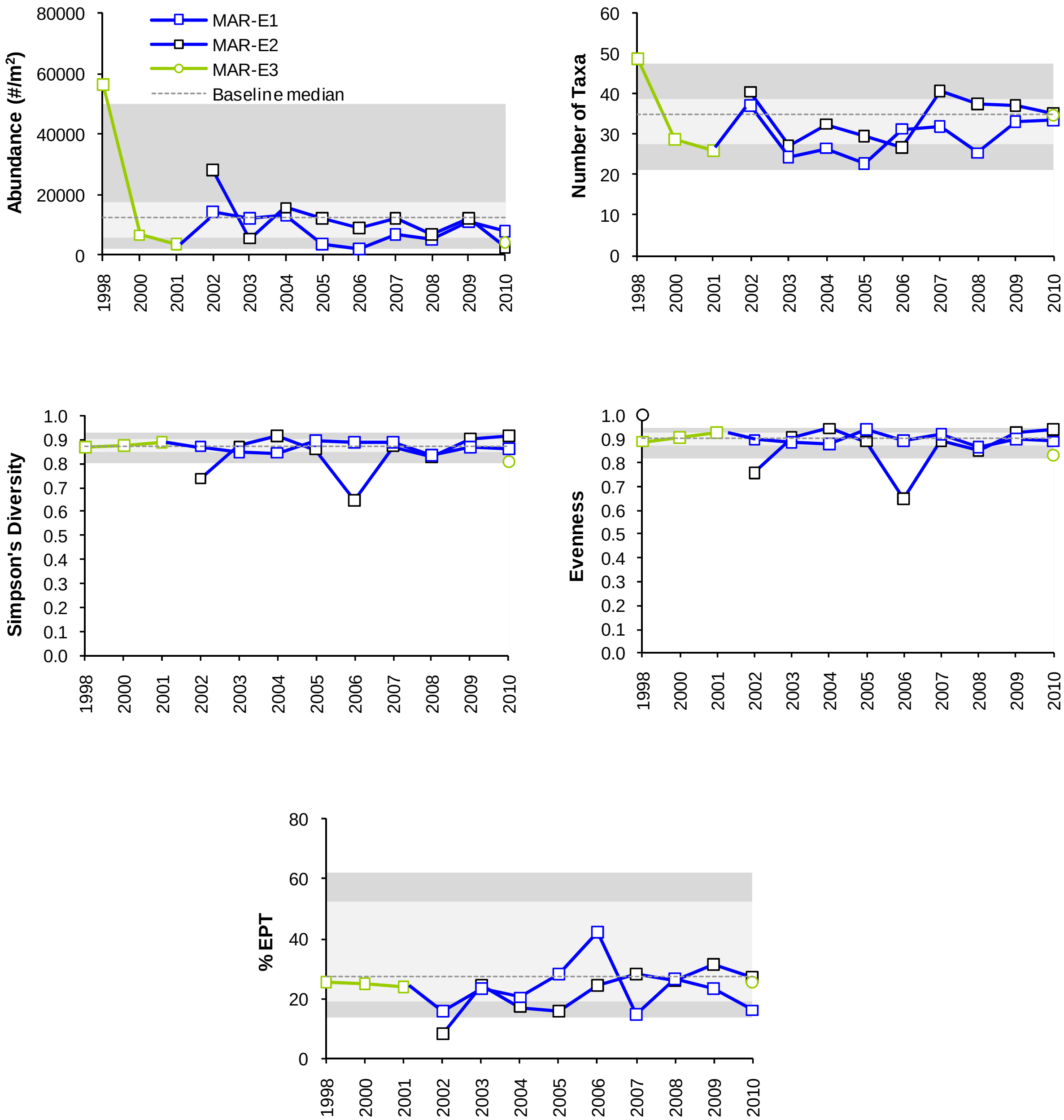
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Table 5.5-11 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints for *test* reach MAR-E2 of the MacKay River.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Linear Time Trend	**Linear Time Trend**	
Abundance	**0.000**	31	Decreasing time trend
Richness	**0.014**	7	Increasing time trend
Simpson's Diversity	**0.002**	11	Increasing time trend
Evenness	**0.004**	9	Increasing time trend
EPT	**0.000**	43	Increasing time trend
CA Axis 1	**0.001**	22	Increasing time trend
CA Axis 2	**0.000**	32	Increasing time trend

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

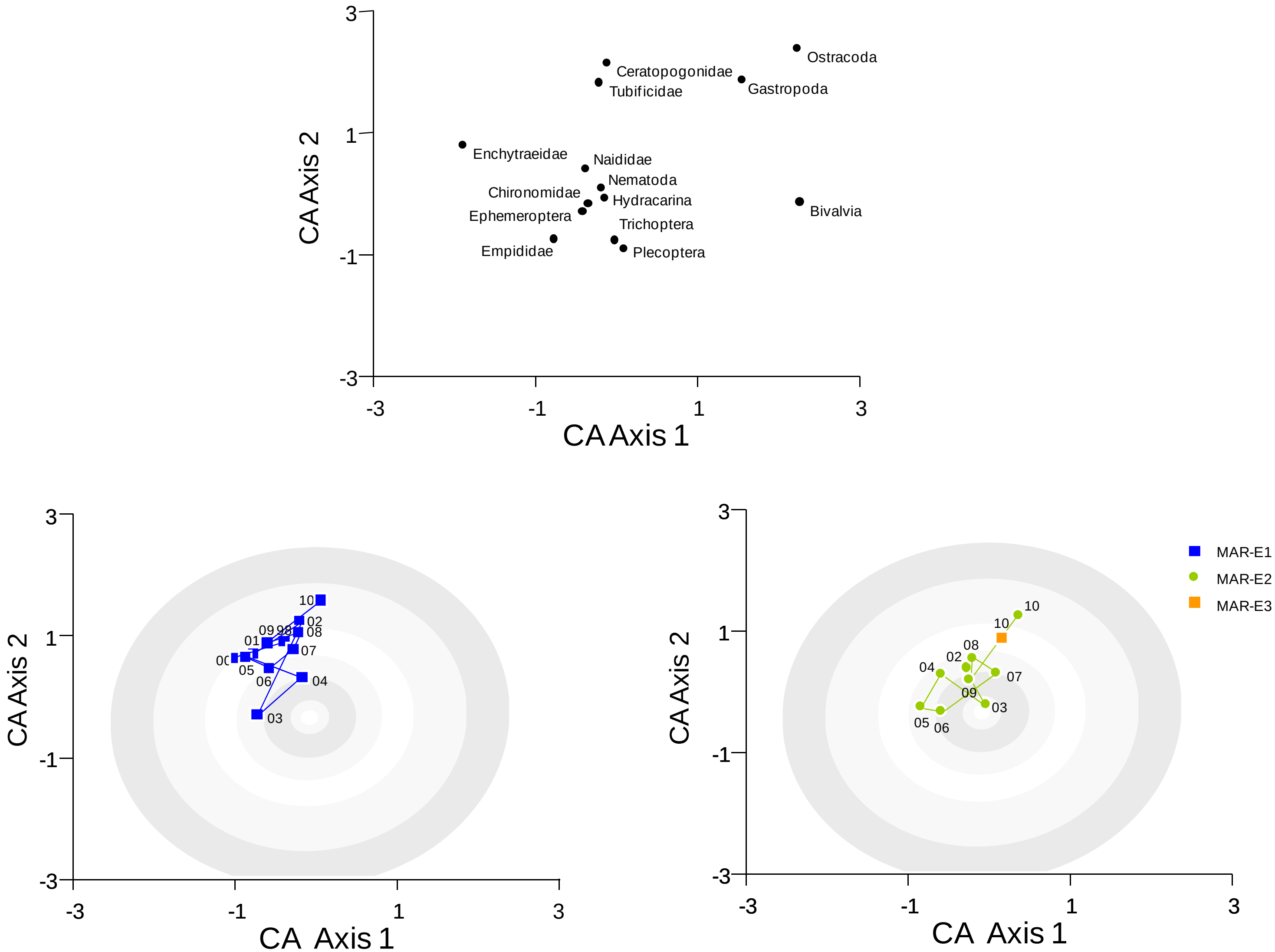
Figure 5.5-7 Variation in benthic invertebrate community measurement endpoints in the MacKay River.



Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.2.3.1.

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.

5.6 CALUMET RIVER WATERSHED

Table 5.6-1 Summary of results for the Calumet River watershed.

Calumet River Watershed	Summary of 2010 Conditions	
Climate and Hydrology		
Criteria	**Canadian Natural Station CR-1** at the mouth	
Mean open-water season discharge	○	
Mean winter discharge	not measured	
Annual maximum daily discharge	○	
Minimum open-water season discharge	○	
Water Quality		
Criteria	**CAR-1** at the mouth	**CAR-2** upstream of Canadian Natural Horizon
Water Quality Index	○	○
Benthic Invertebrate Communities and Sediment Quality		
No Benthic Invertebrate Communities and Sediment Quality component activities conducted in 2010		
Fish Populations		
No Fish Populations component activities conducted in 2010		

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.

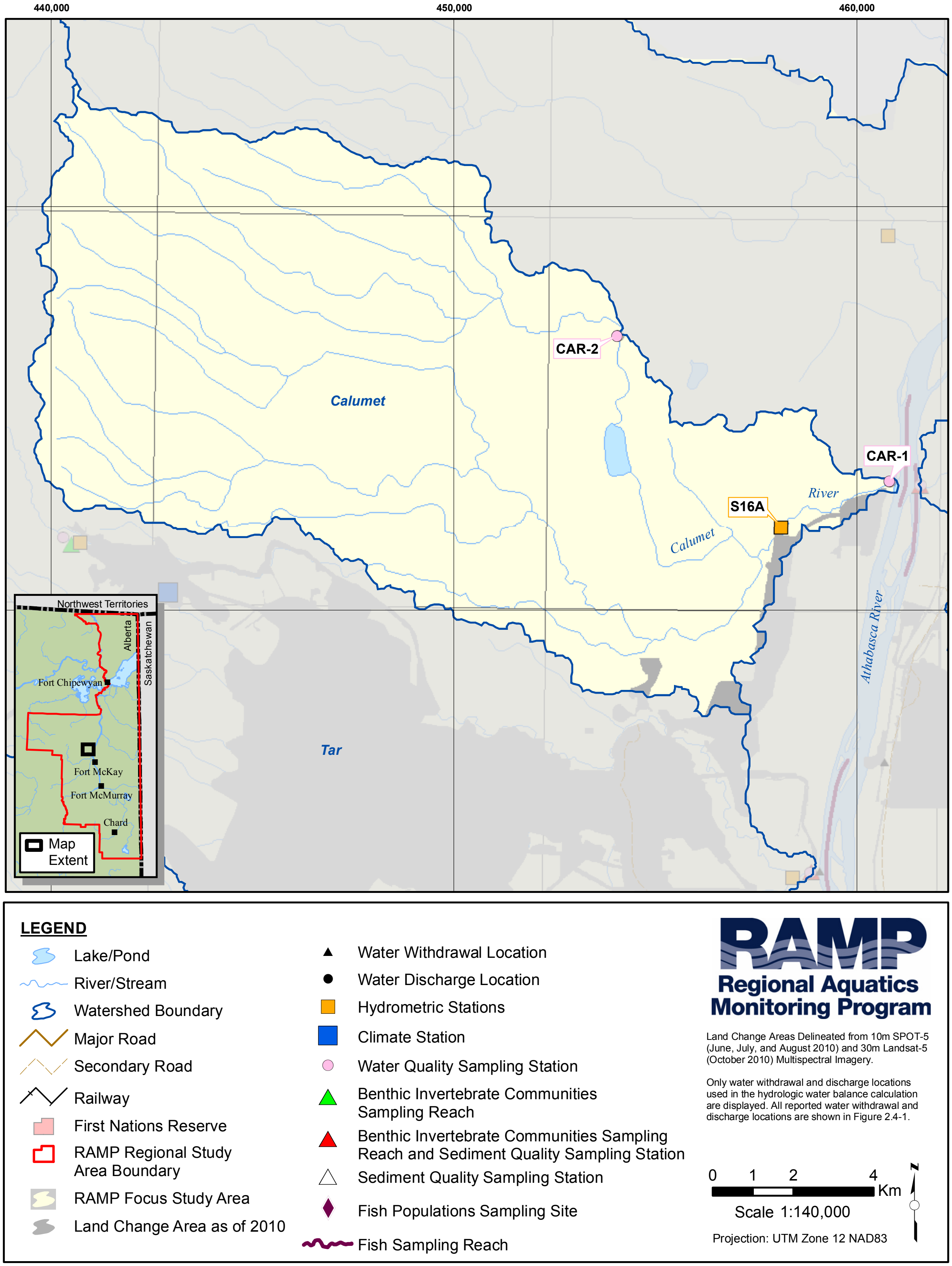
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology.

Figure 5.6-1 Calumet River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K06_Calumet_20110318.mxd

Figure 5.6-2 Representative monitoring stations of the Calumet River, fall 2010.

Water Quality Station CAR-1:
Left Downstream Bank

Water Quality Station CAR-1:
Centre of Channel, facing upstream

Water Quality Station CAR-2:
Centre of Channel, facing upstream

Water Quality Station CAR-2:
Left Downstream Bank

5.6.1 Summary of 2010 Conditions

As of 2010, 1.2% (214 ha) of the Calumet River watershed had undergone land change from focal projects (Table 2.5-2). 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).

The Climate and Hydrology and Water Quality components of RAMP conducted monitoring activities in the Calumet River watershed in 2010. Table 5.6-1 is a summary of the 2010 assessment for the Calumet River watershed, while Figure 5.6-1 denotes the location of the monitoring stations for each RAMP component and the areas with land change as of 2010. Figure 5.6-2 contains fall 2010 photos of the water quality monitoring stations in the watershed.

Hydrology For the 2010 WY, the mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for Station S16A are estimated to be 1.0% lower than the corresponding values from the estimated *baseline* hydrograph; these differences are classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at both *test* station CAR-1 and *baseline* station CAR-2 showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of most water quality measurement endpoints in the Calumet River in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* conditions. The ionic composition of water at *test* station CAR-1 was consistent with previous years while the ionic composition of water at *baseline* station CAR-2 had lower relative bicarbonate concentrations relative to previous years.

5.6.2 Hydrologic Conditions

Station S16A, Calumet River near the Mouth Continuous hydrometric data have been collected from April 24 to October 27, 2010 at Station S16A; 2010 was the first year that Station 16A was operational. Previously, hydrometric data were collected from the mouth of the Calumet River at Station S16 for each open-water period from 2001 to 2004 and at the Canadian Natural Station CR-1 from 2005 to 2009. Only partial records exist for each historical year; therefore, calculated statistics of historical runoff volumes and daily flows for comparison against the 2010 WY data are less robust.

The open-water (May to October) runoff volume in the 2010 WY at Station S16A was 2.5 million m^3. Flows were near historical minimum daily flows recorded during late April and early May and remained below historical median levels for most days from May to July (Figure 5.6-3). Flows increased following rainfall events in late August and early September and exceeded historical maximum values from September 3 until the end of the 2010 WY.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance for the 2010 WY at Station S16A is presented in Table 5.6-2 and described below:

1. The closed-circuited land area from focal projects as of 2010 is estimated to be 1.79 km^2 (Table 2.5-1). The loss of flow to the Calumet River that would have otherwise occurred from this land area is estimated at approximately 27,000 m^3.

2. As of 2010, the area of land change in the Calumet watershed from focal projects that was not closed-circuited is estimated to be 0.35 km^2 (Table 2.5-1). The increase in flow to the Calumet River that would not have otherwise occurred from this land area is estimated at approximately 1,000 m^3.

The estimated cumulative effect of land change in the 2010 WY is a loss of flow 26,000 m^3 at Station S16A (Table 5.6-2). The observed and estimated *baseline* hydrograph are presented in Figure 5.6-3. For the 2010 WY, the mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for Station S16A are estimated to be 1.0% lower than the corresponding values from the estimated *baseline* hydrograph (Table 5.6-3); these differences are classified as **Negligible-Low** (Table 5.6-4).

5.6.3 Water Quality

In 2010, water quality samples were taken in fall from:

- the Calumet River near its mouth (*test* station CAR-1, designated as *baseline* from 2002 to 2004 and *test* from 2005 to 2010); and
- the upper Calumet River (*baseline* station CAR-2, sampled since 2005).

Temporal Trends There were no significant trends in fall concentrations of water quality measurement endpoints at *test* station CAR-1. Trend analysis could not be conducted for *baseline* station CAR-2 due to the insufficient data record for this station (n=6).

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints in fall 2010 were within the range of previously-measured concentrations (Table 5.6-4 and Table 5.6-5) with the exception of:

- sulphate, total phenols, and total mercury at *test* station CAR-1 and sulphate and total mercury at *baseline* station CAR-2, with concentrations that exceeded previously-measured maximum concentrations; and
- total strontium at *test* station CAR-1 and magnesium and total alkalinity at *baseline* station CAR-2, with concentrations that were below previously-measured minimum concentrations.

Ion Balance The ionic composition of water at *test* station CAR-1 in fall 2010 was similar to previous years (Figure 5.6-4). The ionic composition of water at this station has remained consistent since water quality monitoring first began in 2002, with the exception of fall 2007 when cation composition was more calcium-dominated than in other years. In fall 2010, the contribution of bicarbonate to the anion composition of water at *baseline* station CAR-2 was lower than in previous years. Historically, water at *baseline* station CAR-2 has had lower relative concentration of bicarbonate composition than water at *test* station CAR-1 (Figure 5.6-4).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints were below water quality guidelines with the exception of:

- total dissolved phosphorus and total nitrogen at *test* station CAR-1 and *baseline* station CAR-2 (Table 5.6-4 and Table 5.6-5); and
- sulphate and total aluminum at *baseline* station CAR-2 (Table 5.6-5).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in fall 2010 (Table 5.6-6):

- total Kjeldahl nitrogen, total iron, total phenols, sulphide, and total phosphorus at *test* station CAR-1; and
- total Kjeldahl nitrogen, dissolved iron, total iron, total phenols, sulphide, and total phosphorus at *baseline* station CAR-2.

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, **c**oncentrations of all water quality measurement endpoints were within the range of regional *baseline* concentrations at *test* station CAR-1 (Figure 5.6-4). At *baseline* station CAR-2, total mercury, total arsenic, potassium, and sulphate exceeded the 95th percentile of regional *baseline* concentrations. Similar to conditions noted in fall 2009, concentrations of water quality measurement endpoints were generally higher at *baseline* station CAR-2 than at *test* station CAR-1 (Figure 5.6-5).

Water Quality Index The WQI value for *test* station CAR-1 in the Calumet River watershed in fall 2010 indicated a **Negligible-Low** difference from regional *baseline* conditions. The WQI value of 100 at *test* station CAR-1 is consistent with fall 2009. The WQI value of 90 at *baseline* station CAR-2 indicated a **Negligible-Low** difference from regional *baseline* conditions and a change in water quality conditions compared to fall 2009 when the WQI indicated a **Moderate** difference from regional *baseline* conditions, due to concentrations of suspended solids, dissolved phosphorus and total arsenic exceeding regional *baseline* conditions in fall 2009.

Classification of Results In fall 2010, water quality at both *test* station CAR-1 and *baseline* station CAR-2 showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of most water quality measurement endpoints in the Calumet River in fall 2010 were within the range of previously-measured concentrations and were consistent with regional *baseline* conditions. The ionic composition of water at *test* station CAR-1 was consistent with previous years while the ionic composition at *baseline* station CAR-2 had lower relative bicarbonate concentrations relative to historical measurements.

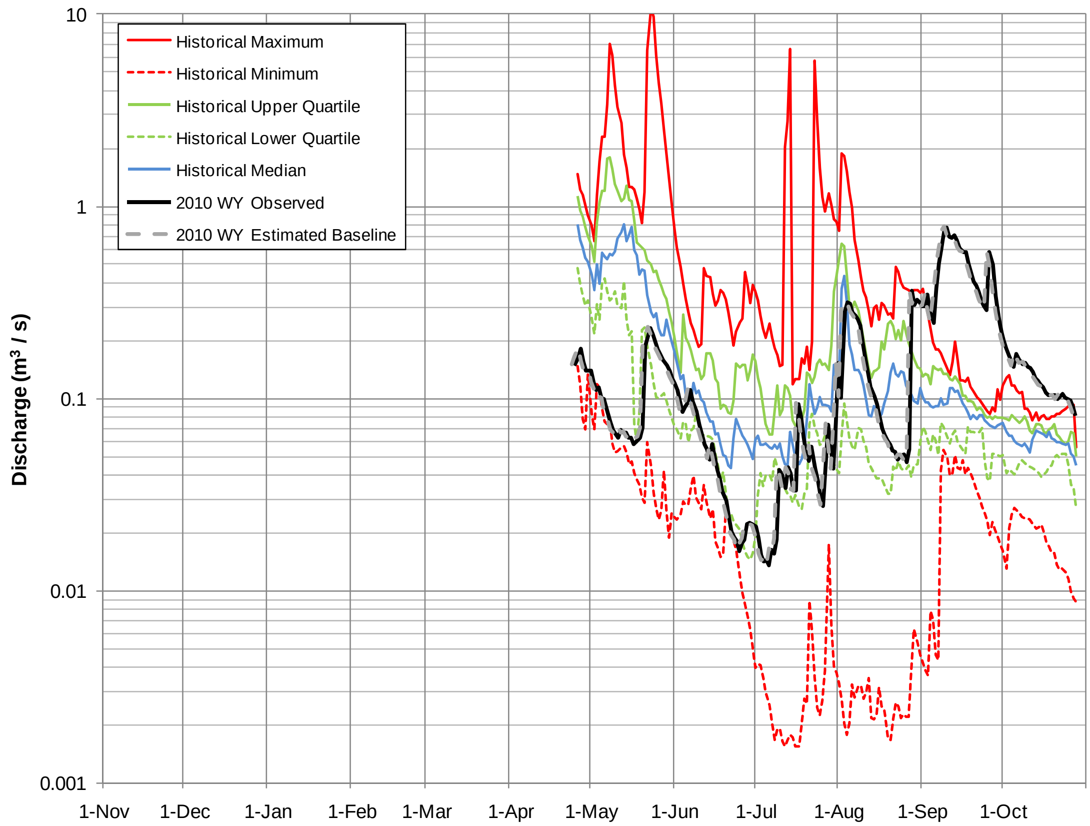
5.6.4 Benthic Invertebrate Communities and Sediment Quality

There were no Benthic Invertebrate Communities and Sediment Quality component activities conducted in the Calumet River watershed in 2010.

5.6.5 Fish Populations

There were no Fish Populations component activities conducted in the Calumet River watershed in 2010.

Figure 5.6-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Calumet River in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph based on RAMP Station S16A, Calumet River near the mouth, provisional data for April 24 to October 27, 2010. The upstream drainage area is 173.5 km^2. Historical values from 2001 to 2009 calculated for the open-water period at Station S16 (2001-2004) and Station CR-1 (2005-2009).

Table 5.6-2 Estimated water balance at Station S16A, Calumet River near the mouth, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**2.591**	**Observed discharge from RAMP Station S16A, Calumet River near the mouth**
Closed-circuited area water loss from the observed *test* hydrograph	-0.027	Estimated 1.79 km^2 of the Calumet River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.001	Estimated 0.35 km^2 of the Calumet River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**2.617**	**Estimated *baseline* discharge from RAMP Station S16A, Calumet River near the mouth**
Incremental flow (change in total discharge)	-0.026	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 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for April 24 to October 27, 2010 for RAMP Station S16A, Calumet River near the mouth.

Table 5.6-3 Calculated change in hydrologic measurement endpoints in the Calumet River watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.162	0.161	-1.0%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	0.788	0.780	-1.0%
Open-water season minimum daily discharge	0.014	0.013	-1.0%

Note: Values are calculated from provisional data for April 24 to October 27, 2010 for RAMP Station S16A, Calumet River near the mouth.

Table 5.6-4 Concentrations of water quality measurement endpoints, mouth of Calumet River (*test* station CAR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	8	8.1	8.2	8.4
Total suspended solids	mg/L	-[1]	<3	8	<3	11	41
Conductivity	µS/cm	-	449	8	188	583	702
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.060**	8	0.025	0.050	**0.076**
Total nitrogen*	mg/L	1.0	**1.30**	8	0.80	**1.30**	**1.54**
Nitrate+nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	36	8	22	31	38
Ions							
Sodium	mg/L	-	48	8	7	51	71
Calcium	mg/L	-	36.0	8	25.3	55.5	67.3
Magnesium	mg/L	-	12.5	8	7.8	18.7	22.5
Chloride	mg/L	230, 860[3]	12	8	2	16	34
Sulphate	mg/L	100[4]	20.5	8	3.6	12.1	14.5
Total dissolved solids	mg/L	-	340	8	151	397	480
Total alkalinity	mg/L		198	8	96	285	337
Selected metals							
Total aluminum	mg/L	0.1	0.088	8	0.040	**0.152**	**0.337**
Dissolved aluminum	mg/L	0.1[2]	0.0041	8	0.0013	0.0034	0.0058
Total arsenic	mg/L	0.005	0.0009	8	0.00088	0.00103	0.00120
Total boron	mg/L	1.2[5]	0.0788	8	0.074	0.087	0.122
Total molybdenum	mg/L	0.073	0.00012	8	0.00010	0.00016	0.00030
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.6	7	<1.2	<1.2	1.7
Total strontium	mg/L	-	0.166	8	0.195	0.246	0.297
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phosphorus	mg/L	0.05	**0.081**	8	**0.066**	**0.092**	**0.099**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.23**	8	0.70	**1.20**	**1.47**
Total iron	mg/L	0.3	**0.535**	8	0.0003	**1.470**	**3.140**
Sulphide	mg/L	0.002[7]	**0.0176**	8	**0.0050**	**0.0125**	**0.0280**
Total phenols	mg/L	0.004	**0.0134**	7	0.0010	**0.0080**	**0.0130**

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 5.6-5 Concentrations of water quality measurement endpoints, upper Calumet River (*baseline* station CAR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.21	5	7.80	8.10	8.21
Total suspended solids	mg/L	-[1]	26	5	<3	3	208
Conductivity	µS/cm	-	610	5	526	577	772
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.117**	5	**0.086**	**0.129**	**0.305**
Total nitrogen*	mg/L	1.0	**2.72**	5	**1.80**	**2.00**	**5.54**
Nitrate+nitrite	mg/L	1.3	<0.071	5	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	44	5	40	48	54
Ions							
Sodium	mg/L	-	69	5	53	65	76
Calcium	mg/L	-	44.5	5	44.0	52.8	68.2
Magnesium	mg/L	-	17.7	5	18.0	20.6	26.6
Chloride	mg/L	230, 860[3]	15.3	5	12.3	16.0	17.0
Sulphate	mg/L	100[4]	**101**	5	45.3	50.6	78.4
Total dissolved solids	mg/L	-	467	5	370	467	547
Total alkalinity	mg/L		188	5	213	238	315
Selected metals							
Total aluminum	mg/L	0.1	**0.207**	5	0.020	0.050	**4.10**
Dissolved aluminum	mg/L	0.1[2]	0.0181	5	0.0036	0.0132	0.0241
Total arsenic	mg/L	0.005	0.0026	5	0.0021	0.0025	0.0050
Total boron	mg/L	1.2[5]	0.0942	5	0.0808	0.0876	0.1280
Total molybdenum	mg/L	0.073	0.00055	5	0.00009	0.00029	0.00080
Total mercury (ultra-trace)	ng/L	5, 13[6]	4.4	5	<1.2	<1.2	2.8
Total strontium	mg/L	-	0.269	5	0.242	0.287	0.356
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phosphorus	mg/L	0.05	**0.324**	5	**0.101**	**0.311**	**1.480**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.65**	5	**1.70**	**1.90**	**5.47**
Total iron	mg/L	0.3	**1.25**	5	**0.551**	**0.721**	**6.68**
Dissolved Iron	mg/L	0.3	**0.561**	5	0.239	**0.369**	**1.500**
Sulphide	mg/L	0.002[7]	**0.039**	5	**0.024**	**0.027**	**0.588**
Total phenols	mg/L	0.004	**0.018**	5	**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.

Table 5.6-6 Water quality guideline exceedances, Calumet River watershed, 2010.

Variable	Units	Guideline	CAR-1	CAR-2
Fall				
Total phosphorus	mg/L	0.05	0.081	0.324
Total nitrogen*	mg/L	1.0	1.301	2.721
Total Kjeldahl nitrogen	mg/L	1.0[3]	1.23	2.65
Dissolved iron	mg/L	0.3[2]	-	0.561
Total aluminum	mg/L	0.1	-	0.207
Total iron	mg/L	0.3	0.54	1.25
Total phenols	mg/L	0.004	0.0134	0.0179
Sulphate	mg/L	50, 100[4]	-	101
Sulphide	mg/L	0.002[1]	0.018	0.039
Total dissolved phosphorus	mg/L	0.05[2]	0.060	0.117

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] 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.

[4] BC maximum concentration guideline for sulphate (B.C. Approved Water Quality Guideline, BC. 2006).

Figure 5.6-4 Piper diagram of fall ion concentrations in Calumet River watershed.

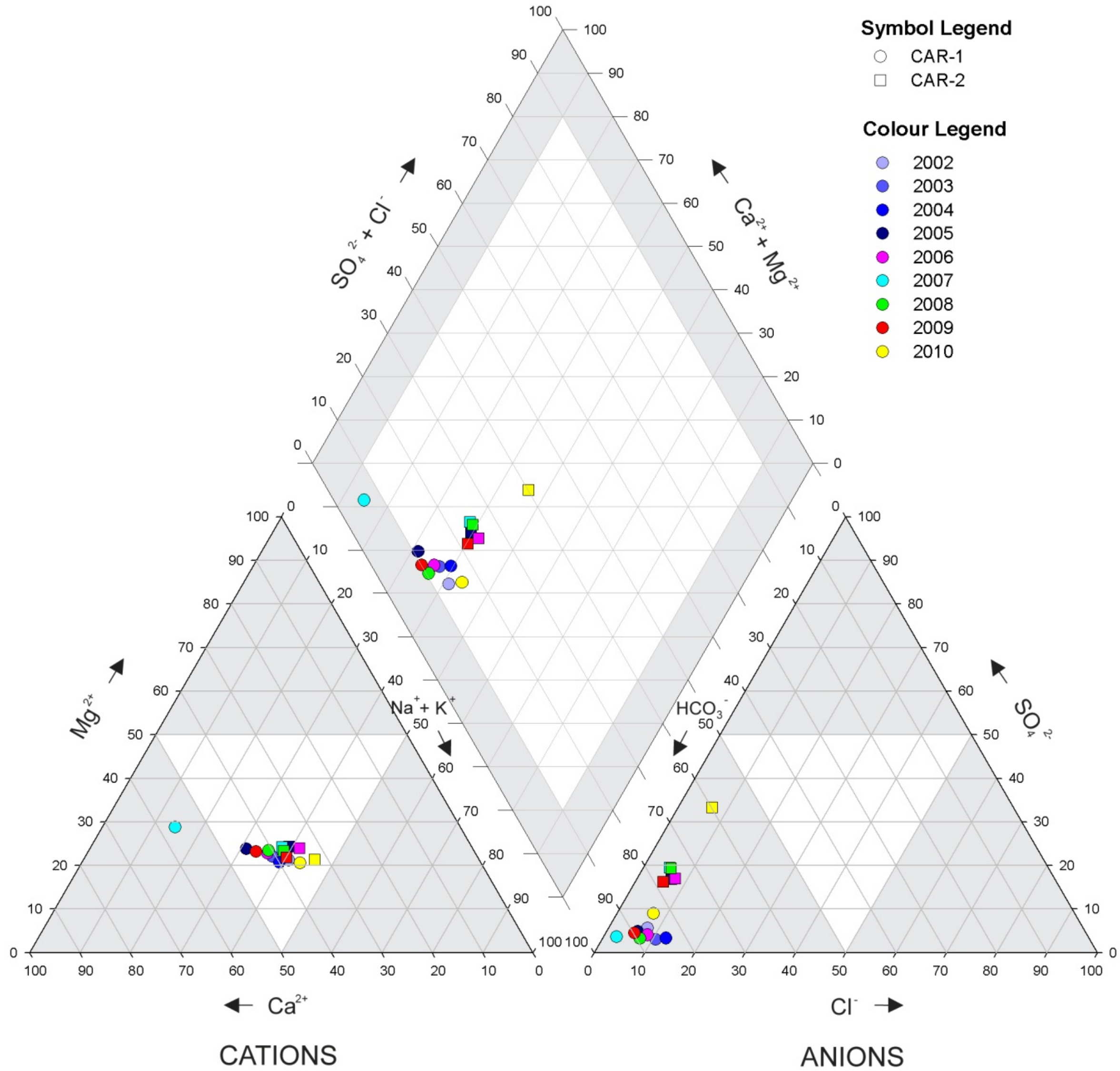
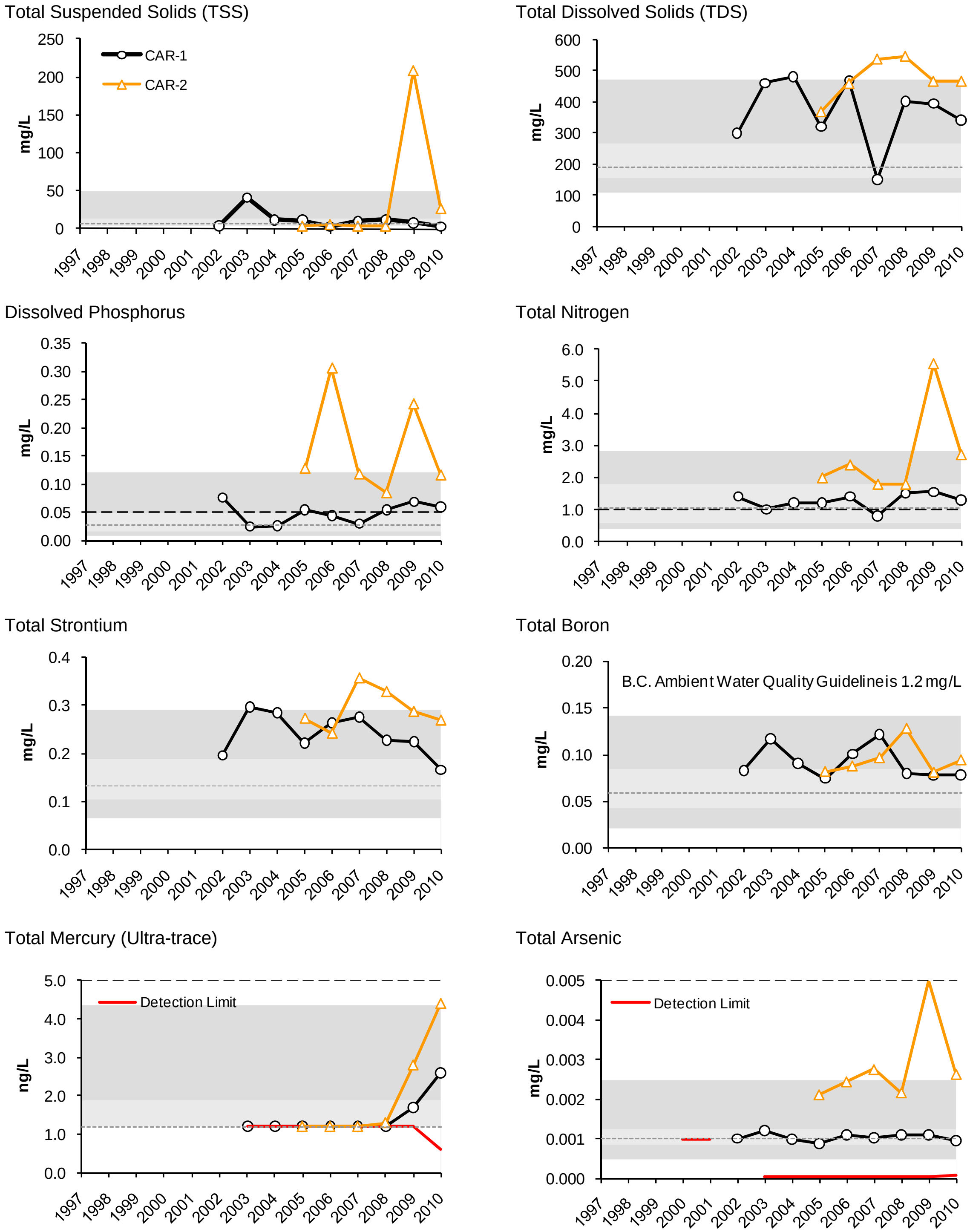


Figure 5.6-5 Concentrations of selected water quality measurement endpoints in the Calumet River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

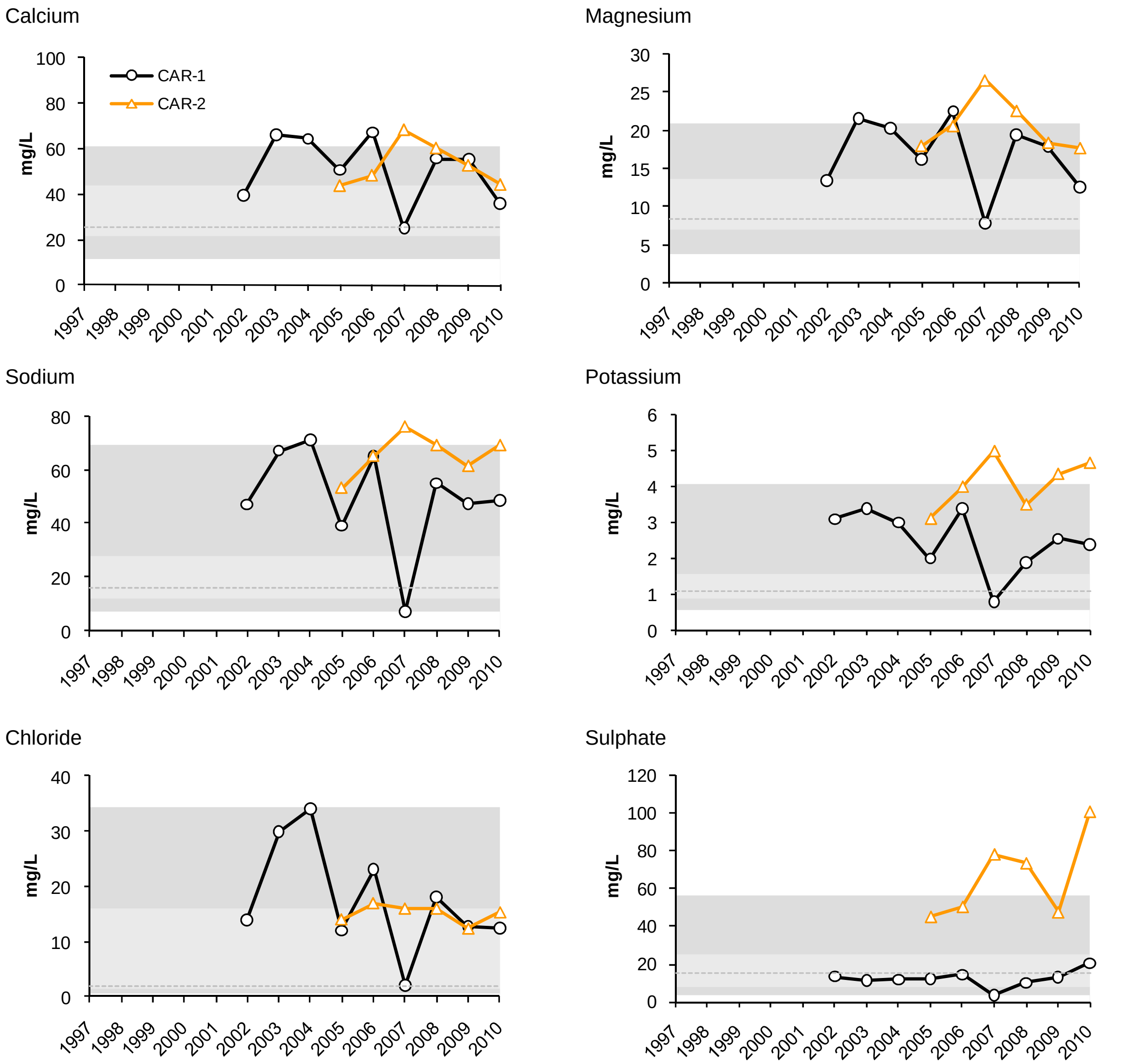


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Section 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.6-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

5.7 FIREBAG RIVER WATERSHED

Table 5.7-1 Summary of results for the Firebag River watershed.

Firebag River Watershed	Summary of 2010 Conditions		
	Firebag River		***Lakes***
Climate and Hydrology			
Criteria	**S27** at the mouth		
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	**FIR-D1** at the mouth	**FIR-E2** upstream of Suncor Firebag	**MCL-1** McClelland Lake
Benthic Invertebrate Communities	○	n/a	n/a
Sediment Quality Index	○	not sampled	n/a
Fish Populations			
No Fish Populations component activities conducted in 2010			

Legend and Notes

○ Negligible-Low

● Moderate

● High

baseline

test

n/a - not applicable, summary indicators for *test* reaches/stations were designated based on comparisons with *baseline* reaches/station. The WQI/SQI was not calculated given the limited existing *baseline* data.

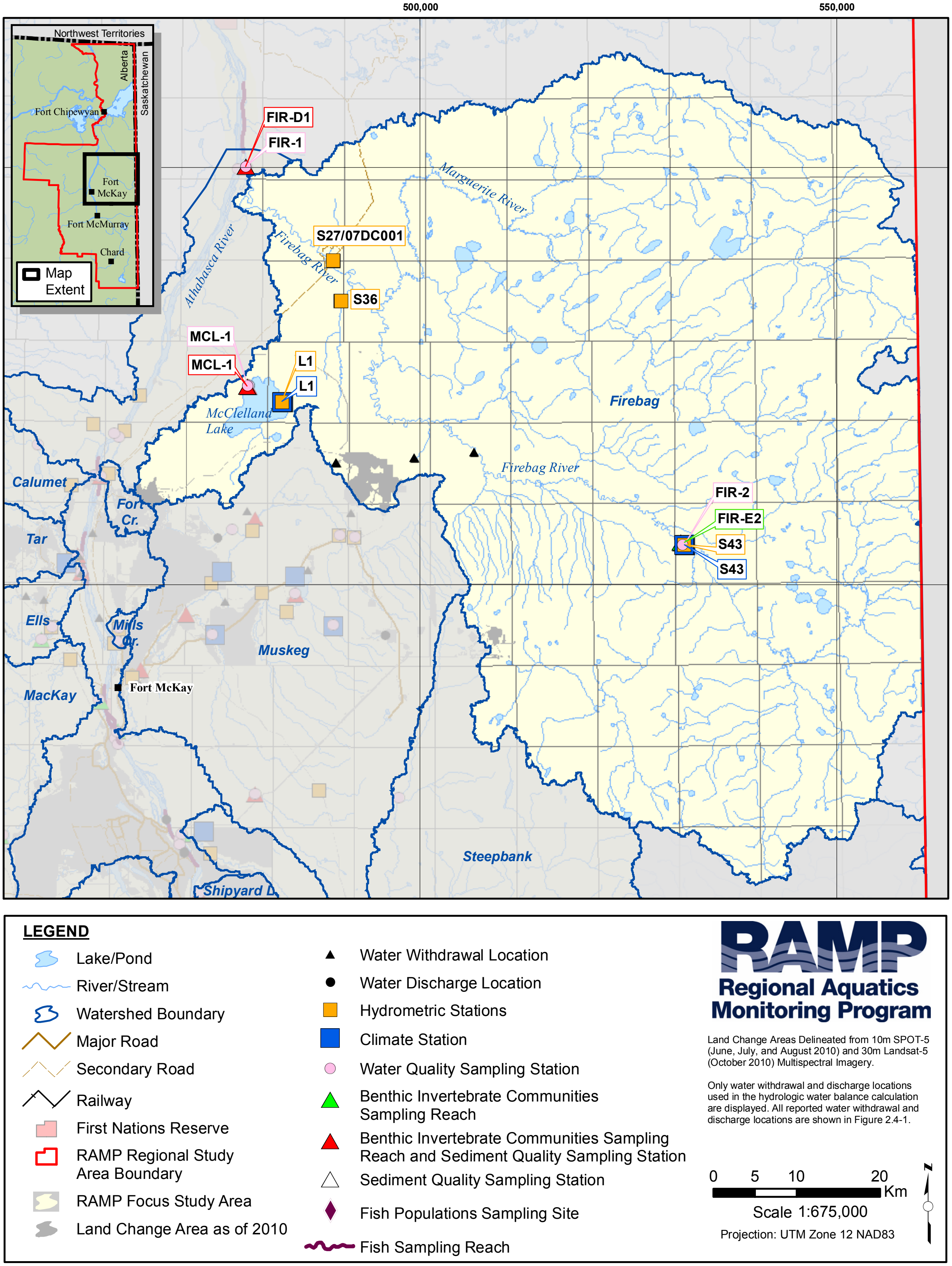
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology.

Figure 5.7-1 Firebag River watershed.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K07_Firebag_20110318.mxd

Figure 5.7-2 Representative monitoring stations of the Firebag River watershed, fall 2010.

Water Quality Station FIR-1: Left Downstream Bank

Benthic Invertebrate Communities Reach FIR-E2: Right Downstream Bank

Water Quality Station FIR-2: Right Downstream Bank

Benthic Invertebrate Communities Reach FIR-D1: Left Downstream Bank

Climate and Hydrology Station S27: Right Downstream Bank

Water Quality Station MCL-1: McClelland Lake

5.7.1 Summary of 2010 Conditions

Approximately 0.73% (4,200 ha) of the Firebag River watershed had undergone land change as of 2010 from focal projects (Table 2.5-2). 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*.

The Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality components of RAMP conducted monitoring activities in the Firebag River watershed in 2010. Table 5.7-1 is a summary of the 2010 assessment of the Firebag River watershed, while Figure 5.7-1 denotes the location of the monitoring stations for each RAMP component, reported focal project water withdrawal and discharge locations, and the area with land change as of 2010. Figure 5.7-2 contains fall 2010 photos of a number of monitoring stations in the watershed.

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.09% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated mean winter discharge is 0.08% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences are classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at *test* station FIR-1 and *baseline* station FIR-2 showed **Negligible-Low** differences from regional *baseline* water quality conditions. The ionic composition of water in fall 2010 at both Firebag River stations and McClelland Lake was consistent with previous sampling years and concentrations of most water quality measurement endpoints in fall 2010 were within the range of regional *baseline* concentrations at the stations in the Firebag River. Concentrations of several water quality measurement endpoints in the Firebag River watershed were near or outside previously-measured minimum concentrations (typically major ions) or maximum concentrations (including total suspended solids, several total metals, total phenols, and DOC), likely as a result of the high river discharges in fall 2010. A WQI was not calculated for McClelland Lake because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Benthic Invertebrate Communities and Sediment Quality Differences in measurement endpoints for benthic invertebrate communities in *test* reach FIR-D1 are classified as **Negligible-Low** because the significant increases in taxa richness, diversity, and evenness over time do not imply a negative change in the benthic invertebrate community and all measurement endpoints were within the range of *baseline* conditions for depositional reaches in the RAMP FSA. The differences in measurement endpoints for benthic invertebrate communities of McClelland Lake are classified as **Negligible-Low** because while there is a significant increase in total abundance at *test* station MCL-1 between the period it has been designated as *test* and the period it was designated as *baseline*, this increase does not imply a negative change in the benthic invertebrate community. Differences in sediment quality observed in fall 2010 between the lower Firebag River and regional *baseline* conditions were **Negligible-Low**. Most sediment quality measurement endpoints were within or below previously-measured concentrations at *test* stations FIR-D1 and MCL-1.

5.7.2 Hydrologic Conditions: 2010 Water Year

WSC Station 07DC001 (RAMP Station S27), Firebag River Continuous annual hydrometric data have been collected for the WSC Station 07DC001 (RAMP Station S27) Firebag River near the mouth from 1972 to 2010. The 2010 water year (WY) annual runoff volume was 743 million m^3. The 2010 open-water period (May to October) runoff volume was 485 million m^3 (Figure 5.7-3), which was 19% lower than the historical mean open-water runoff volume of 599 million m^3. With the exception of the month of December, winter flows were generally higher than historical median values. The peak flow during the freshet was 66 m^3/s on April 22. Flows decreased during most of May, June and July, with six days of mean daily flow in late July below historical minimum flows for those days. Flows then increased in response to rainfall events in late August and early September, reaching a maximum open-water daily flow of 70 m^3/s on September 13 and 14. This value is 38% lower than the historical mean open-water maximum daily flow. Flows decreased from mid-September to approximately the historical median by the end of the 2010 WY. The minimum open-water daily flow of 11.8 m^3/s recorded on July 25 was 24% lower than the historical open-water mean minimum daily flow of 15.6 m^3/s.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth is provided in Table 5.7-2 and described as follows:

1. The closed-circuited land area from focal projects as of 2010 in the Firebag River watershed is estimated to be 2.6 km^2 (Table 2.5-1). The loss of flow to the Firebag River that would have otherwise occurred from this land area is 0.32 million m^3.

2. As of 2010, the area of land change in the Firebag watershed from focal projects that was not closed-circuited is estimated to be 39.1 km^2 (Table 2.5-1). The increase in flow to the Firebag River that would not have otherwise occurred from this land area is estimated at 0.97 million m^3.

3. In the 2010 WY, Imperial withdrew water from three locations in the Firebag watershed, totaling approximately 11,700 m^3.

The estimated cumulative effect is an increase in flow of 0.64 million m^3 to the Firebag River. The resulting observed *test* and estimated *baseline* hydrographs are presented in Figure 5.7-3. The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.09% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated mean winter discharge is 0.08% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.7-3). These differences are classified as **Negligible-Low** (Table 5.7-1).

Station L1, McClelland Lake Water levels recorded at Station L1 increased gradually from November to April (Figure 5.7-4). Lake levels recorded from January 1 to April 29 were higher than previous years (period of record varied between two to six years depending on the date) and possibly from November to December although historical maximum values during this period are not reliable. Lake levels decreased towards historical median levels for most of June, July and August before heavy rainfall events in late August and early September caused an increase of 8 cm from August 25 to September 8. Lake levels receded to near historical median levels by the end of the 2010 WY.

5.7.3 Water Quality

In fall 2010, water quality samples were taken from:

- the Firebag River near its mouth (*test* station FIR-1, first sampled in 2002);
- the Firebag River upstream of all focal project developments (*baseline* station FIR-2, first sampled in 2003); and
- McClelland Lake (*test* station MCL-1, designated as *baseline* from 2000 to 2009 and *test* in 2010).

Temporal Trends The significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were decreasing concentrations of sulphate and total arsenic at *test* station MCL-1 (2000 to 2003, 2006 to 2010), with the decrease in the concentration of total arsenic likely being related to an improvement in the analytical detection limit for total arsenic over the sampling period. No significant trends in fall concentrations of water quality measurement endpoints were detected at *test* station FIR-1 or *baseline* station FIR-2 over the sampling period.

2010 Results Relative to Historical Concentrations In fall 2010, river discharges that were above the upper quartile (Figure 5.7-3) likely contributed to concentrations of a number of water quality measurement endpoints being outside the range of historical concentrations for the fall season. At *test* station FIR-1, concentrations of water quality measurement endpoints that were outside their range of historically-measured concentrations were (Table 5.7-4):

- total suspended solids, total aluminum, total arsenic, and total mercury with concentrations that exceeded their previously-measured maximum concentrations; and
- dissolved organic carbon, conductivity, calcium, chloride, total alkalinity, and total strontium with concentrations that were below their previously-measured minimum concentrations.

At *baseline* station FIR-2, fall 2010 concentrations of water quality measurement endpoints that were outside their range of previously-measured concentrations were (Table 5.7-5):

- total nitrogen, dissolved organic carbon, total aluminum, dissolved aluminum, total boron, total mercury, total phenols, and total Kjeldahl nitrogen, with concentrations that exceeded their previously-measured maximum concentrations; and
- conductivity, pH, calcium, magnesium, total alkalinity, and total strontium, with concentrations that were below their previously-measured minimum concentrations.

At *test* station MCL-1, fall 2010 concentrations of water quality measurement endpoints that were outside their range of previously-measured concentrations were (Table 5.7-6):

- total dissolved solids, total phenols, and pH, with concentrations that exceeded their previously-measured maximum concentrations; and
- total mercury, with a concentration that was below its previously-measured minimum concentrations, likely due to the decrease in the analytical detection limit in summer 2010.

Ion Balance The ionic composition of water sampled in fall 2010 at *test* station FIR-1 and *baseline* station FIR-2 was similar to previous years (Figure 5.7-5). The ionic composition of water at these stations has remained consistent since monitoring began in 2002 with the exception of *baseline* station FIR-2 in 2007 when lower concentrations of calcium were measured. The ionic composition of McClelland Lake, *test* station MCL-1, in fall 2010 was consistent with that of previous years and dominated by magnesium and bicarbonate (Figure 5.7-5).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints in fall 2010 were below water quality guidelines with the exception of total aluminum at *test* station FIR-1 (Table 5.7-4) and total dissolved phosphorus and total nitrogen at *baseline* station FIR-2 (Table 5.7-5).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in fall 2010:

- total phosphorus, total iron, total phenols, and sulphide at *test* station FIR-1 (Table 5.7-4);
- total phosphorus, total iron, total phenols, total Kjeldahl nitrogen, and sulphide at *baseline* station FIR-2 (Table 5.7-5); and
- total phenols at *test* station MCL-1(Table 5.7-6).

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2010 at *test* station FIR-1 were within regional *baseline* fall concentrations with the exception of total mercury, with a concentration that exceeded the 95th percentile of regional *baseline* concentrations and chloride, with a concentration that was below the 5th percentile of regional *baseline* concentrations (Figure 5.7-6). Concentrations of water quality measurement endpoints at *baseline* station FIR-2 in fall 2010 were within regional *baseline* fall concentrations with the exception of total strontium, with a concentration that was below the 5th percentile of regional *baseline* concentrations (Figure 5.7-6). Concentrations of water quality measurement endpoints in McClelland Lake (*test* station MCL-1) were not compared to the regional *baseline* conditions because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Water Quality Index The WQI values for *test* station FIR-1 (98.5) and *baseline* station FIR-2 (100.0) in the Firebag River watershed in fall 2010 indicated **Negligible-Low** differences from regional *baseline* conditions. A WQI was not calculated for McClelland Lake because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Classification of Results In fall 2010, water quality at *test* station FIR-1 and *baseline* station FIR-2 showed **Negligible-Low** differences from regional *baseline* water quality conditions. The ionic composition of water in fall 2010 at both Firebag River stations and McClelland Lake was consistent with previous sampling years and concentrations of most water quality measurement endpoints in fall 2010 were within the range of regional *baseline* concentrations. Concentrations of several water quality measurement endpoints in the Firebag River watershed were near or outside previously-measured minimum concentrations (typically major ions) or maximum concentrations (including total suspended solids, several total metals, total phenols, and DOC), likely as a result of the high river discharges in fall 2010. A WQI was not calculated for McClelland Lake because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

5.7.4 Benthic Invertebrate Communities and Sediment Quality

5.7.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at:

- depositional *test* reach FIR-D1, sampled from 2003 to 2007 and 2010;
- erosional *baseline* reach FIR-E2, sampled from 2003 to 2007 and 2010; and
- McClelland Lake (*test* station MCL-1), designated as *baseline* from 2002 to 2003 and 2006 to 2009 and as *test* in 2010.

Firebag River

2010 Habitat Conditions Water at *test* reach FIR-D1 in fall 2010 was deep (1.0 m), slow-flowing (0.25 m/s), alkaline (pH: 8.1), had moderate conductivity (149 µS/cm), and moderate levels of dissolved oxygen (8.6 mg/L) (Table 5.7-7). The substrate was dominated by sand (79%) and silt (20%) and contained low levels of organic carbon (3%). Water at *baseline* reach FIR-E2 was shallow (0.4 m), moderately-flowing (0.6 m/s), alkaline (pH: 8.0), had moderate conductivity (152 µS/cm) and high levels of dissolved oxygen (10.7 mg/L) (Table 5.7-7). The substrate was equally-dominated by large cobble (23%), small cobble (23%), and large gravel (22%). Periphyton biomass in *baseline* reach FIR-E2 averaged 636 mg/m², which was much higher than regional *baseline* conditions (Figure 5.7-8).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach FIR-D1 was dominated by tubificid worms (47%), chironomids (17%), and bivalves (14%) (Table 5.7-8). Ceratopogonidae (6%) and Cladocera (2%) were present in low relative abundances. Dominant chironomids included *Procladius*, *Chironomous,* and *Micropsectra*/*Tanytarsus*. Although, only one individual was found from each taxon, mayflies (Ephemeroptera; *Baetis*), stoneflies (Plectoptera; *Pteronarcys*) and caddisflies (Trichoptera; *Oecetis*) were observed (Table 5.7-8).

The benthic invertebrate community of *baseline* reach FIR-E2 was dominated by chironomids (47%) and Naididae worms (12%) with subdominant taxa consisting of Ephemeroptera (8%), Coleoptera (8%) and Bivalvia (6%) (Table 5.7-8). Dominant chironomids included *Thienemannimyia gr*., *Cryptochironomus*, *Polypedilum, Stempellinella, Micropsectra,* and *Cricotopus*/*Orthocladius* as well as other forms that prefer clean cold water such as *Tvetenia*. Ephemeroptera were principally of the genera *Baetis, Acerpenna*, and *Paraleptophlebia*. Trichoptera (*Hydropsyche, Oecetis, Lepidostoma*) and Plecoptera (*Isoperla, Taeniopteryx*) were also observed in *baseline* reach FIR-E2 (Table 5.7-8).

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that reach FIR-D1 has been designated as *test* (Hypothesis 1, Section 3.2.3.1; spatial comparisons were not conducted because *test* reach FIR-D1 is depositional and *baseline* reach FIR-E2 is erosional). There were significant increases in taxa richness, diversity, evenness, and CA Axis 1 scores across years with the differences explaining 29% or more of the variation in annual means of all three measurement endpoints (Table 5.7-9); time trends in the other three measurement endpoints for benthic invertebrate communities were not significant. The significant increase in CA Axis 1 scores over the sampling period reflects a decrease in the relative abundance of chironomids at *test* reach FIR-D1 (Table 5.7-8), while increases in taxa richness, diversity and evenness indicate an overall increase in condition of the benthic invertebrate community over the sampling period at *test* reach FIR-D1.

Comparison to Published Literature The high percent of fauna as tubificid worms and chironomids in *test* reach FIR-D1 can indicate some level of nutrient enrichment or other stressor (Hynes 1960, Griffiths 1998). However, *test* reach FIR-D1 has contained (including fall 2010) other organisms that are more sensitive to disturbance and whose presence indicates good water and sediment quality including mayflies, caddisflies and stoneflies as well as sphaeriid fingernail clams (Table 5.7-8).

2010 Results Relative to Regional *Baseline* Conditions Values of measurement endpoints for benthic invertebrate communities in fall 2010 at *test* reach FIR-D1 were within the range of regional *baseline* conditions for depositional reaches (Figure 5.7-9). Abundance, richness, diversity, evenness and percent of the fauna as EPT in 2010 were also within the range of previously-measured values for *test* reach FIR-D1. In addition, the ordination of the benthic invertebrate community at *test* reach FIR-D1 in fall 2010 was similar to that observed for regional *baseline* depositional reaches (Figure 5.7-10).

Classification of Results Differences in measurement endpoints for benthic invertebrate communities in *test* reach FIR-D1 are classified as **Negligible-Low** because the significant increases in taxa richness, diversity, and evenness over time do not imply a negative change in the benthic invertebrate community and all measurement endpoints were within the range of *baseline* conditions for depositional reaches in the RAMP FSA.

McClelland Lake

2010 Habitat Conditions Samples were taken at a depth of 2 m at *test* station MCL-1. The substrate at *test* station MCL-1 in fall 2010 was dominated by sand and organic substrate (15% TOC) comprised of dead and decaying vegetative material, primarily of the plant species, *Chara* (Table 5.7-10).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* station MCL-1 in fall 2010 was dominated by chironomids (80%), with subdominant taxa consisting of naidid worms (9%) and Ostracoda (4%) (Table 5.7-11). Bivalve clams, gastropod snails, caddisflies (Trichoptera), and mayflies (Ephemeroptera) were present in low (1% or less) relative abundances. The dominant chironomids included common species such as *Dicrotendipes*, *Paratanytarsus*, *Einfeldia*, *Tanytarsus*, and *Ablabesmyia*. Mayflies were represented by the common form *Caenis* and caddisflies were represented by *Oxyethira*, and *Phryganea*.

Temporal Comparisons For temporal comparisons, changes in values of measurement endpoints for benthic invertebrate communities at *test* station MCL-1 were compared between the years before and after the station was designated as *test* (Hypothesis 2, Section 3.2.3.1). Total abundance was significantly higher in the period that station MCL-1 has been designated as *test* (i.e., 2010) compared to the period it was designated as *baseline* (2002 to 2009) (Table 5.7-12), and this difference accounts for 20% of the variation in annual mean abundance. There were no significant differences in the other measurement endpoints for benthic invertebrate communities between the *baseline* and *test* sampling periods (Table 5.7-12).

Comparison to Published Literature The benthic invertebrate community at *test* station MCL-1 has fauna relatively typical of lake environments at 2 m of water with dominant taxa consisting of chironomids as well as representative taxa of bivalves (fingernail clams), gastropods, mayflies and caddisflies. Tubificid worms were present in low relative abundance reflecting good water and sediment quality (Brinkhurst 1974).

2010 Results Relative to Historical Conditions Values of all measurement endpoints for benthic invertebrate communities in fall 2010 at *test* station MCL-1 were within the range of previously-measured values (Figure 5.7-11). In addition, the ordination of the benthic invertebrate community at *test* station MCL-1 in fall 2010 was similar to that for regional *baseline* lakes (Figure 5.7-11).

Classification of Results The differences in measurement endpoints for benthic invertebrate communities of McClelland Lake are classified as **Negligible-Low** because while there was a significant increase in total abundance at *test* station MCL-1 between the period it has been designated as *test* and the period it was designated as *baseline*, the increase does not imply a negative change in the benthic invertebrate community.

5.7.4.2 Sediment Quality

In fall 2010, sediment quality samples were taken from:

- *test* station FIR-D1, near the mouth of the Firebag River (sampled from 2002 to 2010); and
- McClelland Lake (*test* station MCL-1, designated as *baseline* from 2002, 2003, and 2006 to 2009 and as *test* in 2010).

2010 Results Relative to Historical Concentrations *Test* station FIR-D1 was dominated almost exclusively by sand and low levels of TOC (Table 5.7-13), resulting in a concentration of total metals normalized to percent fines exceeding the previously-measured maximum concentration (Figure 5.7-13). However, the absolute concentration of total metals at *test* station FIR-D1 was low relative to previously-measured concentrations (Figure 5.7-13). Sediments collected at *test* station MCL-1 in fall 2010 were dominated by silt, which comprised a higher percentage of total sediments than previous years, and levels of TOC below the previously-measured minimum value (Table 5.7-14, Figure 5.7-14).

Concentrations of Fraction-1 hydrocarbons including BTEX were below detection limits in fall 2010 at *test* station FIR-D1 and *test* station MCL-1 (Table 5.7-13, Table 5.7-14). Concentrations of Fraction-3 and Fraction-4 hydrocarbons were lower than previously-measured minimum concentrations and the concentration of Fraction-2 hydrocarbons was within previously-measured concentrations at *test* station FIR-D1. Concentrations of Fraction-3 and Fraction-4 hydrocarbons were within previously-measured concentrations and Fraction 2 was above the previously-measured maximum concentrations at *test* station MCL-1 (Table 5.7-14). Concentrations of absolute total PAHs, including predicted PAH toxicity, were lower than, or within the range of previously-measured concentrations at *test* station FIR-D1 and *test* station MCL-1. The concentration of carbon-normalized total PAHs was above the previously-measured maximum concentration at *test* station FIR-D1 despite the historically-low absolute total PAH concentration and is likely due to historically-low levels of TOC in sediments at this station in fall 2010 (Table 5.7-13).

Direct tests of sediment toxicity to invertebrates at *test* station FIR-D1 showed 96% survival in test organisms of the amphipod *Hyalella* and 70% survival in test organisms of the midge *Chironomus*, which were within the range of historical observations. Ten-day growth of *Chironomus* was higher than the range of historical values and 14-day growth of *Hyalella* was within the range of historical values (Table 5.7-13).

Comparison with Sediment Quality Guidelines No hydrocarbon, PAH, or metal concentrations measured at *test* station MCL-1 or *test* station FIR-D1 exceeded relevant sediment or soil quality guidelines in fall 2010 with the exception of CCME fraction-2 and fraction-3 hydrocarbons at *test* station MCL-1, with concentrations that exceeded the CCME soil-quality guideline (Table 5.7-14).

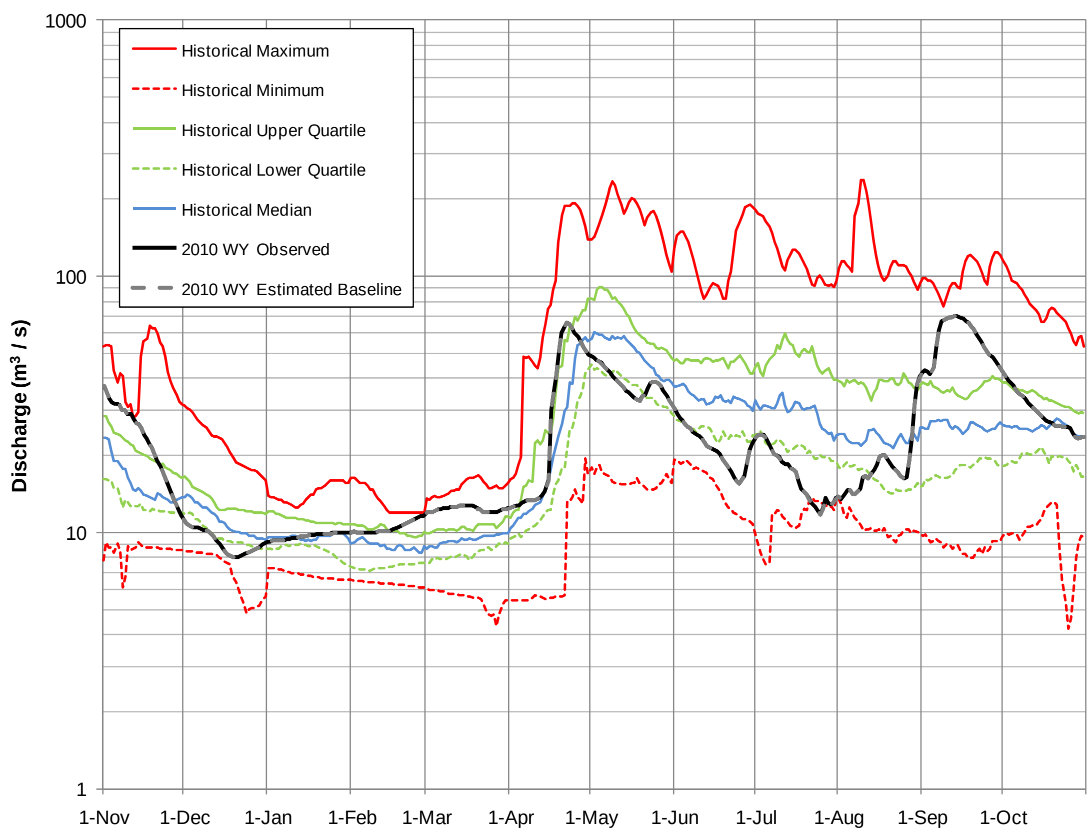
Sediment Quality Index A SQI value of 98.9 was calculated for *test* station FIR-D1 in fall 2010 indicating **Negligible-Low** differences from regional *baseline* sediment quality conditions. A SQI was not calculated for *test* station MCL-1 because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Classification of Results Differences in sediment quality observed in fall 2010 between the *test* station FIR-D1 River and regional *baseline* conditions were **Negligible-Low**. Most sediment quality measurement endpoints were within or below previously-measured concentrations at *test* stations FIR-D1 and MCL-1.

5.7.5 Fish Populations

There were no Fish Populations component activities conducted in the Firebag River watershed in 2010.

Figure 5.7-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Firebag River in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph based on provisional data for WSC Station 07DC001, Firebag River near the mouth, (March 1 to October 31, 2010) and on data for RAMP Station S27 for other months in 2010. The upstream drainage area is 5,988 km^2. Historical values calculated for the period from 1972 to 2009.

Table 5.7-2 Estimated water balance at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**743.04**	**Observed discharge, obtained from WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth**
Closed-circuited area water loss from the observed hydrograph	-0.32	Estimated 2.6 km^2 of the Firebag River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.97	Estimated 39.1 km^2 of the Firebag River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Firebag River watershed from focal projects	-0.01	Imperial reported withdrawals from three separate locations in the Firebag catchment (daily values provided)
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**742.40**	**Estimated *baseline* discharge at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth**
Incremental flow (change in total discharge)	+0.64	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.09%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2010 for WSC Station 07DC001, Firebag River near the mouth and on RAMP Station S27 for other months in 2010.

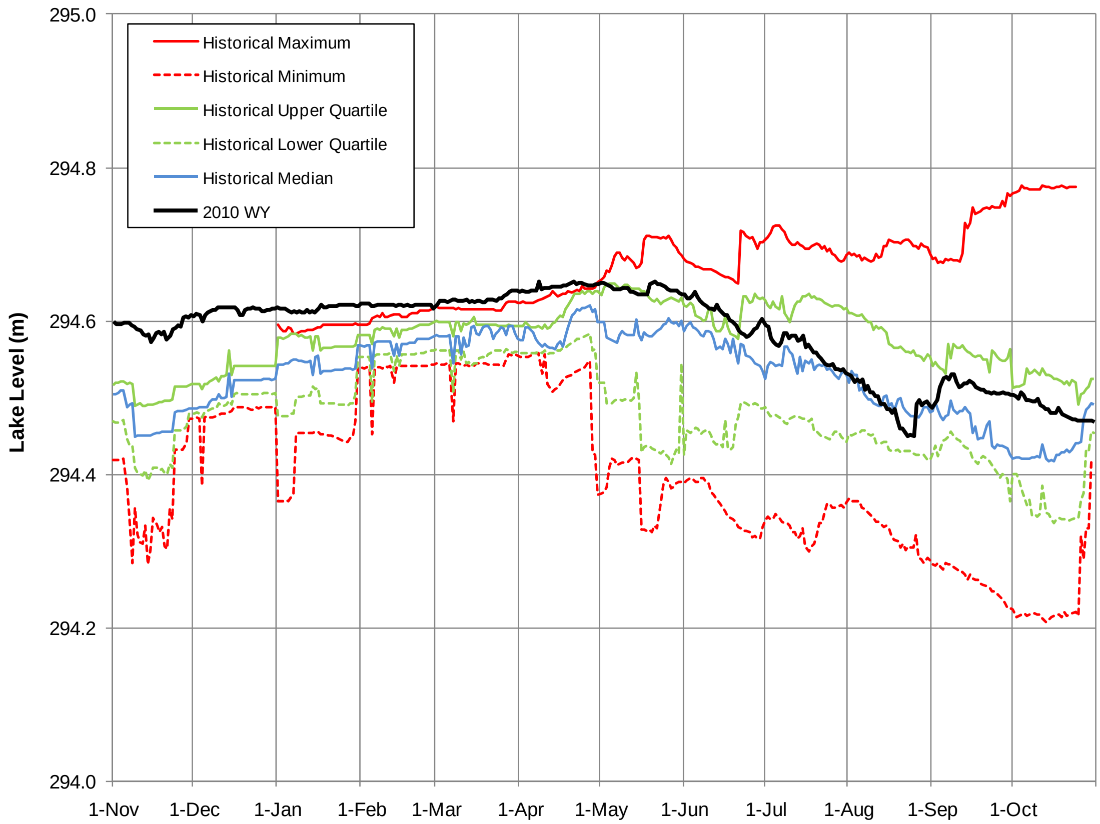
Table 5.7-3 Calculated change in hydrologic measurement endpoints for the Firebag River near the mouth, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	30.47	30.50	+0.09%
Mean winter discharge	13.14	13.15	+0.08%
Annual maximum daily discharge	69.94	70.00	+0.09%
Open-water period minimum daily discharge	11.79	11.80	+0.09%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

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 water level data for the 2010 WY, compared to historical values.



Note: Observed 2010 WY record based on RAMP Station L1, McClelland Lake, 2010 provisional data. Periods of missing data occur from January to March. Historical values calculated for the period from 1997 to 2009 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 the Firebag River (*test* station FIR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.04	8	7.90	8.20	8.20
Total suspended solids	mg/L	-[1]	21	8	<3	4.5	17
Conductivity	µS/cm	-	171	8	178	207	227
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.027	8	0.016	0.033	**0.057**
Total nitrogen*	mg/L	1.0	0.77	8	0.4	0.6	**1.7**
Nitrate+nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	16	8	8	13	16
Ions							
Sodium	mg/L	-	3	8	2	4	4
Calcium	mg/L	-	22.6	8	25.2	30.2	33.2
Magnesium	mg/L	-	7.2	8	6.8	9.0	9.7
Chloride	mg/L	230, 860[3]	1.0	8	1.8	2.0	3.0
Sulphate	mg/L	100[4]	1.8	8	1.7	3.0	10.3
Total dissolved solids	mg/L	-	149	8	60	139	170
Total alkalinity	mg/L		85	8	87	109	114
Selected metals							
Total aluminum	mg/L	0.1	**0.428**	8	0.033	0.064	**0.292**
Dissolved aluminum	mg/L	0.1[2]	0.0068	8	0.0028	0.0052	0.0089
Total arsenic	mg/L	0.005	0.00056	8	0.00028	0.00044	0.00055
Total boron	mg/L	1.2[5]	0.0151	8	0.0136	0.0169	0.0200
Total molybdenum	mg/L	0.073	0.00012	7	0.00011	0.00014	0.00020
Total mercury (ultra-trace)	ng/L	5, 13[6]	4.4	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.0505	7	0.0526	0.0685	0.0767
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.005**	8	<0.003	**0.0032**	**0.006**
Total phenols	mg/L	0.004	**0.0063**	7	<0.001	**0.004**	**0.007**
Total phosphorus	mg/L	0.05	**0.0752**	8	0.0270	**0.0529**	**0.093**
Total iron	mg/L	0.3	**1.050**	8	**0.394**	**0.772**	**1.060**

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 (*baseline* station FIR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.85	7	7.90	8.10	8.30
Total suspended solids	mg/L	-[1]	6	7	<3	3	8
Conductivity	µS/cm	-	154	7	160	171	261
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.053**	7	0.009	**0.061**	**0.096**
Total nitrogen*	mg/L	1.0	**1.28**	7	0.5	0.7	0.8
Nitrate+nitrite	mg/L	1.3	<0.071	7	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	17.4	7	8	13	16
Ions							
Sodium	mg/L	-	4	7	3	4	16
Calcium	mg/L	-	20.5	7	22.9	25.5	28.4
Magnesium	mg/L	-	6.2	7	6.4	7.3	8.7
Chloride	mg/L	230, 860[3]	<0.5	7	<0.5	2.0	2.0
Sulphate	mg/L	100[4]	1.7	7	0.8	2.8	22.6
Total dissolved solids	mg/L	-	134	7	110	140	158
Total alkalinity	mg/L		78	7	81	91	114
Selected metals							
Total aluminum	mg/L	0.1	0.0650	7	0.0154	0.0339	0.0369
Dissolved aluminum	mg/L	0.1[2]	0.0072	7	0.0031	0.0043	0.0066
Total arsenic	mg/L	0.005	0.00052	7	0.00010	0.00056	0.00059
Total boron	mg/L	1.2[5]	0.0168	7	0.0107	0.0130	0.0153
Total molybdenum	mg/L	0.073	0.00016	7	0.00015	0.00019	0.00022
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.7	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.042	7	0.046	0.049	0.068
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0046**	7	**0.0029**	**0.0040**	**0.0090**
Total phosphorus	mg/L	0.05	**0.090**	7	**0.068**	**0.105**	**0.134**
Total iron	mg/L	0.3	**0.594**	7	**0.525**	**0.823**	**1.390**
Total Kjeldahl Nitrogen	mg/L	1.0	**1.21**	7	0.4	0.6	0.7
Total phenols	mg/L	0.004	**0.0154**	7	<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 (*test* station MCL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.71	8	8.10	8.50	8.70
Total suspended solids	mg/L	-[1]	<3	8	<3	<3	5
Conductivity	µS/cm	-	232	8	224	239	253
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.005	8	0.002	0.004	0.013
Total nitrogen*	mg/L	1.0	0.95	8	0.55	1.0	**2.0**
Nitrate+nitrite	mg/L	1.3	<0.071	8	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	13	8	11	13	17
Ions							
Sodium	mg/L	-	5	8	4	4	6
Calcium	mg/L	-	19.8	8	19.3	20.9	25.8
Magnesium	mg/L	-	16.4	8	14.6	16.6	17.3
Chloride	mg/L	230, 860[3]	<0.5	8	<0.5	<1.0	<1.0
Sulphate	mg/L	100[4]	<0.5	8	<0.5	1.2	4.3
Total dissolved solids	mg/L	-	171	8	80	155	167
Total alkalinity	mg/L		127	8	122	129	145
Selected metals							
Total aluminum	mg/L	0.1	0.0042	8	0.0028	0.0166	0.0260
Dissolved aluminum	mg/L	0.1[2]	<0.001	8	0.0004	0.0011	0.0100
Total arsenic	mg/L	0.005	0.00021	8	0.00019	0.00021	0.00100
Total boron	mg/L	1.2[5]	0.0642	8	0.0513	0.0642	0.0670
Total molybdenum	mg/L	0.073	<0.00010	8	<0.00001	<0.00001	<0.00010
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	5	<1.2	<1.2	2.4
Total strontium	mg/L	-	0.129	8	0.112	0.133	0.145
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total Phenols	mg/L	0.004	**0.0225**	8	<0.001	0.003	**0.005**

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 5.7-5 Piper diagram of fall ion concentrations in the Firebag River watershed, fall 2010.

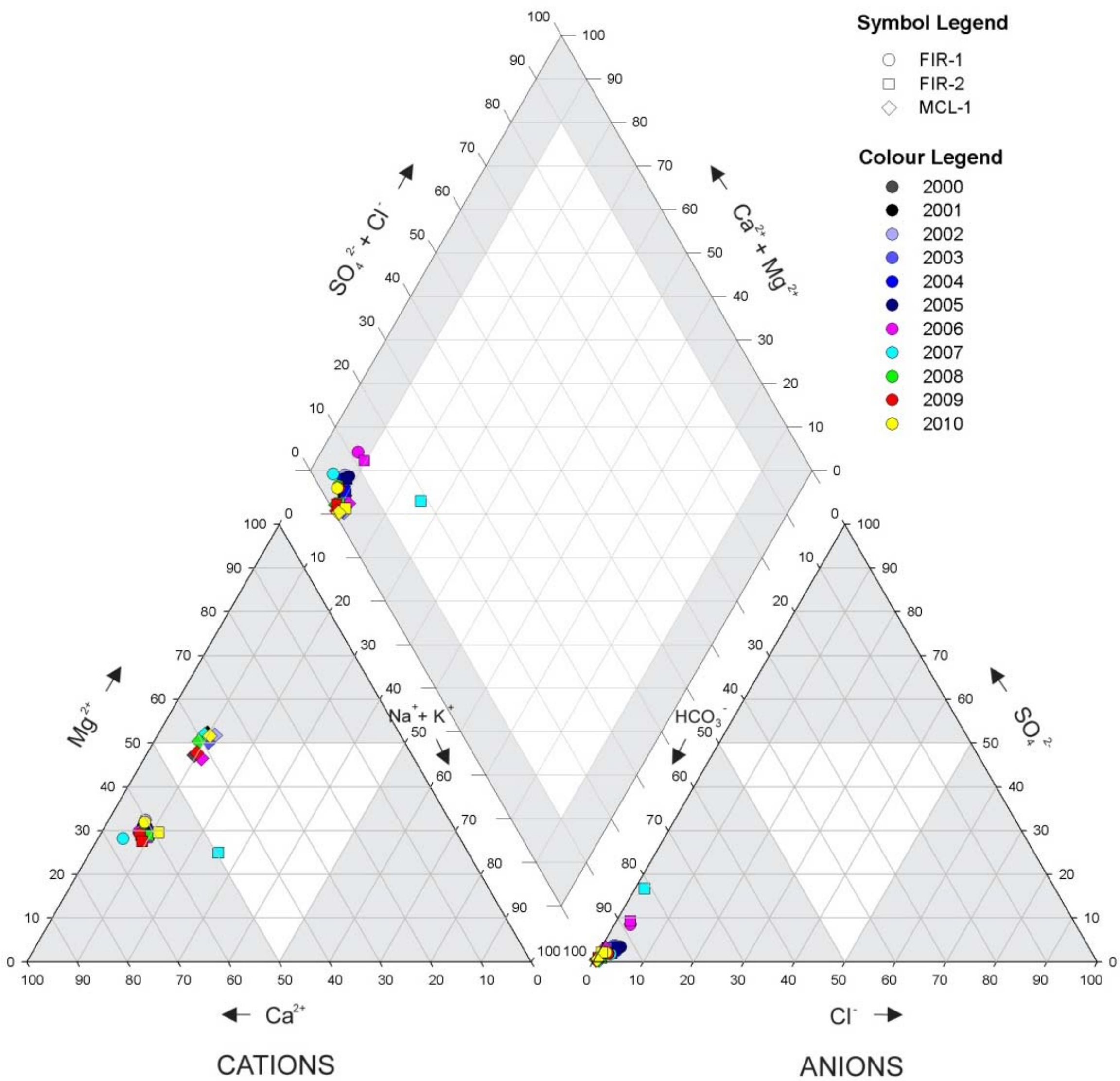
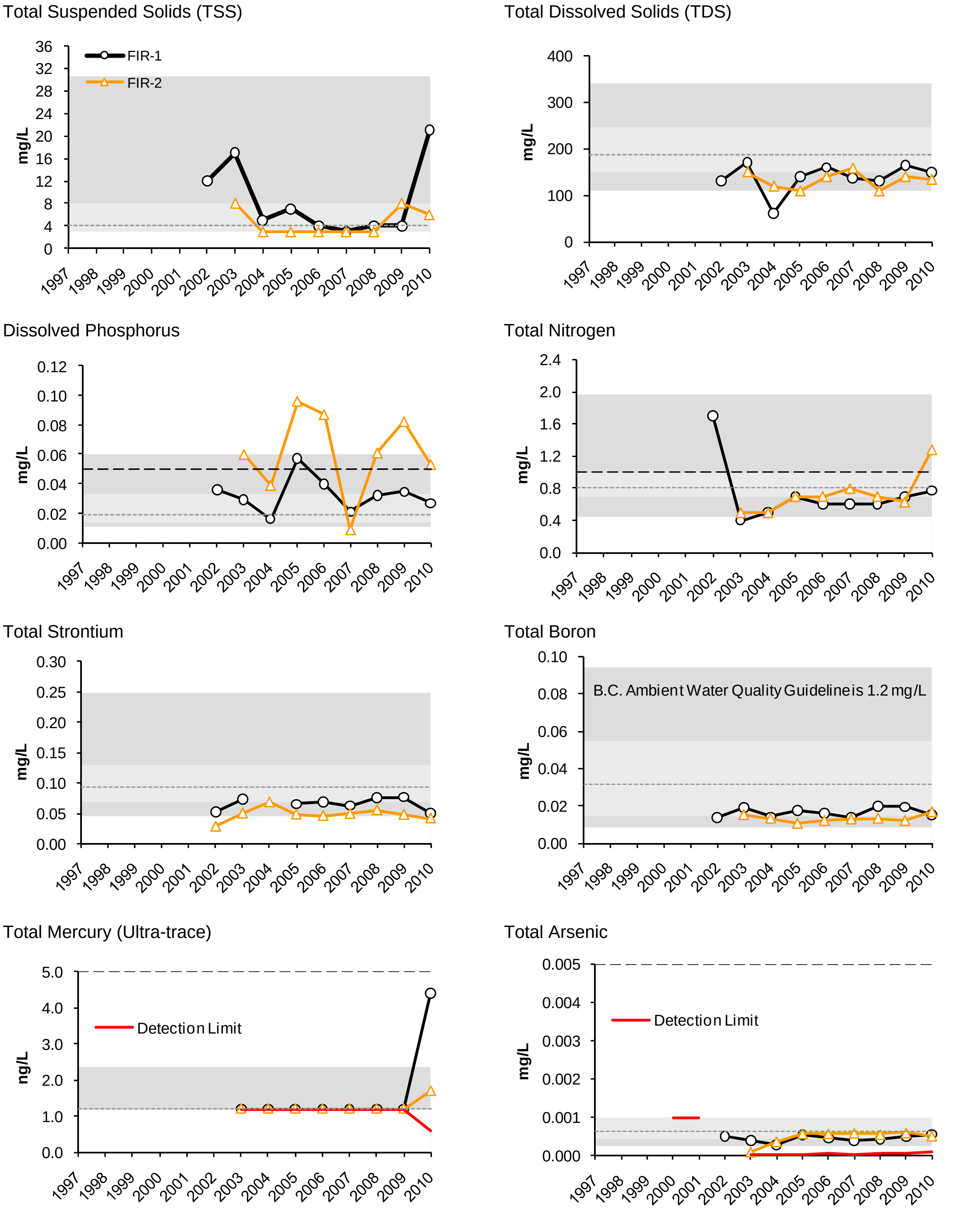


Figure 5.7-6 Concentrations of selected water quality measurement endpoints in the Firebag River watershed (fall 2010) relative to historical concentrations and regional *baseline* fall concentrations.



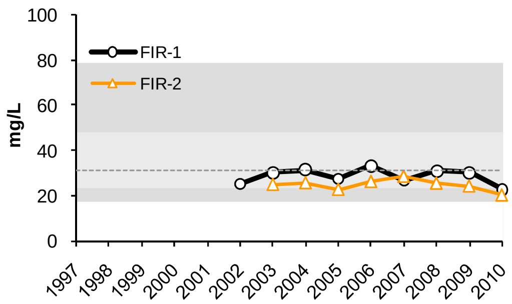
Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

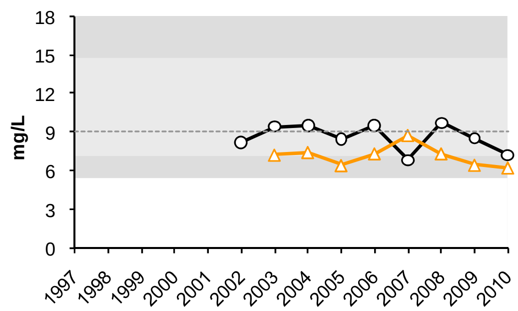
Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.7-6 (Cont'd.)

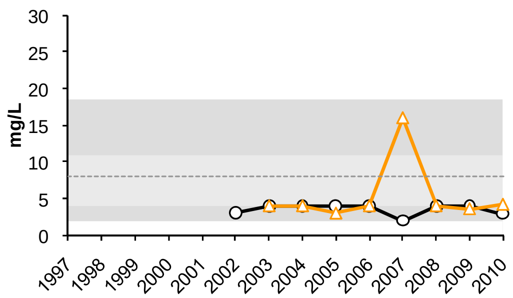
Calcium



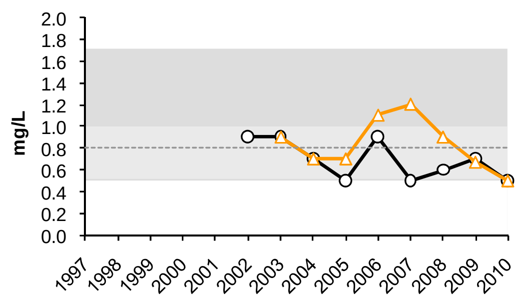
Magnesium



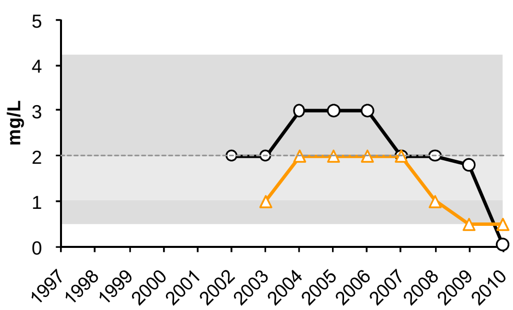
Sodium



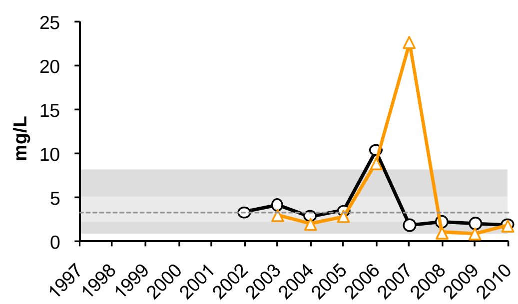
Potassium



Chloride



Sulphate

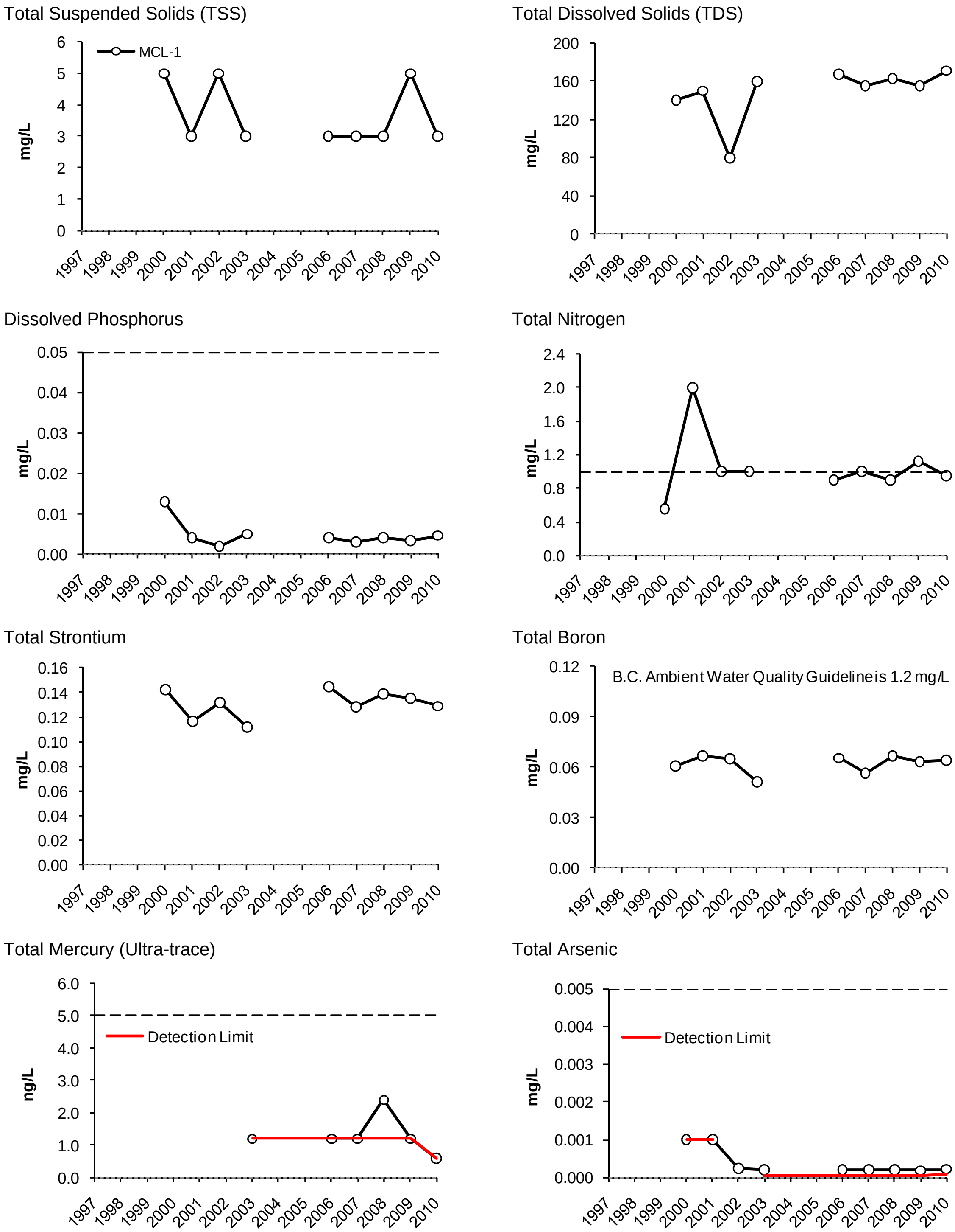


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.7-7 Concentrations of selected water quality measurement endpoints in McClelland Lake (fall 2010) relative to historical concentrations.

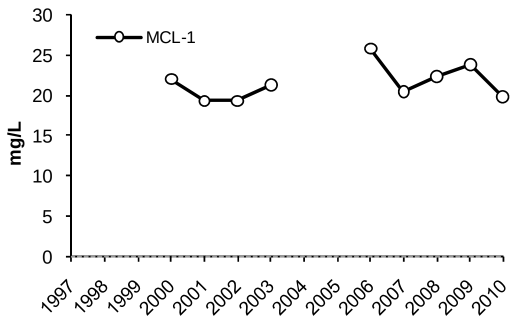


Non-detectable values are shown at the detection limit.

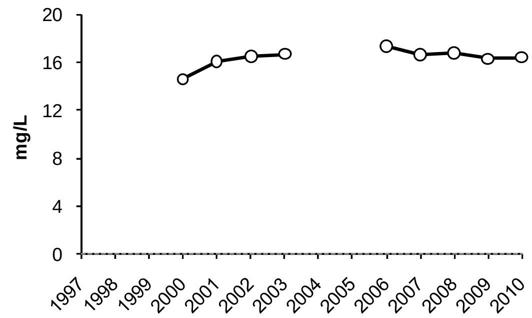
– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Figure 5.7-7 (Cont'd.)

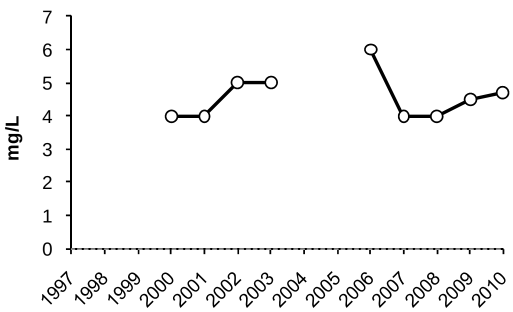
Calcium



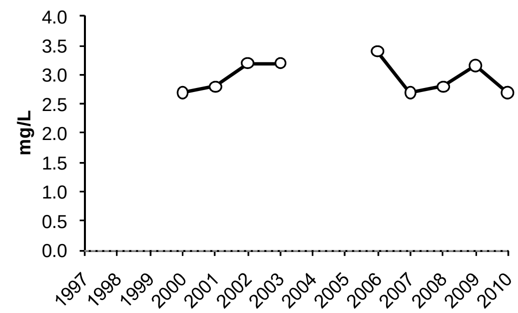
Magnesium



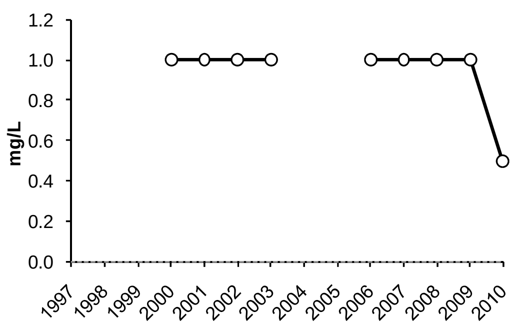
Sodium



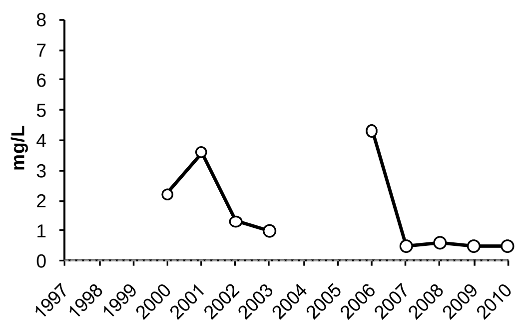
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Table 5.7-7 Average habitat characteristics of benthic invertebrate sampling locations in the Firebag River at *test* reach FIR-D1 and *baseline* reach FIR-E2, fall 2010.

Variable	Units	FIR-D1 Lower *Test* Reach of Firebag River	FIR-E2 Upper *Baseline* Reach of Firebag River
Sample date	-	Sept. 12, 2010	Sept. 25, 2010
Habitat	-	Depositional	Erosional
Water depth	m	1.0	0.4
Current velocity	m/s	0.25	0.6
Field Water Quality			
Dissolved oxygen	mg/L	8.6	10.7
Conductivity	µS/cm	149	152
pH	pH units	8.1	8.0
Water temperature	°C	11.9	8.0
Sediment Composition			
Sand/Silt/Clay	%		17.5
Small Gravel	%		11.5
Large Gravel	%		22
Small Cobble	%		23
Large Cobble	%		23
Boulder	%		3
Bedrock	%		0
Sand	%	79	
Silt	%	20	
Clay	%	1	
Total Organic Carbon	%	3	

Figure 5.7-8 Periphyton chlorophyll *a* biomass in *baseline* reach FIR-E2 of the Firebag River.

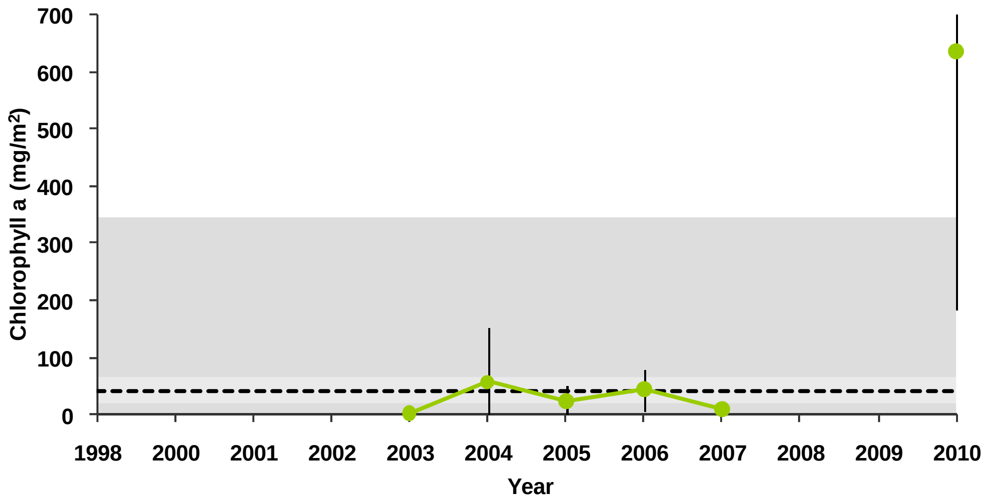


Table 5.7-8 Summary of major taxon abundances of benthic invertebrate community measurement endpoints at *test* reach FIR-D1 and *baseline* reach FIR-E2.

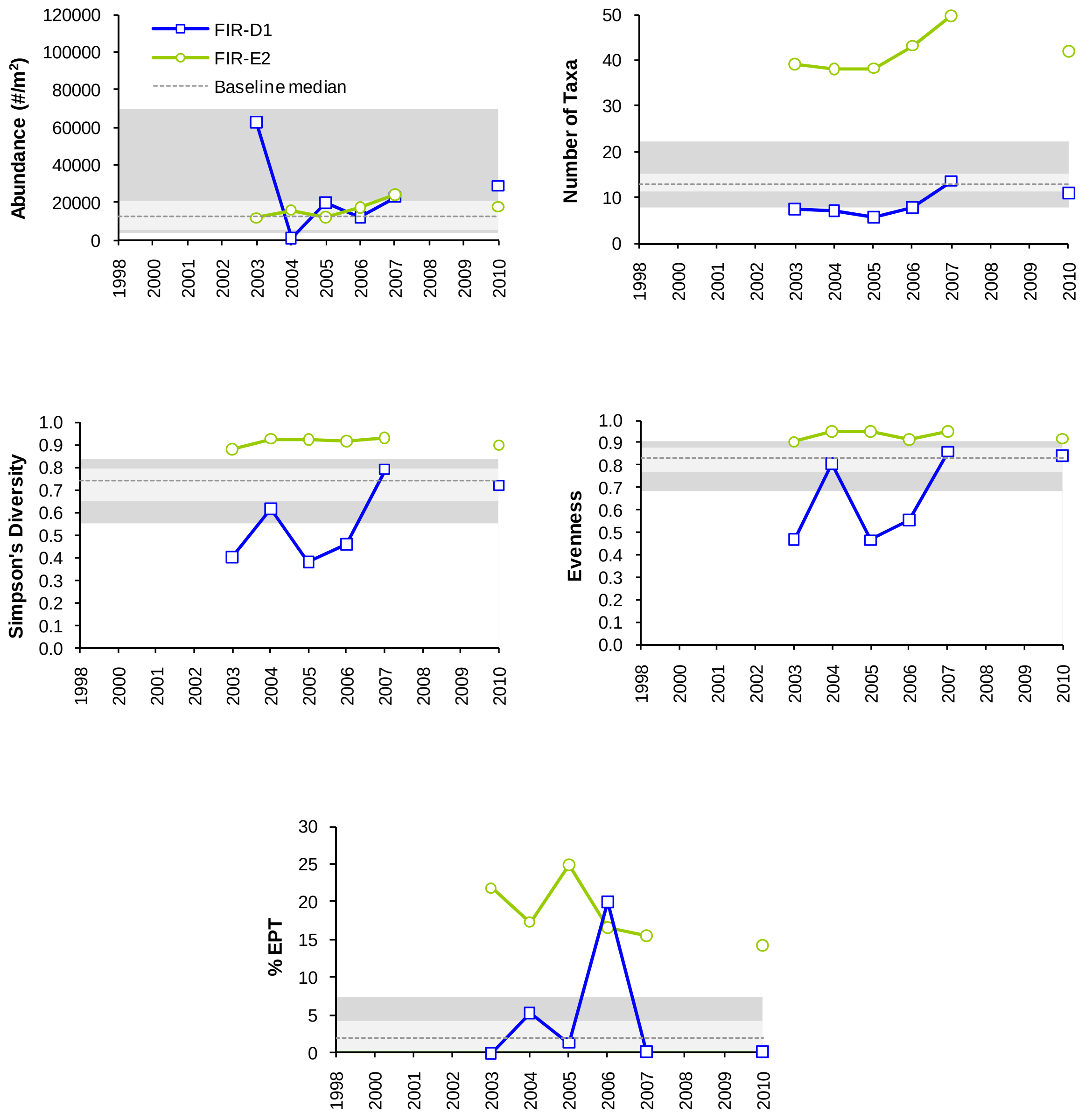
Taxon	Percent Major Taxa Enumerated in Each Year											
	Reach FIR-D1						Reach FIR-E2					
	2003	2004	2005	2006	2007	2010	2003	2004	2005	2006	2007	2010
Amphipoda							<1	<1				
Anisoptera	<1		<1	1		<1	<1	<1	<1	<1	<1	<1
Bivalvia		4	1		2	14	3	3	2		4	6
Ceratopogonidae	<1	2	1	<1	2	6		<1	<1	1	1	1
Chironomidae	96	33	36	52	42	17	63	48	35	7	37	47
Cladocera					13	2		<1	<1		<1	
Coleoptera							2	4	5	5	3	8
Copepoda					<1		1	1	<1		<1	<1
Empididae	<1	2			<1	<1				1	<1	1
Enchytraeidae					1	5	1	<1	<1	<1	1	<1
Ephemeroptera	<1	3			<1	<1	9	12	15	9	13	8
Ephydridae		3										
Gastropoda			<1	0.2		<1	1	<1		<1	3	2
Glossiphoniidae					<1		<1	<1	<1		<1	
Heteroptera	1	<1					<1	<1				
Hydra							<1	<1				
Hydracarina		<1				<1	5	1	11	6	12	5
Lumbriculidae		<1					<1					
Naididae	1	1			2	1	2	5	4	5	8	12
Nematoda	<1	4	1	1	1	<1	2	4	3	2	4	1
Ostracoda		9		<1	18	7	<1	<1	<1	<1	4	1
Plecoptera	<1		<1			<1	2	1	1	1	1	1
Simuliidae					<1		<1	<1	<1	<1	3	2
Tabanidae	<1			<1	<1	<1	<1	<1	<1	1	1	<1
Tipulidae		9	<1		<1	<1	1	<1	<1	1	<1	2
Trichoptera			1	<1		<1	5	7	1	7	2	3
Tubificidae	1	28	6	46	19	47	1	1	1	<1	3	1
Benthic Invertebrate Community Measurement Endpoints												
Total Abundance (No./m^2)	62,517	1,391	19,722	12,483	22,803	28,840	11,930	16,024	12,335	17,518	24,462	17,880
Richness	7	7	6	8	14	11	39	38	38	43	50	42
Simpson's Diversity	0.40	0.62	0.38	0.46	0.79	0.72	0.88	0.92	0.92	0.91	0.93	0.90
Evenness	0.47	0.81	0.47	0.55	0.86	0.84	0.90	0.95	0.95	0.91	0.95	0.92
% EPT	0	5	1	20	<1	<1	22	17	25	17	16	12

Table 5.7-9 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in *test* reach FIR-D1.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Time Trend	Time Trend	
Abundance	0.810	0	No change
Richness	**0.002**	53	Increasing over time
Simpson's Diversity	**0.000**	51	Increasing over time
Evenness	**0.001**	30	Increasing over time
EPT	0.471	5	No change
CA Axis 1	**0.002**	29	Shift reflecting lower relative abundance of chironomids
CA Axis 2	0.185	8	No change

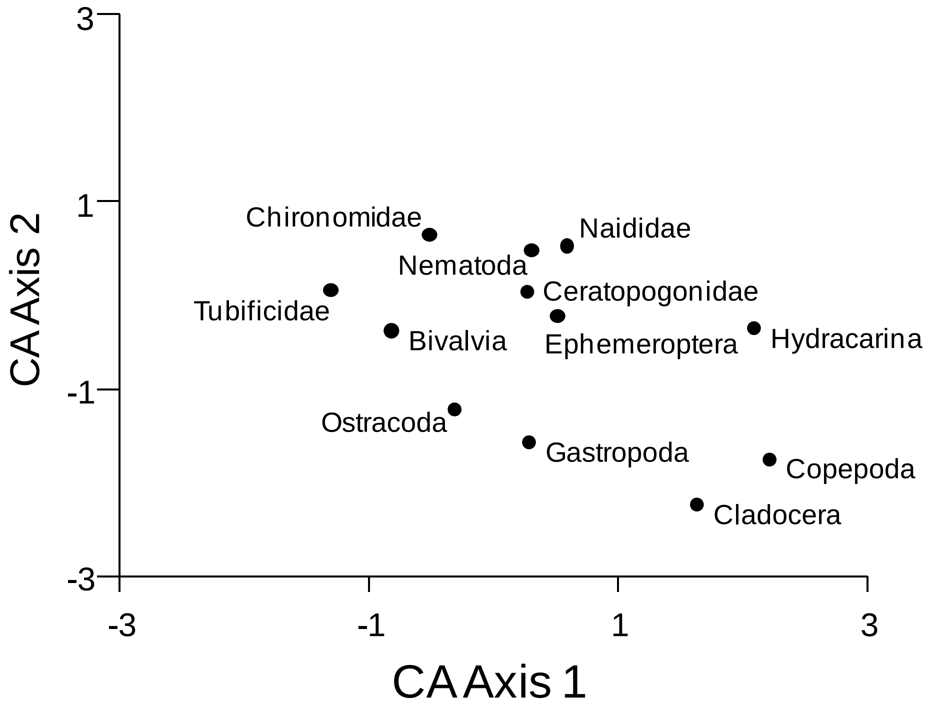
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

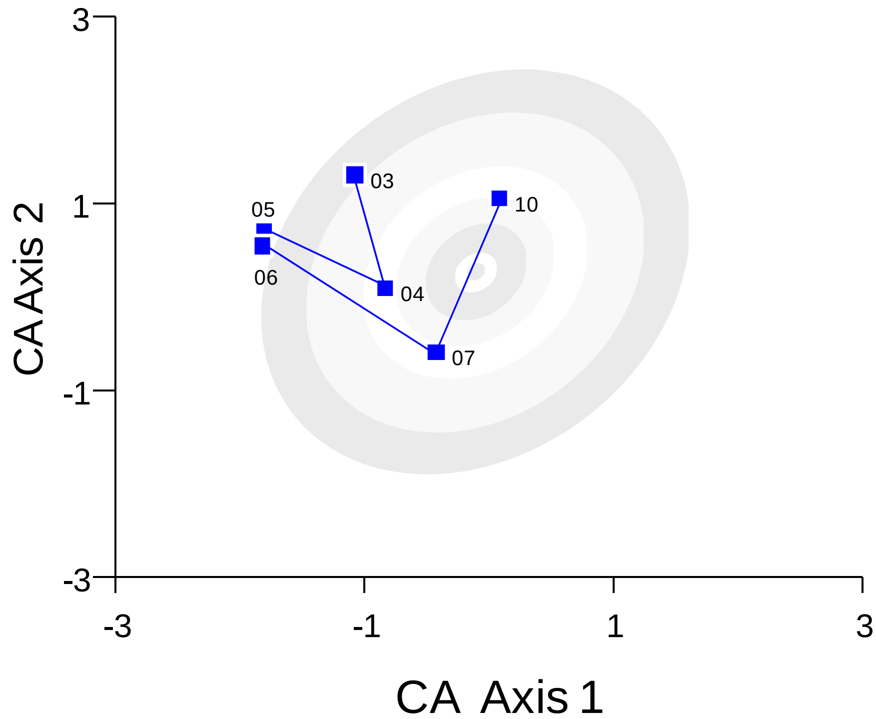
Figure 5.7-9 Variation in benthic invertebrate community measurement endpoints in the Firebag River.



Note: Regional *baseline* values reflect pooled results for all *baseline* lakes sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.7-10 Ordination (Correspondence Analysis) of benthic invertebrate communities in *test* reach FIR-D1 of the Firebag River.





Note: lower panel is the scatterplot of sample scores while the upper panel is the scatterplot of taxa scores. The ellipse in the lower panel is for the *baseline* data.

Table 5.7-10 Average habitat characteristics of benthic invertebrate sampling locations in McClelland Lake, fall 2010.

Variable	Units	McClelland Lake
Sample date	-	Sept. 13, 2010
Habitat	-	Depositional
Water depth	m	2.0
Field Water Quality		
Dissolved oxygen	mg/L	10.1
Conductivity	µS/cm	225
pH	pH units	8.9
Water temperature	°C	13.7
Sediment Composition		
Sand	%	16
Silt	%	66
Clay	%	19
Total Organic Carbon	%	15

Table 5.7-11 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	2010
Amphipoda	11	22	21	7	<1	4	3	4	
Anisoptera			<1	1	<1		<1	<1	<1
Bivalvia	2	8	6	9	<1	1	1	3	<1
Ceratopogonidae				1	<1				
Chaoboridae									
Chironomidae	58	39	24	27	91	41	33	75	80
Cladocera	<1		2	2	1	7	14	<1	2
Copepoda			2	1	1	10	13	<1	1
Ephemeroptera	1	2	8	7	1	12	5	<1	<1
Erpobdellidae	1	<1	<1				<1		
Gastropoda	<1	1		2	<1		<1	1	2
Glossiphoniidae							<1		
Hydracarina	1	<1		1			6	5	<1
Lumbriculidae		<1	<1	<1		8	<1	<1	
Naididae	14	13	7	12	2	12	17	3	9
Nematoda	1	<1	4	<1	1		1	<1	<1
Ostracoda	10	8	15	29	1	3	3	5	4
Trichoptera	1		3	1	<1	2	1	<1	<1
Tubificidae		6	<1		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	47,885
Richness	11	11	6	11	23	12	22	23	1
Simpson's Diversity	0.71	0.71	0.66	0.72	0.76	0.72	0.85	0.74	0.78
Evenness	0.84	0.81	0.91	0.85	0.76	0.82	0.91	0.79	0.83
% EPT	2	2	10	7	2	6	5	2	1

Table 5.7-12 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in McClelland Lake.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Before vs. After	Before vs. After	
Abundance	**0.000**	20	Higher in *test* period
Richness	0.066	6	No difference between *baseline* and *test* period
Simpson's Diversity	0.378	7	No difference between *baseline* and *test* period
Evenness	0.834	0	No difference between *baseline* and *test* period
EPT	0.288	15	No difference between *baseline* and *test* period
CA Axis 1	0.158	30	No difference between *baseline* and *test* period
CA Axis 2	0.094	13	No difference between *baseline* and *test* period

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.7-11 Variation in benthic invertebrate community measurement endpoints in McClelland Lake.

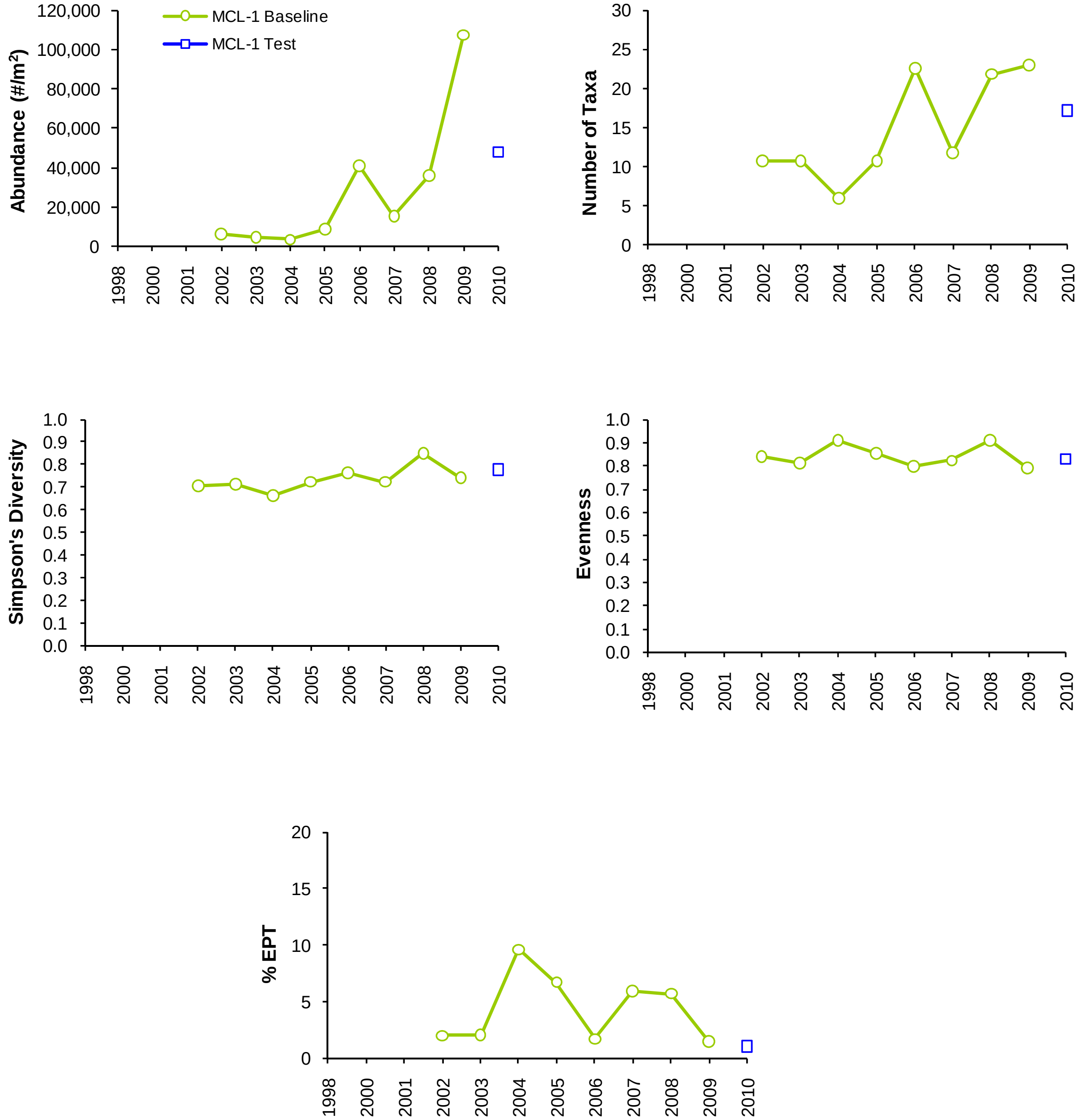
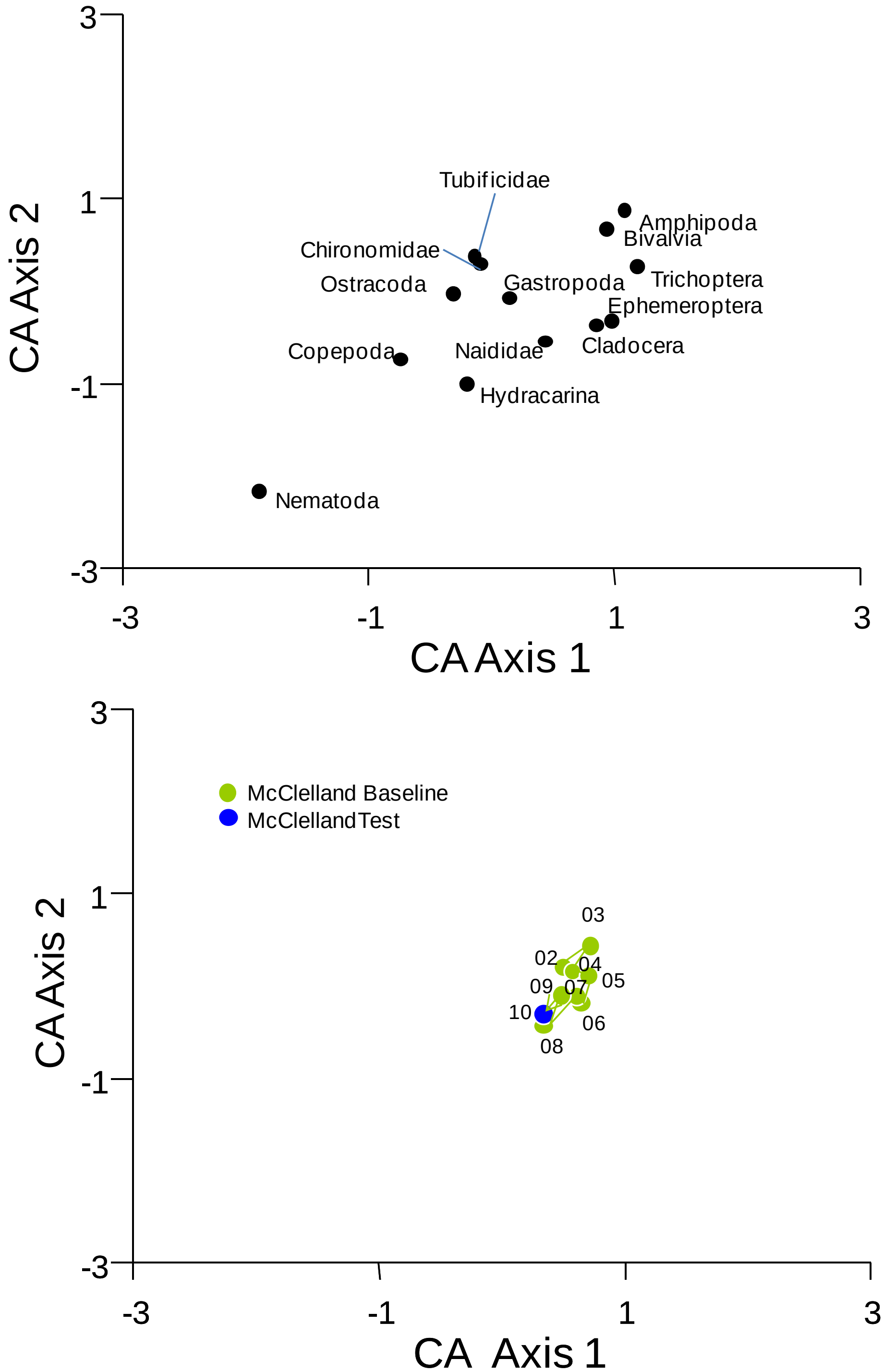


Figure 5.7-12 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in McClelland Lake (MCL-1).



Note: lower panel is the scatterplot of sample scores while the upper panel is the scatterplot of taxa scores.

Table 5.7-13 Concentrations of sediment quality measurement endpoints, Firebag River (*test* station FIR-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2002-2009 (fall data only, station FIR-D1)			
			Value	n	Min	Median	Max
Physical variables[4]							
Clay	%	-	<0.1	5	1	5	8.0
Silt	%	-	0.3	5	1	9	38.0
Sand	%	-	99.7	5	54.0	91	100
Total organic carbon	%	-	0.12	5	0.1	0.8	13.2
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	14	32	40
Fraction 3 (C16-C34)	mg/kg	300[2]	21	3	140	**330**	**1900**
Fraction 4 (C34-C50)	mg/kg	2800[2]	31	3	150	280	1800
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.0100	5	0.00095	0.002	0.01
Retene	mg/kg	-	<0.0018	5	0.00193	<0.06	9.06
Total dibenzothiophenes	mg/kg	-	0.04	5	0.02	0.39	2.12
Total PAHs	mg/kg	-	0.33	5	0.17	1.46	17.19
Total Parent PAHs	mg/kg	-	0.02	5	0.01	0.06	0.29
Total Alkylated PAHs	mg/kg	-	0.30	5	0.16	1.40	16.90
Predicted PAH toxicity[1]	H.I.	-	1.25	5	0.35	0.67	1.44
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7	3	7	8	9
Chironomus growth - 10d	mg/organism	-	2.048	3	1.9	1.942	2.6
Hyalella survival - 14d	# surviving	-	9.6	3	5	8.8	9
Hyalella growth - 14d	mg/organism	-	0.268	3	0.06	0.1	0.226

Values in **bold** indicate concentrations exceeding guidelines.

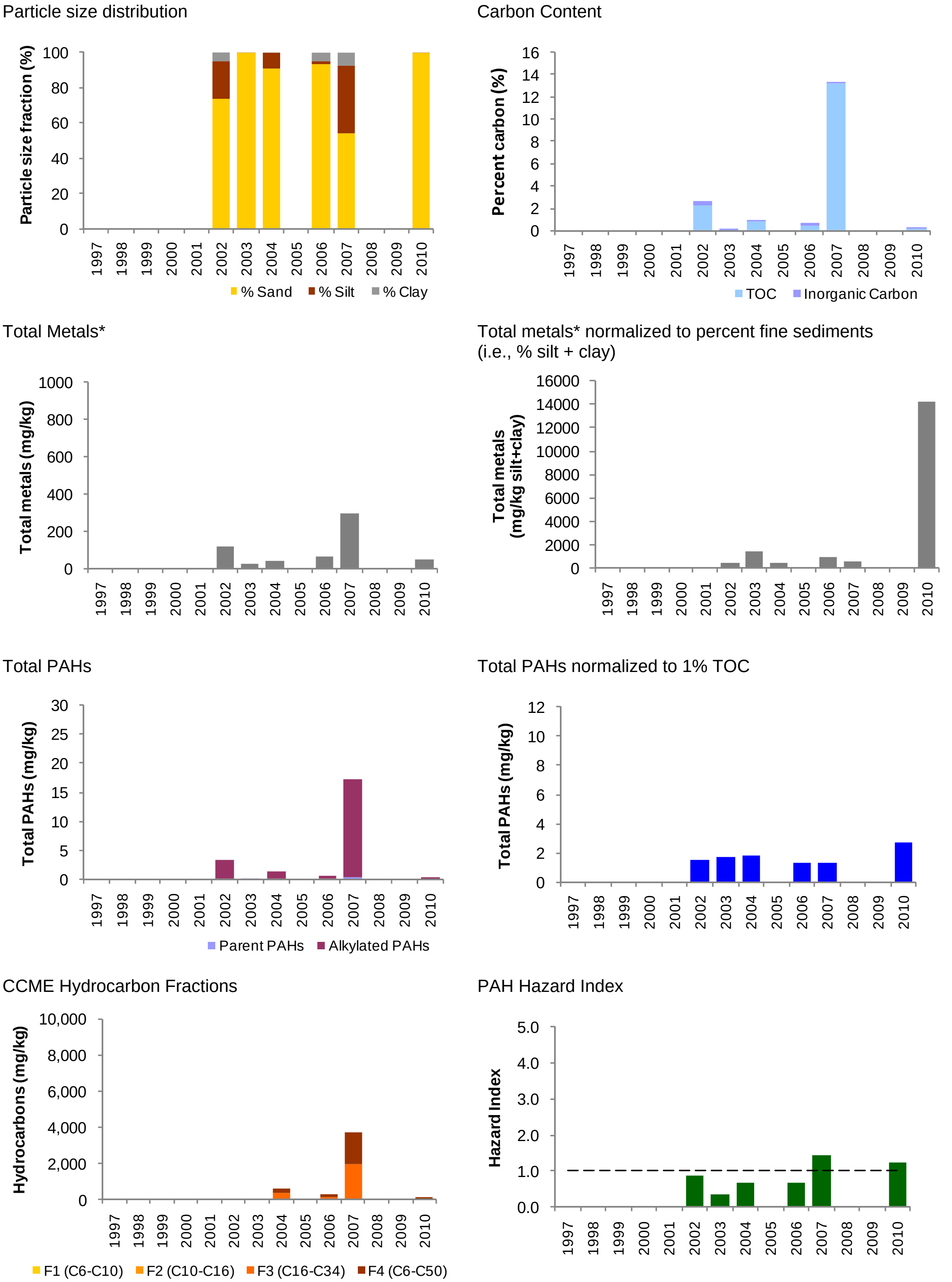
[1] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[2] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[3] Interim sediment quality guideline (ISQG) (CCME 2002).

[4] Value is calculated from an average of 5 replicates.

Figure 5.7-13 Variation in sediment quality measurement endpoints in the Firebag River, *test* station FIR-D1.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Table 5.7-14 Concentrations of sediment quality measurement endpoints, McClelland Lake (*test* station MCL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2002-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	2.8	6	2	26	49
Silt	%	-	59.4	6	14	22	37
Sand	%	-	37.8	6	14	49	83
Total organic carbon	%	-	16.7	6	25.0	28.4	30.5
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	53	<150
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	**53**	**<150**
Fraction 2 (C10-C16)	mg/kg	150[1]	**288**	4	<5	35	**240**
Fraction 3 (C16-C34)	mg/kg	300[1]	**486**	4	**360**	**997**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	288	4	38	583	2400
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.005	3	0.011	0.011	0.024
Retene	mg/kg	-	0.025	6	0.019	0.103	0.161
Total dibenzothiophenes	mg/kg	-	0.025	6	0.025	0.035	0.083
Total PAHs	mg/kg	-	0.261	6	0.363	0.565	0.751
Total Parent PAHs	mg/kg	-	0.023	6	0.053	0.066	0.107
Total Alkylated PAHs	mg/kg	-	0.239	6	0.310	0.503	0.674
Predicted PAH toxicity[3]	H.I.	-	0.068	6	0.039	0.132	0.368
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	3	7.8	9.0	9.2
Chironomus growth - 10d	mg/organism	-	ns	3	1.4	1.5	1.9
Hyalella survival - 14d	# surviving	-	ns	3	7.4	8.0	9.6
Hyalella growth - 14d	mg/organism	-	ns	3	0.2	0.3	0.3

Values in **bold** indicate concentrations exceeding guidelines.

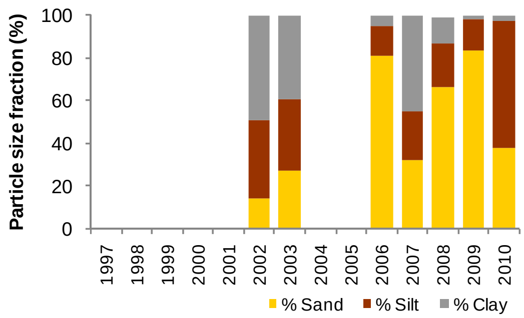
[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

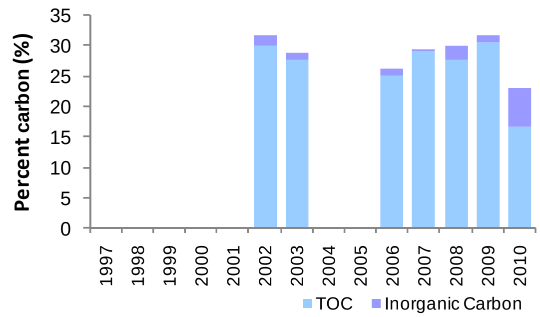
[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Figure 5.7-14 Variation in sediment quality measurement endpoints in McClelland Lake, *test* station MCL-1.

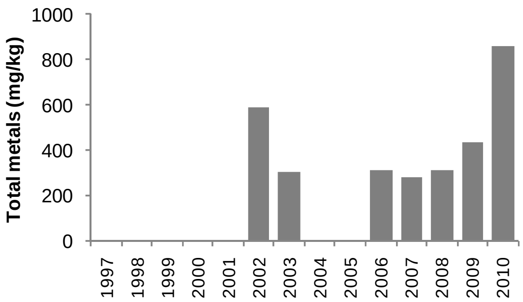
Particle size distribution



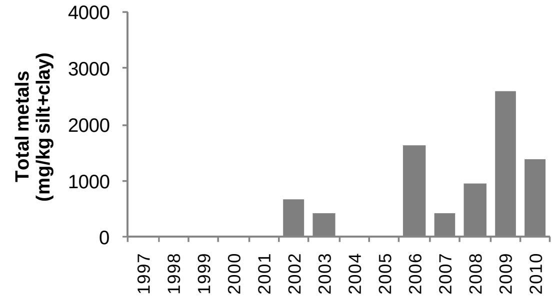
Carbon Content



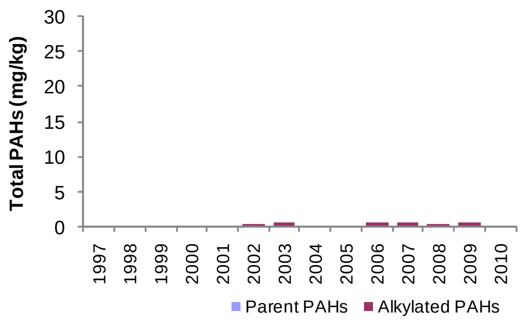
Total Metals*



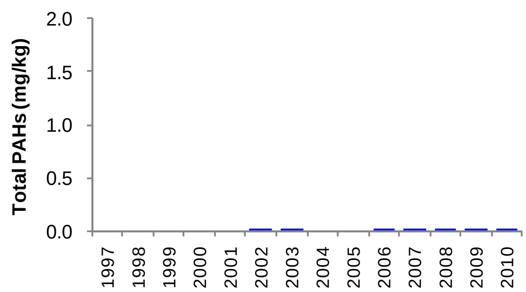
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



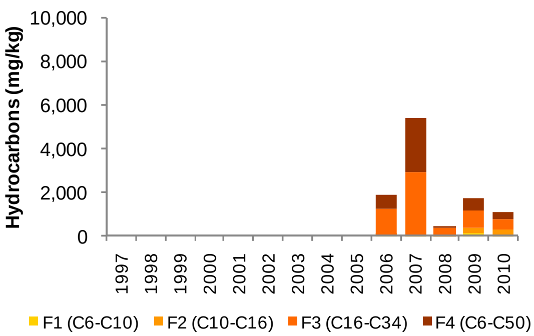
Total PAHs



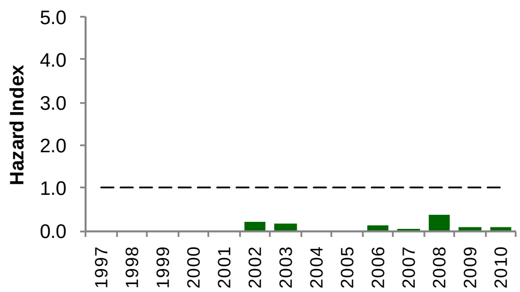
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

5.8 ELLS RIVER WATERSHED

Table 5.8-1 Summary of results for the Ells River watershed.

Ells River Watershed	Summary of 2010 Conditions		
Climate and Hydrology			
Criteria		**S14A** at CNRL 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	**ELR-2A** upstream of Fort McKay water intake
Water Quality Index	○	○	○
Benthic Invertebrate Communities and Sediment Quality			
Criteria	**ELR-D1** lower reach	no reach sampled	**ELR-E2A** upstream of Fort McKay water intake
Benthic Invertebrate Communities	○		n/a
Sediment Quality Index	○		not sampled
Fish Populations			
Fish Populations component activities are included in the Fish Assemblage Monitoring Pilot Study (Section 6.0)			

Legend and Notes

○ Negligible-Low
● Moderate
● High

baseline
test

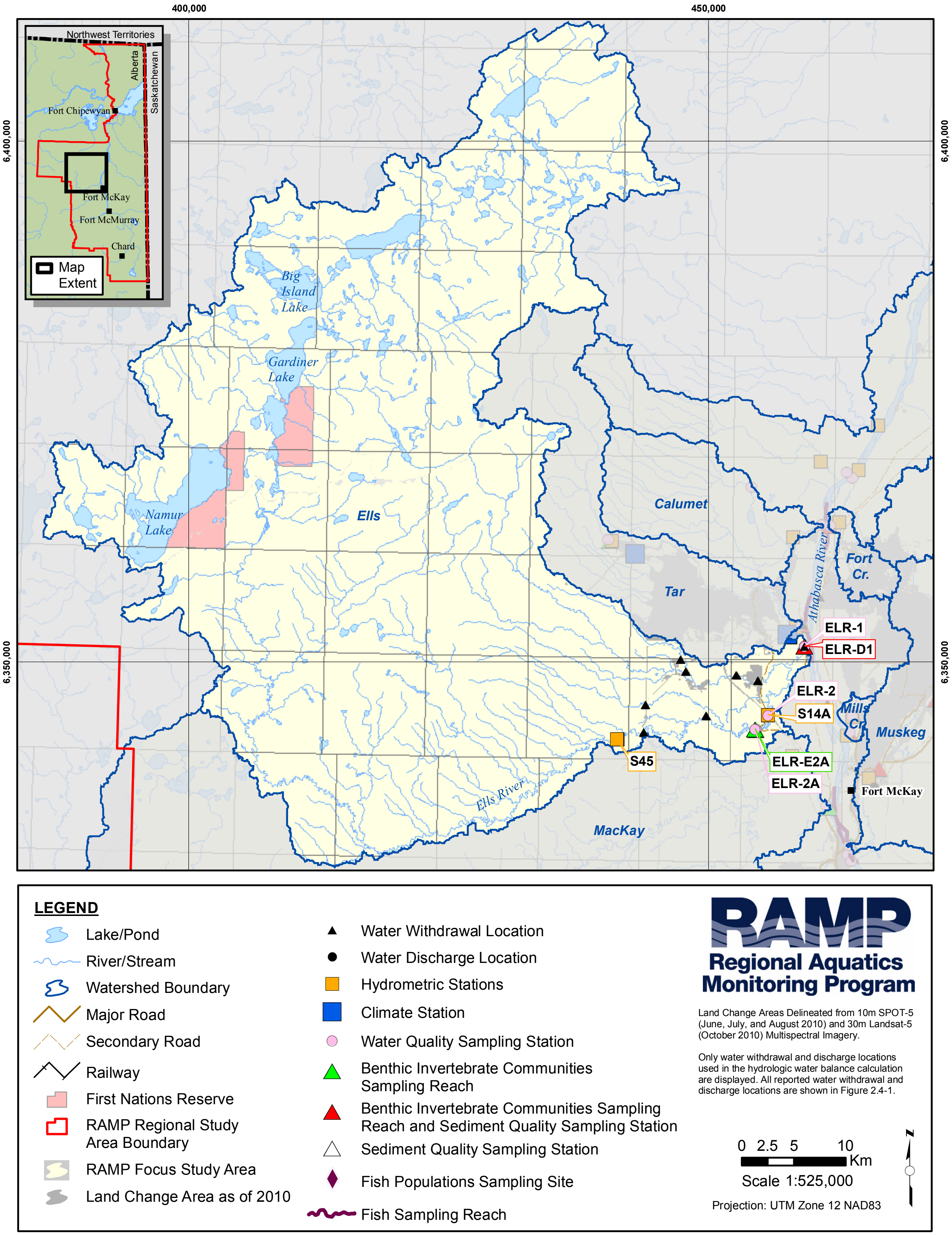
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches as well as comparison to regional baselines; see Section 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology.

Figure 5.8-1 Ells River watershed.



\\hf-nv-san01\gis\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K08_Ells_20110318.mxd

Figure 5.8-2 Representative monitoring stations of the Ells River, fall 2010.

Water Quality Station ELR-1:
Centre of Channel, facing downstream

Water Quality Station ELR-2a:
Right Downstream Bank

Water Quality Station ELR-2:
Left Downstream Bank

Hydrology Station S14A:
Left Downstream Bank

5.8.1 Summary of 2010 Conditions

Approximately 0.4% (937 ha) of the Ells River watershed had undergone land change as of 2010 from focal projects (Table 2.5-2); 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*.

The Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality components of RAMP conducted monitoring activities in the Ells River watershed in 2010. The Fish Populations component did not conduct regular monitoring activities in the Ells River watershed in 2010. However, the pilot study of fish assemblage monitoring in 2010 included two reaches on the Ells River; Section 6 contains the results of this study. Table 5.8-1 is a summary of the 2010 assessment for the Ells River watershed while Figure 5.8-1 denotes the location of the monitoring stations for each

RAMP component, reported focal project water withdrawal and discharge locations, and the area with land change as of 2010. Figure 5.8-2 contains fall 2010 photos of a number of monitoring stations in the watershed.

Hydrology The calculated mean winter discharge, open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.01% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2010 between the Ells River and regional *baseline* fall conditions are classified as **Negligible-Low**. Water quality conditions were consistent with previous years for *test* station ELR-1 and *baseline* station ELR-2 and the fall 2010 concentrations of water quality measurement endpoints at these stations were generally within the range of previously-measured concentrations and regional *baseline* conditions. Water quality at *baseline* station ELR-2A in fall 2010 was similar to that at the other two stations, located further downstream.

Benthic Invertebrate Communities and Sediment Quality Differences in values of measurement endpoints of the benthic invertebrate community across time at *test* reach ELR-D1 are classified as **Negligible-Low** because they were within the range of *baseline* conditions for depositional reaches in the RAMP FSA, and because the significant increases in taxa richness and diversity over time do not imply a negative change in the benthic invertebrate community. Differences in sediment quality observed in fall 2010 between *test* station ELR-D1 and regional *baseline* conditions were **Negligible-Low** with nearly all measurement endpoints within the historical range of concentrations.

5.8.2 Hydrologic Conditions: 2010 Water Year

Ells River above Joslyn Creek (RAMP Station S14A) Continuous annual hydrometric data have been collected for Station S14A from 2008 to 2010 with intermittent periods of flow data available from 2004 to 2008. Comparison of the 2010 water year (WY) hydrologic conditions to historical values is; therefore, less robust than for a number of the other hydrology stations in the RAMP FSA. The 2010 WY runoff volume measured at Station S14A was 188 million m^3. Flows decreased during December 2009 due to river freeze-up and winter flows varied from 0.7 to 1.9 m^3/s from mid-January to mid-March (Figure 5.8-3). Flows then increased in late March due to snowmelt and the freshet peak of 27.4 m^3/s recorded on April 10 was the maximum daily flow recorded in the 2010 WY. Flows increased again in response to rainfall events in late May, followed by decreasing flows throughout June and July with values similar to the historical minimum flows recorded during these months. Flows increased in response to rainfall events in late August, and flows recorded from September 21 to October 25 were higher than the historical maximum flow values recorded for this time period. The minimum open-water daily flow of 2.9 m^3/s recorded on August 21 was 16% higher than the historical open-water mean minimum daily flow of 2.5 m^3/s.

Differences between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The 2010 WY estimated water balance for the Ells River is based on the recorded flows at RAMP Station S14A, which is upstream of some focal projects located within the Ells River watershed. The station cannot be located downstream of all focal projects because of backwater effects associated with the confluence of the Ells River and the Athabasca River at downstream sections of the Ells River. Consequently, the analysis is conservative with differences between the observed *test* hydrograph and the estimated *baseline* hydrograph expected to be lower at the mouth than currently estimated. The 2010 WY estimated water balance for the Ells River above Joslyn Creek (RAMP Station S14A) is presented in Table 5.8-2 and described below:

1. The closed-circuited land area from focal projects as of 2010 in the Ells watershed is estimated to be 1.6 km^2 (Table 2.5-1). The loss of flow to the Ells River that would have otherwise occurred from this land area is estimated at 0.12 million m^3.

2. As of 2010, the area of land change in the Ells watershed from focal projects that was not closed-circuited is estimated to be 7.8 km^2 (Table 2.5-1). The increase in flow to the Ells River that would not have otherwise occurred from this land area is estimated at 0.12 million m^3.

3. In the 2010 WY, Total E&P withdrew 13,415 m^3 of water from eight locations within the catchment to support winter access and drilling activities.

The estimated cumulative effect of land change and water withdrawals is a loss of flow of approximately 18,900 m^3 at RAMP Station S14 in the 2010 WY. The observed and estimated *baseline* hydrographs are presented in Figure 5.8-1. The calculated mean winter discharge, open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.01% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.8-3). These differences are classified as **Negligible-Low** (Table 5.8-2).

5.8.3 Water Quality

In fall 2010, water quality samples were taken from:

- the Ells River near its mouth (*test* station ELR-1, established in 1998, sampled annually since 2002);
- the Ells River upstream of Joslyn Creek (*baseline* station ELR-2, established in 2000, sampled annually since 2004); and
- the Ells River upstream of the Fort MacKay water intake (*baseline* station ELR-2A, initiated as a new station in fall 2010).

Temporal Trends The following statistically significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- An increasing concentration of total nitrogen at *test* station ELR-1 (1998, 2002 to 2010); and
- A decreasing concentration of chloride at *baseline* station ELR-2 (2004 to 2010).

No trend analysis could be conducted for water quality at *baseline* station ELR-2A as this station was first sampled in 2010.

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within the range of historical concentrations in fall 2010 (Table 5.8-4 and Table 5.8-5) with the exception of:

- total nitrogen, total mercury, and total Kjeldahl nitrogen, with concentrations that exceeded their previously-measured maximum concentrations, and total molybdenum with a concentration that was equal to its previously-measured minimum concentration at *test* station ELR-1; and

- total nitrogen, dissolved organic carbon, total mercury, total phenols, and total Kjeldahl nitrogen, with concentrations that exceeded their previously-measured maximum concentrations at *baseline* station ELR-2.

Given *baseline* station ELR-2A was first sampled in 2010, no historical data were available for comparison with fall 2010 results (Table 5.8-6). Although the concentrations of total mercury were historically high at *test* station ELR-1 and *baseline* station ELR-2 in fall 2010, these concentrations were equal to or lower than the concentration of mercury measured at *baseline* station ELR-2A in fall 2010.

Ion Balance The ionic composition of water in fall 2010 at all three water quality monitoring stations was similar and dominated by calcium and bicarbonate (Figure 5.8-4). The ionic composition of sampled water at *test* station ELR-1 and *baseline* station ELR-2 has remained consistent since water quality monitoring first began in 1998. The exception to this trend was at *baseline* station ELR-2 in 2007 when anionic composition was more dominated by bicarbonate than in other years. The ion balance across all three stations was very similar in fall 2010.

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints measured in the Ells River in fall 2010 were below water quality guidelines (Table 5.8-4 to Table 5.8-6) with the exception of total aluminum at all three stations and total nitrogen at *baseline* stations ELR-2 and ELR-2A.

Other Water Quality Guideline Exceedances Concentrations of total iron, total Kjeldahl nitrogen, total phenols, and sulphide exceeded relevant water quality guidelines at all stations in fall 2010 (Table 5.8-4 to Table 5.8-6).

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, concentrations of all water quality measurement endpoints were within the range of regional *baseline* concentrations (Figure 5.8-5).

Water Quality Index The WQI value was 100 for both *test* station ELR-1 and *baseline* station ELR-2A and 98.7 for *baseline* station ELR-2, indicating **Negligible-Low** differences in water quality from regional *baseline* conditions at all stations in fall 2010.

Classification of Results Differences in water quality in fall 2010 between the Ells River and regional *baseline* fall conditions are classified as **Negligible-Low**. Water quality conditions were consistent with previous years for *test* station ELR-1 and *baseline* station ELR-2 and the fall 2010 concentrations of water quality measurement endpoints at these stations were generally within the range of previously-measured concentrations and regional *baseline* conditions. Water quality at *baseline* station ELR-2A in fall 2010 was similar to that at the other two stations, located further downstream.

5.8.4 Benthic Invertebrate Communities and Sediment Quality

5.8.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at:

- depositional *test* reach ELR-D1, sampled since 2003; and
- erosional b*aseline* reach ELR-E2A, sampled for the first time in 2010. The original upstream reach on the Ells River, *baseline* reach ELR-E2, sampled from 2003 to 2006, was moved further upstream in fall 2010 due to increased development of focal projects.

2010 Habitat Conditions Water at *test* reach ELR-D1 in fall 2010 was shallow (0.4 m), alkaline (pH: 8.2), had moderate conductivity (188 µS/cm) and low total organic carbon (3%), and a substrate dominated by sand (69%) and silt (24%) (Table 5.8-7). Water at *baseline* reach ELR-E2A in fall 2010 was shallow (0.3 m), fast-flowing (1.1 m/s), alkaline (pH: 8.2), had moderate conductivity (180 µS/cm) and a substrate dominated by large gravel (33.5%) and small and large cobble (27% each) (Table 5.8-7). Periphyton biomass in *baseline* reach ELR-E2A averaged 55.1 mg/m^2, which is within the range of variation for regional *baseline* conditions (Figure 5.8-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of *test* reach ELR-D1 in fall 2010 was dominated by chironomids (45%) with subdominant taxa consisting of tubificid (29%) and Naididae worms (11%) (Table 5.8-8). Ostracoda and Ceratopogonidae were present in low relative abundances (Table 5.8-8). The most dominant chironomids included the common *Polypedilum*, *Procladius*, and *Micropsectra/Tanytarsus*. Although, they had low relative abundance, mayflies (Ephemeroptera; *Caenis, Baetis, Heptagenia*), stoneflies (Plectoptera; *Pteronarcella*) and caddisflies (Trichoptera; *Oecetis*) were observed in this reach.

The benthic invertebrate community of *baseline* reach ELR-E2A in fall 2010 was dominated by chironomids (43%) and Ephemeroptera (18%) with subdominant taxa consisting of Trichoptera (10%) and Naididae worms (10%) (Table 5.8-8). Hydracarina were present in low relative abundances. Dominant chironomids included the common *Polypedilum, Stempellinella,* and *Micropsectra/Tanytarsus* as well as other taxa that prefer clean, cold water such as *Tvetenia*. Ephemeroptera were primarily of the genera *Acentrella, Acerpenna*, and *Heptagenia*, while Trichoptera were represented by the genera *Psychomyia, Lepidostoma*, and the very common *Hydropsyche* (Table 5.8-8). Plecoptera (*Pteronarcys, Isoperla*) were present in low relative abundance.

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that *test* reach ELR-D1 has been designated as *test* (Hypothesis 1, Section 3.2.3.1; spatial comparisons were not conducted because *test* reach ELR-D1 is depositional and *baseline* reaches ELR-E2 and ELR-E2A are erosional). A significant increase in taxa richness and diversity was observed across years with the relative change explaining 30 to 40% of the variation in annual means values (Table 5.8-9); time trends in the other five measurement endpoints for benthic invertebrate communities were not significant.

Comparison to Published Literature *Test* reach ELR-D1 in fall 2010 had a moderately high total abundance (36,000 per m^2) and a relatively high percent of the fauna as tubificid worms, potentially indicating some level of enrichment (Hynes 1960, Griffiths 1998). Increased taxa richness in some cases can reflect modest nutrient enrichment (Hynes 1960). The benthic invertebrate community in *test* reach ELR-D1 in fall also contained representative mayflies, caddisflies and stoneflies indicating that dissolved oxygen levels have been consistently high.

2010 Results Relative to Regional *Baseline* Conditions Values of all benthic invertebrate community measurement endpoints in fall 2010 were within the range of regional *baseline* depositional reaches (Figure 5.8-7). Abundance, richness and diversity were higher in 2010 than previously measured at *test* reach ELR-D1. In addition, the ordination of the benthic invertebrate community at *test* reach ELR-D1 in fall 2010 was similar to that for regional *baseline* depositional reaches (Figure 5.8-8).

Classification of Results Differences in values of measurement endpoints of the benthic invertebrate community across time at *test* reach ELR-D1 are classified as **Negligible-**

Low because they were within the range of *baseline* conditions for depositional reaches in the RAMP FSA, and because the significant increases in taxa richness and diversity over time do not imply a negative change in the benthic invertebrate community (Table 3.2-6).

5.8.4.2 Sediment Quality

Sediment quality was sampled in fall 2010 in the Ells River near its mouth at *test* station ELR-D1 in the same location as the benthic invertebrate communities *test* reach ELR-D1. This station was designated as *baseline* in 1998 and *test* from 2002 to present.

2010 Results Relative to Historical Concentrations 2010 sediment quality data from *test* reach ELR-D1 were compared directly to data collected at this station in 2006 and 2007. Prior to integration of the Sediment Quality component with the Benthic Invertebrate Communities component of RAMP in 2006, *test* reach ELR-D1 corresponds to pre-2006 sediment quality station ELR-1.

Sediments at *test* station ELR-D1 in fall 2010 were dominated by sand with a moderate proportion of silt, a small proportion of clay and relatively low total organic carbon content (Table 5.8-10). In fall 2010, concentrations of all sediment quality measurement endpoints were within or slightly below previously-measured concentrations with the exception of naphthalene, which was higher than its previously-measured maximum concentration (Table 5.8-10). As in previous years, Fraction-1 hydrocarbons and BTEX (benzene, toluene, ethylene and xylene) were not detectable at *test* station ELR-D1; sediment hydrocarbon concentrations were dominated by Fraction 3 and Fraction 4, which likely indicates the presence of bitumen in sediments (Table 5.8-10). All hydrocarbon fractions and total PAHs (absolute and carbon-normalized concentrations) were near or below historical minimum concentrations observed in this station. The predicted PAH toxicity of 1.95 exceeded the potential chronic toxicity threshold of 1.0 but was within the historical range of values for the lower Ells River (Table 5.8-10).

Direct tests of sediment toxicity to invertebrates at *test* station ELR-D1 showed 84% survival in test organisms of the amphipod *Hyalella* and 76% survival in test organisms of the midge *Chironomus*; both these values were within historical ranges for this station (Table 5.8-10).

Comparison with Sediment Quality Guidelines There were no sediment quality measurement endpoints that exceeded relevant CCME sediment quality guidelines at *test* station ELR-D1 in fall 2010 with the exception of Fraction 3 (C16-C34) hydrocarbons and total arsenic (Table 5.8-10).

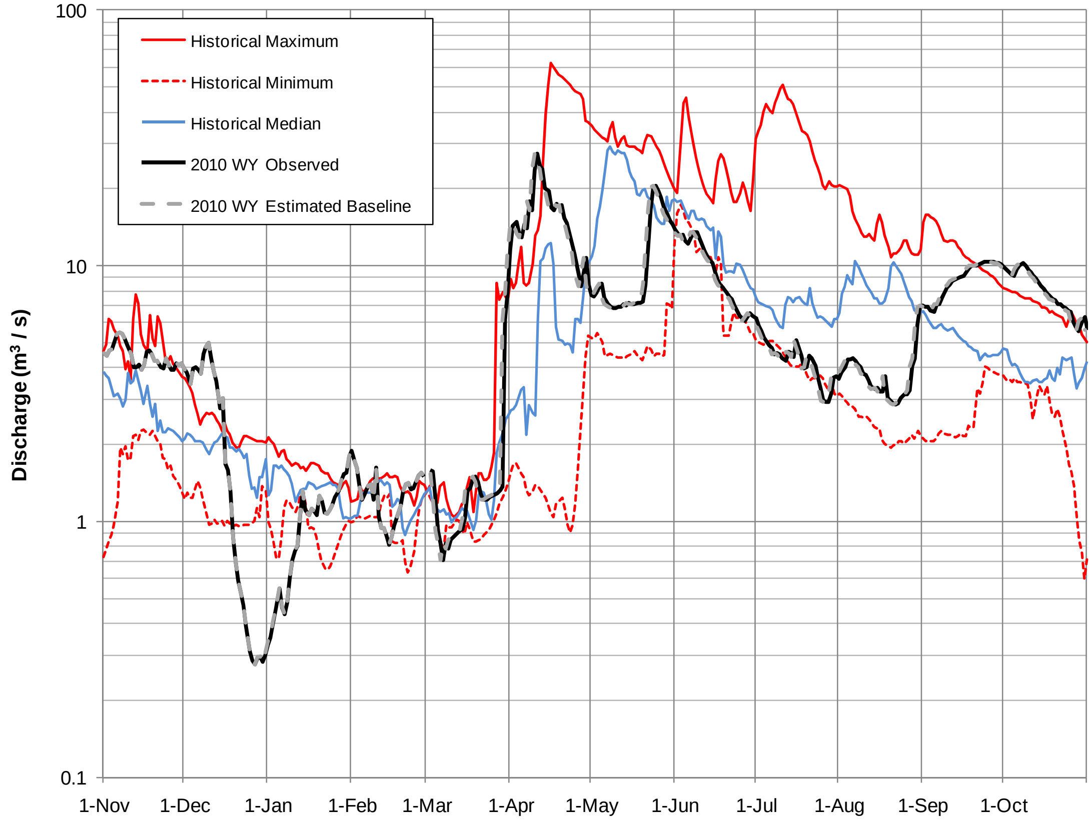
Sediment Quality Index A SQI of 98.9 was calculated for *test* station ELR-D1 for fall 2010, indicating a **Negligible-Low** difference from regional *baseline* conditions. Since 1998, this station has always maintained a SQI designated as **Negligible-Low** with the exception of 2005 and 2006 when sediment conditions indicated a **Moderate** difference from regional *baseline* conditions.

Classification of Results Differences in sediment quality observed in fall 2010 between *test* station ELR-D1 and regional *baseline* conditions were **Negligible-Low** with nearly all sediment quality measurement endpoints within the historical range of concentrations.

5.8.5 Fish Populations

The Fish Populations component did not conduct regular monitoring activities in the Ells River watershed in 2010; however, a second year of a pilot study of fish assemblage monitoring included a reach on the lower Ells River; Section 6 contains the results of this study.

Figure 5.8-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Ells River in the 2010 WY, compared to historical values.



Note: The observed 2010 WY hydrograph is based on Station S14A, Ells River above Joslyn Creek, 2010 provisional data. The upstream drainage area is 2,450 km^2. Historical values are calculated for the period from 2001 to 2009 during the open-water period (May to October), and from 2004 to 2009 for the remaining winter months (November to April), 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 Ells River above Joslyn Creek (RAMP Station S14A), 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**188.20**	**Observed discharge at RAMP Station S14A, Ells River above Joslyn Creek**
Closed-circuited area water loss from the observed *test* hydrograph	-0.12	Estimated 1.6 km^2 of the Ells River watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.12	Estimated 7.8 km^2 of the Ells River watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Ells River watershed from focal projects	-0.01	13,415 m^3 withdrawn from sources upstream of Station S14A for winter access and drilling
Water releases into the Ells 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 Ells River not accounted for by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**188.21**	**Estimated *baseline* discharge at RAMP Station S14A, Ells River above Joslyn Creek**
Incremental flow (change in total discharge)	-0.02	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 discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on RAMP Station S14A, Ells River above Joslyn Creek, 2010 provisional data.

Note: Flow values in this table presented to two decimal places.

Table 5.8-3 Calculated change in hydrologic measurement endpoints for the Ells River watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	7.54	7.54	0.00%
Mean winter discharge	2.17	2.17	-0.05%
Annual maximum daily discharge	27.39	27.39	0.00%
Open-water period minimum daily discharge	2.89	2.89	0.00%

Note: Based on RAMP Station S14A, Ells River above Joslyn Creek, 2010 provisional data.

Note: Flow values in this table presented to three decimal places.

Table 5.8-4 Concentrations of water quality measurement endpoints, mouth of Ells River (*test* station ELR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	9	7.8	8.2	8.4
Total suspended solids	mg/L	-[1]	14	9	3	6	16
Conductivity	µS/cm	-	222	9	175	229	272
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.014	9	0.003	0.008	0.020
Total nitrogen*	mg/L	1.0	**1.32**	9	0.30	0.60	**1.10**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	19	9	11	15	20
Ions							
Sodium	mg/L	-	10.7	9	8.0	11.0	18.0
Calcium	mg/L	-	23.6	9	21.6	24.9	30.4
Magnesium	mg/L	-	7.2	9	6.5	7.7	9.1
Chloride	mg/L	230, 860[3]	1.0	9	<0.5	2.0	4.0
Sulphate	mg/L	100[4]	18.7	9	10.5	15.4	27.9
Total dissolved solids	mg/L	-	165	9	110	166	220
Total alkalinity	mg/L		92	9	76	97	117
Selected metals							
Total aluminum	mg/L	0.1	**0.500**	9	0.060	**0.264**	**0.673**
Dissolved aluminum	mg/L	0.1[2]	0.0148	9	0.0059	0.0171	0.0780
Total arsenic	mg/L	0.005	0.0011	9	0.0005	0.0009	0.0012
Total boron	mg/L	1.2[5]	0.055	9	0.041	0.062	0.083
Total molybdenum	mg/L	0.073	0.00064	9	0.00064	0.00071	0.00084
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.4	7	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.122	9	0.095	0.125	0.140
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.009**	9	<0.002	**0.006**	**0.135**
Total iron	mg/L	0.3	**0.82**	9	**0.45**	**0.70**	**1.14**
Total phenols	mg/L	0.004	**0.006**	9	<0.001	0.004	**0.110**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.25**	9	<0.20	0.50	1.00

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 5.8-5 Concentrations of water quality measurement endpoints, upper Ells River (*baseline* station ELR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	6	7.7	8.1	8.3
Total suspended solids	mg/L	-[1]	6	6	<3	4	8
Conductivity	µS/cm	-	206	6	164	190	219
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.011	6	0.004	0.014	0.061
Total nitrogen*	mg/L	1.0	**2.01**	6	0.60	0.70	1.00
Nitrate+nitrite	mg/L	1.3	<0.071	6	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	21	6	10	14	20
Ions							
Sodium	mg/L	-	10	6	3	9	13
Calcium	mg/L	-	22.1	6	20.5	23.8	24.9
Magnesium	mg/L	-	6.9	6	6.2	7.1	7.8
Chloride	mg/L	230, 860[3]	0.72	6	0.87	2.0	3.0
Sulphate	mg/L	100[4]	16.8	6	2.2	12.2	18.9
Total dissolved solids	mg/L	-	155	6	110	147	190
Total alkalinity	mg/L		88	6	73	91	110
Selected metals							
Total aluminum	mg/L	0.1	**0.466**	6	0.052	**0.266**	**0.735**
Dissolved aluminum	mg/L	0.1[2]	0.0138	6	<0.0002	0.0143	0.0255
Total arsenic	mg/L	0.005	0.0010	6	0.0006	0.0009	0.0011
Total boron	mg/L	1.2[5]	0.0494	6	0.0405	0.0559	0.0836
Total molybdenum	mg/L	0.073	0.00058	6	0.00057	0.00067	0.00082
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.0	6	<1.2	<1.2	<1.2
Total strontium	mg/L	-	0.118	6	0.094	0.108	0.137
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total iron	mg/L	0.3	**0.690**	6	0.260	**0.447**	**0.922**
Sulphide	mg/L	0.002[7]	**0.006**	6	**0.003**	**0.005**	**0.014**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.940**	6	0.50	0.62	0.90
Total phenols	mg/L	0.004	**0.025**	6	<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).

[8] Guideline is for Total Nitrogen.

Table 5.8-6 Concentrations of water quality measurement endpoints, upper Ells River (*baseline* station ELR-2A), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010 Value
Physical variables			
pH	pH units	6.5-9.0	8.2
Total suspended solids	mg/L	-[1]	5
Conductivity	µS/cm	-	206
Nutrients			
Total dissolved phosphorus	mg/L	0.05[2]	0.012
Total nitrogen*	mg/L	1.0	**2.311**
Nitrate+nitrite	mg/L	1.0	<0.071
Dissolved organic carbon	mg/L	-	20.4
Ions			
Sodium	mg/L	-	10.2
Calcium	mg/L	-	22.6
Magnesium	mg/L	-	6.88
Chloride	mg/L	230, 860[3]	0.65
Sulphate	mg/L	100[4]	16.6
Total dissolved solids	mg/L	-	158
Total alkalinity	mg/L		88
Selected metals			
Total aluminum	mg/L	0.1	**0.514**
Dissolved aluminum	mg/L	0.1[2]	0.0126
Total arsenic	mg/L	0.005	0.0010
Total boron	mg/L	1.2[5]	0.0485
Total molybdenum	mg/L	0.073	0.0005
Total mercury (ultra-trace)	ng/L	5, 13[6]	2
Total strontium	mg/L	-	0.118
Other variables that exceeded CCME/AENV guidelines in fall 2010			
Total iron	mg/L	0.3	**0.755**
Sulphide	mg/L	0.002[7]	**0.006**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**2.24**
Total phenols	mg/L	0.004	**0.011**

ELR-2A was a new station in 2010.

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 5.8-4 Piper diagram of fall ion concentrations in the Ells River watershed.

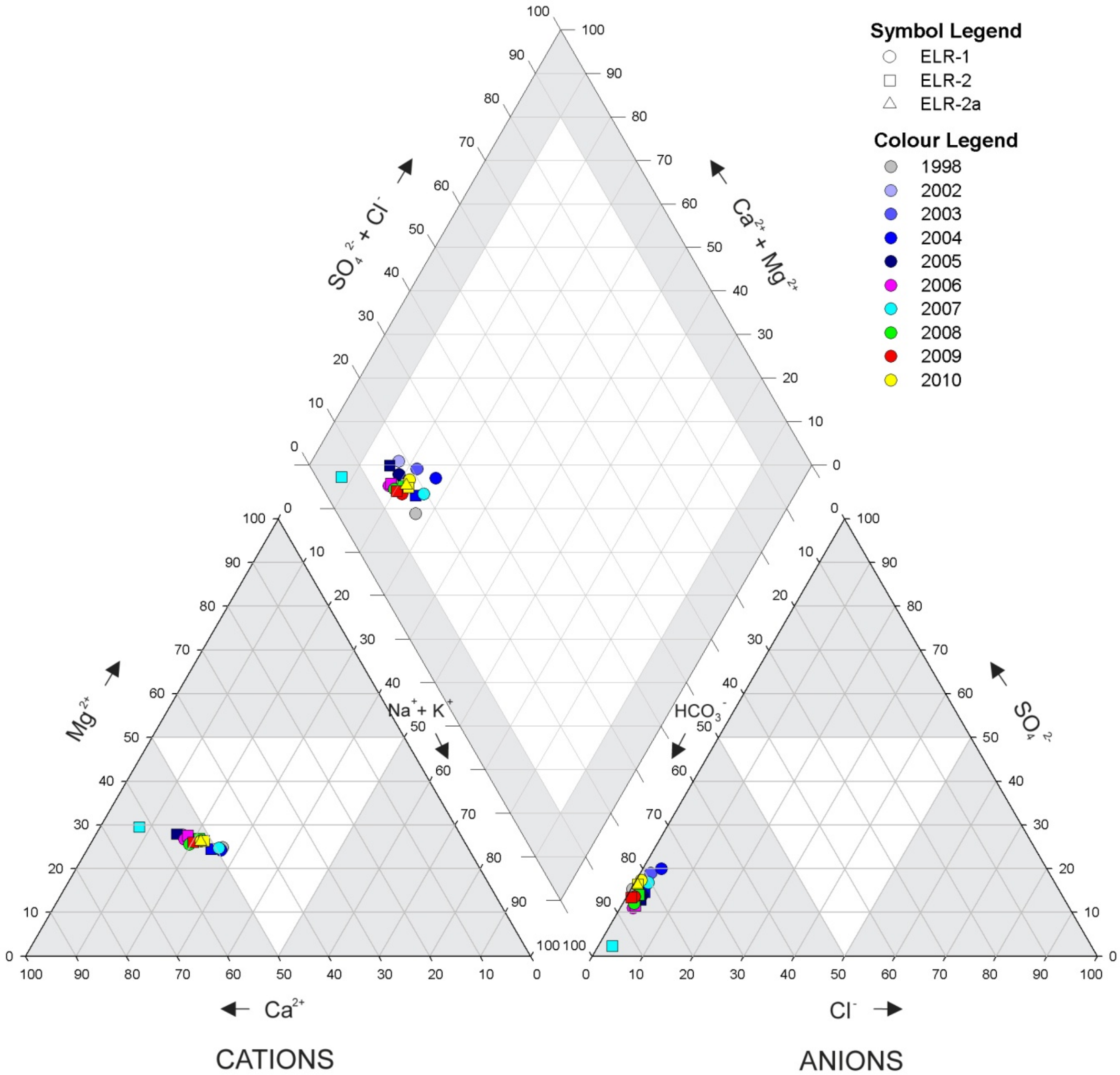
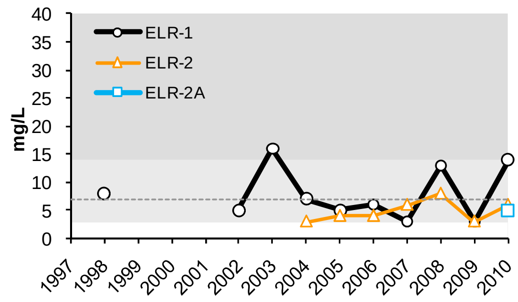
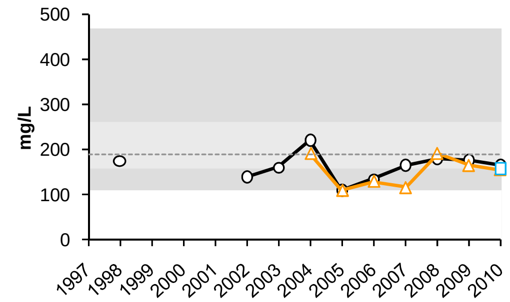


Figure 5.8-5 Selected water quality measurement endpoints in the Ells River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

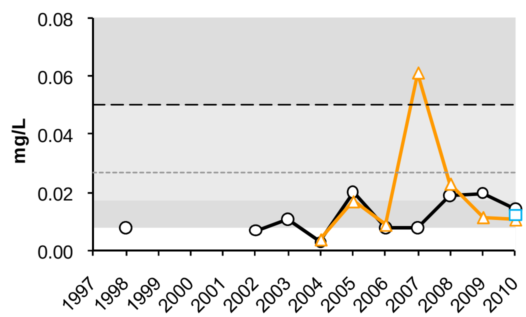
Total Suspended Solids (TSS)



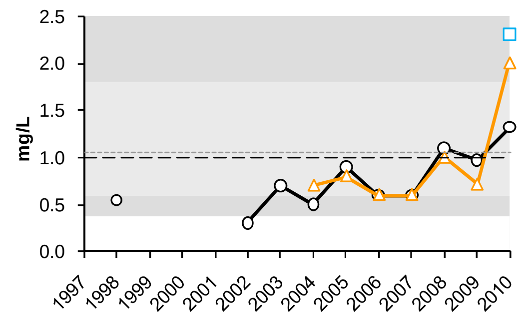
Total Dissolved Solids (TDS)



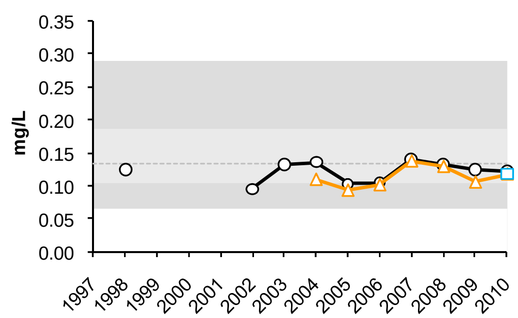
Dissolved Phosphorus



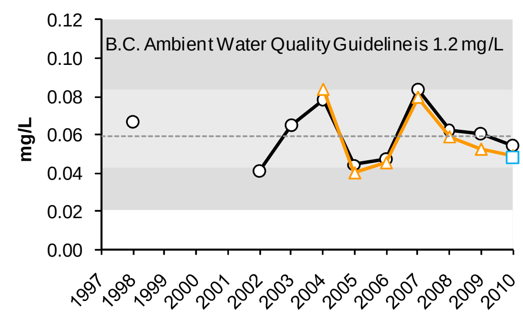
Total Nitrogen



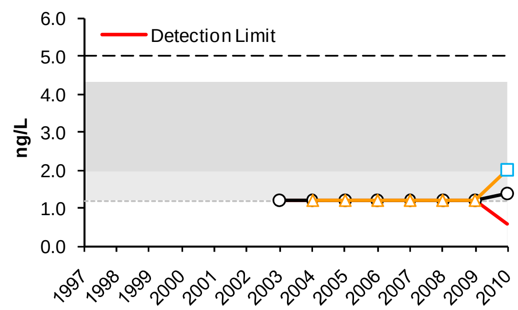
Total Strontium



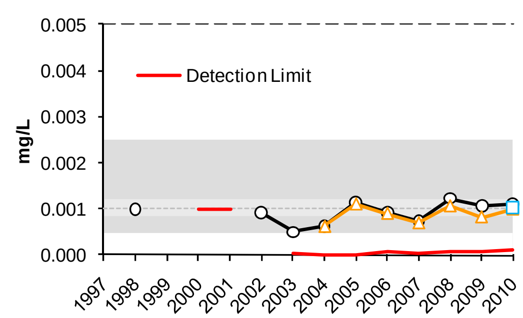
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic

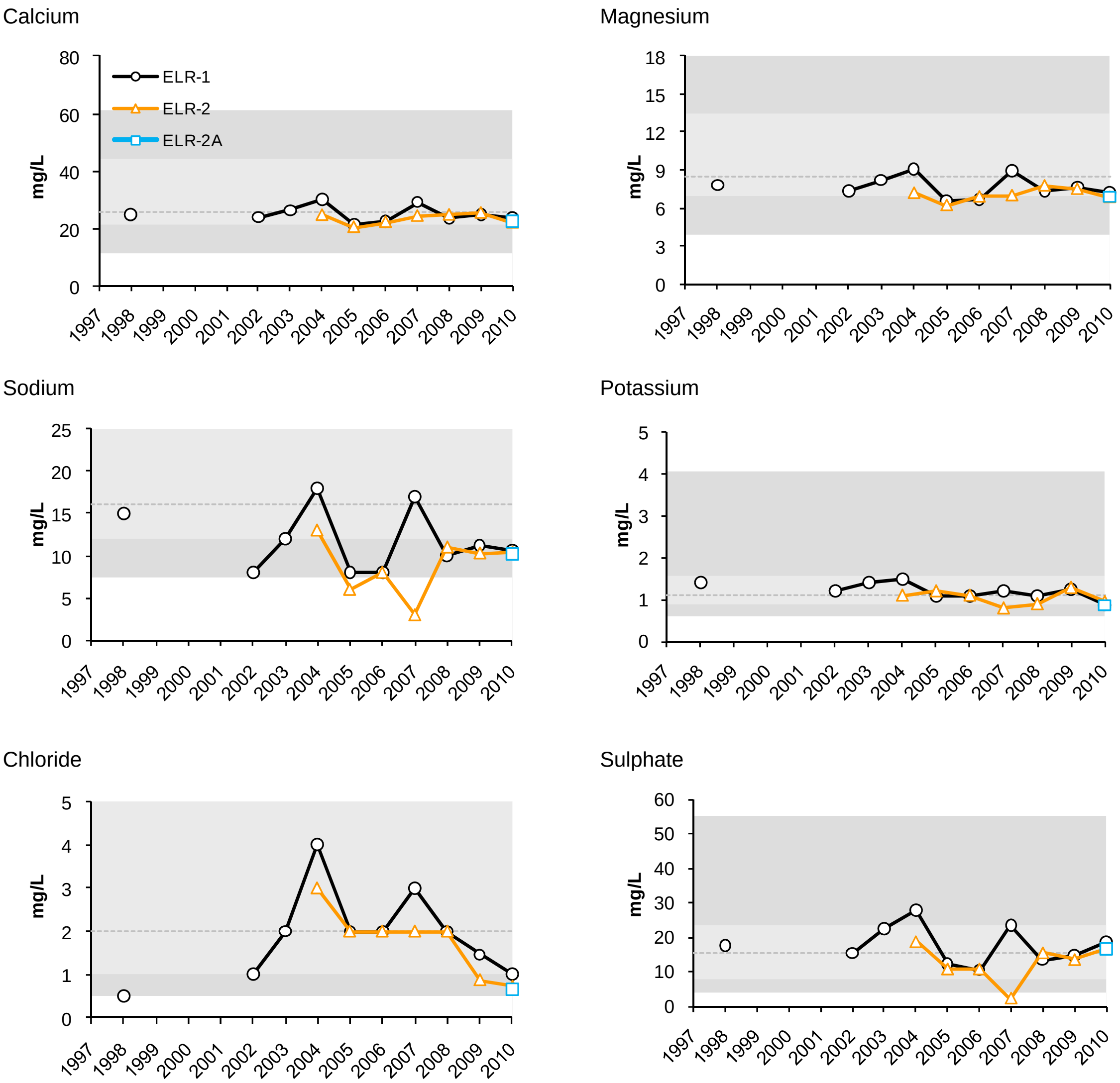


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.8-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.8-7 Average habitat characteristics of benthic invertebrate sampling locations in the Ells River.

Variable	Units	ELR-D1 Lower *Test* Reach of Ells River	ELR-E2A Upper *Baseline* Reach of Ells River
Sample date	-	Sept. 14, 2010	Sept. 12, 2010
Habitat	-	Depositional	Erosional
Water depth	m	0.4	0.3
Current velocity	m/s	0.35	1.1
Field Water Quality			
Dissolved oxygen	mg/L	10.4	9.9
Conductivity	µS/cm	188	180
pH	pH units	8.2	8.2
Water temperature	°C	10.2	11.7
Sediment Composition			
Sand/Silt/Clay	%		0
Small Gravel	%		0
Large Gravel	%		33.5
Small Cobble	%		27
Large Cobble	%		27
Boulder	%		12.5
Bedrock	%		0
Sand	%	69	
Silt	%	24	
Clay	%	7	
Total Organic Carbon	%	3	

Figure 5.8-6 Periphyton chlorophyll *a* biomass in *baseline* reach ELR-E2A of the Ells River.

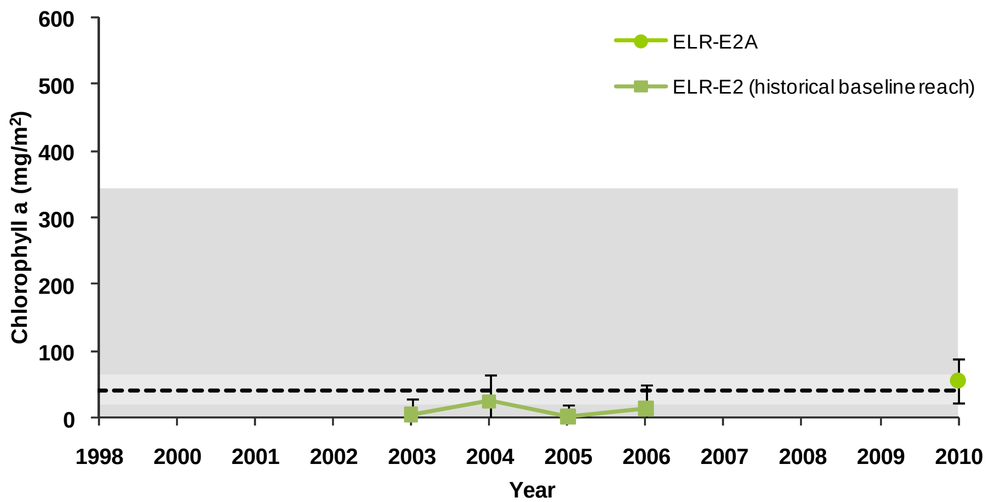


Table 5.8-8 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in *test* reach ELR-D1 and *baseline* reaches ELR-E2 and ELR-E2A.

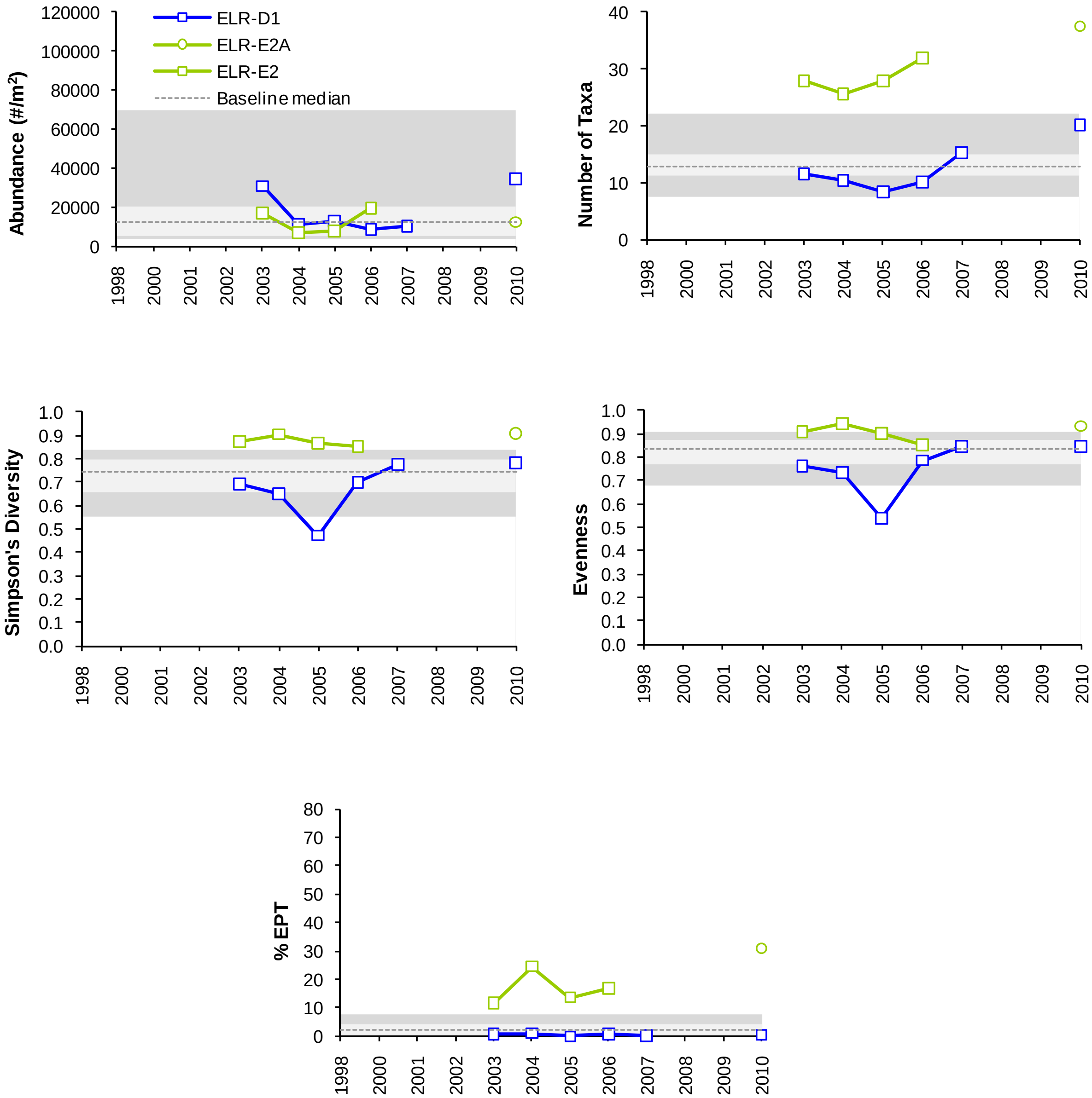
Taxon	Percent Major Taxa Enumerated in Each Year										
	Reach ELR-D1						Reach ELR-E2				Reach ELR-E2A
	2003	2004	2005	2006	2007	2010	2003	2004	2005	2006	2010
Anisoptera	<1	<1	<1	<1	<1	<1	<1	2	<1	<1	<1
Athericidae			<1				<1	<1		<1	<1
Bivalvia	<1	<1			<1	<1	<1	1	<1		<1
Ceratopogonidae	3	5	1	5	7	3	1	2	<1	2	1
Chironomidae	19	32	17	56	52	45	6	49	35	40	43
Coleoptera		<1			<1	<1		<1	<1	0.3	<1
Copepoda	<1				<1	1		<1		2	<1
Empididae	<1	<1	<1	2	1	1	2	3	1	1	1
Enchytraeidae		<1				<1	1	1	<1	<1	1
Ephemeroptera	<1	<1	<1	1	1	<1	7	15	7	1	18
Gastropoda	<1	<1			1	<1	1	<1	<1	<1	<1
Heteroptera	<1										
Hydracarina	<1	<1		1	1	1	11	8	19	12	9
Lepidoptera											
Megaloptera											
Naididae	24	2	17	4	2	11	13	5	28	21	10
Nematoda	<1	2	<1	3	1	1	1	4	<1	2	2
Ostracoda		<1	5		18	6	<1	<1	<1	1	1
Plecoptera				<1		<1	1	6	3	<1	2
Simuliidae			2		1	1	<1	<1	1	1	1
Tabanidae	<1	1	<1	<1		<1	<1		<1		<1
Tipulidae		<1					<1		<1	0.1	<1
Trichoptera	<1	<1			<1	<1	2	4	2	3	10
Tubificidae	52	55	57	28	18	29	<1	<1	1	1	<1
Zygoptera		<1				<1				<1	
Benthic Invertebrate Community Measurement Endpoints											
Total Abundance (No./m^2)	30,917	11,129	12,939	8,731	10,405	34,606	17,207	6,779	7,592	19,659	12,286
Richness	12	10	9	10	15	20.1	28	26	28	32	37.6
Simpson's Diversity	0.69	0.65	0.47	0.70	0.77	0.79	0.87	0.91	0.87	0.85	0.91
Evenness	0.76	0.73	0.54	0.79	0.85	0.85	0.91	0.94	0.90	0.86	0.93
% EPT	1	1	0	1	<1	<1	12	25	14	17	30

Table 5.8-9 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in *test* reach ELR-D1.

Variable	P-value	Variance Explained (%)	Nature of Changes
	Time Trend	Time Trend	
Abundance	0.643	4	No change
Richness	**0.015**	44	Increasing over time
Simpson's Diversity	**0.041**	30	Increasing over time
Evenness	0.079	23	No change
EPT	0.728	3	No change
CA Axis 1	0.132	13	No change
CA Axis 2	0.223	11	No change

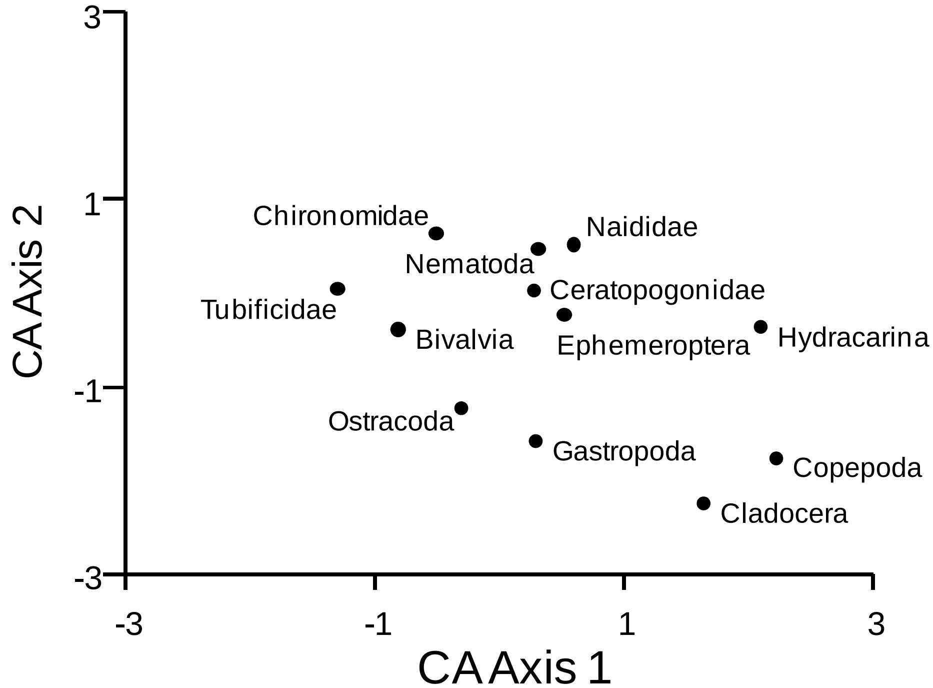
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

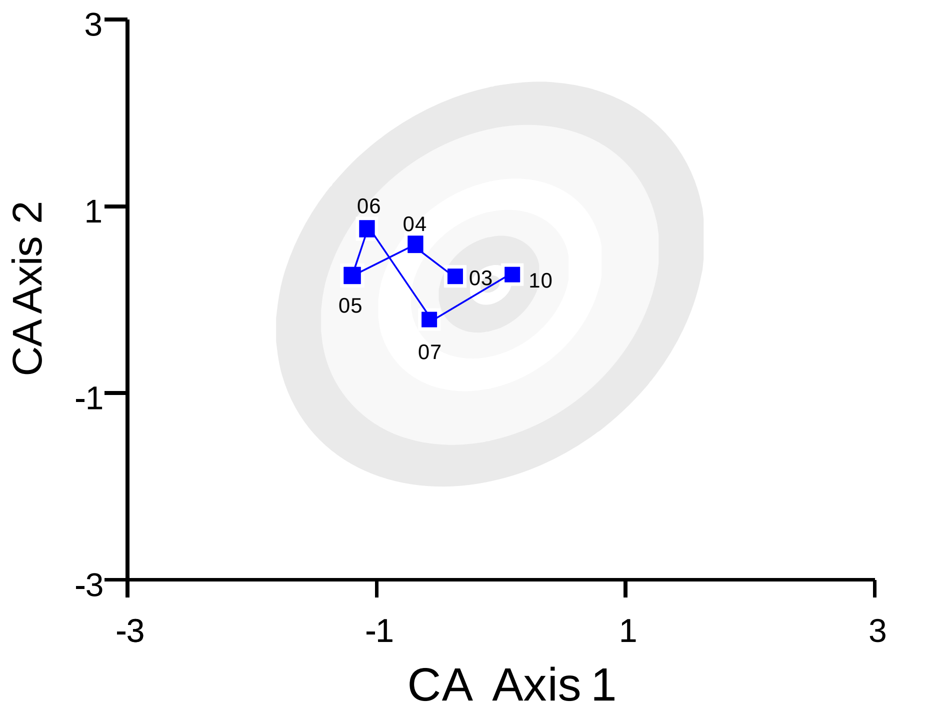
Figure 5.8-7 Variation in benthic invertebrate community measurement endpoints in the Ells River.



Note: shading indicates normal range limits for each measurement endpoint based on the distribution of annual means in *baseline* reaches.

Figure 5.8-8 Ordination (Correspondence Analysis) of benthic invertebrate communities in *test* reach ELR-D1.





Note: lower panel is the scatterplot of sample scores while the upper panel is the scatterplot of taxa scores. The ellipse in the lower panel is for the *baseline* data.

Table 5.8-10 Concentrations of selected sediment quality measurement endpoints, Ells River (*test* station ELR-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1998-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	4.4	7	3	7	26
Silt	%	-	20.9	7	3	12	51
Sand	%	-	74.7	7	23	81	94
Total organic carbon	%	-	2.8	7	0.4	1.0	2.8
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]	89	4	73	**230**	**320**
Fraction 3 (C16-C34)	mg/kg	300[1]	**970**	4	**890**	**1900**	**3000**
Fraction 4 (C34-C50)	mg/kg	2800[1]	640	4	510	1045	1600
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0044	7	0.0009	0.0036	0.0094
Retene	mg/kg	-	0.195	6	0.067	0.201	0.293
Total dibenzothiophenes	mg/kg	-	3.266	7	1.278	5.427	9.885
Total PAHs	mg/kg	-	11.18	7	4.809	16.156	25.096
Total Parent PAHs	mg/kg	-	0.234	7	0.218	0.391	0.571
Total Alkylated PAHs	mg/kg	-	10.95	7	4.461	15.765	24.525
Predicted PAH toxicity[3]	H.I.	-	1.951	7	1.179	1.512	2.506
Metals that exceed CCME guidelines in 2010							
Arsenic	mg/kg	5.9	6.46				
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.6	4	5.0	6.7	7.4
Chironomus growth - 10d	mg/organism	-	2.322	4	0.720	1.552	2.800
Hyalella survival - 14d	# surviving	-	8.4	4	8.0	8.7	10.0
Hyalella growth - 14d	mg/organism	-	0.214	4	0.116	0.128	1.600

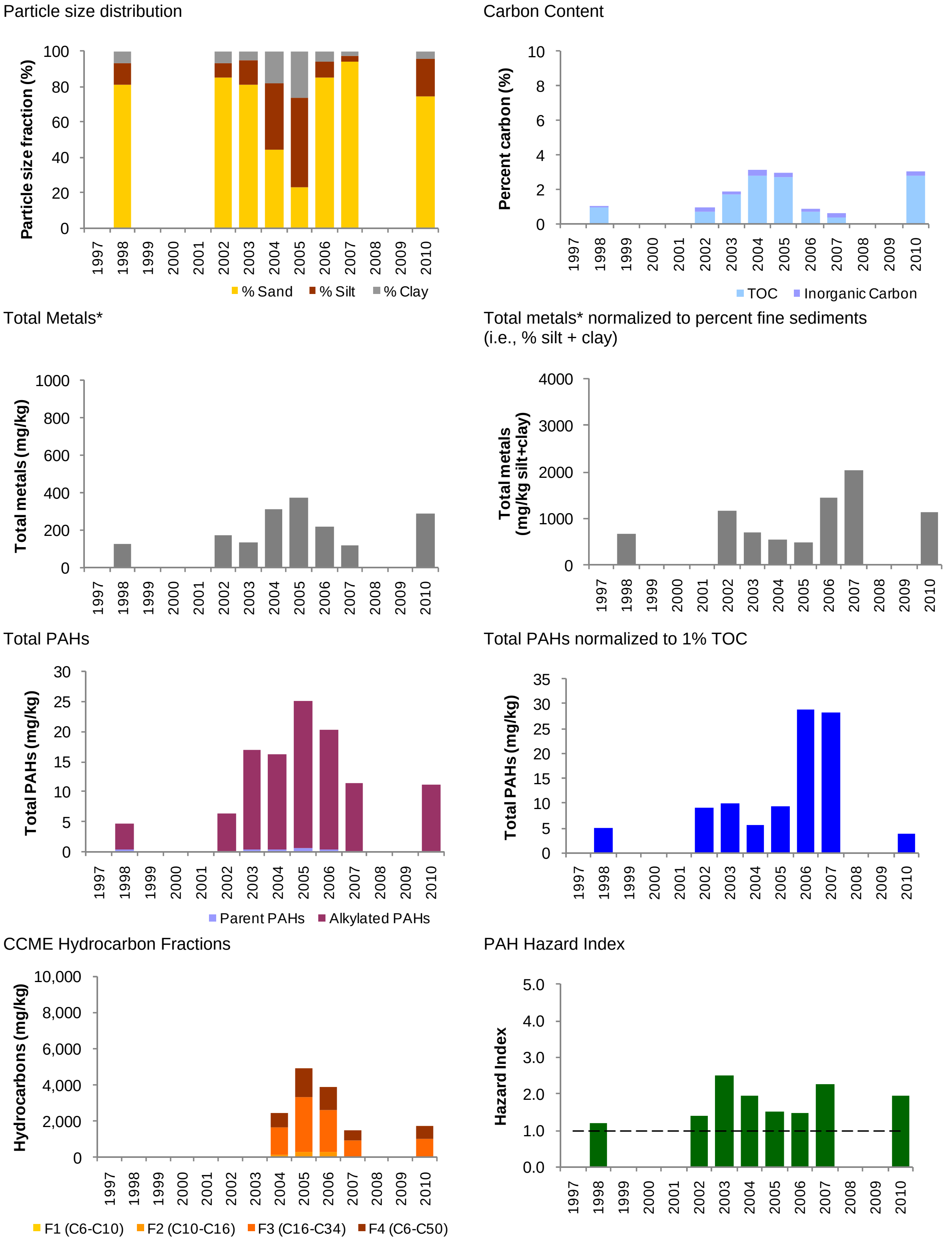
Values in **bold** indicate concentrations exceeding guidelines.

[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.

Figure 5.8-9 Variation in sediment quality measurement endpoints in the Ells River, *test* station ELR-D1.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

5.9 CLEARWATER-CHRISTINA RIVER WATERSHEDS

Table 5.9-1 Summary of results for the Clearwater-Christina River watersheds.

Clearwater-Christina River Watershed	Summary of 2010 Conditions			
	Clearwater River		*Christina River*	
Climate and Hydrology				
Criteria				**Christina River** at the mouth (estimated)
Mean open-water season discharge				○
Mean winter discharge				○
Annual maximum daily discharge				○
Minimum open-water season discharge				○
Water Quality				
Criteria	**CLR-1** upstream of Fort McMurray	**CLR-2** upstream of Christina River	**CHR-1** at the mouth	**CHR-2** upstream of Janvier
Water Quality	○	○	○	○
Benthic Invertebrate Communities and Sediment Quality				
No Benthic Invertebrate Communities and Sediment Quality component activities conducted in 2010				
Fish Populations				
No Fish Populations component fish tissue activities conducted in 2010				

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; see Section 3.2.2.3 for a detailed description of the classification methodology.

Figure 5.9-1 Clearwater-Christina River watersheds.

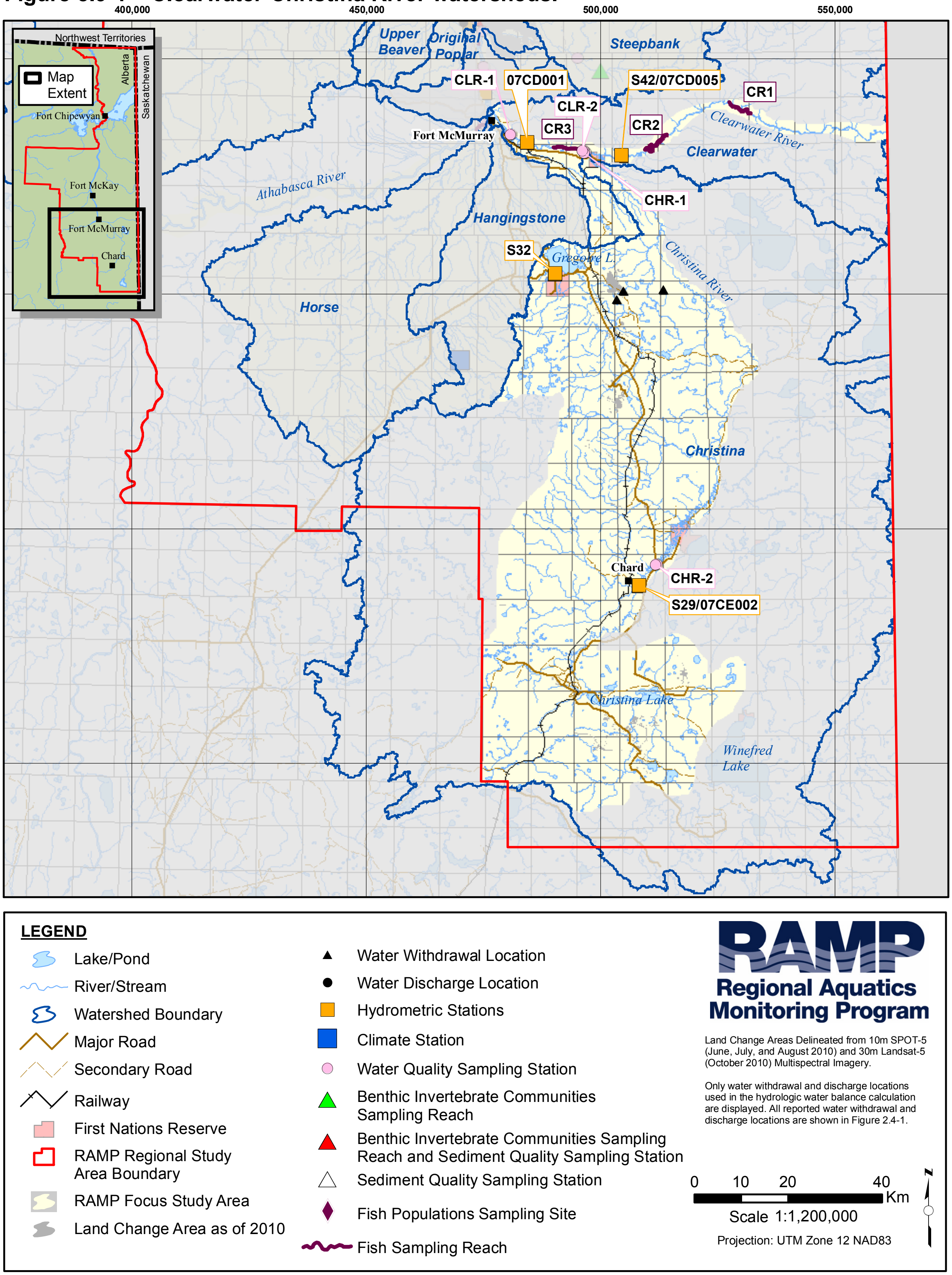


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Figure 5.9-2 Representative monitoring stations of the Clearwater-Christina River watersheds, fall 2010.

Water Quality Station CHR-1 (Christina River): Right Downstream Bank

Water Quality Station CLR-1 (Clearwater River): Right Downstream Bank

Water Quality Station CHR-2 (Christina River): Right Downstream Bank

Water Quality Station CLR-2 (Clearwater River): Centre of Channel, facing downstream

5.9.1 Summary of 2010 Conditions

As of 2010, approximately 0.4% (5,277 ha) of the Christina River watershed had undergone land change from focal projects and other oil sands developments (Table 2.5-2). 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 MEG Energy and Devon Energy projects near Christina Lake is designated as *test*.

2. The Clearwater River downstream of the confluence with the Christina River is designated as *test*.

3. The Clearwater River upstream of the confluence with the Christina River is designated as *baseline*.

The Climate and Hydrology, Water Quality, and Fish Populations components of RAMP conducted monitoring activities in the Clearwater-Christina River system in 2010.

Table 5.9-1 is a summary of the 2010 assessment of the Clearwater-Christina River system, while Figure 5.9-1 denotes the location of the monitoring stations for each RAMP component, reported focal project water withdrawal and discharge locations and the areas with land change as of 2010. Figure 5.9-2 contains fall 2010 photos of the water quality monitoring stations in the watersheds.

Hydrology The calculated mean open-water period (May-October) discharge, annual maximum daily discharge and open-water minimum discharge at the mouth of the Christina River are 0.02% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Water Quality In fall 2010, water quality at stations on the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2) and stations on the Christina River (*test* station CHR-1 and *test* station CHR-2) showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of several water quality measurement endpoints were outside the range of historical concentrations in fall 2010; however, these differences generally were consistent with higher river discharges at the time of sampling and may have been the result of historically-high concentrations of suspended materials and some metals known to occur mainly in particulate form, as well as historically-low concentrations of some ions associated with groundwater inputs.

Fish Populations Species richness in 2010 was lower in spring relative to the historical average (2003 to 2009) but within the historical range; lower in summer compared to 2009 when a summer inventory was first conducted; and higher in fall relative to the historical average. Relative abundance of each species was variable over time with no clear trends; the dominant species in each season has remained consistent over time. There has been significant variability in condition of large-bodied KIR species in the Clearwater River over time with no clear increasing or decreasing trends that would indicate a change in the health of fish in the river. Condition can not necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region.

5.9.2 Hydrologic Conditions: 2010 Water Year

Mouth of Christina River Hydrometric data have been estimated for the mouth of the Christina River from 2008 to 2010 by calculating the difference between the measured flow at WSC Station 07CD005, Clearwater River above Christina River and WSC Station 07CD001, Clearwater River above Draper.

The 2010 water year (WY) open-water period (May to October) runoff volume was estimated to be 1,111 million m^3. This value is 17% higher than the historical mean open-water runoff volume calculated from 40 years of available record. Estimated flows in March were above the upper quartile of historical values (Figure 5.9-3) and increased during the freshet in April to a peak of 137 m^3/s on April 20. The maximum daily flow occurred on June 9 and was estimated at 139 m^3/s, which is 14% lower than the corresponding mean historical value. The estimated flows from late June until late August were similar to historical median values. Rainfall during late August and early September resulted in increased flow to an estimated peak of 94 m^3/s on September 11 and 12. Flows decreased to the end of the 2010 WY. The estimated minimum open-water daily flow of 28.5 m^3/s on October 31 was 73% higher than the corresponding mean historical value.

Differences between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph
The estimated water balance for the mouth of the Christina River is presented for two different cases: (i) only focal projects in the Christina River watershed; and (ii) focal projects plus other oil sands developments in the Christina River watershed (Table 5.9-2).

Case 1 – Only focal projects in the Christina River watershed:

1. The closed-circuited land area from focal projects as of 2010 in the Christina River watershed is estimated to be 3.1 km^2 (Table 2.5-1). The loss of flow to the Christina River that would have otherwise occurred from this land area is estimated at 0.32 million m^3.
2. As of 2010, the area of land change in the Christina River watershed from focal projects that was not closed-circuited is estimated to be 33.0 km^2 (Table 2.5-1). The increase in flow to the Christina River that would not have otherwise occurred from this land area is estimated at 0.67 million m^3.
3. From March 1 to October 31, Nexen withdrew 1,897 m^3 of water from various sources to support its industrial activities.

The estimated cumulative effect of land change is an increase of flow of 0.35 million m^3 to the Christina River. The resulting observed and estimated *baseline* hydrographs for this case are presented in Figure 5.9-3. The 2010 WY mean open-water period (May to October) discharge, annual maximum daily discharge and open-water minimum discharge are 0.03% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.9-3). This difference is classified as **Negligible-Low** (Table 5.9-1).

Case 2 – 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 2010 in the Christina River watershed is estimated to be 6.6 km^2 (Table 2.5-1). The loss of flow to the Christina River that would have otherwise occurred from this land area is estimated at 0.67 million m^3.
2. As of 2010, the area of land change in the Christina River watershed from focal projects plus other oil sands developments that was not closed-circuited is estimated to be 46.2 km^2 (Table 2.5-1). The increase in flow to the Christina River that would not have otherwise occurred from this land area is estimated at 0.94 million m^3.
3. The water withdrawal by Nexen of 1,897 m^3 described above is applied to this case as well.

The estimated cumulative effect of land change for this case is an increase in flow of 0.27 million m^3 to the Christina River. The 2010 WY calculated mean open-water period (May-October) discharge, annual maximum daily discharge, and open-water minimum discharge at the mouth of the Christina River are 0.02% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Figure 5.9-3). This difference is also classified as **Negligible-Low** and is within 0.01% of Case 1 (Table 5.9-1)**.**

5.9.3 Water Quality

In fall 2010, water quality samples were taken from:

- the Clearwater River upstream of Fort McMurray (*test* station CLR-1, sampled since 2001);

- the Clearwater River upstream of the confluence with the Christina River (*baseline* station CLR-2, sampled since 2001);
- the Christina River near its mouth (*test* station CHR-1, sampled since 2002); and
- the Christina River upstream of Janvier (*test* station CHR-2, sampled since 2002, designated as *test* in 2010).

Temporal Trends The following significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- An increasing concentration of total nitrogen and a decreasing concentration in sulphate at *test* station CLR-1 (2001 to 2010);
- A decreasing concentration of potassium at *test* station CHR-1 (2002 to 2010); and
- A decreasing concentration of magnesium at *baseline* station CHR-2 (2002 to 2010).

2010 Results Relative to Historical Concentrations River discharges in fall 2010 that were greater than the upper quartile (Figure 5.9-3) may have contributed to the concentrations of water quality measurement endpoints falling outside historical ranges (Figure 5.9-5). These included:

- total suspended solids, total nitrogen, dissolved organic carbon, dissolved aluminum, and total mercury with concentrations that exceeded their previously-measured maximum concentrations at *test* station CLR-1 (Table 5.9-4);
- sodium, chloride, total boron, total molybdenum, and total strontium with concentrations that were below their previously-measured minimum concentrations at *test* station CLR-1 (Table 5.9-4);
- total nitrogen, total aluminum, total arsenic, total mercury, total iron, and total chromium with concentrations that exceeded their previously-measured maximum concentrations at *baseline* station CLR-2 (Table 5.9-5);
- total suspended solids, total aluminum, dissolved aluminum, total mercury, total iron, total chromium, and total copper with concentrations that exceeded their previously-measured maximum concentrations, and dissolved organic carbon and total arsenic with concentrations that were equal to their previously-measured maximum concentrations at *test* station CHR-1 (Table 5.9-6);
- conductivity, sodium, calcium, magnesium, chloride, and total alkalinity with concentrations that were below their previously-measured minimum concentrations at *test* station CHR-1 (Table 5.9-6);
- total suspended solids, total aluminum, and total mercury with concentrations that exceeded their previously-measured maximum concentrations at *test* station CHR-2 (Table 5.9-7); and
- conductivity, sodium, calcium, magnesium, sulphate, total alkalinity, total molybdenum, and total strontium with concentrations that were below their previously-measured minimum concentrations at *test* station CHR-2 (Table 5.9-7).

Ion Balance The ionic composition of water at all other stations in the Clearwater-Christina watersheds in fall 2010 exhibited a shift toward lower proportions of sodium and chloride and higher proportions of calcium and bicarbonate (Figure 5.9-4). This could be due to higher surface water runoff in September 2010 from heavy rain causing a decrease in the influence of saline seeps known to occur in this watershed.

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of total aluminum at all stations and total nitrogen at *test* stations CLR-1, CHR-1, and CHR-2 exceeded relevant water quality guidelines. The concentration of total mercury at *test* station CHR-1 exceeded the AENV guideline for chronic exposure but was below the guideline for acute exposure (5 ng/L) (Table 5.9-4 to Table 5.9-7).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in the Clearwater-Christina River watersheds in fall 2010 (Table 5.9-4 to Table 5.9-7):

- sulphide, total iron, total phenols, and total chromium at *test* station CLR-1;
- sulphide, total phosphorus, dissolved iron, total iron, total phenols, and total chromium at *baseline* station CLR-2;
- sulphide, total phosphorus, dissolved iron, total iron, total Kjeldahl nitrogen, total copper, total phenols, and total chromium at *test* station CHR-1; and
- sulphide, total phosphorus, dissolved iron, total iron, total phenols, and total Kjeldahl nitrogen at *test* station CHR-2.

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, the increased river discharges may have contributed to concentrations of water quality measurement endpoints being outside the range of regional *baseline* concentrations. Concentrations of total suspended solids at *test* station CHR-1 and *test* station CLR-1 and total mercury at *test* station CHR-1 were greater than the 95th percentile of their regional *baseline* concentrations (Figure 5.9-5). Concentrations of water quality measurement endpoints below the 5th percentile of their regional *baseline* concentrations in fall 2010 were: total boron at *test* station CLR-1; magnesium and potassium at *baseline* station CLR-2; potassium at *test* station CHR-1; and sodium, potassium, and sulphate at *test* station CHR-2 (Figure 5.9-5).

Water Quality Index The WQI values for water sampled at all water quality monitoring stations on the Clearwater River (i.e., *test* station CLR-1: 98.7; *baseline* station CLR-2: 93.3) and the Christina River (i.e., *test* station CHR-1: 88.8; *test* station CHR-2: 100) for fall 2010 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.9-9).

Classification of Results In fall 2010, water quality at stations on the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2) and stations on the Christina River (*test* station CHR-1 and *test* station CHR-2) showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of several water quality measurement endpoints were outside the range of historical concentrations in fall 2010; however, these differences generally were consistent with higher river discharges at the time of sampling and may have been the result of historically-high concentrations of suspended materials and some metals known to occur mainly in particulate form, as well as historically-low concentrations of some ions associated with groundwater inputs.

5.9.4 Benthic Invertebrate Communities and Sediment Quality

There were no Benthic Invertebrate Communities and Sediment Quality component activities conducted in the Clearwater-Christina River watersheds in 2010.

5.9.5 Fish Populations

In 2010, fish populations monitoring in the Clearwater-Christina River watersheds consisted of a spring, summer, and fall fish inventory on the Clearwater River at *baseline* reaches CR1 and CR2, sampled in the spring and fall since 2003 and in the summer since 2009, and *test* reach CR3, sampled in the spring and fall since 2003, with the exception of 2004 and 2005, and in the summer since 2009.

5.9.5.1 Temporal and Spatial Comparisons

Temporal comparisons to assess changes over time and by season, as well as spatial comparisons among areas of the river, were conducted for the following measurement endpoints: species composition; species richness; catch per unit effort; length-frequency distributions; and condition factor.

Species Composition A total of 1,856 fish were captured in the spring, summer and fall 2010 at the three sampling reaches of the Clearwater River (Table 5.9-10), of which:

- 331 fish comprised of 13 species were captured in the spring;
- 797 fish comprised of 15 species were captured in the summer; and
- 728 fish comprised of 14 species were captured in the fall.

A total of 18 species were captured during the 2010 Clearwater River fish inventory across all three seasons. White sucker was the dominant large-bodied species captured in spring (45%) and fall (29%) and longnose sucker was the dominant species captured in summer (29.9%). The second-most dominant large-bodied species in spring, summer and fall were longnose sucker (16.9%), white sucker (24.8%) and northern pike (7.7%), respectively. Spottail shiner was the dominant small-bodied species in spring (3.6%) and trout-perch was the dominant species in the summer (8.3%) and fall (18.4%). White sucker was the dominant species caught in *baseline* and *test* reaches in all seasons with the exception of *test* reach CR3 in summer where longnose sucker was the dominant species caught (Table 5.9-11).

Species Richness Species richness was compared between *baseline* reaches CR1 and CR2 and *test* reach CR3. The number of species captured in *test* reach CR3 was the same as the number of species captured in *baseline* reaches CR1 and CR2 in spring and fall, while two fewer species were captured in summer in *test* reach CR3 compared to the number of species captured in *baseline* reaches CR1 and CR2 (Table 5.9-11).

Species richness in spring, summer, and fall from 2003 to 2010 is provided in Figure 5.9-6. Species richness was lower in fall and summer 2010 and higher in spring 2010 compared to 2009 (Figure 5.9-6). Species richness in spring 2010 was lower than all years of the Clearwater inventory with the exception of 2005 and 2009, while species richness in fall 2010 was similar to species richness measured since 2006 (Figure 5.9-6).

Catch Per Unit Effort The total catch per unit effort (CPUE) for all species combined and for each large-bodied KIR species across sampling years and seasons is presented in Figure 5.9-7. Catch per unit effort for all species combined was lower in spring 2010 compared to 2008 and 2009. This may be related to river discharges; water flows in the Clearwater River in late May 2010 were below the upper quartile of historical flows (Figure 5.9-3) while in previous years, spring flows exceeded the upper quartile of historical flows (RAMP 2010). The lower water levels made it difficult to access some areas of the river such as vegetated shorelines where some species (i.e., northern pike) inhabit. Discharge in the Clearwater River was higher than the upper quartile in late September, which coincides with higher fall CPUE compared to 2009 (Figure 5.9-7). Higher fall 2009 flows may have meant more habitat in the river that was accessible for fishing. Generally, the CPUE was highest for white sucker and walleye in spring, white sucker and longnose sucker in summer, and white sucker and trout-perch in fall. The species with the highest CPUE have remained consistent in each season throughout the sampling record (Figure 5.9-7).

The comparison of catch per unit effort (CPUE) for all species combined for each season between the *baseline* and *test* reaches from 2003 to 2010 is presented in Figure 5.9-8. Generally, CPUE has been higher in *test* reach CR3 relative to *baseline* reaches CR1 and CR2 throughout the sampling record. This may be due to greater availability of suitable habitat (i.e., harder substrate) for species such as sculpins and sucker, compared to the upstream areas of the river with softer substrates and more vegetation. CPUE was lower in spring and higher in summer and fall 2010 compared to fall 2009 in both *test* and *baseline* reaches. Again, this may be related to the differences in river discharge between 2009 (RAMP 2010) and 2010 (Figure 5.9-3).

CPUE is higher in *test* reach CR-3 compared to *baseline* reaches CR1 and CR2 with the exception of northern pike in all seasons and white sucker in summer (Figure 5.9-9). The lower CPUE for northern pike in *test* reach CR3 may be due to limited suitable habitat for this species in this reach. Northern pike prefer vegetative areas to provide cover, with soft-bottom substrate (Paetz and Nelson 1970), which is more characteristic of the upper portion of the Clearwater River compared to the river downstream of the Christina River confluence.

Length-Frequency Distributions The: (i) mean length-frequency distribution for large-bodied KIR fish species from 2003 to 2009 compared to the length-frequency distribution in 2010 for all seasons combined; and (ii) the length-frequency distribution for each species in each season for 2010 are presented in Figure 5.9-10 to Figure 5.9-14. The species-specific results are as follows:

1. A greater proportion of goldeye caught in 2010 were from larger size classes compared to the historical length-frequency distribution (Figure 5.9-10). There was an increasing shift in dominant length class from spring to fall 2010. The co-dominant length classes for goldeye in 2010 are 376 to 400 mm (spring) and 401 to 425 mm (summer and fall), both comprising 40% of the total annual catch. This is similar to the dominant length class from 2003 to 2009, which was 376 to 400 mm.

2. The length-frequency for longnose sucker in 2010 was similar to the historical length-frequency distribution from 2003 to 2009 (Figure 5.9-11). The dominant length class of longnose sucker captured in 2010 was 151 to 200 mm (historical dominant class: 101 to 150 mm), comprising 27% of the total catch (Figure 5.9-11). There were a greater number of fish captured in the dominant length-class in spring relative to summer and fall; this may be due to a greater proportion of spawning individuals (i.e., adults) captured in spring compared to other seasons.

3. The length-frequency distribution of northern pike in 2010 was consistent with the historical length-frequency distribution from 2003 to 2009 (Figure 5.9-12). The co-dominant length classes for northern pike in 2010 were 501 to 550 mm and 551 to 600 mm, comprising 12% and 10% of the total catch, respectively. The dominant length class in spring-captured northern pike was 551 to 600 mm comprising 18% of the catch and 501 and 550 mm in fall, comprising 16% of the total catch.

4. The dominant length class of walleye in 2010 was 101 to 150 mm compared to the mean historical dominant class of 351 to 400 mm from 2003 to 2009 (Figure 5.9-13). The dominance of smaller length classes in 2010 was due to the increase in the catch of juvenile fish in summer and fall. Walleye from larger length classes (dominant length-class: 301 to 350 mm) were caught primarily in spring during the spawning period for this species, when more adults are occupying the river.

5. The dominant length class of white sucker in 2010 was 351 to 400 mm, comprising 22% of the total catch whereas the historical average co-dominant length class has varied between 101 to 150 mm, 351 to 400 mm, and 401 to 450 mm (Figure 5.9-14). The dominant length-class of white sucker in 2010 was 401 to 450 mm in spring and fall and 351 to 400 mm in summer, although a high proportion of white sucker in the 351 to 400 mm length-class were also captured in spring and fall.

Condition Factor The mean condition factor for each large-bodied KIR species across seasons from 2003 to 2010 is presented in Figure 5.9-15. An analysis of covariance (ANCOVA) was performed on condition of large-bodied KIR fish species captured in adequate sample sizes for statistical analyses (i.e., goldeye, longnose sucker, northern pike, walleye, and white sucker) for each season to determine if there are any differences between fish captured in 2010 and fish captured in previous years. The species-specific results are as follows:

1. Condition of spring-captured goldeye was significantly lower in 2010 compared to all previous sampling years ($p<0.01$). There were no significant differences among years in condition of goldeye in summer ($p=0.3$); sample sizes in fall were too small to perform statistical analyses.

2. There were no significant differences among years in the condition of longnose sucker captured in spring, summer and fall ($p>0.01$).

3. Condition of fall-captured northern pike was significantly higher in 2010 compared to condition of fall-captured northern pike in 2004 and 2008 ($p<0.01$). There were no significant differences in condition of northern pike among years in spring and summer ($p>0.01$).

4. With the exception of 2003, condition of spring-captured walleye was significantly lower in 2010 compared to all previous sampling years ($p<0.01$). Condition of fall-captured walleye was variable across years with significantly higher condition of walleye in 2010 compared to 2008 ($p=0.04$) and significantly lower condition of walleye in 2010 compared to 2006 ($p<0.01$). There was no significant difference in condition of walleye between summer 2009 and summer 2010 ($p>0.15$).

5. Condition of spring-captured white sucker was significantly lower in 2010 compared to 2004, 2007, and 2009 ($p<0.01$). Condition of fall-captured white

sucker was significantly higher in 2010 compared to 2008 ($p<0.01$). There was no significant difference in condition of white sucker between summer 2009 and summer 2010 ($p=0.23$).

5.9.5.2 External Health Assessment

Observed abnormalities were primarily associated with minor skin aberrations or wounds, scars, and fin erosion. In 2010, 35.5%, 12.8%, and 3.6% of fish captured in spring, summer, and fall, respectively, were found to have some type of external abnormality. The 2010 incidence of external abnormalities was higher in spring (13.7%) and summer (7.8%) than in spring and summer 2009, but lower than fall (6.3%) 2009 (RAMP 2010).

Twenty-six of 1,871 fish exhibited some form of external pathological abnormality such as parasites, growths, lesions (open sores) or body deformities (Figure 5.9-16). Northern pike, walleye, white sucker, and longnose sucker were the main species for which pathological abnormalities were recorded, mostly due to their higher catch numbers and relative abundance compared to other species in the river and the selectiveness of boat electrofishing for large-bodied species. A summary from 2003 to 2010 of the percentage of fish of each species exhibiting some form of external pathology is presented in Table 5.9-12. External pathology is primarily observed in northern pike compared to other species; however, the percent pathology in northern pike in 2010 (4.44%) was within the historical range (2.82% to 6.25%).

5.9.5.3 Summary

The Clearwater River fish inventory is a community-driven activity primarily suited for assessing general trends in species composition, abundance, and population variables (i.e., condition of fish and length-frequency distribution) for large-bodied KIR species rather than assessing detailed fish community structure. The type of gear used for the fish inventory is selective for large-bodied species and there is therefore an ability to provide a more detailed assessment of these species compared to small-bodied fish species in the Clearwater River.

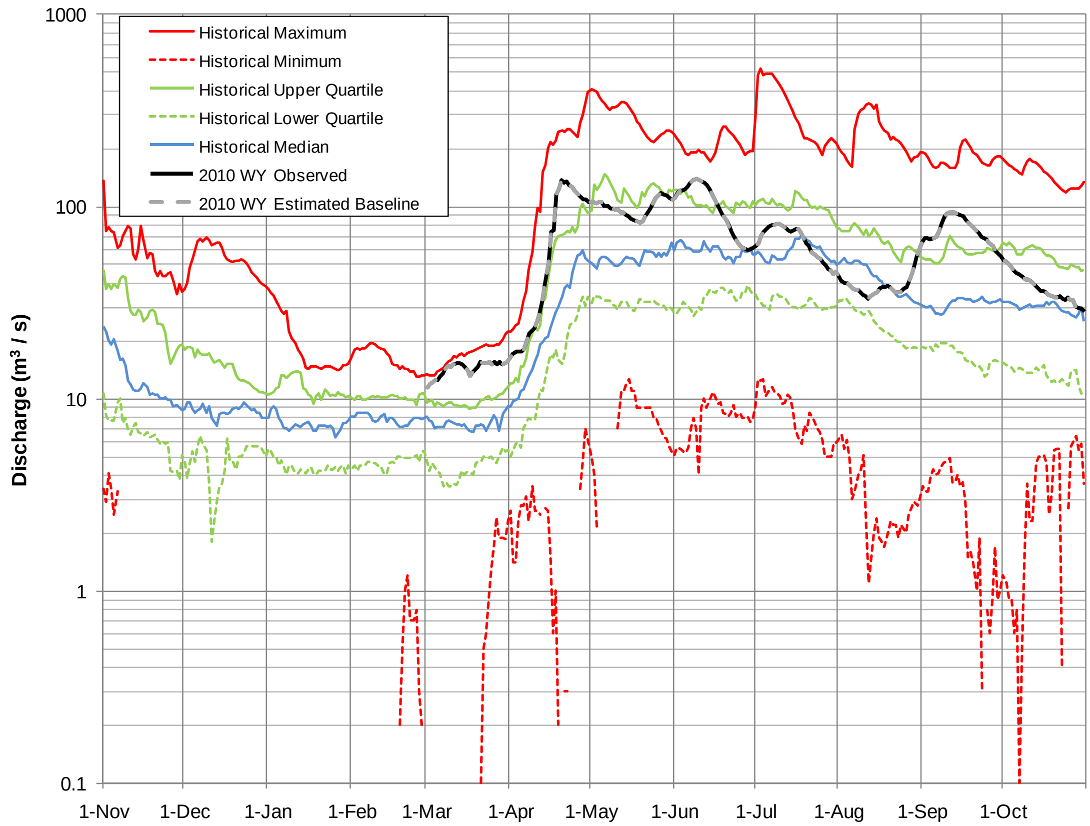
Species richness in 2010 was lower in spring relative to the historical average (2003 to 2009) but within the historical range; lower in summer compared to 2009 when a summer inventory was first conducted; and higher in fall relative to the historical average.

The 2010 Clearwater River inventory results suggest variable relative abundance of each species over time with no clear trends; the dominant species in each season has remained consistent over time.

There has been significant variability in condition of large-bodied KIR species in the Clearwater River over time with no clear increasing or decreasing trends that would indicate a change in the health of fish in the river. Condition cannot necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region.

A second year of a summer inventory in the Clearwater River further increased the understanding of the presence of juvenile fish in the river, such as longnose sucker and goldeye, which may help to provide more information on recruitment trends in these populations.

Figure 5.9-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the mouth of the Christina River in the 2010 WY, compared to historical values.



Note: The 2010 WY estimated *test* hydrograph is calculated as the difference between provisional 2010 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 43-years of record (1967-2009) from March to October, and 21-years of record for other months (1976-1996). Due to this method used, some minimum values were zero or negative and do not appear on this graph.

Note: For clarity, the estimated *baseline* hydrograph from focal projects in the Christina River watershed is shown in the figure; differences between this and the estimated *baseline* hydrograph from focal project plus other oil sands developments in the Christina River watershed are negligible.

Table 5.9-2 Estimated water balance at the mouth of the Christina River, 2010 WY.

Component	Volume (million m^3) Focal Projects	Volume (million m^3) Focal Projects Plus Other Oil Sands Developments	Basis and Data Source
Observed *test* hydrograph (total discharge)	**1,330.6**	**1,330.6**	**Calculated as the difference between provisional 2010 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	-0.320	-0.670	Estimated 3.1 km^2 and 6.6 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 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.674	+0.943	Estimated 33.0 km^2 and 46.2 km^2 of the Christina River watershed with land change from focal projects and from focal projects plus other oil sands developments as of 2010, respectively that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Christina River watershed from projects	-0.002	-0.002	1,897 m^3 of water withdrawn by Nexen from surface lakes and a borrow pit (daily values provided)
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 by figures contained in this table.
Estimated *baseline* hydrograph (total discharge)	**1,330.2**	**1,330.3**	**Estimated *baseline* discharge for the mouth of the Christina River**
Incremental flow (change in total annual discharge)	+0.352	+0.271	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.03%**	**+0.02%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on flows estimated for the mouth of the Christina River, calculated as the difference of 2010 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).

Table 5.9-3 Calculated change in hydrologic measurement endpoints for the mouth of the Christina River, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	69.88	69.90	+0.03%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	138.66	138.70	+0.03%
Open-water season minimum daily discharge	28.49	28.50	+0.03%

Note: Based on flows estimated for the mouth of the Christina River, calculated as the difference of 2010 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 are negligible and do 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 (*test* station CLR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	9	7.5	8.0	8.2
Total Suspended Solids	mg/L	-[1]	64	9	3	15	38
Conductivity	µS/cm	-	180	9	177	230	291
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.02	9	0.012	0.022	0.044
Total nitrogen*	mg/L	1.0	1.72	9	0.30	0.60	0.99
Nitrate+Nitrite	mg/L	1.3	<0.071	9	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	19	9	8	10	16
Ions							
Sodium	mg/L	-	13	9	16	21	31
Calcium	mg/L	-	16.4	9	14.7	17.4	20.1
Magnesium	mg/L	-	5.61	9	4.98	5.70	6.50
Chloride	mg/L	230, 860[3]	13	9	17	25	43
Sulphate	mg/L	100[4]	4.0	9	1.4	5.7	7.7
Total Dissolved Solids	mg/L	-	148	9	60	150	200
Total Alkalinity	mg/L	-	64	9	56	66	74
Selected metals							
Total aluminum	mg/L	0.1	**0.83**	9	**0.14**	**0.58**	**1.46**
Dissolved aluminum	mg/L	0.1[2]	0.016	9	0.006	0.009	0.015
Total arsenic	mg/L	0.005	0.0006	9	0.0005	0.0008	0.0014
Total boron	mg/L	1.2[5]	0.0207	9	0.0275	0.0323	0.0548
Total molybdenum	mg/L	0.073	0.0001	9	0.0002	0.0002	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	3.1	7	<1.2	<1.2	1.5
Total strontium	mg/L	-	0.066	9	0.079	0.099	0.118
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.005**	9	**<0.003**	**0.004**	**0.009**
Total iron	mg/L	0.3	**1.16**	9	0.505	**1.24**	**2.43**
Total phenols	mg/L	0.004	**0.007**	9	<0.001	0.003	**0.009**
Total Chromium (Cr)	mg/L	0.001	**0.0011**	9	0.0003	0.0008	**0.0022**

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 (*baseline* station CLR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	7.9	9	7.2	7.9	8.0
Total Suspended Solids	mg/L	-[1]	22	9	7	14	36
Conductivity	µS/cm	-	158	9	138	202	249
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.019	9	0.010	0.020	0.026
Total nitrogen*	mg/L	1.0	**2.6**	9	0.3	0.5	**1.2**
Nitrate+Nitrite	mg/L	1.3	<0.071	9	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	13	9	6	8	24
Ions							
Sodium	mg/L	-	12.6	9	11.0	18.0	29.0
Calcium	mg/L	-	11.9	9	10.0	11.9	21.6
Magnesium	mg/L	-	4.2	9	3.4	4.2	7.0
Chloride	mg/L	230, 860[3]	16.2	9	16.0	28.0	43.0
Sulphate	mg/L	100[4]	3.7	9	<0.5	5.5	7.7
Total Dissolved Solids	mg/L	-	138	9	40	124	160
Total Alkalinity	mg/L	-	49	9	39	44	51
Selected metals							
Total aluminum	mg/L	0.1	**2.550**	9	**0.102**	**0.237**	**0.701**
Dissolved aluminum	mg/L	0.1[2]	0.0217	9	0.0048	0.0072	0.040
Total arsenic	mg/L	0.005	0.0012	9	0.0004	0.0005	<0.0010
Total boron	mg/L	1.2[5]	0.028	9	0.014	0.024	0.030
Total molybdenum	mg/L	0.073	0.000195	9	0.000095	0.000117	0.000200
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.1	7	<1.2	<1.2	1.2
Total strontium	mg/L	-	0.077	9	0.061	0.084	0.094
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0035**	9	**0.0022**	**0.005**	**0.013**
Total iron	mg/L	0.3	**2.42**	9	**0.545**	**0.79**	**2.07**
Dissolved iron	mg/L	0.3	**0.324**	9	0.162	0.222	**0.672**
Total Phenolics	mg/L	0.004	**0.006**	8	<0.001	0.002	**0.007**
Phosphorus, total	mg/L	0.05	**0.056**	8	0.032	0.0425	**0.074**
Total chromium	mg/L	0.001	**0.0029**	8	0.0003	0.0005	**0.0014**

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 (*test* station CHR-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.12	8	8.10	8.30	8.40
Total Suspended Solids	mg/L	-[1]	76	8	<3	22	49
Conductivity	µS/cm	-	210	8	244	293	375
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.023	8	0.018	0.024	**0.054**
Total nitrogen*	mg/L	1.0	**1.74**	8	0.60	**1.05**	**1.80**
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	25	8	14	20	25
Ions							
Sodium	mg/L	-	13	8	16	26	34
Calcium	mg/L	-	22.0	8	25.4	27.6	30.2
Magnesium	mg/L	-	6.96	8	7.80	8.45	9.42
Chloride	mg/L	230, 860[3]	10	8	17	26	41
Sulphate	mg/L	100[4]	4.48	8	2.20	6.85	8.49
Total Dissolved Solids	mg/L	-	184	8	140	190	250
Total Alkalinity	mg/L	-	86	8	95	107	120
Selected metals							
Total aluminum	mg/L	0.1	**3.23**	8	**0.24**	**0.60**	**0.84**
Dissolved aluminum	mg/L	0.1[2]	0.0288	8	0.0066	0.0095	0.0182
Total arsenic	mg/L	0.005	0.00174	8	0.00070	0.00106	0.00174
Total boron	mg/L	1.2[5]	0.035	8	0.0271	0.0515	0.0740
Total molybdenum	mg/L	0.073	0.0003	8	0.0002	0.0004	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	**5.1**	7	<1.2	<1.2	2.4
Total strontium	mg/L	-	0.093	8	0.078	0.127	0.150
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide (S_2)	mg/L	0.002[7]	**0.006**	8	**<0.003**	**0.006**	**0.011**
Phosphorus, total	mg/L	0.05	**0.123**	8	0.049	**0.063**	**0.131**
Total Kjeldahl Nitrogen	mg/L	1.0[8]	**1.67**	8	0.50	0.95	**1.73**
Dissolved Iron (Fe)	mg/L	0.3[2]	**0.364**	8	0.255	**0.434**	**0.957**
Total Iron	mg/L	0.3	**3.10**	7	**0.78**	**1.35**	**2.51**
Total phenolics	mg/L	0.004	**0.0056**	8	<0.001	0.003	**0.014**
Total Chromium	mg/L	0.001	**0.0037**	7	0.0007	**0.0011**	**0.0014**
Total Copper	mg/L	0.002[9]	**0.0025**	7	0.0006	0.0008	0.0012

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.

9 Guideline is hardness dependant.

Table 5.9-7 Concentrations of water quality measurement endpoints, upper Christina River (*test* station CHR-2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.04	8	8.00	8.20	8.30
Total Suspended Solids	mg/L	-[1]	30	8	3	8	22
Conductivity	µS/cm	-	152	8	164	208	268
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.037	8	0.026	0.036	**0.053**
Total nitrogen*	mg/L	1.0	**1.19**	8	0.60	0.85	**1.40**
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	22	8	13	17	26
Ions							
Sodium	mg/L	-	4.8	8	5.0	6.5	10.0
Calcium	mg/L	-	20.8	8	22.6	28.0	35.1
Magnesium	mg/L	-	6.2	8	7.0	8.2	10.6
Chloride	mg/L	230, 860[3]	<0.50	8	<0.50	2.0	2.0
Sulphate	mg/L	100[4]	2.4	8	3.2	5.1	9.6
Total Dissolved Solids	mg/L	-	132	8	130	146	240
Total Alkalinity	mg/L	-	75	8	82	104	138
Selected metals							
Total aluminum	mg/L	0.1	**0.472**	7	0.049	**0.186**	**0.304**
Dissolved aluminum	mg/L	0.1[2]	0.0141	7	0.0041	0.0078	0.0193
Total arsenic	mg/L	0.005	0.0013	7	0.0007	0.0010	0.0016
Total boron	mg/L	1.2[5]	0.0215	7	0.0253	0.0316	0.0459
Total molybdenum	mg/L	0.073	0.00031	7	0.00038	0.00042	0.00071
Total mercury (ultra-trace)	ng/L	5, 13[6]	2.7	7	<1.2	<1.2	1.8
Total strontium	mg/L	-	0.082	7	0.087	0.099	0.156
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0035**	8	**0.0023**	**0.0065**	**0.040**
Total phosphorus	mg/L	0.05	**0.086**	8	0.048	**0.064**	**0.108**
Total iron	mg/L	0.3	**1.89**	7	**1.00**	**1.19**	**2.62**
Dissolved iron	mg/L	0.3[2]	**0.570**	7	**0.406**	**0.657**	**1.410**
Total phenolics	mg/L	0.004	**0.009**	8	<0.001	**0.009**	**0.019**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.12**	8	0.50	0.77	**1.30**

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 5.9-4 Piper diagram of fall ion concentrations in the Clearwater-Christina River watersheds.

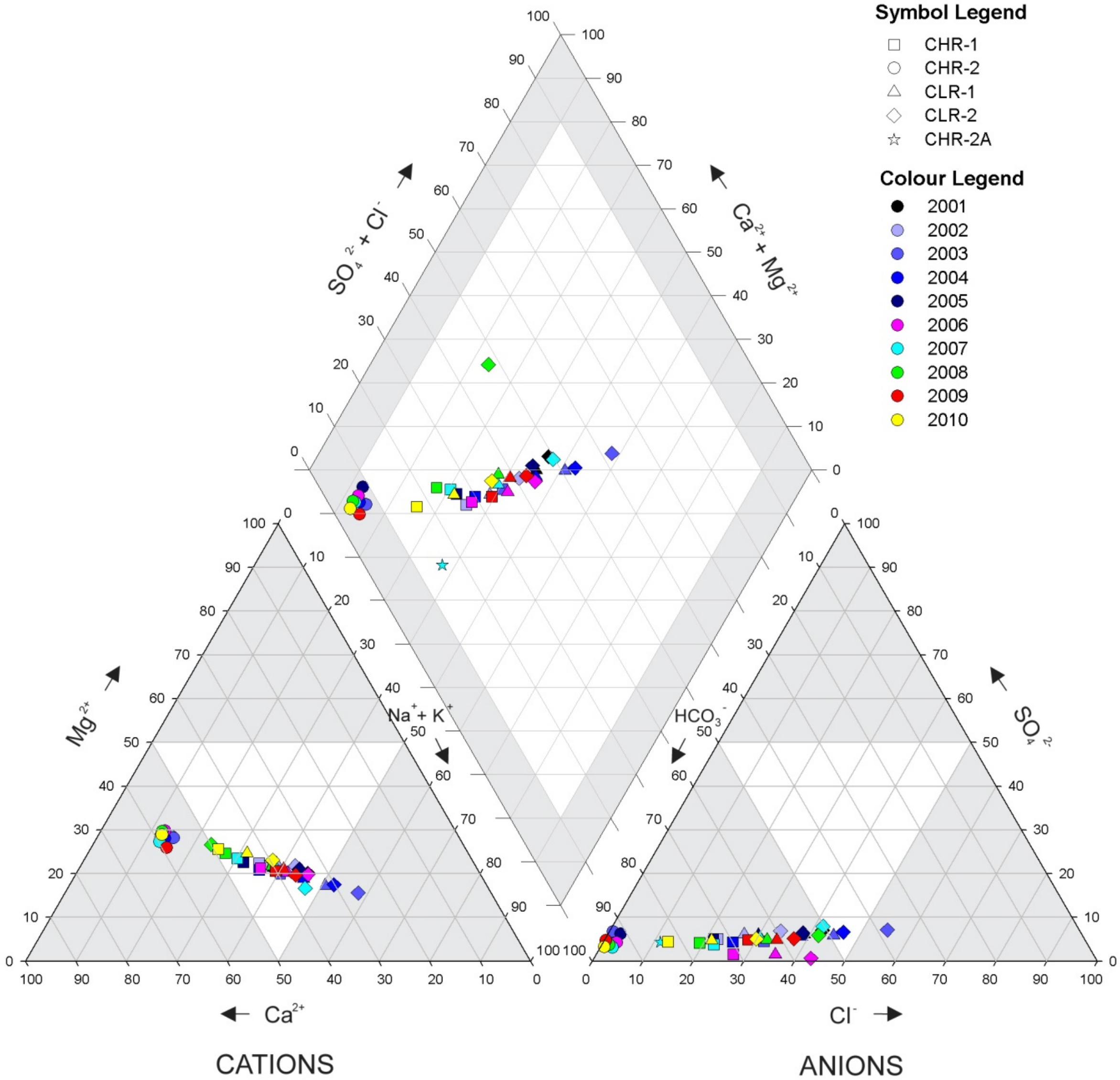
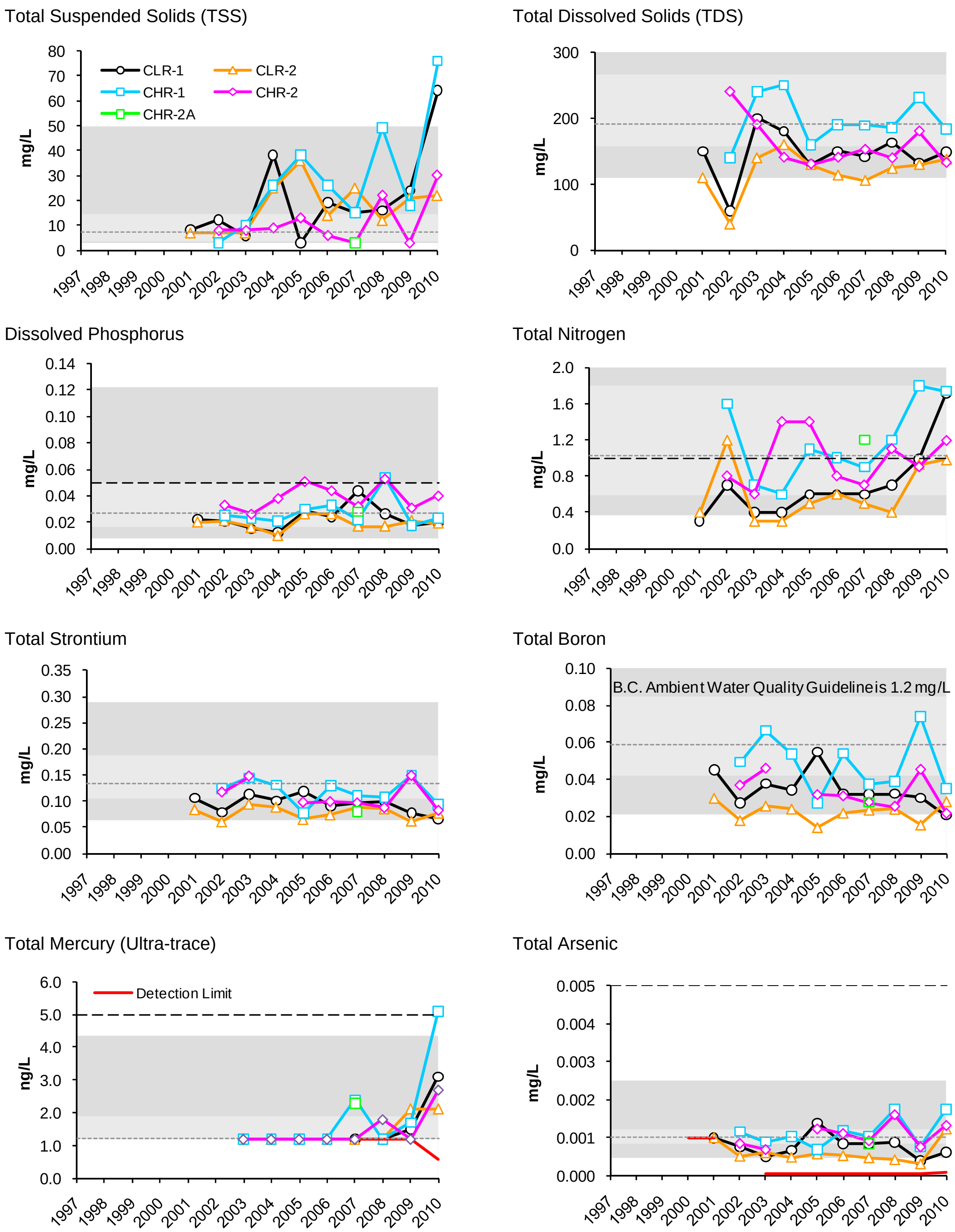


Figure 5.9-5 Concentrations of selected water quality measurement endpoints in the Clearwater and Christina watersheds (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

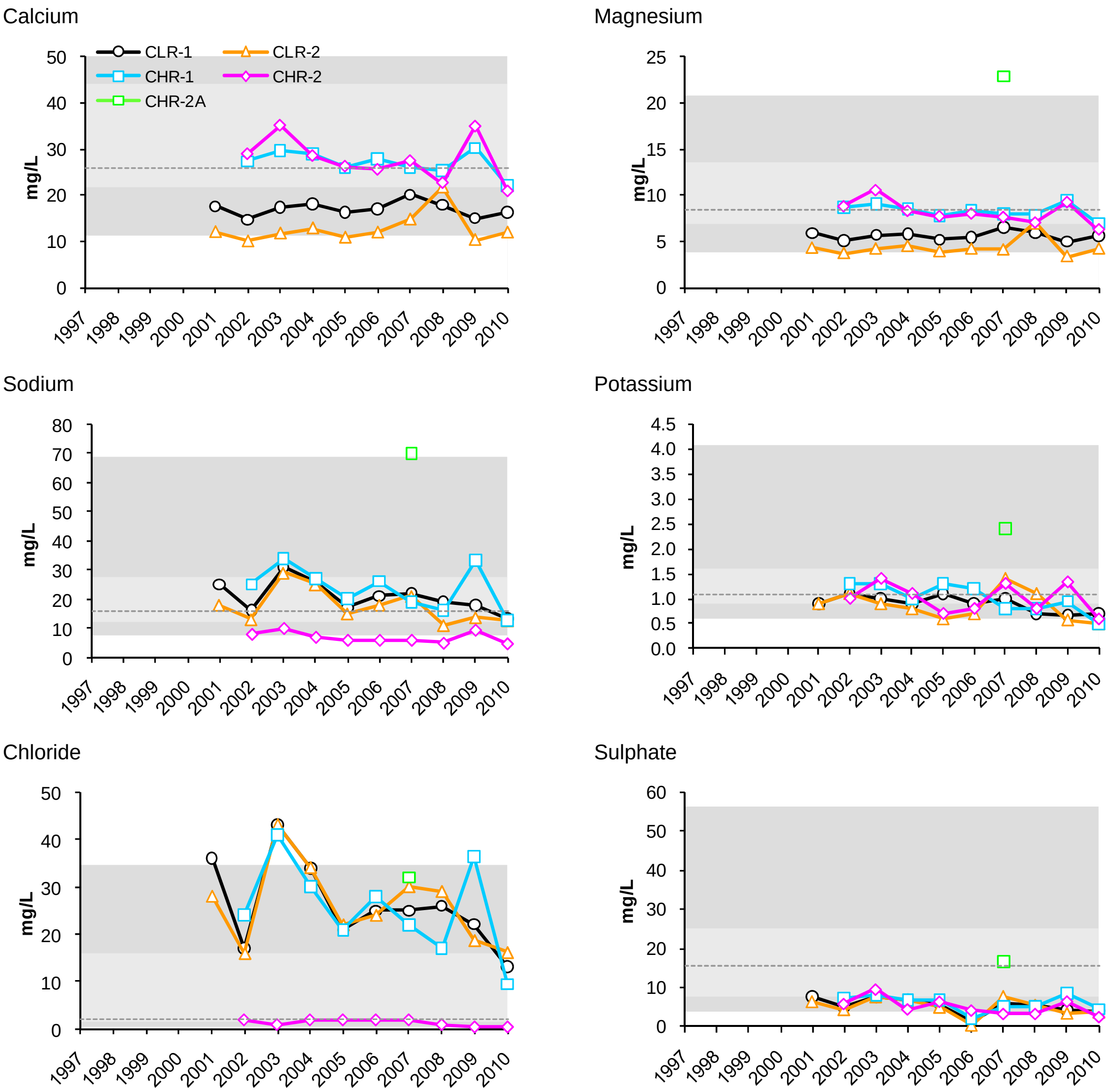


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.9-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b); total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.9-8 Water quality guideline exceedances, Clearwater-Christina River watersheds, 2010.

Variable	Units	Guideline	CLR-1	CLR-2	CHR-1	CHR-2
Fall						
Sulphide	mg/L	0.002[2]	0.0047	0.0035	0.0061	0.0035
Total phosphorus	mg/L	0.05	-	0.056	0.123	0.086
Total aluminum	mg/L	0.1	0.827	2.550	3.230	0.472
Dissolved iron	mg/L	0.3[1]	-	0.324	0.364	0.570
Total iron	mg/L	0.3	1.16	2.42	3.10	1.89
Total Kjeldahl nitrogen	mg/L	1.0[3]	-	-	1.67	1.12
Total mercury (ultra-trace)	ng/L	5, 13[4]	-	-	5.1	-
Total nitrogen*	mg/L	1.0	1.721	-	1.741	1.191
Total copper	mg/L	0.002	-	-	0.00251	-
Total chromium	mg/L	0.001	0.0011	0.0029	0.0037	-
Total phenols	mg/L	0.004	0.0067	0.0062	0.0056	0.0090

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] 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).

[3] Guideline is for total nitrogen.

[4] Draft AENV guidelines for chronic and acute total mercury concentrations respectively (AENV 1999).

Table 5.9-9 Water quality index (fall 2010) for stations in the Clearwater-Christina River watersheds.

Station Identifier	Location	2010 Designation	Water Quality Index	Classification
CLR-1	Upstream of Fort McMurray	*test*	98.7	Negligible-Low
CLR-2	Upstream of Christina River	*baseline*	93.2	Negligible-Low
CHR-1	Near the mouth of the Christina River	*test*	88.7	Negligible-Low
CHR-2	Upstream of Janvier	*test*	100.0	Negligible-Low

Note: see Figure 5.9-1 for the locations of these water quality stations.

Note: see Section 3.2.2.3 for a description of the Water Quality Index.

Table 5.9-10 Species composition of the Clearwater River during spring, summer, and fall, 2010.

Species	Spring		Summer		Fall	
	No.	**%**	**No.**	**%**	**No.**	**%**
Arctic grayling	-	-	-	-	58	8.0
Burbot	1	0.3	4	0.5	2	0.3
Flathead chub	2	0.6	-	-	-	-
Goldeye	37	11.2	7	0.9	4	0.5
Lake chub	5	1.5	11	1.4	-	-
Lake whitefish	4	1.2	8	1.0	2	0.3
Longnose dace	-	-	1	0.1	-	-
Longnose sucker	56	16.9	238	29.9	25	3.4
Mountain whitefish	2	0.6	37	4.6	54	7.4
Northern pike	27	8.2	51	6.4	56	7.7
Pearl dace	-	-	-	-	12	1.6
Slimy sculpin	2	0.6	15	1.9	12	1.6
Spoonhead sculpin	-	-	4	0.5	-	-
Spottail shiner	12	3.6	42	5.3	104	14.3
Trout-perch	4	1.2	66	8.3	134	18.4
Walleye	29	8.8	106	13.3	37	5.1
White sucker	150	45.3	198	24.8	211	29.0
Yellow perch	-	-	9	1.1	17	2.3
Total # Species	**13**	**-**	**15**	**-**	**14**	**-**
Total # Fish	**331**	**100**	**797**	**100**	**728**	**100**

Table 5.9-11 Species composition of the Clearwater River *baseline* (CR1, CR2) and *test* (CR3) reaches for spring, summer and fall 2010.

Species	Spring				Summer				Fall			
	Baseline	%	Test	%	Baseline	%	Test	%	Baseline	%	Test	%
Arctic grayling	-	-	-	-	-	-	-	-	40	9.0	18	6.3
Burbot	1	0.6	-	-	3	0.6	1	0.4	2	0.5	-	-
Flathead chub	-	-	2	1.1	-	-	-	-	-	-	-	-
Goldeye	7	4.5	30	17.1	1	0.2	6	2.3	-	-	4	1.4
Lake chub	1	0.6	4	2.3	2	0.4	9	3.5	-	-	-	-
Lake whitefish	2	1.3	2	1.1	8	1.5	-	-	2	0.5	-	-
Longnose dace	-	-	-	-	1	0.2	-	-	-	-	-	-
Longnose sucker	15	9.6	41	23.4	108	20.0	130	50.4	9	2.0	16	5.6
Mountain whitefish	2	1.3	-	-	36	6.7	1	0.4	37	8.4	17	5.9
Northern pike	20	12.8	7	4.0	44	8.2	7	2.7	39	8.8	17	5.9
Pearl dace	-	-	-	-	-	-	-	-	11	2.5	1	0.3
Slimy sculpin	-	-	2	1.1	6	1.1	9	3.5	-	-	12	4.2
Spoonhead sculpin	-	-	-	-	2	0.4	2	0.8	-	-	-	-
Spottail shiner	9	5.8	3	1.7	39	7.2	3	1.2	103	23.3	1	0.3
Trout-perch	1	0.6	3	1.7	40	7.4	26	10.1	48	10.9	86	30.1
Walleye	1	0.6	28	16.0	78	14.5	28	10.9	18	4.1	19	6.6
White sucker	97	62.2	53	30.3	164	30.4	34	13.2	121	27.4	90	31.5
Yellow perch	-	-	-	-	7	1.3	2	0.8	12	2.7	5	1.7
Total # Species	**11**	**-**	**11**	**-**	**15**	**-**	**13**	**-**	**12**	**-**	**12**	**-**
Total # Fish	**156**	**100**	**175**	**100**	**539**	**100**	**258**	**100**	**442**	**100**	**286**	**100**

Figure 5.9-6 Seasonal species richness in the Clearwater River, 2003 to 2010.

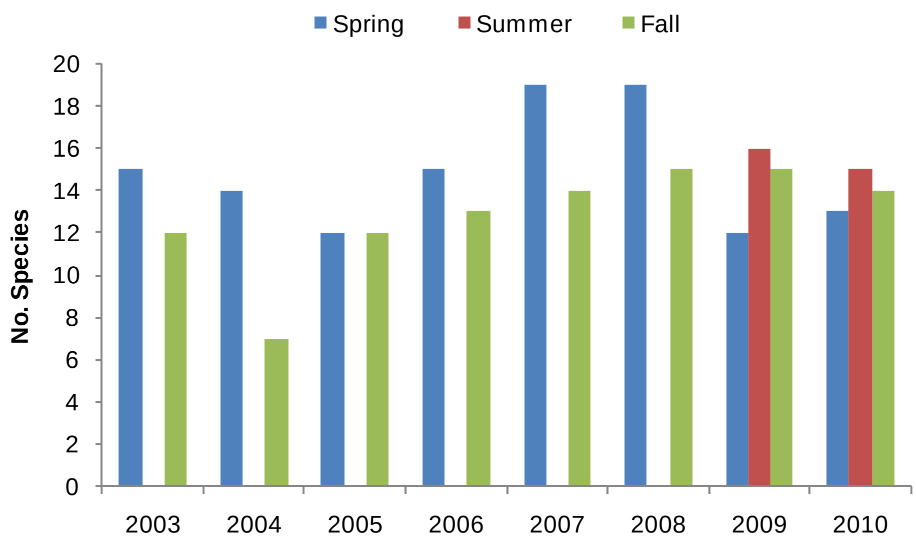


Figure 5.9-7 Seasonal catch per unit effort (CPUE±1SE) of large-bodied KIR species and all species in the Clearwater River, 2003 to 2010.

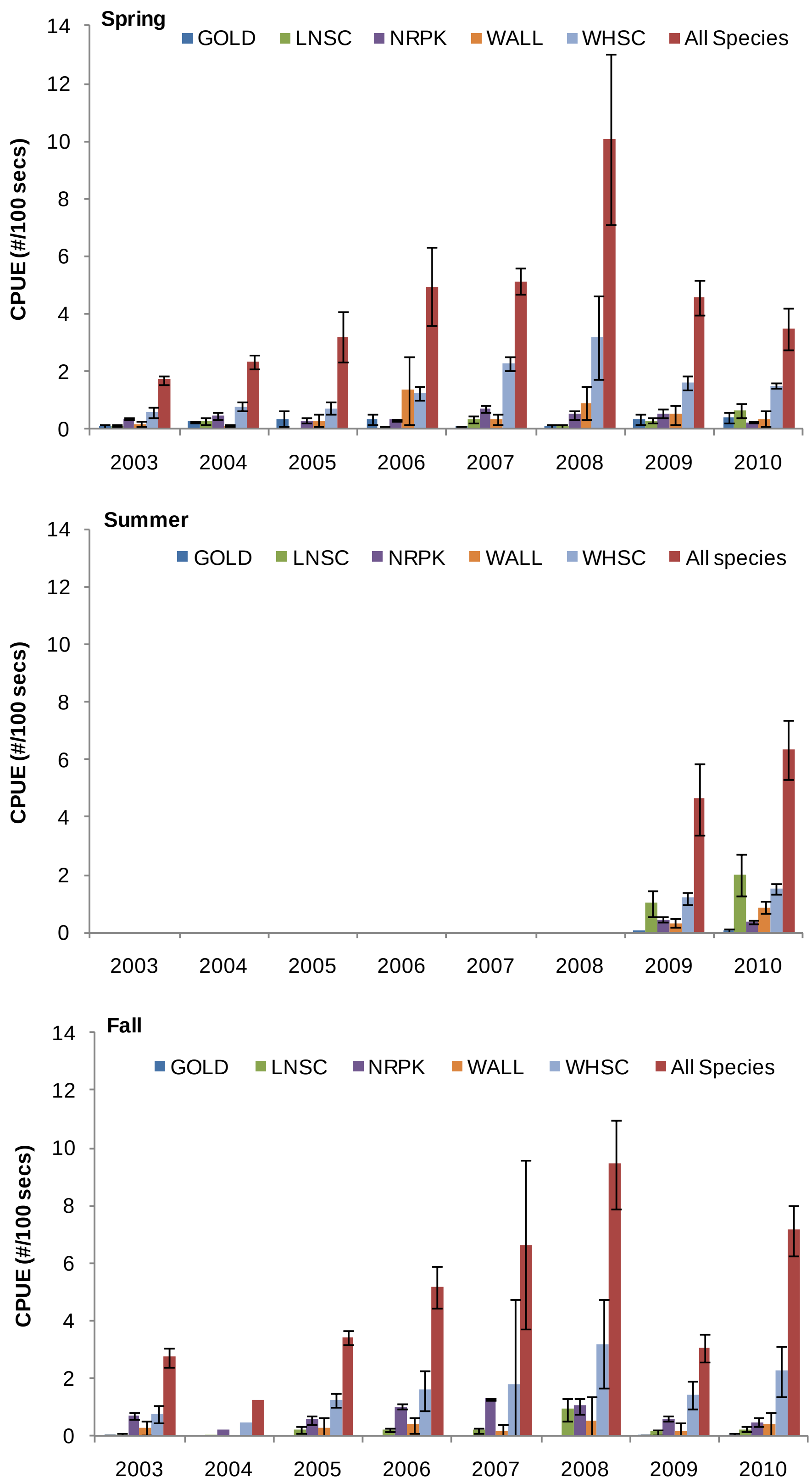


Figure 5.9-8 Seasonal catch per unit effort (CPUE±1SE) for all species combined in *baseline* and *test* reaches of the Clearwater River, 2003 to 2010.

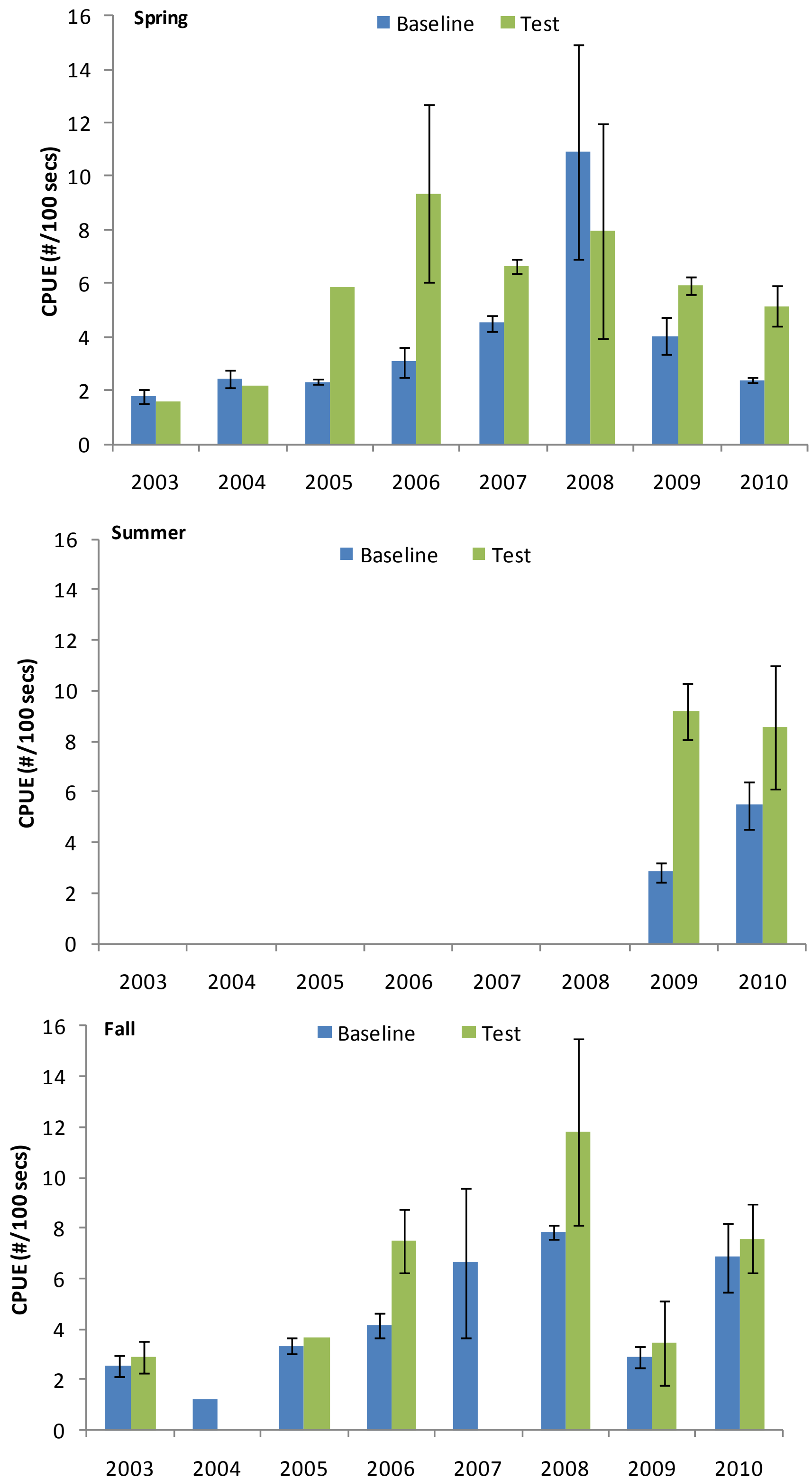


Figure 5.9-9 Seasonal catch per unit effort (CPUE±1SE) for each large-bodied KIR fish species in *baseline* and *test* reaches of the Clearwater River, 2010.

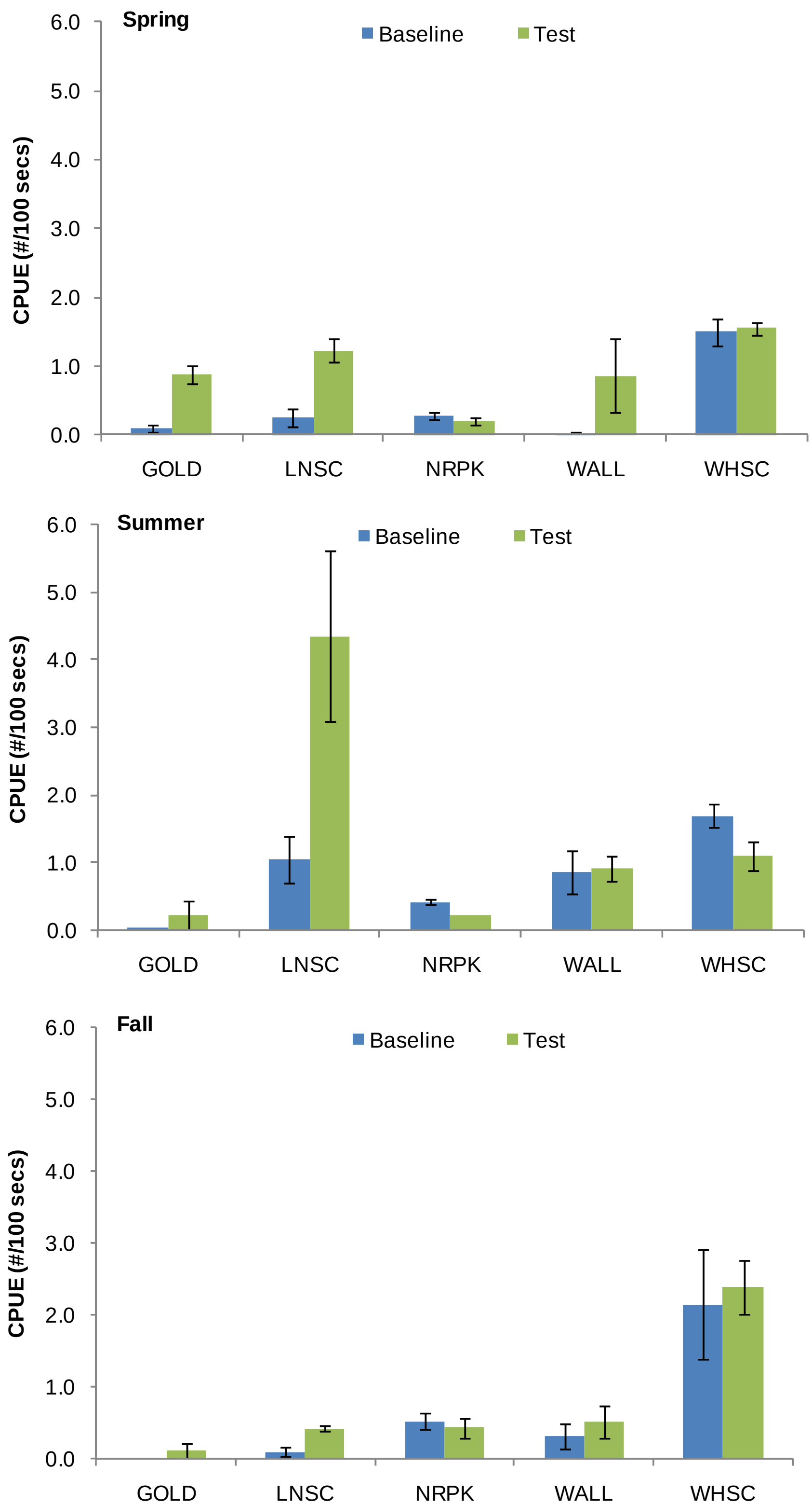


Figure 5.9-10 Relative length-frequency distributions for goldeye captured in 2010 (n=48) versus the average relative frequency from 2003 to 2009 (upper pane) and spring summer and fall 2010 distributions (lower pane); 25 mm length classes.

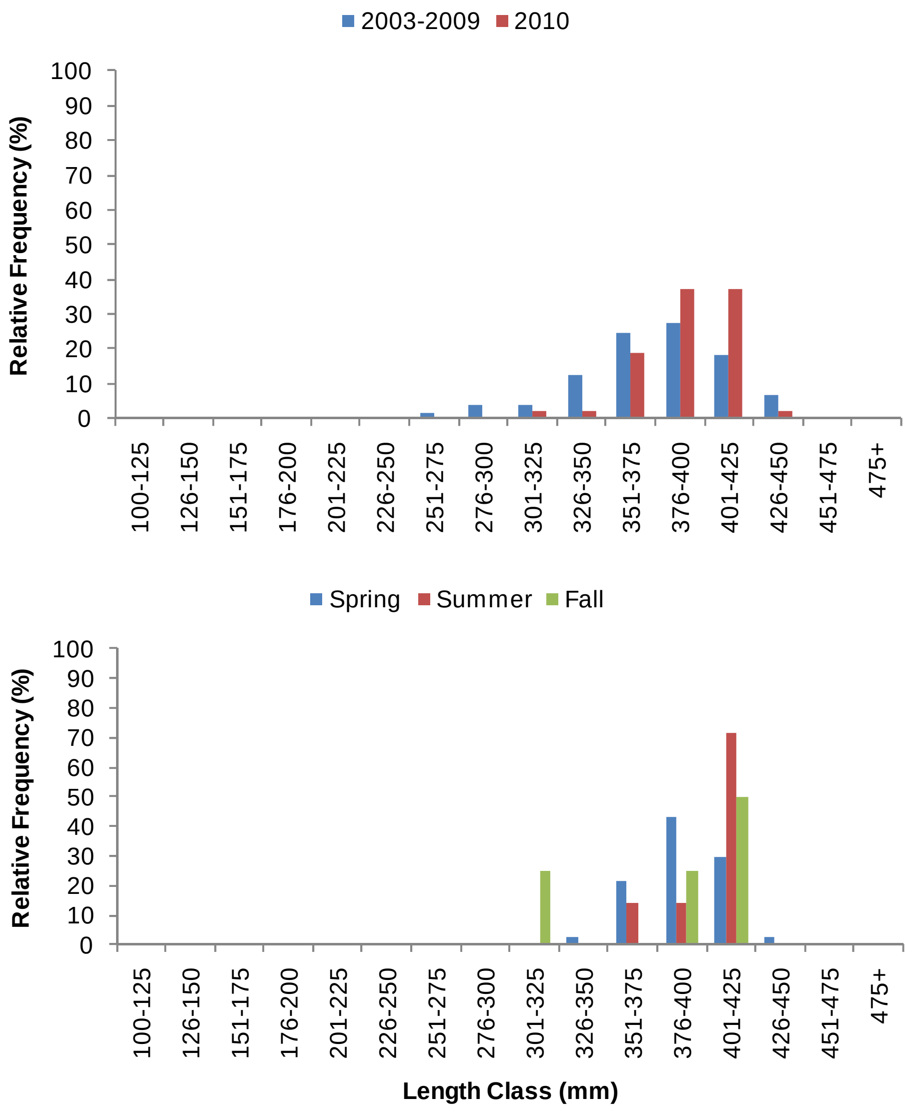
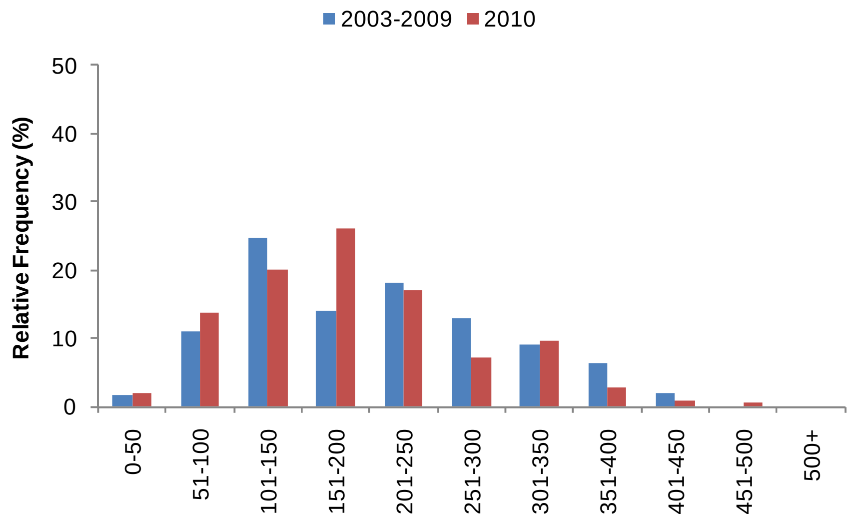


Figure 5.9-11 Relative length-frequency distributions for longnose sucker captured in the Clearwater River, 2010 (n=319) versus the average relative frequency from 2003 to 2009 (upper pane) and spring, summer and fall 2010 distributions (lower pane); 50 mm length classes.



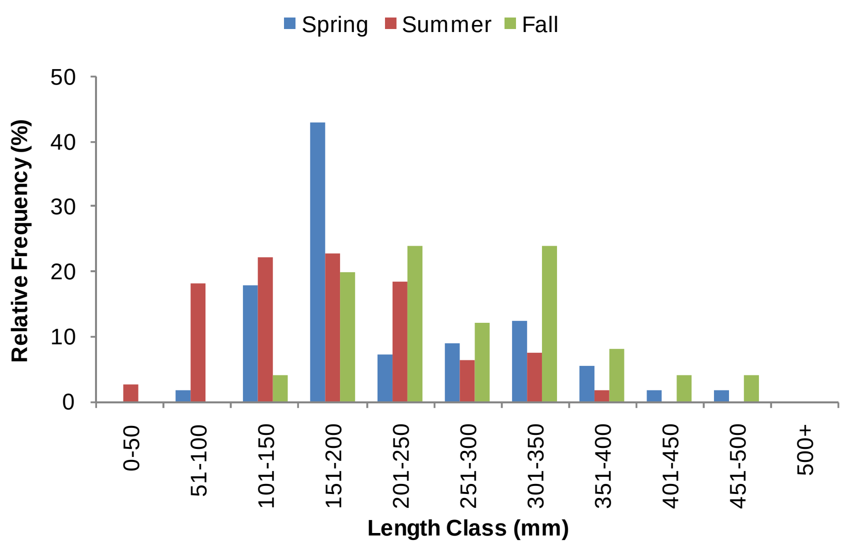


Figure 5.9-12 Relative length-frequency distributions for northern pike captured in 2010 (n=134) versus the average relative frequency from 2003-2009 (upper pane) and spring, summer and fall 2010 distributions (lower pane); 50 mm length classes.

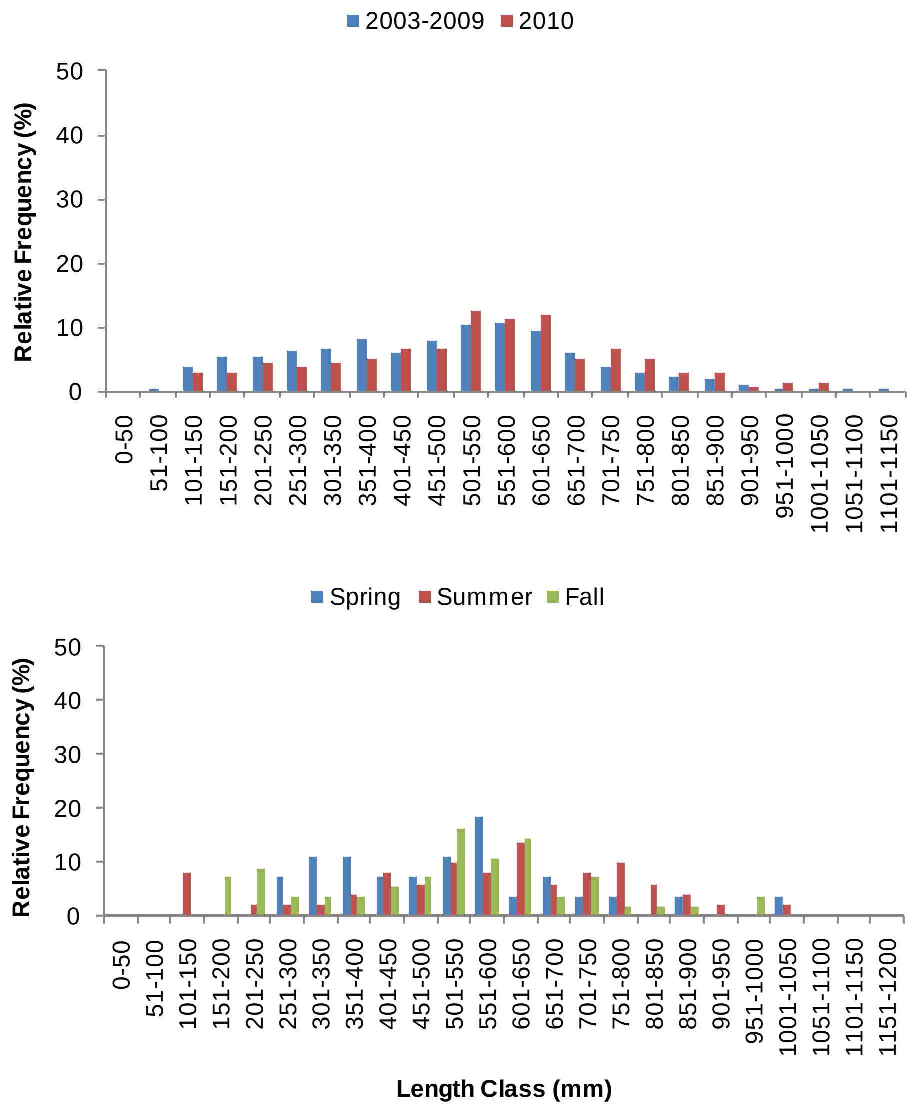


Figure 5.9-13 Relative length-frequency distributions for walleye captured in 2010 (n=172) versus the average relative frequency from 2003 to 2009 (upper pane) and spring, summer and fall 2010 distributions (lower pane); 50 mm length classes.

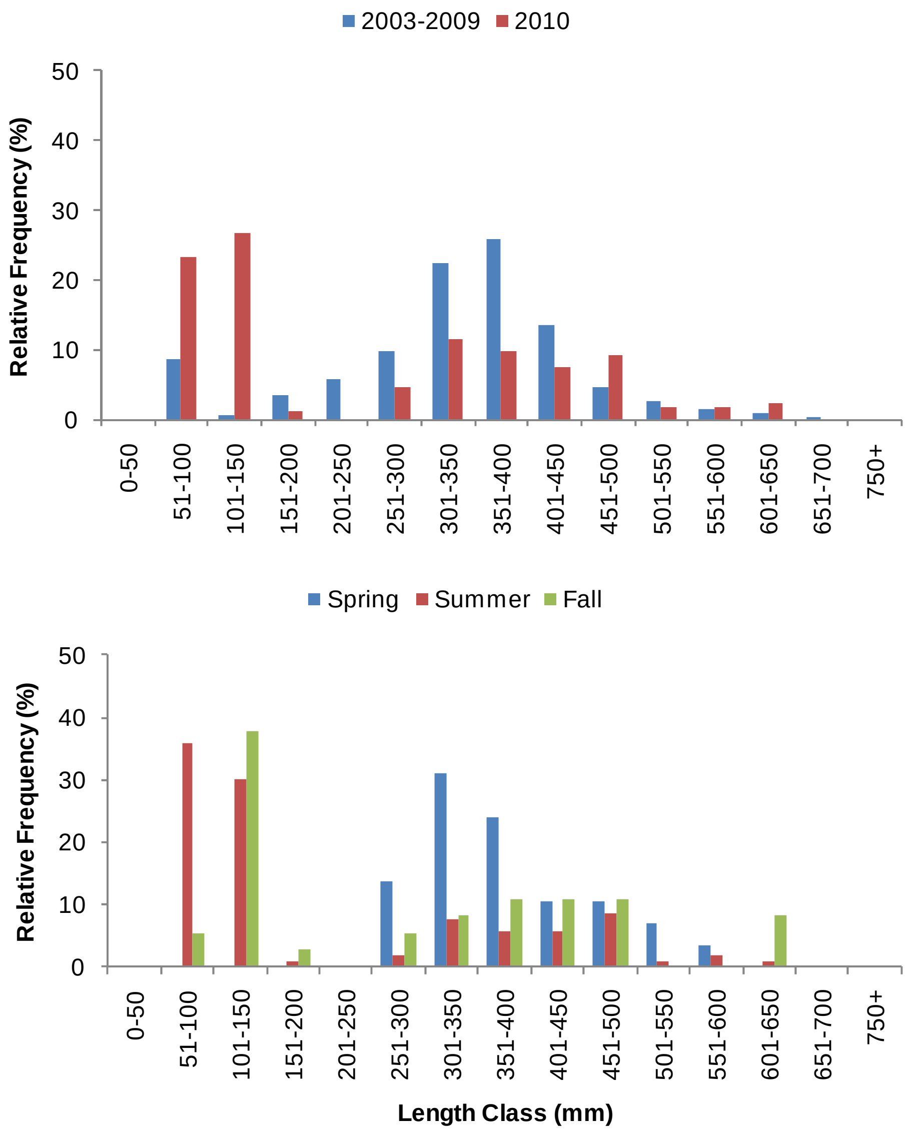


Figure 5.9-14 Relative length-frequency distributions for white sucker captured in 2010 (n=559) versus the average relative frequency from 2003 to 2009 (upper pane) and spring, summer and fall 2010 distributions (lower pane); 50 mm length classes.

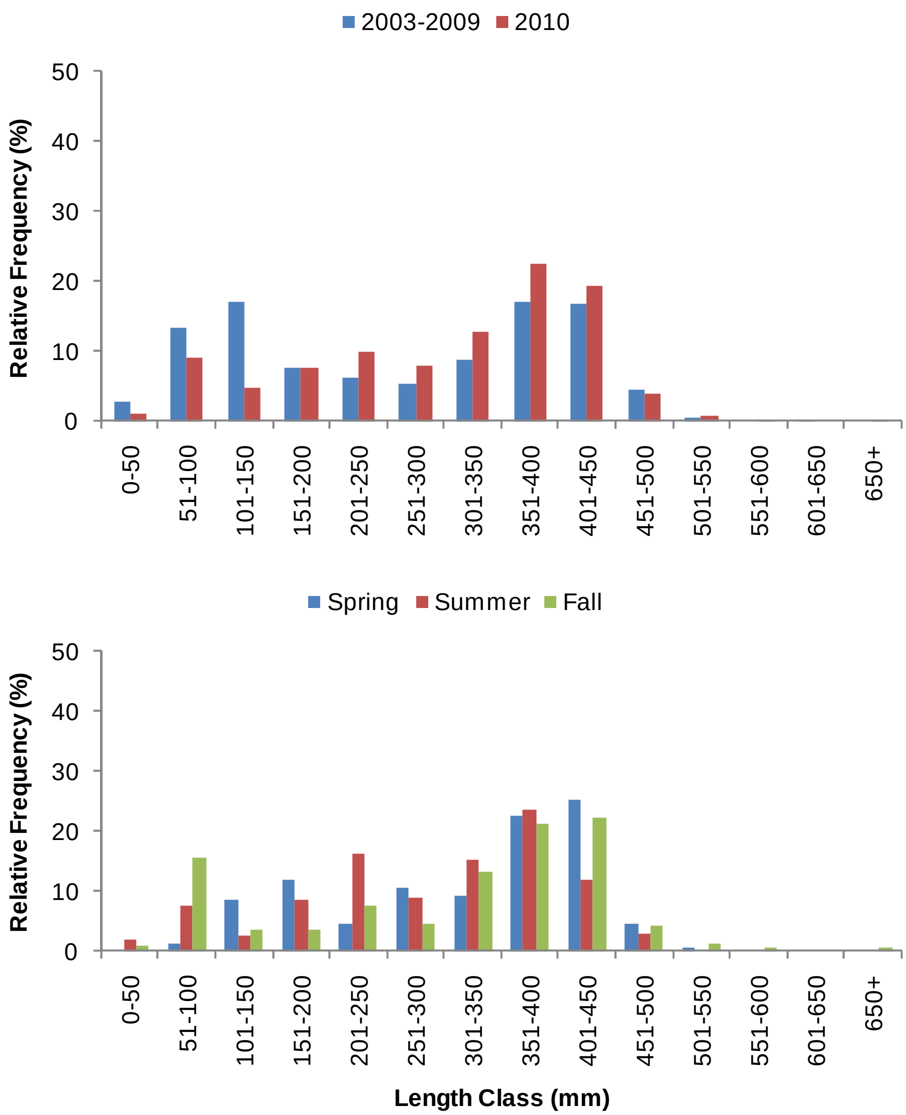
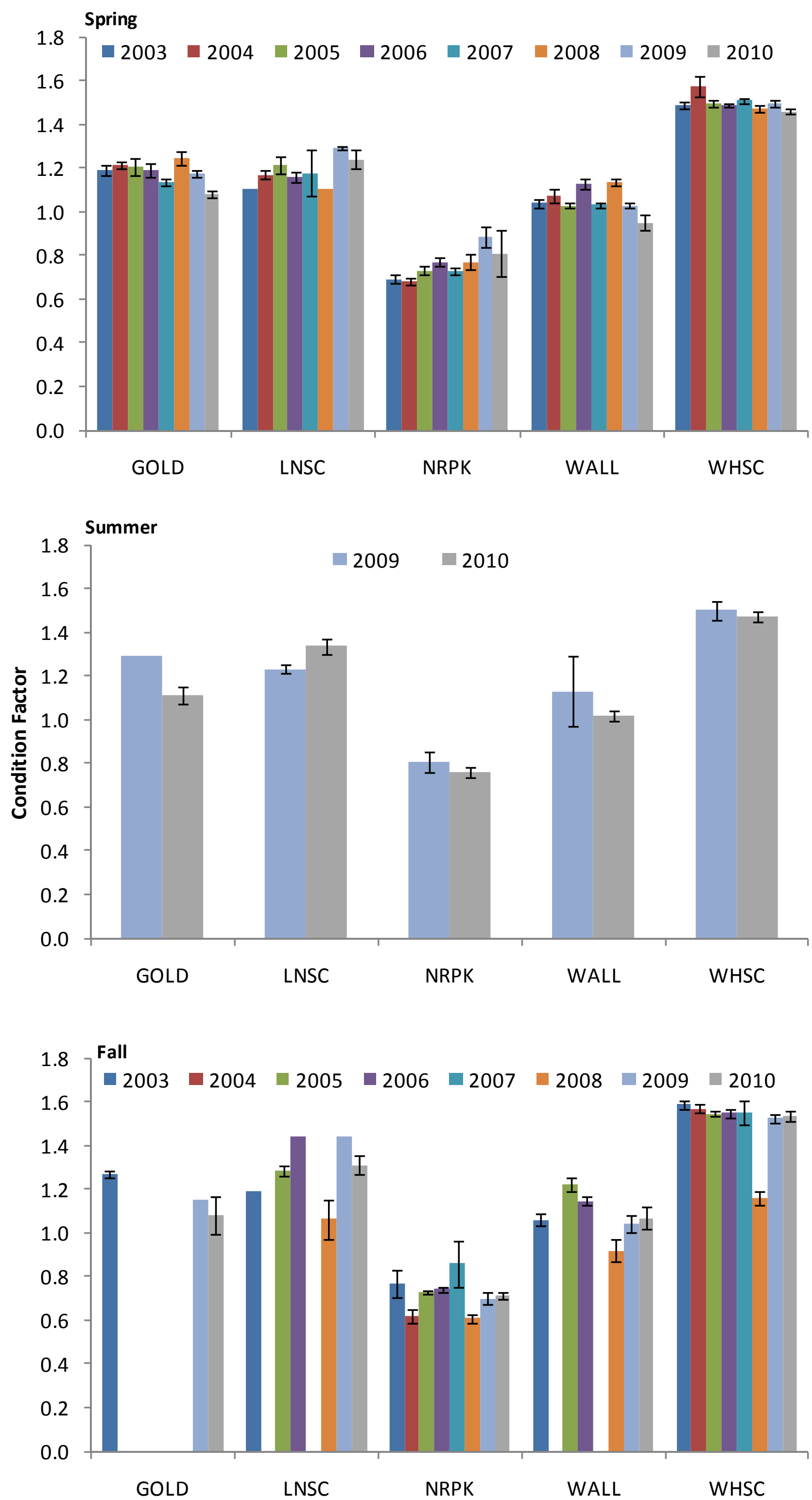


Figure 5.9-15 Condition factor (mean ± 1SE) for large-bodied KIR species captured in the Clearwater River, spring, summer, and fall 2003 to 2010.



Note: Condition factor = $(\text{weight}/\text{length}^3)*10^5$

Figure 5.9-16 Percent of total fish captured in the Clearwater River with external pathology, 2003 to 2010.

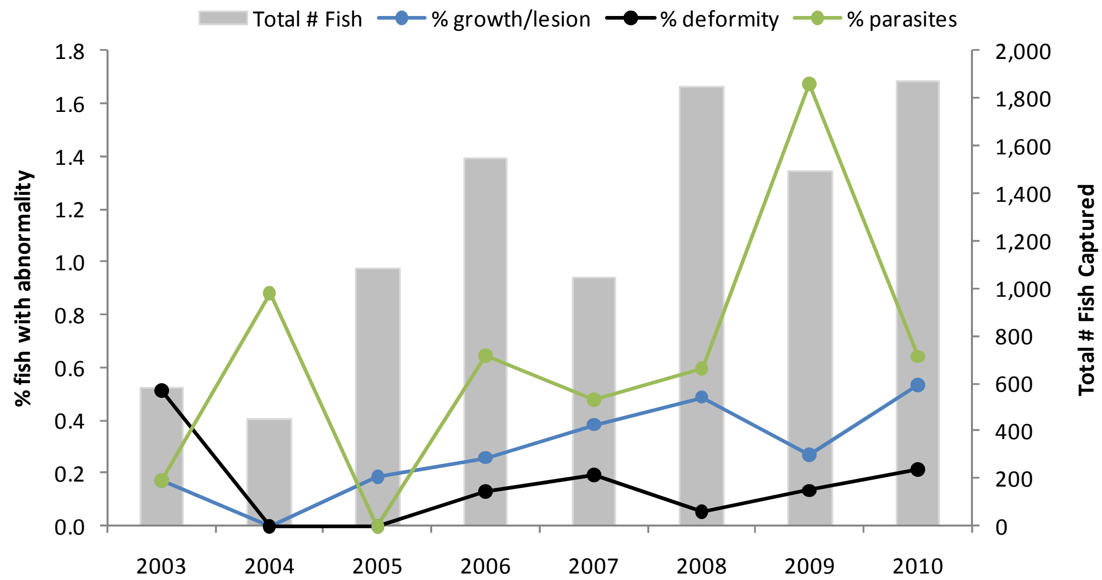


Table 5.9-12 Percent of total fish captured by species with external pathology (i.e., growth/lesion, deformity, and parasite), 2003 to 2010.

Year	Northern Pike	Walleye	Goldeye	White Sucker	Longnose Sucker	Spottail Shiner
2003	2.82	1.67	-	-	-	-
2004	4.65	-	-	-	-	-
2005	-	0.97	1.39	-	-	-
2006	6.25	-	-	0.72	-	-
2007	4.97	-	-	0.73	-	-
2008	6.10	2.53	-	0.97	2.17	-
2009	2.94	3.39	-	3.61	1.73	-
2010	4.44	1.16	-	2.30	1.24	0.63

5.10 HANGINGSTONE RIVER WATERSHED

Table 5.10-1 Summary of results for the Hangingstone River watershed.

Hangingstone River	**Summary of 2010 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 2010	
Benthic Invertebrate Communities and Sediment Quality	
No Benthic Invertebrate Communities and Sediment Quality component activities conducted in 2010	
Fish Populations	
No Fish Populations component activities conducted in 2010	

Legend and Notes

○ Negligible-Low

● Moderate

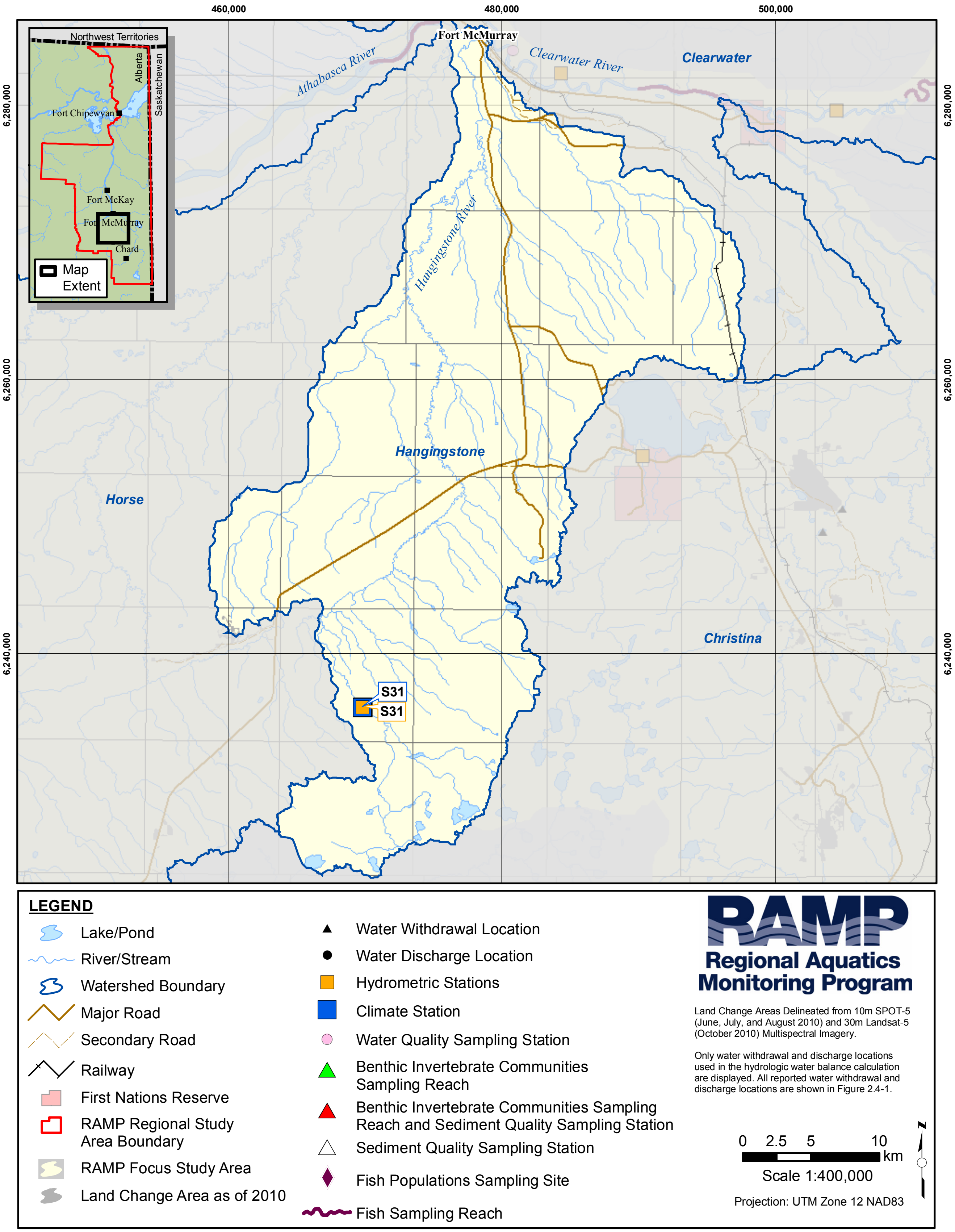
● High

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.



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5.10.1 Summary of 2010 Conditions

Approximately 0.05% (56 ha) of the Hangingstone River watershed had undergone land change as of 2010 from oil sands developments, with no change from 2009 (Table 2.5-2); none of this land change has been due to focal projects as there have been no focal projects in development phase in the Hangingstone River watershed to date.

Only the Climate and Hydrology component of RAMP conducted monitoring activities in the Hangingstone River watershed in 2010. Table 5.10-1 is a summary of the 2010 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 2010 in the Hangingstone River watershed. This land change is due to oil sands developments from companies that were not members of RAMP as of 2010.

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These estimated watershed-level effects of oil sands developments are classified as **Negligible-Low**.

5.10.2 Hydrologic Conditions: 2010 Water Year

WSC Station 07CD004, Hangingstone River at Fort McMurray Continuous annual hydrometric data have been collected for WSC Station 07CD004 from 1970 to 1986, and seasonal data from March to October have been collected every year since 1970. Partial records exist from 1965 to 1969. The open-water (May to October) runoff volume recorded at WSC Station 07CD004 was 85.3 million m^3. This value was 10% lower than the historical mean open-water runoff volume. Flows increased beyond historical upper quartile values in late April due to snowmelt, to a maximum seasonal (March to October) value of 33.3 m^3/s recorded on April 20 (Figure 5.10-2). Flow levels remained above historical median values until June 18. After this date, flows decreased to below median values from June 19 to August 8. Flows increased to a peak of 16.5 m^3/s on August 30 in response to sustained rainfall throughout mid-August. Following this peak, flows decreased until the end of the 2010 water year (WY). The seasonal (March to October) maximum daily flow of 33.3 m^3/s was 21% lower than the historical mean maximum daily flow. The seasonal minimum daily flow of 0.28 m^3/s recorded on March 25 was 63% higher than the historical mean minimum daily flow (Figure 5.10-2).

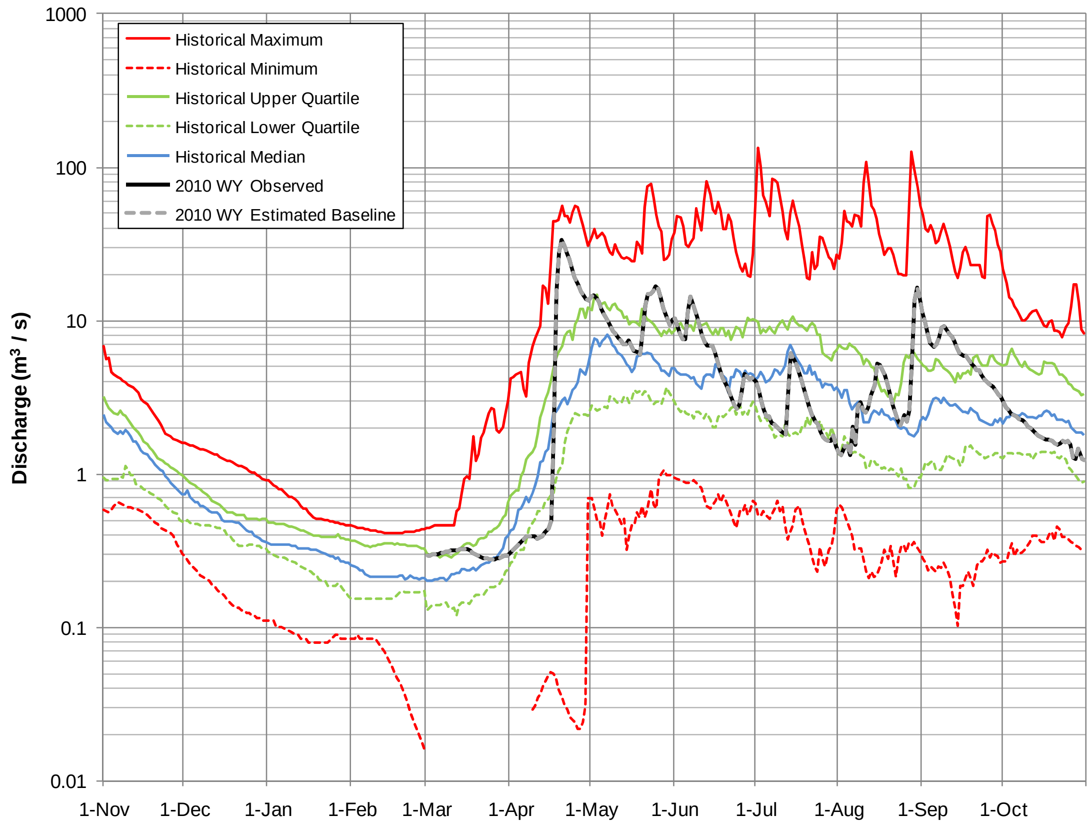
Hydrologic Effects of Oil Sands Developments While there are no focal projects within the Hangingstone River watershed, the effects of non-focal project activities within the basin have been estimated. The non-focal project estimated water balance for March 1 to October 31, 2010 at WSC Station 07CD004 is provided in Table 5.10-3 and described below:

1. The closed-circuited land area from non-focal projects as of 2010 is estimated to be 0.47 km^2 (Table 2.5-1). The loss of flow to the Hangingstone River that would have otherwise occurred from this land area is estimated at 0.054 million m^3.

2. As of 2010, the area of land change from non-focal projects in the Hangingstone watershed that was not closed-circuited is estimated to be 0.09 km^2 (Table 2.5-1). The increase in flow to the Hangingstone River that would not have otherwise occurred is estimated at 0.002 million m^3.

The estimated cumulative effect of these non-focal projects is a decrease in flow of 0.052 million m³ to the Hangingstone River. The observed and estimated hydrographs that would have been observed at WSC Station 07CD004 in the absence of oil sands developments is provided in Figure 5.10-2. The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge are 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (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 the 2010 WY and estimated hydrograph, compared to historical values.



Note: Observed 2010 WY hydrograph based on WSC Station 07CD004, Hangingstone River at Fort McMurray, provisional data for March 1 to October 31, 2010. The upstream drainage area of WSC Station 07CD004 is 962 km², which is slightly smaller than the size of the entire Hangingstone River watershed (1,066 km²). Historical values from March 1 to October 31 calculated for the period from 1965 to 2009, 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 8, 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, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed hydrograph (total discharge)	**110.65**	**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 2010 (Table 2.5-1)
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 2010 that is not closed-circuited (Table 2.5-1)
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 by figures contained in this table
Estimated hydrograph in absence of oil sands development projects (total discharge)	**110.70**	**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 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data for March 1 to October 31, 2010 for WSC Station 07CD004, Hangingstone River at Fort McMurray.

Table 5.10-3 Estimated change in hydrologic measurement endpoints for the Hangingstone River watershed, 2010 WY.

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	5.37	5.37	-0.05%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	33.32	33.30	-0.05%
Open-water period minimum daily discharge	1.22	1.22	-0.05%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Values are calculated from provisional data for March 1 to October 31, 2010 for WSC Station 07CD004, Hangingstone River at Fort McMurray.

Note: Flow values in this table presented to two decimal places.

5.11 MISCELLANEOUS AQUATIC SYSTEMS

Table 5.11-1 Summary of results for the miscellaneous aquatic systems.

Miscellaneous Aquatic Systems	Summary of 2010 Conditions										
	Lakes					*Rivers/Creeks*					
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				🟡	not measured				🟤
Minimum open-water season discharge	not measured	not measured				🟡	not measured				🟤
Water Quality											
Criteria	no station sampled	**ISL-1** Isadore's Lake	**SHL-1** Shipyard Lake			**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	**MIC-1** Mills Creek
Water Quality Index		n/a	n/a			🟡	🟡	🟡	🟡	🟡	🟡
Benthic Invertebrate Communities and Sediment Quality											
Criteria	no reach sampled	**ISL-1** Isadore's Lake	**SHL-1** Shipyard Lake			**POC-D1** Poplar Creek lower reach	**FOC-D1** Fort Creek at the mouth	no reach sampled	**BER-D2** Beaver River upper reach	no reach sampled	no reach sampled
Benthic Invertebrate Communities		🟡	🟡			🟠	🟤		n/a		
Sediment Quality Index		n/a	n/a			🟡	🟡		🟡		

Fish Populations

Criteria		Brutus Lake		Net Lake		Keith Lake		no reaches sampled
		Sub.[3]	Gen.[3]	Sub.[3]	Gen.[3]	Sub.[3]	Gen.[3]	
Human Health	WALL	🟤	🟠	🟤	🟤	ns	ns	
	NRPK	🟤	🟠	🟤	🟠	🟡	🟡	
	LKWH	🟡	🟡	🟡	🟡	🟡	🟡	

Legend and Notes

🟡 Negligible-Low

🟠 Moderate

🟤 High

baseline (green)

test (blue)

[1] For Climate and Hydrology, results are reported for station at the mouth of each watershed.

[2] Species (Sp.): WALL=walleye; NRPK=northern pike; LKWH=lake whitefish

[3] Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada (see Section 3.2.4.2 and Table 3.2-8).

n/a - The WQI/SQI was not calculated given the limited existing *baseline* data.

ns – none sampled

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.

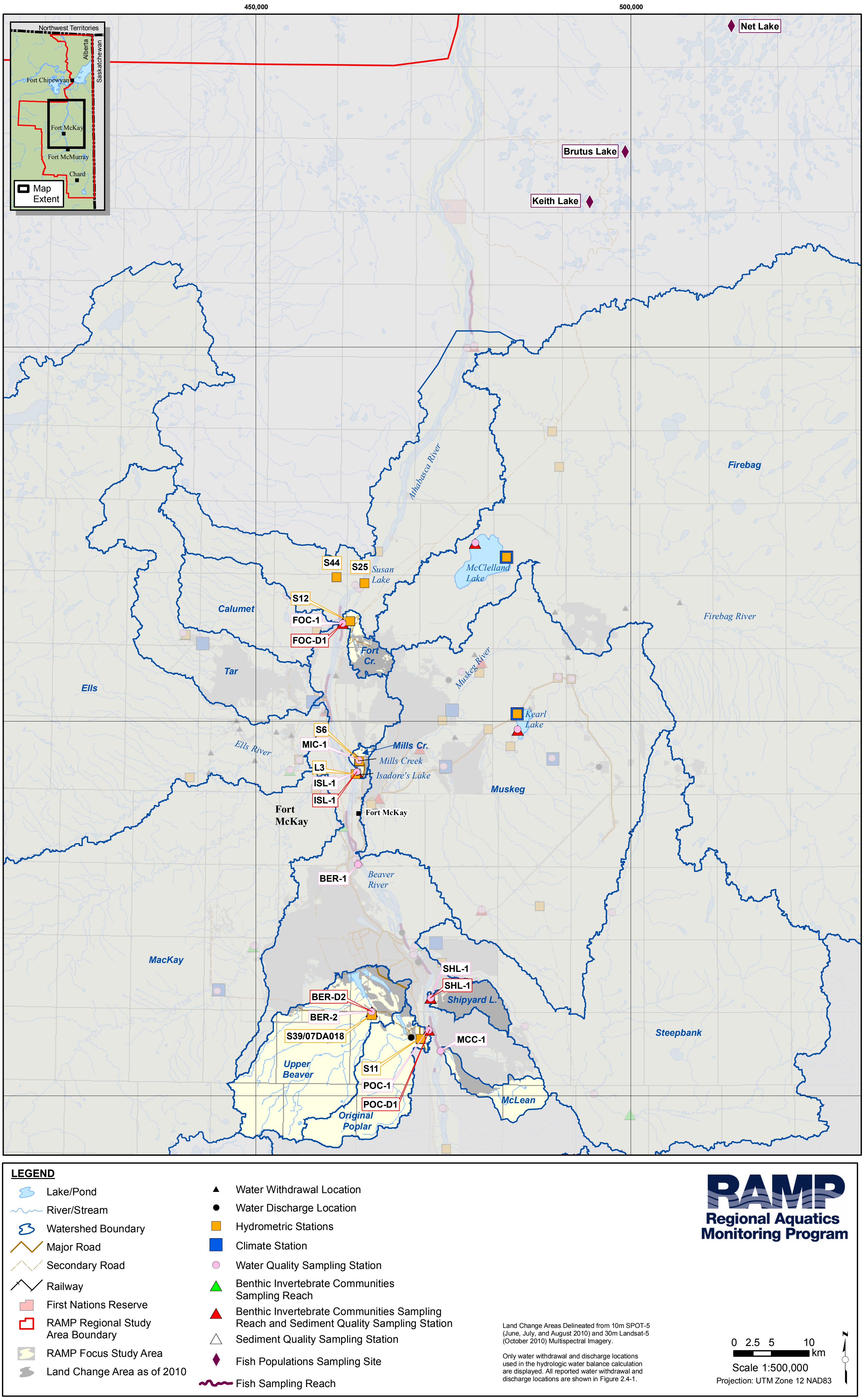
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions; see Section 3.2.2.3 for a detailed description of the classification methodology.

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 3.2.3.1 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; see Section 3.2.3.2 for a detailed description of the classification methodology

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 3.2.4.2 and Table 3.2-8 for a detailed description of the classification methodology.

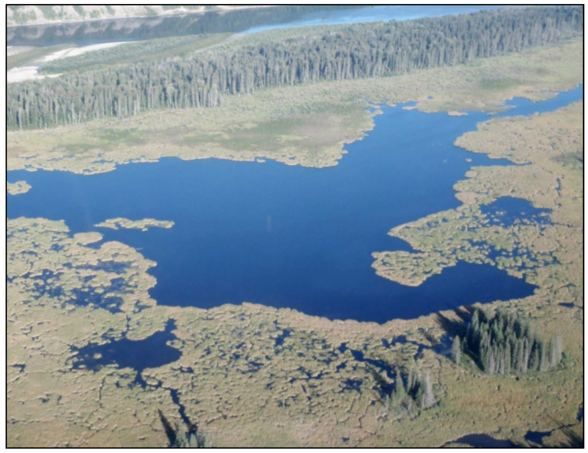
Figure 5.11-1 Miscellaneous aquatic systems.



K:\Data\Project\RAMP1565\GIS_MXD\H_TechRpt\RAMP1565_K11_Misc_20110318.mxd

Figure 5.11-2 Representative monitoring stations of miscellaneous aquatic systems, fall 2010.

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

5.11.1 Summary of 2010 Conditions

This section includes 2010 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 2010 comprises approximately 3.4% (475 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% (2,722 ha) of the Upper Beaver watershed (Table 2.5-2); and
- The Susan Lake outlet is designated as *baseline* for 2010 as are the regional lakes where fish tissue studies were conducted including Brutus, Net, and Keith lakes.

Table 5.11-1 is a summary of the 2010 assessment of the miscellaneous aquatic systems in the RAMP FSA, while Figure 5.11-1 denotes the location of the monitoring stations for each RAMP component, reported focal project withdrawal and discharge locations, and the area of land change for 2010. Figure 5.11-2 contains fall 2010 photos of water quality monitoring stations located in the miscellaneous aquatic systems in the RAMP FSA.

Isadore's Lake and Mills Creek The calculated mean open-water discharge, minimum daily discharge, annual maximum daily discharge, and mean winter discharge are 33% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph for Mills Creek. This difference is classified as **High**.

The water level of Isadore's Lake was above historical upper quartile values until monitoring temporarily ceased in early April due to equipment malfunction. When monitoring resumed in late-June, the water level varied between the historical median and upper quartile values until the end of the 2010 WY.

Differences in water quality in fall 2010 between Mills Creek and regional *baseline* fall conditions are classified as **Negligible-Low**. While concentrations of a number of water quality measurement endpoints were outside regional *baseline* concentrations at *test* station MIC-1, the WQI value of Mills Creek in fall 2010 was 84.1. With respect to Isadore's Lake, the ionic composition of water at *test* station ISL-1 in fall 2010 was dominated by bicarbonate as in past sampling years, and concentrations of water quality measurement endpoints were within the range of previously-measured concentrations and regional *baseline* concentrations. However, increasing concentrations of several major ions have been observed in recent years (including chloride, sodium and sulphate), which are entering the lake from Mills Creek.

Differences in the benthic invertebrate community at *test* station ISL-1 are classified as **Negligible-Low** because there were no significant time trends in any of the measurement endpoints for benthic invertebrate community measurement endpoints and values of all of the benthic invertebrate community measurement endpoints at *test* station ISL-1 in fall 2010 were within the range of previously-measured values.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2010 at *test* station SHL-1 were within previously-measured concentrations with only a few exceptions. The ionic composition of water at *test* station SHL-1 continues to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, likely

[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.

a result of reduced surface-water inflow and increased groundwater influence in the lake associated with focal projects in the upper portion of the Shipyard Lake watershed. A WQI was not calculated for McClelland Lake because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Differences in the benthic invertebrate community at *test* station SHL-1 as compared to *baseline* conditions are classified as **Negligible-Low**. The increasing time trends in abundance and richness were significant and explained more than 20% of the variation in annual means but did not imply a negative change to the benthic invertebrate community. The direction of change in CA Axis 2 scores implies a decrease in the relative abundance of Amphipoda, which could indicate more stressful conditions; however, this was not reflected in the other measurement endpoints.

Poplar Creek and Beaver River The calculated mean open-water discharge (May to October) is 23.5% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **High**. The annual maximum daily discharge is 0.9% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**. The open-water minimum daily discharge is 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low**.

Concentrations of most water quality measurement endpoints were within previously-measured concentrations at *test* stations BER-1 and POC-1 and *baseline* station BER-2 and were generally consistent with regional *baseline* conditions in fall 2010. Differences in water quality in fall 2010 between *test* stations BER-1 and POC-1 and *baseline* station BER-2 and regional *baseline* conditions were classified **Negligible-Low.**

Differences in the benthic invertebrate community at *test* station POC-D1 as compared to *baseline* conditions are classified as **Moderate**, because of the significantly lower percent EPT at *test* station POC-D1 as compared to *baseline* reach BER-D2. Differences in sediment quality observed in fall 2010 in *test* reach POC-D1 and *baseline* reach BER-D2 compared to regional baseline conditions were **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within or below previously-measured concentrations at both reaches.

McLean Creek Concentrations of water quality measurement endpoints at *test* station MCC-1 were within previously-measured concentrations and within regional *baseline* conditions in fall 2010. The ionic composition of water at *test* station MCC-1 has been stable in recent sampling years compared to variability observed during historical years. The difference in water quality between *test* station MCC-1 and regional *baseline* conditions was **Negligible-Low**.

Fort Creek The calculated mean open-water period (May to October) discharge volume is 11.4% greater in the observed *test* flow volume than in the estimated *baseline* flow volume. This difference is classified as **Moderate**. In addition to changes in flow volume, variability in daily flow has also increased due to focal project activity in the watershed.

Differences in water quality in fall 2010 between *test* station FOC-1 and regional *baseline* fall conditions are classified as **Negligible-Low**. This indicates an improvement in water quality from 2009 with most water quality measurement endpoints within the range of previously-measured concentrations and within regional *baseline* water quality conditions. However, large increases in the concentration of sulphate have been observed at *test* station FOC-1 since 2008, which appear to have occurred in the absence of other apparent changes in water quality.

Differences in the benthic invertebrate community at *test* reach FOC-D1 as compared to *baseline* conditions are classified as **High** because decreases in richness and evenness were significant and richness, diversity and evenness were below the 5th percentile of regional *baseline* conditions. There was also a shift in dominant taxa from chironomids in the *baseline* period to the more tolerant tubificid worms at *test* reach FOC-D1 in the *test* period suggesting a negative change in the benthic invertebrate community. Differences in sediment quality observed in fall 2010 between *test* station FOC-D1 and regional *baseline* conditions were **Negligible-Low** with nearly all sediment quality measurement endpoints within previously-measured concentrations.

Regional Lakes Mercury concentrations in all northern pike and 73% of walleye from Brutus Lake in 2010 exceeded the Health Canada guideline for subsistence fishers, and mercury concentrations in two walleye exceeded the guidelines for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye. Given that all northern pike and most walleye exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike and walleye, dependent on the quantity of fish consumed. Mercury concentrations in fish from Brutus Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes. Mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health.

Mercury concentrations in lake whitefish and northern pike from Keith Lake were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Mercury concentrations in fish from Keith Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes.

Mercury concentrations in all captured walleye and all but one northern pike from Net Lake in 2010 exceeded the Health Canada guideline for subsistence fishers. The majority of walleye and two northern pike exceeded the guideline for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye and to general consumers consuming walleye given almost all walleye exceeded the general consumer guideline. Given that all northern pike exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike, dependent on the quantity of fish consumed. With the exception of two fish, mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Overall, the mercury concentrations in fish sampled from Net Lake were higher in northern pike and walleye compared to mercury concentration in fish from other regional lakes.

5.11.2 Mills Creek and Isadore's Lake

Monitoring was conducted in 2010 in the Mills Creek watershed for the Climate and Hydrology and Water Quality components and in Isadore's Lake for the Water Quality and Benthic Invertebrate Communities and Sediment Quality components.

5.11.2.1 Hydrologic Conditions: 2010 Water Year

Mills Creek at Highway 63 (RAMP Station S6) Continuous hydrometric data during the open-water season (May to October) have been collected at the RAMP Station S6 from 1997 to 2010 with annual data collected from 2006 to 2010. In the 2010 water year (WY), the open-water runoff and annual runoff volumes were 0.50 million m^3 and 0.73 million m^3, respectively. The 2010 WY annual runoff volume was 19% lower than the historical mean annual runoff, and the 2010 WY open-water runoff volume was 35% lower than the historical mean open-water runoff volume. Flows from November to December 2009 were lower than previously recorded during these months (Figure 5.11-3). Flows remained near the historical minimum values from January to March 2010. Flows increased in April due to snowmelt with the highest daily flow value of 0.12 m^3/s on April 30. This peak flow was 9% higher than the historical maximum flow recorded for this date. The highest open-water period flow recorded in the 2010 WY was 0.11 m^3/s on May 20. Although close to the annual maximum flow, this value was 37% lower than the historical mean open-water maximum daily flow. Flows decreased during late May and into June and remained close to the lower quartile of historical values for much of July and August. Rainfall in late August and early September increased flows in September to greater than historical median values. Flows then decreased to the historical lower quartile values by the end of the 2010 WY. The minimum open-water flow of 0.012 m^3/s recorded on August 21 was 33% lower than the mean historical minimum daily flow.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at Mills Creek is presented in Figure 5.11-3 and described below:

1. The closed-circuited land area from focal projects as of 2010 in the Mills Creek watershed is estimated to be 2.1 km^2 (Table 2.5-1). The loss of flow to Mills Creek that would have otherwise occurred from this land area is estimated at 0.38 million m^3.

2. As of 2010, the area of land change in the Mills Creek watershed from focal projects that was not closed-circuited is estimated to be 0.5 km^2 (Table 2.5-1). The increase in flow to Mills Creek that would not have otherwise occurred is estimated at 0.02 million m^3.

The estimated cumulative effect of land change is a loss of flow of 0.36 million m^3 to Mills Creek. The resulting observed and estimated *baseline* hydrographs for the RAMP Station S6 are presented in Figure 5.11-3. The calculated mean open-water discharge, minimum daily discharge, annual maximum daily discharge, and mean winter discharge are 33% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.11-3). This difference is classified as **High** (Table 5.11-1).

Station L3, Isadore's Lake Continuous lake level data have been collected at **Station L3** since February 2000. In the 2010 WY, lake levels at Isadore's Lake decreased from November to mid-December 2009 and remained near historical median values until March 2010 (Figure 5.11-4). Lake levels increased above historical upper quartile values in early April before monitoring temporarily ceased on April 11 due to equipment malfunction. When monitoring resumed on June 28 lake levels varied between the historical median and upper quartile values until the end of the 2010 WY.

5.11.2.2 Water Quality

In fall 2010, water quality samples were taken from:

- Isadore's Lake (*test* station ISL-1, sampled in 2000, 2001, and annually since 2004); and
- Mills Creek (*test* station MIC-1, initiated as a new RAMP station in fall 2010 as a tributary to Isadore's Lake).

Water quality monitoring was initiated in Mills Creek in fall 2010 to assess the potential influence of water quality going into Isadore's Lake because of changes that have been observed in the ionic character of water in Isadore's Lake in recent years.

Temporal Trends The following (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- Increasing concentrations of total dissolved solids, chloride, sodium, and sulphate at *test* station ISL-1 (2000, 2001, 2004- 2010); and
- A decreasing concentration in total arsenic at *test* station ISL-1 (2000, 2001, 2004-2010) (this trend is likely related to improvements in the analytical detection limit for total arsenic over the sampling period).

Trend analysis could not be completed for *test* station MIC-1 because there is only one year of data for this station.

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within the range of historical concentrations in fall 2010 at *test* station ISL-1 with the exception of (Table 5.11-4):

- chloride, dissolved organic carbon, and total strontium with concentrations that exceeded previously-measured maximum concentrations; and
- total mercury with a concentration that was below the previously-measured minimum concentration. In summer 2010, the analytical detection limit for total mercury was reduced by half relative to previous years resulting in a detectable concentration lower than the minimum historical concentration.

No historical data were available for test station MIC-1 for comparison with 2010 results because *test* station MIC-1 was only first sampled in 2010 (Table 5.11-5).

The high concentrations of various ions (e.g., chloride, strontium) measured in Isadore's Lake in fall 2010 are in contrast with ion concentrations measured in other waterbodies sampled by RAMP in fall 2010, and were at or near previously-measured minimum concentrations, likely because of a strong influence of surface-water runoff associated with heavy rainfall in late August and early September (Figure 5.11-3).

Ion Balance In the first two years of sampling (2000 and 2001), the ionic composition of water at *test* station ISL-1 was dominated by calcium and bicarbonate (Figure 5.11-5). Since 2004, the anion composition has shifted to a greater proportion of sulphate while calcium and magnesium continue to dominate the cation composition (Figure 5.11-5). The ionic composition in fall 2010 of water at *test* station MIC-1 was consistent with that of *test* station ISL-1 with slightly lower concentrations of magnesium (Figure 5.11-5). The consistent ionic composition between Mills Creek and Isadore's Lake supports the hypothesis that flows from Mills Creek has been responsible for determining the ion composition of Isadore's Lake in recent years.

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines The concentration of sulphate at *test* stations MIC-1 and ISL-1 and total nitrogen at *test* station ISL-1 exceeded relevant water quality guidelines in fall 2010 (Table 5.11-4 and Table 5.11-5).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in fall 2010 (Table 5.11-6):

- sulphide, total phenols, and total Kjeldahl nitrogen at *test* station ISL-1; and
- total iron at *test* station MIC-1.

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, concentrations of all water quality measurement endpoints at *test* station MIC-1 were within the range of regional *baseline* concentrations (Figure 5.11-6) with the exception of:

- total dissolved solids, total strontium, calcium, magnesium, and sulphate with concentrations that exceeded the 95th percentile of regional *baseline* concentrations; and
- dissolved phosphorus, total mercury, and total arsenic with concentrations that were below the 5th percentile of regional *baseline* concentrations.

Concentrations of water quality measurement endpoints in Isadore's Lake were not compared to regional *baseline* concentrations because lakes were not included in the calculation of regional *baseline* conditions given the ecological differences between lakes and rivers (Figure 5.11-6).

Water Quality Index The WQI value of Mills Creek in fall 2010 was 84.1 (Table 5.11-7) indicating a **Negligible-Low** difference in water quality compared to regional *baseline* conditions. The WQI was not calculated for lakes in 2010 based on concerns raised by the recent RAMP Peer Review regarding potential differences in regional water quality characteristics between lakes and flowing waters (AITF 2011).

Classification of Results Differences in water quality in fall 2010 between Mills Creek and regional *baseline* fall conditions are classified as **Negligible-Low**. While concentrations of a number of water quality measurement endpoints were outside regional *baseline* concentrations at *test* station MIC-1, the WQI value of Mills Creek in fall 2010 was 84.1. With respect to Isadore's Lake, the ionic composition of water at *test* station ISL-1 in fall 2010 was dominated by bicarbonate as in past sampling years, and concentrations of water quality measurement endpoints were within the range of previously-measured concentrations and regional *baseline* concentrations. However, increasing concentrations of several major ions have been observed in recent years (including chloride, sodium and sulphate), which are entering the lake from Mills Creek.

5.11.2.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at depositional *test* station ISL-1 in Isadore's Lake (sampled from 2006 to 2010).

2010 Habitat Conditions Water in Isadore's Lake in fall 2010 was alkaline (pH: 7.2) and had a high conductivity (563 µS/cm) and the substrate was dominated by silt (82%) and low total organic carbon (3%) (Table 5.11-8).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of Isadore's Lake in fall 2010 was dominated by chironomids (50%) and copepods (22%) with subdominant taxa consisting of Ostracoda (14%) and Nematoda

(12%) (Table 5.11-9). Dominant chironomids included common species such as *Einfeldia*, *Chironomus*, *Dicrotendipes*, and *Endochironomus*.

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* station ISL-1 from 2006 to 2010 (Hypothesis 1, Section 3.2.3.1). There were no significant time trends in any of the measurement endpoints for benthic invertebrate communities (Table 5.11-10).

Comparison to Published Literature The percent of the benthic invertebrate community fauna as Chironomidae has been within the expected range for lake conditions (e.g., Griffiths 1998) and the percent of the fauna as tubificid worms has remained low indicating that there has been no environmental contamination or enrichment (Hynes 1960, Griffiths 1998).

2010 Results Relative to Historical Conditions Values of all of the benthic invertebrate community measurement endpoints at *test* station ISL-1 in fall 2010 were within the range observed in previous years (Figure 5.11-7). Total abundance, richness, diversity and evenness have increased from the previous two years of sampling in Isadore's Lake. Total abundance in fall 2010 was 23,623 per m^2, which was almost twice as high as 2009. There was an average of eight taxa per sample in 2010, which was higher than the previous two years, but slightly below 2006 when there were ten taxa per sample. Simpson's Diversity and evenness were within the range of previously-measured values and higher than 2009. Less than 1% of the fauna consisted of EPT taxa with only one individual Ephemeropteran (*Caenis* sp.) observed, which was more than previous years of sampling (Figure 5.11-7).

Classification of Results Differences in the benthic invertebrate community at *test* station ISL-1 are classified as **Negligible-Low** because there were no significant time trends in any of the measurement endpoints for benthic invertebrate community measurement endpoints and values of all of the benthic invertebrate community measurement endpoints at *test* station ISL-1 in fall 2010 were within the range of previously-measured values.

Sediment Quality

Sediment quality in fall 2010 was sampled in Isadore's Lake (*test* station ISL-1, sampled in 2001 and continuously from 2006 to 2010) in the same location as the sampling for benthic invertebrate communities was conducted at *test* station ISL-1.

2010 Results Relative to Historical Concentrations In fall 2010, concentrations of low-molecular-weight hydrocarbons (CCME Fraction-1, including BTEX) were below detection limits and concentrations of heavier hydrocarbon fractions (CCME F2 to F4) were within previously-measured concentrations (Table 5.11-11). Concentrations of all other sediment quality measurement endpoints were within previously-measured concentrations with the exception of naphthalene, which had a concentration that exceeded its previously-measured maximum concentration (Table 5.11-11 and Figure 5.11-8).

Comparison to Sediment Quality Guidelines There were no sediment quality measurement endpoints with concentrations that exceeded sediment or soil quality guidelines in fall 2010 with the exception of Fraction 3 (C16-C34) hydrocarbons and arsenic (Table 5.11-11).

5.11.3 Shipyard Lake

Monitoring was conducted in Shipyard Lake in fall 2010 for the Water Quality and the Benthic Invertebrate Communities and Sediment Quality components.

5.11.3.1 Water Quality

Water quality samples were taken from Shipyard Lake in fall 2010 at *test* station SHL-1 (sampled annually from 1998 to 2010).

Temporal Trends The following statistically significant (α=0.05) trends in fall concentrations of water quality measurement endpoints were detected:

- decreasing concentrations of total phosphorus, sulphate, and arsenic (trends in arsenic are likely related to improvements in the analytical detection limit over the sampling period); and
- increasing concentrations of total boron, chloride, magnesium, potassium, and sodium.

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints at *test* station SHL-1 in fall 2010 were within previously-measured concentrations (Table 5.11-12) with the exception of:

- sodium and chloride with concentrations that exceeded previously-measured maximum concentrations;
- calcium and sulphate with concentrations that were below previously-measured minimum concentrations; and
- total mercury with a concentration that was below the previously-measured minimum concentration. In summer 2010, the analytical detection limit of mercury was reduced by half relative to previous years resulting in an observed concentration lower than the historical minimum concentration.

Ion Balance The ionic composition of water at *test* station SHL-1 in fall 2010 was a continuance of recent trends towards increasing relative concentrations of sodium and chloride (Figure 5.11-5). As discussed in RAMP (2010) the shift in the ionic composition of water in Shipyard Lake from calcium-bicarbonate to sodium/chloride is a result of reduced surface-water inflow and increases in groundwater influence in the lake's catchment area.

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints at *test* station SHL-1 in fall 2010 were within water quality guidelines with the exception of total nitrogen (Table 5.11-12).

Other Water Quality Guideline Exceedances Concentrations of sulphide, total iron, total phenols, and total Kjeldahl nitrogen exceeded water quality guidelines in fall 2010 at *test* station SHL-1 (Table 5.11-6).

Classification of Results Concentrations of most water quality measurement endpoints in fall 2010 at *test* station SHL-1 were within previously-measured concentrations with only a few exceptions. The ionic composition of water at *test* station SHL-1 continues to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, likely a result of reduced surface-water inflow and increased groundwater influence in the lake associated with focal projects in the upper portion of the Shipyard Lake watershed. The WQI was not calculated for lakes in 2010 based on concerns raised by the recent RAMP Peer Review regarding potential differences in regional water quality characteristics between lakes and flowing waters (AITF 2011).

5.11.3.2 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 in Shipyard Lake (depositional *test* station SHL-1, sampled from 2000 to 2010).

2010 Habitat Conditions Water at *test* station SHL-1 in fall 2010 was alkaline (pH: 7.9) and had a high conductivity (403 µS/cm) and the substrate was dominated by silt (58%) and sand (24%) and moderate levels of organic carbon (12%) (Table 5.11-13).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* station SHL-1 in fall 2010 was dominated by copepods (27%), chironomids (26%), and Naididae (12%) with subdominant taxa consisting of Ostracoda (9%), Cladocera, (6%), and Gastropoda (5%) (Table 5.11-14). Dominant chironomids included common forms such as *Einfeldia*, *Chironomous,* and *Dicrotendipes*. Gastropoda (snails) included *Armiger crista, Valvata sincera, and Gyraulus*.

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* station SHL-1 from 2006 to 2010 (Hypothesis 1, Section 3.2.3.1). There was a significant increase in abundance, richness, and diversity and a significant change in CA Axis 1 and CA Axis 2 scores over time at *test* station SHL-1, with the significant changes in total abundance, taxa richness, and CA Axis 2 scores explaining more than 20% of the variation in annual means (Table 5.11-15). The significant change in the CA Axis 2 reflects decreasing relative abundance of amphipods and increasing relative abundances of water mites (Hydracarina) over time (Table 5.11-14).

Comparison to Published Literature The benthic invertebrate community at *test* station SHL-1 in fall 2010 had a faunal composition that would be expected in a lake (Brinkhurst, 1974). The community contained relatively high abundances of fingernail clams (Bivalvia: Sphaeriidae) and snails (Gastropoda), with mayflies (Ephemeroptera) and caddisflies (Trichoptera) present, and low relative abundances of tubificid worms and chironomids (Brinkhurst, 1974, Parsons *et al*. 2010).

2010 Results Relative to Historical Conditions The values of total abundance and taxa richness were greater than previously-measured values and the values of diversity, evenness, and percent EPT were within the range of previously-measured values in fall 2010 at *test* station SHL-1 (Figure 5.11-9). Total abundance increased in 2010 to approximately 63,500 individuals per m^2, which is almost twice as high as the previously-measured maximum value in 2008. An average of 27 taxa was found per sample in 2010, which is higher than any previous sampling years. Diversity and evenness were relatively consistent in comparison with previous sampling years. About 5% of the fauna consisted of EPT taxa (Figure 5.11-9), dominated by Ephemeroptera (*Caenis* sp.) and Trichoptera (*Polycentropus, Oecetis, Phryganea, Phryganea*).

Classification of Results Differences in the benthic invertebrate community at *test* station SHL-1 as compared to *baseline* conditions are classified as **Negligible-Low**. The increasing time trends in abundance and richness were significant and explained more than 20% of the variation in annual means but did not imply a negative change in the benthic invertebrate community. The direction of change in CA Axis 2 scores implies a reduction in the relative abundance of Amphipoda, which could indicate more stressful conditions; however, this was not reflected in the other measurement endpoints.

Sediment Quality

Sediment quality in fall 2010 was sampled in Shipyard Lake at *test* station SHL-1 in the same location as the benthic invertebrate community sampling. Sediment quality has been sampled at this station every year from 2001 to 2010 with the exception of 2005.

2010 Results Relative to Historical Concentrations Sediments at *test* station SHL-1 in fall 2010 were dominated by silt with lesser amounts of clay and sand (42%, 27%, and 30% respectively (Table 5.11-16). TOC levels were moderate (13%) and within previously-measured concentrations (Table 5.11-16). Low-molecular-weight hydrocarbons (CCME Fraction 1 and BTEX) were below detection limits at *test* station SHL-1 and concentrations of heavier hydrocarbon fractions in fall 2010 were within previously-measured fall concentrations at all *test* stations (Table 5.11-16 and Figure 5.11-10). Concentrations of all other sediment quality measurement endpoints at *test* station SHL-1 in fall 2010 were within previously-measured concentrations (Table 5.11-16 and Figure 5.11-10).

Comparison to Sediment Quality Guidelines Concentrations of F2 and F3 hydrocarbons and total arsenic exceeded CCME soil quality guidelines at *test* station SHL-1 in fall 2010 (Table 5.11-16).

5.11.4 Poplar Creek and Beaver River

Monitoring was conducted in the Poplar Creek and Beaver River watersheds in 2010 for the Climate and Hydrology (Poplar Creek only), Water Quality, and Benthic Invertebrate Communities and Sediment Quality components.

5.11.4.1 Hydrologic Conditions: 2010 Water Year

WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 Continuous hydrometric data during the open-water (May to October) period have been collected for the WSC Station 07DA007 (RAMP Station S11) from 1973 to 1986 and from 1996 to 2010 with annual data collected from 1973 to 1986. The open-water runoff volume during the 2010 WY was 22.2 million m^3. This value is 3% higher than the historical mean open-water runoff volume of 21.6 million m^3. Flows during the 2010 water year (WY) were generally below historical median flows until August 7 and above historical median flows from early August to the end of the 2010 WY (Figure 5.11-11). Flows decreased steadily from May to August with the exception of one rainfall-induced peak flow on May 26 that was 3.2 m^3/s; approximately 50% greater than the median historical flow recorded for this day. Flows continued to decrease through June and July to below the historical lower quartile value and increased to above the historical upper quartile in response to rainfall in August and early September. A peak flow of 4.6 m^3/s on September 11 was the maximum daily flow in the 2010 WY during the open-water period (May to October); this peak flow was 41% lower than the historical mean open-water maximum daily flow. All flows in September were between the historical median and upper quartile flow levels. The minimum open-water daily flow of 0.11 m^3/s on July 29 was 83% higher than the mean historical minimum daily flow of 0.06 m^3/s.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The 2010 WY estimated water balance for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 is presented in Table 5.11-17 and described below:

1. The closed-circuited land area from focal projects as of 2010 is estimated to be 3.1 km^2 (Table 2.5-1). The loss of flow to Poplar Creek that would have otherwise occurred from this land area is estimated at 0.42 million m^3.

2. As of 2010, the area of land change from focal projects in the Poplar Creek watershed that was not closed-circuited is estimated to be 1.7 km^2 (Table 2.5-1). The increase in flow to Poplar Creek that would not have otherwise occurred from this land area is estimated at 0.05 million m^3.

3. From April 24 to October 31, Syncrude reported a total discharge of 5.18 million m^3 of water to Poplar Creek via the Poplar Creek spillway.

The estimated cumulative effects of land change and water discharges is an increase in flow of 4.81 million m^3 to Poplar Creek in the 2010 WY. The resulting observed and estimated *baseline* hydrographs for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 are presented in Figure 5.11-11. The calculated mean open-water discharge (May to October) is 23.4% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.11-17). This difference is classified as **High** (Table 5.11-18). The annual maximum daily discharge is 0.9% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low** (Table 5.11-18). The open-water minimum daily discharge is 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference is classified as **Negligible-Low** (Table 5.11-18).

5.11.4.2 Water Quality

In fall 2010, water quality samples were taken from:

- the Beaver River near its mouth (*test* station BER-1, sampled from 2003 to 2010);
- the upper Beaver River upstream of all focal project developments (*baseline* station BER-2, sampled from 2008 to 2010); and
- Poplar Creek near its mouth (*test* station POC-1, sampled from 2000 to 2010).

Sampling was also conducted at *baseline* station BER-2 in winter, spring, and summer in 2010. The upper Beaver River flows via the Poplar Creek Reservoir to Poplar Creek (i.e., it is hydrologically connected to *test* station POC-1) rather than to the lower Beaver River where *test* station BER-1 is located. The lower Beaver River was isolated from the upper Beaver watershed in the early 1970s through the development of Syncrude's Mildred Lake project. The lower Beaver River is downstream of a seepage-collection pond at the toe of the dam of the Mildred Lake tailings facility (seepage collected in this pond is pumped back into the tailings facility).

Temporal Trends There were no statistically significant (α=0.05) trends in fall concentrations of water quality measurement endpoints at *test* station BER-1 and *test* station POC-1. Trend analyses could not be completed for *baseline* station BER-2 due to an insufficient length of time series data for this station.

2010 Results Relative to Historical Concentrations Concentrations of water quality measurement endpoints that were outside previously-measured concentrations at *test* stations BER-1 and POC-1 were:

- total nitrogen, total Kjeldahl nitrogen, and total phosphorus with concentrations that exceeded previously-measured maximum concentrations, total magnesium with a concentration that was below the previously-measured minimum concentrations, and total molybdenum with a concentration that was equal to the previously-measured minimum concentration at *test* station POC-1 (Table 5.11-19). In previous years, concentrations of total mercury were below analytical detection limits, but the decrease of the analytical detection limit for total mercury in 2010 resulted in a total mercury concentration at *test* station POC-1 in fall 2010 that was below the previously-measured minimum concentration; and

- total nitrogen, total phenols, and total Kjeldahl nitrogen, with concentrations that exceeded previously-measured maximum concentrations and sulphate with a concentration that was below previously-measured minimum concentrations at *test* station BER-1 (Table 5.11-20). Some of the major ions were near previously-measured minimum concentrations (Table 5.11-20); the relatively low ion concentrations in fall 2010 likely relate to a greater influence of surface runoff caused by long periods of rain in late August and early September (Figure 5.11-11).

Concentrations of most water quality measurement endpoints in fall 2010 at *baseline* station BER-2 represented either historical minimum or maximum concentrations (Table 5.11-19). Concentrations of a number of water quality measurement endpoints at *baseline* station BER-2 were higher or lower than previously-measured in 2008 and 2009 including suspended solids, total aluminum, total nitrogen, and total mercury with concentrations that exceeded the previously-measured maximum concentrations and nearly all major ions with concentrations that were below previously-measured minimum concentrations (Table 5.11-21).

Ion Balance The ionic composition of water at *test* station POC-1 has been highly variable across sampling years (Figure 5.11-12). In fall 2010, the ionic composition at *test* station POC-1 was dominated by bicarbonate, calcium, and sodium, which was similar to the ionic composition of water in fall 2006 and 2008. The ionic composition of water at *baseline* station BER-2 was similar to the previous two years and was similar to *test* station POC-1 in fall 2010 (Figure 5.11-12). The ionic composition of water at *test* station BER-1 has also been highly variable across sampling years. In fall 2010, the ionic composition at *test* station BER-1 was similar to fall 2009, dominated by bicarbonate, calcium, and sodium and with a higher relative concentration of sulphate than either *baseline* station BER-2 and *test* station POC-1 (Figure 5.11-12).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of the following water quality measurement endpoints exceeded water quality guidelines in fall 2010 (Table 5.11-18 to Table 5.11-19):

- total mercury at *baseline* station BER-2 with a concentration that exceeded AENV guidelines for chronic exposure, but was below guidelines for acute exposure;

- total phosphorus at *test* station POC-1 and *baseline* station BER-2; and

- total nitrogen and total aluminum at *test* station POC-1, *test* station BER-1, and *baseline* station BER-2.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in 2010 (Table 5.11-6):

- sulphide, total Kjeldahl nitrogen, total iron, dissolved iron, and total phenols in fall at *test* station BER-1;
- sulphide, total aluminum, total phosphorus, total Kjeldahl nitrogen, total iron, dissolved iron, total chromium, and total phenols in fall at *baseline* station BER-2;
- sulphide, total nitrogen, dissolved cadmium, total cadmium, total iron, total phenols, total phosphorus, and total aluminum in winter at *baseline* station BER-2;
- sulphide, total phosphorus, total Kjeldahl nitrogen, total nitrogen, total cadmium, total chromium, total aluminum, dissolved iron, total phenols, and total iron in summer at *baseline* station BER-2;
- sulphide, total dissolved phosphorus, total phosphorus, total nitrogen, total Kjeldahl nitrogen, dissolved iron, total aluminum, total cadmium, total phenols, and total iron in summer at *baseline* station BER-2; and
- sulphide, total Kjeldahl nitrogen, total iron, total chromium, total phosphorus, and total phenols in fall at *test* station POC-1.

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2010 at *test* station BER-1, *test* station POC-1 and *baseline* station BER-2 were within regional *baseline* concentrations (Figure 5.11-13) with the following exceptions:

- total dissolved solids and chloride at *test* station BER-1 with fall 2010 concentrations that exceeded the 95th percentile of regional *baseline* concentrations;
- total suspended solids and total mercury at *baseline* station BER-2 with fall 2010 concentrations that exceeded the 95th percentile of regional *baseline* concentrations; and
- total mercury at *test* station POC-1 with a concentration that was below the 5th percentile of regional *baseline* concentrations.

Water Quality Index The WQI values for fall 2010 for *test* stations BER-1 and POC-1 and *baseline* station BER-2 indicated **Negligible-Low** differences from regional *baseline* concentrations (Table 5.11-6), which is an improvement in water quality at all stations relative to 2009.

Classification of Results Concentrations of most water quality measurement endpoints were within previously-measured concentrations at *test* stations BER-1 and POC-1 and *baseline* station BER-2 and were generally consistent with regional *baseline* conditions in fall 2010. Differences in water quality in fall 2010 between *test* stations BER-1 and POC-1 and *baseline* station BER-2 and regional *baseline* conditions were classified as **Negligible-Low.**

5.11.4.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at:

- depositional *test* reach POC-D1, sampled since 2008; and
- depositional *baseline* reach BER-D2, sampled since 2008. This reach was used as *baseline* for comparison with *test* reach POC-D1.

2010 Habitat Conditions Water at *test* reach POC-D1 in fall 2010 was deep (0.8 m), slow-flowing (0.3 m/s), alkaline (pH: 8.2) and had high conductivity (309 µS/cm) with a substrate dominated by sand (68%) and a moderate amount of silt (23%), and low total organic carbon (3%) (Table 5.11-22). Water at *baseline* reach BER-D2 in fall 2010 was deep (0.7 m), slow-flowing (0.5 m/s), slightly alkaline (pH: 7.9) and had high conductivity (229 µS/cm) with a substrate dominated by sand (88%) and low total organic carbon (1%) (Table 5.11-22).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach POC-D1 was dominated by chironomids (20%) and Tubificidae worms (22%) with subdominant taxa consisting of Ostracoda (14%) and Bivalvia (10%) (Table 5.11-23). Dominant chironomid genera consisted primarily of *Stempellina* and *Polypedilum*.

The benthic invertebrate community at *baseline* reach BER-D2 was dominated by chironomids (20%) and tubificid worms (22%) with subdominant taxa consisting of Ceratapogonidae (11%), Hydracarina (8%), and Coleoptera (8%) (Table 5.11-23). Dominant chironomid consisted primarily of *Cryptochironomus, Paralauterborniella, Polypedilum, Paratendipes*, and *Paracladopelma* and Coleoptera were mainly from the genus *Dubiraphia.* Ephemeroptera (6%; *Hexagenia limbata*) were present in this reach (Table 5.11-23).

Temporal and Spatial Comparisons For temporal comparisons, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* reach POC-D1 (Hypothesis 1, Section 3.2.3.1). There was a significant increase in abundance, richness, diversity and evenness as well as a significant time trend in CA Axis 1 scores at *test* reach POC-D1, all of which explained more than 20% of the differences in annual means (Table 5.11-24). The significant increase in CA Axis 1 scores at *test* reach POC-D1 indicates a shift towards *baseline* conditions in fall 2010.

For spatial comparisons, changes in mean values of measurement endpoints for benthic invertebrate communities (Hypothesis 3, Section 3.2.3.1) were tested between t*est* reach POC-D1 and *baseline* reach BER-D2. Abundance was significantly higher and percent EPT was significantly lower at *test* reach POC-D1 than *baseline* reach BER-D2, and both these differences explained more than 20% of the variation in the mean values of the measurement endpoints (Table 5.11-24).

Comparison to Published Literature The benthic invertebrate community at *test* reach POC-D1 in fall 2010 was what would be expected for a sand-based stream. The percent of taxa as tubificid worms was consistent with *baseline* conditions comprising 22% of the fauna with chironomids accounting for 20% of the taxa (Table 5.11-23 and Figure 5.11-14), indicating that the benthic invertebrate community is not overtly stressed (Hynes 1960, Griffiths 1998). The benthic invertebrate community at *test* reach POC-D1 included clams, snails, mayflies and caddisflies. The community was potentially somewhat unusual in having a relatively high proportion of the tolerant Enchytraeidae worm (17%) and Ostracoda (14%).

2010 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints for benthic invertebrate communities at *test* reach POC-D1 were within regional *baseline* depositional conditions (Figure 5.11-14). Abundance at *test* reach POC-D1 was higher than *baseline* reach BER-D2 in fall 2010 but within previously-measured values. Taxa richness per sample (~ 20) and diversity at *test* reach POC-D1 exceeded previously-measured values for this reach and *baseline* reach BER-D2. Percent EPT was low in 2010 similar to prior years (Figure 5.11-14). CA axis scores for *test* reach POC-D1 were within regional *baseline* depositional conditions (Figure 5.11-15).

Classification of Results Differences in the benthic invertebrate community at *test* station POC-D1 as compared to *baseline* conditions are classified as **Moderate**, because of the significantly lower percent EPT at *test* station POC-D1 compared to *baseline* reach BER-D2.

Sediment Quality

Sediment quality was sampled in fall 2010 at:

- *test* station POC-D1 (sampled intermittently from 1997 to 2010); and
- *baseline* station BER-D2 (sampled from 2008 to 2010).

2010 Results Relative to Historical Concentrations Sediments at *test* station POC-D1 in fall 2010 were dominated by sand (62%) with smaller proportions of silt and clay (27% and 11%, respectively) (Table 5.11-25). Concentrations of all measured total hydrocarbon fractions and PAHs in fall 2010 were within previously-measured fall concentrations with the exception of naphthalene with a concentration that exceeded previously-measured maximum concentrations (Table 5.11-25 and Figure 5.11-16).

Sediments at *baseline* station BER-D2 in fall 2010 were dominated by sand 87%) (Table 5.11-26). Concentrations of all sediment quality measurement endpoints in fall 2010 were within or below previously-measured minimum concentrations with the exception of naphthalene with a concentration that exceeded the previously-measured maximum concentration (Table 5.11-26 and Figure 5.11-17).

Direct tests of sediment toxicity to invertebrates at *test* station POC-D1 showed that growth and survival of the amphipod *Hyalella* and the midge *Chironomus* were within previously-measured values with the exception of *Chironomus* growth which exceeded the previously-measured maximum value (Table 5.11-25). Direct tests of sediment toxicity to invertebrates at *baseline* station BER-D2 showed that survival for both *Hyalella* and *Chironomus* were within previously-measured values while growth in *Hyalella* and *Chironomus* were lower than previously-measured minimum and higher than previously-measured maximum values, respectively (Table 5.11-26).

Comparison with Sediment Quality Guidelines With the exception of concentrations of F3 hydrocarbons, which exceeded CCME soil quality guidelines at *test* station POC-D1 (Table 5.11-25), there were no sediment quality guideline exceedances at *test* station POC-D1 (Table 5.11-25) or *baseline* station BER-D2 (Table 5.11-26).

Sediment Quality Index The SQI values for *test* station POC-D1 and *baseline* station BER-D2 were 89.9 and 98.7, respectively (Table 5.11-27) indicating **Negligible-Low** differences in sediment quality conditions compared to regional *baseline* conditions.

Classification of Results Differences in sediment quality observed in fall 2010 in *test* reach POC-D1 and *baseline* reach BER-D2 compared to regional *baseline* conditions were **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within or below previously-measured concentrations at both reaches.

5.11.5 McLean Creek

Monitoring was conducted in the McLean Creek watershed in 2010 for the Water Quality component.

5.11.5.1 Water Quality

In fall 2010, water quality samples were collected near the mouth of McLean Creek at *test* station MCC-1, sampled from 1999 to 2010.

Temporal Trends A significant (α=0.05) decreasing concentration of total arsenic was observed at *test* station MCC-1. This trend is likely related to improvements in the analytical detection limit for arsenic over the sampling period.

2010 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints at *test* station MCC-1 in fall 2010 were within previously-measured concentrations with the exception of total nitrogen, total mercury, and total Kjeldahl nitrogen, with concentrations that exceeded previously-measured maximum concentrations and total chromium with a concentration that was below the previously-measured minimum concentration (Table 5.11-28).

Ion Balance The ionic composition of water at *test* station MCC-1 has been consistent since fall 2008 and dominated by calcium and bicarbonate (Figure 5.11-12).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of total nitrogen and total aluminum exceeded relevant water quality guidelines at *test* station MCC-1 in fall 2010 (Table 5.11-28).

Other Water Quality Guideline Exceedances Concentrations of sulphide, total phenols, total Kjeldahl nitrogen, total iron, and total chromium exceeded relevant water quality guidelines at *test* station MCC-1 in fall 2010 (Table 5.11-6).

2010 Results Relative to Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints at *test* station MCC-1 in fall 2010 were within regional *baseline* concentrations (Figure 5.11-13).

Water Quality Index The WQI value of 100 for *test* station MCC-1 in fall 2010 indicated **Negligible-Low** differences from regional *baseline* conditions (Table 5.11-7).

Classification of Results Concentrations of water quality measurement endpoints at *test* station MCC-1 were within previously-measured concentrations and within regional *baseline* conditions in fall 2010. The ionic composition of water at *test* station MCC-1 has been stable in recent sampling years compared to variability observed during historical years. The difference in water quality between *test* station MCC-1 and regional *baseline* conditions was **Negligible-Low**.

5.11.6 Fort Creek

Monitoring was conducted in the Fort Creek watershed in 2010 for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality components.

5.11.6.1 Hydrologic Conditions: 2010 Water Year

Fort Creek at Highway 63 (RAMP Station S12) Hydrometric data have been collected during the open-water period (May to October) at RAMP Station S12 from 2000 to 2001 and 2006 to 2010. The 2010 WY open-water runoff volume at Station S12 was 1.9 million m^3, which was 31% higher than the mean historical open-water runoff volume of 1.4 million m^3. Daily flows exceeded the historical maximum daily flow values for at least one day each month during the open-water season (Figure 5.11-18). The maximum open-water daily flow of 0.4 m^3/s on May 20 was 22% below the mean historical maximum daily flow. Similar variability was seen during the low flow period where flows were below the historical minimum daily flow for at least one day in each of May, June and July (Figure 5.11-18). The minimum open-water daily flow of 0.02 m^3/s on July 8 was 34% less than the mean historical open-water minimum daily flow. This variability in daily flows is likely due to the fact that focal project development in the watershed as of 2010 has resulted in 62.5% of the watershed as not being cleared.

Differences Between Observed *Test* Flow Volume and Estimated *Baseline* Flow Volume The estimated water balance at RAMP Station S12 is presented in Table 5.11-29 and described below:

1. The closed-circuited land area from focal projects as of 2010 in the Fort Creek watershed is estimated to be 0.3 km^2 (Table 2.5-1). 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. As of 2010, the area of land change from focal projects in the Fort Creek watershed that was not closed-circuited is estimated to be 19.7 km^2 (Table 2.5-1). The increase in flow to Fort Creek that would not have otherwise occurred from this land area is estimated at 0.21 million m^3.

The estimated cumulative effect of this land change is an increase in flow of 0.19 million m^3 to Fort Creek. The calculated mean open-water period (May to October) discharge volume is 11.4% greater in the observed *test* flow volume than in the estimated *baseline* flow volume. This difference is classified as **Moderate** (Table 5.11-1). In addition to changes in flow volume, variability in daily flow has also increased due to focal project activity in the watershed. This variability in daily flow was sufficiently large to adjust the expected flow characteristics previously evident at this station. The 2010 WY showed no discernible freshet or precipitation-driven annual maximum daily discharge dominating the annual hydrograph, and also does not display an open-water minimum daily flow following a sustained dry period as is typical in previous years and for other systems. For this reason, the two daily measurement endpoints (annual maximum daily discharge and open-water season minimum discharge) would not be valid points of comparison with historical data for this station for the 2010 WY.

5.11.6.2 Water Quality

In fall 2010, water quality samples were taken from the mouth of Fort Creek at *test* station FOC-1 (sampled intermittently from 2000 to 2010).

Temporal Trends A decrease in the concentration of dissolved phosphorus (2000 to 2003 and 2006 to 2010) was the only significant (α=0.05) temporal trend in concentrations of water quality measurement endpoints detected at *test* station FOC-1.

2010 Results Relative to Historical Concentrations In fall 2010, concentrations of water quality measurement endpoints were within previously-measured concentrations with the exception of (Table 5.11-30):

- sulphate and total phenols with concentrations that exceeded previously-measured maximum concentrations; and
- total dissolved phosphorus with a concentration that was below the previously-measured minimum concentration.

Ion Balance In comparison with previous years, the ionic composition of water in fall 2010 at *test* station FOC-1 showed a shift toward an increasing proportion of sulphate, which was not associated with any changes in the cation composition (Figure 5.11-19).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints measured at *test* station FOC-1 were below water quality guidelines (Table 5.11-30).

Other Water Quality Guideline Exceedances Concentrations of total phenols and total iron exceeded water quality guidelines at *test* station FOC-1 in fall 2010 (Table 5.11-6).

2010 Results Relative to Regional *Baseline* Concentrations In fall 2010, concentrations of water quality measurement endpoints at *test* station FOC-1 were within regional *baseline* concentrations (Figure 5.11-20) with the exception of:

- total dissolved solids, calcium, and sulphate with concentrations that exceeded the 95th percentile of their regional *baseline* concentrations; and
- dissolved phosphorus with a concentration that was below the 5th percentile of regional *baseline* concentrations.

Water Quality Index The WQI value for *test* station FOC-1 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.11-7).

Classification of Results Differences in water quality in fall 2010 between *test* station FOC-1 and regional *baseline* fall conditions are classified as **Negligible-Low**. This indicates an improvement in water quality from 2009 with most water quality measurement endpoints within the range of previously-measured concentrations and within regional *baseline* water quality conditions. However, large increases in the concentration of sulphate have been observed at *test* station FOC-1 since 2008, which appear to have occurred in the absence of other apparent changes in water quality.

5.11.6.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2010 at depositional *test* reach FOC-D1 (designated as *baseline* from 2001 to 2003 and as *test* from 2004 to 2010).

2010 Habitat Conditions Water at *test* reach FOC-D1 fall 2010 was shallow (0.3 m), slow-flowing (0.3 m/s), alkaline (pH: 8.2) and had high conductivity (504 µS/cm). The substrate was dominated by sand (87%) and silt (10%) with low amounts of organic carbon (3%) (Table 5.11-31).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach FOC-D1 was dominated by tubificid worms (62%) and chironomids (23%) with subdominant taxa consisting of nematodes (6%), copepods (4%), and Hydracarina (2%) (Table 5.11-32). The most dominant genera of chironomid was the common form *Polypedilum*. One individual from the order Trichoptera (*Oxyethira*) was observed at *test* reach FOC-D1.

Temporal and Spatial Comparisons Two temporal comparisons were conducted for *test* reach FOC-D1.

First, changes in mean values of measurement endpoints for benthic invertebrate communities at *test* reach FOC-D1 were tested between the years before and after the reach were designated as *test* (Hypothesis 2, Section 3.2.3.1). Abundance and taxa richness were significantly lower during the *test* period and CA Axis 1 scores have significantly varied from *baseline* to *test* periods reflecting an overall increase in the relative abundance of tubificid worms (Table 5.11-33). These changes accounted for greater than 20% of the variation in the annual means (Table 5.11-33).

Second, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that reach FOC-D1 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). There was a significant decrease in evenness during the *test* period accounting for more than 20% of the variation in annual mean values (Table 5.11-33).

Comparison to Published Literature The percent of the fauna as tubificid worms at *test* reach FOC-D1 was more than 60% in 2010. The benthic invertebrate community at this reach did not include sphaeriid fingernail clams, which were present during the *baseline* period. The benthic invertebrate community in fall 2010 also did not include species of mayflies or stoneflies, though caddisflies were present. The absence of clams, mayflies and stoneflies and the dominance of worms suggest some level of disturbance relative to the *baseline* period.

2010 Results Relative to Regional *Baseline* Conditions Richness, diversity and evenness were below the 5th percentile of regional *baseline* conditions (Figure 5.11-21). The multivariate CA axis scores were within the regional *baseline* conditions but outside of *baseline* conditions for *test* reach FOC-D1 (Figure 5.11-22). The deviations in CA axis scores reflected a shift in dominance of tubificid worms and a smaller proportion of chironomids.

Classification of Results Differences in the benthic invertebrate community at *test* reach FOC-D1 as compared to *baseline* conditions are classified as **High** because decreases in richness and evenness were significant and richness, diversity and evenness were below the 5th percentile of regional *baseline* conditions. There was also a shift in dominant taxa from chironomids in the *baseline* period to the more tolerant tubificid worms at *test* reach FOC-D1 in the *test* period suggesting a negative change in the benthic invertebrate community.

Sediment Quality

Sediment quality was sampled in fall 2010 at *test* station FOC-D1 in the same location as the benthic invertebrate communities *test* reach FOC-D1. *Test* reach FOC-D1 was designated as *baseline* from 2001 to 2004 and as *test* from 2005 to 2010.

2010 Results Relative to Historical Concentrations Sediments at *test* station FOC-D1 were dominated by sand (91%) and low levels of total organic carbon (3%) (Table 5.11-34). The proportions of sand, silt and TOC were within historical values while the proportion of clay was below the previously-measured minimum value (Table 5.11-34 and Figure 5.11-23). Low-molecular-weight hydrocarbons (CCME Fraction 1 and BTEX) were below detection limits at *test* station FOC-D1 in fall 2010 while concentrations of heavier hydrocarbon fractions and all PAHs were within previously-measured concentrations with the exception of fraction F4 (C16-C50), which exceeded the previously-measured maximum concentration (Table 5.11-34).

Direct tests of sediment toxicity to invertebrates at *test* station FOC-D1 showed that growth and survival of both the amphipod *Hyalella* and the midge *Chironomus* were within previously-measured historical values (Table 5.11-34).

Comparison of Sediment Quality Measurement Endpoints to Sediment Quality Guidelines In fall 2010, concentrations of all sediment quality measurement endpoints at *test* station FOC-D1 were within sediment quality guidelines with the exception of CCME F3 hydrocarbons (Table 5.11-34).

Sediment Quality Index A SQI value of 93.2 was calculated for test station FOC-D1 for fall 2010 indicating a **Negligible-Low** difference from regional *baseline* conditions (Table 5.11-27). The SQI values for *test* station FOC-D1 have been variable since sediment quality monitoring began in 2000 ranging from 76.5 to 100 (n=5).

Classification of Results Differences in sediment quality observed in fall 2010 between *test* station FOC-D1 and regional baseline conditions were **Negligible-Low** with nearly all sediment quality measurement endpoints within previously-measured concentrations.

5.11.7 Susan Lake Outlet

Monitoring was conducted at the Susan Lake outlet in 2010 for the Climate and Hydrology component.

5.11.7.1 Hydrologic Conditions: 2010 Water Year

Susan Lake Outlet (RAMP Station S25) Continuous hydrometric data during the open-water season (May to October) have been collected for RAMP Station S25 in 2002 and 2006 to 2010, but the data record is intermittent in all five years. In the 2010 WY, data were collected from June 27 to October 30 with data missing from July 28 to August 10 due to equipment malfunction. Comparison of the 2010 WY hydrologic conditions to historical values is; therefore, less robust than for a number of the other hydrology stations in the RAMP FSA. Flows from June 27 to July 27 were similar to the historical median values (Figure 5.11-24). After monitoring resumed on August 10, flows decreased to a new historical low of 0.016 m^3/s on August 22. Flows increased in response to rainfall in late August and early September and peaked at 0.14 m^3/s on September 7. This value was both the highest daily flow recorded in the 2010 WY and a new maximum flow recorded on this date. Flows decreased to near historical median values recorded from late September to the end of the 2010 WY.

5.11.8 Regional Lakes Fish Tissue

The Fish Populations component for miscellaneous aquatic systems consisted of tissue analysis for mercury on target fish species captured in fall 2010 from Brutus, Keith and Net lakes, lakes that were part of ASRD's Fall Walleye Index Netting Program. All three lakes are located north of Fort McMurray and the Firebag Watershed in the Richardson Backcountry (Figure 5.11-1). The lakes are in a remote region with no direct road access. The lakes are primarily used for recreational angling with access by air or ATV vehicle.

This section includes results from 2010 for the three sampled lakes as well as comparisons to other lakes sampled by RAMP and ASRD in the RAMP Regional Study Area (RSA) from 2002 to 2009 and spatial comparisons of mercury in fish using RAMP data and data collected from other studies.

5.11.8.1 Brutus Lake

Brutus Lake is 153 ha in size and approximately 15 m deep. There are no historical data for mercury concentrations in fish tissue from this lake to assess temporal comparisons.

Whole-Organism Metrics

A total of 11 lake whitefish (eight female and three male), nine northern pike (four female, four male and one unsexed), and 19 walleye (nine female, nine male and one unsexed) from Brutus Lake were sampled for fish tissue (muscle) analysis. The fork length of fish sampled were as follows:

1. Lake whitefish – fork length ranged from a 248 mm immature six year old female to a 405 mm mature 16 year old female. Male lake whitefish (average fork length: 367 mm, average age: nine years) were larger than female lake whitefish (average fork length: 345 mm, average age: 11 years). The average length of all sampled lake whitefish was 352 mm and the average age was ten years.

2. Northern pike – fork length ranged from a 482 mm immature five year old male to a 617 mm mature three year old female. Female pike (average fork length: 580 mm, average age: five years) were larger than male pike (average fork length 539 mm, average age: five years). The average length of all sampled northern pike was 560 mm and the average age was five years.

3. Walleye – fork length ranged from a 190 mm immature one year old unsexed fish to a 512 mm mature 14 year old female. Female walleye (average fork length: 417 mm, average age: eight years) were larger than male walleye (average fork length: 343 mm, average age: six years). The average length of all sampled walleye was 370 mm and the average age was seven years.

Mercury Concentrations

Total mercury concentrations in muscle of individual lake whitefish, northern pike and walleye collected from Brutus Lake in 2010 are presented in Table 5.11-35 and Figure 5.11-25:

1. Mercury concentration in lake whitefish tissue averaged 0.114 mg/kg and ranged from 0.06 mg/kg in a 248 mm immature female to 0.22 mg/kg in a 378 mm mature female.

2. Mercury concentration in northern pike averaged 0.361 mg/kg) and ranged from 0.26 mg/kg in a 582 mm mature female to 0.49 mg/kg in a 575 mm mature female.

3. Mercury concentrations in walleye tissue averaged 0.298 mg/kg and ranged from 0.10 mg/kg in a 190 mm immature unsexed fish to 0.59 mg/kg in a 473 mm mature female.

Regressions between mercury concentration and fork length (log_{10}-transformed) were statistically significant for walleye ($p<0.01$; $r^2 = 0.86$). No significant relationship was detected between fork length and mercury concentrations for lake whitefish and northern pike ($p>0.01$). A regression of mercury concentration by age for walleye was statistically significant ($p <0.01$; $r^2 = 0.91$). No significant relationship was detected between age and mercury concentrations in lake whitefish or northern pike ($p=0.85$ and $p=0.90$, respectively).

Potential Risks of Mercury in Fish Tissue to Human Health

A summary of 2010 lake whitefish, northern pike and walleye muscle mercury concentrations from Brutus Lake relative to Health Canada fish consumption guidelines is as follows (Table 5.11-35).

Lake Whitefish Mercury concentrations in lake whitefish were below the Health Canada subsistence fisher and general consumer guidelines with the exception of one fish, which exceeded the guideline for subsistence fishers of 0.20 mg/kg. None of the lake whitefish sampled exceeded the Health Canada guideline for general consumers (0.50 mg/kg).

Northern Pike Mercury concentrations in northern pike sampled exceeded the Health Canada guideline for subsistence fishers (0.20 mg/kg), with all nine fish sampled exceeding the subsistence fishers guideline. None of the sampled northern pike exceeded the Health Canada guideline for general consumers (0.5 mg/kg).

Walleye Mercury concentrations in walleye exceeded the Health Canada guideline for subsistence fishers (0.2 mg/kg) with 74 % of fish sampled (14 of the 19 sampled fish) exceeding the guideline of 0.20 mg/kg. Two of the 14 fish that exceeded the subsistence fisher guideline also exceeded the guideline for general consumers (0.5 mg/kg). The exceedances were generally consistent with increasing length of fish, with all fish greater than > 400 mm exceeding guidelines and only 50% of fish less than <400 mm exceeding guidelines.

5.11.8.2 Keith Lake

Keith Lake is 188 ha in size and greater than 2 m deep (maximum depth was not recorded). There are no historical data for mercury concentrations in fish tissue from this lake to assess temporal comparisons.

Whole-Organism Metrics

A total of eight lake whitefish (four female, three male and one unsexed) and four northern pike (one female and three male) from Keith Lake were sampled for fish tissue (muscle) analysis. Walleye were not captured in this lake. The fork length of fish sampled were as follows:

1. Lake whitefish - fork length ranged from a 220 mm immature young-of-year fish to a 399 mm mature 11 year old female. Female lake whitefish (average fork length: 352 mm, average age: seven years) were larger than male fish (average fork length: 317 mm, average age: six years). The average length of all sampled fish was 322 mm and the average age was seven years.

2. Northern pike - fork length ranged from a 479 mm mature three year old male to a 631 mm mature six year old male. Male northern pike (average fork length: 597 mm, average age: four years) were larger than the one female captured (fork length: 517 mm, age: four years). The average length of all sampled fish was 532 mm and the average age was four years.

Mercury Concentrations

Total mercury concentrations in muscle of individual lake whitefish and northern pike collected from Keith Lake in 2010 are presented in Table 5.11-35 and Figure 5.11-25:

1. Mercury concentration in lake whitefish tissue averaged 0.045 mg/kg and ranged from 0.02 mg/kg in a 313 mm immature female to 0.07 mg/kg in a 342 mm mature female.

2. Mercury concentration in northern pike averaged 0.083 mg/kg and ranged from 0.05 mg/kg in a mature male to 0.12 mg/kg in mature male.

Regressions between mercury concentration and fork length (log_{10}-transformed) were not statistically significant for either lake whitefish or northern pike. In addition, regressions of mercury concentration by age were not statistically significant for either lake whitefish or northern pike ($p=0.19$ and $p=0.32$, respectively).

Potential Risks of Mercury in Fish Tissue to Human Health

A summary of 2010 lake whitefish and northern pike muscle mercury concentrations from Keith Lake relative to Health Canada fish consumption guidelines is as follows:

Lake Whitefish Mercury concentrations in lake whitefish did not exceed the Health Canada guidelines for general consumers and subsistence fishers.

Northern Pike Mercury concentrations in northern pike did not exceed the Health Canada guideline for general consumers and subsistence fishers.

5.11.8.3 Net Lake

Net Lake is the largest of the three lakes sampled in 2010 (264 ha) and approximately 7 m deep in the deepest portion of the lake. There are no historical data for mercury concentrations in fish tissue from this lake to assess temporal comparisons.

Whole-Organism Metrics

A total of 12 lake whitefish (six female and six male), ten northern pike (four female, four male and two unsexed), and 20 walleye (seven female, 12 male and one unsexed) from Net Lake were sampled for fish tissue (muscle) analysis. The fork length of fish sampled were as follows:

1. Lake whitefish – fork length ranged from a 240 mm immature two year old female to 473 mm female (maturity and age unknown). Males (average fork length: 385 mm, average age: five years) were larger than females (average fork length: 362 mm, average age: three years). The average length of all sampled fish was 373 mm and the average age was four years.

2. Northern pike – fork length ranged from a 395 mm immature two year old female to a 630 mm mature seven year old male. Male northern pike (average fork length: 544 mm, average age: six years) were larger than

female fish (average fork length: 491 mm, average age: four years). The average length of all sampled fish was 518 mm and the average age was five years.

3. Walleye – fork length ranged from a 218 mm mature two year old male to a 512 mm mature 15 year old female. Female walleye (average fork length: 400 mm, average age: nine years) were larger than male fish (average fork length: 338 mm, average age: nine years). The average length of all sampled fish was 363 mm and the average age was nine years.

Mercury Concentrations

Total mercury concentrations in muscle of individual lake whitefish, northern pike and walleye collected from Net Lake in 2010 are presented in Table 5.11-35 and Figure 5.11-25:

1. Mercury concentration in lake whitefish tissue averaged 0.124 mg/kg and ranged from 0.03 mg/kg in a 450 mm immature male (the largest fish caught) to 0.22 mg/kg in an unsexed fish.

2. Mercury concentration in northern pike averaged 0.44 mg/kg and ranged from 0.20 mg/kg in an unsexed fish to 1.08 mg/kg in a 630 mm mature male.

3. Mercury concentrations in walleye averaged 0.66 mg/kg and ranged from 0.24 mg/kg in a 218 mm mature male to 1.42 mg/kg in a 475 mm mature male.

Regressions between mercury concentration and fork length ($\log_{10}$-transformed) were statistically significant for walleye ($p < 0.01$; $r^2 = 0.74$). No significant relationship was found between fork length and mercury concentrations for lake whitefish and northern pike ($p>0.01$). A regression of mercury concentration by age for walleye was statistically significant ($p < 0.01$; $r^2 = 0.74$). Regressions of mercury concentration by age were not statistically significant for either lake whitefish or northern pike ($p=0.69$ and $p=0.04$, respectively).

Potential Risks of Mercury in Fish Tissue to Human Health

A summary of 2010 lake whitefish, northern pike and walleye muscle mercury concentrations from Net Lake relative to Health Canada fish consumption guidelines is as follows:

Lake Whitefish Mercury concentrations in two of the 12 (17%) lake whitefish captured exceeded the Health Canada guideline for subsistence fishers and none exceeded the guideline for general consumers.

Northern Pike Mercury concentrations in nine of the ten (90%) northern pike captured exceeded the subsistence fisher guideline and two of the nine northern pike that exceeded the subsistence fisher guideline also exceeded the guideline for general consumers (0.5 mg/kg).

Walleye Mercury concentrations in all 20 walleye captured exceeded the Health Canada guideline for subsistence fishers (0.2 mg/kg) and 11 of the 20 walleye exceeded the general consumers guideline (0.5 mg/kg).

5.11.8.4 Spatial Comparisons

The mercury concentrations in lake whitefish, northern pike and walleye sampled from lakes by RAMP and ASRD (Table 5.11-36) between 2002 and 2010 are provided in Figure 5.11-26. Most of the sampled lakes are in the upper (southern) portion of the RAMP RSA (i.e., Gregoire Lake, Christina Lake, and Winefred Lake) while some are on the eastern border of the RAMP RSA (Big Island and Gardiner lakes) and Lake Claire is to the north in close proximity to the Athabasca River Delta. Generally, mercury concentrations in lake whitefish and walleye from Net Lake are higher than all other sampled lakes.

Spatial comparisons using an ANCOVA for each species indicated that there are significant differences in mercury concentrations in fish between lakes ($p<0.01$ for all species). However, there are several factors that could influence the concentration of mercury in fish, including the size of the waterbody, the amount of vegetation or wetlands near the waterbody, the quality of the water (particularly the concentration of mercury), DOC and pH, as well as the amount of mercury found in the sediment (Beckvar *et al.* 1996, Heyes *et al.* 2000). When factoring in size of lake (Table 5.11-36) as a predictor of the mercury load in the system, there was no significant correlation between lake size and concentration of mercury in fish ($p=0.57$). Other information for these lakes including water quality and physical characteristics were not available and; therefore, could not be included in the analyses.

5.11.8.5 Regional Comparisons

To provide a regional context for the results from the 2010 Regional Lakes Fish Tissue program, Figure 5.11-27 to Figure 5.11-29 provide regional descriptions of mean fish tissue mercury concentrations in lakes 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, RAMP 2010). To standardize the mean mercury concentration in each lake for each species, the concentration was standardized to mean weight of fish.

Lake Whitefish In waterbodies in which lake whitefish have been captured, weight-standardized mean mercury concentrations in 85% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, while weight-standardized mean mercury concentrations in 15% of the waterbody-year combinations exceeded the Health Canada subsistence fisher guideline. There were no lakes with weight-standardized mean mercury concentration in lake whitefish that exceeded the Health Canada general consumer guideline (Figure 5.11-27).

Northern Pike In waterbodies sampled for northern pike, weight-standardized mean mercury concentrations in 73% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline; and weight-standardized mean mercury concentrations in 27% of the waterbody-year combinations exceeded the Health Canada subsistence fisher guideline (Figure 5.11-28). There were no lakes with weight-standardized mean mercury concentration in northern pike that exceeded the Health Canada general consumer guideline.

Walleye In waterbodies sampled for walleye, weight-standardized mean mercury concentrations in 50% of the waterbody-year combinations were below the Health Canada subsistence fisher guideline, 33% of waterbody-year combinations exceeded the Health Canada subsistence fisher guideline, and 17% of waterbody-year combinations exceeded the Health Canada general consumer guideline (Figure 5.11-29). The waterbody-year combinations with weight-standardized mean mercury concentrations in walleye that exceeded the Health Canada general consumer guideline were primarily located outside and to the south of the RAMP FSA and years prior to focal project development (Figure 5.11-28). Keith and Brutus lakes, sampled in 2010 within the RAMP FSA are the only lakes with general consumer guideline exceedances for walleye within the RAMP FSA. An exceedance of the Health Canada general consumer guideline for the weight-standardized mean mercury concentration in walleye was measured in Lake Athabasca in 1977, which is located within the RAMP RSA and downstream of focal projects. Since then, the weight-standardized mean mercury concentration in walleye in Lake Athabasca has been below the Health Canada general consumer guideline (Figure 5.11-29). 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).

On a local scale, wetlands and land clearing are potential sources of mercury to surface waterbodies. Wetlands are an important source of methylmercury production in boreal ecosystems (St. Louis *et al.* 1996, Grigal 2002). Prior to any development, wetlands are dewatered during the dewatering phase, water from wetlands drain into groundwater or nearby surface water sources. Studies in experimental lakes in Ontario have indicated that methylmercury inputs into lakes were higher from wetland areas than precipitation (i.e., atmospheric deposition) (St. Louis *et al.* 1996). In comparison to surface water, wetlands capture and hold the majority of atmospherically deposited mercury (Heyes *et al.* 2000). Removal of vegetation cover in preparation for development of focal projects could lead to increased mercury concentrations in water from eroded sediments or dissolved organic carbon (DOC) entering surface waters (Grigal 2002).

Although oil sands development could lead to increased availability of methylmercury to fish in the lakes and rivers in the region, RAMP has not observed an increase in mercury concentrations in fish from lakes or rivers in the vicinity of oil sands development.

5.11.8.6 Classification of Results

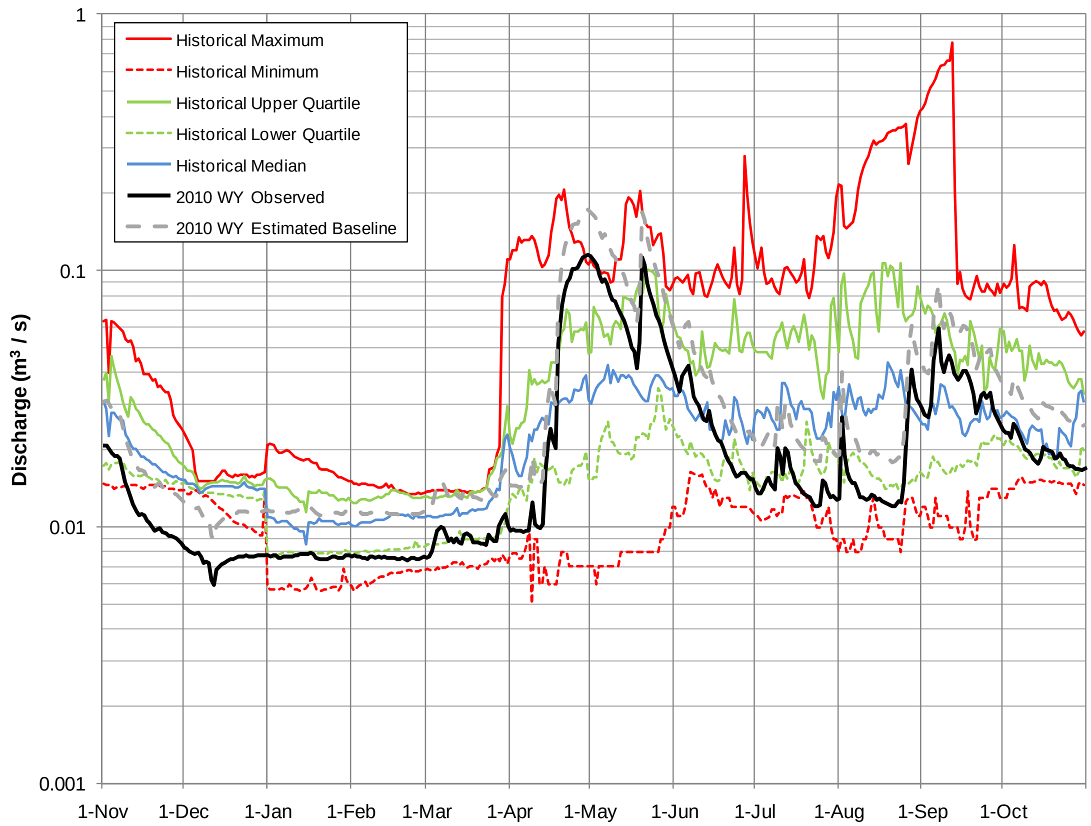
Mercury concentrations are classified based on the potential risk to subsistence fishers and general consumers (see Section 3.2.4.2 and Table 3.2-8).

Mercury concentrations in all northern pike and 73% of walleye from Brutus Lake in 2010 exceeded the Health Canada guideline for subsistence fishers and mercury concentrations in two walleye exceeded the guidelines for general consumers. These results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye. Given that all northern pike and most walleye exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike and walleye, dependent on the quantity of fish consumed. Mercury concentrations in fish from Brutus Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes. Mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health.

Mercury concentrations in lake whitefish and northern pike from Keith Lake were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Mercury concentrations in fish from Keith Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes.

Mercury concentrations in all captured walleye and all but one northern pike from Net Lake in 2010 exceeded the Health Canada guideline for subsistence fishers and the majority of walleye and two northern pike exceeded the guideline for general consumers. These results indicate a **High** risk to health of subsistence fishers consuming northern pike and walleye to general consumers consuming walleye. Given that almost all northern pike exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike and walleye, dependent on the quantity of fish consumed. With the exception of two fish, mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Overall, the mercury concentrations in fish sampled from Net Lake were higher in northern pike and walleye compared to mercury concentration in fish from other regional lakes.

Figure 5.11-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Mills Creek in the 2010 WY, compared to historical values.



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 value was calculated, using a Digital Elevation Model (DEM), to be that portion of the catchment located to the north and east of Highway 63. Field observations further supported this drainage area estimate; however, this value may be further updated in the future using a higher-resolution DEM analysis.

Note: Historical values from May to October were calculated from data collected from 1997 to 2009 and from 2006 to 2009 for other months.

Table 5.11-2 Estimated water balance at Station S6, Mills Creek at Highway 63, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	0.73	**Observed discharge, obtained from Station S6, Mills Creek at Highway 63**
Closed-circuited area water loss from the observed *test* hydrograph	-0.38	Estimated 2.1 km^2 of the Mills Creek watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
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 2010, that is not closed-circuited (Table 2.5-1)
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	1.09	**Estimated *baseline* discharge at RAMP Station S6, Mills Creek at Highway 63**
Incremental flow (change in total discharge)	-0.36	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 3.2.1.4.

Note: The observed discharge volume is calculated from 2010 WY provisional data for Station S6, Mills Creek at Highway 63.

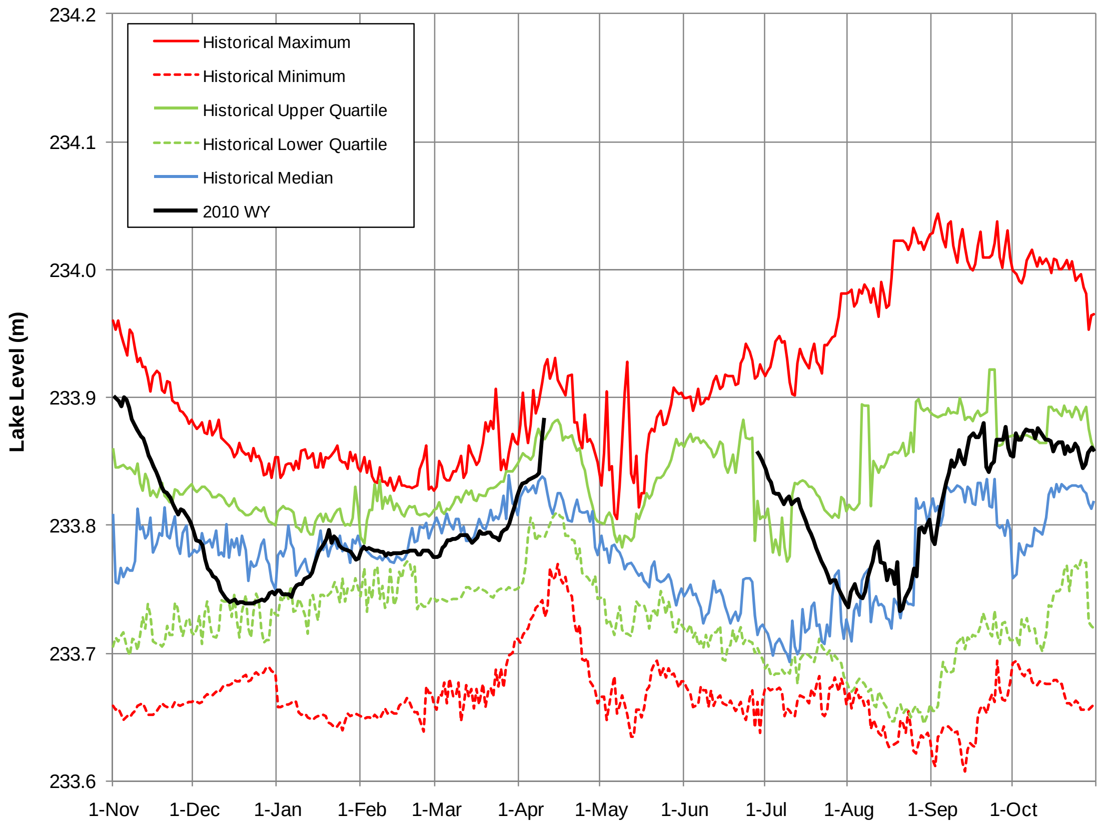
Note: The drainage area for Station S6, Mills Creek at Highway 63 is assumed to be approximately 6 km^2 (two-thirds of the catchment). This value was calculated, using a Digital Elevation Model (DEM), to be that portion of the catchment located to the north and east of Highway 63. Field observations further supported this drainage area estimate; however, this value may be further updated in the future using a higher-resolution DEM analysis.

Table 5.11-3 Calculated change in hydrologic measurement endpoints for the Mills Creek watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.047	0.031	-33%
Mean winter discharge	0.013	0.009	-33%
Annual maximum daily discharge	0.173	0.116	-33%
Open-water season minimum daily discharge	0.018	0.012	-33%

Note: Values are calculated from 2010 WY provisional data for Station S6, Mills Creek at Highway 63.

Figure 5.11-4 Isadore's Lake: 2010 hydrograph and historical context.



Note: Based on provisional 2010 WY data recorded at Station L3, Isadore's Lake. Historical values were calculated for the period 2000 to 2009.

Table 5.11-4 Concentrations of water quality measurement endpoints, Isadore's Lake (*test* station ISL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	8	7.7	8.2	8.3
Total Suspended Solids	mg/L	-[1]	6	8	<3	6	10
Conductivity	µS/cm	-	609	8	353	539	672
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.011	8	0.004	0.008	**0.067**
Total nitrogen*	mg/L	1.0	**1.08**	8	0.30	0.95	**1.25**
Nitrate+Nitrite	mg/L	1.3	<0.071	8	<0.05	<0.10	<0.30
Dissolved organic carbon	mg/L	-	12.1	8	8.0	11.0	12.0
Ions							
Sodium	mg/L	-	12.5	8	6.0	11.0	13.0
Calcium	mg/L	-	66.8	8	37.0	64.6	85.4
Magnesium	mg/L	-	30.6	8	25.6	30.0	36.0
Chloride	mg/L	230, 860[3]	22.6	8	4.0	14.0	20.2
Sulphate	mg/L	100[4]	**130**	8	64	106	**148**
Total Dissolved Solids	mg/L	-	419	8	250	340	456
Total Alkalinity	mg/L	-	158	8	122	159	227
Selected metals							
Total aluminum	mg/L	0.1	0.0230	8	0.0056	0.0185	**0.1820**
Dissolved aluminum	mg/L	0.1[2]	<0.0010	8	0.0005	<0.0010	<0.0200
Total arsenic	mg/L	0.005	0.00078	8	0.00048	0.00093	0.00456
Total boron	mg/L	1.2[5]	0.0424	8	0.0350	0.0418	0.0491
Total molybdenum	mg/L	0.073	<0.00010	8	<0.000008	0.000018	0.000125
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.0	6	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.248	8	0.162	0.222	0.244
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0065**	8	**0.003**	**0.008**	**0.015**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.01**	8	<0.20	0.80	**1.20**
Total phenols	mg/L	0.004	**0.0065**	8	0.0010	0.0030	**0.0070**

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 5.11-5 Concentrations of water quality measurement endpoints, Mills Creek (*test* station MIC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010 Value
Physical variables			
pH	pH units	6.5-9.0	8.14
Total suspended solids	mg/L	-[1]	<3
Conductivity	µS/cm	-	859
Nutrients			
Total dissolved phosphorus	mg/L	0.05[2]	<0.001
Total nitrogen*	mg/L	1.0	0.451
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	8.4
Ions			
Sodium	mg/L	-	10.5
Calcium	mg/L	-	139
Magnesium	mg/L	-	36.1
Chloride	mg/L	230, 860[3]	21.1
Sulphate	mg/L	100[4]	**192**
Total dissolved solids	mg/L	-	607
Total alkalinity	mg/L		254
Selected metals			
Total aluminum	mg/L	0.1	<0.003
Dissolved aluminum	mg/L	0.1[2]	0.0024
Total arsenic	mg/L	0.005	0.0003
Total boron	mg/L	1.2[5]	0.036
Total molybdenum	mg/L	0.073	<0.0001
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6
Total strontium	mg/L	-	0.318
Other variables that exceeded CCME/AENV guidelines in fall 2010			
Total iron	mg/L	0.3	**0.52**

MIC-1 was a new station for 2010

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 5.11-5 Piper diagram of fall ion balance in Isadore's Lake, Mills Creek and Shipyard Lake.

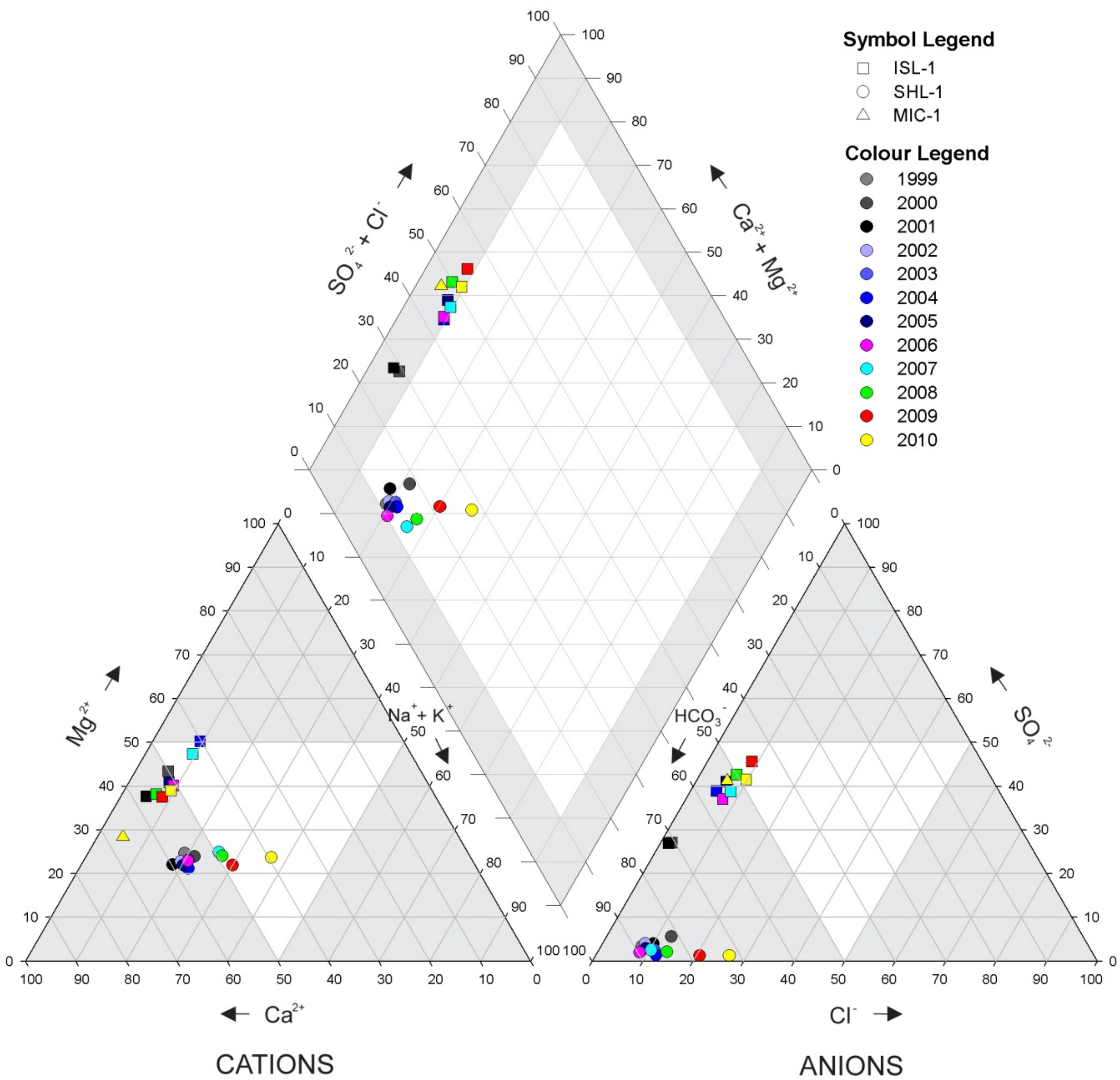
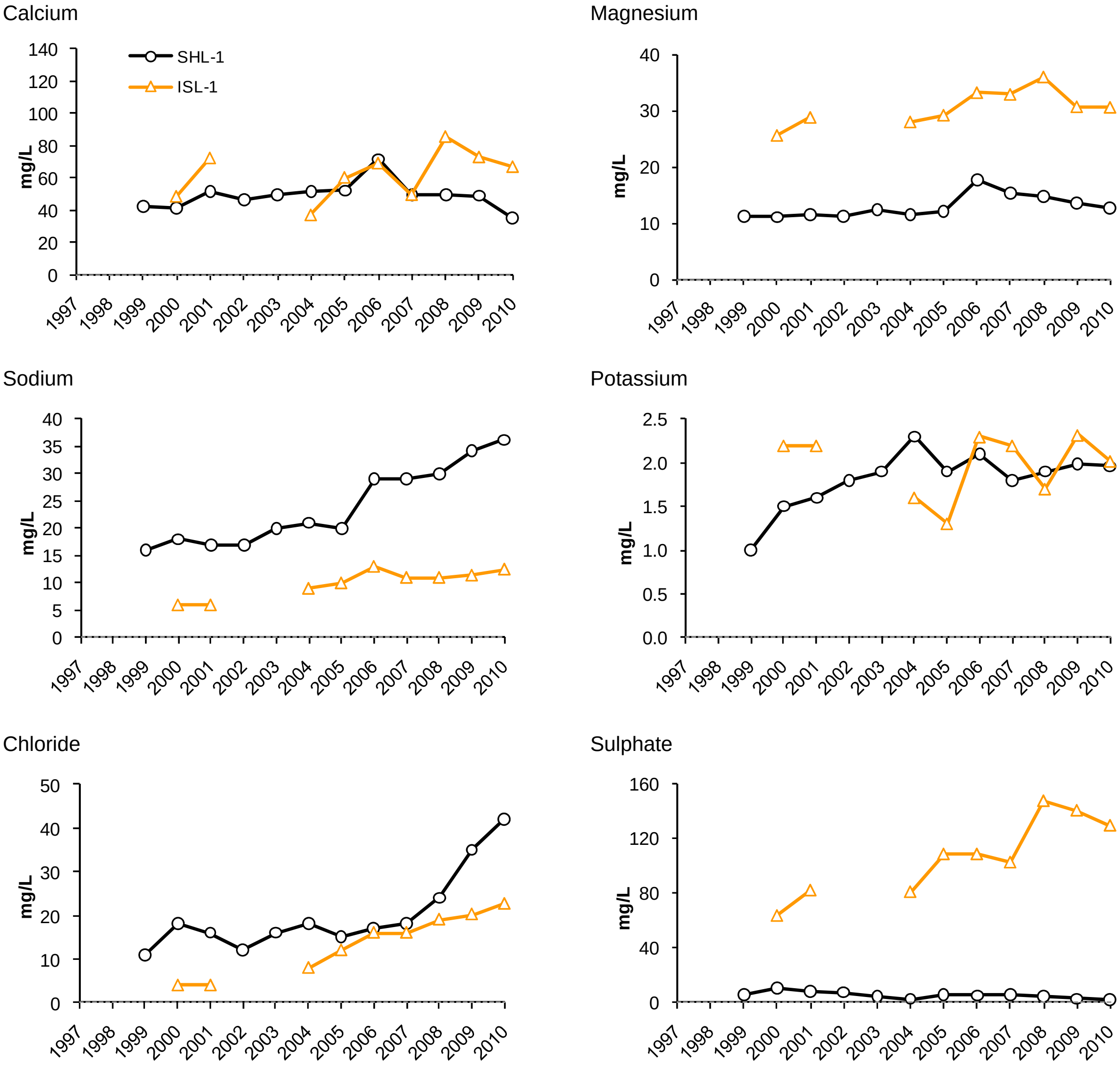


Figure 5.11-6 Concentrations of selected fall water quality measurement endpoints, Isadore's Lake (ISL-1) and Shipyard Lake (SHL-1) (fall 2010), relative to historical concentrations.

Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Figure 5.11-6 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Table 5.11-6 Water quality guideline exceedances in *baseline* station BER-1, *test* station POC-1, *test* station MCC-1, *test* station ISL-1, *test* station SHL-1, and *test* station FOC-1, 2010.

Variable	Units	Guideline	POC-1	BER-1	BER-2	MCC-1	ISL-1	SHL-1	MIC-1	FOC-1
Winter										
Sulphide	mg/L	0.002[2]	ns	ns	0.0028	ns	ns	ns	ns	ns
Total nitrogen*	mg/L	1.0	ns	ns	1.094	ns	ns	ns	ns	ns
Dissolved cadmium	mg/L	[5]	ns	ns	0.000009	ns	ns	ns	ns	ns
Total cadmium	mg/L	[5]	ns	ns	0.000017	ns	ns	ns	ns	ns
Total iron	mg/L	0.3	ns	ns	1.07	ns	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	0.0057	ns	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	0.068	ns	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	0.19	ns	ns	ns	ns	ns
Spring										
Sulphide	mg/L	0.002[2]	ns	ns	0.018	ns	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	0.096	ns	ns	ns	ns	ns
Total Kjeldahl nitrogen	mg/L	1.0 [4]	ns	ns	1.93	ns	ns	ns	ns	ns
Total nitrogen*	mg/L	1.0	ns	ns	2.001	ns	ns	ns	ns	ns
Total cadmium	mg/L	[5]	ns	ns	0.000014	ns	ns	ns	ns	ns
Total chromium	mg/L	0.001	ns	ns	0.0022	ns	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	2.52	ns	ns	ns	ns	ns
Dissolved iron	mg/L	0.3[3]	ns	ns	0.986	ns	ns	ns	ns	ns
Total iron	mg/L	0.3	ns	ns	2.64	ns	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	0.0088	ns	ns	ns	ns	ns
Summer										
Sulphide	mg/L	0.002[2]	ns	ns	0.0088	ns	ns	ns	ns	ns
Total dissolved phosphorus	mg/L	0.05	ns	ns	0.0876	ns	ns	ns	ns	ns
Total phosphorus	mg/L	0.05	ns	ns	0.121	ns	ns	ns	ns	ns
Total nitrogen*	mg/L	1.0	ns	ns	1.501	ns	ns	ns	ns	ns
Total Kjeldahl nitrogen	mg/L	1.0[4]	ns	ns	1.43	ns	ns	ns	ns	ns
Dissolved iron	mg/L	0.3[3]	ns	ns	0.969	ns	ns	ns	ns	ns
Total aluminum	mg/L	0.1	ns	ns	0.72	ns	ns	ns	ns	ns
Total cadmium	mg/L	[5]	ns	ns	0.000010	ns	ns	ns	ns	ns
Total phenols	mg/L	0.004	ns	ns	0.0062	ns	ns	ns	ns	ns
Total iron	mg/L	0.3	ns	ns	1.94	ns	ns	ns	ns	ns
Fall										
Sulphate	mg/L	100[1]	-	-	-	-	130	-	192	-
Sulphide	mg/L	0.002[2]	0.0085	0.0241	0.0135	0.0129	0.0065	0.0045	-	-
Total mercury (ultra-trace)	mg/L	5, 13[6]	-	-	10.6	-	-	-	-	-
Total phosphorus	mg/L	0.05	0.064	-	0.144	-	-	-	-	-
Total Kjeldahl nitrogen	mg/L	1.0[4]	2.04	1.61	2.37	1.45	1.01	1.29	-	-
Total nitrogen*	mg/L	1.0	2.111	1.681	2.441	1.521	1.081	1.361	-	-
Total aluminum	mg/L	0.1	1.09	0.22	2.17	0.572	-	-	-	-
Total chromium	mg/L	0.001	0.00138	-	0.0036	0.00107	-	-	-	-
Dissolved iron	mg/L	0.3[3]	-	1.42	0.81	-	-	-	-	-
Total iron	mg/L	0.3	1.08	2.13	3.23	0.72	-	0.42	0.52	0.51
Total phenols	mg/L	0.004	0.0070	0.0147	0.0092	0.0095	0.0065	0.0095	-	0.0145

MIC-1 was a new station in 2010

BER-1, MCC-1, POC-1, ISL-1, SHL-1, MIC-1 and FOC-1 were sampled only in fall 2010.

BER-2 was sampled in winter, spring, summer, and fall 2010.

ns = not sampled

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] 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

[5] Guideline is hardness dependent

[6] Draft AENV guidelines for chronic and acute total mercury concentrations, respectively (AENV 1999).

Table 5.11-7 Water quality index (fall 2010) for miscellaneous watershed stations.

Station Identifier	Location	2010 Designation	Water Quality Index	Classification
POC-1	Near the mouth of Poplar Creek	*test*	100.0	Negligible-Low
FOC-1	Near the mouth of Fort Creek	*test*	86.7	Negligible-Low
BER-1	Near the mouth of Beaver River	*test*	91.1	Negligible-Low
BER-2	Upper Beaver River	*baseline*	85.3	Negligible-Low
MCC-1	Near the mouth of McLean Creek	*test*	100.0	Negligible-Low
MIC-1	Mills Creek	*test*	84.1	Negligible-Low

Note: see Figure 5.11-1 for the locations of these water quality stations.

Note: see Section 3.2.2.3 for a description of the Water Quality Index.

Table 5.11-8 Average habitat characteristics of benthic invertebrate sampling locations in Isadore's Lake.

Variable	Units	Isadore's Lake
Sample date	-	Sept. 13, 2010
Habitat	-	Depositional
Water depth	m	2.0
Field Water Quality		
Dissolved oxygen	mg/L	7.2
Conductivity	µS/cm	563
pH	pH units	7.6
Water temperature	°C	15.0
Sediment Composition		
Sand	%	9
Silt	%	82
Clay	%	9
Total Organic Carbon	%	3

Table 5.11-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Isadore's Lake.

Taxon	Percent Major Taxa Enumerated in Each Year				
	ISL-1				
	2006	2007	2008	2009	2010
Amphipoda	<1				<1
Anisoptera			<1		<1
Bivalvia					<1
Ceratopogonidae	<1				
Chaoboridae	<1			<1	<1
Chironomidae	2	57	19	7	50
Cladocera		4			
Copepoda	3	4	11	67	22
Ephemeroptera		1			<1
Erpobdellidae					
Gastropoda				<1	<1
Glossiphoniidae					
Hydracarina			8		<1
Lumbriculidae					
Naididae	4	1	6		2
Nematoda	72	32	49	25	12
Ostracoda	1	2	7	<1	14
Trichoptera					
Tubificidae				<1	
Zygoptera					
Benthic Invertebrate Community Measurement Endpoints					
Total Abundance (No./m^2)	33,987	20,110	13,870	10,948	23,623
Richness	10	9	6	5	<1
Simpson's Diversity	0.41	0.63	0.66	0.46	0.61
Evenness	0.42	0.75	0.69	0.62	0.71
% EPT	0	1	0	0	<1

Table 5.11-10 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Isadore's Lake (ISL-1).

Variable	P-value Time Trend	Variance Explained (%) Time Trend	Nature of Changes
Abundance	0.784	1	No change
Richness	0.118	19	No change
Simpson's Diversity	0.232	11	No change
Evenness	0.052	31	No change
EPT	0.614	7	No change
CA Axis 1	0.904	0	No change
CA Axis 2	0.153	38	No change

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.11-7 Annual changes in values of benthic invertebrate community measurement endpoints in Isadore's Lake, *test* station ISL-1.

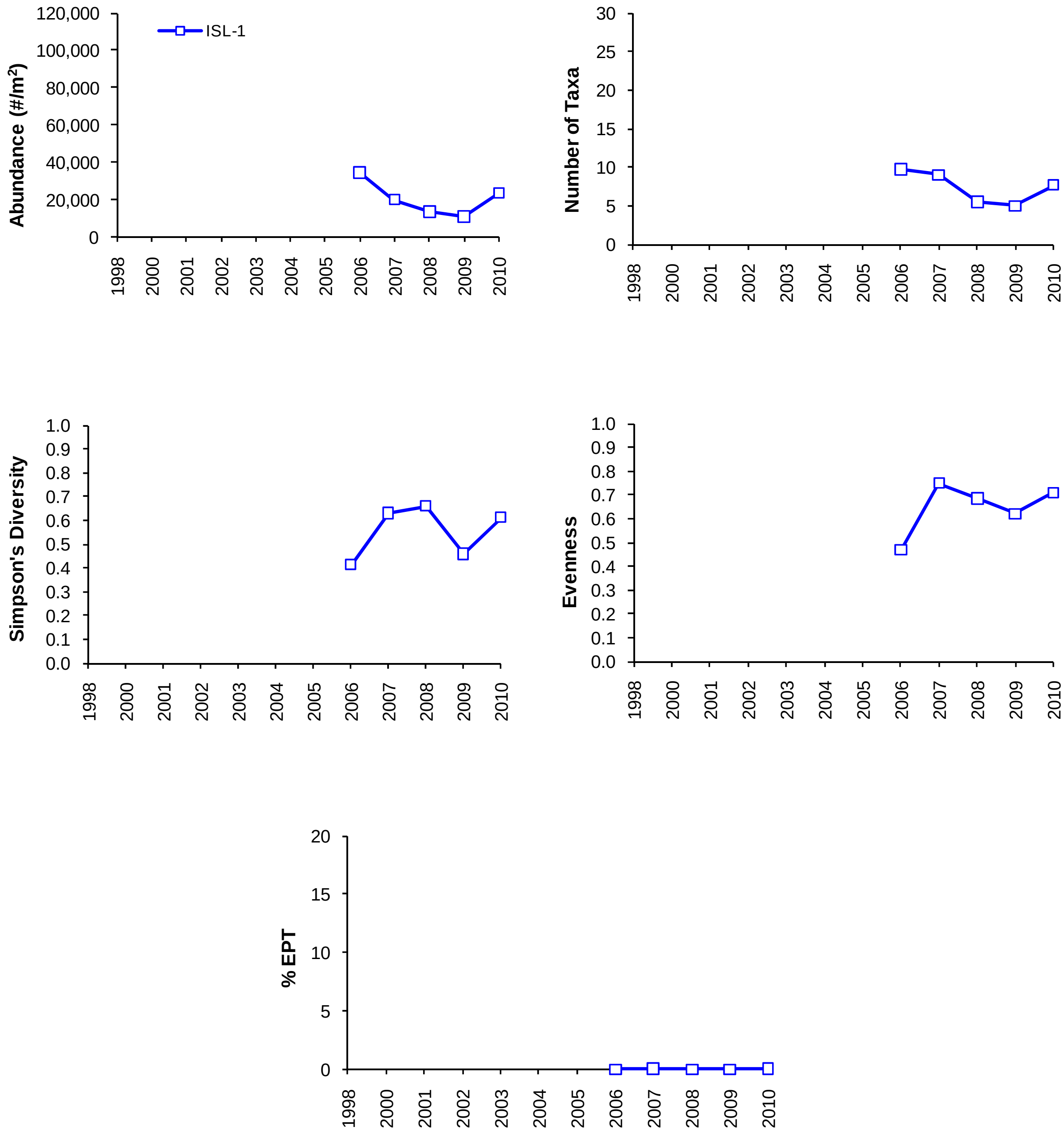


Table 5.11-11 Concentrations of sediment quality measurement endpoints, Isadore's Lake (*test* station ISL-1), fall 2010.

Variables	Units	Guideline	September 2010	2001-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	26.2	5	19	26	57
Silt	%	-	63.6	5	39	54	62
Sand	%	-	10.2	5	3	12	35
Total organic carbon	%	-	3.9	5	1.3	4.5	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	8	<50
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	8	**<50**
Fraction 2 (C10-C16)	mg/kg	150[1]	72	4	<5	20	91
Fraction 3 (C16-C34)	mg/kg	300[1]	**323**	4	150	**538**	**4600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	232	4	89	396	**3500**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.011	5	0.006	0.007	0.009
Retene	mg/kg	-	0.050	5	0.037	0.066	0.071
Total dibenzothiophenes	mg/kg	-	0.198	5	0.145	0.170	0.261
Total PAHs	mg/kg	-	1.578	5	1.279	1.362	2.056
Total Parent PAHs	mg/kg	-	0.147	5	0.100	0.169	0.375
Total Alkylated PAHs	mg/kg	-	1.432	5	1.115	1.142	1.881
Predicted PAH toxicity[3]	H.I.	-	0.700	5	0.072	0.559	1.287
Metals that exceed CCME guidelines in 2010							
Arsenic	mg/kg	5.9	**6.21**	5	4.17	**7.10**	**7.40**
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	3	7.0	7.0	9.0
Chironomus growth - 10d	mg/organism	-	ns	3	1.9	2.4	2.6
Hyalella survival - 14d	# surviving	-	ns	3	8.0	9.6	9.8
Hyalella growth - 14d	mg/organism	-	ns	3	0.2	0.3	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).

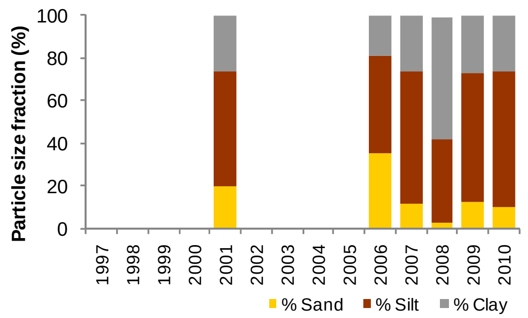
[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

[4] 2002 *Hyalella* test based on 10-day test period.

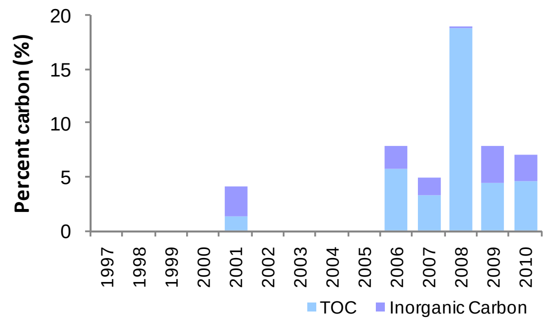
ns – not sampled

Figure 5.11-8 Variation in sediment quality measurement endpoints in Isadore's Lake, *test* station ISL-1.

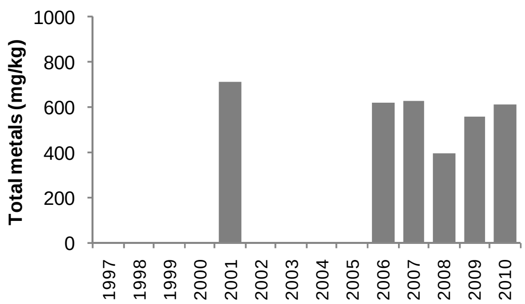
Particle size distribution



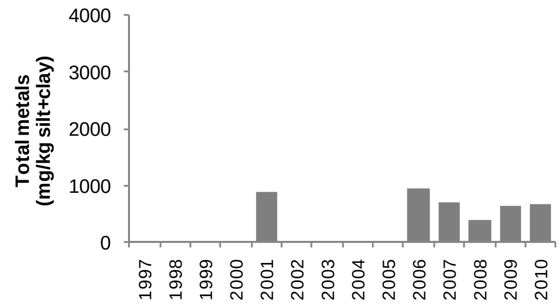
Carbon Content



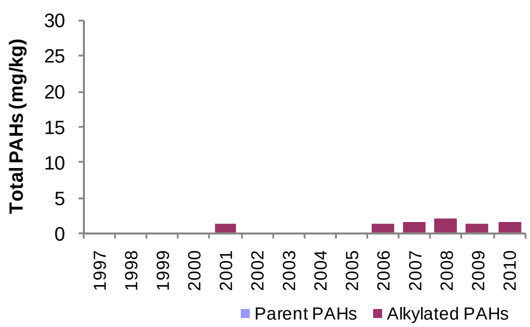
Total Metals*



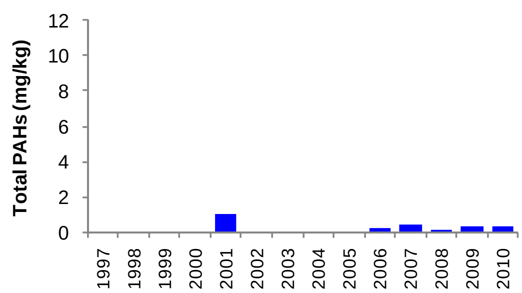
Total metals* normalized to percent fine sediments
(i.e., % silt + clay)



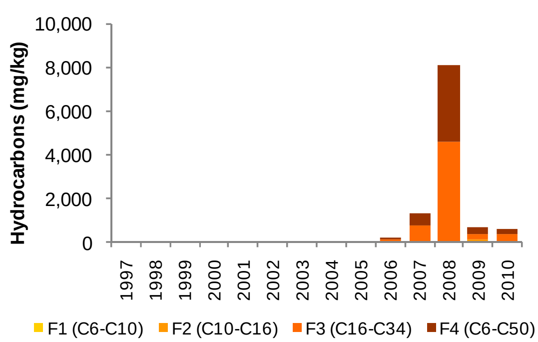
Total PAHs



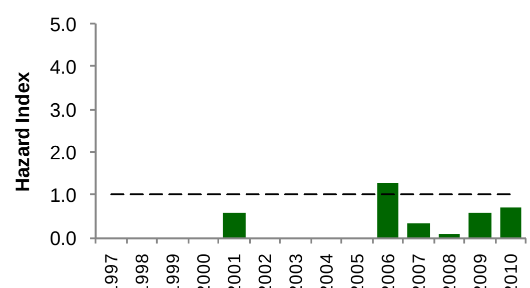
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0).

Table 5.11-12 Concentrations of water quality measurement endpoints, Shipyard Lake (*test* station SHL-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	11	7.7	8.1	8.2
Total Suspended Solids	mg/L	-[1]	<3	11	<3	<3	15
Conductivity	µS/cm	-	444	11	358	394	509
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.0046	11	0.0036	0.0090	0.0260
Total nitrogen*	mg/L	1.0	**1.36**	11	0.30	0.90	**1.40**
Nitrate+Nitrite	mg/L	1.3	<0.071	11	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	19.1	11	16.7	20	24
Ions							
Sodium	mg/L	-	36	11	16	20	34
Calcium	mg/L	-	35.0	11	41.7	49.7	71.8
Magnesium	mg/L	-	12.7	11	11.1	12.0	17.7
Chloride	mg/L	230, 860[3]	42	11	11	17	35
Sulphate	mg/L	100[4]	2.6	11	2.8	5.9	10.5
Total Dissolved Solids	mg/L	-	274	11	200	270	320
Total Alkalinity	mg/L	-	160	11	159	186	251
Selected metals							
Total aluminum	mg/L	0.1	0.0078	11	<0.002	0.010	**0.140**
Dissolved aluminum	mg/L	0.1[2]	<0.001	11	0.0003	0.0015	<0.010
Total arsenic	mg/L	0.005	0.0005	11	0.0004	0.0005	<0.001
Total boron	mg/L	1.2[5]	0.0739	11	0.0270	0.0430	0.0744
Total molybdenum	mg/L	0.073	<0.0001	11	0.00002	0.00007	0.0002
Total mercury (ultra-trace)	ng/L	5, 13[6]	<0.6	7	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.127	11	0.121	0.156	0.209
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0045**	11	**0.003**	**0.009**	**0.014**
Total iron	mg/L	0.3	**0.42**	11	0.27	**0.42**	**1.48**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.29**	11	0.20	0.80	**1.30**
Total phenols	mg/L	0.004	**0.0095**	11	<0.001	**0.006**	**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.

Table 5.11-13 Average habitat characteristics of benthic invertebrate sampling locations in Shipyard Lake.

Variable	Units	Shipyard Lake
Sample date	-	Sept. 8, 2010
Habitat	-	Depositional
Water depth	m	1.9
Field Water Quality		
Dissolved oxygen	mg/L	7.1
Conductivity	µS/cm	403
pH	pH units	7.9
Water temperature	°C	14.9
Sediment Composition		
Sand	%	24
Silt	%	58
Clay	%	15
Total Organic Carbon	%	12

Table 5.11-14 Summary of major taxon abundances and benthic invertebrate community measurement endpoints, Shipyard Lake.

Taxon	Percent Major Taxa Enumerated in Each Year										
	SHL-1										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Amphipoda	7		2	3		2	2	2	1	<1	<1
Anisoptera	<1	1	<1			<1			<1		<1
Bivalvia	7	<1	8	6	1	<1	2	1	1	2	3
Ceratopogonidae		1	<1	1			6			<1	<1
Chaoboridae	3	53	1	32	1	<1	6			2	<1
Chironomidae	25	40	48	32	3	30	37	27	40	20	26
Cladocera	3				<1	2		1	3	<1	6
Copepoda	1	<1		9	1	3	1	11	16	16	27
Enchytraeidae										7	
Ephemeroptera	16	1	2			<1	<1	3	6	<1	4
Erpobdellidae							1				<1
Gastropoda	18	1	7	5	1	2	<1	3	2	7	5
Glossiphoniidae		<1	<1	<1							<1
Hydracarina		1	<1		<1	1		3	2	2	4
Lumbriculidae						<1					
Naididae	8	<1	3		4	9	16	6	5	3	12
Nematoda			3	2	2	1	1	1	1	5	4
Ostracoda	6	2	25	8	87	5	22	40	22	32	9
Trichoptera	2	1	<1		<1	1	1	1	<1	<1	<1
Tubificidae	1		1	3	1	7			<1	<1	<1
Zygoptera	3		1		<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	63,476
Richness	13	6	13	4	9	15	12	15	21	11	1
Simpson's Diversity	0.84	0.43	0.77	0.61	0.21	0.63	0.72	0.74	0.84	0.62	0.83
Evenness	0.92	0.55	0.84	0.83	0.24	0.69	0.72	0.81	0.89	0.71	0.87
% EPT	19	1	2	<1	<1	1	<1	2	4	<1	5

Table 5.11-15 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Shipyard Lake (SHL-1).

Variable	P-value Time Trend	Variance Explained (%) Time Trend	Nature of Changes
Abundance	**0.000**	34	Increase over time
Richness	**0.000**	33	Increase over time
Simpson's Diversity	**0.002**	8	Increase over time
Evenness	0.080	2	No change
EPT	0.941	0	No change
CA Axis 1	**0.002**	6	Change over time
CA Axis 2	**0.000**	27	Change over time

Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.11-9 Annual changes in values of benthic invertebrate community measurement endpoints in Shipyard Lake, *test* station SHL-1.

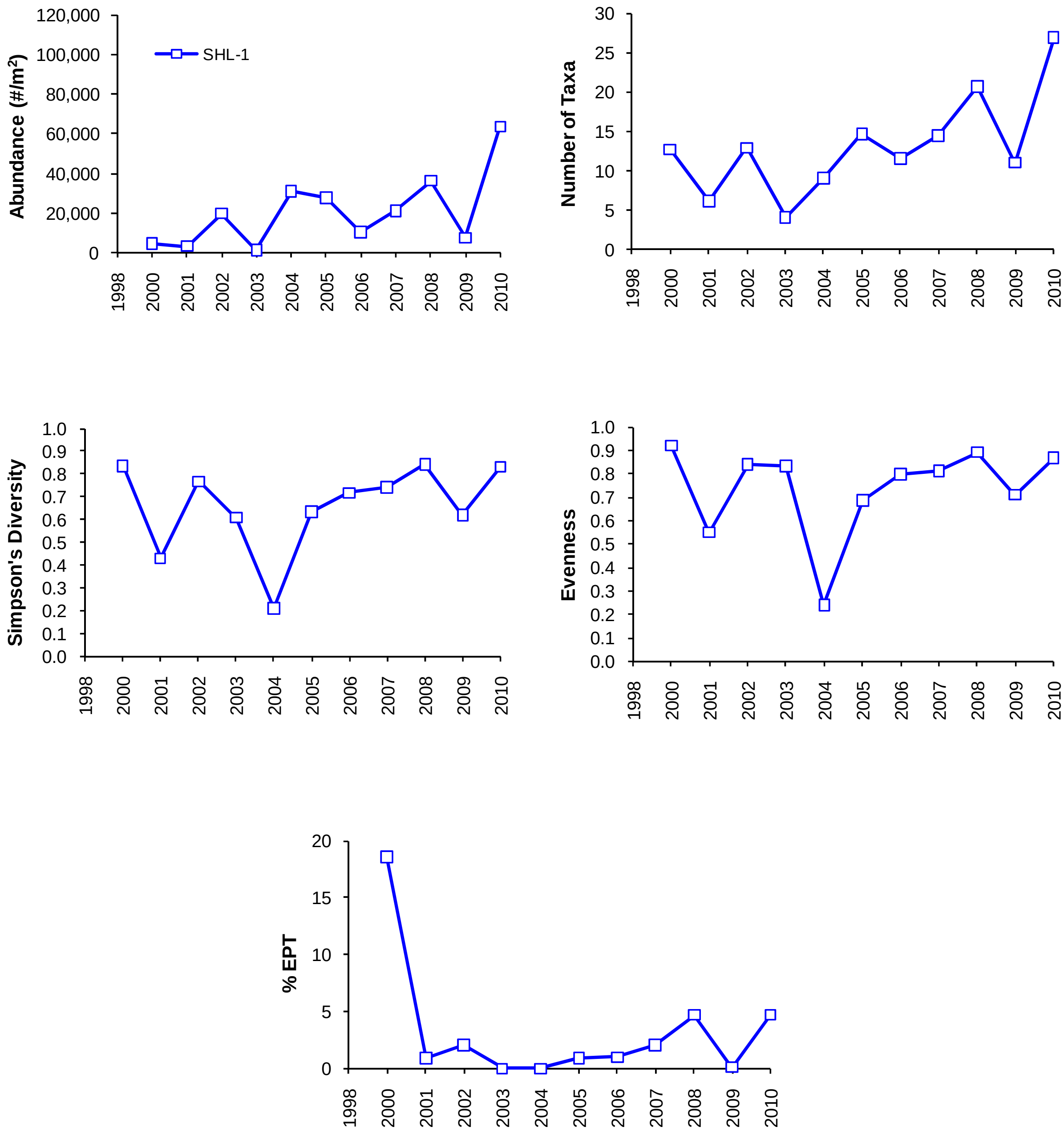


Table 5.11-16 Concentrations of sediment quality measurement endpoints, Shipyard Lake (*test* station SHL-1), fall 2010.

Variables	Units	Guideline	September 2010	2001-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	30.4	8	3	45	60
Silt	%	-	42.4	8	36	41	69
Sand	%	-	27.2	8	2.0	4.5	40.8
Total organic carbon	%	-	13.4	8	5.5	13.1	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<10	5	<5	<5	150
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	5	<5	<5	**150**
Fraction 2 (C10-C16)	mg/kg	150[1]	**<158**	5	<5	<5	**243**
Fraction 3 (C16-C34)	mg/kg	300[1]	**939**	5	290	**780**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	450	5	<5	230	919
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.011	6	0.011	0.021	0.031
Retene	mg/kg	-	0.058	8	0.046	0.088	0.199
Total dibenzothiophenes	mg/kg	-	0.587	8	0.265	0.576	2.622
Total PAHs	mg/kg	-	5.436	8	2.276	4.225	13.865
Total Parent PAHs	mg/kg	-	0.245	8	0.231	0.272	5.886
Total Alkylated PAHs	mg/kg	-	5.191	8	2.020	3.929	8.464
Predicted PAH toxicity[3]	H.I.	-	1.101	8	0.097	0.763	3.786
Metals that exceed CCME guidelines in 2010							
Arsenic	mg/kg	5.9	**5.97**	8	5.50	**6.87**	**7.80**
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	ns	5	5.6	7.6	8.2
Chironomus growth - 10d	mg/organism	-	ns	5	1.5	2.0	2.6
Hyalella survival - 14d [4]	# surviving	-	ns	5	6.0	7.7	8.4
Hyalella growth - 14d [4]	mg/organism	-	ns	5	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).

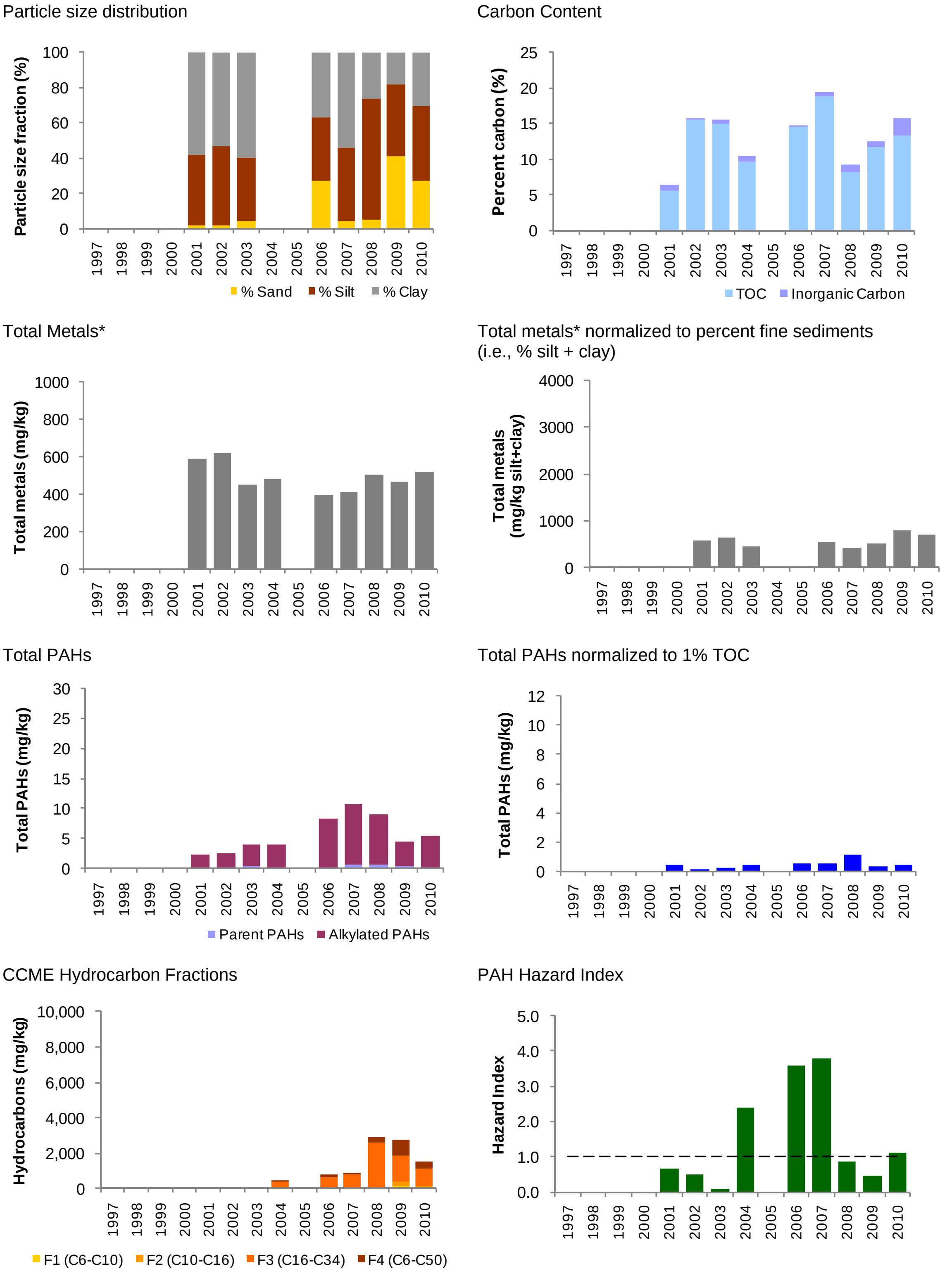
[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[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.

[4] 2002 *Hyalella* test based on 10-day test period.

ns – not sampled

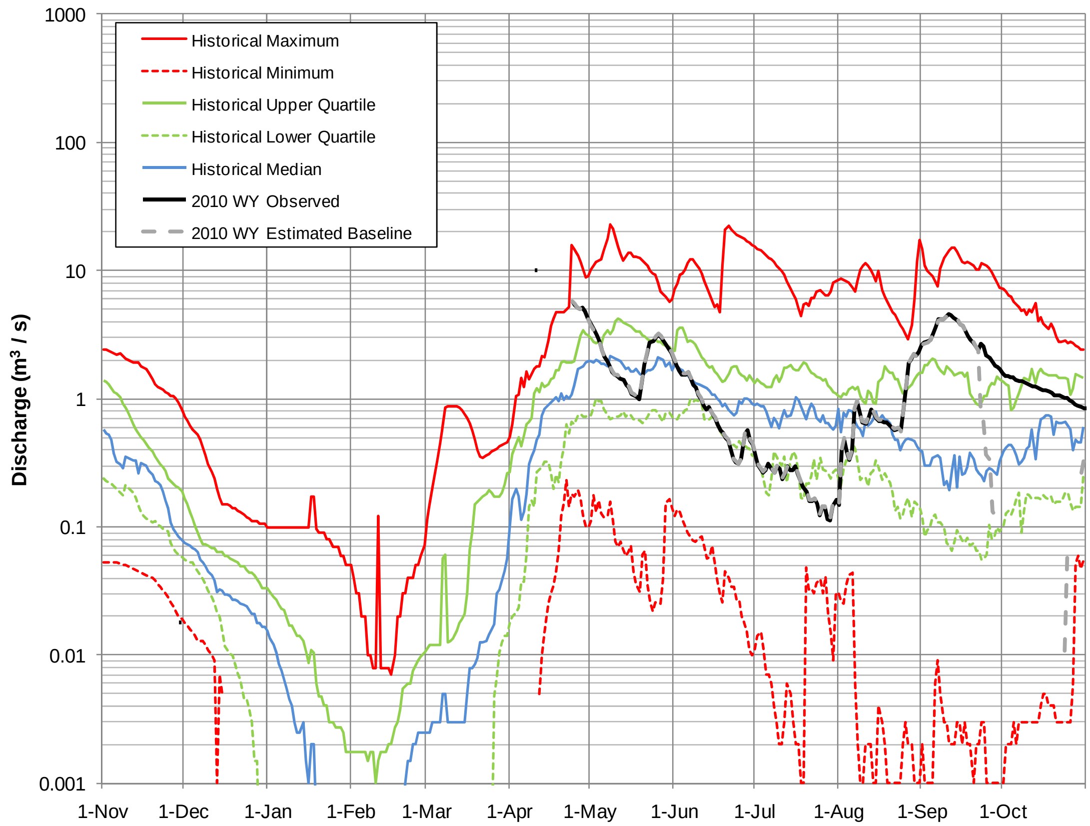
Figure 5.11-10 Variation in sediment quality measurement endpoints in Shipyard Lake, *test* station SHL-1.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.11-11 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Poplar Creek in 2010, compared to historical values.



Note: Observed values are calculated from provisional data for April 24 to October 31, 2010 WY 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 1973 to 1986 and 1996 onwards, and from 1973 to 1986 for other months.

Note: Minor differences (within expected measurement error) were calculated between observed flows at Station S11 and flow releases from the Poplar Creek Spillway that led estimated *baseline* values to be slightly negative for a number of days during the fall, 2010. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a), and do not appear on the graph due to the logarithmic scale used.

Table 5.11-17 Estimated water balance at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**25.30**	**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	-0.42	Estimated 3.1 km^2 of the Poplar Creek watershed is closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.05	Estimated 1.7 km^2 of the Poplar Creek watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Poplar Creek watershed from focal projects	0	None reported
Water releases into the Poplar Creek watershed from focal projects	0	None reported
Diversions into or out of the watershed	+5.18	Diversion from original upper Beaver River catchment area into Poplar Creek via the spillway (daily values provided by Syncrude).
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 by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**20.49**	**Estimated *baseline* discharge at WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63.**
Incremental flow (change in total discharge)	+4.81	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+23.5%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Values are calculated from provisional data for April 24 to October 31, 2010 for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63. The upstream drainage area is 151 km^2.

Note: Minor differences (within expected measurement error) were calculated between observed flows at Station S11 and flow releases from the Poplar Creek Spillway that led estimated *baseline* values to be slightly negative for a number of days during the fall, 2010. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a).

Table 5.11-18 Calculated change in hydrologic measurement endpoints for the Poplar Creek watershed, 2010 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	1.13	1.40	+23.4%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	5.76	5.71	-0.9%
Open-water season minimum daily discharge	0.115	0.113	-1.8%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Values are calculated from provisional data for April 24 to October 31, 2010 for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63. The upstream drainage area is 151 km^2.

Note: Minor differences (within expected measurement error) were calculated between observed flows at Station S11 and flow releases from the Poplar Creek Spillway that led estimated *baseline* values to be slightly negative for a number of days during the fall, 2010. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a).

Table 5.11-19 Concentrations of water quality measurement endpoints, Poplar Creek (*test* station POC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	10	7.9	8.3	8.4
Total Suspended Solids	mg/L	-[1]	35	10	4	10	61
Conductivity	µS/cm	-	344	10	308	451	1590
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.009	10	0.007	0.013	0.027
Total nitrogen*	mg/L	1.0	**2.11**	10	0.3	1.0	**2.0**
Nitrate+Nitrite	mg/L	1.0	<0.071	10	0.07	<0.10	<0.10
Dissolved organic carbon	mg/L	-	26	10	10	24	32
Ions							
Sodium	mg/L	-	30	10	27	48	238
Calcium	mg/L	-	28.9	10	28.2	37.3	72.1
Magnesium	mg/L	-	9.7	10	10.0	13.4	29.3
Chloride	mg/L	230, 860[3]	7.2	10	7.0	32.0	**321**
Sulphate	mg/L	100[4]	14.7	10	10.4	15.6	44.2
Total Dissolved Solids	mg/L	-	248	10	200	275	890
Total Alkalinity	mg/L	-	152	10	135	184	304
Selected metals							
Total aluminum	mg/L	0.1	**1.09**	10	**0.21**	**0.36**	**1.44**
Dissolved aluminum	mg/L	0.1[2]	0.0057	10	0.0019	0.0077	0.0121
Total arsenic	mg/L	0.005	0.00099	10	0.00075	0.00106	0.00232
Total boron	mg/L	1.2[5]	0.123	10	0.039	0.120	0.178
Total molybdenum	mg/L	0.073	0.00020	10	0.00020	0.00029	0.00072
Total mercury (ultra-trace)	ng/L	5, 13[6]	0.8	7	<1.2	<1.2	2
Total strontium	mg/L	-	0.16	10	0.15	0.24	0.51
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.009**	10	**<0.003**	**0.007**	**0.010**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.04**	10	0.20	0.90	**1.93**
Total iron	mg/L	0.3	**1.08**	10	**0.70**	**1.39**	**3.63**
Total chromium	mg/L	0.001	**0.00138**	10	0.00051	0.00079	**0.00350**
Total phosphorus	mg/L	0.05	**0.064**	10	0.029	0.036	**0.060**
Total phenols	mg/L	0.004	**0.007**	10	**<0.001**	**0.008**	**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.

Table 5.11-20 Concentrations of water quality measurement endpoints, lower Beaver River (*test* station BER-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	7	8.0	8.2	8.3
Total Suspended Solids	mg/L	-[1]	7	7	<3	11	35
Conductivity	µS/cm	-	644	7	566	871	1430
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.018	7	0.004	0.008	0.022
Total nitrogen*	mg/L	1.0	**1.68**	7	0.70	0.90	**1.45**
Nitrate+Nitrite	mg/L	1.3	<0.071	7	<0.071	<0.10	<0.10
Dissolved organic carbon	mg/L	-	43	7	15	31	52
Ions							
Sodium	mg/L	-	68	7	53	77	181
Calcium	mg/L	-	57.7	7	49.1	70.2	91.4
Magnesium	mg/L	-	17.6	7	15.5	19.1	27.9
Chloride	mg/L	230, 860[3]	55.4	7	55.0	94.0	221.0
Sulphate	mg/L	100[4]	51	7	54	72	**117**
Total Dissolved Solids	mg/L	-	472	7	450	650	830
Total Alkalinity	mg/L	-	194	7	158	239	294
Selected metals							
Total aluminum	mg/L	0.1	**0.219**	7	0.031	**0.265**	**5.130**
Dissolved aluminum	mg/L	0.1[2]	0.0092	7	0.0017	0.0065	0.0445
Total arsenic	mg/L	0.005	0.0009	7	0.0007	0.0009	0.0021
Total boron	mg/L	1.2[5]	0.111	7	0.088	0.136	0.169
Total molybdenum	mg/L	0.073	0.0003	7	0.0002	0.0003	0.0004
Total mercury (ultra-trace)	ng/L	5, 13[6]	3.5	7	<1.2	<1.2	8.1
Total strontium	mg/L	-	0.240	7	0.233	0.294	0.425
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0241**	7	**<0.003**	**0.018**	**0.038**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.61**	7	0.60	0.80	**1.38**
Dissolved iron	mg/L	0.3[2]	**1.420**	7	**0.046**	**0.465**	**1.870**
Total iron	mg/L	0.3	**2.13**	7	**1.79**	**2.39**	**5.88**
Total phenols	mg/L	0.004	**0.0147**	6	0.0020	**0.0075**	**0.0104**

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 5.11-21 Concentrations of water quality measurement endpoints, upper Beaver River (*baseline* station BER-2), fall 2010.

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	7.8	2	8.2	8.2	8.3
Total Suspended Solids	mg/L	-[1]	93	2	6	8	10
Conductivity	µS/cm	-	255	2	315	380	445
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	**0.037**	2	0.067	0.070	0.074
Total nitrogen*	mg/L	1.0	**2.44**	2	**1.30**	**1.73**	**2.16**
Nitrate+Nitrite	mg/L	1.3	<0.071	2	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	32	2	25	29	34
Ions							
Sodium	mg/L	-	20.9	2	31.0	42.3	53.5
Calcium	mg/L	-	22.5	2	29.7	32.8	35.8
Magnesium	mg/L	-	7.5	2	10.3	10.8	11.3
Chloride	mg/L	230, 860[3]	0.68	2	1.67	1.84	2.00
Sulphate	mg/L	100[4]	13.2	2	14.8	15.1	15.3
Total Dissolved Solids	mg/L	-	210	2	238	285	332
Total Alkalinity	mg/L	-	118	2	151	188	225
Selected metals							
Total aluminum	mg/L	0.1	**2.170**	2	0.266	**0.349**	**0.431**
Dissolved aluminum	mg/L	0.1[2]	0.0344	2	0.0116	0.0194	0.0272
Total arsenic	mg/L	0.005	0.00175	2	0.00137	0.00154	0.00171
Total boron	mg/L	1.2[5]	0.0893	2	0.163	0.191	0.218
Total molybdenum	mg/L	0.073	0.00020	2	0.00030	0.00043	0.00055
Total mercury (ultra-trace)	ng/L	5, 13[6]	**10.6**	2	<1.2	1.4	1.5
Total strontium	mg/L	-	0.146	2	0.175	0.2085	0.242
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0135**	2	**0.0112**	**0.0141**	**0.017**
Total phosphorus	mg/L	0.05	**0.144**	2	**0.102**	**0.105**	**0.108**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**2.37**	2	**1.20**	**1.65**	**2.09**
Dissolved iron	mg/L	0.3[2]	**0.806**	2	**0.991**	**1.076**	**1.160**
Total iron	mg/L	0.3	**3.23**	2	**1.79**	**1.97**	**2.14**
Total phenols	mg/L	0.004	**0.0092**	2	**0.0047**	**0.0064**	**0.0080**
Total chromium	mg/L	0.001	**0.00360**	**2**	0.00061	0.00065	0.00068

BER-2 only sampled previously 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.

Figure 5.11-12 Piper diagram of fall ion balance at *test* station BER-1, *baseline* station BER-2, *test* station POC-1, and *test* station MCC-1, 1999-2010.

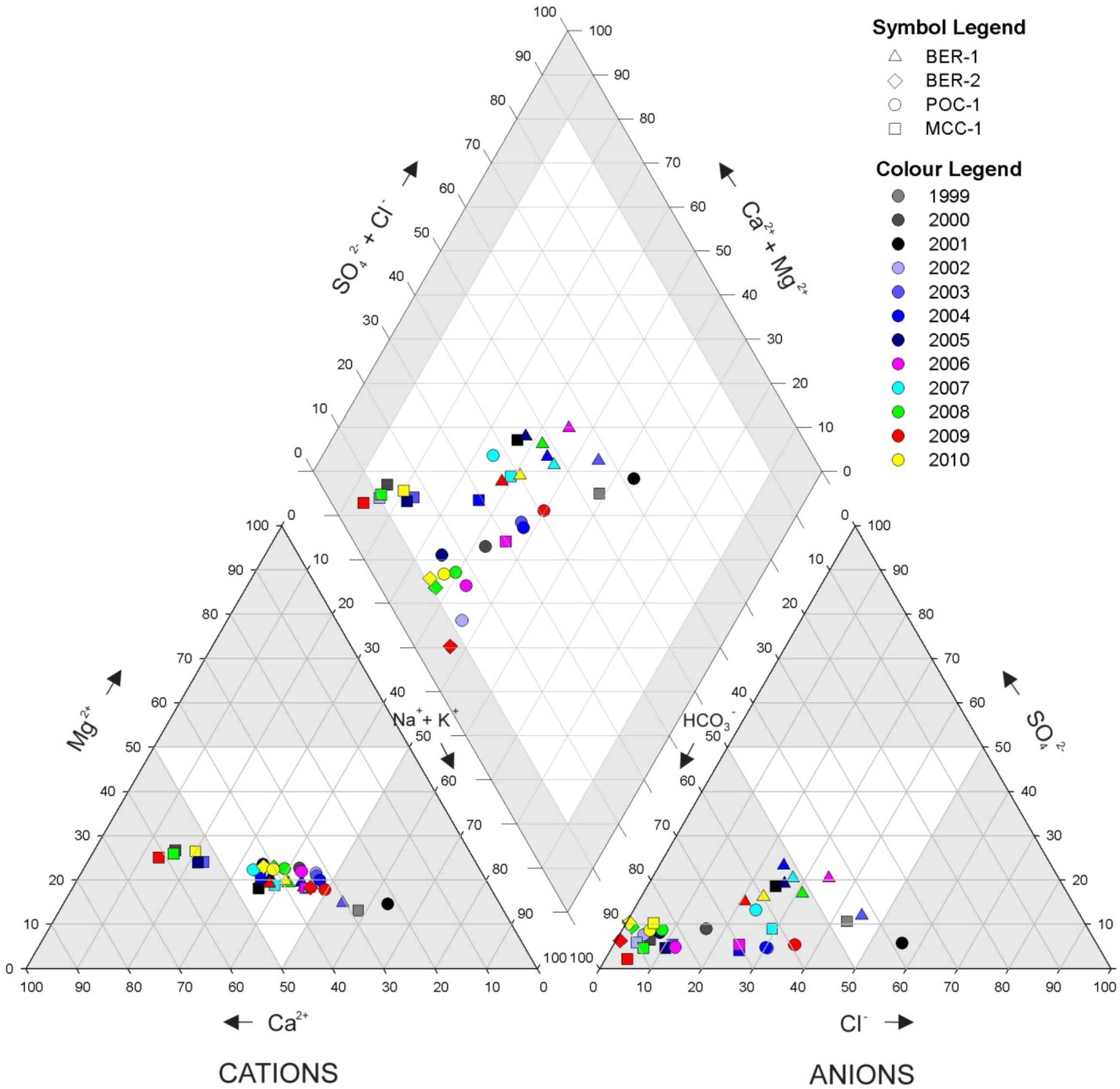
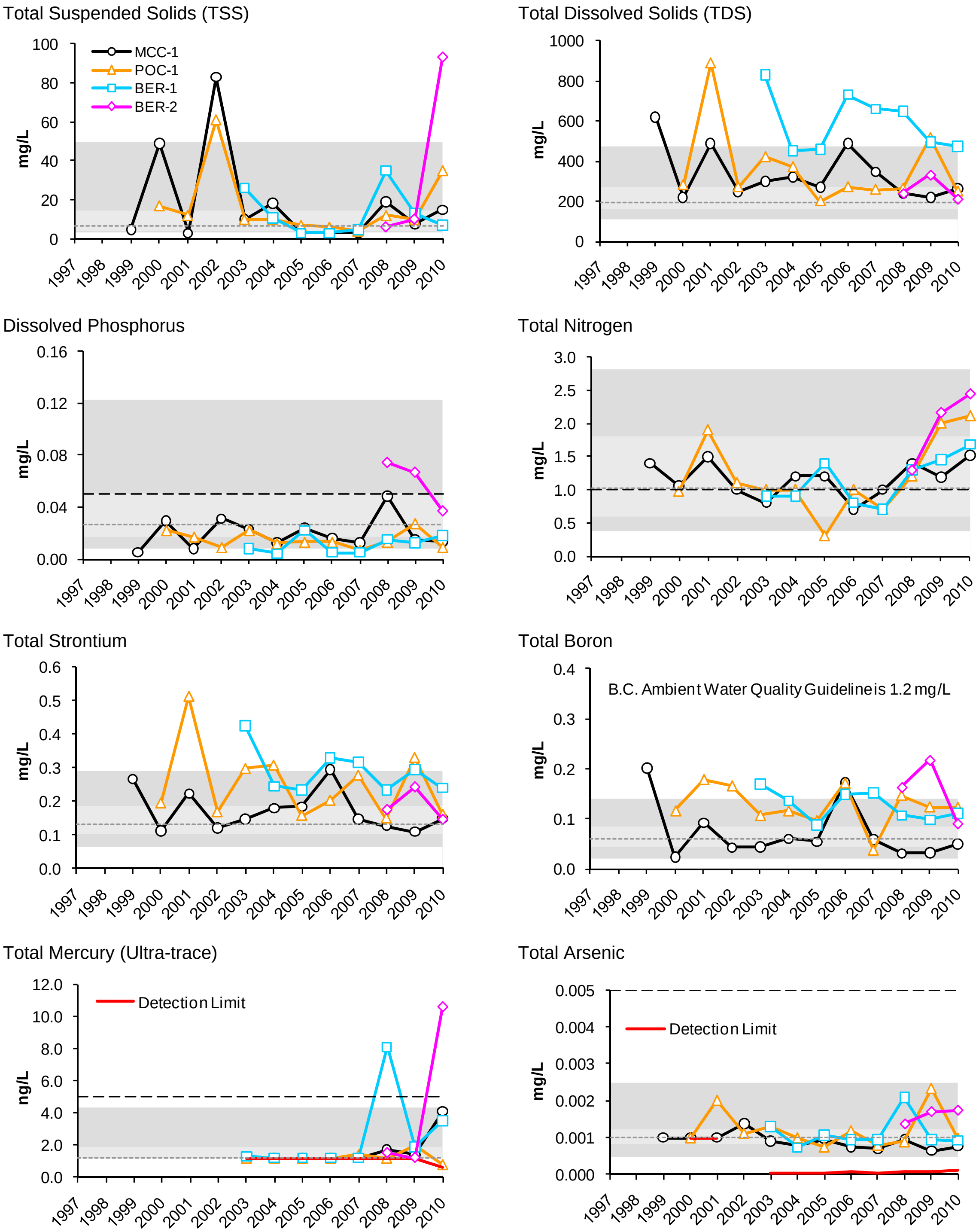


Figure 5.11-13 Concentrations of selected water quality measurement endpoints in *test* station BER-1, *test* station POC-1, and *test* station MCC-1 (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

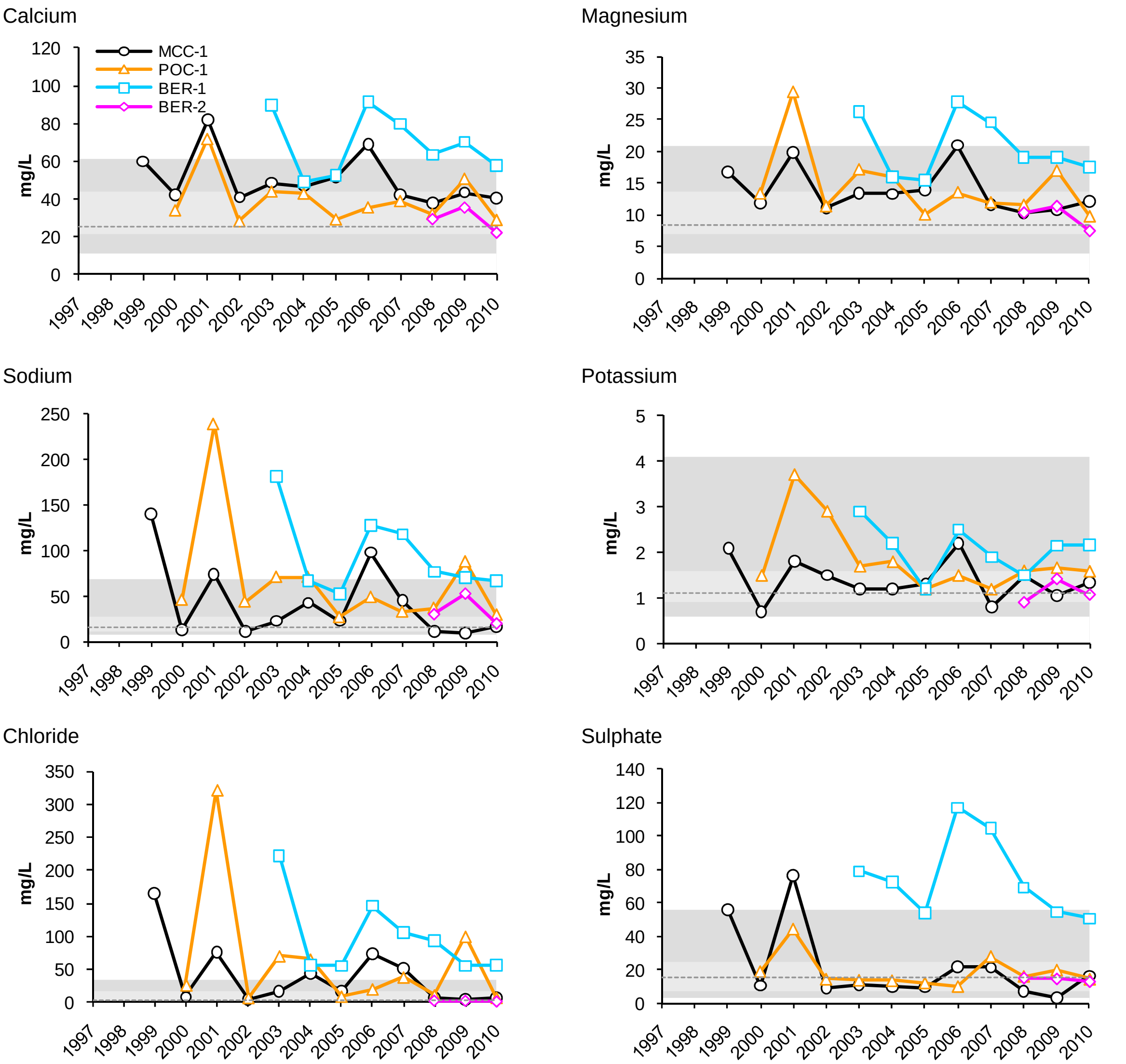


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.11-13 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality, from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.11-22 Average habitat characteristics of benthic invertebrate sampling locations in the Beaver River (BER-D2) and Poplar Creek (POC-D1).

Variable	Units	POC-D1 Lower *Test* Reach of Poplar Creek	BER-D2 Upper *Baseline* Reach of the Beaver River
Sample date	-	Sept. 14, 2010	Sept. 7, 2010
Habitat	-	Depositional	Depositional
Water depth	m	0.8	0.7
Current velocity	m/s	0.3	0.5
Field Water Quality			
Dissolved oxygen	mg/L	9.4	8.7
Conductivity	µS/cm	309	229
pH	pH units	8.2	7.7
Water temperature	°C	11.5	12.0
Sediment Composition			
Sand	%	68	88
Silt	%	23	6
Clay	%	9	6
Total Organic Carbon	%	3	1

Table 5.11-23 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Upper Beaver River and Lower Poplar Creek.

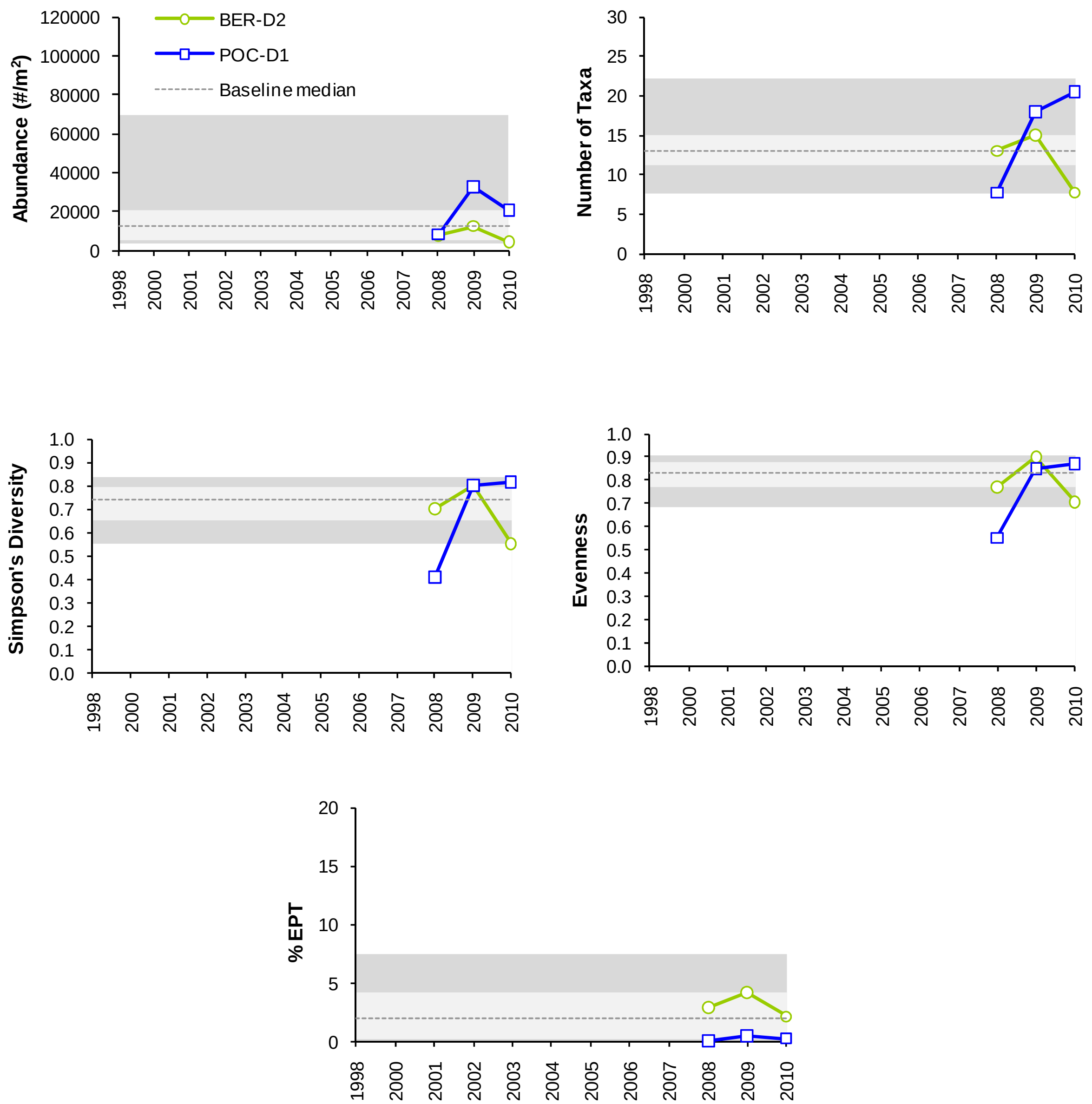
Taxon	Percent Major Taxa Enumerated in Each Year					
	Baseline reach BER-D2			*Test* reach POC-D1		
	2008	2009	2010	2008	2009	2010
Bivalvia	1	<1	<1	1	4	10
Ceratopogonidae	6	4	11	2		5
Chironomidae	84	71	32	21	64	20
Coleoptera		10	8	<1	1	<1
Copepoda	<1	<1	1			2
Empididae	1	<1			<1	<1
Enchytraeidae	<1	<1			<1	17
Ephemeroptera	4	6	6	<1	<1	<1
Gastropoda	<1	1	3		<1	<1
Glossiphoniidae	<1					
Hydracarina	1	>1	8			<1
Naididae	<1	4	5	<1	<1	1
Nematoda	1	<1	<1	2	1	5
Ostracoda	1		6	1	4	14
Tabanidae		<1	1	<1	<1	
Trichoptera	<1		<1	<1	<1	<1
Tubificidae	1	2	19	72	22	22
Benthic Invertebrate Community Measurement Endpoints						
Total Abundance (No./m^2)	7687	12,618	4,696	8,345	32,810	20,518
Richness	13	15	8	8	18	21
Simpson's Diversity	0.7	0.80	0.55	0.41	0.8	0.81
Evenness	0.77	0.90	0.70	0.55	0.85	0.87
% EPT	3	4	2	<1	<1	<1

Table 5.11-24 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in *test* reach POC-D1 and *baseline* reach BER-D2.

Variable	P-value		Variance Explained (%)		Nature of Changes
	Baseline* vs. *Test	**Time Trend**	***Baseline* vs. *Test***	**Time Trend**	
Abundance	**0.001**	**0.007**	44	27	Increase in POC-D1 and a decrease in BER-D2
Richness	0.087	**0.000**	11	65	Increase in POC-D1 and a decrease in BER-D2
Simpson's Diversity	0.896	**0.000**	0	61	Increase in POC-D1 and a decrease in BER-D2
Evenness	0.487	**0.004**	3	48	Increase in POC-D1 and a decrease in BER-D2
EPT	**0.007**	0.381	84	8	Higher at BER-D2
CA Axis 1	0.114	**0.000**	12	64	Shift towards *baseline* conditions from 2008 to 2010 at POC-D1
CA Axis 2	0.719	0.433	1	7	No change

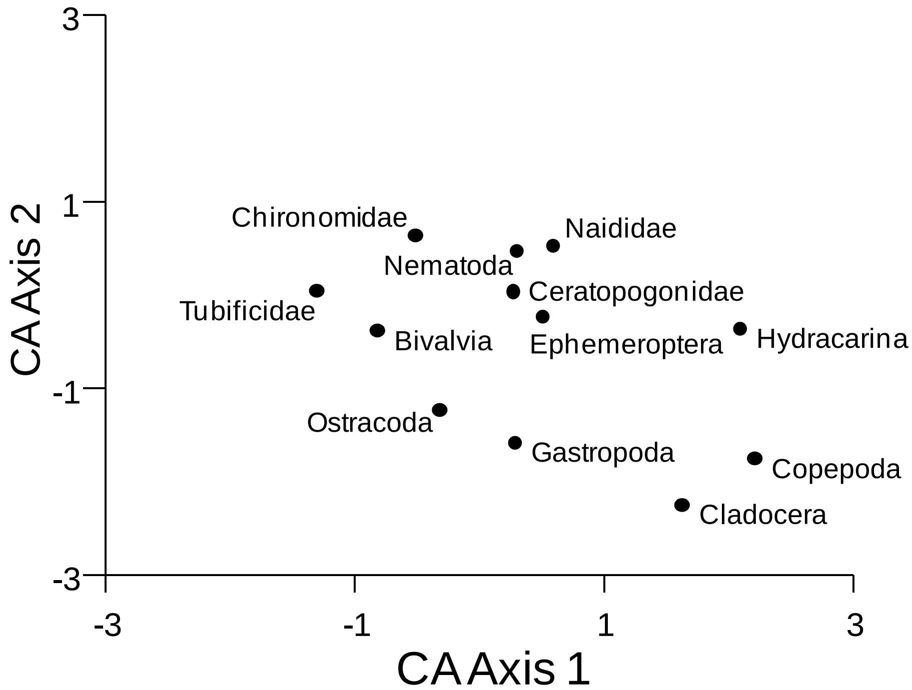
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

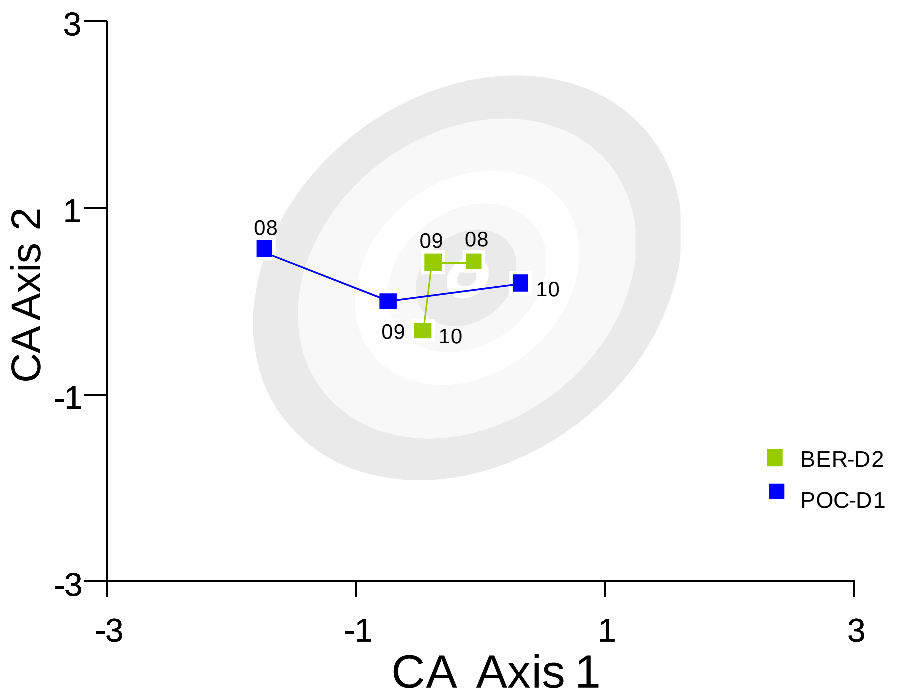
Figure 5.11-14 Variation in benthic invertebrate community measurement endpoints in Beaver River and Poplar Creek.



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.11-15 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 5.11-25 Concentrations of sediment quality measurement endpoints, lower Poplar Creek (*test* station POC-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	10.9	5	10	20	35
Silt	%	-	27.2	5	12	63	73
Sand	%	-	62.0	5	13	24	63
Total organic carbon	%	-	2.5	5	1.1	2.1	2.5
Total hydrocarbons							
BTEX	mg/kg	-	<20	3	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<20	3	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	39	3	<5	120	143
Fraction 3 (C16-C34)	mg/kg	300[1]	**924**	3	170	**1400**	**2830**
Fraction 4 (C34-C50)	mg/kg	2800[1]	970	3	54	1400	**2820**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.021	5	0.002	0.006	0.018
Retene	mg/kg	-	0.105	4	0.048	0.106	0.114
Total dibenzothiophenes	mg/kg	-	2.892	5	0.307	0.944	3.898
Total PAHs	mg/kg	-	8.594	5	1.753	3.400	13.256
Total Parent PAHs	mg/kg	-	0.254	5	0.148	0.201	0.434
Total Alkylated PAHs	mg/kg	-	8.340	5	1.605	3.191	12.821
Predicted PAH toxicity[3]	H.I.	-	1.261	5	0.159	0.618	4.154
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.4	3	7.4	8.4	9.0
Chironomus growth - 10d	mg/organism	-	2.446	3	1.612	1.7	2.426
Hyalella survival - 14d	# surviving	-	8.6	4	8.0	8.4	9.0
Hyalella growth - 14d	mg/organism	-	0.134	4	0.100	0.204	0.264

Values in **bold** indicate concentrations exceeding guidelines.

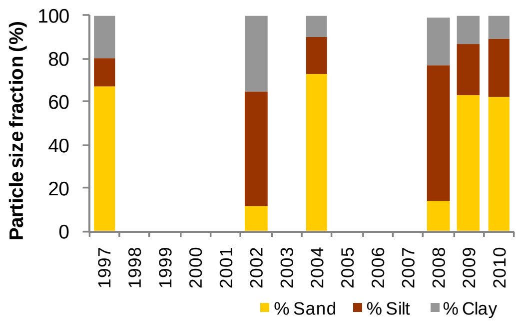
1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

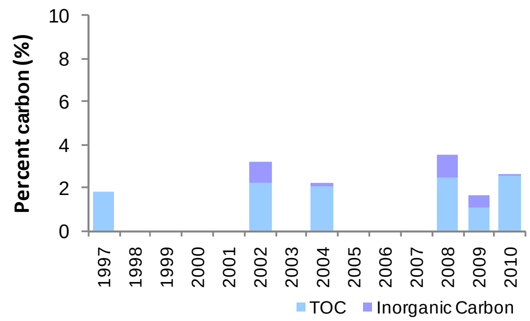
3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Figure 5.11-16 Variation in sediment quality measurement endpoints at *test* station POC-D1.

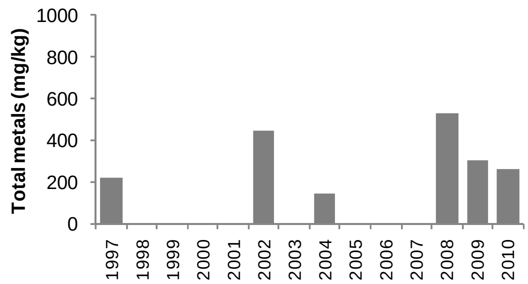
Particle size distribution



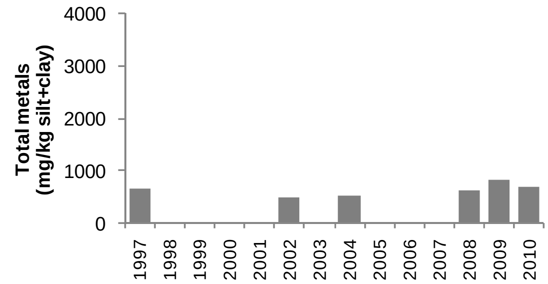
Carbon Content



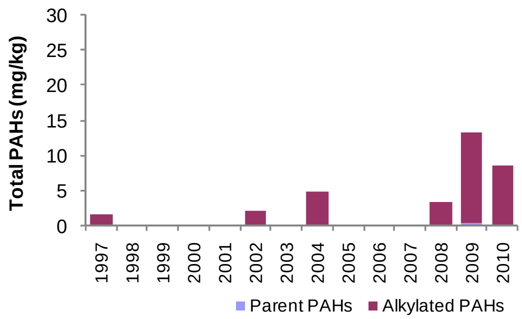
Total Metals*



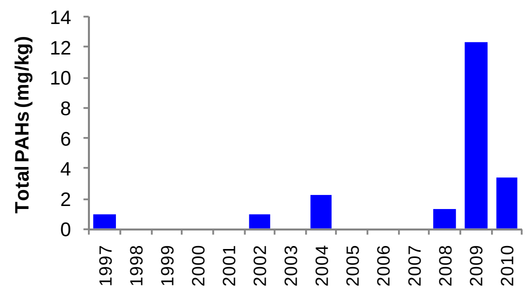
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



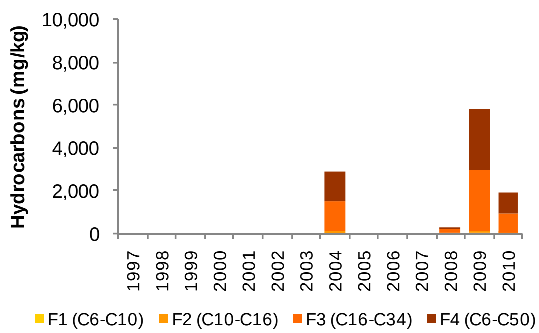
Total PAHs



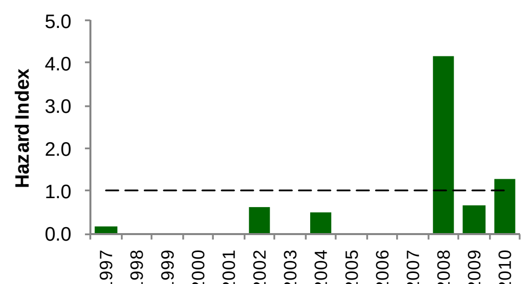
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Table 5.11-26 Concentrations of sediment quality measurement endpoints, upper Beaver River (*baseline* station BER-D2), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2008-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	6.0	2	5	7	9
Silt	%	-	6.6	2	1	11	21
Sand	%	-	87.4	2	70	82	94
Total organic carbon	%	-	0.4	2	0.2	1.1	2.0
Total hydrocarbons							
BTEX	mg/kg	-	<10	1	<20	<20	<20
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	1	<20	<20	<20
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	1	40	40	40
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	1	119	119	119
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	1	94	94	94
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.003	2	0.001	0.001	0.001
Retene	mg/kg	-	0.005	2	0.005	0.263	0.520
Total dibenzothiophenes	mg/kg	-	0.007	2	0.001	0.008	0.015
Total PAHs	mg/kg	-	0.114	2	0.018	0.361	0.704
Total Parent PAHs	mg/kg	-	0.008	2	0.004	0.010	0.017
Total Alkylated PAHs	mg/kg	-	0.105	2	0.014	0.350	0.686
Predicted PAH toxicity[3]	H.I.	-	0.489	1	0.881	0.881	0.881
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-					
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.0	2	7.4	8.1	8.8
Chironomus growth - 10d	mg/organism	-	2.626	2	2.088	2.114	2.14
Hyalella survival - 14d	# surviving	-	9.0	2	8.6	9.1	9.6
Hyalella growth - 14d	mg/organism	-	0.174	2	0.242	0.339	0.436

Sediment quality was only sampled at BER-D2 in fall 2008.

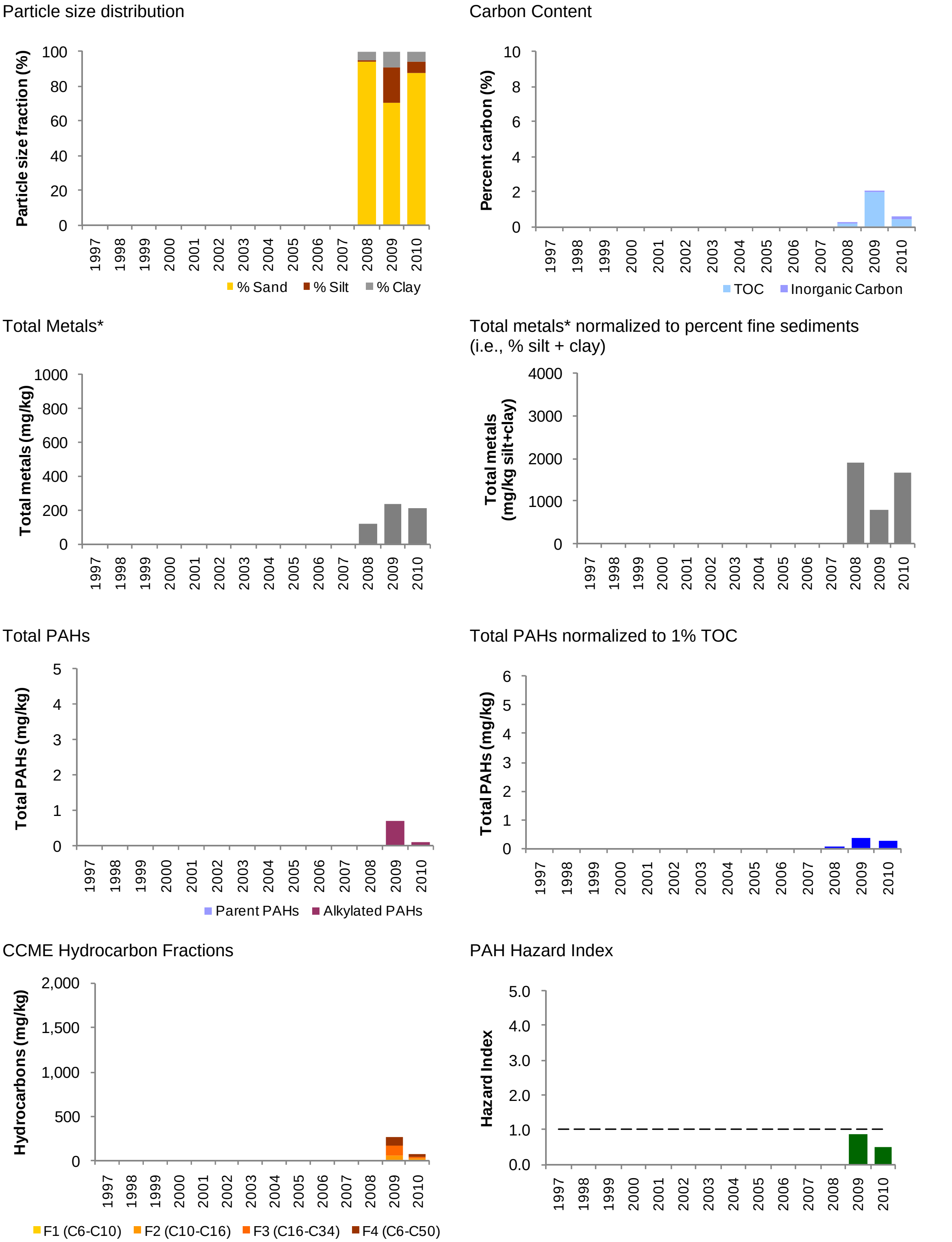
Values in **bold** indicate concentrations exceeding guidelines.

[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.

Figure 5.11-17 Variation in sediment quality measurement endpoints at *test* station BER-D2.



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Table 5.11-27 Sediment quality index (fall 2010) for miscellaneous watershed stations.

Station Identifier	Location	2010 Designation	Sediment Quality Index	Classification
POC-D1	mouth of Poplar Creek	*test*	89.9	Negligible-Low
FOC-D1	mouth of Fort Creek	*test*	93.2	Negligible-Low
BER-D2	upper Beaver River	*baseline*	98.7	Negligible-Low

Note: see Figure 5.11-1 for the locations of these sediment quality stations.

Note: see Section 3.2.3.2 for a description of the Sediment Quality Index.

Table 5.11-28 Concentrations of water quality measurement endpoints, McLean Creek (*test* station MCC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	11	8.0	8.3	8.6
Total Suspended Solids	mg/L	-[1]	15	11	<3	8	83
Conductivity	µS/cm	-	337	11	289	402	1000
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.014	11	0.005	0.016	0.048
Total nitrogen*	mg/L	1.0	**1.52**	11	0.70	**1.18**	**1.50**
Nitrate+Nitrite	mg/L	1.3	<0.071	11	<0.05	<0.10	<1.00
Dissolved organic carbon	mg/L	-	28	11	14	25	35
Ions							
Sodium	mg/L	-	16.5	11	10.3	23.0	140
Calcium	mg/L	-	40.6	11	37.9	46.9	81.7
Magnesium	mg/L	-	12.2	11	10.3	13.3	21.0
Chloride	mg/L	230, 860[3]	6.6	11	4.8	17.0	165
Sulphate	mg/L	100[4]	16.5	11	3.2	10.6	76.4
Total Dissolved Solids	mg/L	-	264	11	218	300	620
Total Alkalinity	mg/L	-	147	11	141	174	319
Selected metals							
Total aluminum	mg/L	0.1	**0.57**	11	0.07	**0.33**	**2.58**
Dissolved aluminum	mg/L	0.1[2]	0.0070	11	0.0003	0.0085	0.0157
Total arsenic	mg/L	0.005	0.0008	11	0.00065	0.00095	0.00138
Total boron	mg/L	1.2[5]	0.049	11	0.024	0.054	0.201
Total molybdenum	mg/L	0.073	0.00029	11	0.00012	0.00016	0.00050
Total mercury (ultra-trace)	ng/L	5, 13[6]	4.1	7	<1.2	<1.2	1.7
Total strontium	mg/L	-	0.149	11	0.110	0.148	0.294
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Sulphide	mg/L	0.002[7]	**0.0129**	11	**<0.003**	**0.008**	**0.025**
Total Kjeldahl nitrogen	mg/L	1.0[8]	**1.45**	11	0.40	1.00	**1.40**
Total iron	mg/L	0.3	**0.72**	11	**0.36**	**0.61**	**3.46**
Total chromium	mg/L	0.001	**0.001**	11	**0.008**	**0.038**	**0.072**
Total phenols	mg/L	0.004	**0.0095**	11	<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).

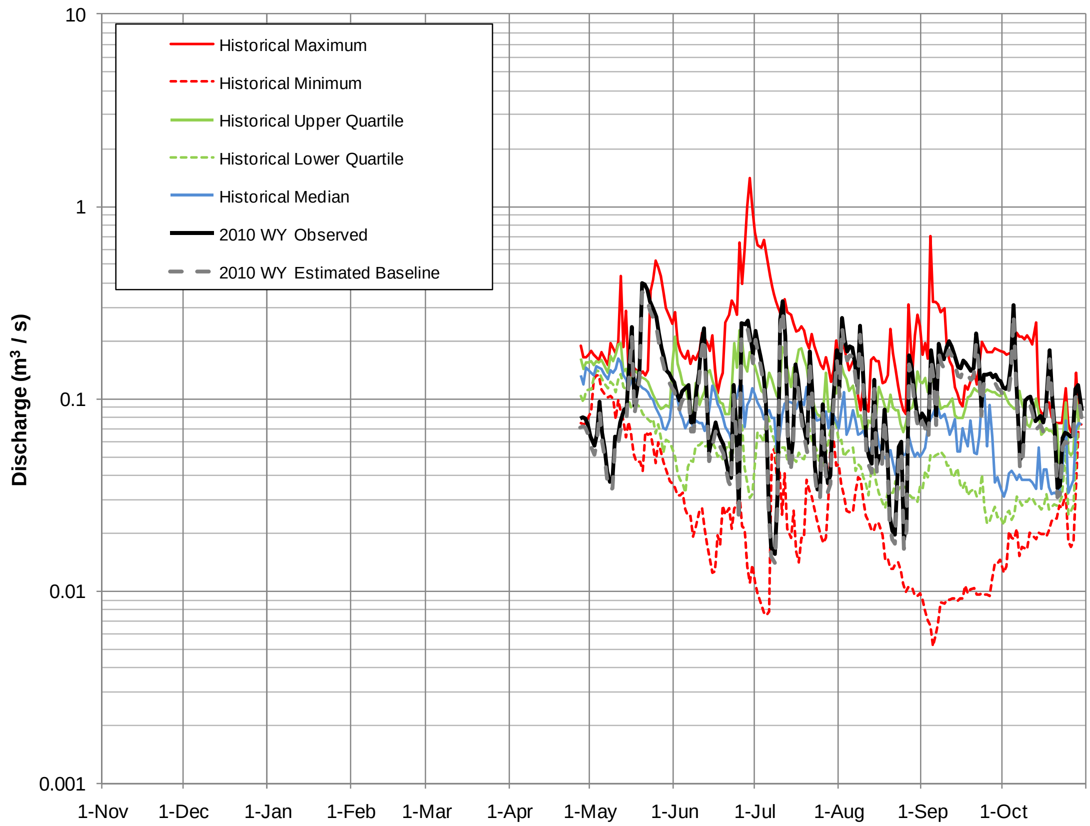
[5] B.C. ambient water quality guideline for boron (B.C. 2003).

[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 5.11-18 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Fort Creek in the 2010 WY, compared to historical values.



Note: Observed 2010 WY hydrograph based on Station S12, Fort Creek at Highway 63, 2010 WY provisional data from April 27 to October 30. The upstream drainage area is 31.9 km^2. Historical values from April 27 to October 30, 2010 were calculated using data collected from 2000 to 2002 and from 2006 to 2009.

Table 5.11-29 Estimated water balance at Station S12, Fort Creek at Highway 63, 2010 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* discharge	1.90	**Observed *test* discharge, obtained from Station S12, Fort Creek at Highway 63**
Closed-circuited area water loss from the observed *test* discharge	-0.02	Estimated 0.3 km^2 of Fort Creek watershed closed-circuited by focal projects as of 2010 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.21	Estimated 19.7 km^2 of Fort Creek watershed with land change from focal projects as of 2010 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Fort Creek watershed from oil sands development projects	0	None reported
Water releases into the Fort Creek watershed from oil sands development projects	0	None reported
Diversions into or out of the watershed	0	None reported
The difference between observed and estimated discharge on tributary streams	0	No focal projects on tributaries of Fort Creek not accounted for by figures contained in this table
Estimated *baseline* discharge	1.71	**Estimated *baseline* discharge at RAMP Station S12, Fort Creek at Highway 63**
Incremental flow (change in total discharge)	+0.19	Total discharge from observed *test* volume less total discharge of estimated *baseline* volume
Incremental flow (% of total discharge)	**+11.4%**	**Incremental flow as a percentage of total discharge of estimated *baseline* volume**

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Observed discharge volume is calculated from provisional data from April 27 to October 30, 2010 for Station S12, Fort Creek at Highway 63.

Table 5.11-30 Concentrations of water quality measurement endpoints, Fort Creek (*test* station FOC-1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	1997-2009 (fall data only)			
			Value	n[7]	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	9	8.1	8.3	8.4
Total Suspended Solids	mg/L	-[1]	5	9	3	14	61
Conductivity	µS/cm	-	570	9	432	520	573
Nutrients							
Total dissolved phosphorus	mg/L	0.05[2]	0.006	9	0.009	0.012	0.020
Total nitrogen*	mg/L	1.0	0.55	9	0.40	0.63	1.00
Nitrate+Nitrite	mg/L	1.3	<0.071	9	<0.05	<0.10	<0.10
Dissolved organic carbon	mg/L	-	12	9	11	13	14
Ions							
Sodium	mg/L	-	12	9	8	10	18
Calcium	mg/L	-	83.1	9	69.4	80.7	91.9
Magnesium	mg/L	-	18.2	9	14.3	17.7	20.1
Chloride	mg/L	230, 860[3]	2.8	9	2.0	2.2	7.0
Sulphate	mg/L	100[4]	68.3	9	3.7	7.8	39.5
Total Dissolved Solids	mg/L	-	383	9	260	330	370
Total Alkalinity	mg/L	-	239	9	231	277	304
Selected metals							
Total aluminum	mg/L	0.1	0.074	9	0.031	0.057	**0.85**
Dissolved aluminum	mg/L	0.1[2]	<0.001	9	<0.001	0.002	0.090
Total arsenic	mg/L	0.005	0.0003	9	0.0002	0.0005	0.0010
Total boron	mg/L	1.2[5]	0.055	9	0.026	0.050	0.073
Total molybdenum	mg/L	0.073	<0.00010	9	0.00003	0.000098	<0.00010
Total mercury (ultra-trace)	ng/L	5, 13[6]	1.3	5	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.206	9	0.142	0.175	0.235
Other variables that exceeded CCME/AENV guidelines in fall 2010							
Total phenols	mg/L	0.004	**0.145**	8	<0.001	0.003	**0.027**
Total iron	mg/L	0.3	**0.509**	9	0.065	**0.710**	**1.940**

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] FOC-1 was sampled in both September and October 2000.

Figure 5.11-19 Piper diagram of ion balance in Fort Creek.

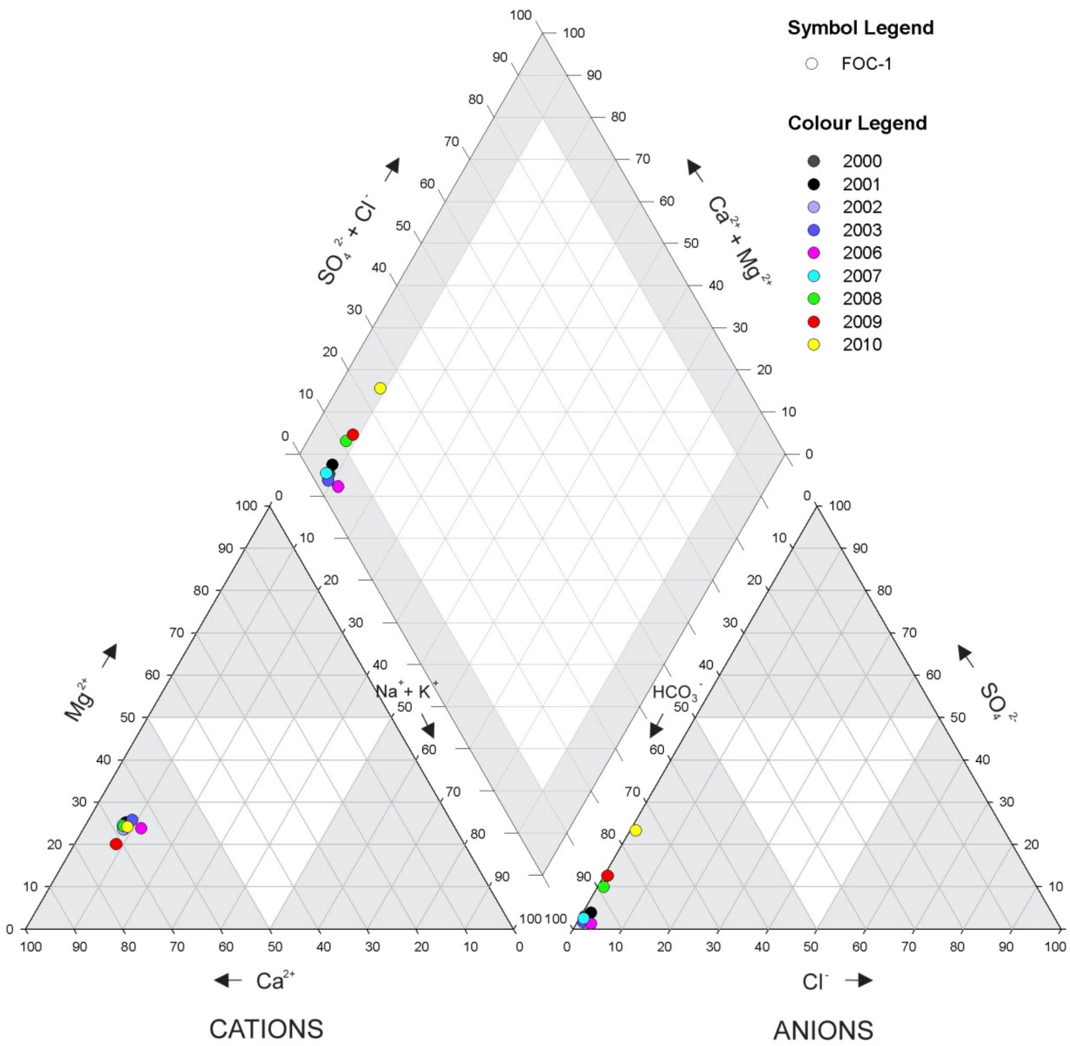
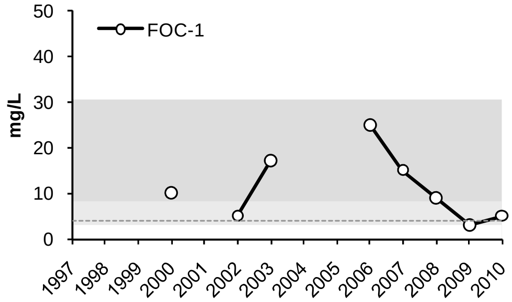
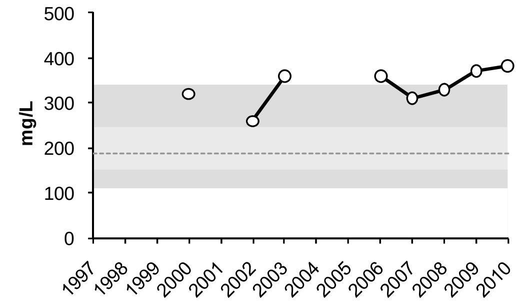


Figure 5.11-20 Concentrations of selected water quality measurement endpoints in Fort Creek (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

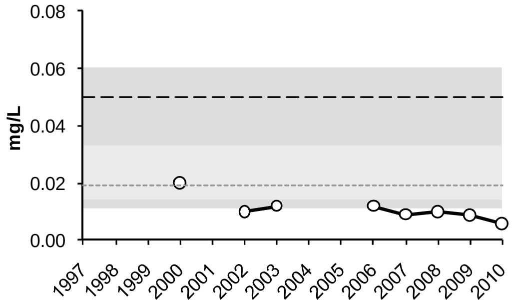
Total Suspended Solids (TSS)



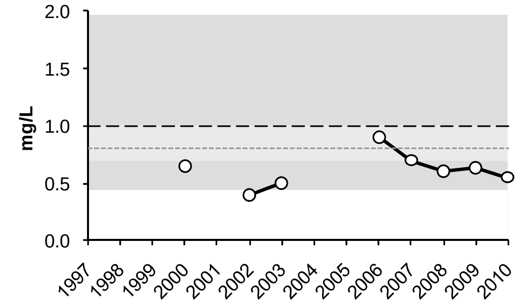
Total Dissolved Solids (TDS)



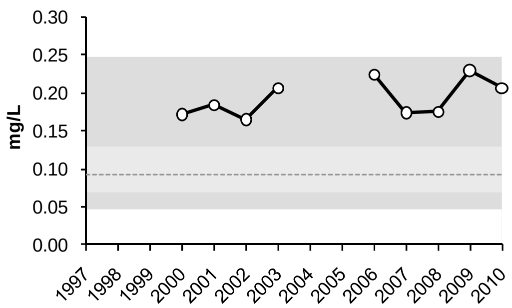
Dissolved Phosphorus



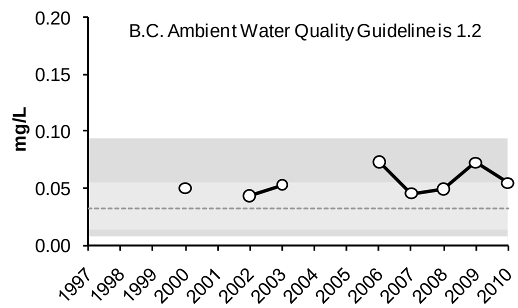
Total Nitrogen



Total Strontium

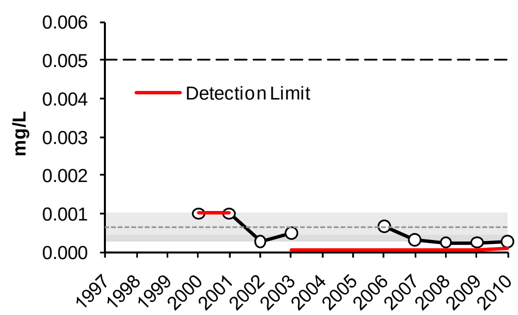


Total Boron



Total Mercury (Ultra-trace)

Total Arsenic

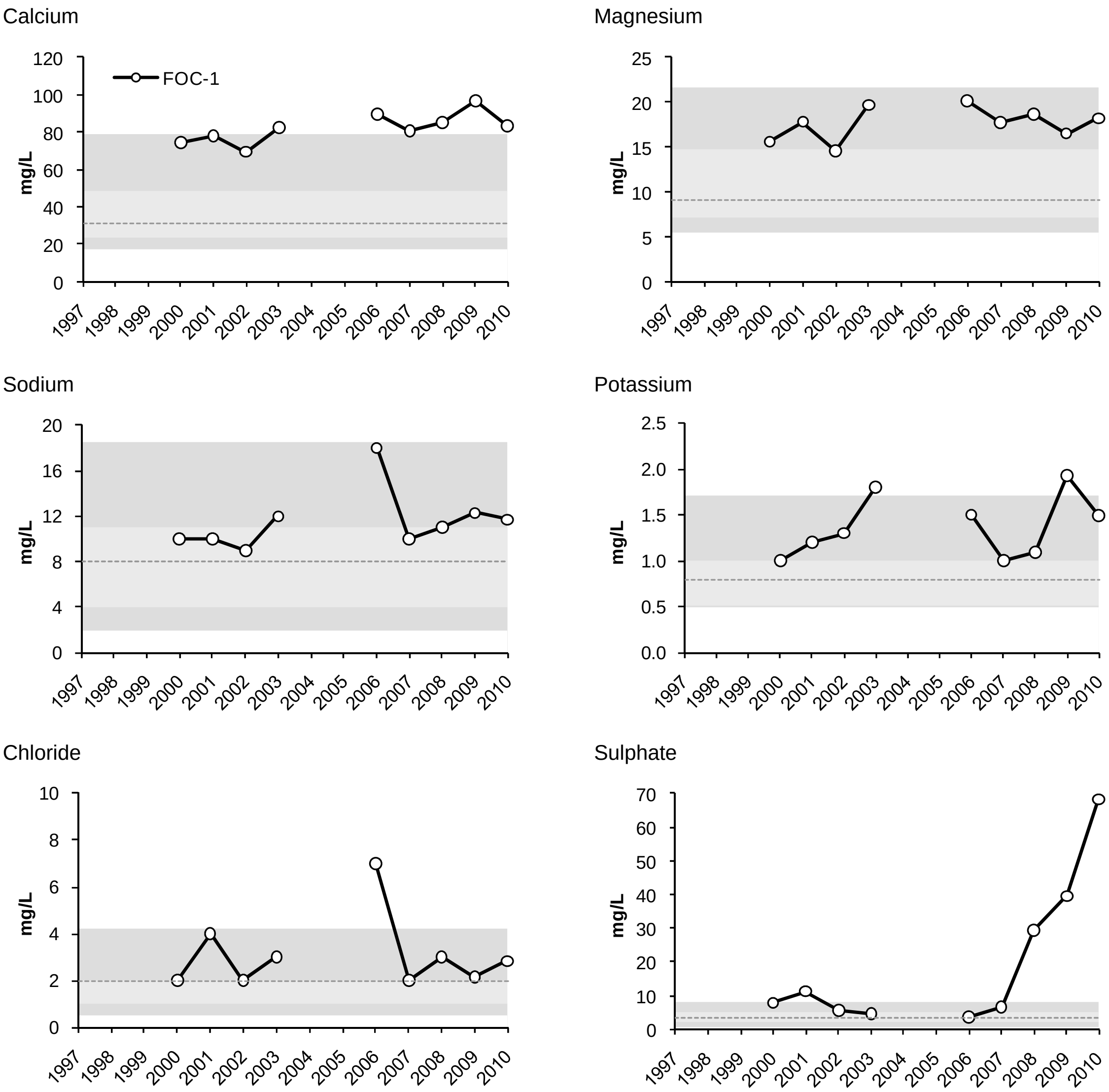


Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Figure 5.11-20 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – Water quality guideline: dissolved phosphorus and total nitrogen (AENV1999b), total arsenic and total mercury (CCME 2007).

Regional *baseline* values reflect pooled results for all *baseline* stations with similar water quality from all years of RAMP sampling. See Sections 3.2.2.3, as well as Appendix D for a discussion of this approach.

Table 5.11-31 Average habitat characteristics of benthic invertebrate sampling locations in lower Fort Creek.

Variable	Units	FOC-D1 Lower *Test* Reach of Fort Creek
Sample date	-	Sept. 9, 2010
Habitat	-	Depositional
Water depth	m	0.3
Current velocity	m/s	0.3
Field Water Quality		
Dissolved oxygen	mg/L	9.6
Conductivity	µS/cm	504
pH	pH units	8.2
Water temperature	°C	12.1
Sediment Composition		
Sand	%	87
Silt	%	10
Clay	%	4
Total Organic Carbon	%	3

Table 5.11-32 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in lower Fort Creek (*test* reach FOC-D1).

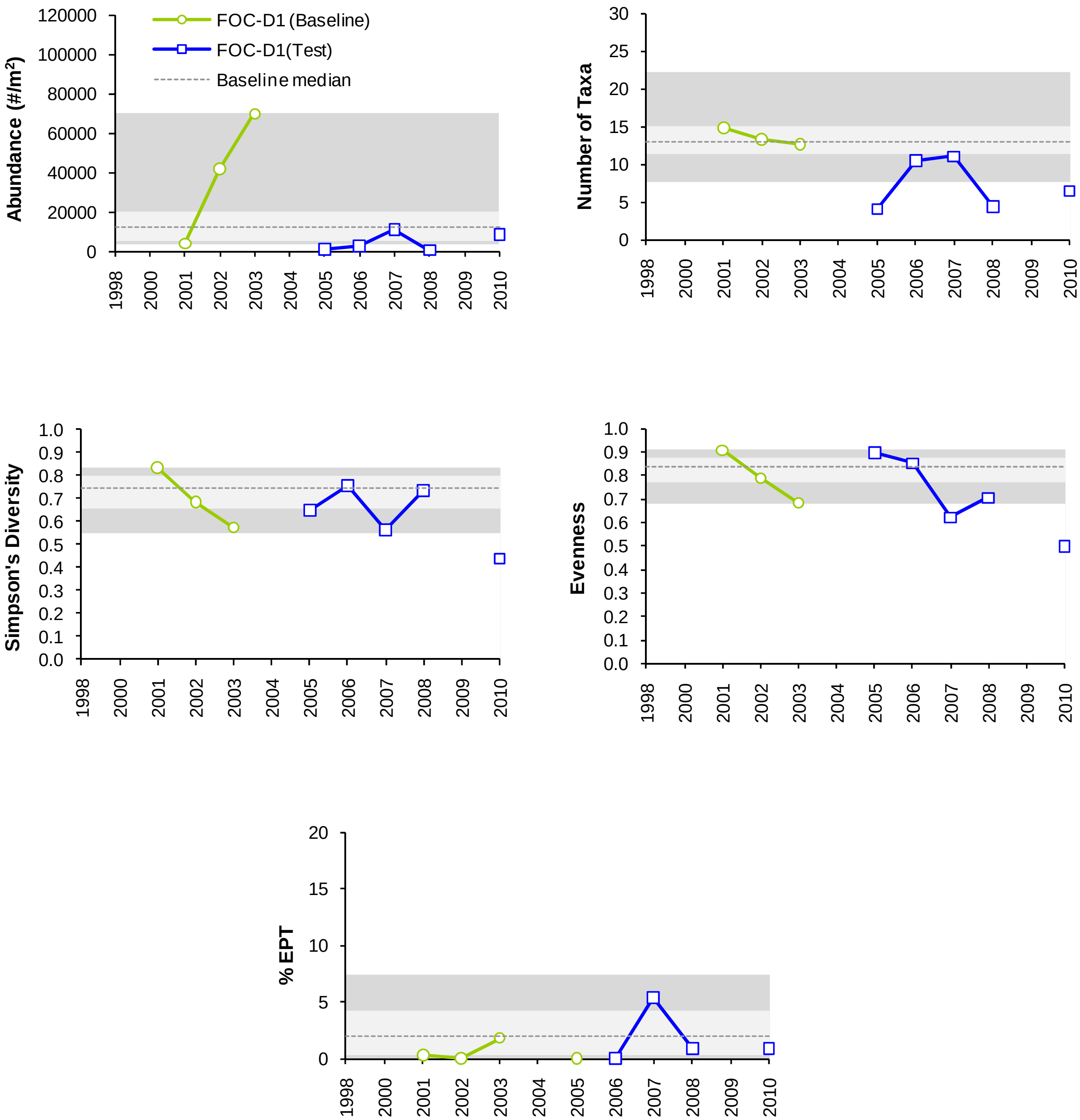
Taxon	Percent Major Taxa Enumerated in Each Year							
	Reach FOC-D1							
	2001	2002	2003	2005	2006	2007	2008	2010
Bivalvia	5	1	<1	8		2		
Ceratopogonidae	<1	<1	1		2	8	1	<1
Chironomidae	80	95	95	56	55	18	68	23
Copepoda	<1	1	1					4
Empididae	1		<1					1
Enchytraeidae	1	<1	1		<1	1	1	
Ephemeroptera	<1					<1	1	
Erpobdellidae		<1						
Gastropoda	<1		<1			1	3	
Glossiphoniidae		<1						
Heteroptera			<1					
Hydracarina	<1		<1					2
Macrothricidae		<1	<1					
Naididae	1	1	<1		1	2		
Nematoda	2	1	1	24	4	1	3	6
Ostracoda	1		<1	6	1	1		1
Plecoptera						1		
Simuliidae			<1					
Tabanidae		<1			1			1
Tipulidae	8	<1	<1		3			1
Trichoptera			<1			<1		<1
Tubificidae		1	<1	6	29	66	22	62
Benthic Invertebrate Community Measurement Endpoints								
Total Abundance (No./m^2)	4,069	41,905	69,802	913	2,948	11,270	591	8,479
Richness	15	13	13	4	10	11	4	6
Simpson's Diversity	0.84	0.69	0.57	0.65	0.76	0.56	0.53	0.44
Evenness	0.91	0.79	0.68	0.9	0.77	0.62	0.70	0.00
% EPT	<1	0	2	0	0	9	<1	<1

Table 5.11-33 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in lower Fort Creek (*test* reach FOC-D1).

Variable	P-value		Variance Explained (%)		Nature of Changes
	Difference between *Baseline* and *Test* from Before to After	Time Trend (*test* period)	Difference between *Baseline* and *Test* from Before to After	Time Trend (*test* period)	
Abundance	**0.027**	0.974	30	0	Lower during the *test* period
Richness	**0.010**	0.707	42	1	Lower during the *test* period
Simpson's Diversity	0.135	0.069	19	28	No change
Evenness	0.335	**0.019**	8	52	Decreasing during the *test* period
EPT	0.568	0.395	4	9	No change
CA Axis 1	**0.033**	0.863	49	0	Shift towards more tubificid worms and fewer chironomids in the *test* period
CA Axis 2	0.969	0.715	0	6	No change

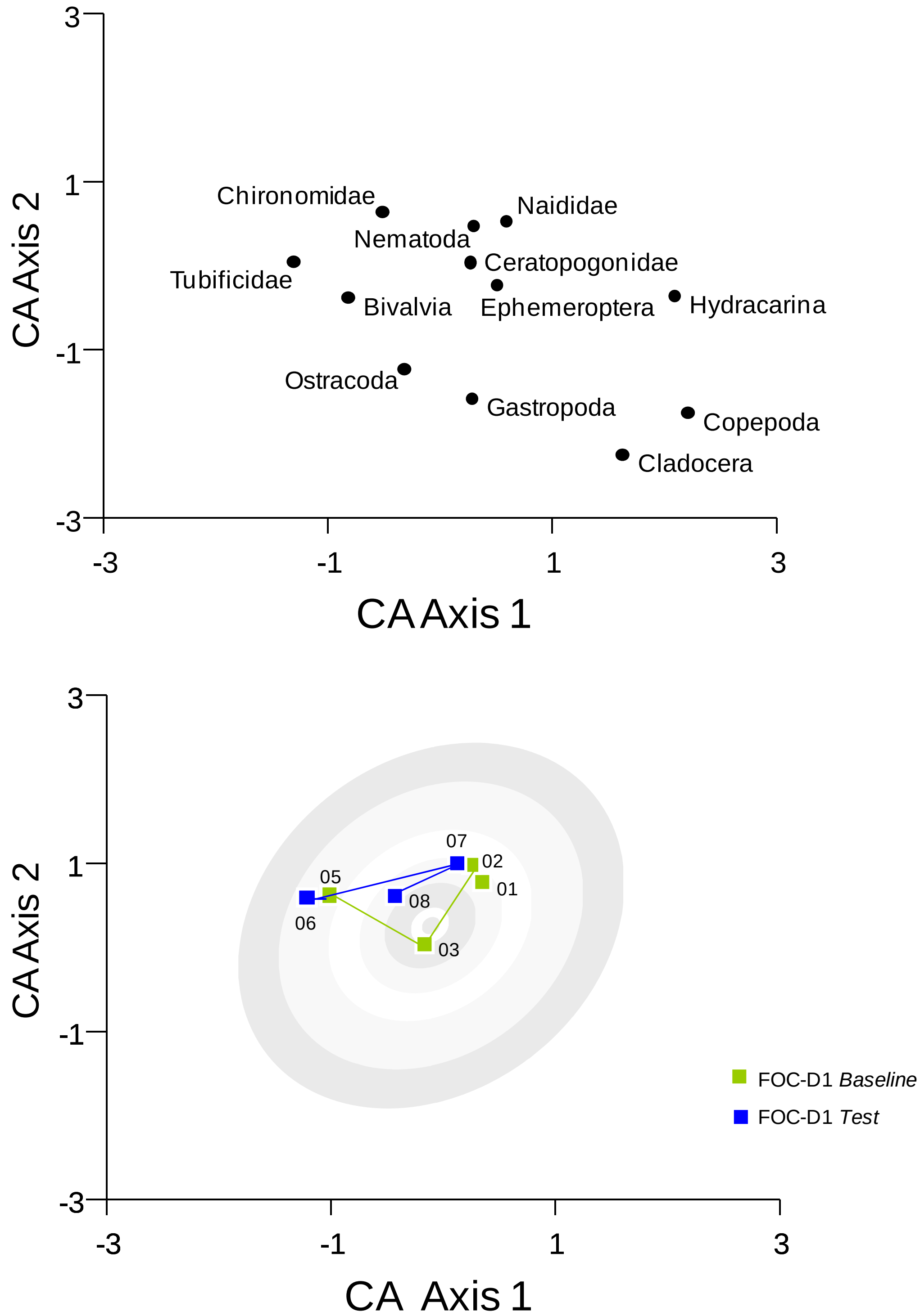
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.11-21 Variation in benthic invertebrate community measurement endpoints in lower Fort Creek (*test* reach FOC-D1).



Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.11-22 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in lower Fort Creek (*test* reach FOC-D1).



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 5.11-34 Concentrations of sediment quality measurement endpoints, Fort Creek (*test* station FOC-D1), fall 2010.

Measurement Endpoint	Units	Guideline	September 2010	2000-2009 (fall data only, station FOC-1)			
			Value	n	Min	Median	Max
Physical variables[4]							
Clay	%	-	3.8	5	4	12.4	17.8
Silt	%	-	4.8	5	3.2	29	52.8
Sand	%	-	91.4	5	36.3	57	92
Total organic carbon	%	-	2.92	5	1.68	3.2	7.1
Total hydrocarbons							
BTEX	mg/kg	-	<10	2	<5	7.5	<10
Fraction 1 (C6-C10)	mg/kg	30[2]	<10	2	<5	7.5	<10
Fraction 2 (C10-C16)	mg/kg	150[2]	93	2	16	93	170
Fraction 3 (C16-C34)	mg/kg	300[2]	**2020**	2	440	1520	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[2]	1980	2	450	975	1500
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[3]	0.0029	5	0.00262	0.008	0.017
Retene	mg/kg	-	0.0812	5	0.0325	<0.38	0.679
Total dibenzothiophenes	mg/kg	-	2.74	5	0.16	1.39	3.22
Total PAHs	mg/kg	-	12.50	5	1.85	4.99	14.26
Total Parent PAHs	mg/kg	-	0.30	5	0.16	0.32	0.87
Total Alkylated PAHs	mg/kg	-	12.20	5	1.69	4.53	13.38
Predicted PAH toxicity[1]	H.I.	-	0.89	4	0.43	0.62	1.05
Metals that exceed CCME guidelines in 2010							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.8	4	7	9	9
Chironomus growth - 10d	mg/organism	-	2.55	4	1.2	1.7	3.0
Hyalella survival - 14d	# surviving	-	9.2	3	6	9	10
Hyalella growth - 14d	mg/organism	-	0.214	3	0.1	0.3	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.

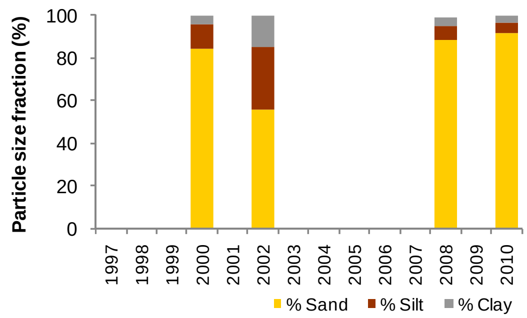
[2] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[3] Interim sediment quality guideline (ISQG) (CCME 2002).

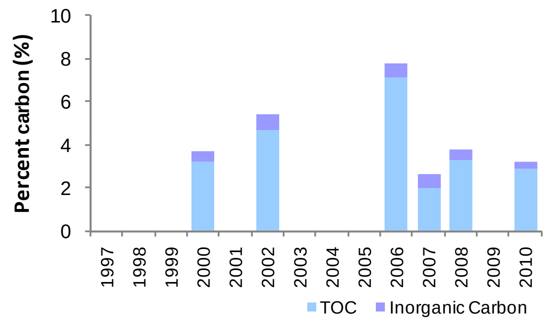
[4] Value is calculated from an average of 5 replicates.

Figure 5.11-23 Variation in sediment quality measurement endpoints in Fort Creek, *test* station FOC-D1.

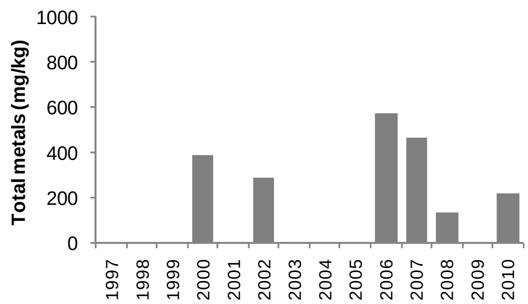
Particle size distribution



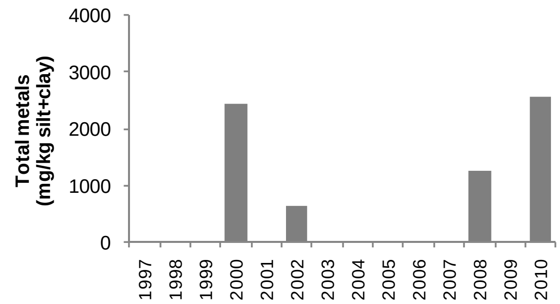
Carbon Content



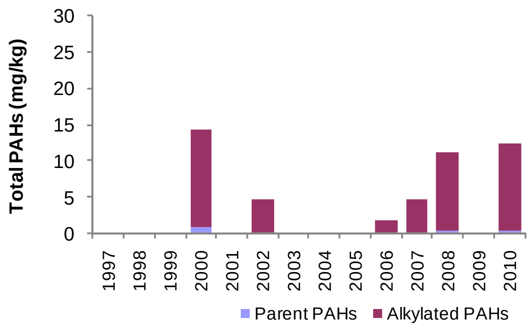
Total Metals*



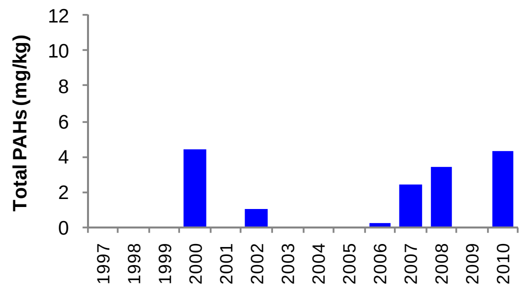
Total metals* normalized to percent fine sediments (i.e., % silt + clay)



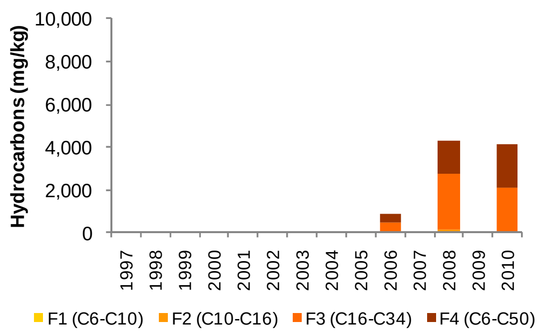
Total PAHs



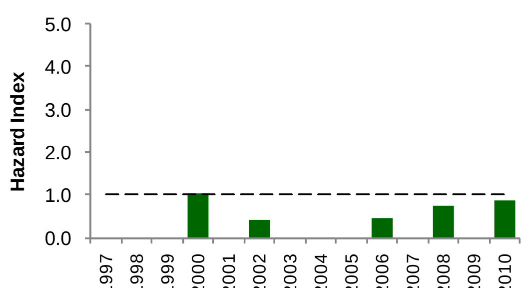
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



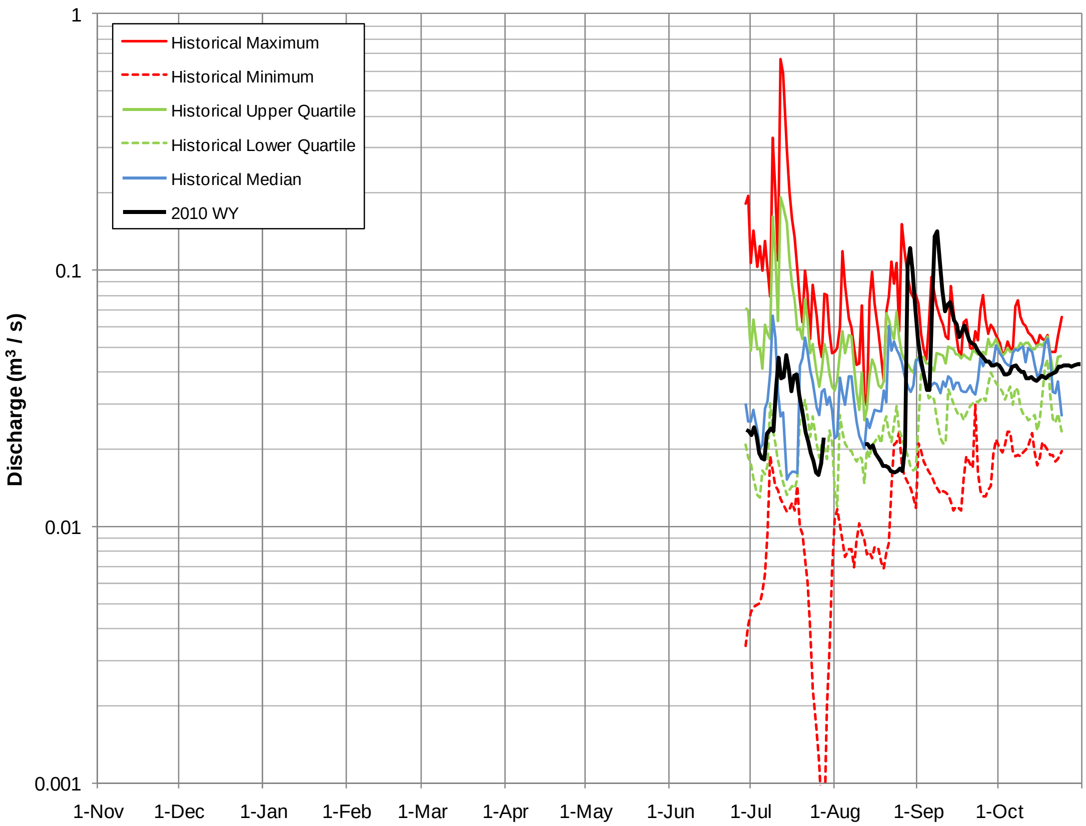
PAH Hazard Index



* Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, St, Th, Ti, Sn, Ag, U, V, Zn (measured in all years).

** Dashed line indicates potential chronic effects level (HI = 1.0)

Figure 5.11-24 Susan Lake Outlet: 2010 WY hydrograph.



Note: Observed 2010 WY hydrograph based on available provisional data for Station S25, Susan Lake Outlet. Historical values are calculated from data collected in 2002 and from 2006 to 2009.

Table 5.11-35 Metrics and mercury concentrations in muscle of walleye, lake whitefish and walleye from Brutus, Keith and Net lakes, fall 2010.

Waterbody	Species	Fish ID	Sex	Length (mm)	Weight (g)	Age (yrs)	Stage/Maturity	Hg (mg/kg)
Brutus Lake	Lake whitefish	1-2	F	248	190	6	Juvenile/Immature	0.095
	Lake whitefish	2-1	M	323	480	-	Adult/Mature	0.059
	Lake whitefish	2-2	F	276	270	-	Adult/Mature	0.081
	Lake whitefish	2-3	F	345	510	13	Adult/Mature	0.087
	Lake whitefish	2-5	M	392	680	6	Adult/Mature	0.107
	Lake whitefish	3-1	F	398	750	12	Adult/Mature	0.158
	Lake whitefish	3-2	M	385	670	11	Adult/Mature	0.119
	Lake whitefish	3-3	F	360	580	10	Adult/Mature	0.103
	Lake whitefish	3-4	F	405	700	16	Adult/Mature	0.115
	Lake whitefish	3-4	F	363	590	10	Adult/Mature	0.104
	Lake whitefish	3-5	F	378	670	9	Adult/Mature	**0.221**
	Northern pike	4-1	F	547	1,050	5	Adult/Mature	**0.364**
	Northern pike	4-2	M	518	1,080	4	Adult/Mature	**0.267**
	Northern pike	4-4	M	553	1,200	5	Adult/Mature	**0.304**
	Northern pike	4-5	M	482	550	5	Juvenile/Immature	**0.471**
	Northern pike	5-1	F	617	1,520	3	Adult/Mature	**0.374**
	Northern pike	5-2	F	575	1,220	5	Adult/Mature	**0.485**
	Northern pike	5-3	F	582	1,320	6	Adult/Mature	**0.261**
	Northern pike	5-4	-	-	-	-	-	**0.330**
	Northern pike	5-5	M	602	1,370	5	Adult/Mature	**0.390**
	Walleye	1-1	F	256	150	2	Juvenile/Immature	0.122
	Walleye	1-2	M	242	130	2	Juvenile/Immature	0.153
	Walleye	1-3	M	230	110	2	Juvenile/Immature	0.155
	Walleye	1-4	F	283	220	3	Juvenile/Immature	**0.228**
	Walleye	1-5	U	190	60	1	Juvenile/Immature	0.102
	Walleye	2-1	F	345	400	5	Juvenile/Immature	**0.224**
	Walleye	2-2	M	361	460	5	Adult/Mature	**0.257**
	Walleye	2-3	M	295	220	3	Juvenile/Immature	**0.201**
	Walleye	2-5	M	336	380	4	Juvenile/Immature	0.185
	Walleye	3-1	F	429	890	9	Adult/Mature	**0.354**
	Walleye	3-2	M	430	790	9	Adult/Mature	**0.402**
	Walleye	3-3	M	412	640	9	Adult/Mature	**0.325**
	Walleye	3-4	F	455	930	9	Adult/Mature	**0.332**
	Walleye	3-4	M	355	410	5	Adult/Mature	**0.216**
	Walleye	3-5	M	430	280	11	Adult/Mature	**0.397**
	Walleye	4-1	F	512	1,390	14	Adult/Mature	**0.485**
	Walleye	4-2	F	492	1,230	12	Adult/Mature	**0.527**
	Walleye	4-3	F	473	1,120	11	Adult/Mature	**0.568**
	Walleye	4-4	F	505	1,320	8	Adult/Mature	**0.431**
Keith Lake	Lake whitefish	1-1	U	220	110	<1	Juvenile/Immature	0.018
	Lake whitefish	2-1	F	276	280	4	Adult/Mature	0.032
	Lake whitefish	2-2	M	343	560	5	Adult/Mature	0.027
	Lake whitefish	2-3	M	305	370	7	Adult/Mature	0.057
	Lake whitefish	2-4	F	342	520	6	Adult/Mature	0.073
	Lake whitefish	2-5	M	303	340	5	Adult/Mature	0.043
	Lake whitefish	3-1	F	390	870	8	Adult/Mature	0.067
	Lake whitefish	3-2	F	399	310	11	Adult/Mature	0.041

Bolded values denote exceedances of the Health Canada guideline for subsistence fishers (0.20 mg/kg).

Bolded and shaded values denote exceedances of the Health Canada guideline for general consumers (0.50 mg/kg).

Table 5.11-35 (Cont'd.)

Waterbody	Species	Fish ID	Sex	Length (mm)	Weight (g)	Age (yrs)	Stage/Maturity	Hg (mg/kg)
Keith Lake	Northern pike	4-1	M	479	830	3	Adult/Mature	0.050
(Cont'd.)	Northern pike	4-2	F	517	910	4	Adult/Mature	0.069
	Northern pike	4-3	M	500	500	3	Adult/Mature	0.093
	Northern pike	5-1	M	631	1,650	6	Adult/Mature	0.119
Net Lake	Lake whitefish	1-1	F	240	180	2	Juvenile/Immature	0.074
	Lake whitefish	2-1	M	350	675	4	Juvenile/Immature	0.089
	Lake whitefish	2-2	F	314	450	2	Juvenile/Immature	0.142
	Lake whitefish	2-3	F	290	350	2	Juvenile/Immature	0.098
	Lake whitefish	3-1	M	396	900	5	Juvenile/Immature	0.101
	Lake whitefish	3-2	M	383	700	6	Juvenile/Immature	0.151
	Lake whitefish	3-3	M	350	650	5	Juvenile/Immature	0.115
	Lake whitefish	3-4	M	380	800	4	Adult/Mature	0.116
	Lake whitefish	3-5	F	449	1,400	-	-	**0.219**
	Lake whitefish	4-1	F	473	1,650	-	-	**0.221**
	Lake whitefish	4-2	M	450	1,450	4	Juvenile/Immature	0.031
	Lake whitefish	4-3	F	405	1,150	6	Adult/Mature	0.129
	Northern pike	4-3	M	495	680	-	-	**0.440**
	Northern pike	3-1	-	-	-	-	-	**0.256**
	Northern pike	3-2	M	463	675	4	Adult/Mature	**0.325**
	Northern pike	3-3	F	490	750	5	Adult/Mature	**0.420**
	Northern pike	4-1	F	515	900	4	Adult/Mature	**0.472**
	Northern pike	4-2	F	395	400	2	Juvenile/Immature	**0.249**
	Northern pike	5-1	M	630	1,625	7	Adult/Mature	**1.080**
	Northern pike	5-2	-	-	-	-	-	0.197
	Northern pike	5-3	F	565	1,000	5	Adult/Mature	**0.308**
	Northern pike	5-4	M	587	1,350	8	Adult/Mature	**0.651**
	Walleye	1-1	M	265	190	3	Juvenile/Immature	**0.388**
	Walleye	1-2	F	237	150	3	Juvenile/Immature	**0.409**
	Walleye	1-3	M	218	83	2	Adult/Mature	**0.240**
	Walleye	1-4	M	252	149	4	Juvenile/Immature	**0.342**
	Walleye	1-5	F	223	106	2	Adult/Mature	**0.285**
	Walleye	2-1	M	302	275	5	Juvenile/Immature	**0.490**
	Walleye	2-2	M	354	650	11	Adult/Mature	**0.706**
	Walleye	2-3	M	349	515	8	Adult/Mature	**0.609**
	Walleye	2-4	M	375	550	10	Adult/Mature	**0.630**
	Walleye	2-5	M	283	250	4	Juvenile/Immature	**0.379**
	Walleye	3-1	F	401	650	7	Adult/Mature	**0.674**
	Walleye	3-2	M	403	650	12	Adult/Mature	**0.925**
	Walleye	3-3	F	453	1,000	8	Juvenile/Immature	**0.922**
	Walleye	3-4	M	402	700	11	Adult/Mature	**0.902**
	Walleye	3-5	M	415	820	13	Adult/Mature	**0.432**
	Walleye	4-1	F	512	1,600	15	Adult/Mature	**0.895**
	Walleye	4-2	-	-	-	-	-	**0.472**
	Walleye	4-3	F	483	1,150	11	Adult/Mature	**0.864**
	Walleye	4-4	M	475	1,200	13	Adult/Mature	**1.420**
	Walleye	4-5	F	494	1,400	15	Adult/Mature	**1.160**

Bolded values denote exceedances of the Health Canada guideline for subsistence fishers (0.20 mg/kg).

Bolded and shaded values denote exceedances of the Health Canada guideline for general consumers (0.50 mg/kg).

Figure 5.11-25 Mercury concentration (mg/kg) by fork length (mm) in muscle of lake whitefish, walleye and northern pike captured from Brutus, Keith, and Net lakes, September 2010.

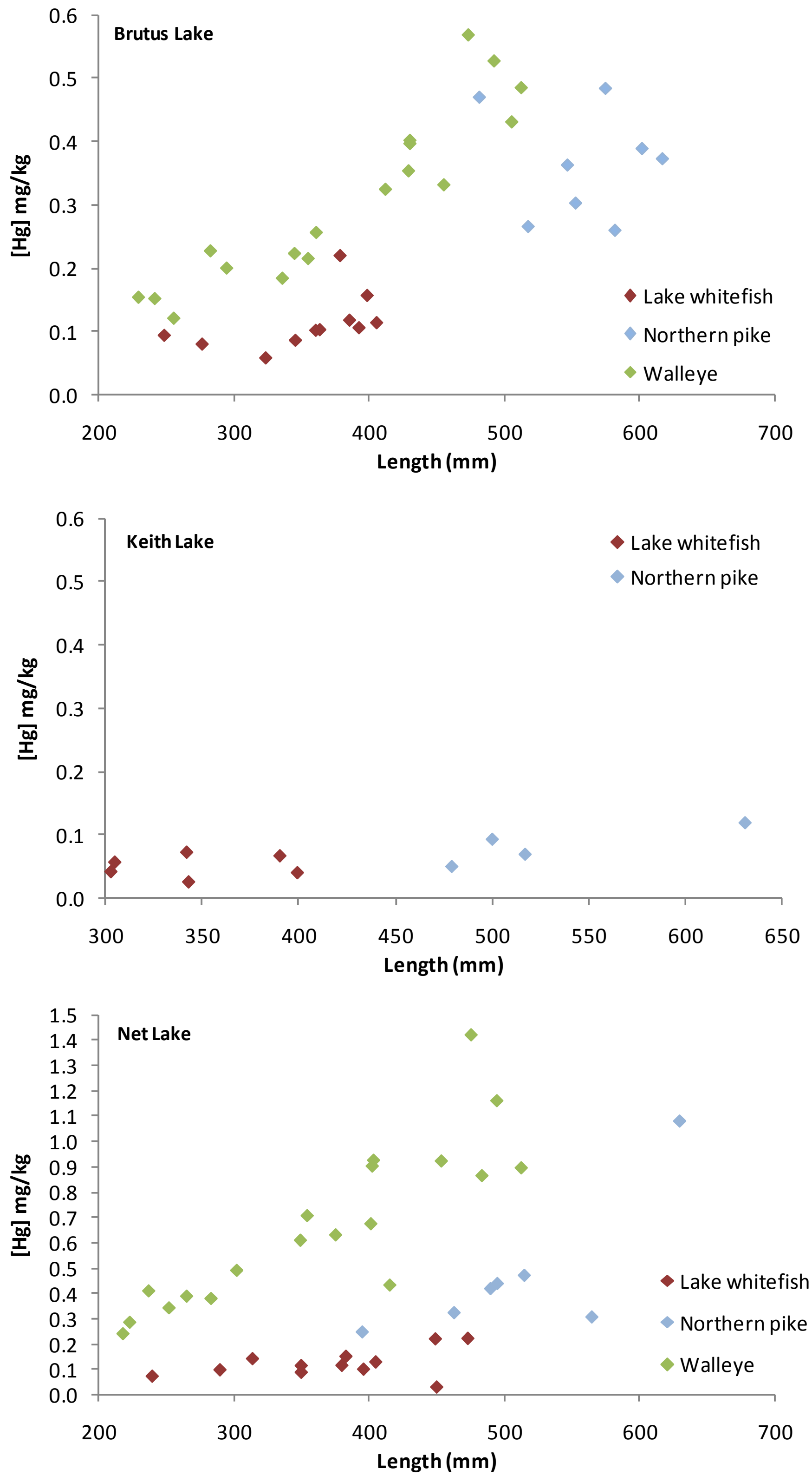


Table 5.11-36 Size and depth information for lakes sampled within the RAMP FSA for mercury in fish muscle tissue, 2002 to 2010.

Lake	Year Sampled	Size (ha)	Max Depth (m)	Mean Depth (m)
Gregoire Lake	2002, 2007	2,580	7.2	3.9
Christina Lake	2003	3,038	32.9	17.4
Lake Claire	2003	143,000	-	-
Winefred Lake	2004	11,200	13.4	8.2
Gardiner Lake	2008	2,410	13.7	6.1
Big Island Lake	2008	1,578	14.9	5.2
Jackson Lake	2009	312	17	-
Brutus Lake	2010	153	~15	-
Keith Lake	2010	188	>2	-
Net Lake	2010	264	~8	-

Figure 5.11-26 Comparison of mercury concentrations in muscle tissue of lake whitefish, northern pike and walleye sampled in lakes within the RAMP RSA (2002-2010).

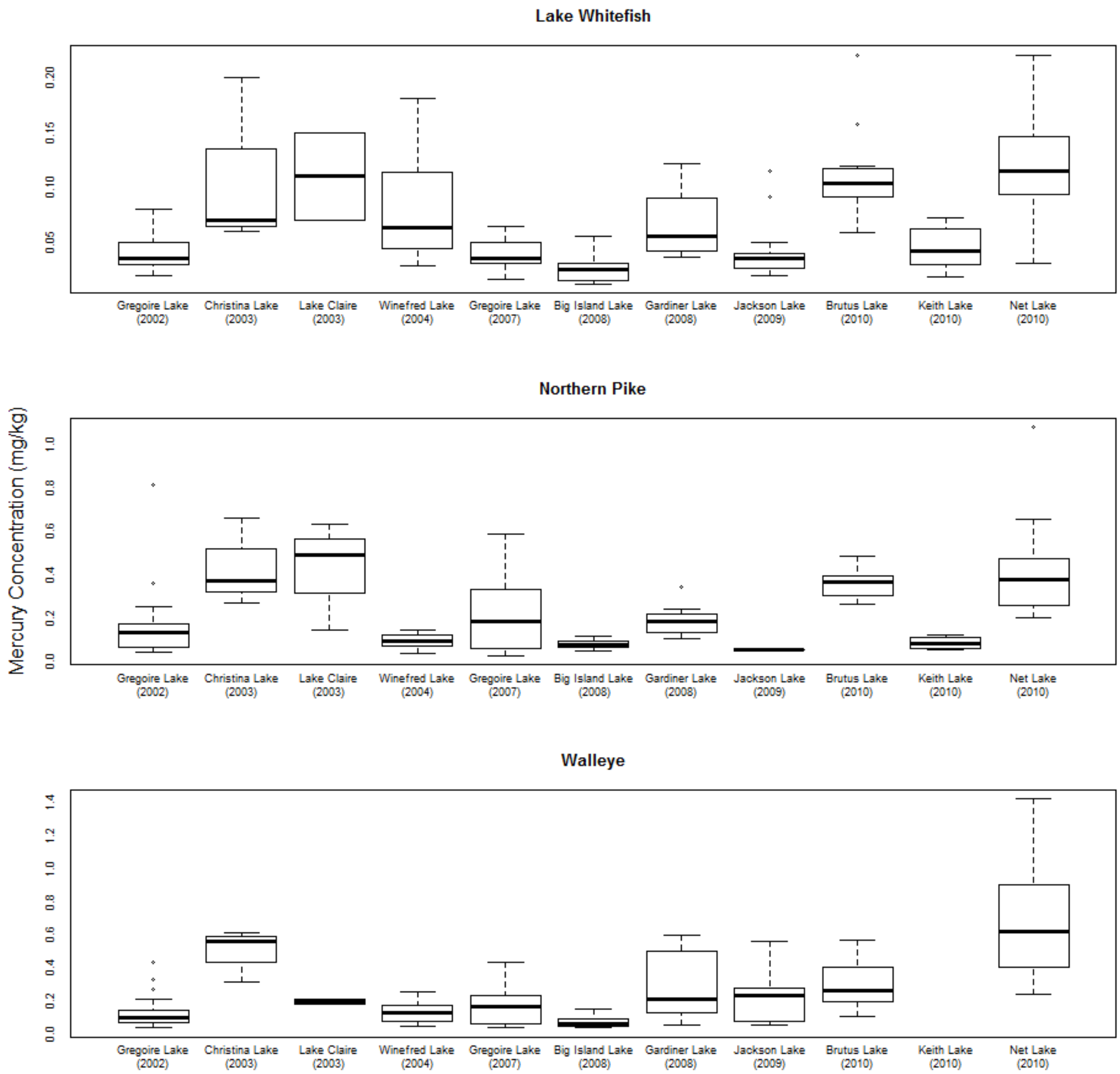


Figure 5.11-27 Weight-standardized mean mercury concentrations in lake whitefish from lakes and rivers in northern Alberta, 1975-2010.

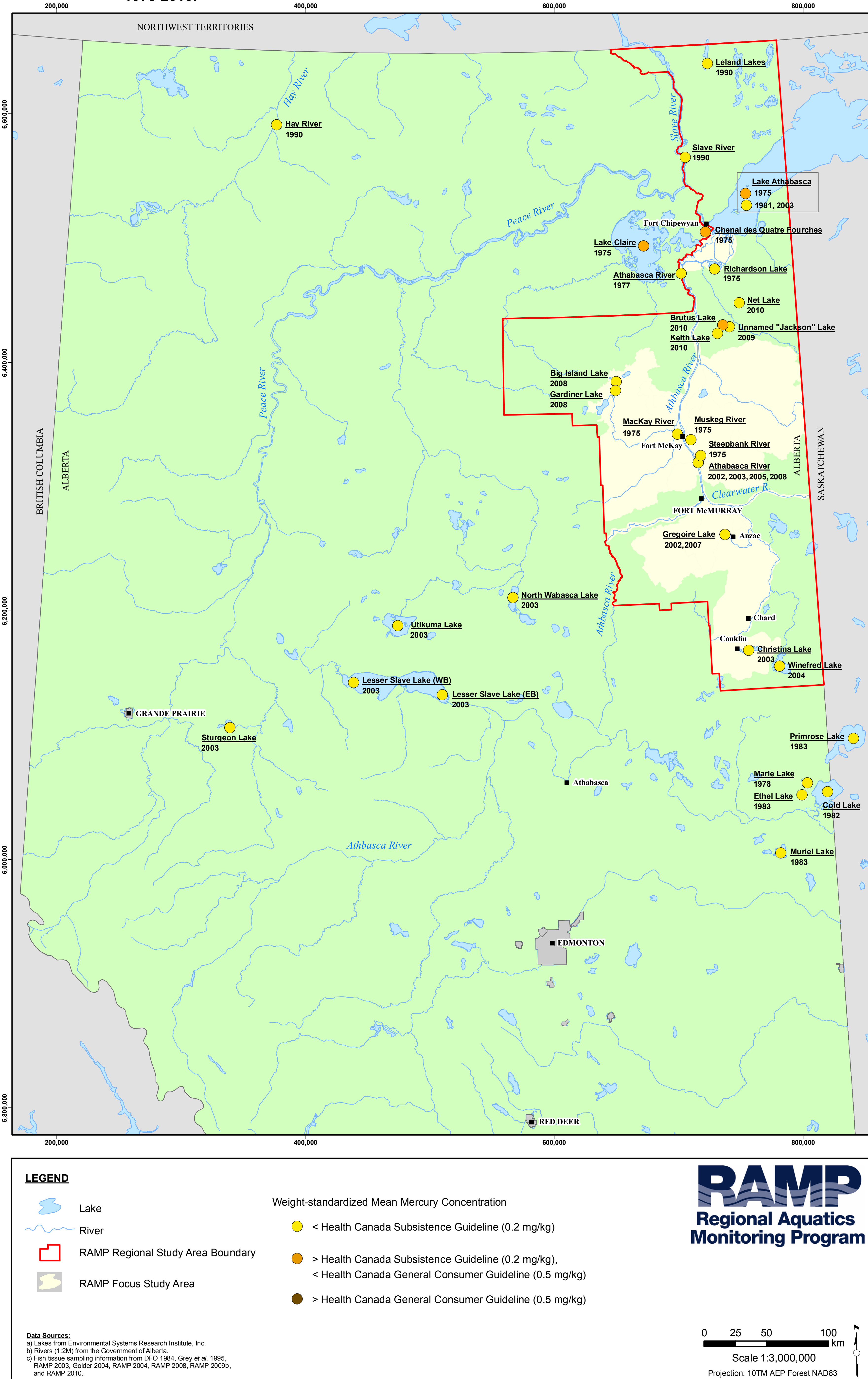


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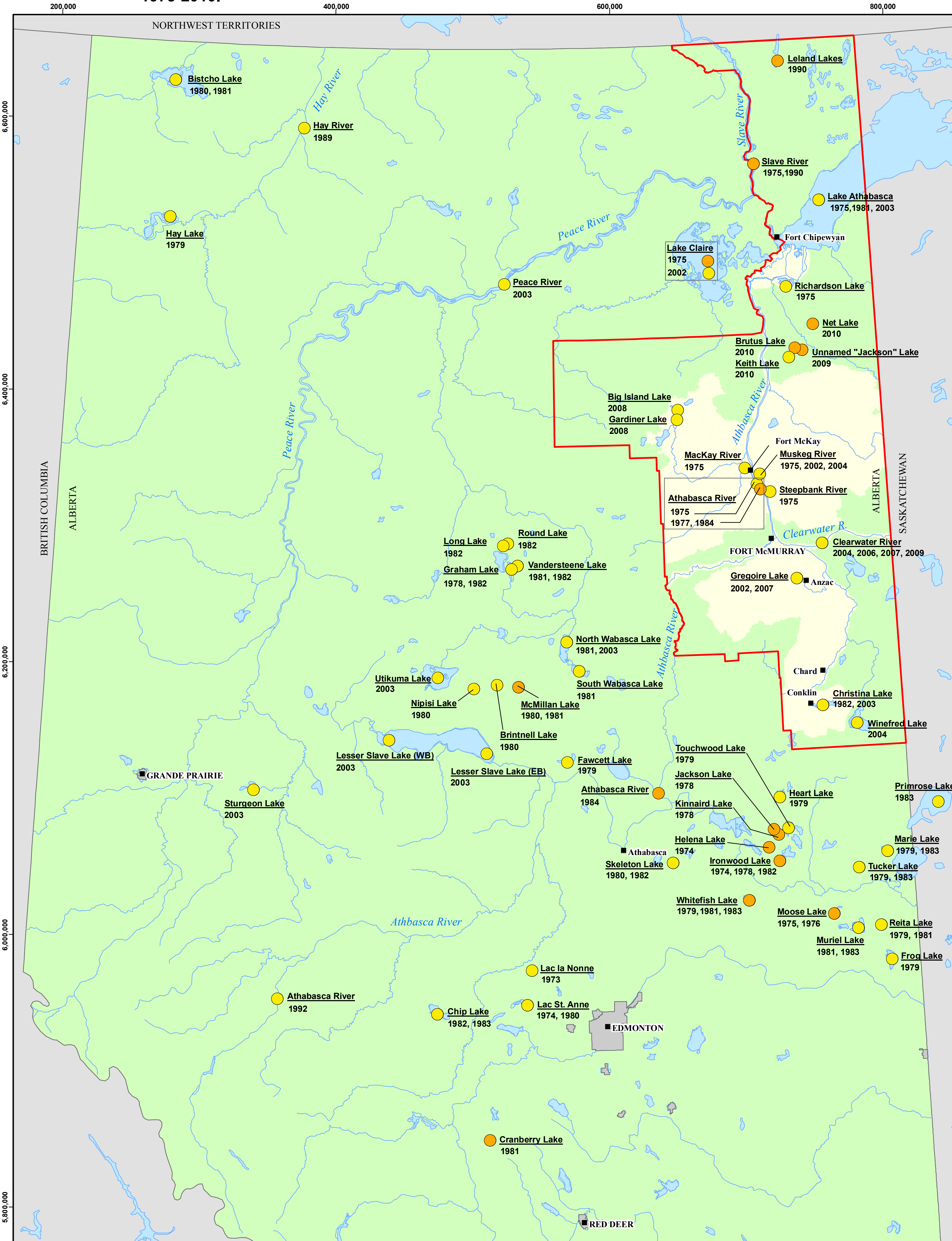
Figure 5.11-28 Weight-standardized mean mercury concentrations in northern pike from lakes and rivers in northern Alberta, 1975-2010.



LEGEND

Lake

River

RAMP Regional Study Area Boundary

RAMP Focus Study Area

Weight-standardized Mean Mercury Concentration

< Health Canada Subsistence Guideline (0.2 mg/kg)

> Health Canada Subsistence Guideline (0.2 mg/kg),
< Health Canada General Consumer Guideline (0.5 mg/kg)

> Health Canada General Consumer Guideline (0.5 mg/kg)

RAMP
Regional Aquatics Monitoring Program

0 25 50 100 km

Scale 1:3,000,000

Projection: 10TM AEP Forest NAD83

Data Sources:
a) Lakes from Environmental Systems Research Institute, Inc.
b) Rivers (1:2M) from the Government of Alberta.
c) Fish tissue sampling information from DFO 1984, Grey *et al.* 1995, RAMP 2003, Golder 2004, RAMP 2004, RAMP 2008, RAMP 2009b, and RAMP 2010.

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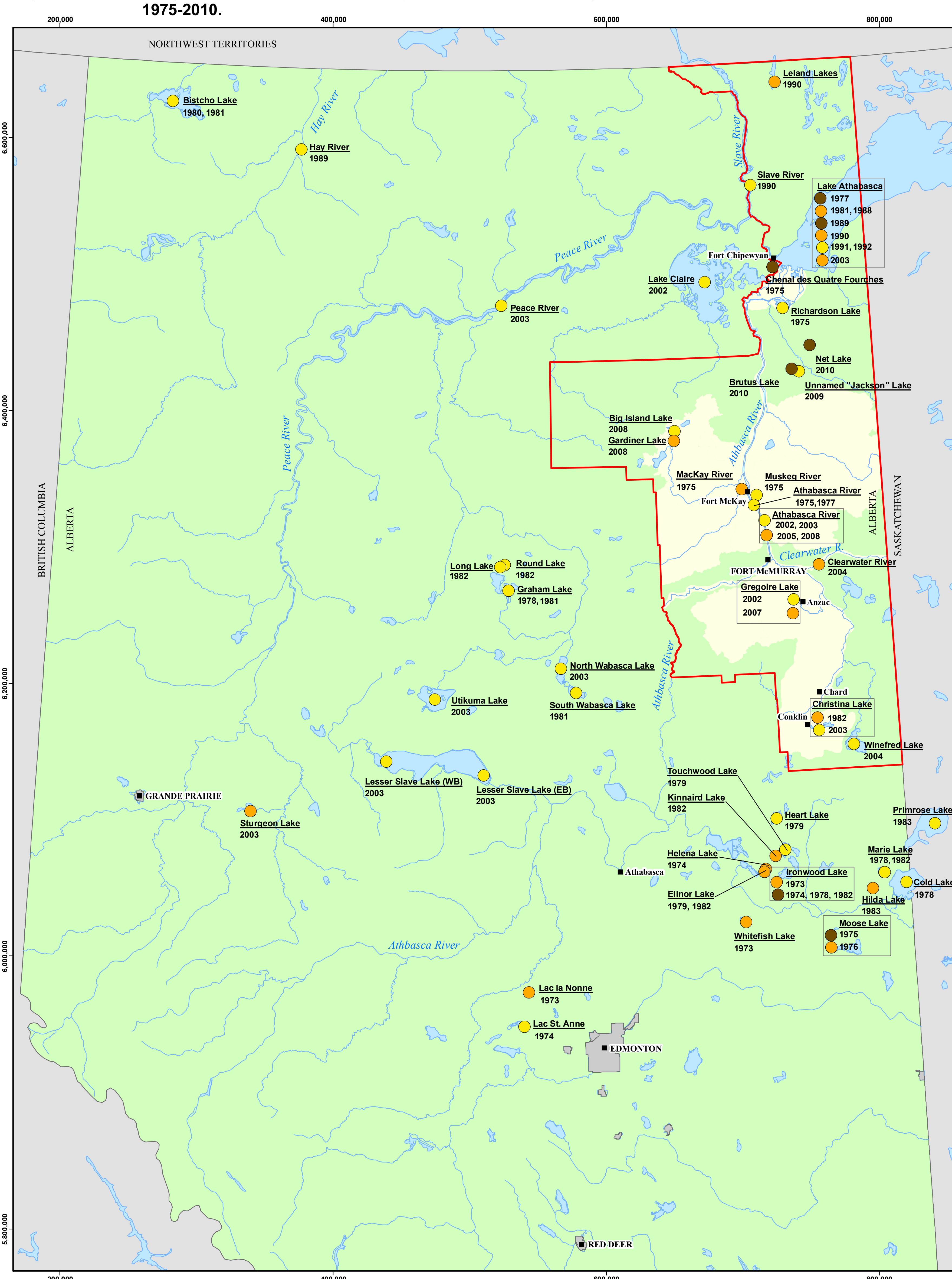
Figure 5.11-29 Weight-standardized mean mercury concentrations in walleye from lakes and rivers in northern Alberta, 1975-2010.



LEGEND

- Lake
- River
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area

Weight-standardized Mean Mercury Concentration

- < Health Canada Subsistence Guideline (0.2 mg/kg)
- > Health Canada Subsistence Guideline (0.2 mg/kg), < Health Canada General Consumer Guideline (0.5 mg/kg)
- > Health Canada General Consumer Guideline (0.5 mg/kg)

RAMP
Regional Aquatics Monitoring Program

0 25 50 100 km
Scale 1:3,000,000
Projection: 10TM AEP Forest NAD83

Data Sources:
a) Lakes from Environmental Systems Research Institute, Inc.
b) Rivers (1:2M) from the Government of Alberta.
c) Fish tissue sampling information from DFO 1984, Grey *et al.* 1995, RAMP 2003, Golder 2004, RAMP 2004, RAMP 2008, RAMP 2009b, and RAMP 2010.

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5.12 ACID-SENSITIVE LAKES

This section presents the results of the Acid-Sensitive Lakes (ASL) component of RAMP for 2010.

5.12.1 General Characteristics of the ASL Component Lakes in 2010

The ASL component lakes are typically small and shallow with a median area of 1.32 km^2 and a median maximum depth of only 1.83 m (Table 5.12-1). The chemical variables measured in the 50 RAMP lakes from 1999 to 2010 are summarized in Table 5.12-2. The RAMP ASL component lakes cover a large variety of lake types from softwater to hardwater. Historically, the pH of the lakes has ranged from 3.97 to 9.46 with a median pH of 6.77. Gran alkalinity has ranged from negative values to 1802 μeq/L with a median value of 196 μeq/L. Concentrations of sulphate are relatively low and range from 0.02 mg/L to 19.0 mg/L (median concentration: 1.21 mg/L). By conventional standards, most of the RAMP ASL component lakes are considered humic with a median dissolved organic carbon (DOC) concentration of 21.5 mg/L (Korteleinen *et al*. 1989, Forsius 1992, Driscoll *et al.* 1991). In general, nitrates are quite low in concentration (median 3.0 μg/L) although individual lakes may have nitrate concentrations greater than two orders of magnitude from the median concentration. Nitrates are highly variable both between lakes and between years within each lake. Total phosphorus ranges from 3.0 μg/L to 341 μg/L with a median of 39.0 μg/L. The much lower concentrations of dissolved phosphorus (median: 11 μg/L) indicate that a large fraction of the phosphorus is bound to suspended particulates.

Lakes having "unusual" water chemistry were identified in the 2010 monitoring data as those below or above the 5th and 95th percentile for the three measurement endpoints: pH, Gran alkalinity, and DOC (Table 5.12-3). Generally, these lakes were identified in previous years as having "unusual" water chemistry (e.g., RAMP 2009b). Three lakes (169/SM9, 287/SM8 and Clayton Lake/BM7) had very low levels of Gran alkalinity. All three lakes are found in organic soils in upland regions, two in the Stony Mountains and one in the Birch Mountains. The highest values of Gran alkalinity and buffering capacities in the ASL component lakes were found in Lake 270/NE9, Lake 271/NE10 and Kearl Lake/NE11, all located within mineral soils northeast of Fort McMurray. These lakes also had the highest values of pH. The lowest concentrations of DOC were found in two Birch Mountains Lakes (Namur and Legend lakes) and the highest concentrations of DOC were found in Lake 268/NE5 located northeast of Fort McMurray and Lake 165/WF1 and Lake 223/WF4 both in the West of Fort McMurray sub-region.

In general, lakes with lowest levels of Gran alkalinity and pH are found in organic soils in the upland regions. Unique to the ASL component lakes are lakes such as Kearl Lake that are simultaneously high in pH and high in DOC. Most coloured (high DOC) lakes typically have low pH (Korteleinen *et al.* 1989).

The chemistry of the ASL component lakes is discussed further in Appendix G.

5.12.2 Temporal Trends

5.12.2.1 Among-Year Comparisons of Measurement Endpoints

Comparisons of the ASL measurement endpoints among years were conducted using a one-way ANOVA. The results were very similar to those reported in previous years with nitrate being the only measurement endpoint to show a significant change over the nine years ($p<0.01$). Concentrations of nitrates are extremely variable in the ASL component lakes with a coefficient of variation for this variable between 200% and 300%

(Table 5.12-4). The variability in the concentration of nitrate makes it very difficult to detect a change in nitrates in the ASL component lakes attributable to acidification. Overall, there has been a decrease in the median concentration of nitrates between 2002 and 2010, the opposite of what is expected in an acidification scenario triggered by nitrogen emissions from oil sands developments. Therefore, there is no indication that acidification is occurring from nitrogen deposition.

5.12.2.2 Among-Year Comparisons of Measurement Endpoints using the General Linear Model

There were no significant relationships between any of the ASL measurement endpoints and year in the 50 ASL component lakes with the exception of DOC (p=0.002). Based on the individual regression coefficients, the concentration of DOC declined in 29 of the 50 ASL component lakes between 2002 and 2010. A significant decrease in the concentration of DOC with year was also measured for the 10 lakes in the Stony Mountain subregion analyzed separately (p=0.0004). The Stony Mountain Lakes are considered to have a high sensitivity to acidic deposition. The GLM was also applied to the combined grouping of lakes in the Canadian Shield and Caribou Mountain subregions, which are considered baseline lakes. These lakes are the farthest of all ASL component lakes from oil sands development and should not show any effects from acid deposition. There were no significant decreases in DOC in these *baseline* lakes. The relationships between DOC and year for all 50 lakes, the Stony Mountain lakes and the *baseline* lakes are presented in Figure 5.12-1.

Results in 2010 were different from those observed in 2009 when a significant decrease in DOC was also observed in the Caribou Mountains and Canadian Shield lakes (RAMP 2010). The 2009 results suggested that the significant decline in DOC observed in the 50 ASL component lakes was a natural phenomenon rather than a response to acidification. In 2010, the same explanation cannot be applied to the decrease in concentrations of DOC in 2010 given it was not observed in the *baseline* lakes. It is unlikely that the decrease in DOC in the ASL component lakes is caused by acidification given a response to acidification would have been expected first in Gran alkalinity or in pH rather than concentrations of DOC; significant between-year differences in Gran alkalinity and pH were not detected. Changes in concentrations of DOC will be monitored over time to determine whether a decrease in DOC continues in the ASL component lakes and whether the decrease in DOC is attributable to acidification.

5.12.3 Critical Loads of Acidity and Critical Load Exceedances

The critical loads of acidity (CL) were calculated for each ASL component lake from 2002 to 2010 using the Henriksen steady state water chemistry model.

The runoff to each lake, an influential term in the Henriksen model, was calculated using the isotopic mass balance (IMB) technique; the values for each lake are presented in Appendix G. Figure 5.12-2 provides the distribution of runoff (water yields) and the critical load in all 50 lake catchments from 2002 to 2010. As noted by Gibson *et al.* (2010), water yields vary considerably between years. For example, in Kearl Lake, the water yields changed three- to four-fold over the nine years of data (Appendix G). The highest values of water yield occurred in years with high precipitation. This is especially evident in 2005, where the median water yield (263 mm/y) is more than twice that observed in 2007 (106 mm/y) (Figure 5.12-2). Significant changes in the runoff to a lake imply that the critical load, and the acid sensitivity of each lake, will vary between years, depending upon the hydrologic regime.

The estimates of the critical loads of acidity for each individual RAMP lake between 2002 and 2010 are provided in Table 5.12-5 and summary statistics are provided in Table 5.12-6. Critical loads in 2010 ranged from -0.483 keq H^+/ha/yr to 5.369 keq H^+/ha/yr with a median CL of 0.410 keq H^+/ha/y.

Mean critical loads in 2010 in the six subregions are provided in Table 5.12-7. Consistent with results from previous years, low critical loads are found in lakes in the Stony Mountains, Birch Mountains, and Canadian Shield subregions. Negative critical loads were calculated for many of the lakes, especially in the Stony Mountains. By the critical load criterion, the Stony Mountain lakes, having the lowest critical loads, are the most acid-sensitive of the RAMP ASL component lakes.

5.12.4 Comparison of Critical Loads of Acidity to Modeled Net Potential Acid Input

Lakes having a modeled Net PAI greater than the critical load are identified individually in Table 5.12-8; the results are summarized in Table 5.12-9. The percentage of such lakes ranged from a low of 18.4 % (9 of 49 lakes) in 2005 to a high of 32.6% (15 of 46 lakes) in 2007 (Table 5.12-9). Differences between years reflect differences between water yields and the base cation concentrations in each lake.

The percentage of ASL component lakes in which the modeled Net PAI is greater than the critical load (18.4 to 32.6%) is considerably higher than the 8% of 399 regional lakes reported in a study conducted for the NO_xSO_x Management Working Group within CEMA (WRS 2006). The higher proportion in the ASL component lakes largely reflects a bias in the selection of lakes for the RAMP program in which the most poorly-buffered lakes in the region were chosen in the initial phase of the program. The estimates of Net PAI published in CEMA (2010c) may also be biased high. By incorporating both approved and existing industries in the calculation of the PAI, the estimates of Net PAI reported in Table 5.12-9 represent future risk (not current risk) to the ASL component lakes. For comparison to other regions, Henriksen *et al.* (2002) reported that 11% to 26% of lakes in four sensitive regions of Ontario had levels of PAI exceeding the critical load. This study did not include modifications to the model for organic anions or use of isotopic estimates of runoff.

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 5.12-8 summarizes the key chemical characteristics of the lakes having the modelled Net PAI greater than the critical load. As expected, these are generally small lakes of low pH, low conductivity, low alkalinity and high DOC. While these lakes are scattered throughout most of the oil sands region, the majority are found in the Stony Mountain subregion (Table 5.12-5).

5.12.5 Comparisons to Modelled PAI

5.12.5.1 Mann-Kendall Trend Analysis on Measurement Endpoints

Mann-Kendall trend analysis was applied to test for changes in each measurement endpoint over time in the 50 individual ASL component lakes. Table 5.12-9 provides the value of the S or Z statistic for each measurement endpoint for each lake. Significant changes in a measurement endpoint in a direction (positive or negative) that is consistent with an acidification scenario are indicated in red. The Mann-Kendall test is a non-parametric test that subtracts successive values and ranks the differences as negative or positive. Small monotonic increases or decreases in a measurement endpoint that may not be significant ecologically, or are within the range of analytical error, can result in a false conclusion that a significant acidifying trend is occurring. The results of these analyses must; therefore, be interpreted carefully. To interpret the results of the trend analyses, control charts have been prepared of measurement endpoints in those lakes where significant changes occur in a direction indicative of acidification (Figure 5.12-3). The interpretation of these control charts is discussed in detail in Section 3.2.5.7.

There are fewer significant trends in values of measurement endpoints in 2010 than in previous years. These include the following:

1. A significant decrease in pH over time was detected in Lake 223 in the West of Fort McMurray subregion. The control chart for this lake indicates that the decrease in pH in this lake is small (Figure 5.12-3). Over nine years of data the pH varied by less than 0.3 pH units. This is an example of a small, statistically significant change that is likely insignificant ecologically. The decrease in pH in this lake is not accompanied by a significant increase in the concentrations of sulphate or nitrates that would account for this decrease. Application of the criteria for interpreting control charts suggests that there is no significant trend in pH occurring in Lake 223.

2. No significant decreases in the concentration of Gran alkalinity over time were detected in any of the 50 ASL component lakes. Gran alkalinity actually increased significantly in nine lakes including lakes in the Stony Mountain, Birch Mountain and Canadian Shield subregions.

3. A significant increase in the concentration of sulphate over time was detected in Lake 436 in the Birch Mountains. As with the pH in Lake 223, the increase in sulphate in Lake 436 was very small although the trend was statistically significant (Figure 5.12-3). Concentrations of sulphate increased by less than 1.5 mg/L from 2003 after a decrease of about 1 mg/L from 2001. The increase in sulphate was accompanied by increases in Gran alkalinity and pH in this lake, the opposite of what would be expected under an acidifying scenario. The control charts indicate that no significant trend in sulphate is occurring in Lake 436.

4. A significant increase in concentrations of nitrate over time was detected in Lake 199 from the Birch Mountains. The control chart for Lake 199 indicates that nitrate concentrations in this lake are extremely low and variable with a mean concentration of only 3 µg/L (Figure 5.12-3). The 2008 value approaches the two standard deviation limit of 8 µg/L. The control charts indicate that there is no significant trend in nitrate occurring in this lake.

5. Significant decreases in concentrations of DOC over time were detected in Lakes 287 and 290 from the Stony Mountains and Lake 271 from Northeast of Fort McMurray. It is too early to determine whether these decreases are indicative of acidification. The control charts suggest that there is no significant trend in DOC occurring in these lakes (Figure 5.12-3).

6. Significant increases in the sum of base cation concentrations (SBC) over time were detected in Lake 166 (Stony Mountains), Lake 171 (West of Fort McMurray) and in Lakes 146, 152 and 91 (Caribou Mountains). Acidification should initially result in an increase in base cations as these ions are stripped

from soils in catchments receiving acid deposition. However, none of the increases in the SBC concentrations in these lakes was associated with a significant increase in sulphate concentrations suggesting that these trends cannot be attributed to acidification. Three of the five lakes are found in the Caribou Mountains, a remote area that does not receive acidifying emissions. Three of the lakes (146, 152 and 166) also show significant increases in Gran alkalinity. These increases in Gran alkalinity suggest that the increases in SBC in these lakes are attributable to increased loading of alkalinity (calcium and magnesium bicarbonates) from the catchments rather than calcium and magnesium sulphates. Loading of calcium and magnesium sulphates would reduce (rather than increase) Gran alkalinity and would indicate that acidification is occurring. The control charts suggest that there is no significant trend in SBC over time (Figure 5.12-3). The very high value of SBC in Lake 91 in 2005 exceeding three standard deviations is considered to be an anomalous laboratory error.

In summary, the results of the Mann-Kendall trend analysis do not indicate that acidification is occurring in the ASL component lakes.

5.12.6 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 5.12-5. The greater this ratio in a lake, the greater is the risk for acidification. The ten lakes with the highest ratios are shaded in Table 5.12-5. The ten lakes are scattered throughout the oil sands region and are found in the Stony Mountains, Birch Mountains, Northeast of Fort McMurray and West of Fort McMurray subregions. If acidification is occurring, it should be evident first in these lakes.

Control charts for pH, sum of base cations (SBC), sulphate, DOC, nitrates and Gran alkalinity are presented in Figure 5.12-4 to Figure 5.12-9. As in previous years, the control plots for all measurement endpoints show isolated excursions of two standard deviations during the sampling period. In previous sampling years, exceedances of two standard deviations in a direction indicative of acidification occurred for pH in Lake 290; SBC in lakes 290, 223 and 470; sulphate in lakes 168, 223 and 470; DOC in lakes 172, 223 and 185; Nitrates in lakes 168, 170, 290, 172, 452, 470 and 185, and Gran alkalinity in lakes 289 and 290. In 2010, these exceedances were not observed.

It is notable that concentrations of nitrate actually exceeded three standard deviations in 2010 in Lake 172 (Figure 5.12-8), although the control chart suggests that the concentration in 2010 is an anomaly rather than the result of a trend. There was no significant increase in the concentration of nitrate in the 11 years preceding 2010. Concentrations of nitrate in this lake will be monitored in subsequent years to determine if a real trend is evident.

With the possible exception of nitrates, the control charts do not indicate that acidification is occurring even in these lakes that are most at risk.

5.12.7 Classification of Results

The results of the analysis of the 2010 ASL component lakes data compared to historical data suggest that there has been no significant change in the overall chemistry of the 50 lakes across years. A long-term decline is noted for DOC but this appears to be a regional trend that may reflect other causes or factors other than acidifying emissions. Based on the analysis of among-year differences in concentrations of ASL measurement endpoints, as well as trend analysis and control plotting of ASL measurement endpoints on individual lakes, there is no evidence to suggest that there have been any significant changes in lake chemistry in the ASL lakes attributable to acidification.

The subregion of the Caribou Mountains 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** indication of incipient acidification. The classification is somewhat questionable because the Caribou Mountain lakes are remote from sources of acidifying emissions and considered *baseline* lakes. All three exceedances in measurement endpoints in the Caribou Mountain subregion were attributable to Lake 146/CM1, which had unusual water chemistry in 2010. It is likely that these results and classification are uncharacteristic for this subregion. The remaining subregions were classified as **Negligible-Low**.

Table 5.12-1 Morphometry statistics for the ASL component lakes.

	Lake area (km^2)	Catchment Area (km^2)	Maximum Depth (m)
Minimum	0.034	0.57	0.91
Maximum	44.0	166	27.4
Median	1.32	13.2	1.83

Table 5.12-2 Summary of the chemical characteristics of the ASL component lakes.

Parameter	Mean		Median		Minimum		Maximum		5th	95th
	1999-2010	2010	1999-2010	2010	1999-2010	2010	1999-2010	2010	Percentile 2010	Percentile 2010
Lab pH	6.59	6.80	6.77	6.90	3.97	4.38	9.46	8.74	5.07	7.93
Total alkalinity (µeq/L)	318	357	220	233	0	0	1784	1730	43	1162
Gran alkalinity (µeq/L)	304	340	196	213	-57	-35	1802	1728	12	1147
Specific conductivity (µS/cm)	44	46	32	32	10	10	180	173	11	114
Total dissolved solids (mg/L)	66	64	60	60	0.02	0.02	219	194	17	132
Total suspended solids (mg/L)	7.4	3.8	2.8	1.7	0.025	0.025	175.0	68.0	0.025	8.7
Sodium (mg/L)	2.06	2.28	1.40	1.55	0.18	0.60	10.70	9.90	0.70	6.01
Potassium (mg/L)	0.509	0.483	0.430	0.395	0.003	0.018	2.400	2.230	0.125	1.026
Calcium (mg/L)	5.63	5.62	4.61	4.49	0.002	0.002	32.2	21.2	0.2	16.0
Magnesium (mg/L)	1.816	1.964	1.415	1.575	0.114	0.170	13.640	7.720	0.356	4.829
Bicarbonate (mg/L)	19.3	21.7	13.4	14.2	0.000	0.000	109	105	2.65	69.0
Chloride (mg/L)	0.341	0.271	0.180	0.135	0.015	0.020	2.636	2.210	0.060	1.072
Sulphate (mg/L)	2.40	2.21	1.21	1.18	0.020	0.020	19.0	12.0	0.092	10.2
Total dissolved nitrogen (µg/L)	836	730	693	624	105	280	2891	1880	330	1621
Ammonia (µg/L)	37.3	20.5	16.5	18.0	0.35	8.0	1509	71.0	9.0	49.1
Nitrate + Nitrite (µg/L)	20.4	29.0	3.00	1.50	0.02	0.50	732.9	379.0	0.5	231.2
Total phosphate (µg/L)	54.2	52.4	39.0	36.5	3.0	5.0	341	208	13.5	148.8
Dissolved phosphate (µg/L)	20.5	21.5	11.0	11.0	1.0	4.00	167	104	5.0	83.9
Dissolved inorganic carbon (mg/L)	3.247	3.672	2.040	2.250	0.027	0.200	20.270	18.100	0.400	12.430
Dissolved organic carbon (mg/L)	22.8	22.0	21.5	21.1	6.8	7.0	7.0	45.8	11.4	39.2
Chlorophyll *a* (µg/L)	19.9	16.9	9.1	7.5	0.3	0.3	371.0	153.1	1.5	57.0
Iron (mg/L)	0.397	0.366	0.189	0.126	0.00001	0.00001	3.88	2.26	0.006	1.92
Total nitrogen (µg/L)	1205	1181	968	912	274	357	6558	5740	482	3029
Total Kjeldahl nitrogen (µg/L)	1185	1152	943	866	273	357	6552	5737	478	3028
Sum base cations (meq/L)	534.9	559.4	427.3	452.5	38.2	80.8	2290.9	1922.2	127.1	1461.9
Dissolved aluminum (mg/L)	70.8	70.8	70.8	37.5	0.100	0.67	681	478	1.092	249

Grey shading denotes measurement endpoints for the ASL program. Yellow shading denotes values that are less than the detection limit with values equal to one- half the detection limit.

Table 5.12-3 ASL component lakes with chemical characteristics either below the 5^{th} or above the 95^{th} percentile, 2010.

Lake	Region	pH	Gran Alkalinity (µeq/L)	DOC (mg/L)
5^{th} percentile 2010		**5.07**	**11.8**	**11.445**
95^{th} percentile 2010		**7.93**	**1147**	**39.150**
169 (A24/SM9)	Stony Mountains	4.89	-2.2	15.1
287 (25/SM8)	Stony Mountains	5.32	10.0	11.4
436 Namur Lake (L18/BM2)	Birch Mountains	7.54	450	7.2
444 Legend Lake (L25/BM1)	Birch Mountains	7.07	202	7.0
447 (L28/BM6)	Birch Mountains	5.00	39.6	21.9
448 Clayton Lake (L29/BM7)	Birch Mountains	4.38	-35.2	21.9
175 (P13/BM13)	Birch Mountains	7.65	832	38.6
270 (4/NE9)	Northeast of Fort McMurray	8.02	1268	19.7
271 (6/NE10)	Northeast of Fort McMurray	8.74	1198	20.4
268 (E15/NE5)	Northeast of Fort McMurray	7.49	376	45.0
418 Kearl Lake (418/NE11)	Northeast of Fort McMurray	8.32	1728	28.2
182 (P23/NE6)	Northeast of Fort McMurray	7.66	1084	17.9
165 (A42/WF1)	West of Fort McMurray	7.63	406	39.6
223 (P94/WF4)	West of Fort McMurray	7.11	636	45.8

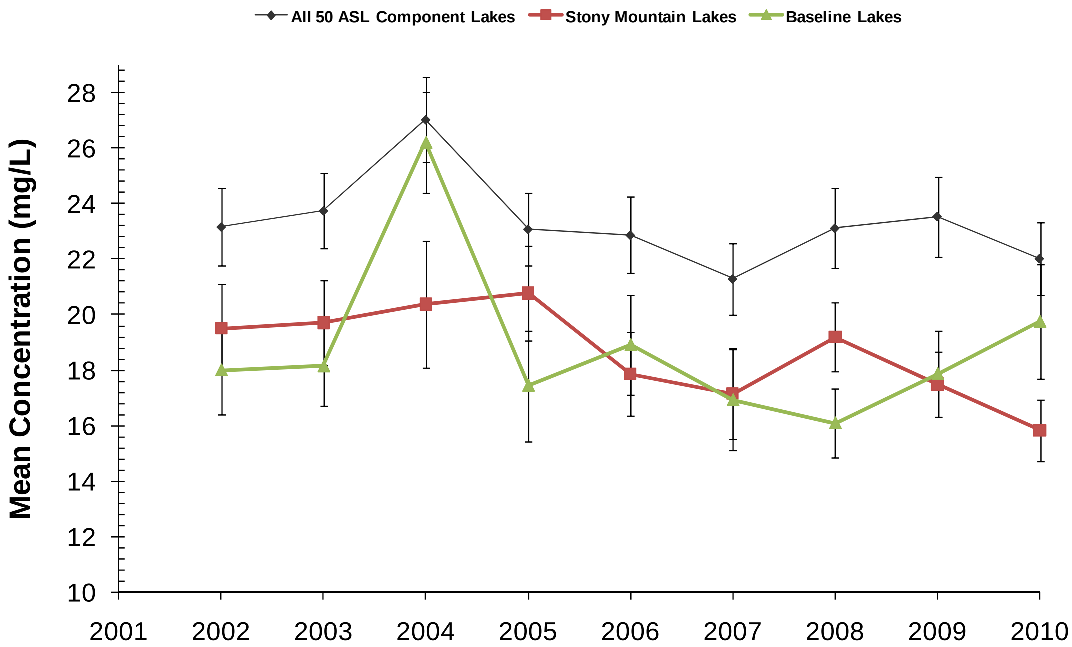
Yellow shading denotes values below the 5^{th} percentile in 2010.

Green shading denotes values above the 95^{th} percentile in 2010.

Table 5.12-4 Summary of nitrate concentrations in the ASL component lakes, 2002-2010.

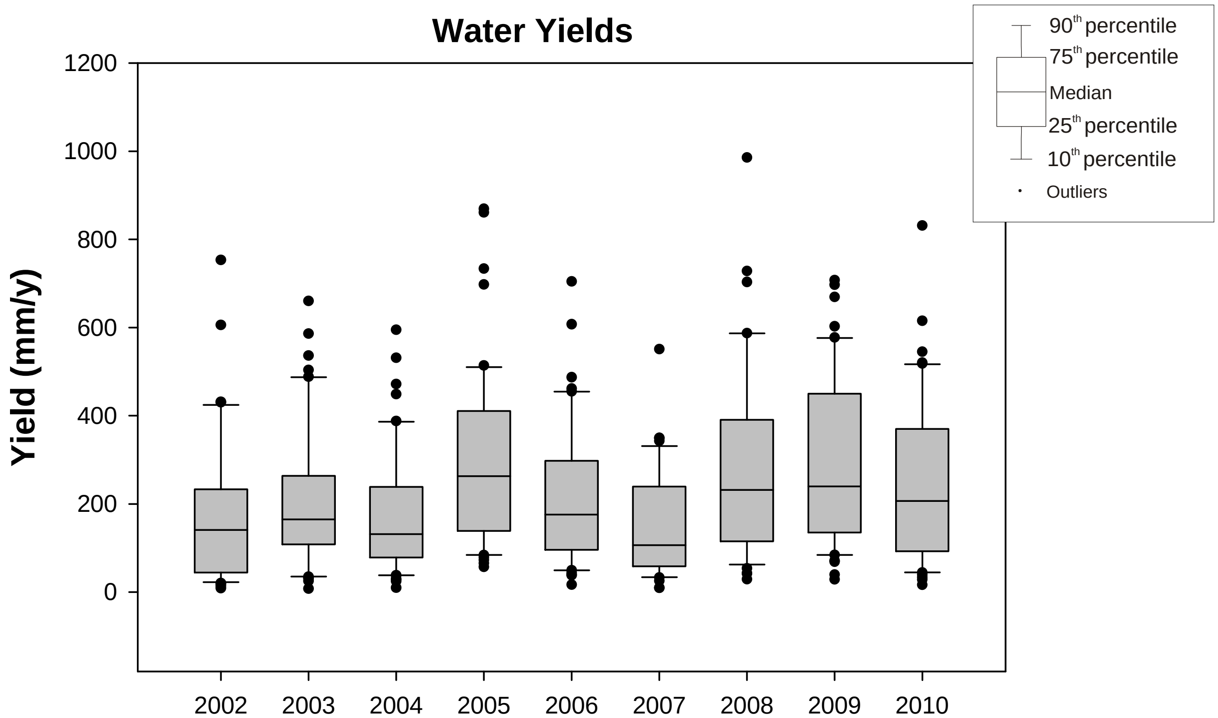
	2002	2003	2004	2005	2006	2007	2008	2009	2010
N	49	50	50	49	48	48	49	50	50
Mean (µg/L)	44	7.5	32.3	11.5	12.9	16.1	13.5	11	29.0
Median (µg/L)	5.26	0.5	1.00	2.96	5.44	2	3	3	1.5
Standard deviation	114	22.3	101	28.7	28.1	50.6	41.8	26.1	81.6
Coefficient of variation (%)	260	298	313	250	217	315	309	237	281

Figure 5.12-1 Concentrations of Dissolved Organic Carbon (± 1SE) in all the 50 ASL component lakes combined, the Stony Mountain lakes, and the *baseline* lakes.



Note: error bars represent one standard error of the mean.

Figure 5.12-2 Distribution of Water Yield and Critical Loads in the 50 ASL component lakes, 2002 to 2010.



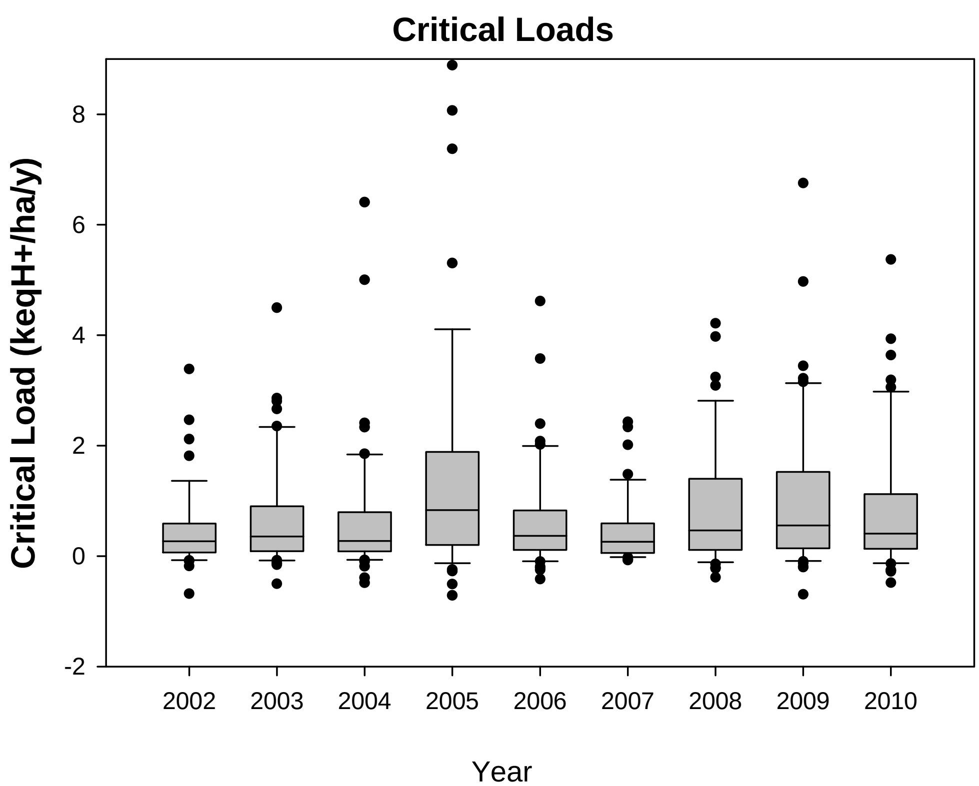


Table 5.12-5 Critical loads of acidity in the RAMP ASL component lakes, 2002 to 2010.

No_x-So_x GIS No.	Original RAMP Designation	Current AENV Name	Gross Catchment Area (km^2)	Critical Loads (keqH+/Ha/y)									
				2002	2003	2004	2005	2006	2007	2008	2009	2010	Net PAI
Stony Mountains Subregion													
168	A21	SM10	18.2	-0.069	-0.080	-0.097	-0.130	-0.099	-0.051	-0.110	-0.096	-0.137	0.150
169	A24	SM9	8.3	-0.182	-0.137	-0.391	-0.509	-0.252	-0.069	-0.226	-0.199	-0.254	0.071
170	A26	SM6	13.1	-0.015	-0.019	-0.028	-0.052	-0.041	-0.008	0.004	-0.025	-0.049	0.080
167	A29	SM5	3.7	-0.072	-0.052	-0.006	0.016	0.099	-0.005	-0.210	0.062	-0.278	0.049
166	A86	SM7	6.9	0.065	0.146	0.192	0.262	0.213	0.150	0.515	0.560	0.340	0.043
287	25	SM8	9.6	-0.089	-0.128	-0.190	-0.273	-0.194	-0.025	-0.145	-0.201	-0.260	0.076
289	27	SM3	7.4	0.036	0.078	0.087	0.159	0.093	0.095	0.112	0.144	0.008	0.057
290	28	SM4	11.7	0.001	0.020	-0.004	-0.004	0.007	-0.007	0.002	0.001	-0.032	0.062
342	82	SM2	15.4	0.065	0.059	0.119	0.158	0.119	0.012	0.117	0.140	0.140	0.027
354	94	SM10	9.6	0.709	0.680	0.816	1.045	0.428	0.153	1.425	1.443	1.035	0.043
West of Fort McMurray Subregion													
165	A42	WF1	10.4	0.385	0.890	1.418	2.189	1.006	0.730	2.227	2.281	1.943	0.044
171	A47	WF2	4.3	0.107	0.173	0.132	0.496	0.153		0.829	0.403	0.180	0.082
172	A59	WF3	51.6	0.006	0.000	0.001	-0.017	-0.026	-0.017	0.038	0.023	0.012	0.049
223	P94	WF4	1.8	0.113	0.091	0.118	1.285	0.197	0.088	0.338	0.327	0.158	0.271
225	P96	WF5	5.0	0.123	0.265	0.230	1.509	0.386	0.203	0.418	0.455	0.556	0.126
226	P97	WF6	4.2	0.088	0.342	0.206	2.710	0.194	0.168	0.290	0.402	0.470	0.169
227	P98	WF7	1.6	0.290	1.147	0.583	0.862	0.956	0.465	1.076	1.489	1.675	0.160
267	1	WF8	23.1	0.197	0.401	0.350	0.937	0.415	0.147		0.760	0.348	0.098
Northeast of Fort McMurray Subregion													
452	L4	NE1	16.8	0.098	0.096	0.073	0.270	0.093	0.067	0.272	0.130	0.080	0.187
470	L7	NE2	15.1	0.176	0.143	0.075	0.316	0.771	0.159	0.235	0.205	0.210	0.175
471	L8	NE3	24.0	0.344	0.609	0.438	1.137	0.626	0.229	0.593	0.496	0.428	0.140
400	L39	NE4	3.2	1.154	0.959	0.788	0.769	1.570	0.793	1.456	1.461	0.851	0.053
268	E15	NE5	7.3	1.363	2.226	1.488	2.383	0.273	0.419	2.052	2.923	2.310	0.097
182	P23	NE6	8.3	0.361	1.256	1.445	4.107	0.350	2.012	0.066	2.376	3.188	0.115
185	P27	NE7	5.9	0.044	0.016	-0.071	0.281	-0.028	0.034	0.052	0.018	0.051	0.101

Shaded values represent modeled Potential Acid Input that exceeds critical loads. PAI obtained from the CEMA (2010) representing the emissions from industrial sources that include all the existing sources and approved sources from 2008. The PAI is the net PAI after correction for N uptake by plants in the catchment (eutrophication). Runoff in all CL measurements estimated using the IMB method from data provided by Gibson *et al.* (pers. comm. 2010).

Table 5.12-5 (Cont'd.)

No$_x$-So$_x$ GIS No.	Original RAMP Designation	Current AENV Name	Gross Catchment Area (km^2)	Critical Loads (keqH+/Ha/y)									
				2002	2003	2004	2005	2006	2007	2008	2009	2010	Net PAI
Northeast of Fort McMurray Subregion – cont'd.													
209	P7	NE8	0.8	0.899	0.808	0.355	0.651	0.428	0.422	2.594	0.877	1.323	0.083
270	4	NE9	11.2	3.385	4.496	5.000	8.066	4.615	1.341	3.973	6.751	5.369	0.076
271	6	NE10	17.1	2.464	2.663	6.406	7.369	3.572	2.334	3.087	4.968	3.638	0.045
418	Kearl Lake	NE11	77.2		2.858	2.407	5.302	1.775	0.814	2.663	2.823	2.082	0.271
Birch Mountains Subregion													
436	L18	BM2	165.5	1.813	2.803	2.333	2.805	2.394	1.327	3.242	3.216	3.055	0.087
442	L23	BM9	33.3	0.268	0.366	0.277	0.378	0.330	0.305	0.445	0.458	0.245	0.029
444	L25	BM1	58.7	0.632	1.072	0.988	0.977	1.107	0.635	1.401	1.627	1.088	0.048
447	L28	BM6	13.7	-0.083	-0.155	0.006	-0.246	-0.214	0.006	0.044	-0.130	0.162	0.039
448	L29	BM7	4.7	-0.683	-0.502	-0.487	-0.713	-0.419	-0.076	-0.385	-0.694	-0.483	0.022
454	L46	BM8	32.5	0.511	0.677	0.394	1.160	0.492	0.355	0.594	0.762	0.391	0.212
455	L47	BM4	37.3	0.725	0.857	1.753	2.266	1.146	0.493	1.401	2.061	1.227	0.152
457	L49	BM5	30.6	0.628	0.938	0.495	1.580	0.721	0.278	0.962	1.155	0.569	0.209
464	L60	BM3	29.8	0.366	0.692	0.509	0.833	0.417	0.245	0.620	0.693	0.498	0.156
175	P13	BM10	5.2	0.403	0.348	0.666	1.500	0.627	0.300	0.826	3.154	0.526	0.133
199	P49	BM11	0.6	0.112	0.152	0.174	0.200	0.215	0.080	0.141	0.148	0.105	0.075
Canadian Shield Subregion													
473	A301	S4	114.6	0.105	0.131	0.102	0.332	0.166		0.214	0.197	0.148	0.014
118	L107	S1	13.4	2.115	2.350	1.852	2.754	2.077	1.479	2.812	2.230	2.301	0.007
84	L109	S2	112.6	0.181	0.208	0.148	0.334	0.156		0.245	0.320	0.166	0.014
88	O-10	S5	4.5	0.275	0.316	0.204		0.289		0.408	0.551	0.213	0.014
90	R1	S3	37.9	0.348	0.482	0.354	0.560	0.451	0.567	0.617	0.595	0.466	0.014
Caribou Mountains Subregion													
146	E52	CM1	24.1	1.151	1.438	1.046	2.555	2.019	2.429	4.211	3.441	3.934	0.027
152	E59	CM2	46.8	0.550	0.637	0.465	1.064	0.665	0.633	0.863	1.100	1.087	0.027
89	E68	CM3	28.0	0.532	0.485	0.271	1.423	0.786	0.583	0.466	0.740	0.794	0.027
97	O-2 E67	CM4	38.1	0.553	0.585	0.309	0.202	0.313	0.364	0.480	0.402	0.972	0.027
91	O-1/E55	CM5	2.8	0.105	0.147	0.121	8.886	1.070	0.342	0.430	0.795	0.313	0.027

Shaded values represent modeled Potential Acid Input that exceeded critical loads. PAI obtained from the CEMA (2010c) representing the emissions from industrial sources that include all the existing sources and approved sources from 2008. The PAI is the net PAI after correction for N uptake by plants in the catchment (eutrophication). Runoff in all CL measurements estimated using the IMB method from data provided by Gibson (pers. comm. 2010).

Table 5.12-6 Summary of Critical Loads in ASL component lakes, 2002 to 2010.

Variable	2002	2003	2004	2005	2006	2007	2008	2009	2010
No. Of Lakes	49	50	50	49	50	46	49	50	50
Minimum CL	-0.683	-0.502	-0.487	-0.713	-0.419	-0.076	-0.385	-0.694	-0.483
Maximum CL	3.385	4.496	6.406	8.886	4.615	2.429	4.211	6.751	5.369
Average CL	0.462	0.681	0.678	1.432	0.650	0.457	0.893	1.076	0.863
Median CL	0.268	0.357	0.274	0.833	0.368	0.261	0.466	0.555	0.410
No. of Lakes in which the PAI is greater than the CL	13	13	13	9	11	15	10	10	11
Percent of Lakes in which the PAI is greater than the CL	26.5	26.0	26.0	18.4	22.0	32.6	20.4	20.0	22.0

Table 5.12-7 Mean critical loads for each ASL component subregion, 2010.

Subregion	Critical Load keq H+/ha/y
Stony Mountains	0.051
West of Fort McMurray	0.668
Northeast of Fort McMurray	1.775
Birch Mountains	0.671
Canadian Shield	0.659
Caribou Mountains	1.420

Table 5.12-8 Chemical characteristics of ASL component lakes having the modeled PAI greater than the critical load in 2010.

No_x-So_x GIS No.	Original RAMP Designation	pH	Gran Alkalinity (µeq/L)	Conductivity (µS/cm)	DOC (mg/L)	Lake Area (km^2)
168	A21	5.19	14	12.87	17.0	1.38
169	A24	4.89	-2.2	11.14	15.1	1.45
170	A26	5.77	34	11.60	14.8	0.71
167	A29	5.98	46	10.48	13.1	1.05
287	25	5.32	10	10.36	11.4	2.176
289	27	6.79	84	13.78	11.9	1.829
290	28	5.90	56	13.78	17.1	0.544
172	A59	5.45	74	28.50	37.1	2.06
223	P94	7.11	636	98.60	45.8	0.032
185	P27	5.15	64	26.10	35.2	0.094
448	L29	4.38	-35.2	17.20	21.9	0.65

Table 5.12-9 Results of Mann-Kendall trend analyses on measurement endpoints for ASL component lakes, 2010.

ID Number	Original Name	Current ANEV Name	pH (units)		Gran Alkalinity (mg/L)		Sulphate (mg/L)		Nitrates and Nitrites		Dissolved Organic Carbon		Sum Base Cations (µeq/L)		Aluminum (µg/L)		Potential Acid Input (keq H^+/ha/y)
			S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	
168	A21	SM10		1.17		-0.16		-2.13		-0.07		-1.85		-1.99	-3		0.150
169	A24	SM9		1.44		-1.15		0.00		-1.11		-0.21		-0.21	-7		0.071
170	A26	SM6		0.89		2.02		-1.03		-0.48		-0.55		-0.75	-1		0.080
167	A29	SM5		1.65		2.65		-0.62		-0.35		0.00		1.30	13		0.049
166	A86	SM7		0.47		2.15		0.31		0.39		0.62		2.18	5		0.043
287	25	SM8	-4		-2		2		3		-20		-12		-1		0.076
289	27	SM3	4		18		8		13		-2		6		-5		0.057
290	28	SM4	8		14		-1		-22		-20		-14		-6		0.062
342	82	SM2	-14		-5		-16		-9		-16		-28		-5		0.027
354	94	SM1	-2		0		13		-5		-14		-16		-3		0.043
165	A42	WF1		1.99		1.87		-0.34		0.47		-0.21		1.30	-11		0.044
171	A47	WF2		1.03		1.25		0.34		-0.07		1.30		1.99	-9		0.082
172	A59	WF3		-0.69		-0.31		-0.89		0.21		0.07		0.34	-11		0.049
223	P94	WF4	-23		-13		4		-14		2		-18		5		0.271
225	P96	WF5	3		-4		-2		-3		-4		-16		-2		0.126
226	P97	WF6	-4		4		4		-1		10		6		-2		0.169
227	P98	WF7	12		8		-4		4		-4		10		2		0.160
267	1	WF8	6		-4		-12		1		-6		-12		-9		0.098
452	L4	NE1		0.69		0.93		-0.21		-0.48		0.00		0.00	7		0.187
470	L7	NE2		0.41		0.93		0.07		0.82		-0.21		0.62	1		0.175
471	L8	NE3		0.75		-1.56		0.07		-0.55		-0.07		-1.85	-1		0.140
400	L39	NE4		1.10		0.93		0.07		0.48		1.24		-0.48	7		0.053
268	E15 (L15b)	NE5		0.16		-0.93		1.40		-0.78		0.31		-0.78	-3		0.097
182	P23	NE6	4		12		-2		11		10		8		1		0.115
185	P27	NE7	-7		12		10		-1		12		8		4		0.101

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.

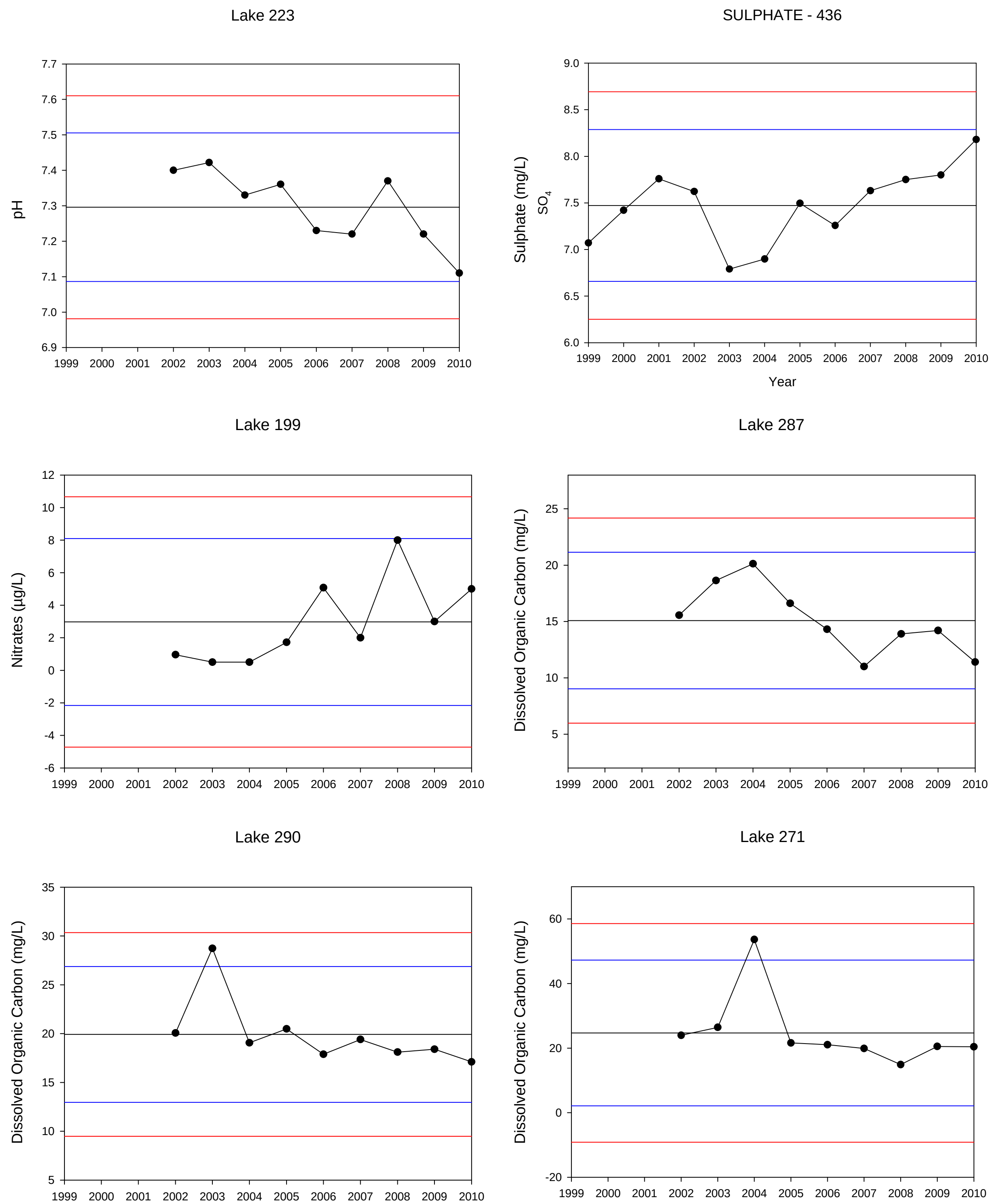
Table 5.12-9 (Cont'd.)

ID Number	Original Name	Current ANEV Name	pH (units)		Gran Alkalinity (mg/L)		Sulphate (mg/L)		Nitrates and Nitrites		Dissolved Organic Carbon		Sum Base Cations (µeq/L)		Aluminum (µg/L)		Potential Acid Input (keq H^+/ha/y)
			S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	S	Z	
209	P7	NE8	-3		18		7		17		-6		10		1		0.083
270	4	NE9	-14		-10		6		1		-16		-16		-3		0.076
271	6	NE10	0		-12		8		-5		-22		-18		-13		0.045
418	Kearl L.	NE11	11		12		-8		-5		12		10		4		0.271
436	L18	BM2		1.92		3.43		2.13		-1.10		-0.89		1.71	-3		0.087
442	L23	BM9		1.44		1.17		-1.30		1.10		-1.17		-1.44	-5		0.029
444	L25	BM1		1.51		1.71		-0.34		0.00		-0.75		1.03	-7		0.048
447	L28	BM6		0.62		1.40		-1.30		-0.55		-0.07		0.48	3		0.039
448	L29	BM7		0.78		-1.32		-1.25		-0.55		0.78		0.00	-4		0.022
454	L46	BM8		-1.17		0.31		-1.58		0.07		0.62		-1.85	-5		0.212
455	L47	BM4		0.62		0.62		-0.41		0.62		1.44		-0.07	-13		0.152
457	L49	BM5		-0.41		-0.62		-1.51		-0.34		1.30		-2.81	7		0.209
464	L60	BM3		-0.75		0.93		-1.03		0.64		1.24		-0.62	9		0.156
175	P13	BM10	-10		-8		-16		1		-8		-8		-3		0.133
199	P49	BM11	-6		-10		0		21		-4		-14		9		0.075
473	A301	S4	22		10		16		5		-6		0		-4		0.014
118	L107	S1		2.34		2.11		0.55		-0.63		1.09		-0.31	1		0.007
84	L109	S2		1.37		-0.31		0.14		-0.89		0.21		-0.62	3		0.014
88	O-10	S5		1.79	-4			0.81		-0.27		-0.36		-1.25	-8		0.014
90	R1	S3		1.99		1.56		1.30		0.00		-0.75		1.17	8		0.014
146	E52	CM1		1.03		3.11		1.03		-0.48		-0.89		1.99	5		0.027
152	E59	CM2		1.30		2.65		-2.40		-0.62		0.75		2.26	3		0.027
89	E68	CM3		-1.17		-0.62		-1.87		0.00		0.00		-1.87	7		0.027
97	O-2 E67	CM4		0.14		0.70		-0.34		-0.75		1.17		-2.95	5		0.027
91	O-1/E55	CM5		1.51		2.02		0.07		-2.26		-1.03		2.95	-1		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.

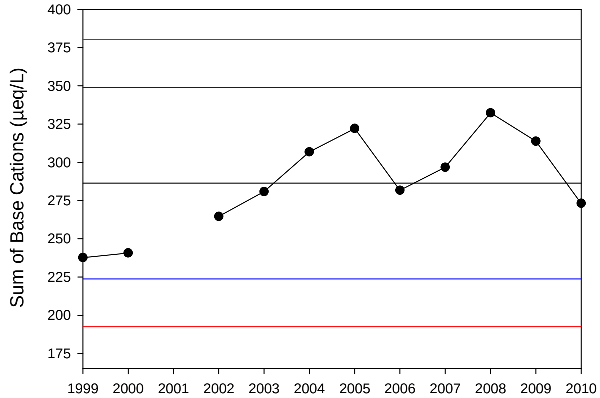
Figure 5.12-3 Control charts of measurement endpoints in ASL component lakes showing significant trends in the Mann-Kendall Trend analysis.



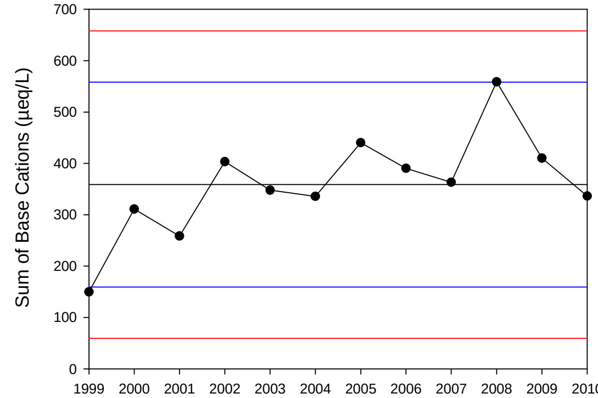
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-3 (Cont'd.)

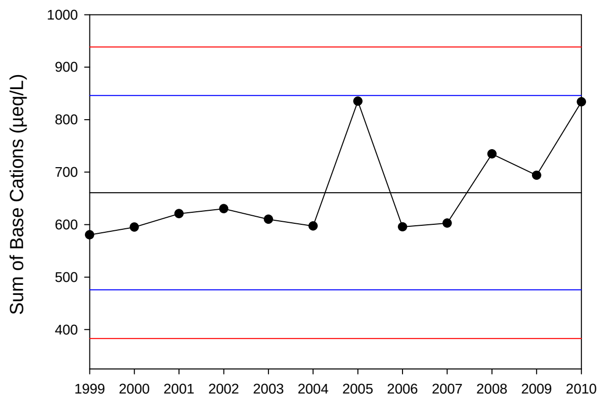
Lake 166



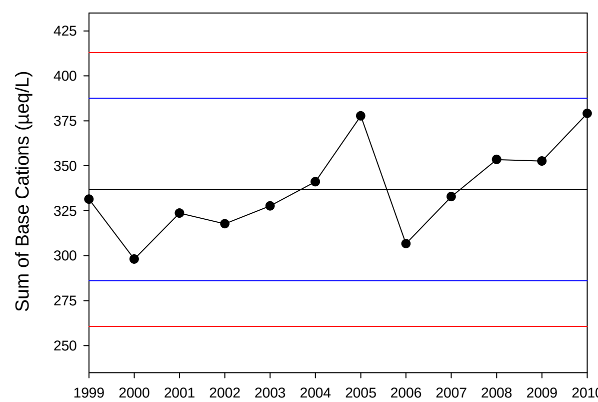
Lake 171



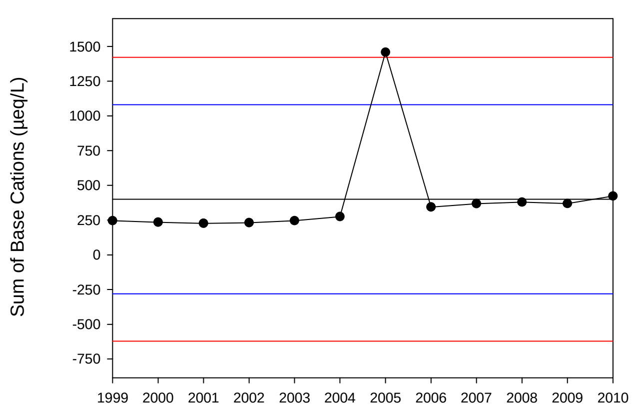
Lake 146



Lake 152



Lake 91



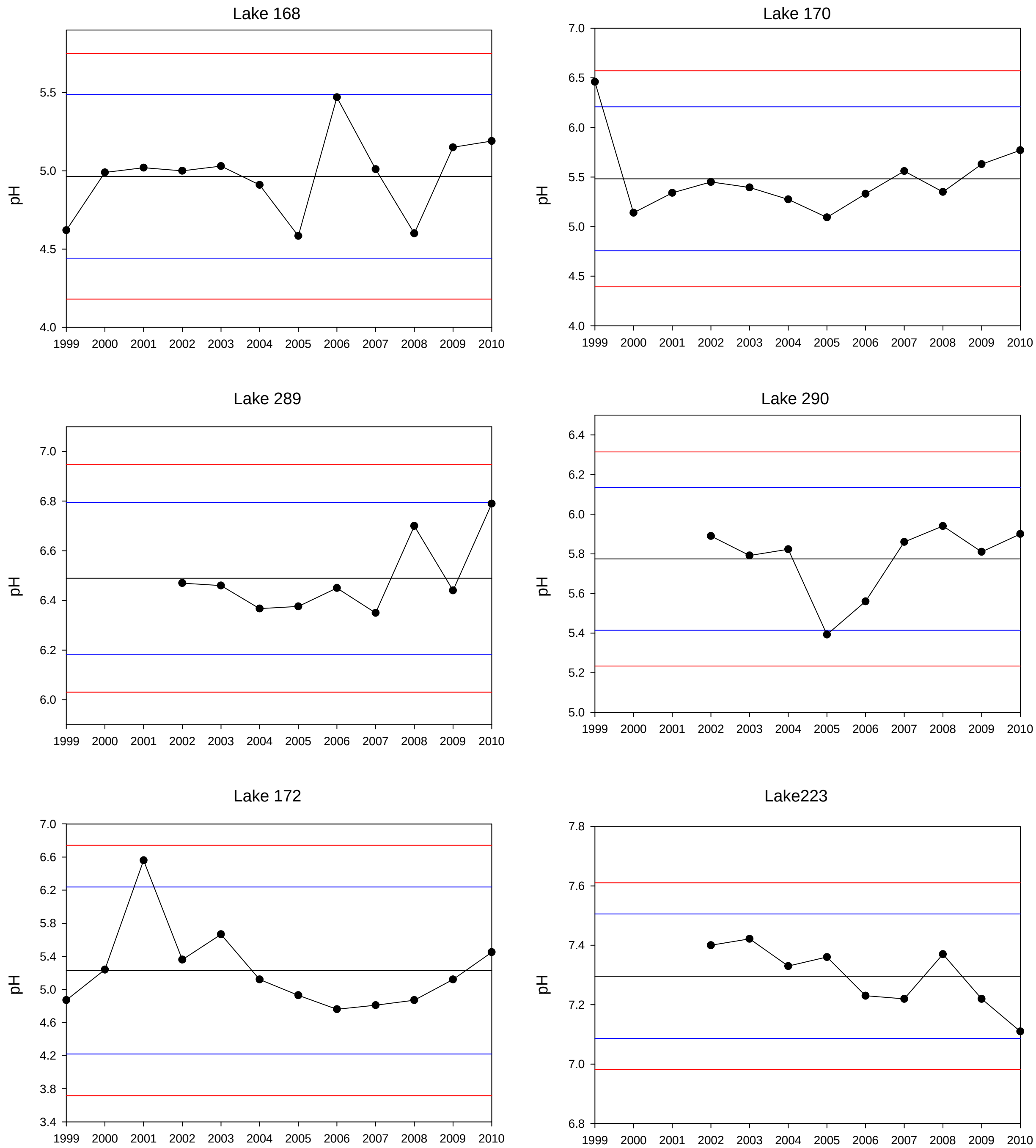
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Table 5.12-10 Acidification risk factor for individual ASL component lakes.

RAMP Lake No.	Original Designation	AENV Designation	Sub-Region	Critical Load (keq/Ha/y) IMB	PAI	Acidification Risk Factor PAI/CL
168	A21	SM 10	Stony Mountains	-0.125	0.15	1.202
169	A24	SM 9	Stony Mountains	-0.251	0.071	0.283
170	A26	SM 6	Stony Mountains	-0.043	0.08	1.853
167	A29	SM 5	Stony Mountains	-0.186	0.049	0.263
166	A86	SM 7	Stony Mountains	0.231	0.043	0.186
287	25	SM 8	Stony Mountains	-0.219	0.076	0.347
289	27	SM 3	Stony Mountains	0.007	0.057	8.465
290	28	SM 4	Stony Mountains	-0.025	0.062	2.449
342	82	SM 2	Stony Mountains	0.090	0.027	0.300
354	94	SM 1	Stony Mountains	0.734	0.043	0.059
165	A42	WF1	West of Fort McMurray	1.764	0.044	0.025
171	A47	WF-2	West of Fort McMurray	0.187	0.082	0.439
172	A59	WF-3	West of Fort McMurray	0.015	0.049	3.203
223	P94	WF-4	West of Fort McMurray	0.231	0.271	1.176
225	P96	WF-5	West of Fort McMurray	0.388	0.126	0.325
226	P97	WF-6	West of Fort McMurray	0.365	0.169	0.463
227	P98	WF-7	West of Fort McMurray	1.109	0.16	0.144
267	1	WF-8	West of Fort McMurray	0.478	0.098	0.205
452	L4	NE 1	Northeast of Fort McMurray	0.187	0.187	0.998
470	L7	NE2	Northeast of Fort McMurray	0.279	0.175	0.628
471	L8	NE 3	Northeast of Fort McMurray	0.590	0.14	0.237
400	L39	NE 4	Northeast of Fort McMurray	1.265	0.053	0.042
268	E15	NE-5	Northeast of Fort McMurray	2.026	0.097	0.048
182	P23	NE6	Northeast of Fort McMurray	1.619	0.115	0.071
185	P27	NE-7	Northeast of Fort McMurray	0.050	0.101	2.016
209	P7	NE-8	Northeast of Fort McMurray	1.002	0.083	0.083
270	4	NE 9	Northeast of Fort McMurray	4.187	0.076	0.018
271	6	NE 10	Northeast of Fort McMurray	3.732	0.045	0.012
418	Kearl Lake	NE 11	Northeast of Fort McMurray	3.028	0.271	0.090
436	L18	BM 2	Birch Mountains	2.690	0.087	0.032
442	L23	BM 9	Birch Mountains	0.267	0.029	0.109
444	L25	BM 1	Birch Mountains	0.988	0.048	0.049
447	L28	BM 6	Birch Mountains	0.139	0.039	0.282
448	L29	BM 7	Birch Mountains	-0.548	0.022	0.040
454	L46	BM 8	Birch Mountains	0.526	0.212	0.403
455	L47	BM 4	Birch Mountains	1.184	0.152	0.128
457	L49	BM 5	Birch Mountains	0.819	0.209	0.255
464	L60	BM 3	Birch Mountains	0.615	0.156	0.254
175	P13	BM-10	Birch Mountains	0.692	0.133	0.192
199	P49	BM-11	Birch Mountains	0.127	0.075	0.592
473	A301	S-4	Canadian Shield	0.192	0.014	0.073
118	L107	S-1	Canadian Shield	2.324	0.007	0.003
84	L109	S-2	Canadian Shield	0.261	0.014	0.054
88	O-10	S-5	Canadian Shield	0.318	0.014	0.044
90	R1	S-3	Canadian Shield	0.590	0.014	0.024
146	E52	CM-1	Caribou Mountains	3.158	0.027	0.009
152	E59	CM-2	Caribou Mountains	0.882	0.027	0.031
89	E68	CM-3	Caribou Mountains	0.656	0.027	0.041
97	O-2 E67	CM-4	Caribou Mountains	0.745	0.027	0.036
91	O-1/E55	CM-5	Caribou Mountains	0.264	0.027	0.102

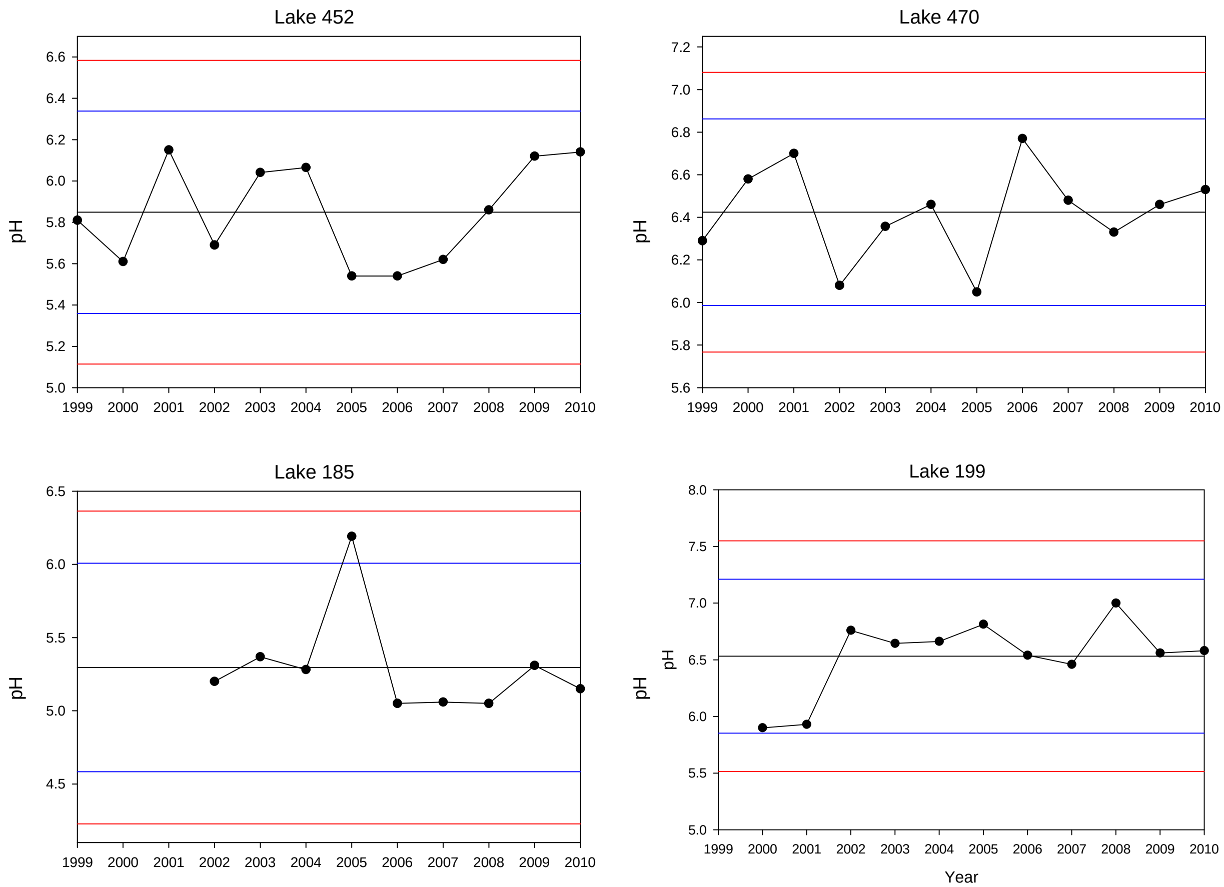
Shaded lakes represent those lakes most at risk to acidification.

Figure 5.12-4 Shewhart control charts of pH in the ten ASL component lakes most at risk to acidification.



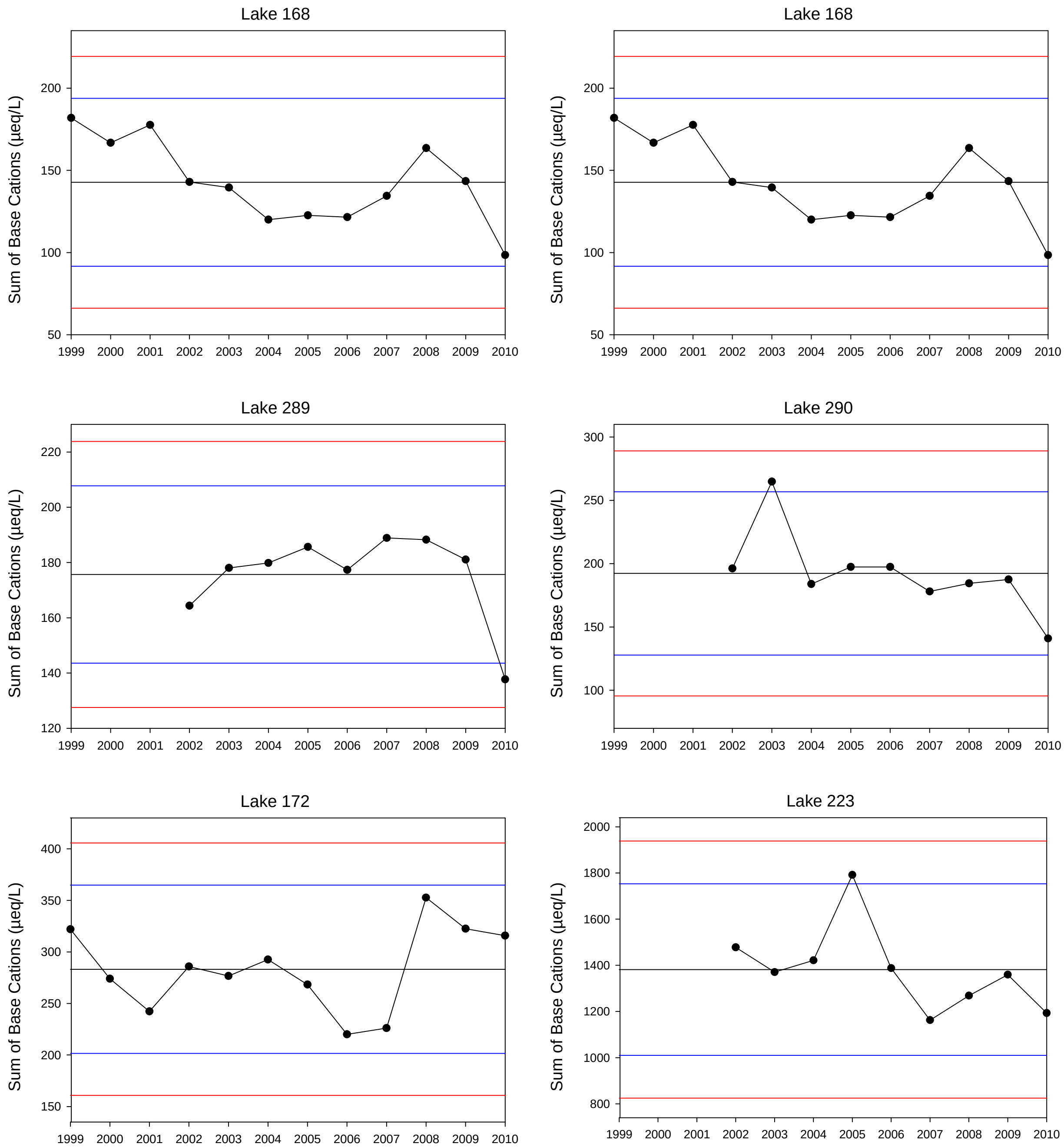
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-4 (Cont'd.)



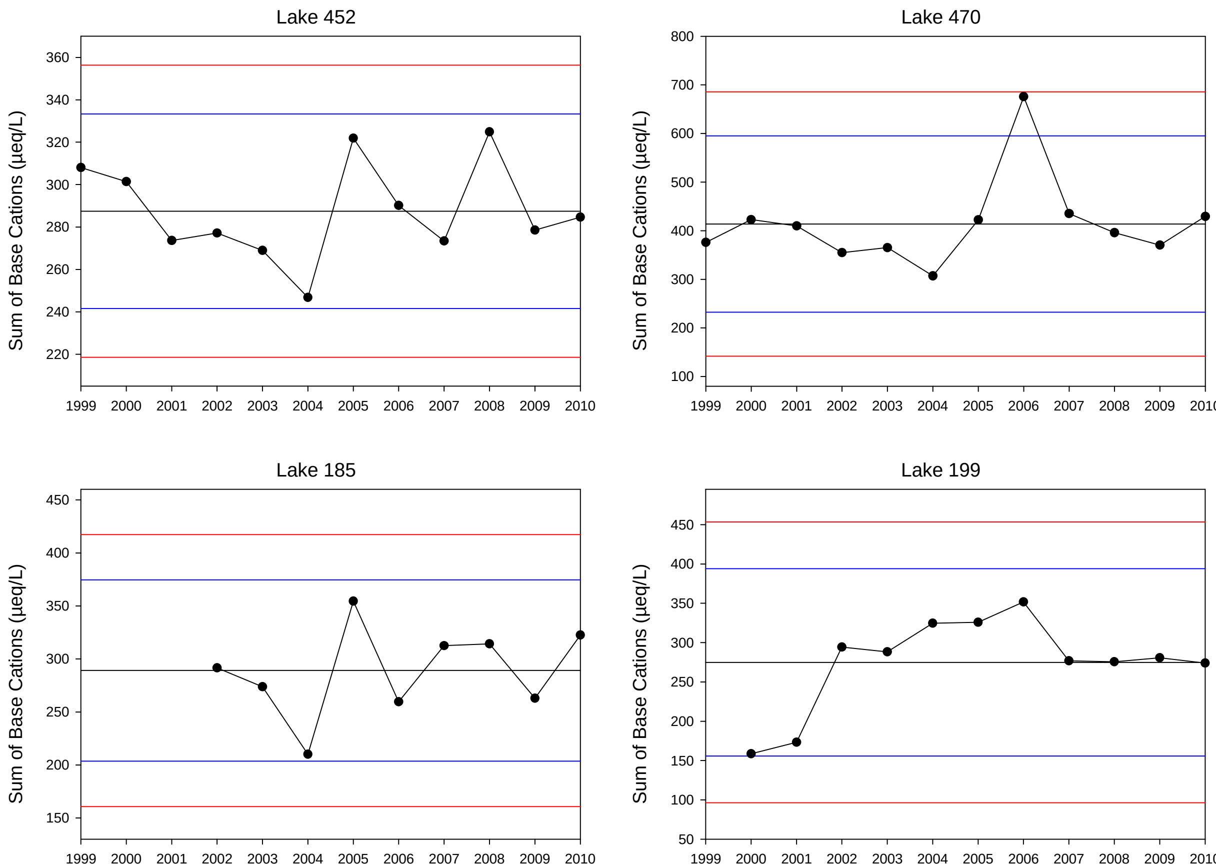
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-5 Shewhart control charts of the sum of base cations in the ten ASL component lakes most at risk to acidification.



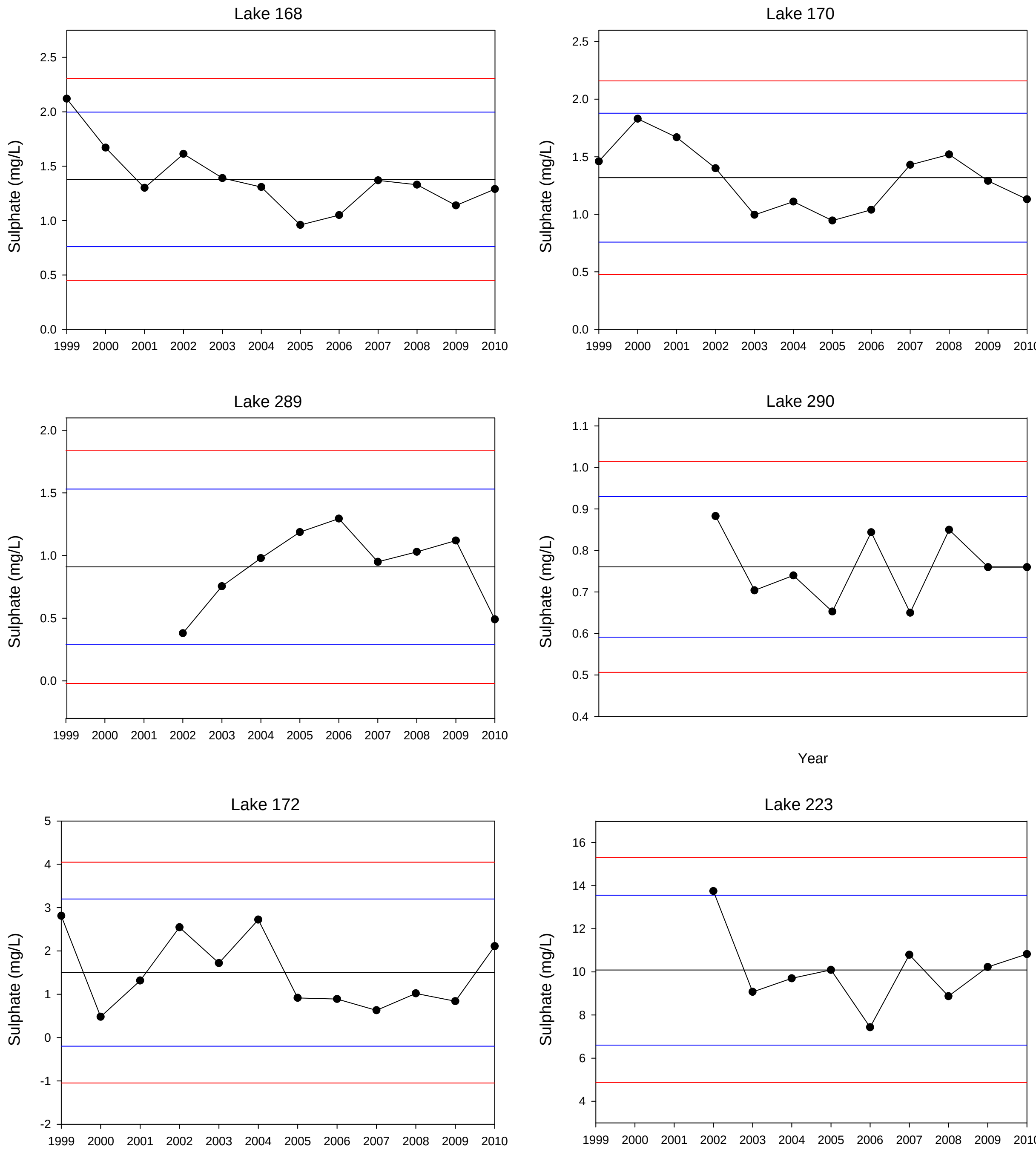
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-5 (Cont'd.)



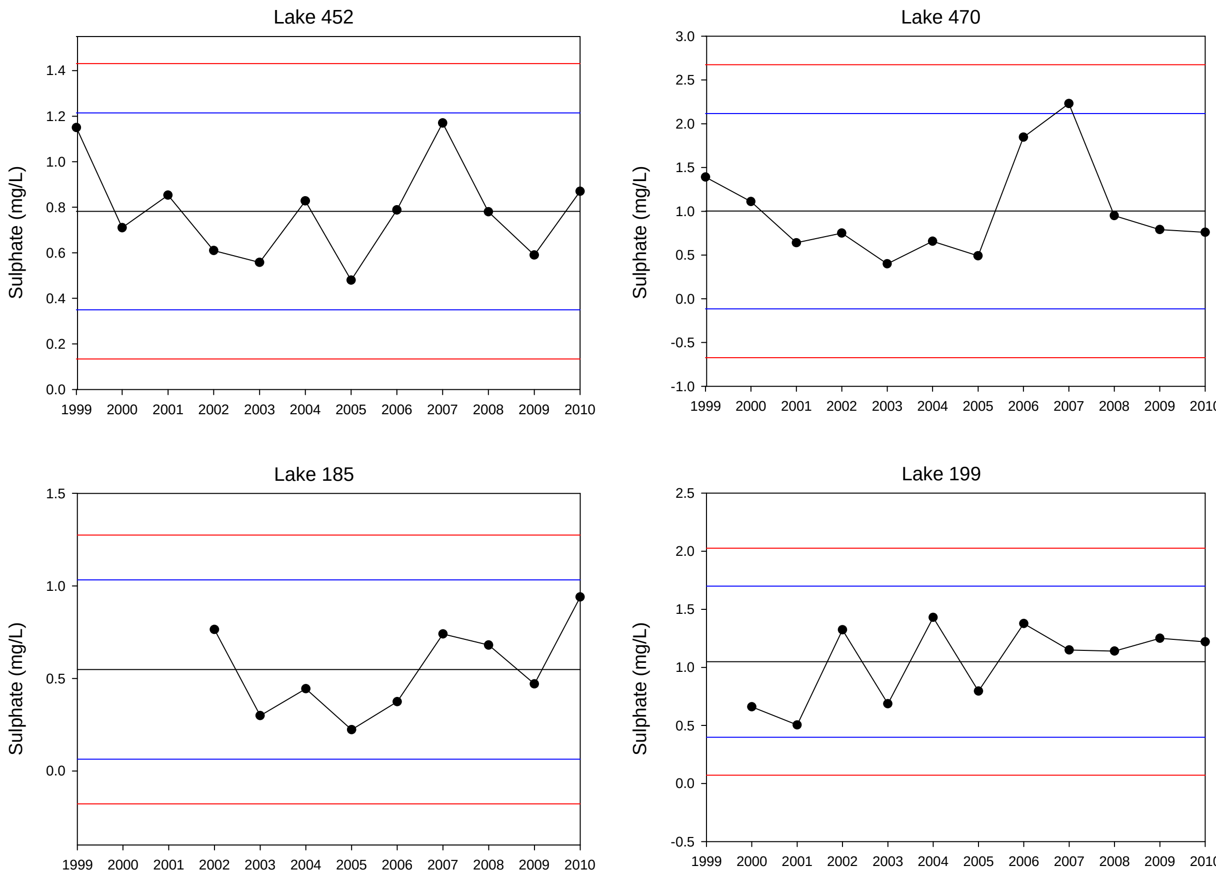
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-6 Shewhart control charts of sulphate in the ten ASL component lakes most at risk to acidification.



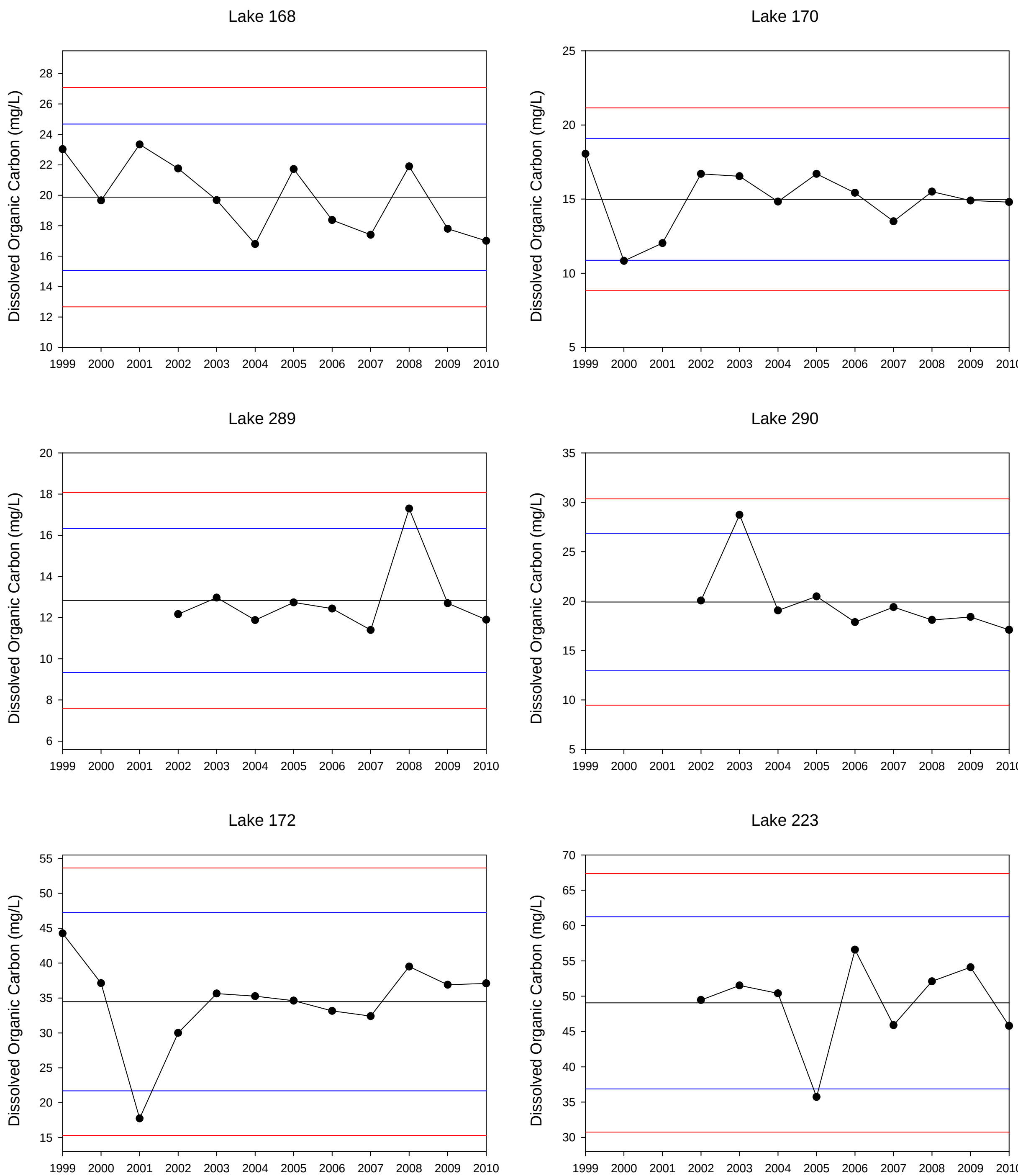
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-6 (Cont'd.)



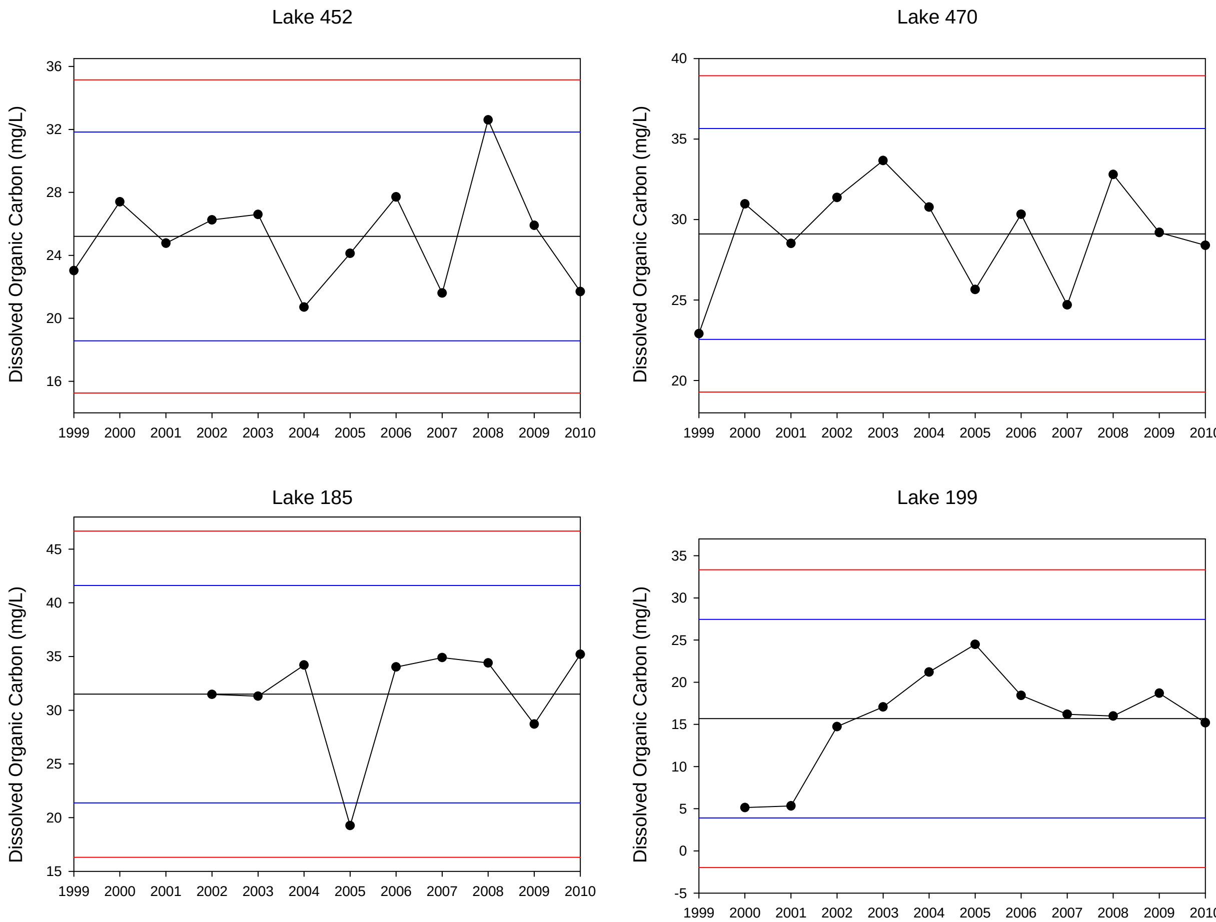
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-7 Shewhart control charts of dissolved organic carbon in the ten ASL component lakes most at risk to acidification.



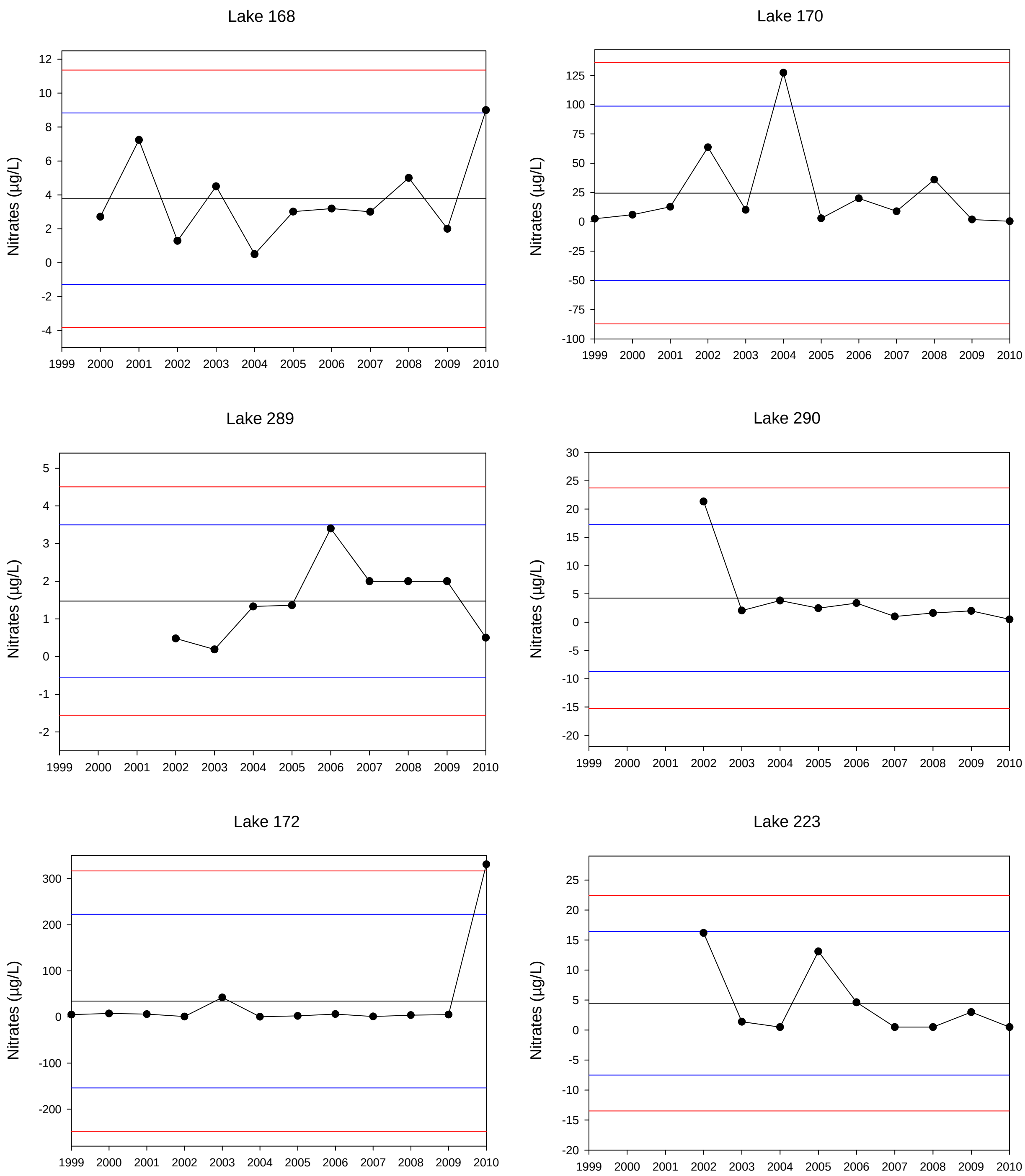
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-7 (Cont'd.)



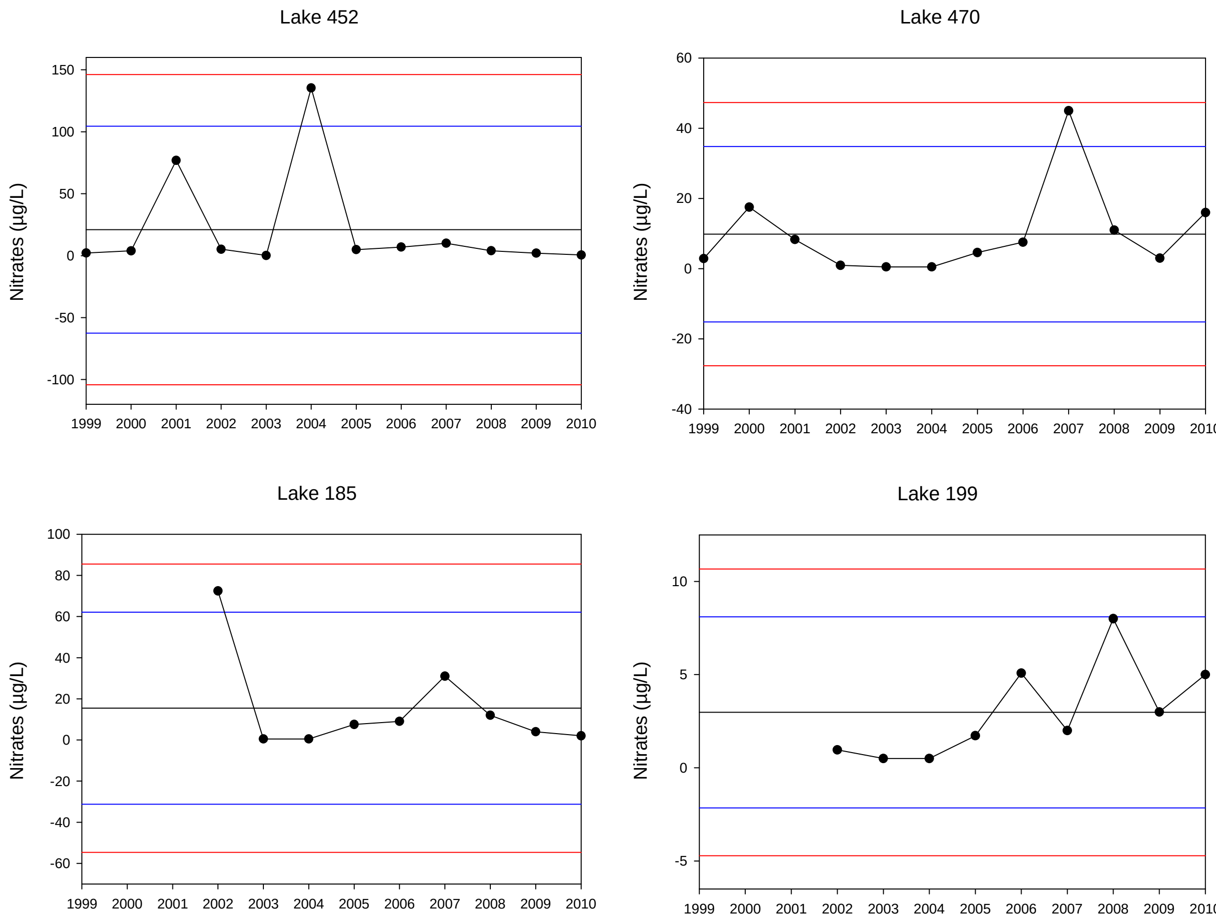
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-8 Shewhart control charts of nitrates in the ten ASL component lakes most at risk to acidification.



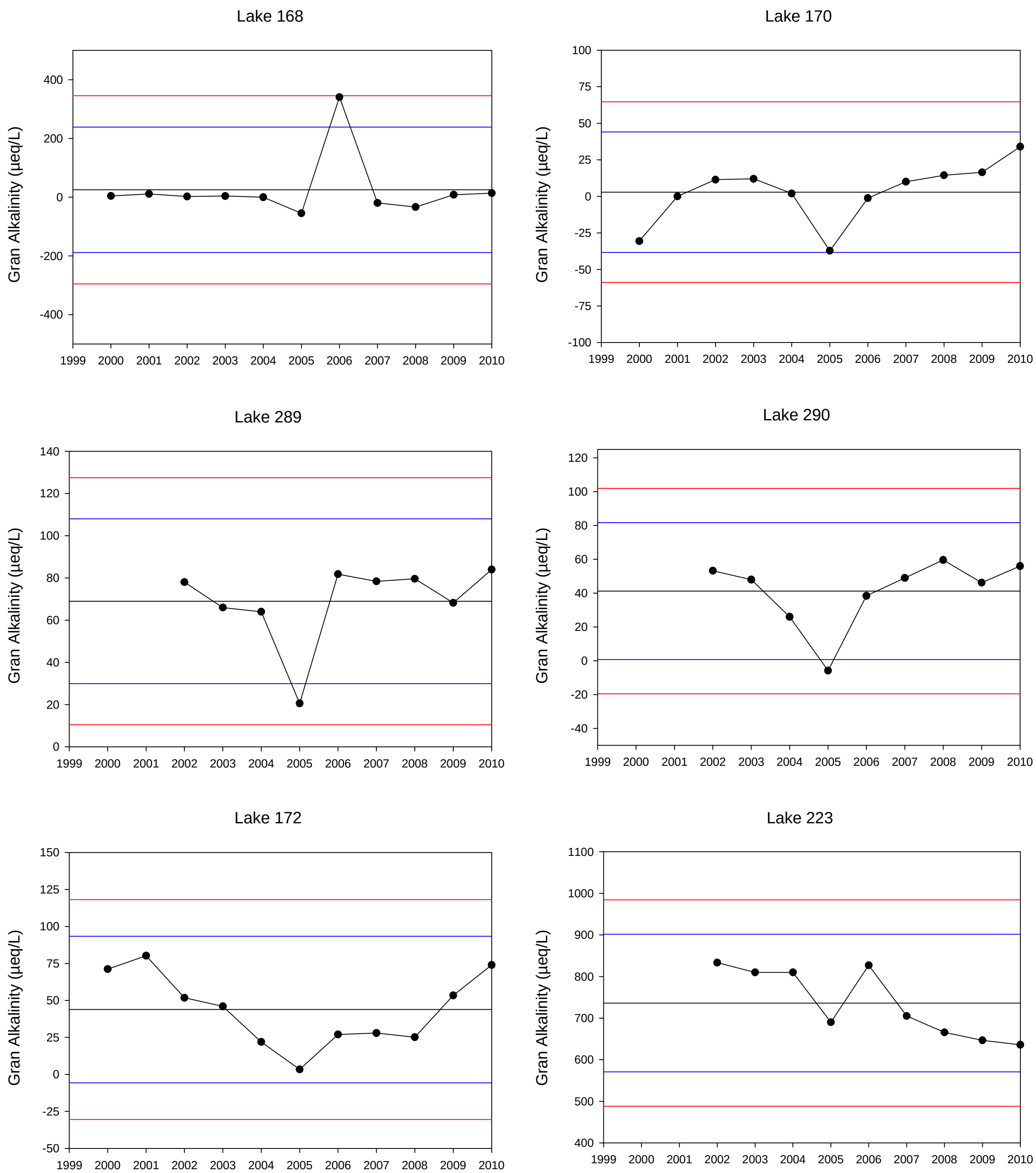
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-8 (Cont'd.)



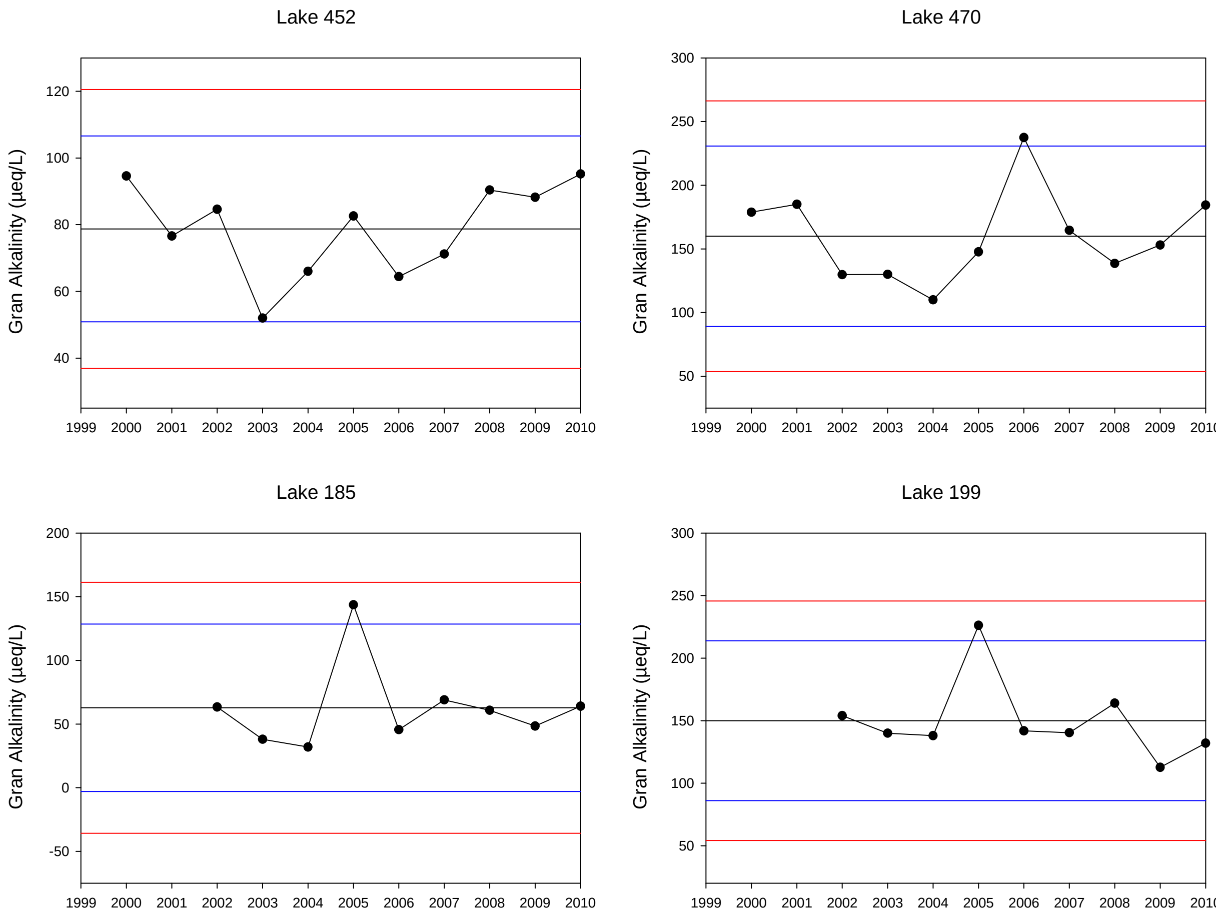
Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line – mean

Figure 5.12-9 Shewhart control charts of Gran alkalinity in the ten ASL component lakes most at risk to acidification.



Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line - mean

Figure 5.12-9 (Cont'd.)



Blue lines: ±2 standard deviations; Red lines: ± 3 standard deviations; black line – mean

6.0 SPECIAL STUDIES

This part of the RAMP 2010 Technical Report presents results from special studies that were conducted in 2010, but are not part of the core monitoring program that is described in Section 3. These assessments were conducted to evaluate the feasibility of new approaches to aquatic monitoring or to refine current methods used by RAMP.

In 2010, there were five studies conducted by RAMP that were not part of the core monitoring program: a comparison of analytical methods for naphthenic acids as part of the Water Quality component, an assessment of the *baseline* condition approach used in the Water Quality component, a comparison between kick net sampling and Neill-Hess sampling for benthic invertebrate communities in erosional reaches as part of the Benthic Invertebrate Communities component, an assessment of the variability of *baseline* conditions used in the Benthic Invertebrate Communities component and a Fish Assemblage Monitoring Pilot Study conducted as part of the Fish Populations component.

6.1 NAPHTHENIC ACIDS IN WATER

6.1.1 Background

Formally, naphthenic acids are a broad group of alkyl-substituted carboxylic acids, with the general formula $C_nH_{2n+Z}O_2$, where n is the number of carbon atoms (typically between 10 and 20), and Z is a negative number corresponding to twice the number of rings in the molecule (i.e., 0, -2, -4, etc.). This group includes numerous compounds with various cyclic and acyclic (aliphatic) structures.

Grewer *et al.* (2010) provides a history of the analysis and interpretation of naphthenic acids in oil sands process waters (OSPW) and ambient surface water samples. Information from this study and other sources has been briefly summarized below.

Naphthenic acids became associated with the environmental chemistry of the oil sands region when MacKinnon and Boerger (1986, cited in Grewer *et al.* 2010) indicated that observed toxicity of oil sands tailings pond waters was likely associated with "polar organic carboxylic acids (naphthenic acids)". This assertion was partly based on their observation that the acid-extracted organic compounds associated with toxicity was very similar in composition to commercial preparations of naphthenic acids, using a Fourier transform infra-red (FTIR) spectrum analysis (Grewer *et al.* 2010).

FTIR-measured concentrations of "naphthenic acids" in oil sands process waters (OSPW) are in the tens to low-hundreds of mg/L (Han *et al.* 2009, Grewer *et al.* 2010), which are concentrations that have been shown to cause toxicity to aquatic organisms (Nero *et al.* 2006). Given concerns about potential accidental release of naphthenic acids to local receiving waters through seepage from tailings facilities, this method also was applied to ambient surface waters samples in various site-specific and regional environmental monitoring programs, including those conducted by RAMP and AENV. From 1997 to 2008, RAMP samples were analyzed by ALS Environmental using this method, with a method detection limit of 1 mg/L.

Different high-resolution techniques were developed and applied to the measurement of "naphthenic acids" in the oil sands region in the mid-2000s, largely in response to concerns regarding potential effects of OSPW toxicity on effective tailings pond reclamation strategies. It became clear that the FTIR method (as well as the newer, high-resolution methods) measured many more acid-extractable organic compounds than those classically defined as "naphthenic acids" by the formula listed above. This included longer-chain acids, more highly oxidized species (i.e., O_3 to O_7, not just O_2), and those with more complex oxy-groups, such as SO_2 to SO_6, and NO_4 (Headley *et al.* 2009, Grewer *et al.* 2010). Assessments of samples of OSPW, commercial naphthenic acids preparations, and ambient river water samples using both low-resolution FTIR and an ultrahigh-resolution method (electrospray ionization Fourier transform ion cyclotron resonance mass spectrometry, or ESI-FT-ICR MS) by Grewer *et al.* (2010) found that most acid-extractable acids present in these mixtures, including in a commercial naphthenic acids mixture, did not fit the accepted definition of naphthenic acids or their oxidized derivatives. They also found that the FTIR method gave generally comparable results to the high-resolution method at high (OSPW-type) concentrations but overestimated naphthenic acids concentrations in ambient river water samples. Fewer than 10% of acid-extractable organics measured by Grewer *et al.* in river water samples from various locations in Alberta were classic naphthenic acids, with ≥70% of these compounds being aliphatic (non-cyclic) fatty acids, particularly palmitic and stearic acids, which are common components of biological cell membranes and routinely found in river waters. Given the complexity of acid-extractable organics found in OSPW and surface-water samples, Grewer *et al.* (2010) suggested the replacement of the term "naphthenic acids" for these analyses with something better representative of the range of compounds measured, such as "oil sands tailings water acid-extractable organics (OSTWAEO)". Given many of these constituent compounds also are present in surface waters outside the oil sands region, the more general term of "acid-extractable organics" is used in this section.

These recent studies have demonstrated the need to improve analytical techniques used to identify acid-extractable organics in OSPW, define those with greatest potential for environmental change, and apply this knowledge to future environmental monitoring programs. Not only do new, high-resolution methods (combined with meaningful toxicological data) potentially allow for more accurate and precise identification of concentrations of concern for this suite of compounds as a whole, precise speciation of many individual acid-extractable organics in a single sample may allow for identification of unique "fingerprints" of different OSPWs. Such "fingerprints" could then be compared with those in ambient surface water samples to potentially identify specific sources of any OSPW-associated organics observed in an ambient sample.

At least four different laboratories are currently developing or using high-resolution analytical techniques for quantification and speciation of naphthenic acids mixtures in water, including:

- AITF (formerly ARC, Vegreville, AB), which uses a GC/MS-ion-trapping method, and was the laboratory used by AENV and RAMP in 2009 and 2010 for analysis ambient water quality samples;
- ALS Environmental Ltd. (Edmonton, AB), who have developed a high- resolution gas chromatography/mass spectrometry (GC/MS, operating at 10,000 resolution), selected-ion method, targeting the following selected ions: m/z 286.2278 (9-FCA), 267.1780 (napthenic acids) and 267.0836 (^{13}C-tetradecanoic);
- Dr. Jon Martin's laboratory at the University of Alberta (Edmonton, AB), which uses an ultra-high-resolution quadrupole, time-of-flight mass spectrometry (Q-TOF MS) and Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS); and
- AXYS Analytical Services Ltd. (Sidney, BC), which uses a high-resolution liquid chromatography/MS/MS method (currently being used to analyze samples collected with passive samplers as part of AENV's ongoing Contaminant Load Study in the Athabasca River).

In 2009, AENV began using AITF for analysis of "naphthenic acids" in surface waters collected for routine monitoring at AENV's Long-Term Regional Network (LTRN) locations. In 2009, RAMP also shifted its naphthenic acids analysis from ALS (using low-resolution FTIR) to AITF, to match the analytical method being used by AENV. AITF's method in 2009 was based on a GC/MS-ion-trapping method, and provided a method detection limit of 20 µg/L. Results in fall 2009 using this higher-resolution technique indicated concentrations of naphthenic acids (acid-extractable organics) of 0.035 to 0.848 mg/L, consistent with previous RAMP data (based on FTIR analysis), which typically returned values of <1 mg/L (RAMP 2009a).

6.1.2 Analyses of 2010 RAMP Water Samples for Naphthenic Acids

6.1.2.1 Methods

Recognizing current uncertainties and ongoing method development in the identification and quantification of acid-extractable organic acids, in 2010 RAMP collected triplicate samples in spring, summer and fall for analysis of these compounds. One set was provided to AITF as previously proposed in the RAMP 2010 sampling design; a second set of samples was provided to Dr. Deib Birkholz at ALS Environmental (Edmonton) for analysis using their HRGC/MS-selected-ion method; and a third set of samples was provided to Dr. Jonathan Martin at University of Alberta. Recognizing the value of these ambient water samples for method development and validation, AITF provided speciation data at no additional cost to RAMP, ALS provided analysis of a subset of samples provided at a significant discount, and Dr. Martin's laboratory also used these samples in their research.

As of the time of reporting, complete analyses of RAMP 2010 samples had been undertaken and data shared with RAMP by AITF and ALS (data from four stations [MIC-1, CAR-1, ATR-MR-E, ATR-FR-CC] could not provided from ALS due to matrix interferences that confounded quantification). Samples provided to University of Alberta had not yet been fully analyzed and reported.

In spring 2010, AITF modified their analytical method to reduce the mass-unit range of compounds measured in an attempt to eliminate some of the compounds not classically defined as naphthenic acids from their results. The AITF 2010 data provide results that may be compared with those from 2009, despite inconsistencies between these methods (D. Humphries, AITF, *pers. comm.*, April 2011).

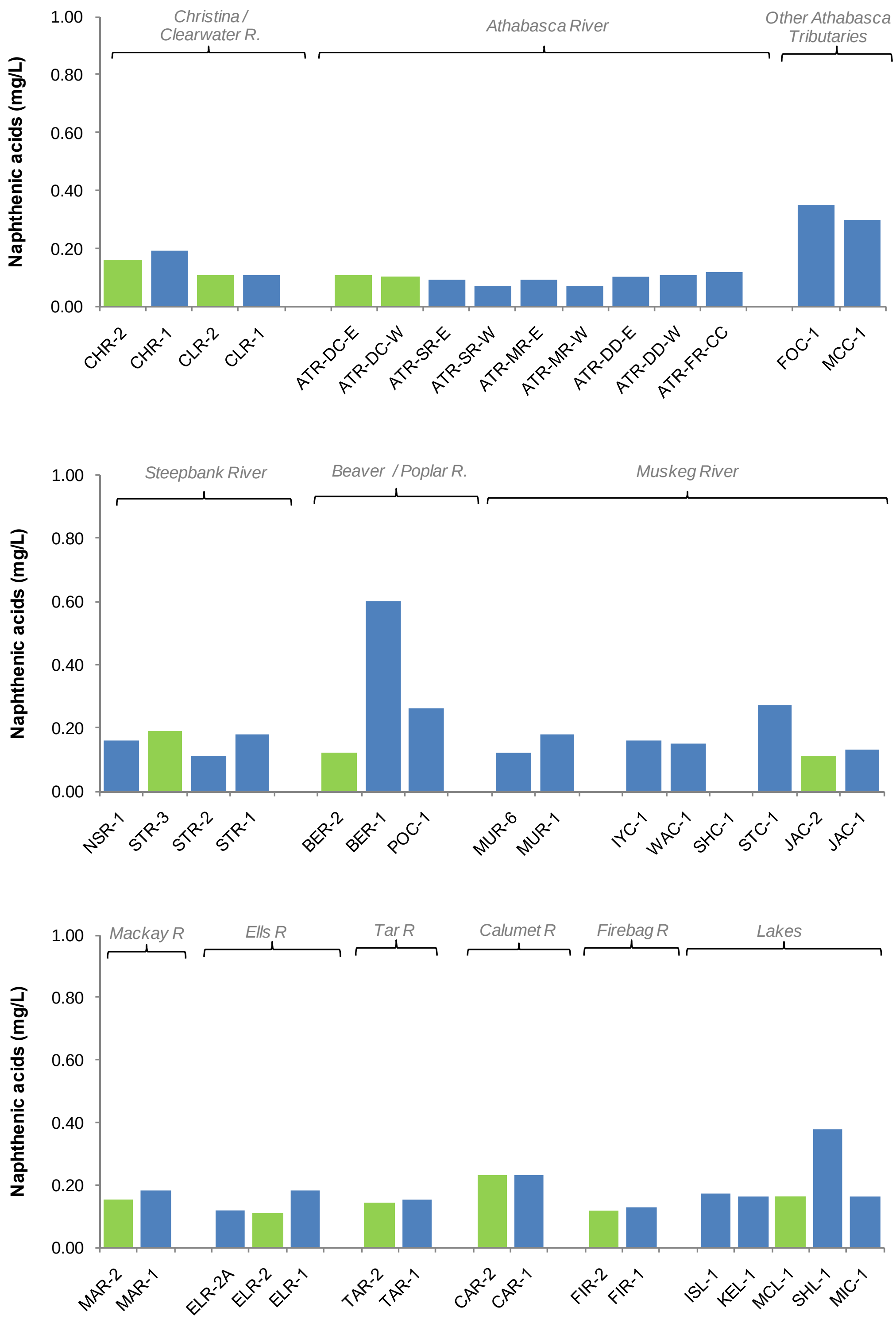
6.1.3 Results and Discussion

Comparison with 2009

Figure 6.1-1 presents results of naphthenic acids analyses performed by AITF from RAMP water quality stations in fall 2010. Observed concentrations and spatial patterns among stations were generally similar between 2009 and 2010 (Figure 6.1-2).

Concentrations at most stations were below 0.2 mg/L. The highest concentration (i.e., 0.6 mg/L) was observed in lower Beaver River (*test* station BER-1), downstream of the Mildred Lake Settling Basin, followed by Shipyard Lake (*test* station SHL-1), Fort Creek (*test* station FOC-1) and McLean Creek (*test* station MCL-1), which are all small watersheds downstream of oil sands developments. The next highest concentrations were in the Calumet River, with similar concentrations in *baseline* station CAR-2 and *test* station CAR-1 (Figure 6.1-1). Concentrations in the Athabasca River mainstem showed gradual increases moving downstream in fall 2010, particularly downstream of the Muskeg River (Figure 6.1-1). In fall 2009, concentrations were gradually decreasing moving downstream along the entire river (Figure 6.1-2).

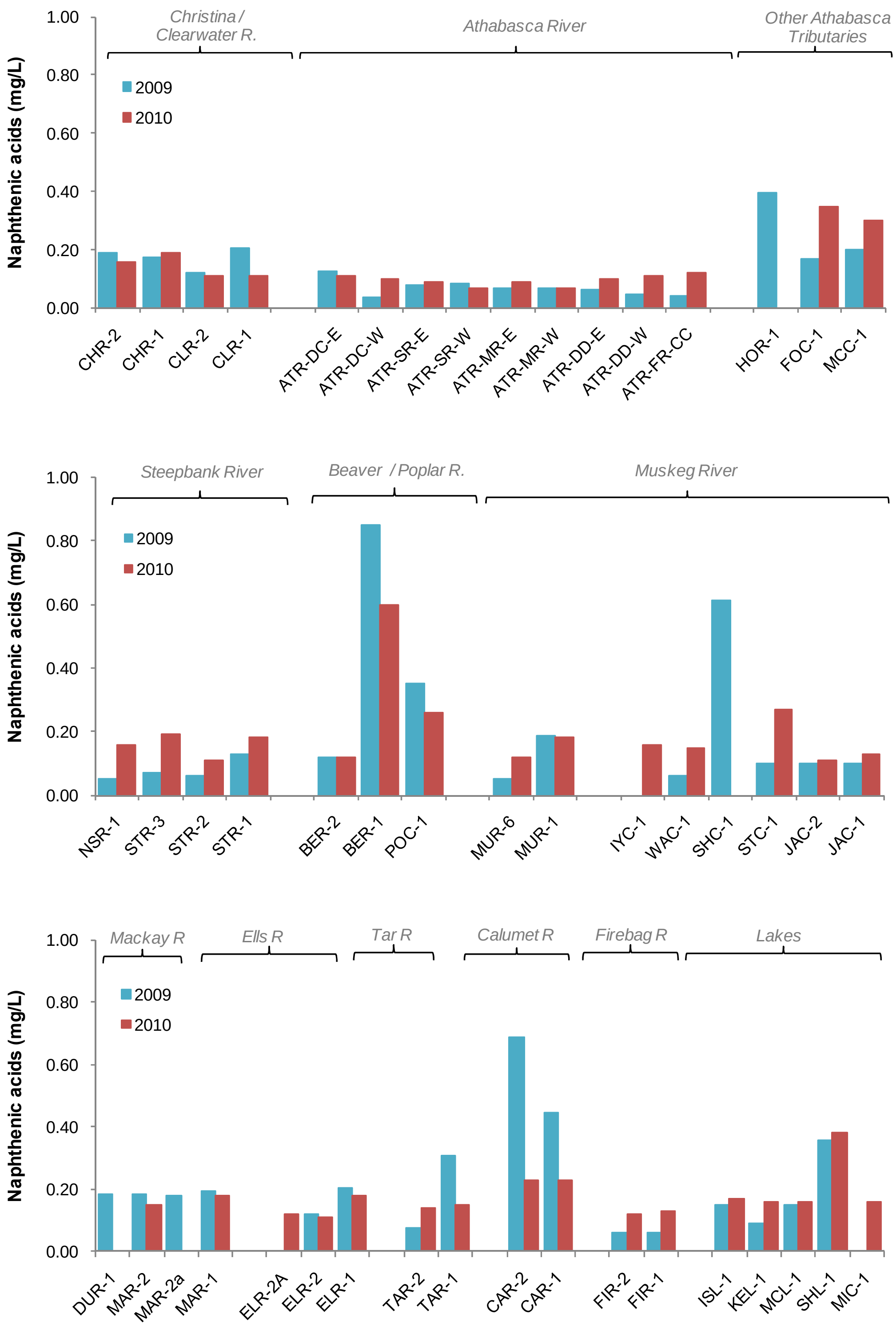
Figure 6.1-1 Concentrations of acid-extractable organic acids (naphthenic acids) in the RAMP FSA, fall 2010.



Note: results were adjusted to allow for comparisons with 2009 results.

Note: green denotes *baseline* stations and blue denotes *test* stations.

Figure 6.1-2 Concentrations of acid-extractable organic acids (naphthenic acids) in the RAMP FSA, fall 2009 and 2010 results.



Comparison of Methods

A comparison of concentrations of naphthenic acids reported by AITF and ALS for fall 2010 is presented in Figure 6.1-3. The method developed and applied by ALS is intended to be specific to specific ions classically defined as naphthenic acids (i.e., $C_nH_{2n+Z}O_2$). Analyses of all fall 2010 RAMP samples using this method returned all non-detectable values (at detection limits ranging from 2 to 5 µg/L), except at lower Beaver River (*test* station BER-1, 0.093 mg/L), lower Firebag River (*test* station FIR-1, 0.034 mg/L), McClelland Lake (*test* station MCL-1, 0.020 mg/L), and McLean Creek (*test* station MCC-1, 0.011 mg/L). Concentrations measured at these locations using the ALS method were approximately one-sixth to one-thirtieth of the corresponding concentration found using the AITF method.

Lower Beaver River exhibited the highest concentration using either method; this creek is known to receive seepage from the Mildred Lake Settling Basin, although most is captured at the creek's head and pumped back into the holding basin (W. Zubot, Syncrude Ltd., *pers. comm.*, April 2010). McLean Creek also showed relatively high concentrations in the AITF method and has a highly modified upper watershed. Although the lower Firebag River and McClelland Lake are both defined as *test*, these stations have very little development in their upper watersheds (see Section 2), and exhibited AITF-determined levels of acid-extractable organics that were similar to the lowest ("background") values of all stations measured in the RAMP 2010 dataset by AITF.

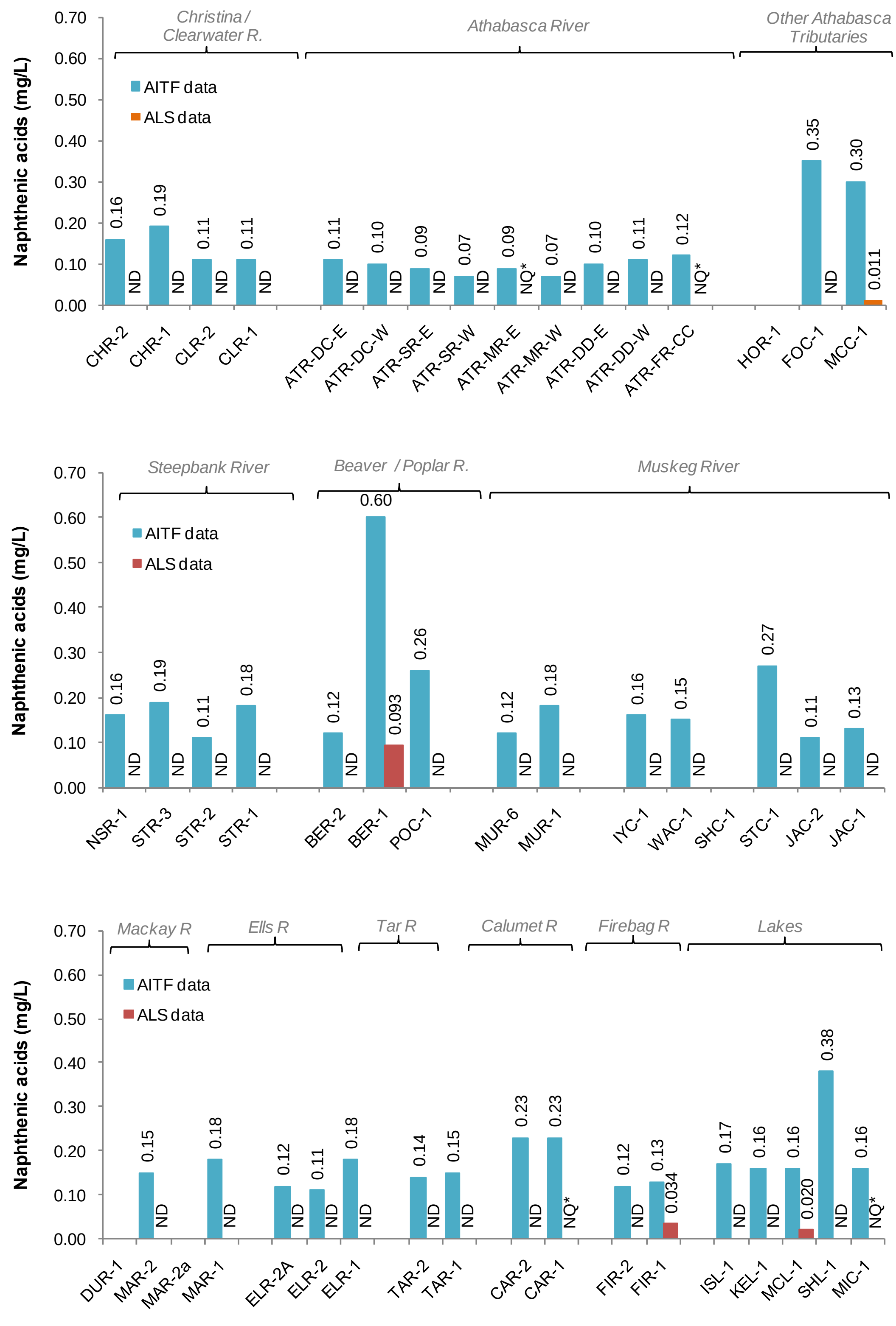
Comparison of data derived through these different methods suggests that: (a) the AITF method measures many more organic compounds than simply naphthenic acids; and (b) concentrations of organic acids conforming to the classic naphthenic acids formula ($C_nH_{2n+Z}O_2$) in ambient waters of the lower Athabasca watershed are low, with the majority of compounds detected by other methods likely being other acid-extractable organic compounds.

6.1.4 Need for Clarity and Agreement Moving Forward

The environmental chemistry of acid-extractable organics ("naphthenic acids") in the oil sands region is continuously being clarified. However, analytical methods remain in flux, with numerous approaches currently being used or developed returning very different results and none having associated, endpoint-specific toxicological data for comparison. It is apparent that each of these methods is measuring a different set of compounds.

While each of these different methods may have advantages for specific applications, for effective environmental monitoring of the ambient aquatic environment in the oil sands region, it is important that a standard method for measurement of naphthenic acids and/or other acid-extractable organic compounds be identified for routine use by regulators, RAMP, other site-specific monitoring programs, and academic researchers. This method should be based on measurement of specific compounds or groups of compounds that have potential for toxicity at environmentally relevant concentrations. This may require a Toxicity Identification Evaluation (TIE) using OSPW samples or an analogous desktop study based on chemical characterization of OSPW and surrounding ambient surface waters in the region. In the absence of a clear toxicological understanding of what compounds are important, it will be difficult to develop and refine an appropriate test for acid-extractable organics in regional surface waters that can be linked to meaningful benchmarks of potential environmental change.

Figure 6.1-3 Concentrations of acid-extractable organic acids (naphthenic acids) measured by AITF for RAMP using three different quantification methods, fall 2010.



*NQ = not quantifiable due to sample matrix interferences.

6.2 WATER QUALITY REGIONAL *BASELINE* ASSESSMENT

6.2.1 Background

Although RAMP water quality data are screened against generic water quality guidelines published by the CCME, AENV, or other provincial jurisdictions (where CCME and AENV guidelines do not exist), use of such generic guidelines may not be appropriate in all circumstances, given natural, site-specific variability in water quality. For example, in the lower Athabasca River and its tributaries, concentrations of various metals may exceed generic guidelines, because insoluble metals present in suspended particulates may indicate high concentrations of metals. However, these particulate metals often are not bioavailable and thus typically contribute little toxicity relative to dissolved metals; this phenomenon has been documented in the region by several authors, including Corkum (1985), Hebben (2009), and Glozier *et al.* (2010). In its guidance for derivation of site-specific water quality objectives, CCME (2003) indicates that it is appropriate to develop site-specific objectives where "the generic water quality guideline for a substance is lower than the upper limit of background at a site under investigation", as is the case for many water quality variables in waterbodies monitored in the RAMP FSA.

Additionally, although RAMP collects water quality data from both *baseline* (upstream) and *test* (downstream) locations in several watersheds, this is not possible in some watersheds, where no *baseline* station may be available for use as an uninfluenced (reference) location for comparison with downstream conditions (e.g., very small watersheds, or those where substantial alteration occurred previous to RAMP's existence).

In the absence of region- or site-specific water quality objectives or thresholds provided by regulators or regional organizations such as CEMA, RAMP has developed a set of regional water quality benchmarks to address these two issues in its own assessments, from data collected by RAMP at *baseline* stations since 1997. These regional *baseline* ranges are intended to represent the range of natural variability in water quality in the region, for use in screening RAMP water quality data collected at both *baseline* and *test* stations. The intent of these benchmarks is to identify regionally meaningful changes in water quality.

Methods used to develop these regional *baseline* ranges are described in Section 3. Put simply, groups of stations that exhibit similar water quality over time are identified through cluster analysis, and water quality data from *baseline* stations (specifically, 5th, 25th, 50th, 75th, and 95th percentiles) within these clusters are used for screening purposes. Observed values outside the central 90% of values (i.e., below 5th percentile or above 95th percentile) are flagged as being outside the documented range of natural variability (although it should be noted that 10% of *baseline* values will, by definition, fall outside this range). This approach is similar to "background concentration procedure" examples outlined in CCME (2003), which defined site-specific objectives using 90th or 95th percentiles of background values, or two standard deviations from the mean, which statistically is similar to using the central 95% of observations. It is also similar to reference-condition-approach (RCA) or bioassessment methods used for benthic invertebrate monitoring, which also are used by the Benthos and Sediment component of RAMP and discussed therein.

The recent RAMP Peer Review (AITF 2011) raised questions about the use of these regional *baseline* ranges as benchmarks in both the Water Quality and Benthic Invertebrate Communities components, particularly with respect to the pooling of spatial and temporal variability in the creation of these ranges. The following analysis of regional water quality characteristics and *baseline* ranges was undertaken to provide context for future discussion of these questions.

The suitability of regional *baseline* ranges as a representation of the range of natural variability in RAMP water quality assessments should consider the following:

1. Similarity of water quality at *baseline* stations within each cluster among stations and among years (i.e., consistency of cluster membership);
2. Variability of *baseline* water quality among stations within clusters; and
3. Variability of *baseline* water quality among years within clusters.

6.2.2 Consistency of Cluster Membership

Previous RAMP assessments of this regional *baseline* approach have focused primarily on the first of the questions listed above (i.e., cluster membership). This topic has been discussed in some detail in previous RAMP technical reports, the RAMP Design and Rationale Document (RAMP 2009b), and elsewhere in this report (i.e., Section 3 and Appendix D).

Since this regional *baseline* method was adopted by RAMP in 2004, various modifications to the statistical approaches to clustering of water quality data have been made, mainly related to data selection and treatment prior to clustering. In 2010, multiple approaches to data pre-treatment and clustering were taken, to assess the potential effect of the analytical techniques used on the final clustering outcome, as discussed in Section 3. In all cases, three groups of stations with consistently similar water quality characteristics over time were identified, namely:

- **Cluster 1 –** Athabasca River mainstem;
- **Cluster 2 –** Tributaries predominantly located along the west bank of the Athabasca River, including the MacKay, Ells, Tar, and Calumet rivers; and
- **Cluster 3 –** Tributaries predominantly located along the east bank of the Athabasca River, including the Muskeg, Steepbank, and Firebag rivers.

These groups of watersheds exhibit various physiographic and hydrographic similarities. Obviously, the Athabasca River is substantially larger than all of its tributaries in the oil sands region, with only 14% of its drainage area occurring downstream of Fort McMurray (WSC 2011); its upper reaches flow through several different landforms and anthropognic developments, including industrial and municipal discharges. Relative to western tributaries to the lower Athabasca River, eastern tributaries generally are characterized by lower gradients, greater proportions of their headwaters comprised of poorly-drained muskeg and peatlands (GSC 2006, AAFC 2007). Annual runoff in eastern tributaries is more dominated by freshet than the higher-gradient western tributaries, with less extreme high flows, particularly in summer and fall, than western tributaries (RAMP hydrology data, RAMP database www.ramp-alberta.org).

Southern tributaries (i.e., Clearwater, Christina, Horse rivers) have not always grouped consistently within these three clusters, and over time have alternately grouped with either western tributaries (as in 2010) or, less frequently, with the Athabasca River mainstem. However, these southern tributaries do not consistently group separately either, based on their water quality. It should be noted that no water quality data from these rivers are used to generate regional *baseline* ranges for comparison, because all of these watersheds contain development upstream of RAMP sampling locations.

6.2.3 Variability Within and Among Clusters

6.2.3.1 Water Quality Characteristics Among Clusters

Stations within these groups/clusters exhibit consistent similarities in water quality, which have been observed repeatedly over time. Generally, concentrations of most metals are higher in the *baseline* Athabasca River stations (Cluster 1) than at *baseline* stations in tributaries sampled by RAMP, particularly for metals present primarily in particulate form, such as aluminum, antimony, copper, lead, silver, and titanium (total suspended solids are generally higher in the Athabasca River as well). However, this trend is reversed for several metals that are present predominantly in dissolved form, particularly boron, lithium, and manganese, which are present in higher concentrations in tributaries. Total dissolved solids and most major ions also are higher in tributaries than in the Athabasca River mainstem, with the notable exception of sodium, potassium, chloride and sulphate, which are all lower in eastern tributaries (Cluster 3) than either western tributaries (Cluster 2) or the Athabasca River mainstem.

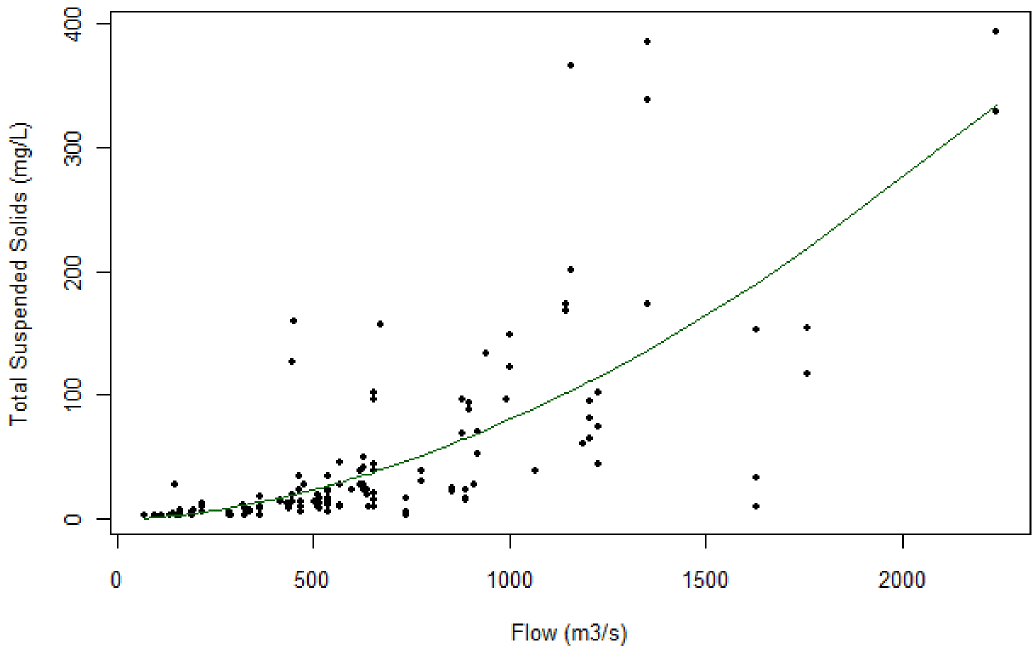
Indicators of organic substances—including total and dissolved organic carbon, total Kjeldahl nitrogen (TKN), total phenolics, and true colour—are typically much higher in tributaries than in the Athabasca River. These organic variables are generally higher in western tributaries than in eastern tributaries. Total sulphides follow a similar pattern.

Differences between tributary groups also are apparent, with water quality stations in eastern tributaries (Cluster 3) exhibiting an ion balance dominated by calcium/bicarbonate, whereas sodium, chloride and sulphate occur at greater concentrations in western tributaries (Cluster 2). Concentrations of most metals are higher in western tributaries than in eastern tributaries.

Spearman's rank correlations for within-cluster water quality data collected by RAMP from 2002 to 2010 (tabulated in Appendix D) reveals additional consistency in differences in water quality among clusters and across years. In the Athabasca River mainstem, concentrations of many variables are significantly correlated ($p<0.01$) with suspended solids (TSS), including most total metals (Al, Sb, As, Ba, Bi, Cr, Co, Cu, Fe, Pb, Li, Ni, Th, Ti, U, V), nutrients (TN, TKN, TP) and organic compounds (TOC, DOC, total phenolics). Conversely, conductivity and most major ions are negatively correlated with TSS, and weakly correlated (negatively or positively) with metals. These correlations suggest a primary influence of river flow on measured water quality in the Athabasca River mainstem, given the positive relationship between Athabasca River flow and TSS (Figure 6.2-1), and the converse, negative relationship between river flow and conductivity.

In tributaries to the lower Athabasca River, most total metals also are highly correlated with suspended materials ($p<0.01$; Cluster 2: Al, Be, Bi, Cd, Cr, Co, Cu, Fe, Pb, Hg, Ag, Th, Tl, Sn, Ti, V, Zn; Cluster 3: Al, Ba, Be, Cd, Cr, Co, Fe, Pb, Mn, Hg, Tl, Th, Sn, Ti, U, V). In all tributaries, several metals typically occurring in dissolved form were positively correlated with major ion concentrations (especially Ba, B, Li, Mn, Sr). Positive correlations of most metals with major ions were stronger in western tributaries, while correlations of metals with suspended solids were stronger in eastern tributaries. Sodium and (especially) chloride in western tributaries did not correlate as strongly with other major ions as in eastern tributaries, which could perhaps indicate point-source influences on water quality at these *baseline* stations of saline seeps, which are known to occur in the region.

Figure 6.2-1 Relationship between river discharge and total suspended solids in the lower Athabasca River, 1997 to 2009.



Contrary to their behaviour in the Athabasca River mainstem, organic compounds and most nutrients in these tributaries were at most weakly correlated with suspended materials (although weakly positively in eastern tributaries, and weakly negatively in western tributaries). These compounds (TOC, DOC, TN, TKN, colour, total phenolics) were strongly correlated with each other in all tributaries; sulphide also was highly correlated with these variables.

Together, these tendencies suggest three dominant components of water quality in streams of the RAMP FSA: (i) particulate-associated materials, which are predominantly comprised of particulate metals; (ii) major ions and some dissolved metals, likely associated with groundwater sources in tributaries; and (iii) organic compounds, which covary among themselves, and are associated with suspended materials in the Athabasca mainstem, but appear to vary more independently of other water quality variables in tributaries.

A separate correlation analysis of all water quality data from 2009 and 2010 only, focused on examining correlations between naphthenic acids measured using high-resolution methods and other water quality variables, identified significant, strong correlations ($p<0.01$) between naphthenic acids and indicators of flow in the Athabasca River mainstem (i.e., positive correlations with most metals and organic compounds, and negative correlations with major ions and conductivity), indicating higher concentrations of acid-extractable organics at higher flows. However, correlations were reversed in tributaries, where naphthenic acids were strongly, positively correlated with major ions. In western tributaries, naphthenic acids were strongly associated with all major ions, TDS, and conductivity, whereas in eastern tributaries, naphthenic acids were strongly associated only with chloride and sulphate. Considered in parallel with the possible range of acid-extractable organic compounds measured by this analysis (see Section 6.1), these patterns suggest that these compounds measured in the Athabasca River mainstem are likely predominantly comprised of fatty acids and other related organic acids originating upstream of Fort McMurray, while organic acids in western tributaries are largely associated with influences of groundwater (which may have high organic-acid and TDS concentrations [AENV 2009]), and that organic acids measured at stations in eastern tributaries may have mixed origins, from both groundwater and from biological decomposition in these watersheds.

6.2.3.2 Among-Year Variability Within Clusters

Year-specific regional *baseline* ranges for selected RAMP water quality measurement endpoints are shown in Figure 6.2-2, specifically an indicator of suspended materials (TSS), ion content (total alkalinity), dissolved metal (total boron) and organic content (DOC). Each figure presents 5th, inter-quartile, and 95th percentile ranges for each variable in each year (blue) from 1997 to 2010, as well as the overall (1997 to 2010) *baseline* range (red) used for water quality screening. Each plot also includes a representative average daily river discharge from September 1 to 15 for each year; these discharge data (collected by RAMP and Water Survey of Canada) are for the Athabasca River downstream of Fort McMurray, and the mouths of the Muskeg River (RAMP station S7, compared with Cluster 2) and Mackay River (RAMP station S26, compared with Cluster 3).

Examination of the TSS plots indicates greatest inter-annual variability of suspended materials in the Athabasca River mainstem, with highest TSS generally occurring in years of highest flow (i.e., 2004 and 2010). Clear relationships with flow are not apparent in data for tributaries. For the Athabasca River, the defined 95th percentile for 1997 to 2010 is near the median concentration in high-flow years, but above the 95th percentile for all other years. For the western tributaries, the 1997 to 2010 95th percentile is within the 95th percentile of three of eleven years of data, and the 75th percentile is below the 95th percentile for most years.

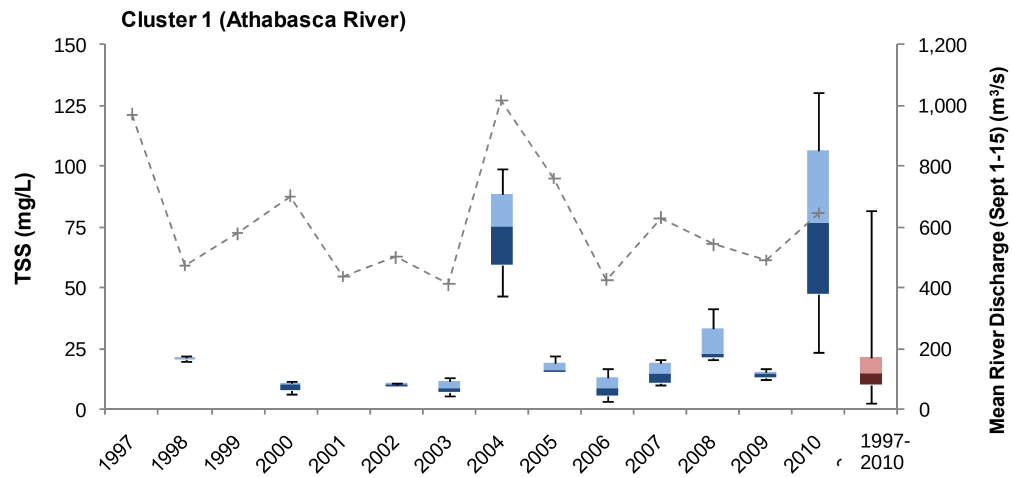
For total alkalinity, an influence of flow on ion composition was seen most clearly in eastern tributaries, while alkalinity in the Athabasca River and western tributaries showed more consistent values over all years. In both the Athabasca River and eastern tributaries, the 1997-2010 95th percentile exceeded individual 95th percentiles annually; for western tributaries, the cumulative 95th percentile was below annual 95th percentiles observed in 1998 and 1999.

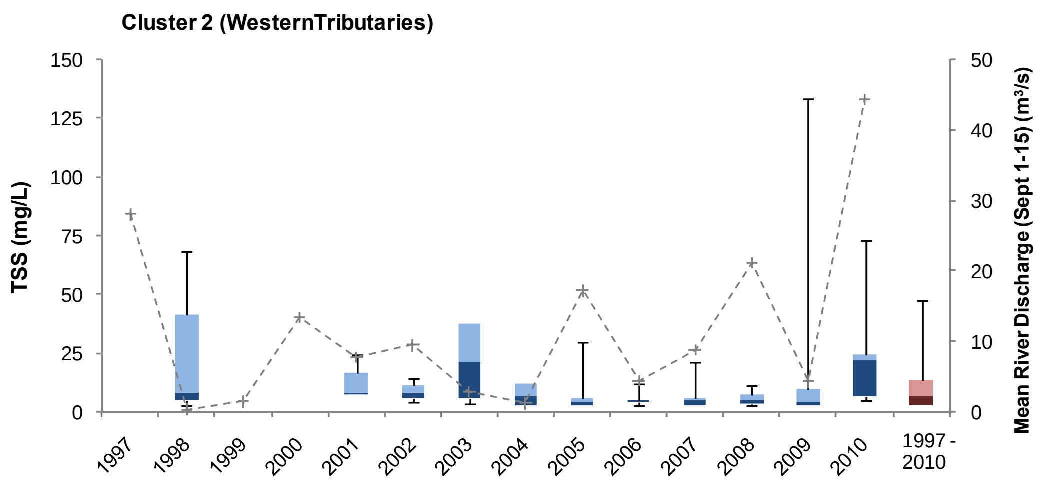
For total boron, concentrations were generally low and consistent in the Athabasca River relative to tributaries, and the associated 1997 to 2010 95th percentile was correspondingly tight. In tributaries, a slight inverse relationship with river flow was suggested, particularly in eastern tributaries. In both sets of tributaries, the 1907 to 2010 95th percentile is below that of three years, and the cumulative 75th percentile is below that of several years.

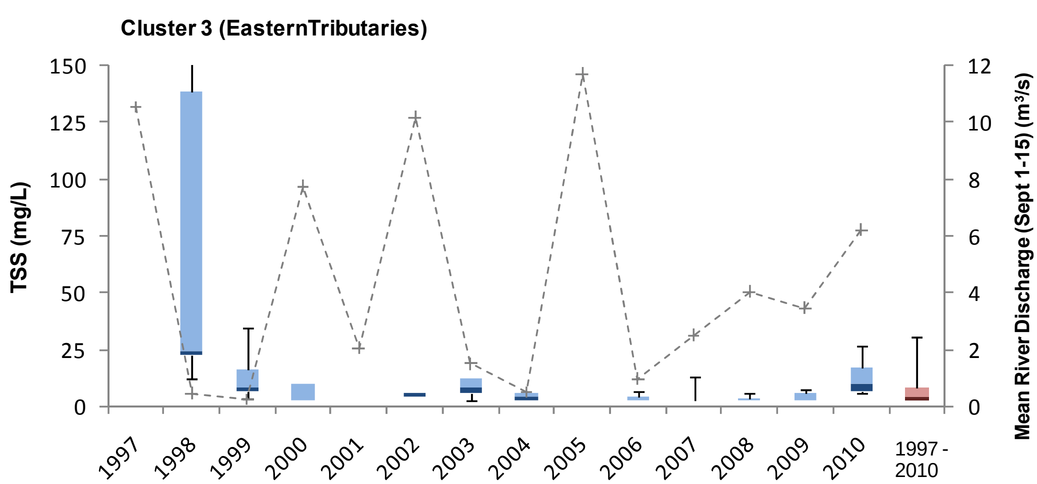
The DOC plot shows the clear influence of flow on organic content in the Athabasca River, and a weaker but still apparent influence of flow on DOC in tributaries. In all groups, the cumulative 95th percentile falls near or below that of multiple years of observations.

Figure 6.2-3 shows average within-year coefficient of variation (CV, equal to standard deviation/mean, from all annual observations) against among-year CV (standard deviation of annual means/grand mean), for selected major ions, suspended solids, nutrients and organic compounds, and metals. Where among-year variability exceeds within-year variability, data fall above the 1:1 line on each chart. Data falling below this 1:1 line indicate greater within-year variability than among-year variability.

Figure 6.2-2 Annual and cumulative regional baseline ranges among clusters, 1997 to 2010, compared with fall river discharge (dashed line)[1].

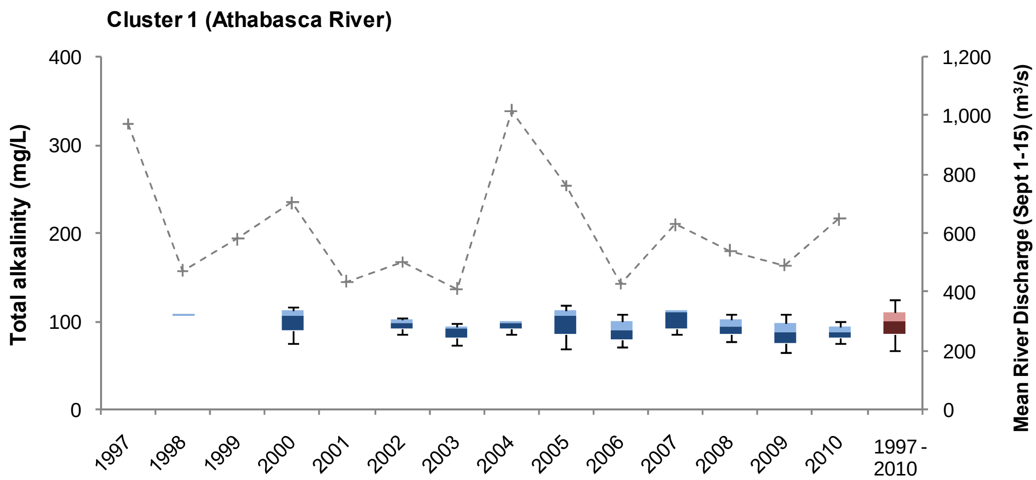


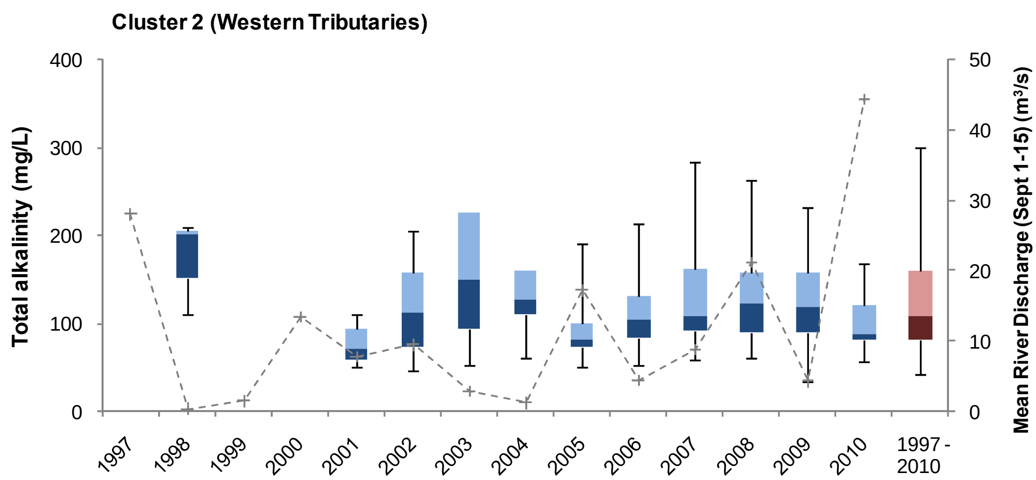


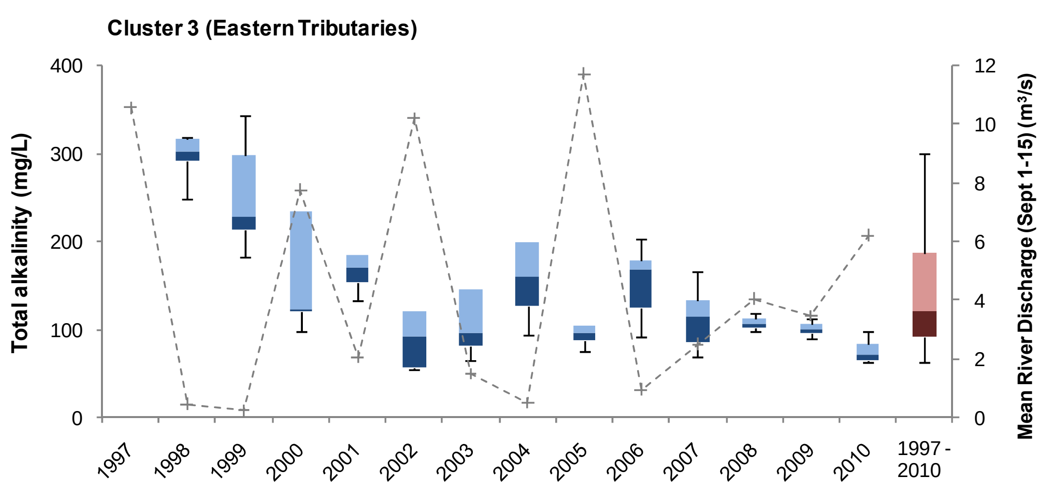


[1] River flows: Cluster 1-Athabasca R. (WSC 07DA001); Cluster 2-MacKay R. (RAMP S26); Cluster 3-Muskeg R. (RAMP S6).

Figure 6.2-2 (Cont'd.)

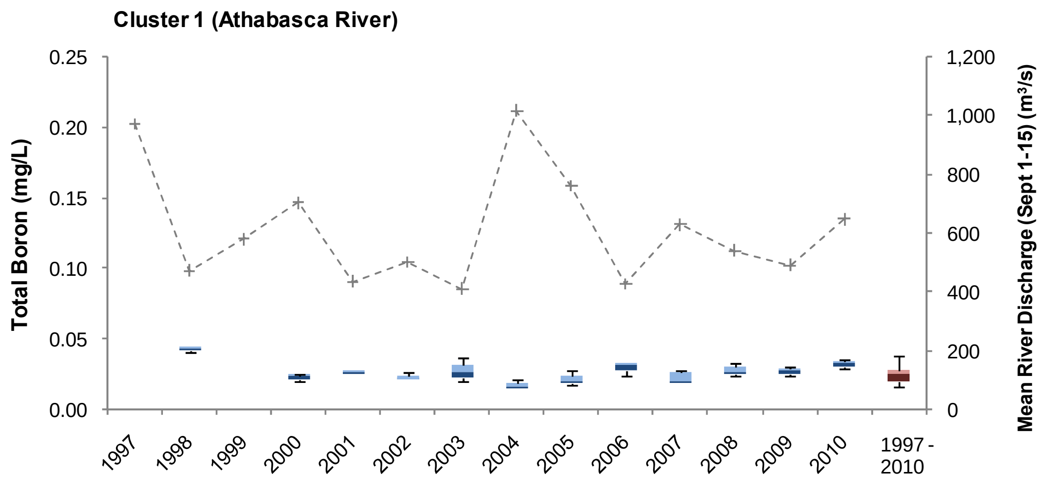


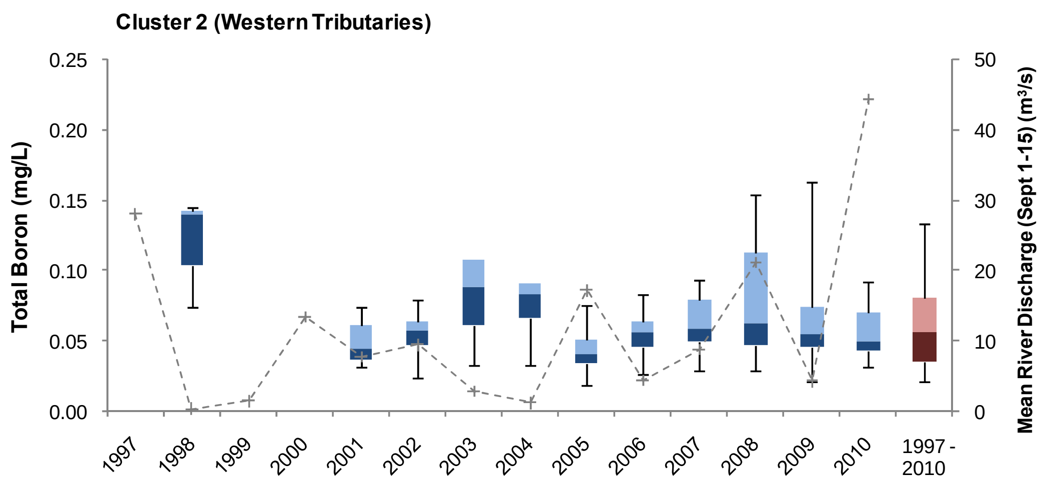


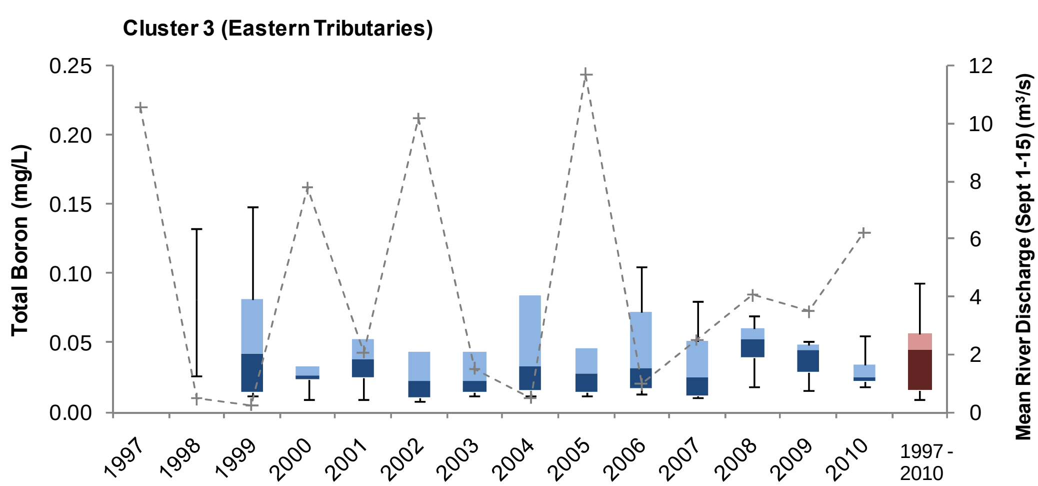


[1] River flows: Cluster 1-Athabasca R. (WSC 07DA001); Cluster 2-MacKay R. (RAMP S26); Cluster 3-Muskeg R. (RAMP S6).

Figure 6.2-2 (Cont'd.)

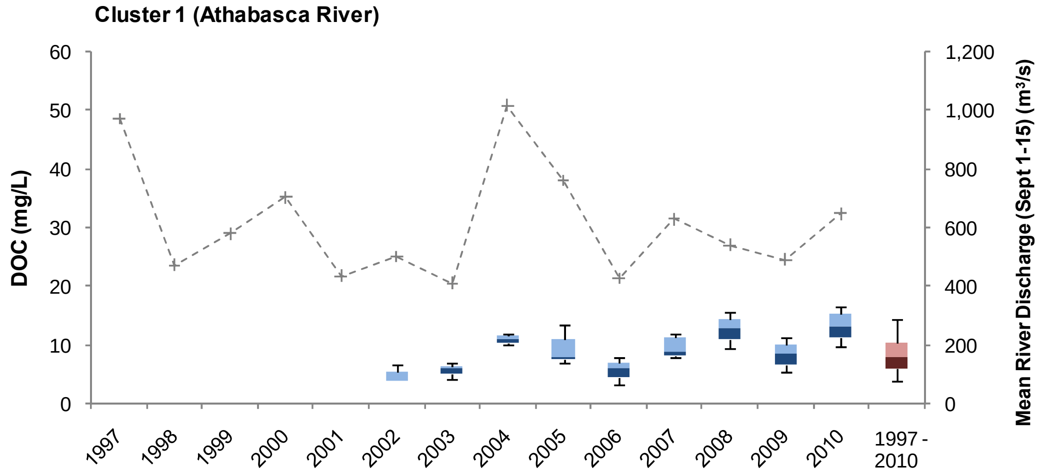


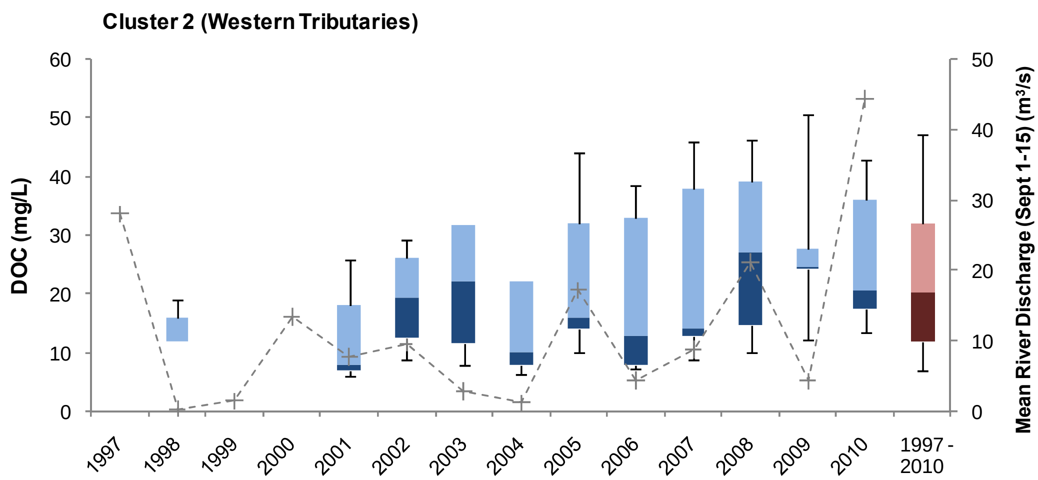


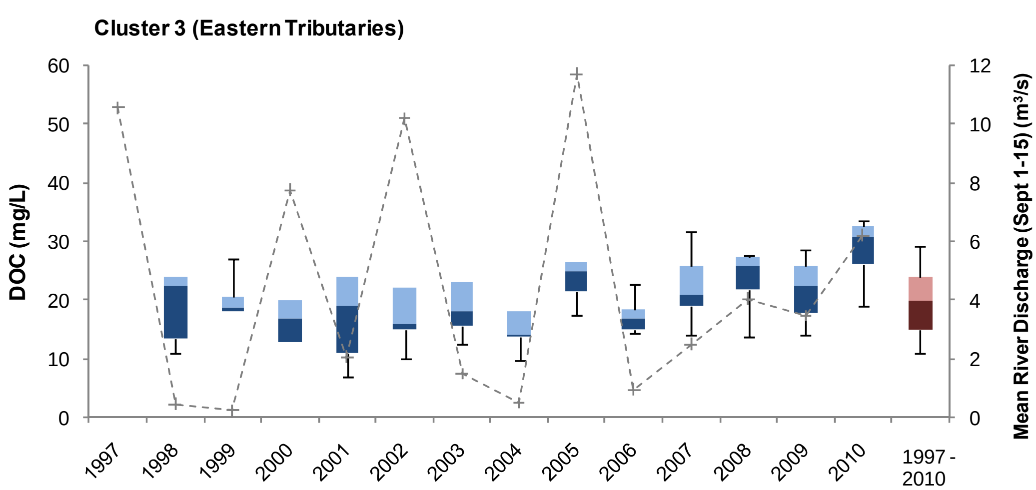


[1] River flows: Cluster 1-Athabasca R. (WSC 07DA001); Cluster 2-MacKay R. (RAMP S26); Cluster 3-Muskeg R. (RAMP S6).

Figure 6.2-2 (Cont'd.)



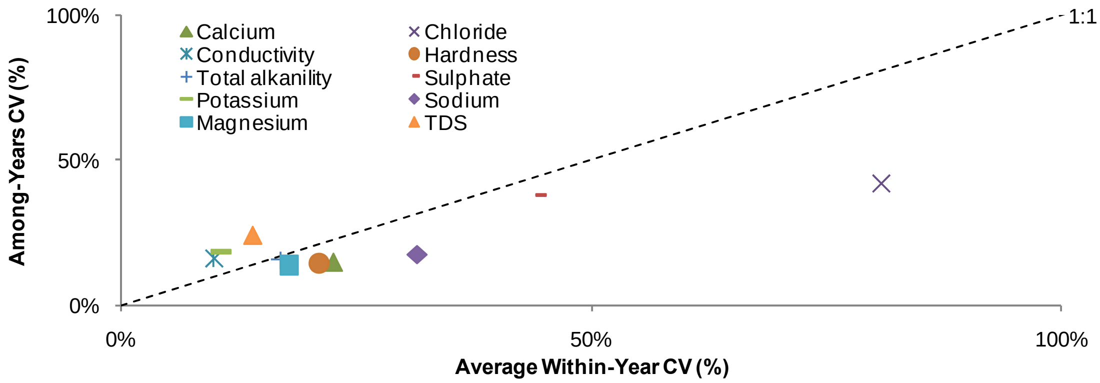




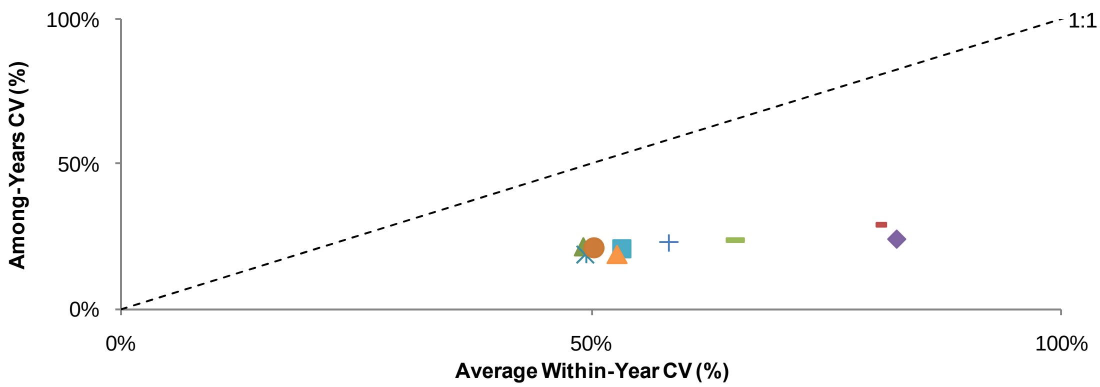
[1] River flows: Cluster 1-Athabasca R. (WSC 07DA001); Cluster 2-MacKay R. (RAMP S26); Cluster 3-Muskeg R. (RAMP S6).

Figure 6.2-3 Comparison of within-year and among-year variability for selected water quality variables measured by RAMP, 1997 to 2010.

Major ions: Cluster 1 (Athabasca River)



Major ions: Cluster 2 (Eastern Tributaries)



Major ions: Cluster 3 (Western Tributaries)

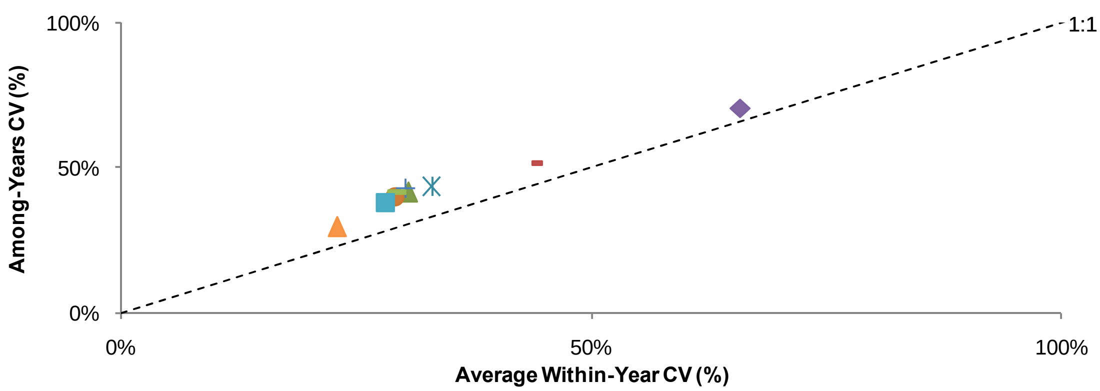
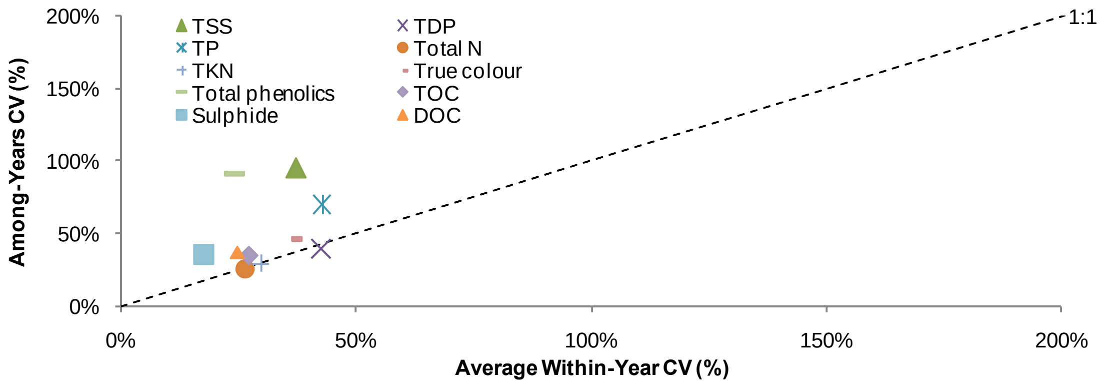
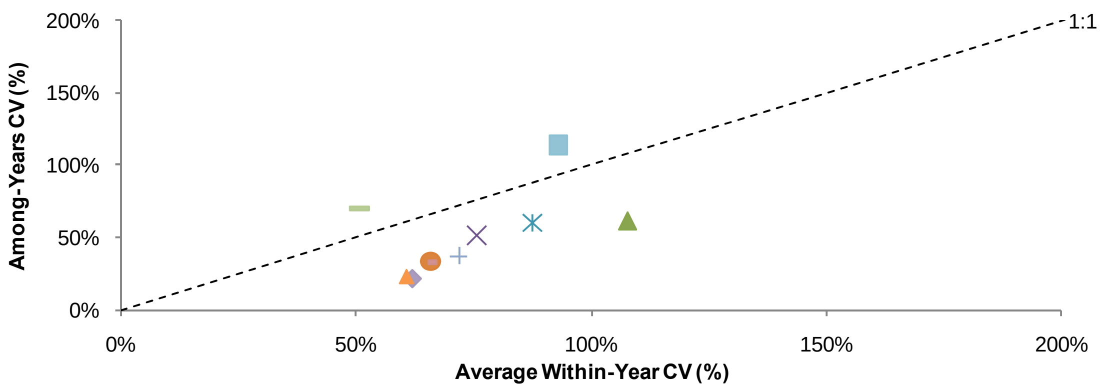


Figure 6.2-3 (Cont'd.)

Suspended solids, organic compounds and nutrients: Cluster 1 (Athabasca River)



Suspended solids, organic compounds and nutrients: Cluster 2 (Eastern Tributaries)



Suspended solids, organic compounds and nutrients: Cluster 3 (Western Tributaries)

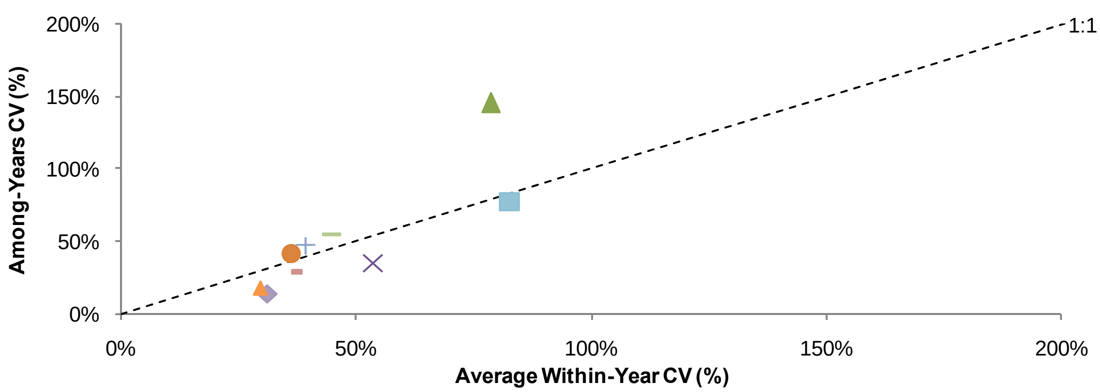
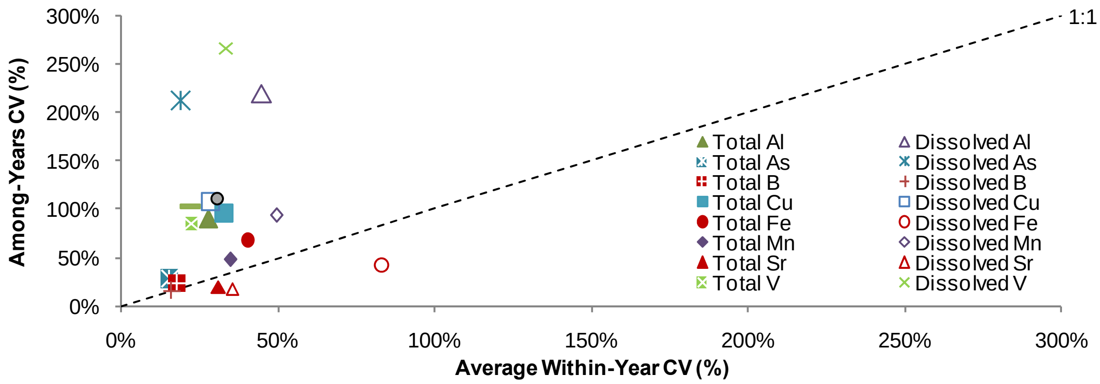
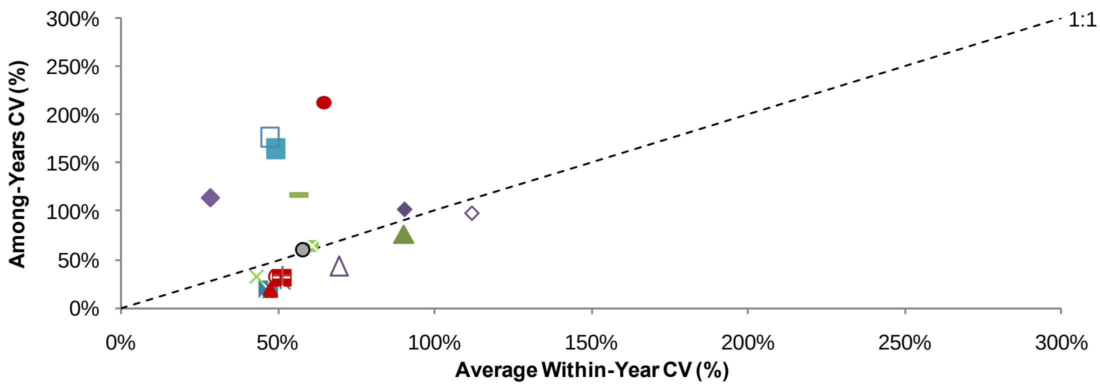


Figure 6.2-3 (Cont'd.)

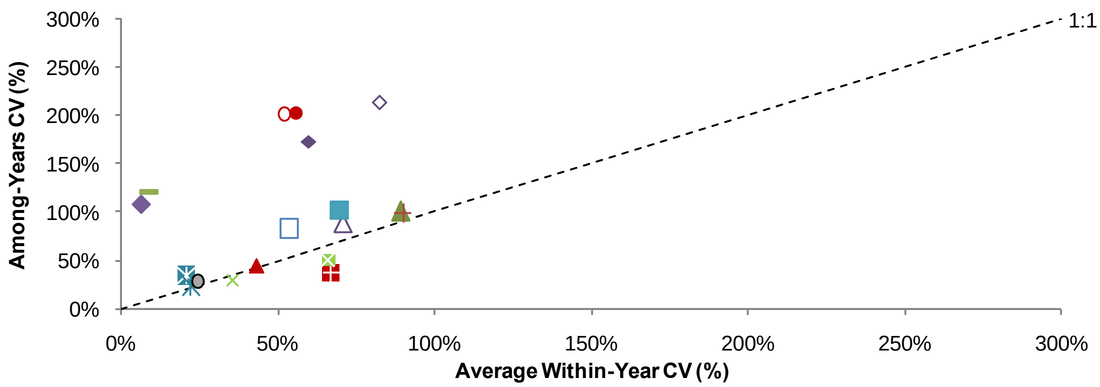
Selected total and dissolved metals: Cluster 1 (Athabasca River)



Selected total and dissolved metals: Cluster 2 (Eastern Tributaries)



Selected total and dissolved metals: Cluster 3 (Western Tributaries)



Differences among clusters and water quality variables are apparent. For major ions, within-year variability is generally similar or greater than among-year variability, particularly in eastern tributaries (consistent with the total alkalinity plot in Figure 6.2-2 mentioned previously). For suspended solids, organics and nutrients, variability was generally greater within years than among years in tributaries, but generally greater among years in the Athabasca River (this may be expected, given the strong influence of river flow on water quality in the Athabasca mainstem). For total and dissolved metals, variability was generally higher among years than within years, particularly in the Athabasca River mainstem; this is consistent with the strong influence of flow on metal concentrations, particularly in the Athabasca River. Metals present predominantly in dissolved form (i.e., B, Sr) typically showed less inter-annual variability than other metals and more similar to major ions than other metals in this regard.

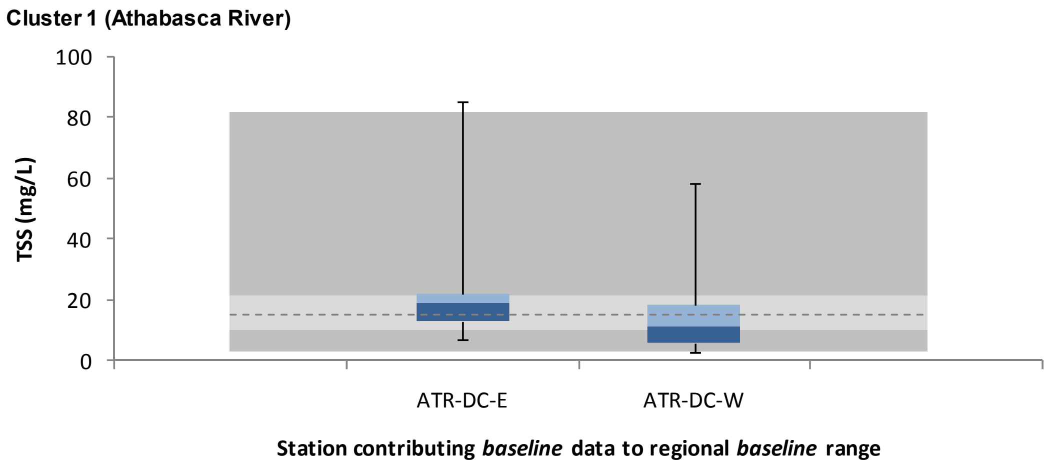
6.2.3.3 Among-Station Variability Within Clusters

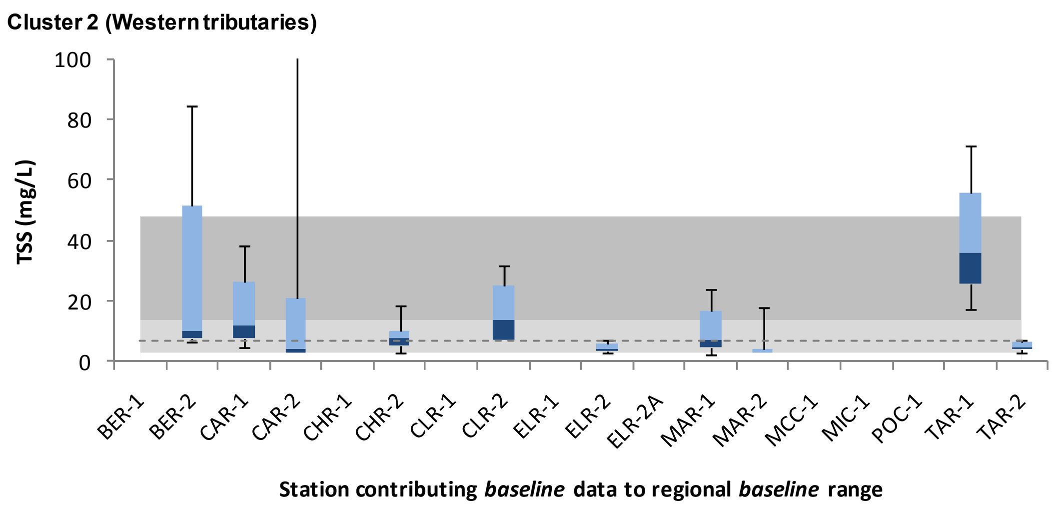
Figure 6.2-4 shows *baseline* data from individual stations that were used to generate regional *baseline* ranges for each cluster, using the same example variables as used in Section 6.2.3.2 above.

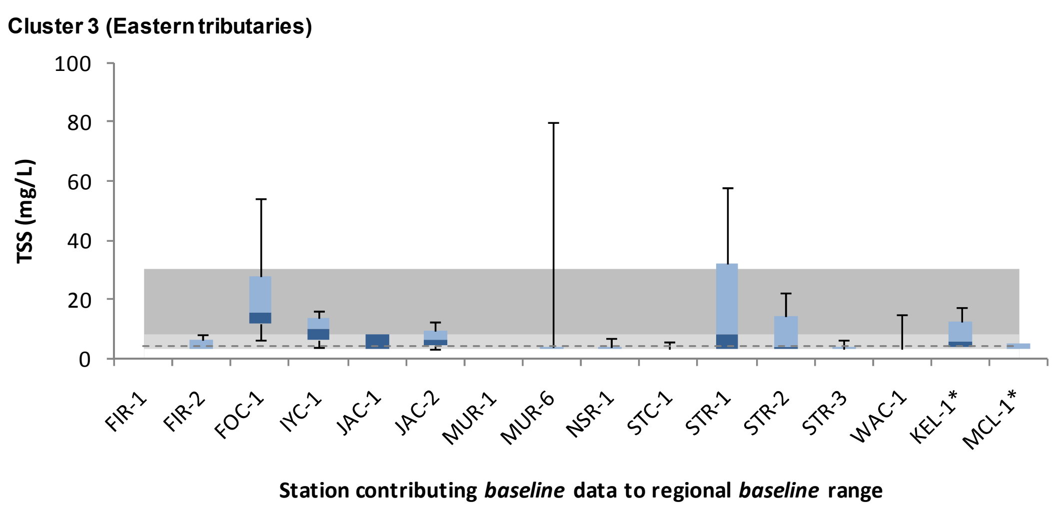
Grey background ranges in these figures correspond to regional baseline ranges as used in Section 5 of this report (i.e., 5^{th}, 25^{th}, 50^{th}, 75^{th}, and 95^{th} percentiles); station-specific box-whisker plots correspond to similar percentiles of data within each station, with 5^{th} and 95^{th} percentiles represented as error bars, as previously done in Figure 6.2-2. Stations in these figures showing no data are those that use these cluster ranges for comparison, but that did not themselves contribute data to regional *baseline* ranges, typically because these stations had *test* status since RAMP sampling began at those locations. For stations that revert from baseline to test during their sampling history, only data from years of baseline status are included in regional ranges and in these graphs. For Cluster 3 (eastern tributaries), data from Kearl and McClelland lakes also are presented, although these data were not included in regional baseline ranges used for screening in the 2010 report; these lake data are discussed further in Section 6.2.3.4 below.

Although variability in water quality among stations within clusters is evident, median values for specific variables generally fall within the inter-quartile range for each cluster, with some exceptions. Some stations showed median values for specific water quality variables that fell below the inter-quartile range, particularly those in upper reaches of watersheds (e.g., FIR-2, NSR-1, IYC-1, STC-1), although this was not always the case. Generally, upper-watershed stations and those from smaller watersheds (e.g., Fort Creek Calumet River) appeared to show greater variability than those from larger watersheds. Water quality in the two stations on the Athabasca River upstream of oil-sands development (upstream of Donald Creek, west and east banks) shows consistent differences (consistent with the influence of the Clearwater River along the east bank at this location) although these are generally smaller than differences observed among tributary stations.

Figure 6.2-4 Variation within and among stations comprising regional *baseline* ranges (1997 to 2010 data).

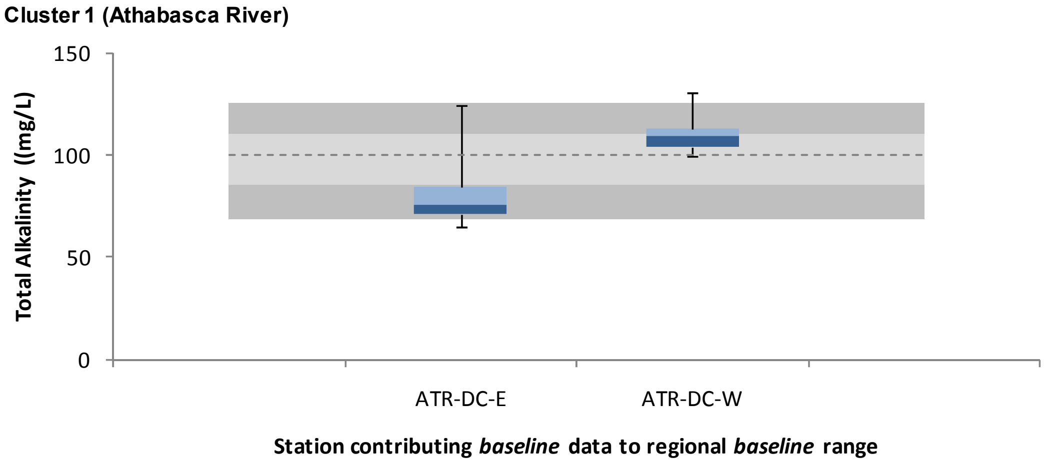


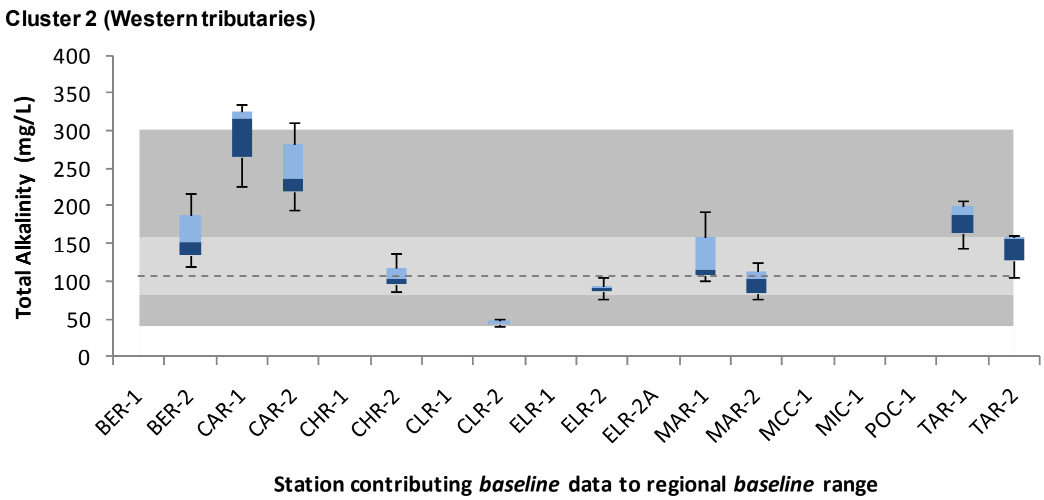


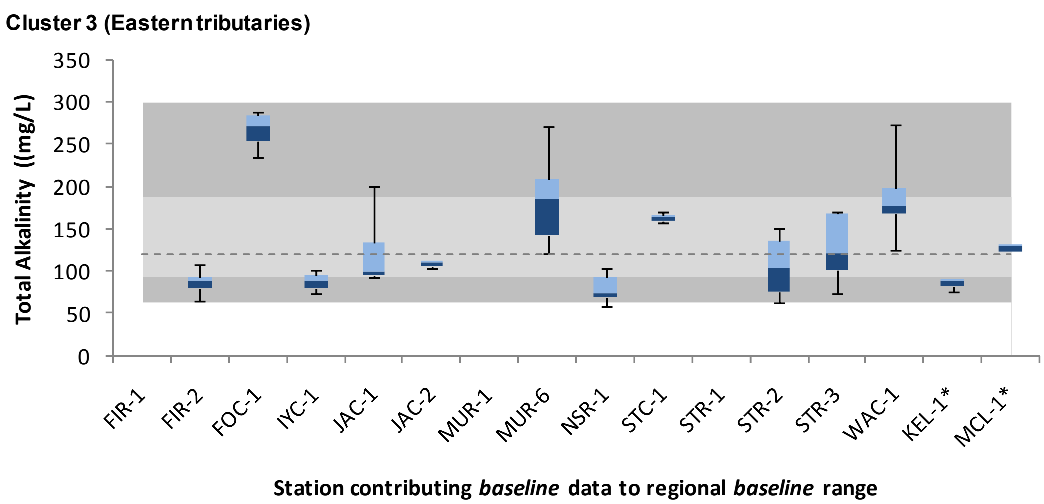


* Kearl Lake (KEL-1) and McClelland Lake (MCL-1) excluded from regional baseline calculations in 2010 (see Section 3).

Figure 6.2-4 (Cont'd.)



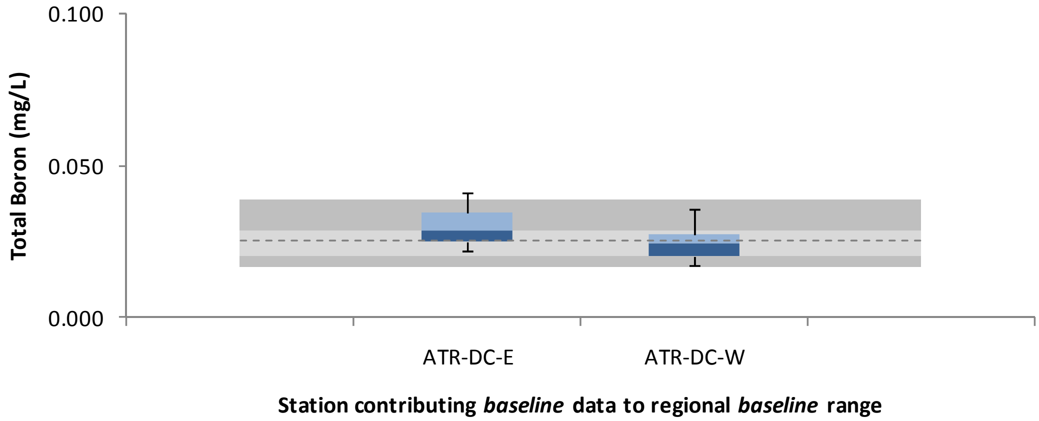




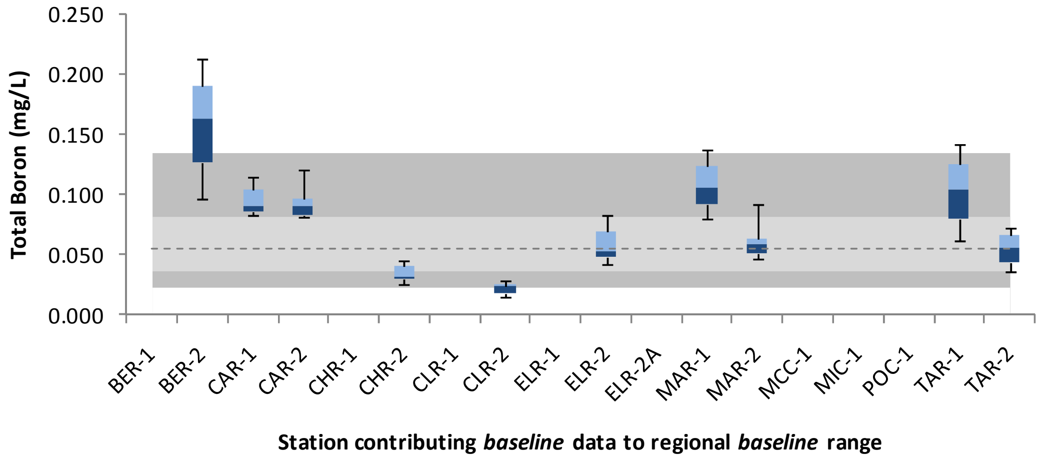
* Kearl Lake (KEL-1) and McClelland Lake (MCL-1) excluded from regional baseline calculations in 2010 (see Section 3).

Figure 6.2-4 (Cont'd.)

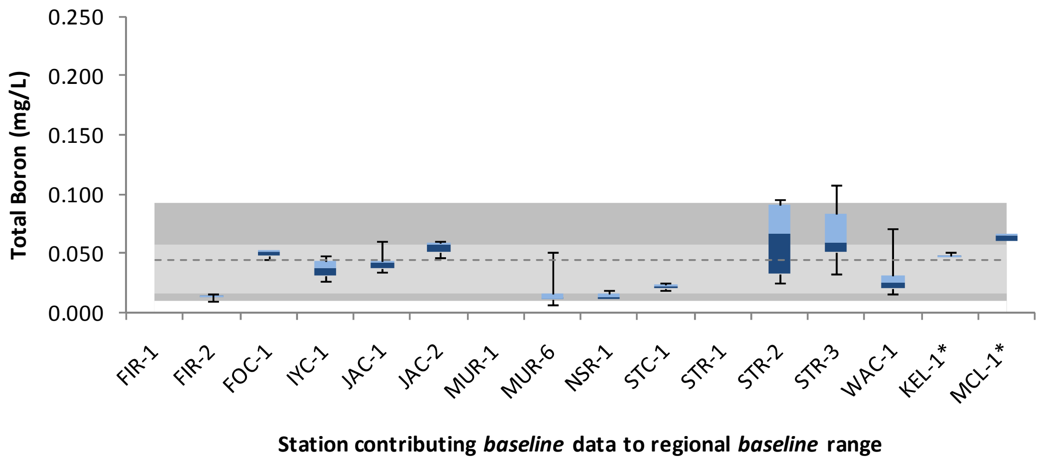
Cluster 1 (Athabasca River)



Cluster 2 (Western tributaries)

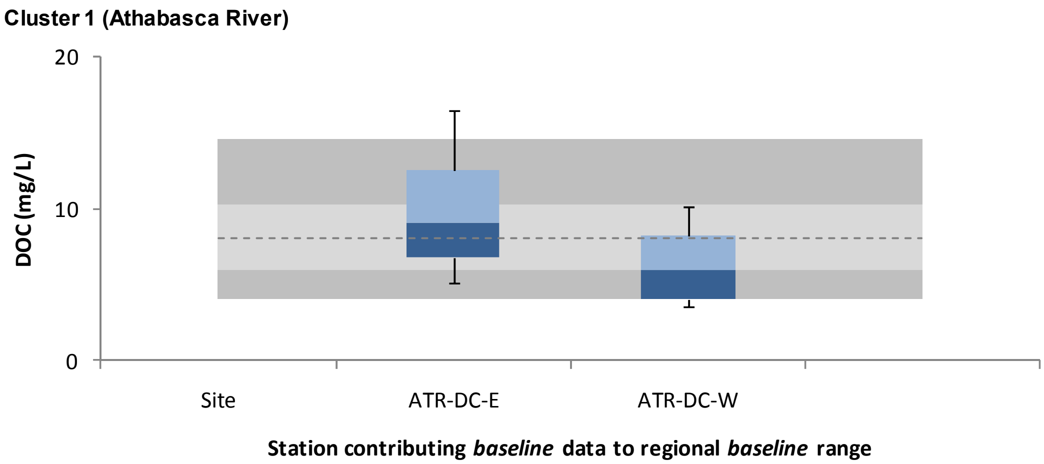


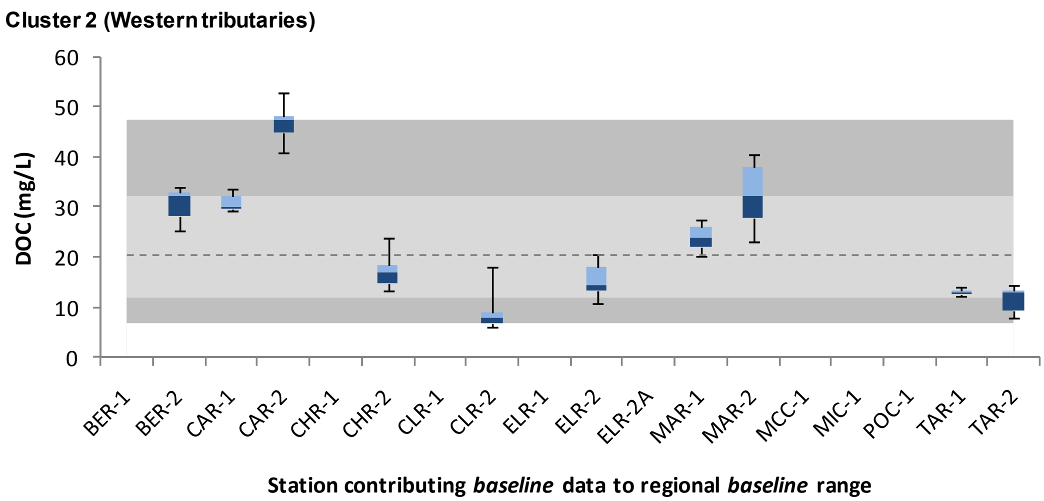
Cluster 3 (Eastern tributaries)

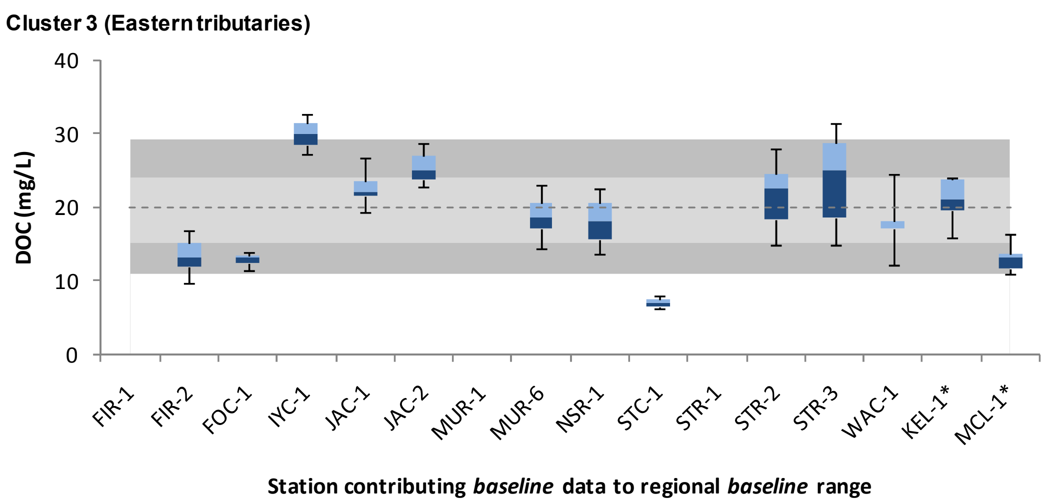


* Kearl Lake (KEL-1) and McClelland Lake (MCL-1) excluded from regional baseline calculations in 2010 (see Section 3).

Figure 6.2-4 (Cont'd.)







* Kearl Lake (KEL-1) and McClelland Lake (MCL-1) excluded from regional baseline calculations in 2010 (see Section 3).

6.2.3.4 Similarities Between *Baseline* Data from Lakes and Streams

Figure 6.2-4 also includes *baseline* data collected from Kearl Lake (1998 to 2009) and McClelland Lake (2000 to 2009), which were included in regional *baseline* ranges calculated in RAMP Technical Reports from 2004 to 2009 (RAMP 2005, 2006, 2007, 2008, 2009a). These data were excluded from regional *baseline* ranges in the 2010 analysis due to a stated concern in the 2010 RAMP Peer Review (AITF 2011) that combining water quality data from these lakes would increase the range of regional *baseline* data used to comparison in the RAMP Technical Report, and potentially mask variability in stream water quality that was outside of background ranges of variability.

As is apparent for the variables shown in Figure 6.2-4, water quality in these shallow lakes is generally similar to water quality in streams. Generally, *baseline* water quality in these lakes fell within the inter-quartile range of regional baseline values, and/or was within the range of water quality observations of streams occurring within watersheds containing these lakes (i.e., the Firebag watershed for McClelland Lake, and the Muskeg watershed for Kearl Lake). These results suggest that inclusion of water quality data from these lakes in the regional *baseline* range did not inflate variability of these ranges to an extent that would obscure any excursions of regional *baseline* conditions in stream water quality.

6.2.4 Future Considerations

A common factor among reference-condition approaches undertaken in RAMP and elsewhere is the aggregation of *baseline*/reference data across years. An underlying assumption of this aggregation is that conditions (water quality, benthic invertebrate community, fish community, etc.) in any given year at a *baseline* location are representative of natural conditions that are sufficient to support aquatic species that have become adapted over time to sustain their populations at this location. However, it may be possible for background conditions in a waterbody to change naturally in ways that cause significant, negative effects on resident biological communities, or that aquatic organisms in one watershed may be incapable of persisting in another nearby waterbody for some reason.

For water quality, specifically, this assumption is best tested by examining biological communities (e.g., benthos and/or fish) at corresponding locations and times with water quality; if community metrics indicate regionally normal (healthy) communities, then presumably water quality also continues to be regionally acceptable. Such effects-based assessments comprise the core of other components of RAMP, and provide a feedback mechanism between the stressor- and effects-based elements of RAMP. Further comparisons of water quality with biological endpoints at various *baseline* locations over time will help to determine the adequacy of regional water quality for maintenance of aquatic life.

The use of the regional *baseline* approach in RAMP and elsewhere is an attempt to define a range of natural variability that is considered acceptable to sustain aquatic life, so that any changes outside that range (i.e., that may threaten aquatic life) may be identified to decision-makers. Given that every sample collected in time and space may be considered unique, the key question to address in designing an analytical framework for regional analysis is: how much change is acceptable? Or, more technically, what are the effect criteria for the assessment? Such questions depend on philosophical questions of what are normal and social considerations of what is acceptable, as much as scientific questions of how these questions are may be defined and stated numerically.

The approach taken in the RAMP water quality component has successfully identified changes in water quality in one or many variables, in several watersheds, since its first implementation in 2004. However, this approach could be further refined though:

- ongoing, paired comparisons with benthic invertebrate community data in *baseline* areas; and
- more comparisons of water quality with hydrometric data and landscape variables, to better understand underlying factors that help determine water quality at a given location.

6.2.5 Alternatives

Alternatively, screening of RAMP data to regional *baseline* ranges could be discontinued. As more data are collected at both *baseline* and (especially) *test* stations year to year, time trend analysis (using various statistical or control-charting techniques) can play a larger role in the identification of meaningful environmental change at locations monitored by RAMP.

Additionally, use of a percentile of background concentrations may be confusing to some reviewers, as, by definition, exceedances beyond these percentile ranges are expected to occur routinely (i.e., 10% of the time) at *baseline* stations. If there is a desire for more absolute, "not-to-exceed" objectives, use of objectives defined as a subset of background values is not an acceptable approach. For specific watersheds of high interest, such as the Athabasca River mainstem or larger tributaries rivers such as the Muskeg, Steepbank, Mackay, Ells, and Firebag rivers, consideration could be given to development of river-specific water quality objectives (SSWQOs), following methods outlined by CCME (2003) or others, which may incorporate direct toxicological assessments or adjustments of existing toxicological data for resident species. However, the drawback to defining SSWQOs in this way is that it would require development of separate SSWQOs for every water quality variable of interest or concern, independently for each watershed.

6.3 COMPARISON OF NEILL-HESS AND KICK NET SAMPLING FOR BENTHIC INVERTEBRATE COMMUNITIES

6.3.1 Introduction

Water levels were high in early September in many of the river reaches because of heavy rainfall in late August and early September. Water levels in most of the erosional reaches (i.e., MacKay River, Steepbank River, and the Firebag River) were high enough that the Neill-Hess cylinder was overtopped, effectively compromising sample integrity (overtopping of the cylinder causes organisms to be flushed from the sample). Sampling of these three rivers was; therefore, postponed until late September when water levels had potentially subsided. Water levels, even in later September had not sufficiently dropped in which case there were some stations within reaches where the Neill-Hess cylinder could not be used. At these locations, a D-framed net was used to a collect a "qualitative" kick samples using protocols from the federal CABIN methodology (Reynoldson *et al.* 2004). Given that kick net samples can be collected under many conditions and because it is possible that high water levels may compromise sampling in future, it was considered appropriate to collect kick net samples synoptically with some Neill-Hess cylinder samples for comparative purposes.

The objective of this analysis was to quantify the influence of the method of sample collection on values of measurement endpoints for benthic invertebrate communities.

6.3.2 Methods

6.3.2.1 Field

Kick net samples at a station (i.e., replicate sampling location within a reach) were collected by walking and kicking substrate along transects for three minutes in a zig-zag fashion, walking from the river's wetted perimeter towards the mid-channel to a maximum depth of approximately 1 m. Debris produced from kicking was collected in a D-framed net with 400 µm mesh.

Kick net samples were collected from the following reaches (Figure 3.1-4):

- *test* reaches MAR-E1 and MAR-E2 and *baseline* reach MAR-E3 on the MacKay River;
- *test* reach STR-E1 and *baseline* reach STR-E2 on the Steepbank River; and
- *baseline* reach FIR-E2 on the Firebag River.

Samples were collected synoptically with Neill-Hess cylinder samples (see Section 3.1.3.2). Two sets of synoptic samples were collected from *test* reaches MAR-E2 and STR-E1 and *baseline* reach STR-E2 and one set of synoptic samples was collected at *test* reach MAR-E1 and *baseline* reaches MAR-E3 and FIR-E2.

Collected samples were preserved in 10% buffered formalin and bottled for transport to the taxonomist.

6.3.2.2 Laboratory

Samples were processed by Dr. Jack Zloty in a manner similar to that used for the Neill-Hess cylinder samples. Organisms were identified to lowest practical taxonomic level.

6.3.2.3 Statistics

For each sample, the following benthic invertebrate community measurement endpoints were calculated:

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

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

  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).

Scatterplots were presented to visualize the effect of sample collection method on values of measurement endpoints for benthic invertebrate communities.

An analysis of variance (ANOVA) was used to test for a significant influence of the sample collection method (Table 6.3-1). The data included in this analysis were from those reaches where two sets of synoptic samples were collected: the duplicate set provided a measure of within-reach variability for both methods of collection. A significant interaction between Reach and Method (i.e., R x M) would imply that the Neill-Hess and kick net samples produced different values of measurement endpoints and that the nature of the difference depended on the reach. The interaction term was tested first for each of the four indices. In the absence of a significant interaction, a significant difference in Method (M) would imply that the Neill-Hess and kick net samples produced different values of measurement endpoints and that the nature of the difference was common to all reaches.

Table 6.3-1 Generic ANOVA table to test for an effect from collection method.

Source	df	F
Reach (R)	2	$\frac{MSR}{MSE}$
Method (M)	1	$\frac{MSM}{MSE}$
Reach x Method (R x M)	1	$\frac{MSR \times M}{MSE}$
Error (E)	8	

6.3.3 Results

There was no significant difference in values of taxa richness between the CABIN kick net samples and the Neill-Hess cylinder samples (Table 6.3-2 and Figure 6.3-1). Generally, both types of samples collected between 20 and 50 taxa, depending on the reach. There were significant differences in diversity and evenness on the interaction term, implying that the differences in values between collection methods were depended on the reach. The Neill-Hess cylinder samples produced higher diversity and evenness in *test* reach STR-E1 and the kick sample produced higher diversity and evenness in *baseline* reach STR-E2, producing the significant interaction (Table 6.3-2). In all reaches, diversity and evenness were high using both types of sampling (> 0.8).

The most significant difference between the two sampling methods was in the values of percent EPT. The kick net samples consistently produced significantly higher percent EPT than the Neill-Hess cylinder samples across all reaches.

Kick net samples tended to produce lower relative abundance of some of the smaller organisms such as chironomids and naidid worms. For example, the Neill-Hess cylinder sample from *baseline* station FIR-E2 contained 45% chironomids while the kick net sample contained only 15% chironomids (Table 6.3-3). The Neill-Hess cylinder sample from the *test* reach MAR-E1 contained 34% naidid worms while the kick net sample contained only 6% naidid worms.

The kick net samples tended to contain larger organisms such as sphaeriid clams and gastropods. For example, the Neill-Hess cylinder sample from *baseline* reach FIR-E2 produced 1% bivalves (i.e., sphaeriid clams) while the kick sample produced 13% bivalves (Table 6.3-3). Clams were similarly more abundant in kick net samples from the *test* reach MAR-E2, *baseline* reach MAR-E3, and *baseline* reach STR-E2 compared to Neill-Hess cylinder samples.

Table 6.3-2 Results of ANOVA testing for differences on values of measurement endpoints for benthic invertebrate communities related to sampling method.

Variable	Source	SS	df	MS	F-Ratio	p-value
Richness	Station	0.031	2	0.015	3.855	0.067
	Method	0.001	1	0.001	0.262	0.623
	Error	0.032	8	0.004		
Simpsons	Station	0.048	2	0.024	28.193	0.001
	Method	0.002	1	0.002	2.253	0.184
	Station x Method	0.009	2	0.004	5.100	0.051
	Error	0.005	6	0.001		
Evenness	Station	0.046	2	0.023	23.703	0.001
	Method	0.002	1	0.002	2.396	0.173
	Station x Method	0.010	2	0.005	5.204	0.049
	Error	0.006	6	0.001		
EPT	Station	0.138	2	0.069	4.602	0.047
	Method	0.057	1	0.057	3.788	0.088
	Error	0.120	8	0.015		

Figure 6.3-1 Scatterplot of richness, diversity, evenness, and percent EPT in kick and Neill-Hess cylinder samples, 2010.

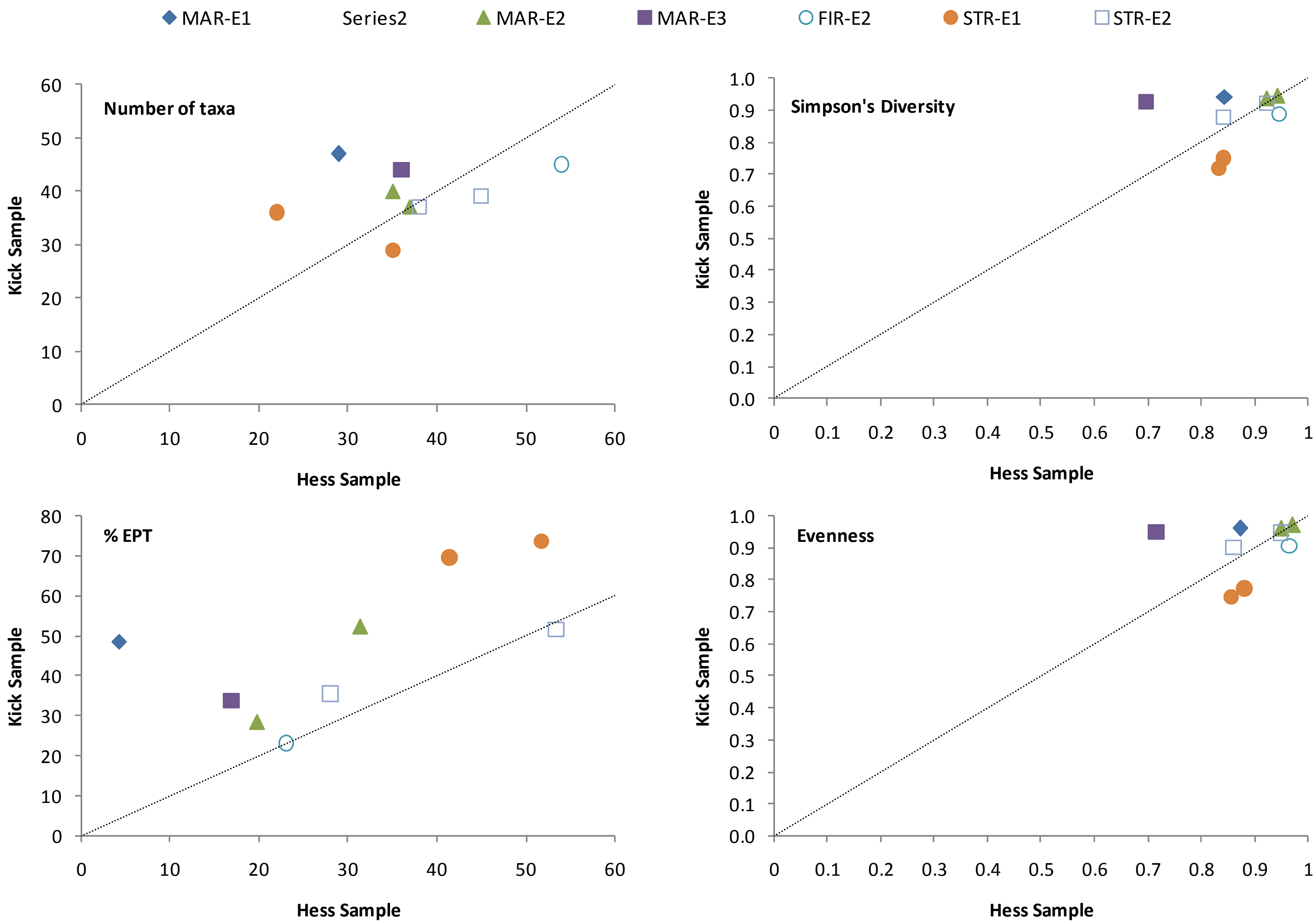


Table 6.3-3 Relative abundance of major benthic invertebrate groups in Neill-Hess cylinder and CABIN kick net samples in reaches in the RAMP FSA, 2010.

Taxon	FIR-E2-1		MAR-E1-1		MAR-E2-1		MAR-E2-10		MAR-E3-10		STR-E1-1		STR-E1-10		STR-E2-1		STR-E2-10	
	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick	Hess	Kick
Anisoptera	<1	<1		1		<1		<1	<1	1	<1	1	1	<1		<1	<1	
Athericidae												<1	<1		<1	5		<1
Bivalvia	1	13	<1	2	2	6	4	14	<1	11					1	4	3	10
Ceratopogonidae	1		<1	1			2	3	1	1	2	2	1				1	
Chironomidae	45	15	45	17	39	11	42	20	20	17	25	7	21	8	30	31	58	45
Coleoptera	2	2		1	<1	1	<1	1		1			<1				<1	<1
Empididae	<1			2		1		2	1	1	3	6	<1	1	6	2	3	5
Enchytraeidae	1		1	<1	3	1	5	5	1		4	1	1				1	
Ephemeroptera	14	15	3	28	25	28	8	5	6	18	40	64	51	70	15	23	14	18
Gastropoda	2	10		4	1	5	1	13	1	4		1	<1		1	1	<1	2
Hydracarina	6	1	1	17	14	14	9	9	5	13	21	5	15	4	5	1	2	1
Naididae	3	2	34	6	7	3	3	1	53	16	2	7	5	2	2	4		1
Nematoda	3		2		<1	3	3		1		<1		1				3	
Ostracoda	1	5			1	1		1										1
Plecoptera	3	4	<1	6	2	9	2	5	2	6	<1	3	<1	2	1	3	4	4
Simuliidae	8	27	<1			2	1		1			1	1	2	<1		2	
Tabanidae	<1		<1		<1			<1	<1							<1		
Tipulidae	<1	2				<1								<1	<1	<1	<1	<1
Trichoptera	7	5	1	14	5	15	10	18	8	10	1	3	<1	2	37	26	11	14
Tubificidae	3	1	13	1	<1		5	1		1				4				<1
Benthic Invertebrate Community Measurement Endpoints																		
Richness	54	47	29	45	35	40	37	37	36	44	22	36	35	29	38	37	45	39
Simpson's Diversity	0.95	0.94	0.84	0.89	0.92	0.94	0.94	0.95	0.70	0.93	0.84	0.75	0.83	0.72	0.92	0.92	0.84	0.88
Evenness	0.96	0.96	0.87	0.91	0.95	0.96	0.97	0.97	0.72	0.95	0.88	0.77	0.86	0.75	0.95	0.95	0.86	0.90
% EPT	23	48	4	23	31	52	20	28	17	34	41	70	52	74	53	51	28	36

6.3.4 Discussion and Recommendations

The CABIN protocol has become (since the inception of RAMP) an alternative methodology for collecting benthos from rivers. Similar procedures are also used in lakes (David *et al.* 1998) and have been used in "acid-sensitive" lakes in the oil sands region (Parsons *et al.* 2010). The traveling kick net method is potentially suitable for use in RAMP because the equipment is robust (necessary for the field component of RAMP) and because this type of gear can collect samples under virtually any habitat conditions with the single caveat that the sample must be collected within a wadeable environment.

Given there was uncertainty whether Neill-Hess cylinder samples could be collected in September 2010 and because there is always the possibility that high water levels observed in 2010 could happen again and inhibit sampling, it was important to quantify the degree of similarity between measurement endpoints from samples collected using the CABIN kick and sweep protocol and from samples collected using the RAMP-conventional Neill-Hess Cylinder.

The CABIN kick net samples generally produced similar number and type of taxa and values of diversity and evenness compared to the Neill-Hess cylinder samples. Kick net samples, however, tended to collect more of the larger organisms such as mayflies, stoneflies, caddisflies and clams, and fewer small organisms such as chironomids and naidid worms resulting in increased percent EPT using a kick net rather than a Neill-Hess cylinder.

The discrepancy in the size of organisms collected is partly due to the difference in mesh size between the two sampling techniques. The kick net samples were collected using a 400 µm mesh, as per the recommendations in the CABIN protocol (Reynoldson *et al.* 2004) while the Neill-Hess cylinder was built with a 220 µm mesh screen.

In future, and if any reach cannot be sampled using the conventional gear (i.e., Neill-Hess cylinder), the preliminary data and assessment in this study demonstrated that some values of measurement endpoints may be comparable between the two sampling techniques (i.e., diversity, evenness, and taxa richness). Similar observations were made by Borisko *et al.* (2007) in a comparison of rapid benthic invertebrate community collection methods in the Toronto area.

The differences observed in percent EPT between the two sampling techniques (i.e., the kick net samples produced significantly higher percent EPT [~ 40% higher] than those produced by the Neill-Hess cylinder would need to be accounted for if kick net sampling was used in future sampling events. Regardless of the difference in percent EPT between the two sampling techniques, the CABIN protocol provides a reliable alternative to the Neill-Hess cylinder method that should be employed during periods of high water levels to ensure that a benthic sample is collected every year.

6.4 PRELIMINARY ASSESSMENT OF EFFECT OF CLIMATE VARIABLES ON BENTHIC INVERTEBRATE COMMUNITY MEASUREMENT ENDPOINTS

6.4.1 Introduction

The RAMP Benthic Invertebrate Communities component has focused on lower reaches of major tributaries to assess the effects of focal projects on benthic invertebrate communities. The lower reaches of the major tributaries are anticipated to be the most likely to respond to oil sands developments because they are at the bottom of watersheds where oil sands developments are active. In addition, the tributaries are more likely than the mainstem Athabasca River to respond to any influence from oil sands developments for at least two reasons. First, the mainstem presents a shifting sand environment that generally contains more tolerant benthic taxa than does non-shifting sands, or gravel/cobble. Second, the mainstem carries a lot of water that will dilute inputs and other stressors associated with oil sands operations. In the context of regional conclusions, if there are no effects in the areas we most expect to see them, then it is unlikely that there will be large-scale effects in a regional context.

The assessment of the condition of benthic invertebrate communities of lower reaches of major tributaries is tiered as follows:

1. An evaluation of trends over time in the lower reaches. Time trends in lower reaches are compared with time trends in *baseline* reaches found in the same watershed and upstream of oil sands developments. The assessment of time trends typically involves the use of analysis of variance, judging the significance of the observed differences relative to the variations within time periods and within reaches.

2. Where and when a lower reach is demonstrated to have produced a significant change that is consistent with an oil sands developments, variations within that lower reach are then judged relative to a range of natural variability in measurement endpoints for benthic invertebrate communities in reaches of similar habitat type, for example, an erosional reach that produces a significant difference compared to an upstream *baseline* erosional reach is then compared to the variation among other *baseline* erosional reaches.

To determine the range of variation in erosional and depositional *baseline* reaches, the lower 5th and upper 95th percentiles were calculated from data for all years and all reaches that, are or have been, classified as *baseline*. This lumping of reaches for the purpose of generating a range of *baseline* variation assumes generally that the composition of the benthic invertebrate communities is going to be broadly similar and that the natural influence of factors such as geology, slope, and discharge are minimal (Imhoff *et al.* 1996, Stanfield and Kilgour 2006). In the event that these influences were not minimal, there is a concern that this approach has the potential to mask effects of oil sands developments by not taking into account other natural causes of variation. Further, it is difficult to understand to the extent possible the periodic effects that are consistent with oil sands developments but that might otherwise be caused by natural variations in climatic factors.

Some potential natural causes of variation have been previously explored by RAMP (2007, Appendix E) for factors such as bankfull river width, substrate texture, chlorophyll *a* densities (for erosional reaches), etc., which explained only <5% of the variation in measurement endpoints for benthic invertebrate communities. Therefore, those variables were not used to modify the range of variation for *baseline* reaches because it would result in a trivial reduction in the size of the range of variation while complicating the overall approach to analysis.

In the recent peer review of RAMP (AITF 2011), there were some concerns raised regarding the size of the range of variability for *baseline* reaches for measurement endpoints and that some of the variation may be related to climatic variables. In the RAMP 2008 and 2009 Technical Reports, the results highlighted cyclic variations in taxa richness and percent of the fauna as EPT taxa in both *baseline* and *test* river reaches (RAMP 2009a, 2010), but did not examine the association between those variations and other regional climatic variability. A good example of the large variations that have occurred in the RAMP FSA is percent EPT in the lower Steepbank River. This reach was first sampled in RAMP in 1998 when less than 50% of the fauna consisted of mayflies, stoneflies and caddisflies (i.e., EPT taxa). Since 1998, the percent of the fauna as EPT has decreased over time relatively consistently until 2008 when approximately 15% of the fauna was species of mayflies, stoneflies and caddisflies (RAMP 2009a). In 2009 and 2010, the percent of the fauna as EPT increased to upwards of 40 to 50% of the total fauna, similar to proportions when RAMP first sampled the lower Steepbank River. To date, there have been no explanations of the causes of those variations with the exception that there were some years when the trend in percent EPT was considered to be potentially due to oil sands developments (i.e., a decrease in organisms that are more sensitive to changes in their environment).

The objective of this study is to provide a preliminary analysis of the potential influences of climatic variables on variations in measurement endpoints for benthic invertebrate communities. Variables that are considered include mean air temperature during the open-water period and annual average discharge. Mean air temperature during the open-water period is considered the most likely to influence the hatching times and frequencies of insects such as chironomids, mayflies, stoneflies, and caddisflies, which are groups that are dominant in the benthic invertebrate communities of the Athabasca River and its tributaries. Mean annual discharge is considered likely to be related to discharge events that influence the benthic invertebrate communities. This study is not exhaustive in all variables that can be explored; however, it is expected that other scientists will continue to explore discharge and climatic variables and their influence on benthic invertebrate communities.

6.4.2 Methods

6.4.2.1 Data Collection

The data used in this assessment were from depositional and erosional river reaches in the RAMP FSA. The following measurement endpoints were calculated using data from 1998 to 2010:

- Abundance (total number of individuals/m^2);
- Taxon richness (number of distinct taxa);
- Simpson's Diversity Index;
- Evenness; and
- Percent EPT.

Average measurement endpoint values were calculated for each reach-year combination based on methods described in Section 3.2.3.1.

6.4.2.2 Air Temperature

Hourly air temperature data were obtained from the weather station 719320 (CYMM) located in Fort McMurray (latitude 56.65N, longitude -111.21W, altitude 369m). Average air temperature for the open-water period between May and October of each year was used from the available data records.

6.4.2.3 Discharge

Discharge data from the RAMP Climate and Hydrology Component database was used for locations provided in Table 6.4-1. Data were acquired from stations located furthest downstream on each river. Mean annual discharge was calculated for each river-year combination.

Table 6.4-1 Location and data from hydrology stations that were used in the study of the influence of discharge on measurement endpoints for benthic invertebrate communities.

Station Location	Station Name	Year
Athabasca River	S24	2001 to 2009
Beaver River	S39	2008, 2009
Calumet River	CR1/S16	CR1 (2001 to 2004)/S16 (2005 to 2009)
Christina River	S29	2002 to 2009
Clearwater River	S42	2009
Ells River	S14/S14A	S14 (2001 to 2007)/S14A (2008 to 2009)
Firebag River	S27	2002 to 2009
Fort Creek)	S12	2000 to 2009
Hangingstone River	S31	2002 to 2009
Jackpine Creek	S2	1998 to 2009
MacKay River	S26	2001 to 2009
Muskeg River	S7	1998 to 2009
Poplar Creek	S11	1998 to 2009
Steepbank River	S38	2009
Tar River	S15/S15A	S15 (2001 to 2006)/S15A (2007 to 2009)

6.4.2.4 Data Analysis

Analysis of covariance (ANCOVA) was used to test for differences in the relationship between measurement endpoints for benthic invertebrate communities and mean air temperature and mean annual discharge. In the full model of the ANCOVA, the predictors of benthic invertebrate community included Reach, Air Temperature (or Discharge), and the interaction term Reach x Air Temperature (or Reach x Discharge). The interaction term tested whether there were significantly different slopes of the relationship between the measurement endpoints and the climate variable (i.e., temperature and discharge) among reaches. The difference in slopes would imply that the influence of climate differed significantly among reaches. The objective was to determine if the influence of the climate variables was approximately similar among reaches, thus demonstrating a strong influence of climate in a regional context. The magnitude of the influence of air temperature and discharge was quantified using percent of variance explained.

6.4.3 Results and Discussion

Variations in measurement endpoints from depositional reaches were not related to variations in discharge or mean air temperature in the open-water period (Table 6.4-2, Figure 6.4-1, and Figure 6.4-2). However, total abundance in erosional reaches decreased with increasing mean annual discharge ($p<0.001$) (Figure 6.4-3). The relationship between discharge and total abundance explained 15% of the variation in total abundance. In some rivers, taxa richness and percent EPT in erosional reaches increased with increasing mean air temperature in the open-water period ($p=0.015$ and $p=0.021$, respectively) with temperature explaining 5% of the variation in taxa richness and percent EPT (Table 6.4-2, Figure 6.4-4).

Table 6.4-2 Results of analysis of covariance testing for the influence of discharge and mean air temperature on variations in measurement endpoints for benthic invertebrate communities.

Climate Variable	Measurement Endpoint	Erosional		Depositional	
		p-value	R^2	p-value	R^2
Discharge	Log Abundance	**<0.001**	**0.15**	0.428	0.01
	Log Richness	0.08	0.04	0.112	0.02
	Simpson's Diversity	0.87	0.00	0.236	0.01
	Evenness	0.73	0.00	0.379	0.01
	Log %EPT	0.01	0.00	0.685	0.00
Air Temperature	Log Abundance	0.445	0.01	0.790	0.00
	Log Richness	**0.015**	**0.05**	0.160	0.02
	Simpson's Diversity	0.227	0.02	0.934	0.00
	Evenness	0.094	0.04	0.670	0.00
	Log %EPT	**0.021**	**0.05**	0.101	0.02

Figure 6.4-1 Scatterplot of measurement endpoints for benthic invertebrate communities in depositional reaches in relation to the mean annual discharge.

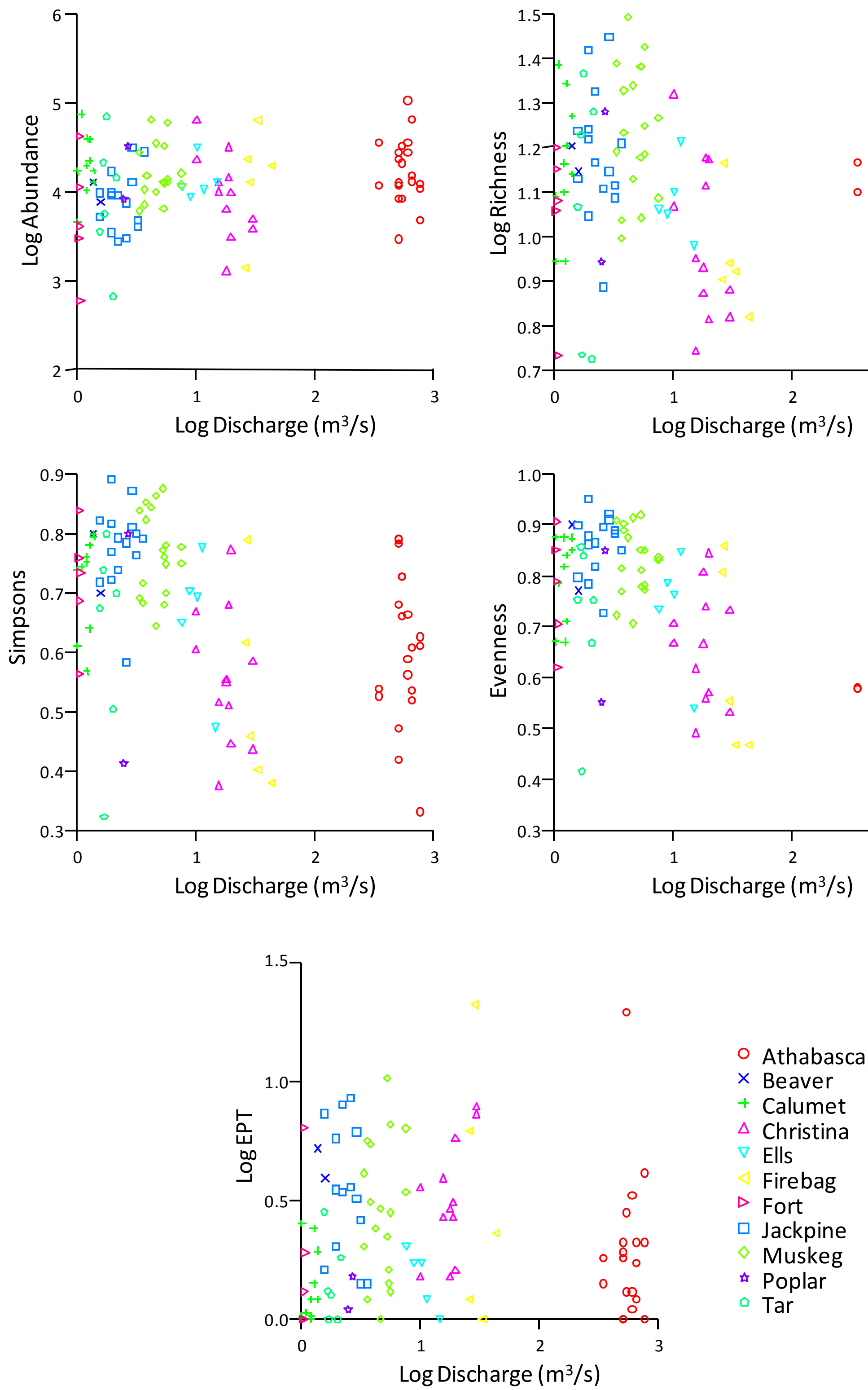


Figure 6.4-2 Scatterplot of measurement endpoints for benthic invertebrate communities in depositional reaches in relation to mean air temperature during the open-water period.

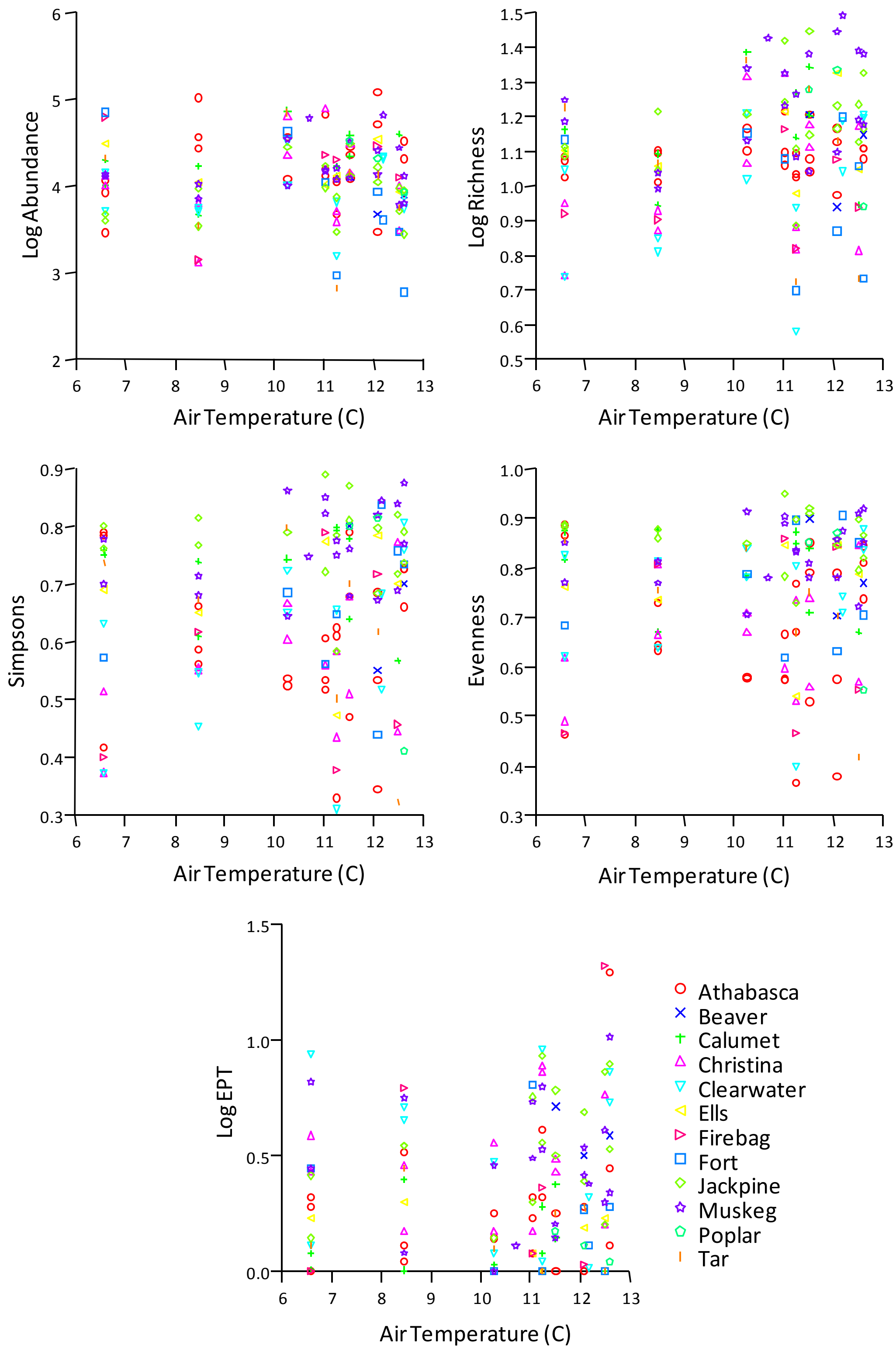


Figure 6.4-3 Scatterplot of measurement endpoints for benthic invertebrate communities in erosional reaches in relation to the mean annual discharge.

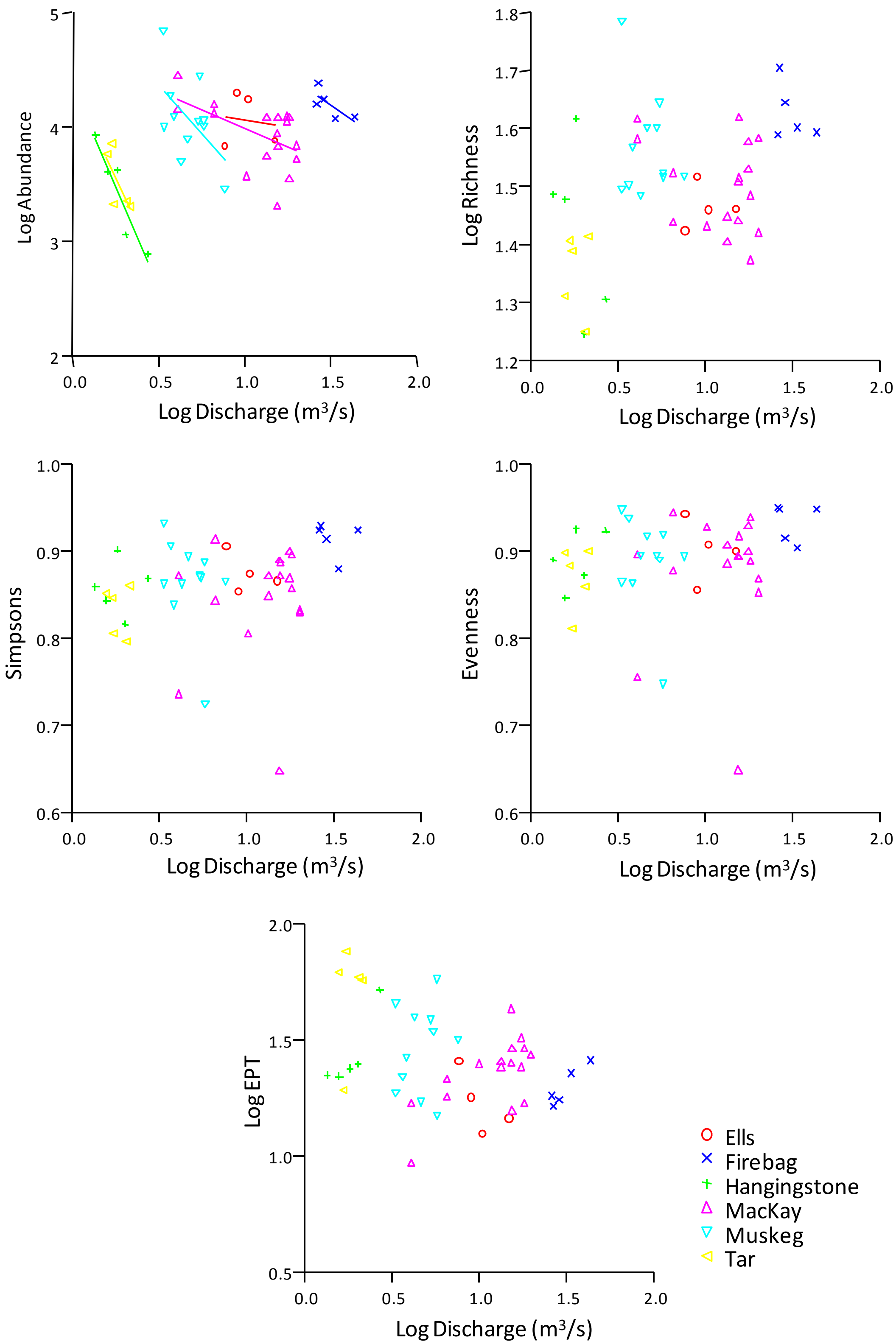
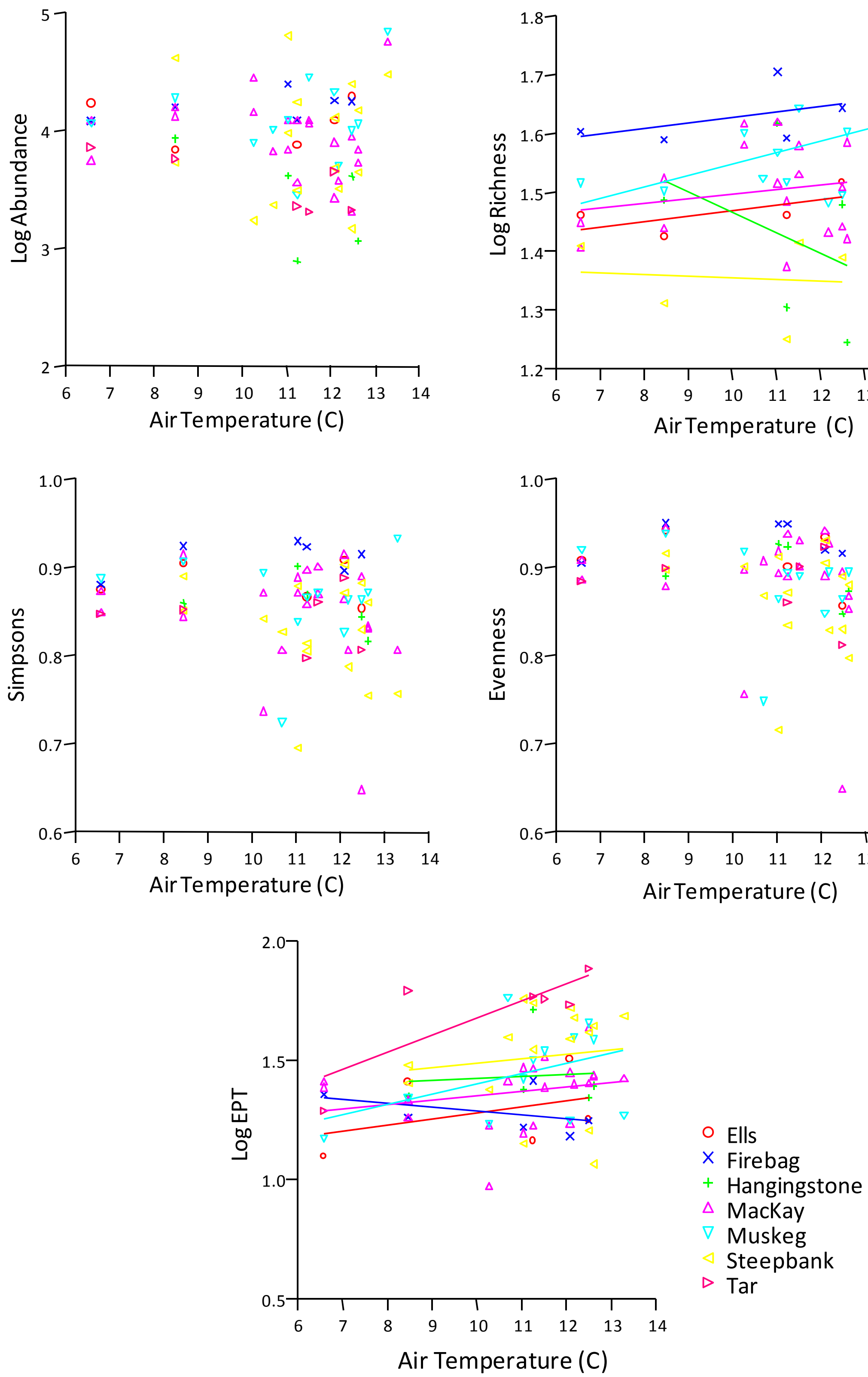


Figure 6.4-4 Scatterplot of measurement endpoints for benthic invertebrate communities in erosional reaches in relation to mean air temperature during the open-water period.



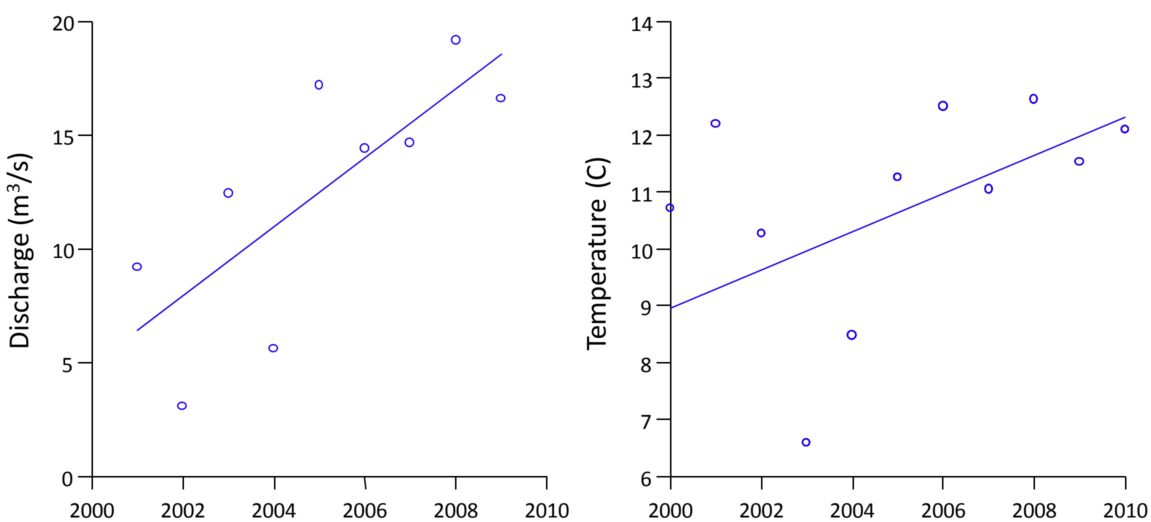
6.4.4 Discussion and Recommendations

The measurement endpoints for benthic invertebrate communities in depositional reaches do not appear to be influenced by climatic variability on a regional scale. The *baseline* range of variation, as calculated by RAMP can; therefore, be considered to be broadly applicable on a regional scale for depositional reaches.

The influence of mean annual discharge and the influence of mean air temperature during the open-water period should be taken into account for the baseline range of variation for taxa richness in erosional reaches. In addition, time trends observed for total abundance, taxa richness, or percent EPT should also consider the potential influence of variations in discharge (climate or operations related) and mean temperature during the open-water period.

Of the erosional *test* reaches sampled by RAMP, there were no significant time trends in abundance, taxa richness or percent EPT in the lower Muskeg River (*test* reach MUR-E1, see Section 5.2) or lower Steepbank River (*test* reach STR-E1, see Section 5.3). There was, however, a significant decreasing trend over time in abundance and an increasing trend over time in taxa richness and percent EPT in the lower MacKay River (*test* reach MAR-E1, see Section 5.5). These differences did not imply a change associated with oil sands developments because of the nature of the change was not negative. However the trends were consistent with increasing discharge and air temperature over time (Figure 6.4-5).

Figure 6.4-5 Scatterplot of mean annual discharge in the MacKay River and mean air temperature.



6.5 FISH ASSEMBLAGE MONITORING PILOT STUDY

6.5.1 Introduction

In an effort to harmonize the monitoring activities under RAMP, a fish assemblage monitoring (FAM) pilot study was initiated in 2009 and continued in 2010 at stations/reaches where the Water Quality, and Benthic Invertebrate Communities and Sediment Quality components conduct sampling. The objective of the fish assemblage monitoring program is to assess the health of fish populations in tributaries that are potentially influenced by oil sands activities similarly to monitoring objectives of other components in RAMP.

6.5.1.1 Study Design Considerations

In 2009, sampling of fish assemblages was conducted at 11 locations including the Beaver, Dunkirk, Horse, MacKay, Muskeg, Steepbank and Tar rivers and Jackpine and Poplar creeks (RAMP 2010). The 2009 analysis was primarily designed to evaluate the ability to assess fish assemblage metrics between *test* and *baseline* reaches following methods developed by 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 analyses also examined variations in measures of community composition including an Assemblage Tolerance Index (ATI) (Whittier *et al.* 2007a) multivariate ordination axis scores, and a modified Index of Biotic Integrity (IBI) (Karr 1981).

Given the limited number of fish species in the lower Athabasca region and the low abundance in small tributaries to the Athabasca River, the 2009 survey did not produce adequate sample sizes to compare the metrics established by the USEPA protocols. The USEPA protocols indicate that with adequate fishing effort, 30 times as many individual fish as the expected number of species should be captured to reduce the effect of rare species on the Index of Biotic Integrity (IBI) and other metric scores (Hughes and Peck 2008, Kanno *et al.* 2009, Dußling *et al.* 2004). These protocols were derived from USEPA fish assemblage studies in the northwestern US, where fish assemblages can contain upwards of 60 to 70 fish species per reach with a high abundance of each individual species. The rivers in this region are generally more productive because of higher water temperatures and higher nutrient loads.

The recommended reach length to be surveyed should be at least 40 times the wetted width with a minimum length of 150 m (Peck *et al.* 2006) and if that distance were to not yield the expected number of individuals, the distance should be increased or the fishing effort increased within a reach. The rationale supporting the requirement that the minimum length of a reach should be 150 m (or 40 x the wetted width) or that the total catch of individual fish should exceed 30 times the number of species is based on a presumed desire to document 95% of the species available in a river reach.

Taking into account this expected level of effort and assuming that there are 12 common fish species in the RAMP FSA (RAMP 2009b) that are expected at almost any reach, an adequate tributary sample should contain a minimum of 360 individuals; an adequate large river sample, with presence of large-bodied species, which are less frequent in smaller tributaries, should contain a minimum 480 individuals. In many of the smaller tributaries in the RAMP FSA, to achieve these sample sizes, the level of effort that would be required could not be completed in one day of sampling. Therefore, for the 2010 fish assemblage monitoring program, an alternative method was derived to determine the adequate level of fishing effort required to characterize the fish assemblage in a river reach.

6.5.1.2 Design and Objectives of the 2010 FAM Program

The recommended method to estimate sampling effort for benthic invertebrate community surveys under the Canadian Environmental Effects Monitoring (EEM) programs for metal mines and pulpmills has a fundamentally different approach, based on signal-to-noise ratios, and the desire to statistically "detect" differences in composition between reaches (Environment Canada 2010). For benthic invertebrate community surveys, individual samples (e.g., Neill-Hess cylinders, Ekman grabs, Ponar grabs, etc.) are collected within stations or sub-reach, with stations/sub-reaches considered to be a random sample, and the unit of replication. The variation among stations/sub-reaches (or replications) is then used to judge the significance of variations between or among reaches (i.e., *test* vs. *baseline*). Within the EEM program, it is considered important to know that the variation in estimates of measurement endpoint values is measured with minimal variance. Therefore, the EEM program dictate a level of sampling effort that would ensure that measurements endpoints within a station/sub-reach are measured to within ±20% of the true (but yet unknown) average value. The technical guidance document for the EEM program recommend that pilot studies be carried out to determine the required sampling effort to ensure that the within-reach variance of measurement endpoints is within ±20% of the true (but yet unknown) average value (Environment Canada 2010).

The 2010 RAMP fish assemblage monitoring survey was designed taking into account the EEM recommendation for pilot studies with the objective of determining the level of effort that would be required in order to estimate conventional (and ecologically fundamental) measurement endpoints for fish assemblages. The objective of this pilot study was to determine the number of sub-reaches that would be required in order to produce estimates of measurement endpoints that were within some acceptable level of precision (i.e., ± 20% of the average sub-reach value).

A secondary objective of this pilot study was to document differences in measurement endpoints of fish assemblages in reaches that have been sampled two years in a row (2009 and 2010) including *test* reach JAC-F1, *test* reach MUR-F1, and *test* reach STR-F1.

6.5.2 Field Methods

6.5.2.1 Fish Sampling and Handling

The methods used to develop a FAM 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 protocols outline the collection of physical habitat, fish, water and sediment chemistry, and benthic invertebrate variables.

The FAM pilot study was conducted from September 14 to September 19, 2010 to assess changes in the fish assemblage of rivers that may potentially be related to focal projects. The study included sampling at six reaches on tributaries of the Athabasca River within the RAMP FSA where Water Quality, Benthic Invertebrate Communities and Sediment Quality components conducted sampling in 2010 (Figure 6.5-1 and Table 6.5-1). Four of these reaches are designated as *test*: the lower Steepbank (STR-F1), lower Muskeg (MUR-F1), lower Ells River (ELR-F1) and lower Jackpine Creek (JAC-F1), while the remaining reaches are designated as *baseline*: the upper Ells River (ELR-F2) and upper Jackpine Creek (JAC-F2) (Table 6.5-1). Two of the reaches were in depositional habitat and four were in erosional habitat. Average wetted widths of reaches ranged from 6 to 28 m, with two reaches ≤ 10 m. The depositional reaches were all ≤10 m wide and the erosional reaches were all ≥20 m wide. The FAM pilot study included reaches of varying stream order and size, upstream and downstream of focal projects, across representative set of watercourses in the RAMP FSA.

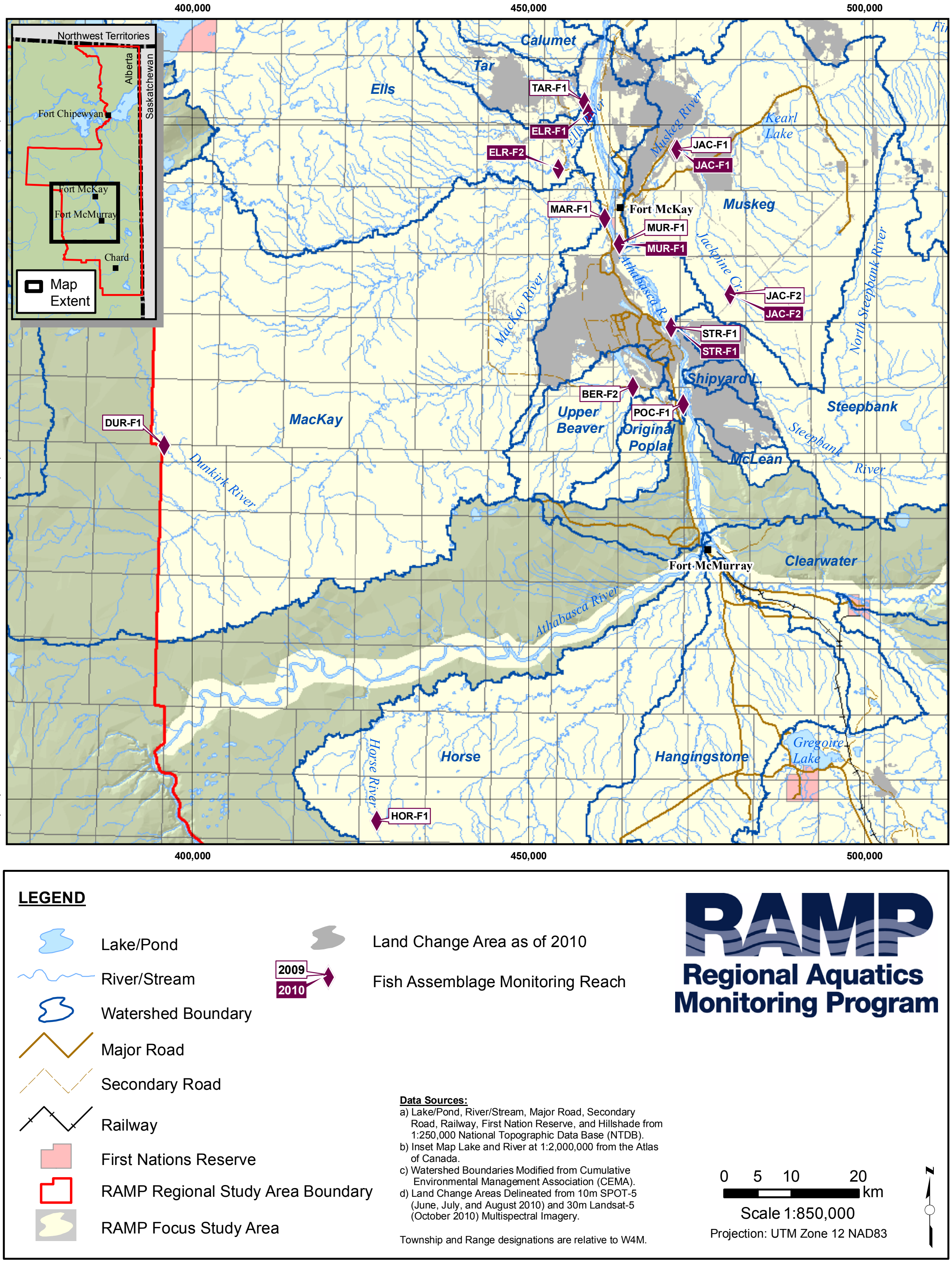
Five of the six reaches were separated into 10 sub-reaches to assess variance and error to determine the number of sub-reaches required to capture the expected fish assemblage within a reach. *Baseline* reach JAC-D2 was not separated into 10 sub-reaches because the depth made it difficult to wade continuously through the entire reach. The wadeable, near-shore area of each sub-reach was electrofished with intensities that varied between 4 and 19 seconds per lineal meter. The catch per sub-reach was standardized by the length of the sub-reach. The width of the electrofishing pass was approximately 2 to 3 m, or from the river bank to a point mid-river based on what the electrofisher operator could reach. Fish from each sub-reach were kept in a holding bucket until the completion of all fishing. For each sub-reach, captured fish were measured for length (± 0.01 mm) and weight (± 0.01 g) and an external assessment was conducted for general health.

Table 6.5-1 Location and designation of fish assemblage monitoring reaches, 2010.

Watershed	Reach	Habitat Type	Reach Designation	Water Quality Station/Benthic Invertebrate Reach	Effort (sec)	Reach Length (m)	Average Wetted Width (m)
Jackpine Creek	JAC-F1	despositional	*test*	JAC-1/JAC-D1	3,863	300	6
Jackpine Creek	JAC-F2*	despositional	*baseline*	JAC-2/JAC-D2	5,161	502	10
Ells River	ELR-F1	erosional	*test*	ELR-1/ELR-D1	4,694	500	23
Ells River	ELR-F2	erosional	*baseline*	ELR-2a/ELR-E2	3,959	500	25
Muskeg River	MUR-F1	erosional	*test*	MUR-1/MUR-E1	2,491	500	28
Steepbank River	STR-F1	erosional	*test*	STR-1/STR-E1	4,997	500	20

* Reach was not separated into subreaches.

Figure 6.5-1 Locations of fish assemblage monitoring reaches in the RAMP Focus Study Area, as part of a two year pilot study, 2009 to 2010.



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6.5.2.2 Fish Habitat Assessments

Habitat assessments were completed at three transects at the downstream, upstream and midpoints of each reach. 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 (Table 6.5-2);
- Wetted width (m);
- Maximum depth (m);
- Velocity and depth (m/sec) (at 25%, 50%, and 75% of the wetted width);
- Overhead and instream cover (%) (Table 6.5-3);
- Substrate (dominant and subdominant particle size) (Table 6.5-4);
- 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 were measured using a Hanna hand-held probe (temperature, conductivity, pH) and a LaMotte Winkler titration kit (dissolved oxygen) and collected at the upstream, middle, and downstream transects of each reach.

Table 6.5-2 Habitat type and code for the fish assemblage monitoring pilot study (adapted from Peck *et al.* 2006).

Habitat Type (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 6.5-3 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 6.5-4 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 (1000-4000 mm) - metre stick to a car
SB	small boulder (250-1000 mm) - basketball to a metre stick
CB	cobble (64-250 mm) - tennis ball to basketball
GC	coarse gravel (16-64 mm) - marble to tennis ball
GF	fine gravel (2-16 mm) - 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

6.5.3 Analytical Approach

6.5.3.1 Measurement Endpoints

Several conventional measurement endpoints of fish assemblage composition were calculated using the fish data:

- Total Abundance – the total number of fish caught in the reach, divided by the lineal length of the reach (# of fish/m);
- Richness (S) – the total number of fish species collected per reach. Higher richness values are typically used to infer a "healthier" fish assemblage;
- Diversity – this metric was computed for each reach following the calculation for Simpson's Diversity (D), calculated as:

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

  p_i is the proportion of the total abundance accounted for by species i

Higher diversity values are typically used to infer a "healthier" fish assemblage;

- Evenness – this metric was computed for each reach following the calculation for evenness (E) as per the EEM guidance documents (Environment Canada 2005), calculated as:

$$E = \frac{1}{\frac{\sum (p_i)^2}{S}}$$

With this index, lower values imply that the fish assemblage is more evenly distributed and healthier, and not dominated by one or a few species; and

- Assemblage Tolerance Index (ATI) - The Assemblage Tolerance Index was developed by Whittier *et al.* (2007a) for stream and river fish assemblages in the western United States to quantify a species' tolerance to an overall human disturbance gradient (Table 6.5-5). For species captured in the RAMP FSA but not assessed by Whittier *et al.* (2007a), a number was assigned based on species similarity to those with calculated values, as per RAMP (2010). With this index, lower tolerance values imply a species that is more sensitive to disturbance.

Table 6.5-5 Tolerance values for fish collected during the 2009 to 2010 fish assemblage monitoring surveys (adapted from Whittier *et al.* 2007a).

Common Name	Species Code	Tolerance Value
Arctic grayling	ARGR	2.0
brook stickleback*	BRST	9.4
burbot	BURB	2.0[1]
finescale dace*	FNDC	7.0
fathead minnow*	FTMN	8.3
lake chub*	LKCH	5.5
longnose dace*	LNDC	6.2
longnose sucker*	LNSC	4.6
northern redbelly dace*	NRDC	7.0[1]
northern pike	NRPK	7.8
pearl dace*	PRDC	6.7
slimy sculpin*	SLSC	3.0[1]
spoonhead sculpin	SPSC	3.0[1]
spottail shiner*	SPSH	7.7
trout-perch*	TRPR	8.4
walleye	WALL	8.7
white sucker*	WHSC	7.6
yellow perch	YLPR	7.4

* Commonly caught fish species of Athabasca River tributaries in the Alberta oil sands region.

[1] Judgment-based score from value for similar species.

6.5.3.2 Precision

The number of sub-reaches required to obtain estimates of measurement endpoints that are within ± 20% of the reach mean was calculated as (from Elliott 1977):

$$n = \frac{s^2}{D^2 \overline{X}^2}$$

Where,

s is the within-reach standard deviation;

$\overline{X}$ is the reach-average index value; and

D is the proposed required precision, here 20% (or D=0.2).

6.5.4 Results

6.5.4.1 Fish Count and Species Composition

Table 6.5-1 provides a summary of the length and width of a watercourse that was sampled at each reach. A total of 12 fish species were collected during the FAM pilot study in 2010, compared to 16 species captured in 2009, although more reaches were sampled in 2009 than in 2010. Fish species richness per reach ranged from five (*baseline* reach JAC-F2) to ten (*test* reach MUR-F1) and number of individuals captured ranged from 64 (*baseline* reach JAC-F2) to 317 (*baseline* reach ELR-F2) (Table 6.5-6). An unknown sucker species was collected at *test* reach ELR-F1 and was; therefore, not included in the total species count. There was no clear pattern in the number of fish captured and number of species between *test* and *baseline* reaches but there was generally higher number of fish captured at erosional reaches compared to depositional reaches.

Table 6.5-6 Number of fish captured by species at each reach for the FAM pilot study, 2010.

Species	Reach					
	JAC-F1 Depositional	JAC-F2 Depositional	ELR-F1 Depositional	ELR-F2 Erosional	MUR-F1 Erosional	STR-F1 Erosional
brook stickleback	19	32	-	-	6	-
finescale dace	75	12	36	161	26	8
lake chub	-	10	-	-	8	-
longnose dace	-	-	4	11	20	63
longnose sucker	3	-	-	13	10	-
northern pike	1	-	-	-	-	-
pearl dace	21	9	49	82	58	64
slimy sculpin	23	-	-	-	19	60
spoonhead sculpin	-	-	-	-	4	3
trout-perch	9	-	1	4	-	7
white sucker	16	1	13	46	5	4
yellow perch	-	-	15	-	1	1
unknown sucker	-	-	1*	-	-	-
Total Fish Captured	**167**	**64**	**118**	**317**	**157**	**210**
Total No. Species	**8**	**5**	**6**	**6**	**10**	**8**

* not included in total species count

6.5.4.2 Temporal Trends

For *test* reach JAC-F1, *test* reach MUR-F1 and *test* reach STR-F1, where sampling was conducted in 2009 and 2010, differences in values of measurement endpoints are presented in Figure 6.5-2 to Figure 6.5-4. Annual within-reach variations of measurement endpoints for fish assemblages in Jackpine Creek, Muskeg River and Steepbank River could not be determined because reaches were not divided into sub-reaches in 2009. The number of fish captured was generally higher in 2010 than 2009 in all three reaches. In 2010, the abundance varied between 0.2 fish per metre in *test* reach MUR-F1 to 0.4 fish per metre in *test* reach JAC-F1 and *test* reach STR-F1 (Figure 6.5-4).

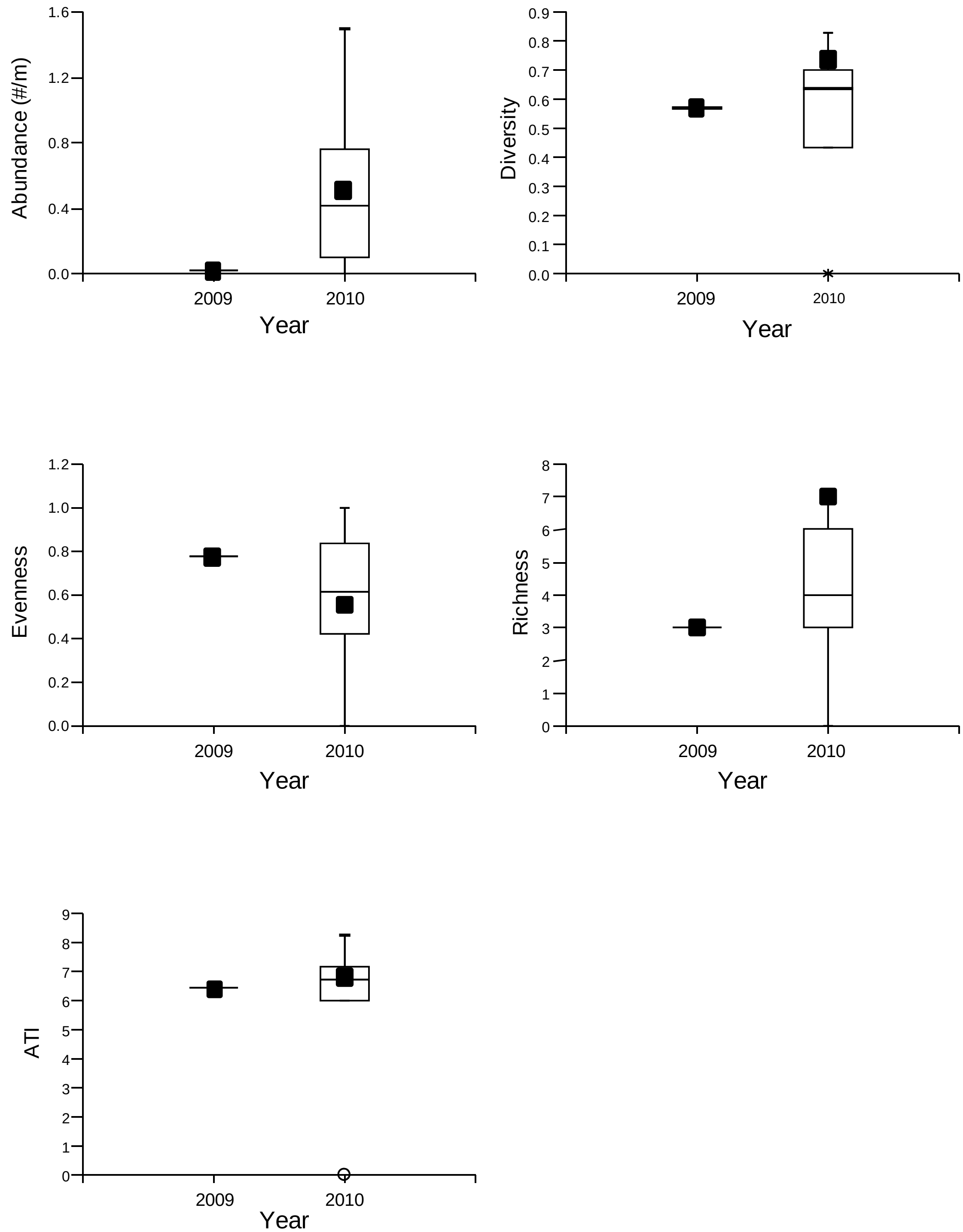
Test reach MUR-F1 produced higher ATI values in 2010 (>6) than in 2009 (<4) implying that the fish assemblage was dominated by more tolerant species in 2010. The Muskeg River fish assemblage was dominated numerically in 2009 by slimy sculpin (74% of the total catch), a species that is considered quite sensitive (ATI value of 3); however, the relative abundance of slimy sculpin was reduced to approximately 12% in 2010 (Table 6.5-7). Pearl dace, with an ATI of 6.7, was not found in the Muskeg River in 2009, and was the most numerically dominant species (38% of the total catch) in 2010. The reduced relative abundance of slimy sculpin and increased relative abundance of pearl dace in 2010 contributed to the higher ATI value in 2010. Continued monitoring at *test* reach MUR-F1 will confirm the stability of the temporal change in the fish assemblage.

Test reach STR-F1 produced an ATI of approximately 6.5 in 2009, while values varied between about 4.5 and 6.5 between sub-reaches in 2010. The Steepbank River fish community was dominated numerically in 2009 by northern redbelly dace (48%), a species which was absent from the catch in 2010. Longsnose dace, pearl dace and slimy sculpin were sub-dominant numerically in the Steepbank River fish assemblage in 2010. The reduction in the ATI value from 2009 to 2010 was partially due to the loss of northern redbelly dace (ATI value of 7) in 2010, and the increase in relative abundance of slimy sculpin (ATI value of 3).

6.5.4.3 Spatial Comparisons for Within-Reach Variation

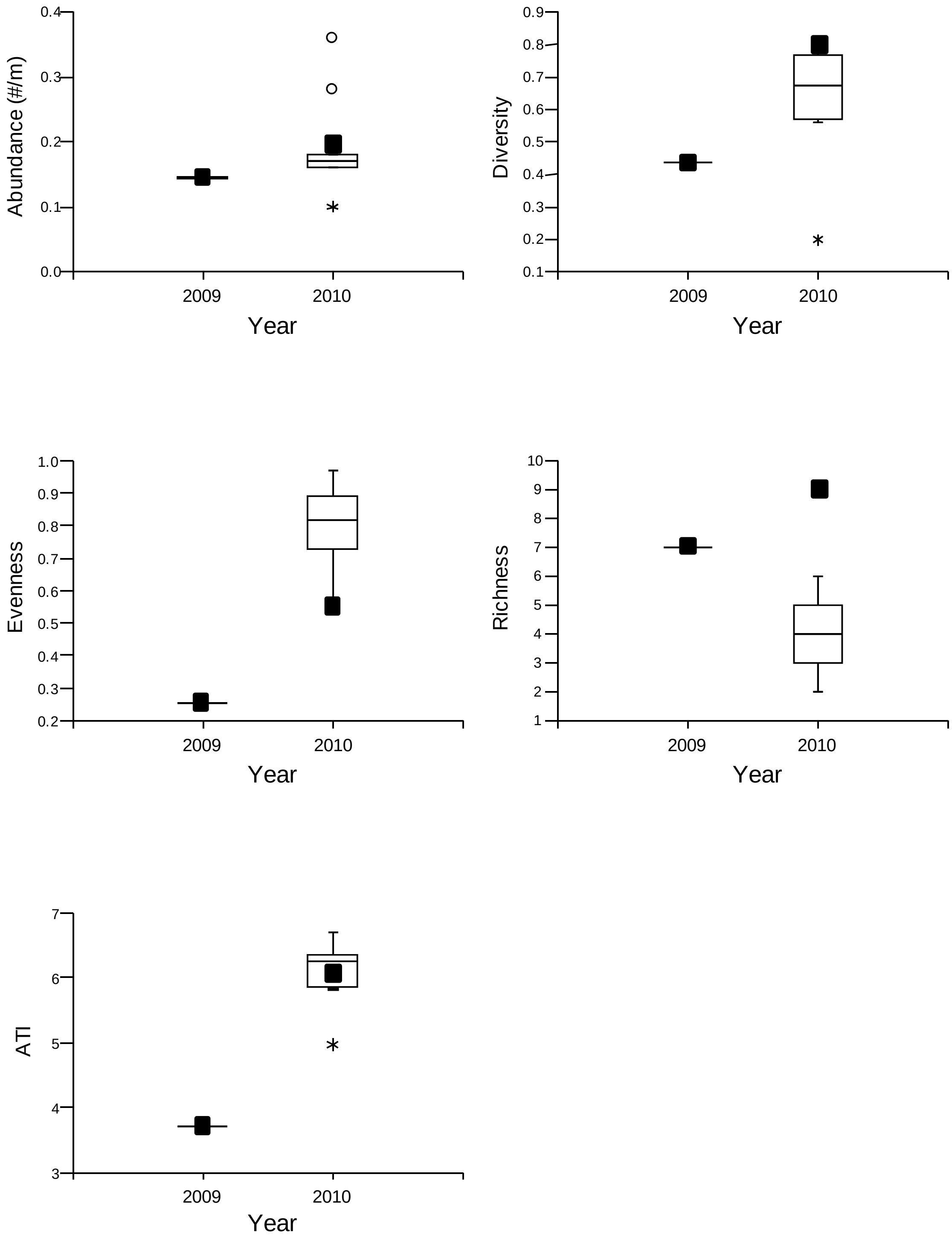
The variation in measurement endpoints across sub-reaches within each reach are provided in Table 6.5-8. Total abundance was the most variable measurement endpoint (within a reach) in 2010; the coefficient of variation (CV) for catch per metre varied between 42 and 99% with greater variability in depositional reaches than erosional reaches (Table 6.5-8). The Assemblage Tolerance Index (ATI) was the most precise measurement endpoint with the coefficient of variation between 3 and 54% with no clear pattern in variability between erosional and depositional reaches (Table 6.5-8).

Figure 6.5-2 Within-reach variation in values of measurement endpoints for fish assemblages in *test* reach JAC-F1, 2009 and 2010.



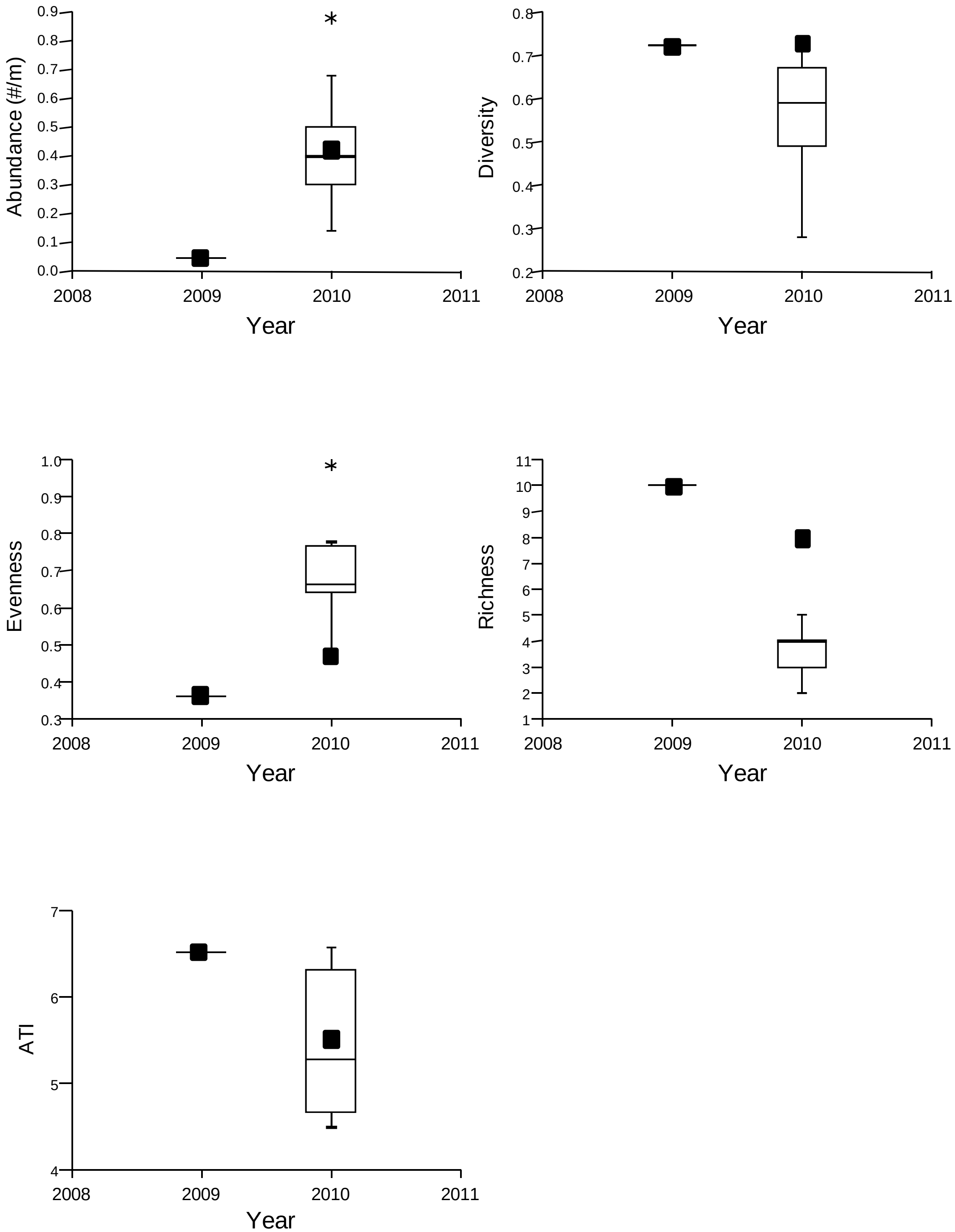
Note: Variations among sub-reaches in 2010 are illustrated using box plots. Black squares denote reach-wide means in 2009 and 2010.

Figure 6.5-3 Within-reach variation in values of measurement endpoints for fish assemblages in *test* reach MUR-F1, 2009 and 2010.



Note: Variations among sub-reaches in 2010 are illustrated using box plots. Black squares denote reach-wide means in 2009 and 2010.

Figure 6.5-4 Within-reach variation in values of measurement endpoints for fish assemblages in *test* reach STR-F1, 2009 and 2010.



Note: Variations among sub-reaches in 2010 are illustrated using box plots. Black squares denote reach-wide means in 2009 and 2010.

Table 6.5-7 Percent of total catch of each fish species in three reaches with two years of data, 2009 to 2010.

Common Name	Code	Tolerance Value	Jackpine Creek *Test* reach JAC-F1		Muskeg River *Test* reach MUR-F1		Steepbank River *Test* reach STR-F1	
			2009	2010	2009	2010	2009	2010
Arctic grayling	ARGR	2.0	0	0	0	0	0	0
brook stickleback	BRST	9.4	0	12.0	5.2	5.4	0	0
burbot	BURB	2.0	0	0	1.7	0	0	0
finescale dace	FNDC	7.0	0	44.5	0	16.1	0	3.8
fathead minnow	FTMN	8.3	0	0	0	0	0	0
lake chub	LKCH	5.5	14.3	0	6.9	8.6	6.1	0
longnose dace	LNDC	6.2	0	0	0	10.8	3.0	30.0
longnose sucker	LNSC	4.6	28.6	1.8	8.6	4.3	6.1	0
northern redbelly dace	NRDC	7.0	0	0	0	0	48.5	0
northern pike	NRPK	7.8	0	1	0	0	0	0
pearl dace	PRDC	6.7	0	12.6	0	37.6	6.1	30.5
slimy sculpin	SLSC	3.0	0	13.5	74.1	11.8	6.1	28.6
spoonhead sculpin	SPSC	3.0	0	0	1.7	3.2	0	1
spottail shiner	SPSH	7.7	0	0	0	0	0	0
sucker unidentified	-	7.6	0	0	1.7	0	0	0
trout perch	TRPR	8.4	0	5.3	0	0	3.0	3.3
unknown	UNK	-	0	0	0	0	15.2	0
walleye	WALL	8.7	0	0	0	0	3.0	0
white sucker	WHSC	7.6	57.1	9.4	0	2.2	3.0	1.9
yellow perch	YLPR	7.4	0	0	0	0	0	<1
Total Number of Species			**3**	**7**	**7**	**9**	**10**	**8**

Table 6.5-8 Coefficient of variation for measurement endpoints for FAM reaches, 2010.

Reach		Coefficient of Variation (%)				
		Abundance	Richness	Diversity	Evenness	ATI
ELR-F1	Depositional	68	34	20	19	3
ELR-F2	Erosional	43	19	20	26	3
JAC-F1	Depositional	99	61	56	62	54
MUR-F1	Erosional	42	33	27	17	8
STR-F1	Erosional	54	26	23	21	15

Note: JAC-F2 was not included because fishing effort was not separated into sub-reaches at this reach.

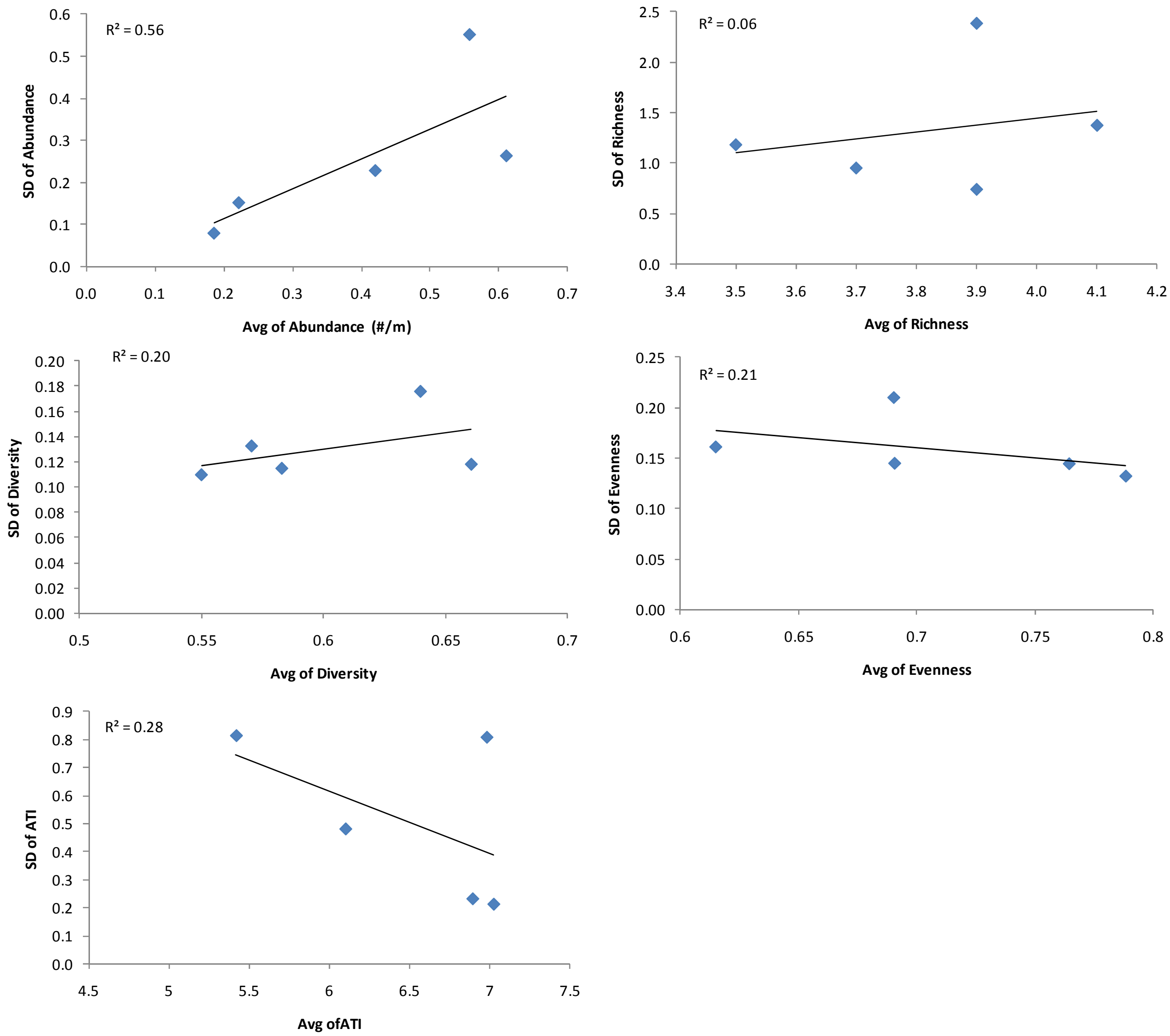
6.5.4.4 Sample Size Requirements for Fish Assemblage Monitoring

The within-reach variation for each measurement endpoint across all reaches is provided in Table 6.5-9. The variance (standard deviation) in abundance, richness and diversity increased with increasing reach average and variance in evenness and ATI decreased with increasing reach average (Figure 6.5-5). Given the differing trends in variability across measurement endpoints, sample size requirements were calculated for the maximum and minimum measurement endpoint values (Table 6.5-9). The number of sub-reaches that would be needed to produce measurement endpoint values that were within ± 20% of the true reach average varied between one and 12, depending on the measurement endpoint (Table 6.5-9). Total abundance was the most variable measurement endpoint, requiring upwards of 12 sub-reaches to be sampled in reaches where abundance is high (0.6 fish per metre), or as few as seven sub-reaches when abundance was lower (0.2 fish per metre). ATI was the most precise measurement endpoint requiring only a single sub-reach to estimate the sub-reach mean. The precision requirement (±20% of the true average of sub-reaches) was met with four sub-reaches for species richness, three sub-reaches for evenness and two sub-reaches for diversity.

Table 6.5-9 Sample size of sub-reaches required for measurement endpoints for fish assemblages to obtain 20% of the true sub-reach average.

Community Index	Minimum/ Maximum Value	Standard Deviation (SD)	Sample Size (n)
Total Abundance (# fish per m)	0.2	0.1	7
	0.6	0.4	12
Richness	3.5	1.2	3
	4.1	1.5	4
Simpson's Diversity	0.55	0.115	2
	0.65	0.140	2
Evenness	0.61	0.175	3
	0.80	0.150	2
Assemblage Tolerance Index (ATI)	5.6	0.75	1
	7.0	0.40	1

Figure 6.5-5 Scatterplot of variance (standard deviation) in relation to average values of measurement endpoints for all FAM sampling reaches, 2010.



Note: each point represents a sampling reach.

6.5.5 Habitat Assessments

Habitat data has been collected in both years of the pilot study and supporting information from the Water Quality and Benthic Invertebrate Communities components is available for further comparison between reaches. Given the objective of the pilot study was to determine if measurement endpoints could be developed to look at differences in fish assemblages between reaches and across years, the supporting data were not evaluated in 2010. The supporting data is primarily collected so that if a change was observed, a more thorough analysis could be conducted by interpreting all environmental characteristics of a reach.

6.5.6 Historical Data

Historical data from the FWMIS (Fisheries and Wildlife Management Information System) database have been collected from various sources to identify the species composition in the vicinity of the fish assemblage monitoring reaches. Table 6.5-10 provides catch per unit effort (a measure of relative abundance) for species captured in other studies in the vicinity of the FAM reaches (i.e., within 500 m of the reach) compared to CPUE of fish species captured in 2009 and 2010 in the RAMP FAM pilot study. Species richness and presence of species is generally the same or higher in 2009 and 2010 compared to previous sampling years at the same location. Data available from historical years can provide a guide of the type of assemblage that should be present in each reach, although keeping in mind that sampling are conducted differently across studies with differing objectives.

Table 6.5-10 CPUE of species captured within and in the vicinity of RAMP FAM reaches (within 500 m), 1999 to 2010.

Watercourse	Reach	Year	No. Species	Brook stickleback	Burbot	Finescale dace	Longnose sucker	Lake chub	Longnose dace	Northern pike	Pearl dace	Slimy sculpin	Spoonhead sculpin	Trout-perch	Walleye	White sucker	Yellow perch
Steepbank River	STR-F1	1999	7	-	0.070	-	0.349	0.233	0.581	-	1.628	1.372	-	1.279	-	-	-
		2000	4	-	-	-	-	0.577	2.309	-	-	4.906	2.597	-	-	-	-
		2004	2	-	-	-	-	-	-	-	-	1.709	1.352	-	-	-	-
		2009	10	-	-	-	0.055	0.055	0.027	-	0.055	0.055	-	0.027	0.027	0.027	-
		2010	8	-	-	0.202	-	-	1.591	-	1.617	1.516	0.076	0.177	-	0.101	0.025
Muskeg River	MUR-F1	1999	4	-	0.097	-	0.645	-	-	-	1.290	1.451	-	-	-	-	-
		2000	4	-	-	-	-	0.833	2.917	-	0.833	15.833	-	-	-	-	-
		2004	2	-	-	-	-	-	-	-	-	0.066	2.831	-	-	-	-
		2009	7	0.146	0.049	-	0.244	0.195	-	-	-	2.097	0.049	-	-	-	-
		2010	10	0.130	-	0.562	0.216	0.173	0.434	-	1.254	0.411	0.087	-	-	0.108	0.022
Jackpine Creek	JAC-F1	1997	8	-	-	-	0.062	0.326	0.139	0.062	0.062	-	0.278	-	0.062	0.685	-
		2000	1	-	-	-	1.379	-	-	-	-	-	-	-	-	-	-
		2009	3	-	-	-	0.090	0.045	-	-	-	-	-	-	-	0.180	-
		2010	8	0.492	-	1.941	0.078	-	-	0.026	0.543	0.595	-	0.233	-	0.414	-
Ells River	ELR-F2	2002	2	-	-	-	-	1.513	0.757	-	-	-	-	-	-	-	-
		2010	5	-	-	4.041	0.328	-	-	-	2.071	-	-	0.101	-	1.162	-

6.5.7 Discussion and Recommendations

The fish assemblage pilot study in 2010 demonstrated that generally, the collection of fish from four sub-reaches would adequately characterize the average sub-reach measurement endpoint values. Total abundance of fish per lineal metre was the most variable measurement endpoint and would require up to 12 sub-reaches in order to produce estimates that were within ±20% of the true mean of sub-reach value. The assemblage tolerance index (ATI) was the most precise index, requiring data from a single sub-reach to achieve the same level of precision.

The measurement endpoint that explains tolerance of species is generally less variable than those that describe abundance or richness because of redundancies among taxa. Northern redbelly dace and finescale dace, for example, are similar species, as are slimy sculpin and spoonhead sculpin. These species may vary in abundance from time to time, and may replace each other, or co-exist. Abundance will; therefore, be variable, while the niches that they occupy will remain occupied by similar species. The result is that generally, the average taxonomic tolerance is generally more stable than the actual count of fish. Measurement endpoints such as ATI are; therefore, excellent measures that can be used for the detection of meaningful trends in taxonomic composition. If the required sample size is based on the requirement to obtain precision in the ATI value, then it is adequate to conclude that a single sub-reach with a catch of approximately 50 fish would be adequate for future monitoring of oil sands development.

The influence of sample size on estimates of species richness, diversity and evenness is that shorter reaches produced fewer species, lower diversity and higher evenness. Thus, any comparison among or within reaches must consider the length of the reach for these key conventional metrics, whereas for measurement endpoints such as abundance and assemblage tolerance index (ATI), a standardized reach length is not as important as there was little variability with reach length.

The measurement endpoints used to make assessments for the Fish Assemblage Monitoring pilot study is not a complete list and more can be evaluated, if this methodology continues to be used as a monitoring tool.

The two year pilot FAM study has helped to determine the level of fishing effort and catch required to provide statistically robust measurement endpoints that can be used to assess potential changes due to oil sands development. Measurement endpoints have been developed based on Canadian EEM protocols, which can be compared across time and space, if the FAM program continues as a monitoring tool under RAMP.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The 2010 RAMP monitoring program results have been discussed in detail in Section 5. This section provides a summary of results for each component of RAMP. Based on results presented in Section 5, Table 7.1-2 provides a summary of the 2010 RAMP monitoring program results by watershed and by component. In addition, 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. Given that the sampling program is designed one year in advance, 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.

7.1 CLIMATE AND HYDROLOGY

7.1.1 Summary of 2010 Results

Hydrologic changes in the RAMP FSA in the 2010 water year (WY) were assessed as **Negligible-Low** in all watersheds with the exception of the Muskeg River, Tar River, Poplar Creek, Mills Creek and Fort Creek watersheds in which at least one measurement endpoint was classified as **Moderate** or **High** (Table 7.1-1). In the 2010 WY, the activities of focal projects and other oil sands developments contributing to hydrologic changes in the RAMP FSA, in order of decreasing importance, were:

- industrial water withdrawals, releases, and diversions;
- closed-circuited land area resulting in a loss of flow to natural watercourses that would have occurred in the absence of focal projects and other oil sands developments; and
- land area that is cleared and not closed-circuited thereby contributing to increased flows to natural watercourses that would not have occurred in the absence of focal projects and other oil sands developments.

The cumulative hydrologic effects of focal projects with respect to the Athabasca River mainstem were evaluated by comparing the observed *test* hydrograph and estimated *baseline* hydrograph for Station S24, Athabasca River below Eymundson Creek. Relative changes from *baseline* to *test* conditions for all four measurement endpoints (i.e., the mean open-water season discharge, mean winter discharge, annual maximum daily discharge, and open-water season minimum daily discharge) were classified as **Negligible-Low** at Station S24 for the 2010 WY (Table 7.1-1). For each of these measurement endpoints, the observed *test* hydrograph value was lower than the estimated *baseline* hydrograph value that would have occurred in the absence of focal projects. The calculated percentage change from *baseline* to *test* ranged from -0.4% (annual maximum daily discharge) to -1.7% (mean winter discharge) (Figure 7.1-1). These values were almost identical when comparing the cumulative effects of focal projects alone with the combined effects of all regional oil sands developments (focal project plus non-focal project oil sands developments). There is no trend from 2004 to 2010 in changes from *baseline* to *test* in the four measurement endpoints (Figure 7.1-1).

Table 7.1-1 Summary assessment of the RAMP 2010 WY hydrologic monitoring results.

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 (+)	Negligible-Low	High (+)
Steepbank River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Tar River	High (-)	*not measured*	High (-)	High (-)
MacKay River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Calumet River	Negligible-Low	*not measured*	Negligible-Low	Negligible-Low
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*	*not measured*	*not measured*

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%.

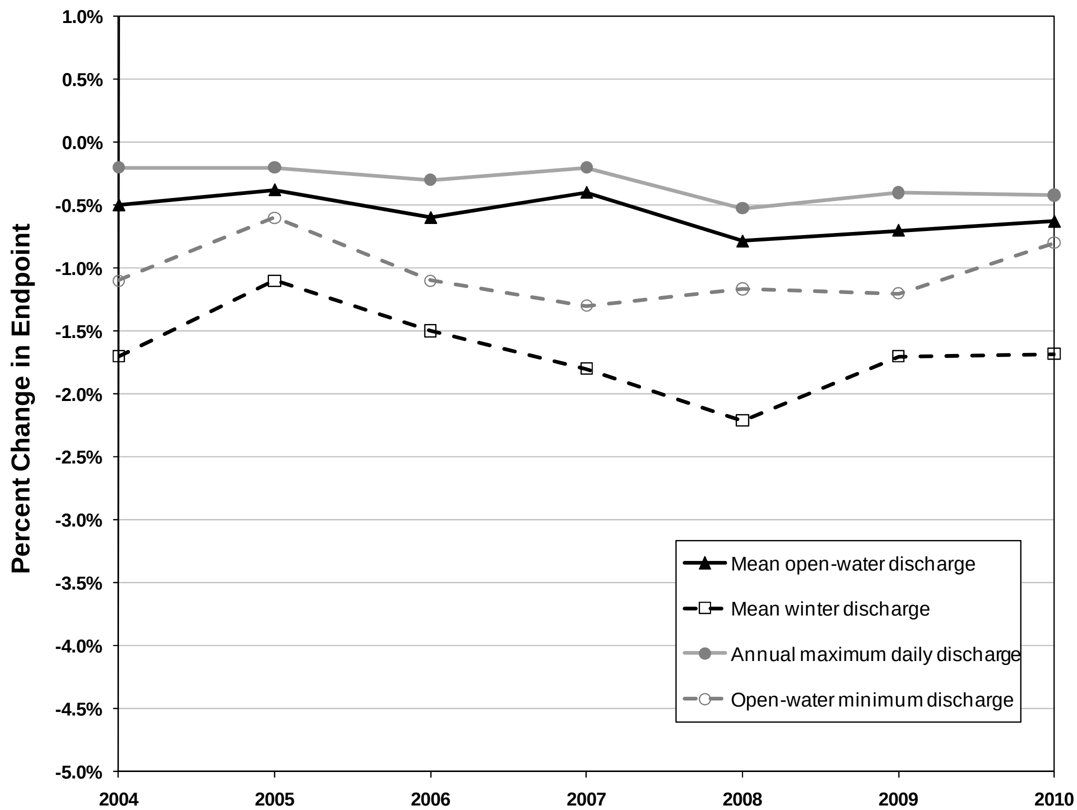
"not measured" means hydrologic information was not obtained for times of year for which the measurement endpoint is applicable.

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).

7.1.2 Study Design Considerations

Oil sands development is continuing to expand within the RAMP FSA. Station S24, Athabasca River below Eymundson Creek measures flows on the Athabasca River downstream of all oil sands development with the exception of oil sands developments occurring in the Firebag River watershed. The confluence of the Firebag and Athabasca River is below the location of Station S24. For the purposes of this report, any focal project activities reported in the Firebag River watershed have been conservatively assessed as potential effects at the upstream Station S24. The RAMP Technical Program Committee have concluded that monitoring on the Athabasca River downstream of development, including downstream of development within the Firebag watershed, will support monitoring goals. Following the recommendation in the 2009 Technical Report (RAMP 2010), the recommendations of the RAMP Technical Program Committee, and reconnaissance work conducted in 2010, a hydrometric monitoring station will be installed further downstream in 2011 to monitor for potentials effects of all oil sands developments. In addition to a new location on the Athabasca River, a station will also be installed at the mouth of the Christina River and at additional locations within the RAMP FSA.

Figure 7.1-1 Changes in values of hydrologic measurement endpoints in the 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.

It is further recommended that the RAMP Climate and Hydrology monitoring network continue to expand to support provision of *baseline* and *test* hydrometric information and regional climate data. Continued monitoring at existing climate and hydrometric stations is also recommended to support enhanced record length and data availability.

As recommended in RAMP (2010), a water year convention was applied to the 2010 analyses and reporting of the RAMP Hydrology component. The application of this approach supports the assessment of hydrologic characteristics for interior northern river systems including those within the RAMP FSA. This approach provides a basis for analysis and reporting that supports seasonal connectivity of flow data as representative of the hydrologic regime. It is recommended that the water year convention continue to be used as the basis for hydrologic assessment in the RAMP FSA (i.e. for the 2011 WY).

The water balance approach, particularly with the provision of daily time-step industrial data, provides a consistent basis for analysis of industrial effects on flows in watersheds within the RAMP FSA including those stations with a limited length of data record. As recommended in RAMP (2010) evaluative research is underway to identify additional approaches, measurement endpoints, and indicators that might further support the evaluation of potential shifts in the timing, magnitude, and frequency of flow conditions in watersheds of the RAMP FSA. The application of additional methods is predominantly limited by the length of the data record (Kundzewicz and Robson 2004), with current applicability of statistical methods limited to a sub-set of tributaries within the RAMP FSA. By comparison, the water balance approach provides a basis for analysis that can be completed for all monitored tributaries within the RAMP FSA. It is anticipated that methods currently under review will serve to complement the existing approach, increase the understanding of hydrologic characteristics of the watersheds in the RAMP FSA, and potentially provide additional assessment criteria for selected locations.

7.1.3 Recommendations

Recommendations related to the Climate and Hydrology component are to continue to:

- monitor existing climate and hydrometric stations to enhance record length and data availability;
- expand the monitoring network to support provision of *baseline* and *test* hydrometric information and regional climate data;
- evaluate additional hydrometric measurement endpoints and indicators (such as the timing and frequency of flow conditions) that would further support RAMP assessment and understanding of aquatic conditions; and
- conduct water balance assessments as a consistent approach applicable to tributary watersheds, independent of the length of the data record, and, as possible, continue to refine inputs such as the time-step of industrial data.

Table 7.1-2 Summary assessment of RAMP 2010 monitoring results.

Watershed/Region	Differences Between *Test* and *Baseline* Conditions					Fish Populations: Human Health Risk from Mercury in Fish Tissue[6]			Acid-Sensitive Lakes: Variation from Long-Term Average Potential for Acidification[7]
	Hydrology[1]	Water Quality[2]	Benthic Invertebrate Communities[3]	Sediment Quality[4]	Sentinel Fish Species[5]	Species	Subs. Fishers	General Cons.	
Athabasca River	🟡	🟡	-	-	🟡 / 🟠	-	-	-	-
Athabasca River Delta	-	-	🟡 / 🟤	n/a	-	-	-	-	-
Muskeg River	🟤	🟡	🟡 / 🟠	🟡	-	-	-	-	-
Jackpine Creek	nm	🟡	🟡	🟡	-	-	-	-	-
Kearl Lake	nm	🟡	🟠	n/a	-	-	-	-	-
Steepbank River	🟡	🟡	🟠	-	-	-	-	-	-
Tar River	🟤	🟡	🟠	🟡	-	-	-	-	-
MacKay River	🟡	🟡	🟡 / 🟠	-	-	-	-	-	-
Calumet River	🟡	🟡	-	-	-	-	-	-	-
Firebag River	🟡	🟡	🟡	🟡	-	-	-	-	-
McClelland Lake	nm	n/a	🟡	n/a					
Ells River	🟡	🟡	🟡	🟡	-	-	-	-	-
Christina River	🟡	🟡	-	-	-	-	-	-	-
Clearwater River	nm	🟡	-	-	-	-	-	-	-
Hangingstone River	🟡	-	-	-	-	-	-	-	-
Fort Creek	🟠	🟡	🟤	🟡	-	-	-	-	-
Beaver River	-	🟡	-	-	-	-	-	-	-
McLean Creek	-	🟡	-	-	-	-	-	-	-
Mills Creek	🟤	🟡	-	-	-	-	-	-	-
Isadore's Lake	nm	n/a	🟡	n/a					
Poplar Creek	🟤	🟡	🟠	🟡	-	-	-	-	-
Shipyard Lake	-	n/a	🟡	n/a	-	-	-	-	-
Brutus Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						WALL	🟤	🟠	
						NRPK	🟤	🟠	
Keith Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						NRPK	🟡	🟡	
Net Lake	-	-	-	-	-	LKWH	🟡	🟡	-
						WALL	🟤	🟤	
						NRPK	🟤	🟠	
Stony Mountains	-	-	-	-	-		-		🟡
West of Fort McMurray	-	-	-	-	-		-		🟡
Northeast of Fort McMurray	-	-	-	-	-		-		🟡
Birch Mountains	-	-	-	-	-		-		🟡
Canadian Shield	-	-	-	-	-		-		🟡
Caribou Mountains	-	-	-	-	-		-		🟠

Legend and Notes

🟡 Negligible-Low change

🟠 Moderate change

🟤 High change

"-" program was not completed in 2010.

nm - not measured in 2010.

n/a - classification could not be completed because there were no *baseline* conditions to compare against.

[1] **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 2010, hydrology results above are for those endpoints that were calculated.

Note: All calculated hydrology measurement endpoints in the Muskeg River watershed were assessed as Negligible-Low with the exception of Annual Maximum Daily Discharge which was assessed as Moderate.

Note: All calculated hydrology measurement endpoints in the Fort Creek watershed were assessed as High with the exception of Annual Maximum Daily Discharge which was assessed as Negligible-Low.

[2] **Water Quality:** Classification based on adaptation of CCME water quality index.

Note: Water quality at all stations in the Athabasca River was assessed as Negligible-Low with the exception of station ATR-DC-E, which was assessed as Moderate.

[3] **Benthic Invertebrate Communities:** Classification based on statistical differences in measurement endpoints between *baseline* and *test* reaches or between *baseline* and *test* periods or trends over time for a reach as well as comparison to regional *baseline* conditions.

Note: Benthic invertebrate communities at the lower and middle reaches of the Muskeg River were assessed as Negligible-Low and benthic invertebrate communities at the upper reach were assessed as Moderate.

Note: Benthic invertebrate communities at all reaches in the Athabasca River Delta was assessed as Negligible-Low with the exception of Fletcher Channel, which was assessed as High.

[4] **Sediment Quality:** Classification based on adaptation of CCME sediment quality index.

[5] **Fish Populations (sentinel species):** Uses Pulp and Paper Environmental Effects Monitoring Criteria (Environment Canada 2010). See Section 3.2.4.3 for a detailed description of the classification methodology.

Note: Differences in trout-perch populations at all *test* sites in the Athabasca River were assessed as Negligible-Low with the exception of *test* Site 3 and *test* Site 5, which was assessed as Moderate.

[6] **Fish Populations (fish tissue):** Uses Health Canada criteria for risks to human health.

LKWH-lake whitefish; WALL-walleye; NRPK-northern pike

Note: For Fish Population Human Health Classification - Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada.

[7] **Acid-Sensitive Lakes:** Classification based the frequency in each region with which values of seven measurement endpoints in 2010 were more than twice the standard deviation from their long-term mean in each lake.

7.2 WATER QUALITY

7.2.1 Summary of 2010 Results

Water quality measured by RAMP at various waterbodies in fall 2010, especially in tributaries to the Athabasca River, was strongly influenced by high flows that were related to rainfall events in late August and early September. At many sampling stations, these high flows likely contributed to historically-low concentrations of most major ions and historically high concentrations of suspended particulates and several variables typically associated with suspended particulates, including total aluminum, total mercury, and total nitrogen, relative to data collected by RAMP in previous years.

The following waterbodies in 2010 exhibited changes from historical and/or regional *baseline* conditions:

- **Isadore's Lake** – Increasing concentrations of several major ions have been evident in recent years (including chloride, sodium and sulphate), which are entering the lake from upstream Mills Creek (a location of aggregate quarrying operations), as confirmed by RAMP sampling established in this creek in 2010.
- **Shipyard Lake** – Although water quality remains generally within regional *baseline* conditions, concentrations of sodium and chloride continue to increase to concentrations exceeding regional *baseline* conditions.
- **Fort Creek** – Concentrations of sulphate have increased over the past three years, although no other water quality variables are showing similar increases.
- **Athabasca River** – *Baseline* station ATR-DC-E (upstream of Donald Creek, east bank) exhibited water quality that showed moderate differences from historical *baseline* conditions in the Athabasca River, although this was likely due to the strong influence of Clearwater River water at this location in fall 2010. Total mercury exceeded the AENV chronic guideline of 5 ng/L at all stations in fall 2010, with concentrations decreasing from upstream to downstream stations of oil sands developments.

Aside from these localized changes, water quality in the RAMP FSA in 2010 was largely consistent with regional *baseline* conditions (Table 7.1-2).

7.2.2 Study Design Considerations

Analyses of naphthenic acids in water samples from RAMP stations by multiple laboratories in 2010 indicated that naphthenic acids as classically defined (i.e., $C_nH_{2n+Z}O_2$) are likely a negligible portion of the group of acid-extractable organic compounds historically measured as naphthenic acids for RAMP and other monitoring programs in the Athabasca oil sands region. The current state of knowledge, analytical chemistry techniques, and related aquatic toxicology associated with these compounds is complex and in flux. Given the potential importance of these compounds in the Athabasca oil sands region as potential toxicants and a tool for identifying sources of future changes in water quality, there is an urgent need for regulators and researchers to clarify these issues and agree upon an accepted standard for use in routine monitoring and to revisit all toxicological data associated with these compounds.

7.2.3 Recommendations

The following recommendations are outlined to further improve monitoring conducted for the Water Quality component:

1. Additional *baseline* stations should be established for ongoing RAMP water quality sampling, particularly stations that are expected to remain *baseline* well into the future given the steady decline in the number of stations designated as *baseline* in the current RAMP water quality design, and the need to continually update the ranges of natural variability of water quality in the RAMP FSA.

2. Add seasonal sampling of water quality to assess any differences in water quality that may occur across seasons.

3. Include PAH analyses in water samples. Analyses of PAHs were eliminated from the Water Quality component given the concentrations were always below detection limits. However, with improvements in analytical detection limits over time, analyses of these compounds should be revisited.

7.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

7.3.1 Benthic Invertebrate Communities

7.3.1.1 Summary of 2010 Results

The Benthic Invertebrate Communities component characterizes changes in river reaches and lakes that are considered most likely to be affected by focal projects. Within the major tributaries, samples are collected in lower reaches where changes from all upstream developments are anticipated to be the most significant. Differences in the lower reaches are in part judged against observations in upper reaches that are classified as *baseline*. Differences within reaches (and lakes) are used to judge changes over time in rigorous analyses of variance. Where changes are observed, differences among reaches of a similar nature are used to put those changes into context. A summary of the key findings from the 2010 results are provided below.

Athabasca River Delta: Differences in the values of measurement endpoints for benthic invertebrate communities in Big Point Channel, Goose Island Channel and the Embarras River are classified as **Negligible-Low** because there were no significant time trends in any measurement endpoints for benthic invertebrate communities or differences from historical conditions in the ARD. Differences in values of measurement endpoints for benthic invertebrate communities in Fletcher Channel are classified as **High** because of a decrease over time in diversity, evenness, and percent EPT, all of which are typically associated with a negative change in the benthic invertebrate community. The increase in total abundance at Fletcher Channel is potentially indicative of an increase in available nutrients.

Lakes: Differences in benthic invertebrate communities of lakes are difficult to classify because there is a general lack of information on *baseline* lake conditions in the RAMP FSA. Some new benthic invertebrate community data were published by Parsons *et al.* (2010) for acid-sensitive lakes, but the field methods used in this study were not similar to the methods used in RAMP and thus cannot be directly or easily compared. Therefore, differences are assessed based on historical years in each lake, which is difficult in lakes with shorter sampling periods, such as Isadore's Lake. Differences in measurement endpoints for benthic invertebrate communities in Kearl Lake were classified as

Moderate and differences in McClelland, Isadore's and Shipyard lakes were classified as **Negligible-Low.** This is the first year that Kearl Lake has been classified as **Moderate**.

Rivers: Differences in measurement endpoints for benthic invertebrate communities in the lower *test* reach of Fort Creek were classified as **High** because changes in richness and evenness were large and significant and because richness, diversity and evenness were outside of regional *baseline* conditions for depositional reaches in the RAMP FSA. The classification of **High** was also justified because of the shift in dominant taxon from chironomids during the period when the reach was *baseline* to the more tolerant tubificid worms once the reach became *test*.

Changes in the following reaches were classified as **Moderate**:

- **Muskeg River** – Differences in measurement endpoints for benthic invertebrate communities in 2010 in the upper *test* reach of the Muskeg River were classified as **Moderate** because there were significant differences in the values of the measurement endpoints from the *baseline* period to the *test* period. The upper *test* reach of the Muskeg River had moderately lower taxa richness in the *test* period relative to the *baseline* period.

- **Poplar Creek** – This was the third year of sampling for benthic invertebrate communities in the lower *test* reach of Poplar Creek. This reach was included as a negative control, to demonstrate the ability of the RAMP benthic invertebrate community sampling methods to detect changes. Differences in measurement endpoints for benthic invertebrate communities of the lower *test* reach of Poplar Creek were classified as **Moderate** because of significantly lower percent EPT compared to the upper *baseline* reach. There has been a significant increase in diversity over time at this reach and; therefore, does not imply a negative change in the benthic invertebrate community.

- **Tar River** – Differences in measurement endpoints for benthic invertebrate communities in the lower *test* reach of the Tar River were classified as **Moderate** because of the significantly large decrease in total abundance, taxa richness, diversity and evenness over time compared to the period when the reach as designated as *baseline*. Values of measurement endpoints in 2010 in the lower *test* reach remained within the range of values observed in other *baseline* depositional reaches.

- **Steepbank River** – The values of measurement endpoints of the benthic invertebrate community at the lower *test* reach of the Steepbank River have remained generally stable across time and consistent to those for the upper *baseline* reach of the Steepbank River, with a presence of fauna typically associated with a robust healthy community including a high relative abundance of EPT taxa. However, the strong statistical differences in abundance and richness in the lower *test* reach indicate a **Moderate** difference from the upper *baseline* reach. Lower abundance and richness compared to the median *baseline* conditions have been evident since 2000 at the lower *test* reach but are not significant. There were no exceedances of values of measurement endpoints outside of the range of *baseline* conditions.

- **MacKay River** – Differences in the values of measurement endpoints for benthic invertebrate communities for the middle *test* reach of the MacKay River were classified as **Negligible-Low** because there was a significant decrease in total abundance over time explaining more than 20% of the variance in total abundance. Significant increases were observed in richness, diversity, evenness and percent of the fauna as EPT taxa and an increase in the values of these measurement endpoints does not imply a negative change in the benthic invertebrate community.

Changes in the following reaches were classified as **Negligible-Low**:

- **Muskeg River** – Differences in measurement endpoints for benthic invertebrate communities in 2010 in the lower *test* reach of the Muskeg River were classified as **Negligible-Low** because there were no significant time trends in the values of the measurement endpoints. The lower *test* reach had an increase in percent of the fauna as tubificid worms, and a decrease in the percent of the fauna as chironomids, mayflies, stoneflies and caddisflies. Differences in measurement endpoints for benthic invertebrate communities in 2010 in the middle *test* reach of the Muskeg River were classified as **Negligible-Low** because, although there was a significant decrease in total abundance over time, the statistical signal explained less than 20% of the variation in annual means.

- **Jackpine Creek** – Differences in measurement endpoints for benthic invertebrate communities in the lower *test* reach of Jackpine Creek are classified as **Negligible-Low** because the significant increase in taxa richness, diversity, evenness, and percent EPT do not suggest a negative change in the benthic invertebrate community.

- **MacKay River** – Differences in measurement endpoints of benthic invertebrate communities of the lower *test* reach of the MacKay River are classified as **Negligible-Low** because, although there were significant decreases in abundance and richness in the *test* period compared to the *baseline* period and a decrease in abundance during the *test* period, the statistical signal in the differences over time explained very little variance in total abundance and richness. It should be noted, however, that there was also a relatively strong time trend in CA Axis 2 scores suggesting a decrease in the percent of the community as EPT taxa. Values of all measurement endpoints were within regional *baseline* conditions.

- **Firebag River** – Differences in the values of measurement endpoints for benthic invertebrate communities in the lower *test* reach of the Firebag River were classified as **Negligible-Low** because increases in taxa richness, diversity, and evenness over time do not imply a negative change in the benthic invertebrate community. The benthic invertebrate community in fall 2010 contained representative species of mayfly, caddisfly and stonefly groups, indicating good water and sediment quality.

- **Ells River** – Differences in measurement endpoints for benthic invertebrate communities in the lower *test* reach of the Ells River were classified as **Negligible-Low** because increases in abundance, richness, diversity and evenness did not imply a negative change in the benthic invertebrate community.

7.3.2 Study Design Considerations

High water levels in September 2010 resulted in a delay in sampling reaches on the MacKay, Steepbank and Firebag Rivers (erosional reaches) until later in the month. The high flows also highlighted a potential issue with the sampling device (Neill-Hess cylinder) used to collect benthic samples from erosional reaches in that it can become flooded in deep water and compromise the sample. The federal CABIN protocol for collecting benthos in rivers was thus used to collect synoptic samples at some replicates within reaches of the MacKay, Steepbank and Firebag rivers in September 2010. The results of the analysis in comparing the data between the two sampling techniques suggest that CABIN kick-net samples collect larger organisms than the Neill-Hess cylinder, resulting in higher percent EPT but similar taxa richness, diversity and evenness in the kick-net samples. The kick-net sampler, with larger mesh, also collects a higher relative abundance of fingernail clams, and lower relative abundances of chironomids and naidid worms and other small organisms. Those differences will need to be considered if Neill-Hess cylinder samples cannot be collected and kick-net samples are collected instead.

In response to questions raised regarding the high unexplained variability in benthic invertebrate community measurement endpoints (AITF 2011), an analysis of potential sources of variability in annual means of measurement endpoints in relation to climatic variables was conducted for river reaches. Increasing mean annual discharge was associated with decreasing total abundance and increasing temperature during the open-water period was associated with increasing taxa richness and percent EPT in erosional rivers. The influences were relatively minor accounting for generally less than 5% of the total variation in the annual means of the measurement endpoints. The analysis did not find strong correlations among reaches between values of measurement endpoints for benthic invertebrate communities and annual average discharge or mean air temperature during the open-water period in depositional rivers. This analysis is considered preliminary and additional analyses are being carried out by other researchers at the University of Waterloo under funding from Environment Canada. It is anticipated that the results of the analysis would be used in subsequent analyses of the RAMP benthic community dataset and may be useful for understanding when extreme variations are driven by climate variables or activities of focal projects.

7.3.3 Sediment Quality

7.3.3.1 Summary of 2010 Results

Sediments in the RAMP FSA naturally contain concentrations of hydrocarbons and PAHs that may exceed environmental-quality guidelines.

In fall 2010, differences in sediment quality from regional *baseline* conditions were assessed as **Negligible-Low** at all sampling locations (Table 7.1-2), with concentrations of metals, hydrocarbons and PAHs in sediments generally within previously-measured concentrations throughout the RAMP FSA. The following exceptions are noted:

1. Although total PAHs were within historical ranges at nearly all locations sampled in 2010, predicted PAH toxicity (an equilibrium-partitioning-based estimate of the potential for chronic toxicity of sediment-borne PAHs to sediment-dwelling organisms) was historically-high at several stations, including the middle *test* station of the Muskeg River and the ARD *test* stations on Fletcher Channel and the Embarras River, and sufficiently high to potentially cause toxicity to benthic organisms. Typically, in previous years, high PAH toxicity values were related to the concentration of PAHs with relatively low concentrations of total hydrocarbons, which are used in the equilibrium-partitioning calculation to help estimate bioavailability. Where PAH toxicity exceeded the potential chronic toxicity threshold of 1.0, benthic invertebrate communities and sediment toxicity tests did not

indicate impoverished community composition with the exception of Fletcher Channel in the ARD, where benthic invertebrate communities showed lower richness and diversity than previous years and survival of the amphipod *Hyallela azteca* was below historical lows and laboratory controls.

2. A statistically significant increase in total PAHs from 1999 to 2010 was noted in Big Point Channel (BPC-1) in the ARD, although concentrations remain low relative to most other regional locations and this trend was not evident in concentrations of carbon-normalized total PAHs. Significant increasing or decreasing concentrations of total PAHs were not observed at any other station in the ARD.

7.3.3.2 Recommendations

Analysis of sediment cores would be the best means of addressing questions related to historical increases in PAHs and other hydrocarbons in sediments in the ARD. It is worthwhile to note that several research programs were planning to collect sediment cores from the ARD in 2010; these data should be very helpful in clarifying historical trends in sediment quality.

Given ongoing changes in the hydrology of the ARD, consideration also could be given to the use of sediment traps in some channels (especially Fletcher Channel), to estimate sediment deposition rates (which may be changing over time as natural succession occurs in the ARD) and also to specifically assess concentrations of hydrocarbons and metal in sediments deposited in the ARD in a given year.

If possible, additional *baseline* stations should be established for ongoing RAMP sediment quality sampling (harmonized with depositional benthos sampling reaches). The emphasis should be on establishing stations that are expected to remain *baseline* well into the future because of the steady decline in the number of stations designated *baseline* in the current RAMP sediment quality design. These additional *baseline* stations will make it possible to continually update the understood range of natural variability of sediment quality in the RAMP FSA.

7.4 FISH POPULATIONS

The 2010 RAMP Fish Population component consisted of:

- Fish inventories on the Athabasca and Clearwater rivers;
- Sentinel species monitoring on the Athabasca River; and
- Mercury analyses of fish tissue collected from three regional lakes: Brutus Lake; Keith Lake; and Net 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 and continued in 2010 as a potential new approach to monitoring fish populations in the RAMP FSA.

7.4.1 Summary of 2010 Results

7.4.1.1 Fish Inventory

In 2010, 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 Key Indicator Resource (KIR) fish species.

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. A shift in species dominance from white sucker to walleye was observed in spring, from goldeye to northern pike in summer, and from walleye to goldeye in fall, although lake whitefish dominates the catch in fall.

As of 2010, 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 for some of the KIR species. However, the variability of this measurement endpoint among years does not indicate consistent negative or positive changes in the fish populations and likely reflects natural variability over time.

The fish health assessment undertaken as part of the Athabasca and Clearwater fish inventories, has indicated that abnormalities observed in 2010 in all species were within the historical range and consistent with studies done in the upper Athabasca River and the Athabasca River Delta, Peace River and Slave River prior to major oil sands development.

The Clearwater River fish inventory is also a community-driven activity that focuses on population variables (i.e., condition of fish and length-frequency distribution) of large-bodied KIR species. The type of gear used for the fish inventory is selective for large-bodied species and there is therefore an ability to provide a more detailed assessment of these species compared to small-bodied fish species in the Clearwater River. A summary of the main results of the Clearwater River fish inventory is as follows:

1. Species richness in 2010 was lower in spring relative to the historical average (2003 to 2009) but within the historical range; lower in summer compared to 2009 when a summer inventory was first conducted and higher in fall relative to the historical average.
2. The 2010 Clearwater River inventory results suggest variable relative abundance of each species over time with no clear trends; the dominant species (white sucker) in each season has remained consistent over time.
3. There has been significant variability in the condition of large-bodied KIR species in the Clearwater River over time with no clear increasing or decreasing trends that would indicate a change in the health of fish in the river. Condition can not necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the RAMP FSA.

A second year of a summer inventory in the Clearwater River further increased the understanding of the presence of juvenile fish in the river, such as longnose sucker and goldeye, which may help to provide more information on recruitment trends in these populations.

7.4.1.2 Sentinel Species Monitoring

As outlined in RAMP (2009b), the Athabasca River sentinel species program was developed to evaluate spatial differences in measurement endpoints between *baseline* and *test* sites. In addition, results from the 2010 study can be compared to past sentinel programs to assess possible trends over time. Based on the differences in measurement endpoints in trout-perch, the following assessments were made:

- Female trout-perch at the *test* site upstream of the Muskeg River and male and female trout-perch at the *test* site downstream of the Muskeg River indicated a **Negligible-Low** difference from the upstream *baseline* site because none of the measurement endpoints exceeded the effects criteria;
- Male trout-perch at the *test* site upstream of the Muskeg River indicated a **Moderate** difference from the upstream *baseline* site because weight-at-age exceeded the effects criteria;
- Male trout-perch at the *test* site downstream of the Firebag River indicated a **Moderate** difference from upstream *baseline* site because weight-at-age exceeded the effects criteria; and
- Female trout-perch at the *test* site downstream of the Firebag River indicated a **Moderate** difference from the upstream *baseline* site because weight-at-age, GSI and condition exceeded the effects criteria; however, this response was not observed in previous sentinel programs.

Generally, there is little evidence to suggest that characteristics of trout-perch populations between sites and across years on the Athabasca River have changed due to increasing activities from the focal projects and other oil sands developments given that trout-perch from sites closer to intense mining activity do not show substantial differences from *baseline* fish, suggesting that female trout-perch at the *test* site downstream of the Firebag River are responding to localized conditions unrelated to oil sands development.

7.4.1.3 Fish Tissue

In 2010, the potential risk to human health related to fish consumption was assessed using individual samples of northern pike, walleye, and lake whitefish collected from three regional lakes, including Brutus Lake, Keith Lake, and Net Lake.

Mercury concentrations in all northern pike and 73% of walleye from Brutus Lake in 2010 exceeded the Health Canada guideline for subsistence fishers, and mercury concentrations in two walleye exceeded the guidelines for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye. Given that all northern pike and most walleye exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike and walleye, dependent on the quantity of fish consumed. Mercury concentrations in fish from Brutus Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes. Mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health.

Mercury concentrations in lake whitefish and northern pike from Keith Lake were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Mercury concentrations in fish from Keith Lake were generally within the historical range of mercury concentrations in fish sampled from other regional lakes.

Mercury concentrations in all captured walleye and all but one northern pike from Net Lake in 2010 exceeded the Health Canada guideline for subsistence fishers. The majority of walleye and two northern pike exceeded the guideline for general consumers. The results indicate a **High** risk to the health of subsistence fishers consuming northern pike and walleye and to general consumers consuming walleye, given that most fish exceeded the guideline for general consumers. Given that all northern pike exceeded the guideline for subsistence fishers, there is a **Moderate** risk to general consumers consuming northern pike, dependent on the quantity of fish consumed. With the exception of two fish, mercury concentrations in lake whitefish were below any Health Canada consumption guidelines indicating a **Negligible-Low** risk to human health. Overall, the mercury concentrations in fish sampled from Net Lake were higher in northern pike and walleye compared to mercury concentration in fish from other regional lakes.

7.4.2 Recommendations

The following recommendations are outlined to further improve monitoring conducted for the Fish Populations component:

1. A *baseline* reach upstream of oil sands development on the Athabasca River should be considered for future fish inventories. Although fish are highly migratory through the Athabasca River, it will help to provide more information on their habitat range and utility of the river.

2. Ageing structures should be taken from large-bodied KIR species during the Athabasca and Clearwater inventories. Collection of ageing structures has been done historically and needs to be reinstated to assess recruitment rates in these fish populations.

3. 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 were developed in 2009 and continue to be improved. 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.

4. 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. Given the variability in mercury concentrations in fish across lakes, it is necessary to continue sampling lakes in the region so that data can be provided to Alberta Health and Wellness and Health Canada in order to establish human consumption guidelines for lakes commonly used for sportfishing.

5. 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 to relation the specific consumption guidelines established by the Government of Alberta for these watercourses (GOA 2009).

6. During the fish assemblage and sentinel species monitoring, RAMP collaborated with personnel from Environment Canada who were assessing physiological indicators (liver MFO activity [EROD], steroid production, gonadal histology, parasite load and composition, and muscle stable isotopes) in sentinel species. The collaboration of the two studies was beneficial in adding more information to the assessment of fish populations. A continuation of the collaboration between the two programs is recommended to assess the ecological and physiological changes that may occur in fish populations due to oil sands development. The results of the work completed by Environment Canada were not complete before the 2010 RAMP Technical Report was completed and; therefore, could not be included.

7.5 ACID-SENSITIVE LAKES

7.5.1 Summary of 2010 Results

There have been minor changes in the chemistry of the 50 ASL component lakes over the nine years of monitoring (2002 to 2010). Concentrations of nitrates and DOC were the only measurement endpoints to show significant changes over time. The changes in nitrate were not consistent with an acidification scenario and there is no indication that acidification is occurring from nitrogen deposition. There was a significant decrease in DOC in the ASL component lakes but this decrease was not accompanied by significant decreases in Gran alkalinity or in pH, which would be expected in a response to acidification. As observed in 2009, the significant decrease in DOC may be a natural phenomenon rather than a response to acidification and will continue to be monitored.

Critical loads of acidity were calculated for each lake using the Henriksen critical load model modified to account for the contributions of both strong and weak organic acids. Critical loads were calculated using values of runoff derived from the isotopic mass balance technique (Gibson *et al.* 2010). Lakes located in the upland regions, in particular, the Stony Mountains, had the lowest critical loads and were therefore the most acid-sensitive. Critical loads of the ASL component lakes varied significantly between years in response to hydrologic conditions suggesting that the acid-sensitivity of these lakes varies between years. The critical loads of acidity were compared to modeled rates of acid deposition expressed as the Net Potential Acid Input, which corrects for nitrogen uptake by plants in lake catchments (eutrophication). Eleven (22 %) of the 50 lakes had PAI values greater than the critical load. The percentage of ASL component lakes in which the modeled Net PAI was greater than the critical load is higher than results from a study for the NO_xSO_x Management Working Group within CEMA looking at 399 regional lakes where only 8% of the lakes had PAI values greater than the critical load (WRS 2006). The higher proportion in the ASL component lakes reflects a bias in the ASL component design that preferentially selected the most poorly-buffered lakes for monitoring. The rates of critical load exceedance in the ASL component lakes were closer to rates observed in acid-sensitive regions in Ontario. A critical load exceedance does not necessarily mean that acidification of a lake is a certainty or imminent.

Time trend analysis was applied to key measurement endpoints in all 50 ASL component lakes to detect changes that might indicate incipient acidification. As in previous years, most of the significant trends in measurement endpoints were either small and within analytical error or inconsistent with any reasonable acidification scenario. There were no significant decreases in Gran alkalinity in any of the 50 ASL component lakes. The decrease in DOC noted above was observed in three of the 50 lakes.

The *baseline* subregion of the Caribou Mountains had the highest rate of measurement endpoints exceeding two standard deviations of the mean for each lake in a direction indicative of acidification. This subregion was classified as **Moderate** (Table 7.1-2), which is unexpected given that the Caribou Mountain lakes are remote from sources of acidifying emissions and considered *baseline* lakes. All three exceedances in this region were attributable to Lake 146/CM1, which had water chemistry in 2010 that was uncharacteristic of the subregion. The remaining subregions are classified in 2010 as **Negligible-Low**.

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9.0 GLOSSARY AND LIST OF ACRONYMS

9.1 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 2010) or were (prior to 2010) 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/100 seconds). 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.
Simpson's 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.

9.2 LIST OF ACRONYMS

ABMI	Alberta Biodiversity Monitoring Institute
ADL	analytical detection limit
ADC	Acoustic Digital Current
ADV	Acoustic Doppler Velocimeter
AED	Alberta Economic Development
AENV	Alberta Environment
AEP	Alberta Environment Protection
Albian	Albian Sands Energy Inc.
ALPAC	Alberta-Pacific Forest Industries Inc.
ALS	ALS Environmental
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
AITF	Alberta Innovates Technology Futures
ARD	Athabasca River Delta
ASL	Acid Sensitive Lakes
ASRD	Alberta Sustainable Resource Development
ATI	Assemblage Tolerance Index
AWRI	Alberta Wetland Research Institute
AXYS	AXYS Analytical Services
BC MOELP	BC Ministry of Environment, Lands and Parks
Birch Mountain	Birch Mountain Resources Ltd.
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CA	Correspondence Analyses
CABIN	Canadian Aquatic Biomonitoring Network
CCME	Canadian Council of Ministers of the Environment
CEMA	Cumulative Environmental Management Association
CFRAW	Carbon Dynamics, Food Web Structure, and Reclamation Strategies in Athabasca Oil Sands Wetlands (CFRAW)

CL	Critical Load
CNRL	Canadian Natural Resources Limited
COC	chain of custody
CONRAD	Canadian Oil Sands Network for Research and Development
COSI	Centre for Oil Sands Innovation
CPUE	Catch Per Unit Effort
CV	Coefficient of Variation
CWN	Canadian Water Network
CWQG	Canadian Water Quality Guidelines
CYMM	Fort McMurray Airport Code
DFO	Fisheries and Oceans Canada
DL	Detection Limit
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EC	Environment Canada
EDA	Exploratory Data Analysis
EEM	Environmental Effects Monitoring
EIA	Environmental Impact Assessment
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency (US)
EPT	Ephemeroptera, Plecoptera and Trichoptera
ERCB	Energy Resources Conservation Board
EROD	Ethoxyresorufin-O-deethylase
FAM	Fish Assemblage Monitoring
FWMIS	Fisheries and Wildlife Management Information System
FSA	Focus Study Area
FTIR	Fourier Transform Infra-red
FWIN	Fall Walleye Index Netting
GC/MS	Gas Chromatography-Mass Spectrometry
GLM	General Linear Model
GOA	Government of Alberta
GPS	Global Positioning System
GPP	Generator Powered Pulsator
GSI	Gonad Somatic Index

HI	Hazard Index
IBI	Index of Biotic Integrity
ICP/MS	Inductively Coupled Plasma Mass Spectroscopy
IFN	Instream Flow Needs
INAC	Indian and Northern Affairs Canada
IMB	Isotopic Mass Balance
ISQG	Interim Sediment Quality Guidelines
JACOS	Japan Canada Oil Sands Limited
KIR	Key Indicator Resource
LSI	Liver Somatic Index
LTRN	Long-term Regional Network
MAKESENS	Mann-Kendall test for trend and Sen's slope estimates
MDL	Method Detection Limit
MFO	Mixed-function Oxygenase
NAD	North American Datum
NRBS	Northern River Basins Study
NSERC	Natural Sciences and Engineering Research Council of Canada
NSMWG	NO_x and SO_x Management Working Group
OSPW	Oil Sands Process Waters
OSTWAEO	Oil Sands Tailings Water Acid-extractable Organics
PAD-EMP	Peace-Athabasca Delta Ecological Monitoring Program
PAH	Polycyclic Aromatic Hydrocarbon
PAI	Potential Acid Input
PCA	Principal Component Analysis
PEL	Probable Effect Level
ppb	parts per billion
ppm	parts per million
ppq	parts per quadrillion
QA	Quality Assurance
QC	Quality Control
RAMP	Regional Aquatics Monitoring Program
RCA	Reference Condition Approach
RMCC	Research and Monitoring Coordinating Committee
RMWB	Regional Municipality of Wood Buffalo

RSA	Regional Study Area
RSDS	Regional Sustainable Development Strategy
SAGD	Steam Assisted Gravity Discharge
SD	Standard Deviation
SM	Surface Mine
SOP	Standard Operating Procedures
SPOT-5	Satellite Pour l'Observation de la Terre
SQI	Sediment Quality Index
SSWQO	Site-specific Water Quality Objectives
STP	Sewage Treatment Plant
SWE	Snow Water Equivalent
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
TOR	Terms of Reference
TPH	Total Petroleum Hydrocarbons
TRH	total recoverable hydrogen
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VOC	volatile organic compounds
WBEA	Wood Buffalo Environmental Association
WQI	Water Quality Index
WSC	Water Survey of Canada
WY	Water Year