

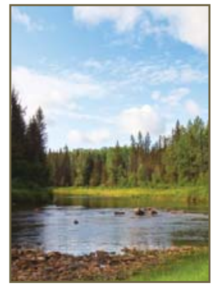


Regional Aquatics Monitoring Program

2011 TECHNICAL REPORT

FINAL

REGIONAL AQUATICS MONITORING PROGRAM

2011 Technical Report

FINAL

Prepared for:

RAMP STEERING COMMITTEE

Prepared by:

The RAMP 2011 Implementation Team

Consisting of:

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

APRIL 2012
RAMP1696

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ACKNOWLEDGEMENTS

Funding for RAMP in 2011 was provided by Suncor Energy Inc. (Suncor), Syncrude Canada Ltd. (Syncrude), Shell Canada Energy (Shell), Canadian Natural Resources Limited (Canadian Natural), Imperial Oil Resources (Imperial Oil), Nexen Inc. (Nexen), Husky Energy (Husky), Total E&P Canada Ltd. (Total E&P), MEG Energy Corp. (MEG Energy), Dover Operating Corp. (DOC), ConocoPhillips Canada (ConocoPhillips), Devon Energy Corp. (Devon Energy), Cenovus Energy (Cenovus), Japan Canada Oil Sands Limited (JACOS), Teck Resources Ltd. (Teck, formerly SilverBirch Energy Ltd.), and Hammerstone Corporation (Hammerstone).

The RAMP chairperson during the 2011 program year was Tomas Romero (ConocoPhillips). Sarah Aho (Suncor) was chair of the Technical Program Committee, Richard Kavanagh (Canadian Natural) was chair of the Finance Subcommittee and National Public Relations 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 Aboriginal 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 Subcommittee and the Communications Subcommittee;
- Syncrude, Canadian Natural, Suncor, Nexen, Shell Canada Energy, and ConocoPhillips for their contribution towards the fish inventory program;
- Alberta Environment & Water (AEW) for providing water quality data from their ongoing LTRN monitoring programs for inclusion in RAMP;
- Water Survey of Canada (WSC) for access to their hydrology data for stations in the oil sands region;
- AEW for conducting field work required for the Acid-Sensitive Lakes component; and
- Local residents/anglers who provided information for the Fish Tag Return Program.

In addition, the 2011 RAMP Implementation Team would like to acknowledge the following contractors and laboratories that assisted with the program:

- Alberta Innovates Technology Futures (chemical analyses);
- ALS Laboratory Group (chemical analyses);
- AXYS Analytical Services Ltd. (chemical analyses);
- Dr. Jack Zloty (benthic invertebrate taxonomy);
- Flett Research Ltd. (non-lethal fish tissue analyses);
- HydroQual Laboratories Ltd. (toxicity testing);
- North/South Consultants Inc. (fish ageing);
- University of Alberta Limnological Laboratory (chemical analyses for ASL component);
- Dr. Jonathan Martin, University of Alberta (naphthenic acids analyses); and
- Dr. John Gibson, University of Victoria (run-off estimates for ASL component).

2011 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 (surface mining and *in situ* extraction) can be identified and assessed. In 2011, 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., Teck Resources Ltd., Cenovus Energy, Japan Canada Oil Sands Ltd., 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 represents the Regional Study Area (RSA) of RAMP. 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, High Hills 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 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 2011 Technical Report to define those projects owned and operated by the 2011 industry members of RAMP listed above that were under construction or operational in 2011 in the RAMP FSA. For 2011, these projects included a number of oil sands projects and a limestone quarry project.

2011 RAMP industry members do have other projects in the RAMP FSA that were in the application stage as of 2011, or had received approval in 2011 or earlier, but construction had not yet started as of 2011. These projects are noted throughout this technical report, but are not designated as focal projects, as these projects in 2011 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 2011 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, AEW 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 2011 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 2011) or were (prior to 2011) 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 2011 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 2011, it is estimated that approximately 94,300 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 2011 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 2011 MONITORING RESULTS

A tabular summary of the 2011 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 calculated from the observed *test* hydrograph were 0.5%, 1.4%, 0.3% and 1.9% lower, respectively, than from the estimated *baseline* hydrograph when only focal projects are considered. These differences were all classified as **Negligible-Low**. The results of the hydrologic assessment are essentially identical to results for the case in which focal projects plus other oil sands developments are considered.

Water Quality Differences in water quality measured in fall 2011 between all *test* and one of the upper *baseline* stations in the Athabasca River were classified as **Negligible-Low** compared to the regional *baseline* conditions, with the exception of the *test* station at the Muskeg River on the west bank of the Athabasca River, which showed **Moderate** differences from regional *baseline* conditions due to high TSS and associated particulate metals. Concentrations of water quality measurement endpoints at *test* stations were generally similar to those at the upstream *baseline* stations at Donald Creek on the east and west banks of the Athabasca River and consistent with regional *baseline* conditions. Concentrations of total aluminum and total iron exceeded guidelines at all stations, but no upstream-downstream station trends were observed.

Benthic Invertebrate Communities and Sediment Quality Benthic invertebrate communities were monitored at four locations in the Athabasca River Delta (ARD) in fall 2011:

1. Differences in measurement endpoints for benthic invertebrate communities in Big Point Channel in fall 2011 were classified as **Negligible-Low** because with the exception of the weak significant difference in Correspondence analysis (CA) Axis 1 scores, there were no significant time trends in any measurement endpoints for benthic invertebrate communities. All measurement endpoints were within previously-measured values for this reach.

2. Differences in measurement endpoints for benthic invertebrate communities in Fletcher Channel in fall 2011 were classified as **Moderate** because significant decreases in diversity and evenness accounted for greater than 20% of the variance in annual means. In addition, diversity and evenness in 2011 were lower than the range of previously-measured values for reaches in the delta, while EPT was higher in 2011 than previous years. The high relative abundance of tubificid worms in Fletcher Channel has been consistently observed since sampling began in 2002.

3. Differences in measurement endpoints for benthic invertebrate communities in Goose Island Channel in fall 2011 were classified as **Negligible-Low** because there were no strongly significant time trends in any measurement endpoints for benthic invertebrate communities. Values for all measurement endpoints were within previously-measured values for the reach and for all reaches in the ARD.

4. Differences in measurement endpoints for benthic invertebrate communities in the Embarras River in fall 2011 were classified as **Negligible-Low** because measurement endpoints were within previously-measured values for reaches in the ARD. High relative abundances of mayflies and caddisflies at this reach indicate that the community is robust and healthy.

Concentrations of sediment quality measurement endpoints at all five stations in the ARD showed generally low concentrations of hydrocarbons, metals and PAHs, which were similar to previously-measured concentrations. Similar to previous years, PAHs at all stations in fall 2011 were dominated by alkylated species indicating a petrogenic origin of these compounds. Sediment fractions at all stations in 2011 showed higher proportions of sand and lower concentrations of silt and clay than measured previously with the exception of Goose Island Channel, where silt was the dominant substrate. From 1999 to 2010, an increase in concentrations of total PAHs was observed in Big Point Channel, although this trend was not evident in concentrations of carbon-normalized total PAHs. In fall 2011, total PAH concentrations at this station were near previously-measured minimum concentrations. With the exception of Goose Island Channel, all stations in the ARD exhibited a decrease in total PAHs and total organic carbon in fall 2011 relative to fall 2010. The increase in total organic carbon in Goose Island Channel relative to 2010 may be related to the historically low proportions of silt and clay in fall 2010. Generally coarser sediments present at most delta stations in 2011 (with associated lower TOC, metals and total PAHs) relative to previous years may relate to the sedimentary regime in the delta in 2011, with less fine sediment deposited in 2011 due to high Athabasca River mainstem flows in summer 2011. The PAH Hazard Index was higher than previously-measured values for Goose Island Channel, and above the potential chronic toxicity threshold, while this measurement was lower than previously-measured at *test* station ATR-ER. The increase in the Hazard Index value at this station related to low concentrations of total hydrocarbons, rather than high concentrations of total PAHs; however, it suggests greater bioavailability of PAHs in sediments. Acute and chronic toxicity of sediments were lower than previously-measured for *Hyalella* survival at the station in the Embarras River, whereas growth for *Hyalella* was higher than previously-measured at stations in Big Point and Fletcher channels. Additionally, there was a significant improvement in *Chironomus* survival compared to 2010 at the station in Fletcher Channel.

Fish Populations (fish inventory) The Athabasca River fish inventory is considered to be a community-driven activity, primarily suited for assessing general trends in abundance and population variables for large-bodied species, rather than detailed community structure.

As of 2011, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, age-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition in some 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 indicated that abnormalities observed in 2011 in all species were within the historical range and consistent with studies done prior to the major oil sands development in the upper Athabasca River, the ARD, and the Peace and Slave rivers.

Fish Populations (fish tissue) Measurement endpoints used in the assessment for the Athabasca River fish tissue program included metals and tainting compounds in fish tissue of both individual and composite samples. Potential human health risks from contaminated fish tissue were predicted from both individual and composite samples. In 2011, the mean concentration of mercury in lake whitefish was lower than previous years, with the exception of 2008 and the mean concentration of mercury in walleye was higher in 2011 compared to previous years, with the exception of 2003. The mean mercury concentration across all size classes of lake whitefish were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. The mean mercury concentration in size classes of walleye greater than 300 mm exceeded the subsistence fishers guideline for consumption indicating a **High** risk to subsistence fishers and a **Moderate** risk to general consumers.

Muskeg River Watershed

Hydrology The calculated mean open-water discharge was 7.1% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Moderate.** The calculated mean winter discharge and the open-water period minimum daily discharge were 85% and 261% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph, respectively. These differences were classified as **High**. The calculated annual maximum daily discharge was 4.4% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**.

Water Quality Concentrations of many water quality measurement endpoints in Jackpine Creek were higher than previously-measured maximum concentrations, primarily in dissolved species. Concentrations of water quality measurement endpoints in other portions of the Muskeg River watershed in fall 2011 were mostly within the range of previously-measured concentrations and generally consistent with regional *baseline* conditions. Differences in water quality in fall 2011 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions were classified as **Negligible-Low**. Shelley Creek could not be sampled in 2011 because water has been diverted from this creek by approved oil-sands development.

Benthic Invertebrate Communities and Sediment Quality Benthic invertebrate communities were monitored at five *test* reaches in the Muskeg River watershed in fall 2011:

1. Differences in the measurement endpoints of benthic invertebrate communities at the lower *test* reach of the Muskeg River in fall 2011 were classified as **Negligible-Low** because the significant increase in total abundance in 2011 relative to 2010 and previous years did not coincide with changes in other measurement endpoints that would imply a negative change to the benthic invertebrate community (i.e., richness and diversity were also higher). The increase in total abundance (> 150,000 individuals per m^2 in 2011) could imply a significant increase in available habitat (or nutrients) for the benthic invertebrate community. The benthic invertebrate community at this reach; however, appears to be in good condition given the high relative abundances of mayflies, caddisflies and the presence of stoneflies. The percent of the fauna as worms (tubificids and naidids) was generally consistent with previous years indicating no significant change in the quality of the habitat (i.e., water and sediment quality).

2. Differences in the measurement endpoints of benthic invertebrate communities at the middle *test* reach of the Muskeg River in fall 2011 were classified as **Negligible-Low** because there was an increase in percent EPT, which does not imply a negative change and all measurement endpoints with the exception richness were within the range of variation for *baseline* depositional reaches. In fall 2011, richness exceeded the 95^{th} percentile of regional *baseline* conditions, which was not indicative of degraded habitat.

3. Differences in the measurement endpoints of benthic invertebrate communities at the upper *test* reach of the Muskeg River in fall 2011 were classified as **Moderate** because the decrease in taxa richness from the *baseline* period to the *test* period explained 25% of the variation in annual means. In addition, the shift in composition suggested by variations in CA Axis 2 scores reflected an absence of *Hydracarina* in the reach over the last three years, an increase in tubificid worms in 2011, and a decrease in the relative abundance of mayflies. The absence of *Hydracarina* (i.e., water mites) were informative given that mites are not good “indicators” of water or substrate quality and the increase in the relative abundance of tubificid worms may indicate degraded conditions of the water or sediment quality. The percent of the fauna as tubificids has always been higher at this reach than the middle *test* reach despite the fact that the middle *test* reach has been designated as *test* since RAMP began sampling this reach in 2000. The decrease in the relative abundance of mayflies at the upper *test* reach may also indicate degraded conditions.

4. Differences in the benthic invertebrate community at the lower *test* reach of Jackpine Creek as of fall 2011 were classified as **Negligible-Low** because of the significant increases over time in taxa richness, diversity, and evenness at reach JAC-D1 once the reach became *test* do not imply a negative change in the benthic invertebrate community. In addition, values of some measurement endpoints in fall 2011 for benthic invertebrate communities at both the lower *test* reach and the upper *baseline* reach of Jackpine Creek exceeded the range of regional *baseline* conditions, but were not indicative of degraded conditions.

5. Differences in measurement endpoints for benthic invertebrate communities in Kearl Lake were classified as **Moderate** because of the significant decrease in percent EPT (i.e., mayflies and caddisflies) compared to the period when Kearl Lake was designated as *baseline* and the increase in multivariate CA Axis scores. The benthic invertebrate community of Kearl Lake contained a diverse fauna and included several taxa that are typically associated with relatively good water and sediment quality in lakes (e.g., the mayfly *Caenis* and the caddisfly *Mystacides*). The benthic invertebrate community of Kearl Lake in fall 2011 also contained higher relative abundances of ostracods and mites (totaling over 40% of total numbers) compared to previous years and compared to other lakes in *baseline* condition in the RAMP FSA

Sediment quality at all Muskeg River watershed stations sampled in fall 2011 was generally consistent with that of previous years and regional *baseline* conditions. Concentrations of total PAHs at all stations were within previously-measured concentrations with a few exceptions where concentrations of PAHs were lower than previously-measured concentrations. Differences in sediment quality in fall 2011 at all four stations in the Muskeg River watershed were classified as **Negligible-Low** compared to regional *baseline* conditions.

Fish Populations Differences in measurement endpoints for fish assemblages between the lower and upper *test* reaches of the Muskeg River and regional *baseline* conditions were classified as **Negligible-Low** because most measurement endpoints were within the regional range of variation of *baseline* reaches. Differences in measurement endpoints for fish assemblages between the middle *test* reach of the Muskeg River and regional *baseline* conditions were classified as **Moderate** because all measurement endpoints were lower than the range of variation of *baseline* reaches (i.e., abundance, species richness, diversity, evenness, and the ATI value).

Differences in measurement endpoints for fish assemblages between the lower *test* reach of Jackpine Creek and regional *baseline* conditions were classified as **Negligible-Low** given that median values of all measurement endpoints were within the regional range of variation of *baseline* reaches.

Steepbank River Watershed

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge were 0.37%, 0.46%, 0.25% and 0.24% greater, respectively, in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low.**

Water Quality Concentrations of many water quality measurement endpoints in the Steepbank River watershed in fall 2011 were higher than previously-measured concentrations, particularly at the middle *test* station of the Steepbank River, the *test* station on the North Steepbank River, and the upper *baseline* station of the Steepbank River. Although several ions were near previously-measured maximum concentrations at the lower *test* station of the Steepbank River, there were few variables that exceeded previously-measured maximum concentrations, perhaps due to the longer period of record at this station. When compared with regional *baseline* conditions for fall (1997 to 2011), concentrations of water quality measurement endpoints were generally consistent. The ionic composition at all water quality monitoring stations in the Steepbank River watershed in fall 2011 was consistent with previous years, despite historically high concentrations of ions at several stations. Differences in water quality in fall 2011 at water quality monitoring stations compared to regional *baseline* water quality conditions were classified as **Negligible-Low** for the middle *test* station of the Steepbank River, the *test* station on the North Steepbank River, and the upper *baseline* station on the Steepbank River. *Test* station STR-1 showed a **Moderate** difference from regional *baseline* conditions due to regionally high concentrations of some ions, suspended solids and some metals, although nearly all measurement endpoints were within previously-measured concentrations at this station.

Benthic Invertebrate Communities Differences in measurement endpoints of the benthic invertebrate community at the *test* reach of the Steepbank River were classified as **Moderate** because total abundance, richness, percent EPT, and CA Axis scores were significantly lower in this reach than the upper *baseline* reach. The benthic invertebrate community; however, was diverse at the lower *test* reach, and although it was numerically dominated by tolerant naidids, many other taxa that require cool, clean water, were documented indicating that there hasn't been an increase in degraded conditions at this reach over time. With the exception of total abundance, all values of measurement endpoints of benthic invertebrate communities were within the range of *baseline* conditions at both reaches of the Steepbank River.

Fish Populations Differences in fish assemblages observed in fall 2011 between the lower *test* reach of the Steepbank River and regional *baseline* conditions were classified as **Negligible-Low** with all median values of measurement endpoints within the range of regional *baseline* variability.

Tar River Watershed

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge were 17.6% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **High**.

Water Quality Differences in water quality observed in fall 2011 between the Tar River and regional *baseline* fall conditions were classified as **Negligible-Low**. All water quality measurement endpoints at the upper *baseline* station and the lower *test* station of the Tar River in fall 2011 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 of the benthic invertebrate communities at the lower *test* reach of the Tar River were 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* and because two of the five measurement endpoints were outside the range of variation for *baseline* depositional reaches. Percent EPT and CA axes scores 1 and 2 also varied over time (linearly) during the *test* period. In addition, the statistical signal in all of these differences explained more than 20% of the variance in the values of these measurement endpoints. The benthic fauna at the lower *test* reach was dominated numerically by tubificid worms, indicating that the reach is potentially exhibiting degrading conditions.

Differences in sediment quality observed in fall 2011 between the lower *test* station of the Tar River and regional *baseline* conditions were classified as **Moderate**, primarily because of high metal concentrations relative to *baseline* data. These high metal concentrations were likely related to the relatively high percent-fines measured in fall 2011 at *test* station TAR-D1, given similar metal concentrations were observed in TAR-1 in 2004, when percent-fines was similar to that observed in 2011. With the exception of total metals, concentrations of most other sediment quality measurement endpoints were within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although CCME Fraction-4 and total hydrocarbons represented historical minimum concentrations.

Fish Populations Differences in measurement endpoints for fish assemblages at the lower *test* reach of the Tar River and regional *baseline* conditions were classified as **Negligible-Low** given there were no measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

MacKay River Watershed

Hydrology The 2011 WY mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph were 0.05% lower than from the estimated *baseline* hydrograph; these differences were classified as **Negligible-Low**.

Water Quality Concentrations of all water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of previously-measured concentrations with the exception of total arsenic, which exceeded previously-measured concentrations at the upper *baseline* station. Water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of regional *baseline* concentrations with the exception of total mercury, which was below the 5th percentile at the middle *test* station and the upper *baseline* station of the MacKay River. Water quality in fall 2011 at both *test* stations and the *baseline* station was very similar with differences relative to regional *baseline* water quality conditions were classified as **Negligible-Low**.

Benthic Invertebrate Communities Differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of the MacKay River were classified as **Moderate** because percent EPT was significantly higher at the upper *baseline* reach compared to this reach and abundance and richness were significantly higher during the *baseline* period for this reach, although the statistical signal in the difference explained slightly less than 20% of the variance in annual means. Despite having a lower proportion of EPT taxa compared to the upper *baseline* reach, the benthic invertebrate community at the lower *test* reach still had a number of sensitive mayfly, stonefly and caddisfly taxa that are typical of an erosional watercourse. Differences in measurement endpoints of benthic invertebrate communities for the middle *test* reach of the MacKay River were classified as **Negligible-Low** because the significant increases in richness, diversity, and percent EPT did not imply a negative change in the benthic invertebrate community. The benthic invertebrate community at the middle *test* reach was diverse, and contained a number of sensitive chironomid, mayfly, stonefly and caddisfly taxa typical of an erosional watercourse.

Fish Populations Differences in measurement endpoints for fish assemblages between the lower and middle *test* reaches of the MacKay River and the regional *baseline* conditions were classified as **Negligible-Low** given there were no median values of measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

Calumet River Watershed

Hydrology The 2011 WY mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph were estimated to be 1.0% lower than from the estimated *baseline* hydrograph; these differences were classified as **Negligible-Low**.

Water Quality In fall 2011, water quality at the lower *test* station and the upper *baseline* station of the Calumet River showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of all water quality measurement endpoints at the lower *test* station in fall 2011 were within the range of regional *baseline* concentrations with the exception of total dissolved solids, dissolved phosphorous, total strontium, total arsenic and sodium, which exceeded the 95th percentile of regional *baseline* concentrations. The ionic composition of water at the lower *test* station was consistent with previous years, and the ionic composition of the upper *baseline* station returned to that of historical measurements after a deviation in fall 2010.

Firebag River Watershed

Hydrology The calculated mean open-water period discharge was 0.12% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph; the mean winter discharge and open-water minimum daily discharge were 0.11% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated annual maximum daily discharge was 0.10% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality In fall 2011, 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 2011 at both Firebag River stations and McClelland Lake was consistent with previous sampling years. Concentrations of most water quality measurement endpoints at the lower *test* station and upper *baseline* station of the Firebag River were within the range of regional *baseline* concentrations in fall 2011. Many water quality measurement endpoints, primarily ions and select metals, exceeded previously-measured maximum concentrations at all stations in the Firebag River watershed (Firebag River stations, McClelland Lake, and Johnson Lake).

Benthic Invertebrate Communities and Sediment Quality The differences in measurement endpoints for benthic invertebrate communities of McClelland Lake were classified as **Negligible-Low** because, while there were significant increases in total abundance, taxa richness, and diversity between the period the lake has been designated as *test* and the period it was designated as *baseline*, these increases generally imply improvements in water and/or sediment quality, particularly given that the dominant organisms in the lake did not change over time. The general composition of the community in terms of relative abundances, presence of fully aquatic forms and presence of generally sensitive taxa such as the mayfly *Caenis* and the caddisfly *Mystacides* all suggested that the benthic invertebrate community in McClelland Lake was in good condition and generally consistent with the community during the *baseline* period. The benthic invertebrate community of Johnson Lake was indicative of good water and sediment quality conditions due to a large relative abundance of permanent aquatic forms such as Amphipoda and bivalve clams, the presence of relatively sensitive and large aquatic insect larvae (caddisflies *Molanna*, *Molannodes* and *Oecetis*), and a low relative abundance of tubificid worms.

Concentrations of sediment quality measurement endpoints in McClelland Lake were generally within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although concentrations of silt and total organic carbon were higher than previously-measured maximum concentrations and concentrations of sand and naphthalene were lower than previously-measured minimum concentrations. Sediment toxicity to invertebrates showed historically high survival of both *Hyalella* and *Chironomus*, and historically high growth of *Hyalella* in McClelland Lake. Fall 2011 represented the first year of sampling in Johnson Lake; sediment quality was generally similar to McClelland Lake, with the exception of concentrations of total hydrocarbons and total metals that were slightly higher, and measurement endpoints for sediment toxicity that were slightly lower.

Ells River Watershed

Hydrology The 2011 WY mean winter discharge (November to March) was 0.05% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**. The calculated mean open-water discharge (May to October), the annual maximum daily discharge, and the open-water minimum daily discharge were 0.07% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2011 between the Ells River and regional *baseline* fall conditions were classified as **Negligible-Low**. Water quality conditions were consistent with previous years for the lower *test* station and the middle *test* station of the Ells River and 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 2011 was similar to that at the other two stations and consistent with results from fall 2010 at this station.

Benthic Invertebrate Communities and Sediment Quality Differences in values of benthic invertebrate community measurement endpoints at the lower *test* reach of the Ells River were classified as **Negligible-Low** because the significant increase in taxa richness over time did not imply a negative change in the benthic invertebrate community. In addition, although evenness in fall 2011 was lower than regional *baseline* conditions, there were no other measurement endpoints that exceeded the range of *baseline* conditions and evenness was lower in 2005 than 2011. It should be noted; however, that habitat conditions at the lower *test* reach were of marginal quality for benthic invertebrate communities. The high relative abundance of tubificid worms, the absence of caddisflies and stoneflies, and the low relative abundance of mayflies, indicated an environment that was slightly limiting to depositional fauna. Differences in sediment quality observed in fall 2011 between the lower *test* station of the Ells River and regional *baseline* conditions were classified as **Moderate**, with concentrations of PAHs exceeding regional *baseline* conditions but within previously-measured concentrations at this station.

Fish Populations Differences in the fish assemblage observed in fall 2011 between the lower *test* reach of the Ells River and regional *baseline* conditions were classified as **Negligible-Low** with all median values of measurement endpoints within the range of regional *baseline* variability.

Clearwater-Christina River System

Hydrology The 2011 WY mean open-water period (May to October) discharge, annual maximum daily discharge, and open-water minimum discharge at the mouth of the Christina River were 0.02%, 0.03%, and 0.02%, respectively, greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality In fall 2011, water quality at stations on the Clearwater River, the Christina River, and the High Hills River indicated **Negligible-Low** differences from regional *baseline* conditions.

Concentrations of several water quality measurement endpoints were outside the range of previously-measured concentrations; however, this could be related to low water levels in September 2011, which would contribute to increases in conductivity, nutrients and dissolved species of metals. Concentrations of water quality measurement endpoints that were outside of regional *baseline* conditions were all lower than the 5^{th} percentile of the range of *baseline* variation.

Benthic Invertebrate Communities and Sediment Quality Differences in values of measurement endpoints of benthic invertebrate communities at the lower *test* reach of the Clearwater River were classified as **Moderate** because of the significant differences in abundance, richness, and percent EPT between the lower *test* reach and the upper *baseline* reach. It should be noted that although the values of these measurement endpoints were generally lower at the *test* reach, values have increased in the two recent sampling years (2008 and 2001) to a level consistent with the *baseline* reach. Values of measurement endpoints at the *test* reach of the Clearwater River were well within the range of *baseline* conditions. In addition, the lower *test* reach was diverse, and contained a number of taxa considered sensitive to degrading habitat conditions including chironomids (e.g., *Lopesocladius*), mayflies (*Ametropus neavei*), and stoneflies (e.g., *Isoperla* and *Taeniopteryx*). There was a high percentage of worms, indicating potential organic enrichment as well as a high percent of chironomids and EPT taxa, which reflect good water quality.

Concentrations of sediment quality measurement endpoints at the lower *test* station and the upper *baseline* station of the Clearwater River in fall 2011 were generally lower than previously measured. The substrate at both stations was comprised almost entirely of sand, with low concentrations of total organic carbon. Direct measurements of sediment toxicity indicated good survival (i.e., ≥90%) at both stations. Differences in sediment quality in fall 2011 were classified as **Negligible-Low** compared to regional *baseline* conditions.

Fish Populations (fish inventory) Species richness in 2011 was higher than all years in spring, with the exception of 2007 and 2008; significantly higher than summer 2010; and lower than fall 2010 but within the historical range (2003 to 2011).

The relative abundance of fish species in the Clearwater River was variable without any clear trends observed over time. Similarly, there has been no marked shift in species dominance from year to year. There have been no significant differences in condition of large-bodied KIR fish species in the Clearwater River across years. Condition cannot necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region. In 2011, a shift towards a younger age class was observed in northern pike and walleye. Although uncertain, this may reflect increasing fishing pressure on adult fish over the years within the Clearwater River causing a shift to a population dominated by younger individuals.

Fish Populations (fish assemblage) The fish assemblage at the *baseline* reach of High Hills River was generally consistent with other *baseline* erosional reaches in the region and all median values of measurement endpoints were within the range of regional *baseline* conditions. The fish assemblage had a high proportion of slimy sculpin, which are typical of riffle habitat with faster flowing water.

Hangingstone River Watershed

Hydrology The 2011 WY mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge were 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were 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 for Mills Creek were 37% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **High**.

The water level in Isadore's Lake increased in late June and early July in response to rainfall events and backwater effects from the Athabasca River to the maximum recorded lake level over the 12-year record period at Isadore's Lake. Following the increase in lake levels in July, water levels receded to near lower quartile levels by the end of the 2011 WY.

Differences in water quality in fall 2011 between Mills Creek and regional *baseline* fall conditions were classified as **Moderate**, likely due to relatively high concentrations of many ions and other dissolved species that exceeded the 95th percentile of regional *baseline* concentrations. The ionic compositions of *test* stations in Isadore's Lake and Mills Creek were similar, with an increase in bicarbonate relative to previous years.

Differences in the benthic invertebrate community in Isadore's Lake were classified as **Negligible-Low** because there were no significant time trends in any of the benthic invertebrate community measurement endpoints. In addition, diversity was the only measurement endpoint that was outside (below) the range of previously-measured values. Historically, Isadore's Lake has had a unique benthic invertebrate community compared to other lakes in the region (e.g., McClelland, Kearl and Shipyard lakes), with low diversity and a high abundance of nematodes. While there has been very little negative change over time, the benthic invertebrate community in Isadore's Lake has been representative of a degraded system since sampling was initiated in 2006.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2011 in Shipyard Lake were within previously-measured concentrations with only a few exceptions (i.e., sulphate and total strontium). The ionic composition of water continues to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, perhaps due to 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 upper 93% of the Shipyard Lake watershed has been disturbed).

Differences in the benthic invertebrate community in Shipyard Lake in fall 2011 were 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 lake contained a number of fully aquatic forms including amphipods, clams and snails, indicating generally good water and sediment quality. Sediment quality was very similar to that observed in previous years, although Fraction-4 hydrocarbons were historically high. Three non-alkylated PAHs—benz[a]anthracene, benz[a]pyrene, and chrysene—exceeded the relevant CCME Interim Sediment Quality Guideline (ISQG) by approximately two times, but were between six and 12 times lower than the CCME Probable Effect Level (PEL).

Poplar Creek and Beaver River The calculated mean open-water discharge (May to October) was 4.9% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph of Poplar Creek. This difference was classified as **Negligible-Low**. The annual maximum daily discharge was 1.2% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**. The open-water minimum daily discharge was 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**.

Concentrations of several water quality measurement endpoints, primarily ions and other dissolved species, were historically high and/or exceeded regional *baseline* concentrations at the lower *test* station of the Beaver River, resulting in a **Moderate** difference from regional *baseline* conditions. Although concentrations of several measurement endpoints were historically high at *test* station POC-1 and *baseline* station BER-2, water quality was generally similar to regional *baseline* conditions, with differences classified as **Negligible-Low**.

Differences in measurement endpoints of benthic invertebrate communities at the lower *test* reach of Poplar Creek were classified as **Moderate** because of the significant difference in percent EPT and CA Axis scores compared to the upper *baseline* reach of the Beaver River, implying a negative change in the benthic invertebrate community. The benthic invertebrate community at the lower *test* reach was generally in good condition, reflected by low relative abundance of tubificid worms and higher relative abundance of fingernail clams; however, the low relative abundance of mayflies and caddisflies, and absence of stoneflies potentially indicated some level of disturbance.

Differences in sediment quality observed in fall 2011 at the lower *test* station of Poplar Creek and the upper *baseline* station of the Beaver River compared to regional *baseline* conditions were classified as **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within the range or lower than previously-measured concentrations at both stations.

Differences in measurement endpoints for fish assemblages between the lower *test* reach of Poplar Creek and regional *baseline* conditions were classified as **Negligible-Low** because the decrease in the assemblage tolerance index (ATI) value in fall 2011 for this reach did not imply a negative change in the fish assemblage. A lower ATI value indicates that there is a greater proportion of sensitive fish species in the fish assemblage compared to the *baseline* reaches in the region.

McLean Creek Concentrations of water quality measurement endpoints at the *test* station on McLean Creek were often higher than previously-measured maximum concentrations and higher than regional *baseline* concentrations in fall 2011. Many ions and dissolved species of water quality measurement endpoints caused a shift in ionic balance, as well as a **Moderate** difference from regional *baseline* concentrations.

Fort Creek The calculated mean open-water period (May to October) discharge volume was 11.3% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Moderate**. In addition to changes in flow volume, variability in daily flow had also increased due to focal project activity in the watershed.

Differences in water quality in fall 2011 between the *test* station on Fort Creek and regional *baseline* conditions were classified as **Negligible-Low**. Relatively high concentrations of several water quality measurement endpoints were observed in fall 2011 at the *test* station on Fort Creek, but these were within the range of previously-measured concentrations and within regional *baseline* water quality conditions. Only total iron exceeded relevant water quality guidelines. A large increase in the concentration of sulphate have been observed at this station since 2008 (although a slight decrease was observed in 2011), which appeared to have occurred in the absence of other apparent changes in ionic composition.

Differences in measurement endpoints of benthic invertebrate communities at the *test* reach of Fort Creek were classified as **High** because decreases in abundance, richness, diversity and evenness were significant and abundance, richness, diversity and evenness were below the 5^{th} 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 in the *test* period suggesting degradation of habitat quality at this reach.

Differences in measurement endpoints for fish assemblages between the *test* reach of Fort Creek and regional *baseline* conditions were classified as **Negligible-Low** given that median values of all measurement endpoints were within the regional range of variation of *baseline* reaches.

Big Creek, Pierre River, Red Clay Creek, and Eymundson Creek Differences in water quality in fall 2011 between *baseline* stations on Big Creek, Pierre River, and Red Clay Creek and regional *baseline* fall conditions were classified as **Negligible-Low**. Differences in water quality were classified as **Moderate** at the *baseline* station on Eymundson Creek, where concentrations of several water quality measurement endpoints exceeded water quality guidelines or regional *baseline* concentrations. The *baseline* station on Eymundson Creek also differed from the other *baseline* stations (Big Creek, Pierre River, and Red Clay Creek) in its ion balance, with a higher concentration of sulphate and less bicarbonate, which may suggest greater groundwater influence at this station

Acid-Sensitive Lakes

Results of the analysis of the 2011 RAMP lakes compared to historical data suggest that there was no significant change in the overall chemistry of the 50 RAMP lakes across years that were attributable to acidification. A long-term decline was noted for DOC, although this appeared to be the result of factors other than acidifying emissions (e.g., hydrology). 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 was no evidence to suggest acidification in these lakes.

A summary of the state of the RAMP lakes in 2011 with respect to the potential for acidification was prepared for each physiographic subregion by examining deviations from the mean chemical concentrations of measurement endpoints (in a direction indicative of acidification) for each lake within a subregion. A two standard deviation criterion was used in each case. In general, data in 2011 were more variable than previous years resulting in a greater number of exceedances of the two standard deviation criterion than in previous years. In most cases, these exceedances were caused by one lake in a subregion having unusual water chemistry in 2011 (e.g., Lake 225/WF5 in the West of Fort McMurray subregion, Lake 448/BM7 in the Birch Mountains and Lake 146/CM1 in the Caribou Mountains). There was no indication that acidification has occurred in any lakes and that these exceedances were caused by other factors influencing water chemistry such as changes in hydrology or groundwater inputs. Taking into account these other factors, the subregions were classified as having a **Negligible-Low** indication of incipient acidification.

Integration Analysis of RAMP Data

Over the last several years, RAMP has made an increasing effort to harmonize and integrate its monitoring components (i.e., water quality, sediment quality, benthic invertebrate communities and fish assemblages) with respect to space and time. This harmonization provided an opportunity to undertake exploratory analyses to gain a better understanding of possible relationships between environmental variables and the observed temporal and spatial variability in benthic invertebrate communities and fish assemblages of the region. From this analysis, the following general patterns were observed:

- Benthic invertebrate communities tended to be more abundant, rich and diverse during sampling periods or in rivers with low flows, which logically coincided with higher ion concentrations in water (conductivity, DOC, alkalinity);

- Benthic invertebrate community tended to be more abundant with increasing periphyton biomass. This may reflect a response to increasing food availability, particularly for grazing taxa such as Ephemeroptera and Plecoptera (among others), which also were found to increase with increasing periphyton;

- Neither benthos nor periphyton correlated with nutrient concentrations nor sediment chemistry (PAHs, metals, hydrocarbons), suggesting the variation in benthos communities is related to other chemical or physical factors unrelated to oil sands chemicals;

- As with benthic evenness, fish abundance and the fish assemblage tolerance index (ATI) in depositional reaches varied negatively with variables related to discharge; however, unlike benthic communities, fish richness and diversity were either not related (erosional reaches) or negatively associated (depositional reaches) with general ion concentrations in water; and

- Fish abundance was lower in depositional reaches with higher sediment concentrations of hydrocarbons/PAHs/metals; however, it is possible that fish assemblages were more difficult to capture in deeper pool/run depositional habitats using backpack/boat electrofishing gear.

Generally, strong relationships between variables describing benthic invertebrate communities and fish assemblages and environmental variables were limited; however, the above correlations do suggest some areas that warrant further investigation. As well, future analyses will need to consider other potential factors that may play a role in the observed variation in aquatic biota of the region.

Summary and Recommendations

The following table provides a summary of the 2011 RAMP monitoring program results, by watershed and component.

The report concluded 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 the 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's 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;

- Continue to 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;

- Continue analyzing CCME 4-fraction Total Petroleum Hydrocarbons in water samples, with this suite of analytes replacing Total Recoverable Hydrocarbons;

- Continue to analyze for PAHs in water to further clarify sources of within- and among-watershed variability observed in PAH concentrations;

- Evaluate whether sampling erosional habitat in the mainstem Athabasca River is feasible based on habitat availability. If so, consider sampling benthic invertebrate communities using a Neill-Hess cylinder; otherwise, sampling could be conducted in more abundant depositional habitat using a grab sampling device, recognizing that the benthic invertebrate communities in depositional habitat will be dominated by more tolerant species;

- 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;

- Continue to develop more thorough protocols for assessing fish pathology in individual fish. RAMP is continuing to collect data on fish abnormalities and working with a fish pathologist to develop a better understanding of abnormalities in fish in Northern Alberta. RAMP is facilitating the analyses of fish with abnormalities submitted by community members and continues to find means to work with communities to assess fish health; and

- Based on the first year of the fish assemblage monitoring program, it was evident that there is value to the increased harmonization of the RAMP components in an effort to assess the surface watercourse conditions on a holistic basis. It is; therefore, recommended that RAMP continue this monitoring activity to gain more years of data to assess trends in fish assemblage measurement endpoints over time and in relation to water quality, hydrology, benthos, and sediment quality.

Summary assessment of RAMP 2011 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]	Fish Assemblages[5]	Species	Subs. Fishers	General Cons.	
Athabasca River	🟡	🟡 / 🟠	-	-	-	LKWH WALL	🟡 🟤	🟡 🟠	-
Athabasca River Delta	-	-	🟡 / 🟠	n/a	-	-	-	-	-
Muskeg River	🟤	🟡	🟡 / 🟠	🟡	🟡 / 🟠	-	-	-	-
Jackpine Creek	nm	🟡	🟡	🟡	🟡	-	-	-	-
Kearl Lake	nm	🟡	🟠	n/a	-	-	-	-	-
Steepbank River	🟡	🟠	🟠	-	🟡	-	-	-	-
Tar River	🟤	🟡	🟠	🟠	-	-	-	-	-
MacKay River	🟡	🟡	🟠 / 🟡	-	🟡	-	-	-	-
Calumet River	🟡	🟡	nm	nm	nm	-	-	-	-
Firebag River	🟡	🟡	nm	nm	nm	-	-	-	-
McClelland Lake	nm	n/a	🟡	n/a	-				
Johnson Lake	-	n/a	n/a	n/a	-				
Ells River	🟡	🟡	🟡	🟠	🟡	-	-	-	-
Christina River	🟡	🟡	nm	nm	nm	-	-	-	-
Clearwater River	nm	🟡	🟠	🟡	-	-	-	-	-
High Hills River	-	🟡	n/a	-	n/a				
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	-	-	-	-	-
Big Creek	-	🟡	-	-	-		-		-
Pierre River	-	🟡	-	-	-		-		-
Red Clay Creek	-	🟡	-	-	-		-		-
Eymundson Creek	-	🟠	-	-	-		-		-
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 2011.

nm - not measured in 2011.

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-MR-W, 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 all reaches in the Athabasca River Delta was assessed as Negligible-Low with the exception of Fletcher Channel, which was assessed as Moderate.

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 the middle reach of the MacKay River were assessed as Negligible-Low and benthic invertebrate communities at the lower reach were assessed as Moderate.

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

[5] **Fish Populations (Fish Assemblages):** Classification based on exceedances of measurement from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Note: Fish assemblages at the lower and upper reaches of the Muskeg River were assessed as Negligible-Low and fish assemblages at the middle reach were assessed as Moderate.

[6] **Fish Populations (Fish Tissue):** Uses Health Canada criteria for risks to human health.

LKWH - lake whitefish; WALL - walleye.

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 2011 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 (i.e., Athabasca, Cold Lake and Peace River deposits) 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 26.90 billion m^3 (169.3 billion barrels) of remaining established bitumen reserves[1] (ERCB 2011) 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 (including Wabasca) 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 2011).

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 22% of the estimated established bitumen reserves in the Athabasca oil sands region were under active development as of the end of 2010, and 3.8% of the estimated established bitumen reserves of the Athabasca oil sands region had been extracted by the end of 2010 (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 2010		32,487
Mineable	30,966	
in situ	1,491	
Cumulative Production as of 31 December 2010		5,500
Mineable	4,830	
in situ	669	
Remaining Established Reserves		139,747

Data from ERCB (2011); all figures are as of December 31, 2010.

* 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.

[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.

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 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 (i.e., for status and trends reporting and compliance or approval requirements) and surveillance monitoring (i.e., typically short-term to address specific questions) in the Athabasca oil sands region, in addition to RAMP, include but are not limited to (Dowdeswell *et al.* 2010):

Long-term Monitoring

- 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 and ground 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.
- 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.
- Government of Alberta – monitors the environment of the Athabasca oil sands region through the following ministries:
    - The Alberta Sustainable Resource Development (ASRD) monitors and manages the fisheries resource in the Athabasca oil sands region;
    - 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 and Water (AEW, formerly Alberta Environment [AENV]) has been monitoring water quality of the Athabasca River since the 1970s and the Muskeg River since the 1990s. AEW 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).

- Environment Canada – Environment Canada undertakes a number of monitoring activities in the oil sands region 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.
- Industry – individual oil sands companies, including both members and non-members of RAMP, undertake regular aquatic monitoring programs in streams and rivers near their operations to meet approval requirements stipulated by regulatory agencies such as AEW, Fisheries and Oceans, and Environment Canada.

Surveillance Monitoring and Research

- 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.
- 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).
- Environment Canada is actively involved in monitoring and research in the oil sands region and has partnered with AEW, universities and other government departments on a number of projects. Areas of research include ecological flow needs, tailings pond management, chemical profiling of hydrocarbons to distinguish those naturally occurring from industrial (Oilsands Advisory Panel 2010).

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 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 2011 of Hatfield Consultants Partnership, Kilgour and Associates Ltd., and Western Resource Solutions) primarily carry out the fieldwork, data analysis and reporting as defined by the Program. A Finance Sub-committee focuses on issues related to the budget and funding for the annual monitoring. Finally, RAMP has a Communications Sub-Committee for the purpose of 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 2011, RAMP was funded by Suncor Energy Inc. (Suncor), 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), MEG Energy Corp. (MEG Energy), Devon Energy Corp. (Devon), ConocoPhilips Canada (ConocoPhillips), Dover Operating Corp, Japan Canada Oil Sands Limited (JACOS), Teck Resources Ltd. (Teck) and Cenovus Energy Inc. (Cenovus).

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

Figure 1.2-1 RAMP organizational structure[1].

STEERING COMMITTEE

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

Finance Sub-Committee	Technical Program Committee	Communications Sub-Committee	Investigators
All funding participants.	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 2011.

2 Formerly known as SilverBirch Energy Ltd.

1.2.2 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.

1.3 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[3], 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.

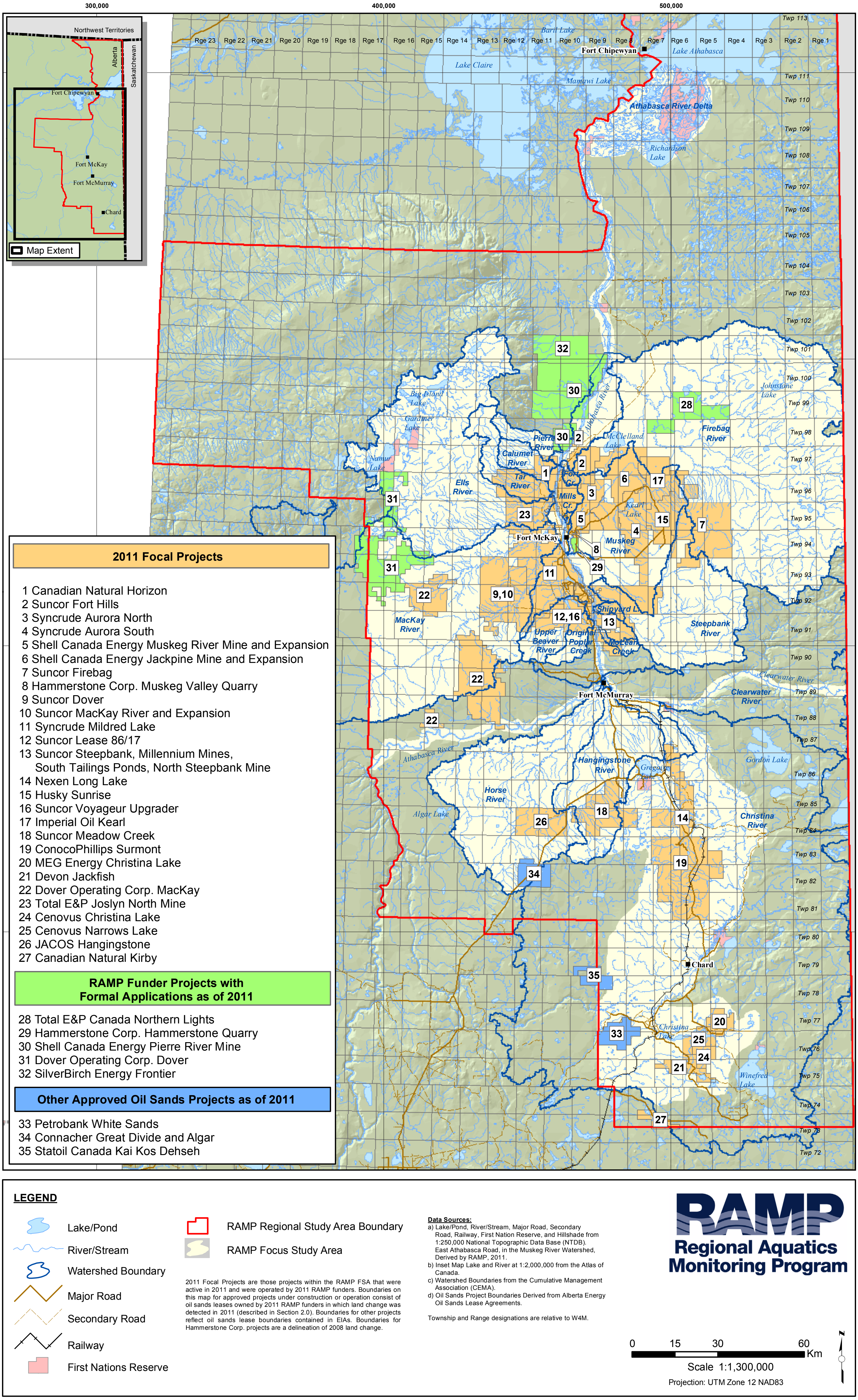
Within the RSA, a Focus Study Area (FSA) is defined by the watersheds in which oil sands development is occurring or is planned, as well as those parts of the Athabasca and Clearwater River channels within the RSA (Figure 1.3-1). Much of the Program's intensive monitoring activity is conducted within 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, AEW 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 2009a) as well as an analysis of the water quality conditions and long-term trends on the Athabasca River (Hebben 2009).

The 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

[3] There was no 2011 census conducted in the RMWB.

Figure 1.3-1 RAMP study areas.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_A_StudyArea_20120420.mxd characterized by a predominantly sub-humid mid-boreal ecoclimate, closed stands of trembling aspen, balsam poplar with white spruce, black spruce, and balsam fir occurring in late successional stages, as well as cold and poorly-drained fens and bogs covered primarily with tamarack and black spruce. The western part of the southern portion of the RAMP FSA has little relief and is poorly-drained.

The northern portion of the RAMP FSA, dominated by the Athabasca River from Fort McMurray to the ARD, is part of the Slave River Lowlands Ecoregion of the Boreal Plains Ecozone. The mineable portion of the estimated, established bitumen reserves of the Athabasca 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.

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 *in situ* oil sands developments in the southern portion of the RAMP FSA including the Cenovus Christina Lake, Cenovus Narrow Lake, ConocoPhilips Surmont, Devon Jackfish, MEG Energy Christina Lake, and Nexen Long Lake projects and portions of the Suncor Meadow Creek Project and the Canadian Natural Kirby Project;

- Hangingstone River – a river originating in the southwestern portion of the RAMP FSA, joining the Clearwater River immediately upstream of Fort McMurray, includes the *in situ* Suncor Meadow Creek, and portions of the JACOS *in situ* Hangingstone and Nexen Long Lake projects;

- 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 Hangingstone Project and the Suncor *in situ* Meadow Creek Project;

- 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, part of the Suncor *in situ* Firebag Project and part of the Husky *in situ* Sunrise Thermal Project;

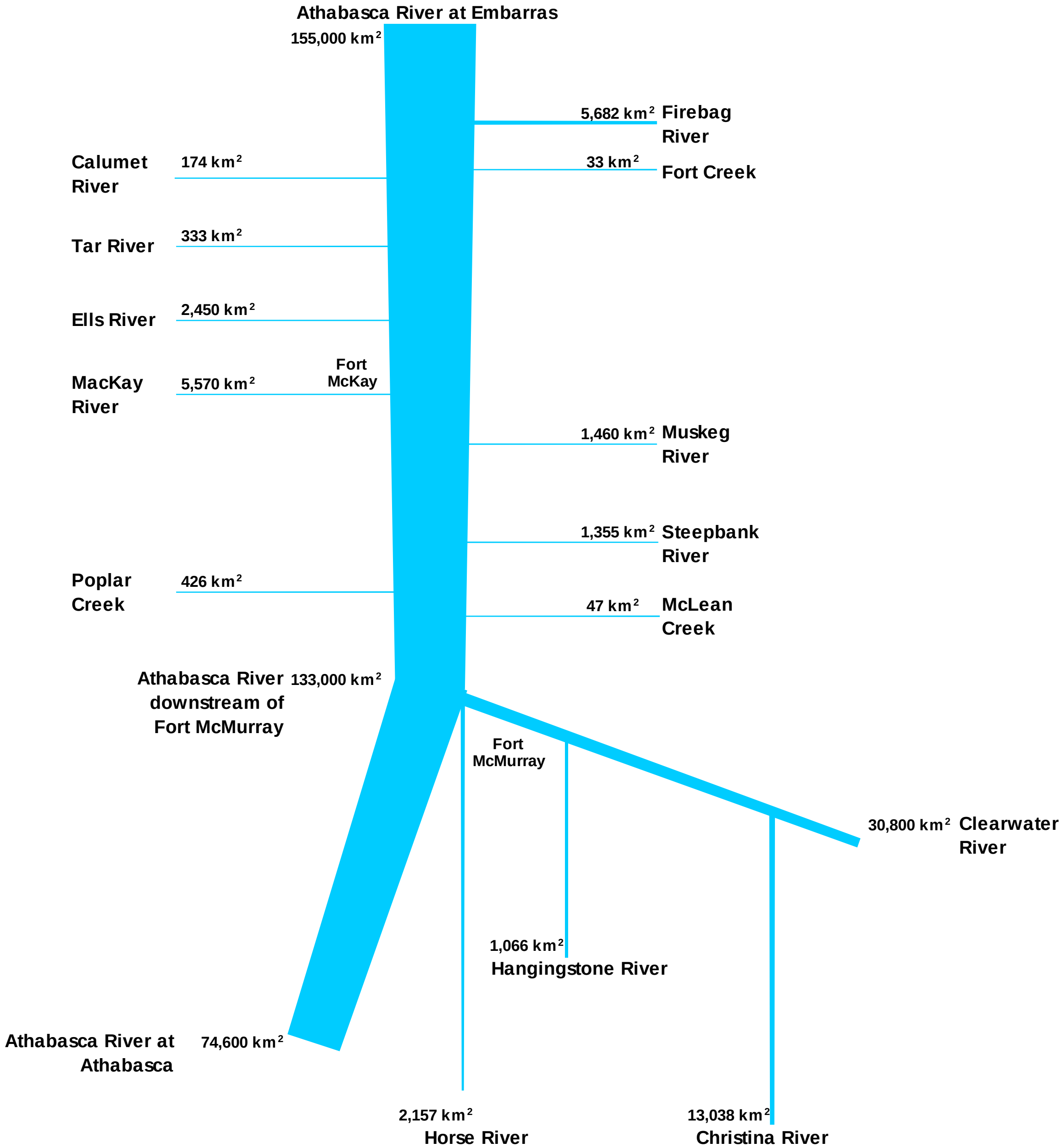
- Muskeg River – flows from the east and drains several oil sands development areas, including Shell Muskeg River Mine and Expansion, Shell Jackpine Mine, Syncrude Aurora North Mine, part of the Suncor *in situ* Firebag Project and small portion of the Suncor Fort Hills Project, Imperial Oil Kearl Project, Husky *in situ* Sunrise Thermal Project, and Hammerstone Muskeg Valley Quarry and Hammerstone quarry;
- MacKay River – flows from the west and the watershed includes the Suncor *in situ* MacKay River development and expansion and Suncor Dover Project, Dover Operating Corp. MacKay Project and portions of Syncrude Mildred Lake Project area;
- Ells River – flows from the west and whose watershed includes the Total E&P Joslyn North Mine Project, and a small portion of the Canadian Natural Horizon Project, and the Dover Operating Corp. Dover development; 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, and portions of the Total E&P Joslyn North Mine;
- 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, the Suncor Fort Hills Project and portions of the Husky *in situ* Sunrise project, and the Imperial Oil Kearl Project.

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, Stanley 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), Dover Operating Corp. MacKay Project, Shell Pierre River Mine (in application), Teck Frontier (in application), JACOS Hangingstone Project, Shell Muskeg River Mine and expansion, and Suncor (Lease 86/17) and Syncrude Mildred Lake 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, Kearl Lake, and Johnson 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.

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.

1.4 GENERAL RAMP MONITORING AND ANALYTICAL APPROACH

1.4.1 Focal Projects

While most of the 2011 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 2011 Technical Report and is defined as those projects owned by 2011 industry members of RAMP (Section 1.2.1) that were under construction or operational in 2011 in the RAMP FSA. For 2011, 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.

2011 industry members of RAMP do have other projects in the RAMP FSA that were in the application stage as of 2011, or that received approval in 2011 or earlier, but that had not yet started construction as of 2011. 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 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 2011 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 2011) or were (prior to 2011) 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* hydrologic conditions and regional climate 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 AEW 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 and Water 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) for three years 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 one 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, including 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 on the larger rivers (i.e., Athabasca and Clearwater rivers) - monitor and assess temporal and spatial changes in species presence, relative abundance and population variables in the spring, summer (as of 2008 in the Athabasca and 2009 in the Clearwater), and fall. 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;
- tissue sampling for organic and inorganic chemicals - 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. 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 the Alberta Sustainable Resources Development [ASRD]) on selected lakes in the region;

- sentinel fish species in tributaries - monitoring potential effects of stressors on populations of fish species that have limited movement relative to the location of the potential stressors. 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;

- fish assemblage and fish habitat assessments in tributaries - focuses on characterizing the fish assemblage on the basis of total abundance, taxonomic richness, diversity, and an assemblage tolerance index, in areas downstream of focal projects relative to fish assemblages upstream of focal projects. Also assesses habitat conditions and any potential change(s) over time that would influence the fish assemblage in a river; and

- monitoring of spring spawning use of tributary habitat - fish fence monitoring 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.

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.

1.4.5.5 Acid-Sensitive Lakes

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

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

- establish a database of water quality to detect and assess cumulative effects and regional trends 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 AEW, 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 2010 RAMP Peer Review

In 2010, RAMP contracted nine external reviewers to determine whether the current program is meeting the objectives outlined in Section 1.2.2 as well as determine whether the current program was able to answer the following questions:

1. Can the present program detect changes if they occur?
2. Can the source of any potential change(s) be identified by the present program?
3. Are the appropriate questions being asked by the program and the appropriate criteria being monitored to answer those questions?

Recommendations that resulted from this peer review are available on the RAMP website (AITF 2011). These recommendations were taken into consideration during the 2011 monitoring program and during the development of this report and are also available on the RAMP website.

1.4.7 Overall Analytical Approach for 2011

The overall analytical approach for the 2011 RAMP Technical Report is a weight-of-evidence approach that builds on analytical approaches used in RAMP in previous years and are 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 2010 Technical Reports (RAMP 2005, RAMP 2006, RAMP 2007, RAMP 2008, RAMP 2009a, RAMP 2010 and RAMP 2011).

Second, the analysis of RAMP results for 2011 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 2011.

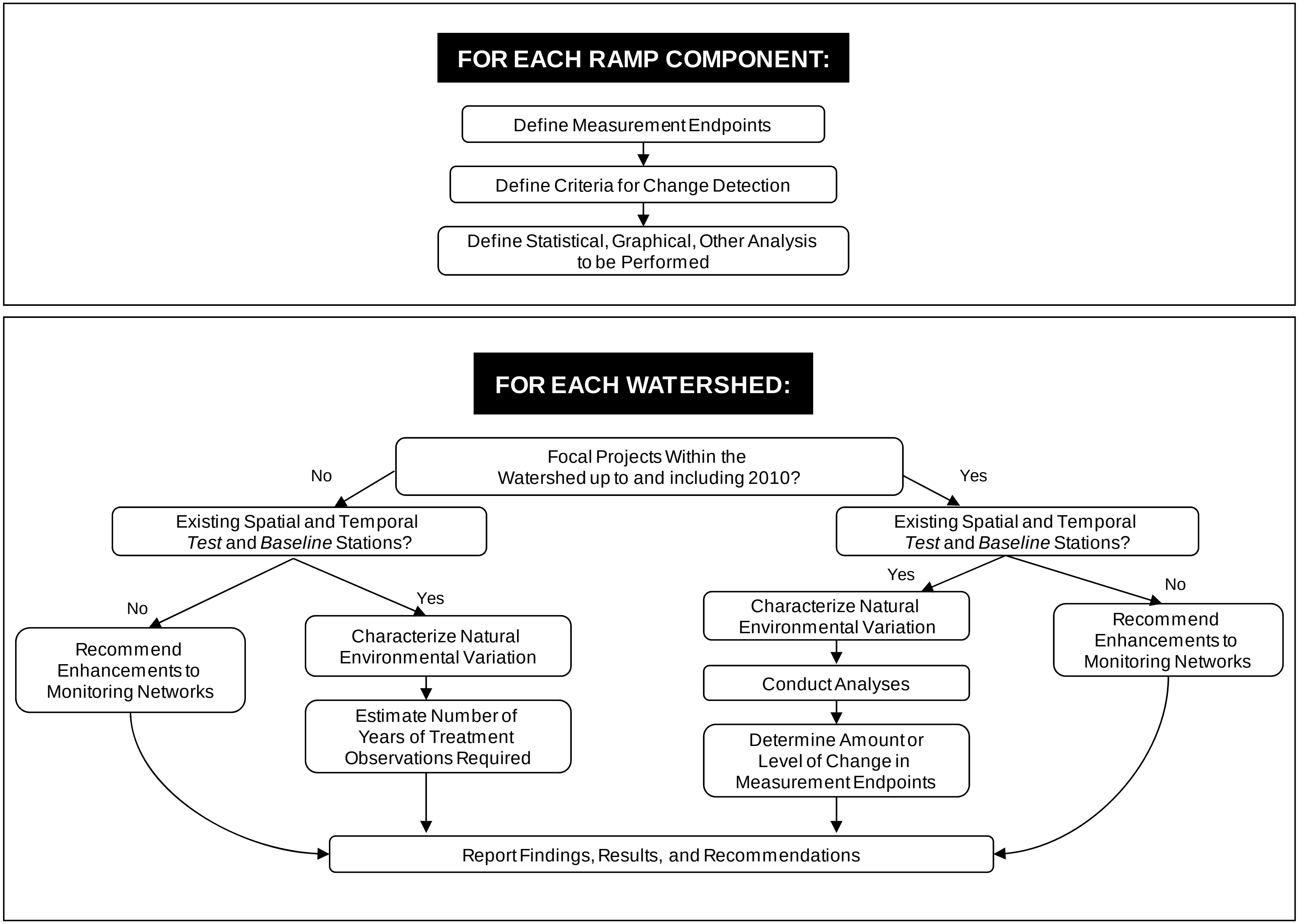


Table 1.4-1 Measurement endpoints and criteria for determination of change used in the analysis for the RAMP 2011 Technical Report.

RAMP Component	Measurement Endpoints Used in 2011 Technical Report[1]	Criteria for Determining Change Used in 2011 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.

CCME is the Canadian Council of Ministers of the Environment. USEPA is the United States Environmental Protection Agency.

Table 1.4-1 (Cont'd.)

RAMP Component	Measurement Endpoints Used in 2011 Technical Report	Criteria for Determining Change Used in 2011 Technical Report
Fish Populations: Fish Inventory	Relative abundance (catch per unit effort) Age-frequency Percent composition Condition factor	The RAMP fish inventory activity is generally considered to be a stakeholder-driven activity that is best suited for assessing general trends in abundance and population parameters for large-bodied species. It is not specifically designed for assessing environmental effects of focal project activities.
Fish Populations: Fish Assemblage Monitoring	Abundance Richness (number of taxa) Simpson's Diversity Evenness Assemblage Tolerance Index	The fish assemblage monitoring program was initiated in 2011 and; therefore, a criterion to determine change has not been established given there is only one year of data. Qualitative comparisons between test and baseline reaches will be conducted to assess the differences in measurement endpoints.
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 2011 within each subregion with endpoint values greater than two standard deviations from the mean is calculated. Negligible-Low: subregion has <2% of endpoint-lake combinations exceeding ± 2SD criterion. Moderate: subregion has 2% to 10 % of 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.

CCME is the Canadian Council of Ministers of the Environment. USEPA is the United States Environmental Protection Agency.

1.5 ORGANIZATION OF THE RAMP 2011 TECHNICAL REPORT

Together with this Introduction, the RAMP 2011 Technical Report contains 10 sections within which the results of the 2011 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 2011 – This section contains:

- a description of the activities in 2011 for each of the focal projects;
- a list of projects owned by 2011 industry members of RAMP that were in the application stage as of 2011, or which received approval in 2011 (or earlier) but were not in the construction phase as of 2011;
- a list of active oil sands projects in the RAMP study areas owned or operated by companies that were not members of RAMP in 2011;
- a list of report focal project water withdrawal and discharge locations; and
- a summary of land change occurring up to 2011 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: 2011 RAMP Monitoring Activities – This section of the report contains concise descriptions of the RAMP monitoring program that was conducted in 2011 for each RAMP component, and includes:

- an overview of the 2011 program;
- a description of any other information that was obtained (i.e., information from regulatory agencies, 2011 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 2010 field program;
- a description of the challenges and issues encountered during 2011 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.

2.0 SUMMARY OF FOCAL PROJECT ACTIVITIES IN 2011

This section provides information on oil sands and other developments in the Regional Aquatics Monitoring Program (RAMP) Focus Study Area (FSA) needed to support the assessment of the 2011 monitoring results. In particular, this information is important for confirming the classification of sampling stations as *baseline* or *test* as development continues to expand over time resulting in changes to these classifications. Five sets of information are looked at: development status of focal projects; development status of other oil sands projects in the RAMP FSA; summary of focal project activities in 2011; summary of focal project water withdrawals and discharges from surface water sources; and RAMP FSA land change analysis for 2011.

2.1 DEVELOPMENT STATUS OF FOCAL PROJECTS

The development status of all RAMP industry member projects, as of the end of 2011 in the RAMP FSA, is presented in Table 2.3-1. In the RAMP FSA, areas downstream of focal projects that have started land disturbance activities 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 2011 monitoring results for all RAMP components.

2.2 DEVELOPMENT STATUS OF OTHER OIL SANDS PROJECTS

There were three approved oil sands projects active in the RAMP FSA in 2011 whose operators were not members of RAMP in 2011 (Table 2.3-2). 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 2011

The information, with respect to any changes to watercourses within a watershed that might influence water and sediment quality, and benthic invertebrate and fish habitat, provided in this section is used to interpret the 2011 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). The information provided in this section reflects changes within the 2011 Water Year (i.e., November 1, 2010 to October 31, 2011) for consistency with analyses conducted for the Climate and Hydrology Component.

2.3.1 Suncor Energy Inc.

As of 2011, development activities were underway for 12 of Suncor's 22 focal projects (i.e., projects with a specified first year of disturbance, Table 2.3-1). Suncor focal project activities and related use/discharge of water in 2011 included:

- Steepbank, Millennium, and Voyageur projects – discharge of approximately 11 million m^3 of water from holding ponds and site drainage at the Voyageur Upgrader, and withdrawal of 29 million m^3 from the Athabasca River;

Table 2.3-1 Status and activities of developments owned by 2011 industry members of RAMP in the RAMP Focus Study Area.

2011 RAMP Industry Member	Development	Focal Projects	Location (Township-Range-Meridian)	Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2011 Status
Suncor Energy	Lease 86/17	√	92-10-W4M	mine	280,000	1964	1967	Closed in 2002
	Steepbank Mine	√	91,92-9-W4M	mine	294,000	1996	1997	Operational
	Millennium Mine	√	91,92-9-W4M	mine		1998	2000	Operational
	Steepbank Debottleneck Phase 3	√		mine	4,000		2007	Operational
	North Steepbank Mine Extension	√	92,93-9-W4M	mine	180,000	2006	2007	Construction
	Millennium Debottlenecking	√		mine	23,000		2008	Operational
	South Tailings Pond	√	90,91-8-W4M, 91-9-W4M	tailings		2003	2005	Construction
	Voyageur: Voyageur Upgrader 3 Phase 1	√	91,92-10-W4M	mine	127,000	2005	--	Approved
	Voyageur: Voyageur Upgrader 3 Phase 2	√		mine	63,000		--	Approved
	Voyageur: South Phase 1	√		mine	120,000	2007	--	Application
	Firebag (Phases 1 &2, cogeneration and expansion)	√	93,94,95,96-4,5,6,7-W4M	*in situ*	95,000	2000	2002	Operational
	Firebag Phase 3	√		*in situ*	52,500	--	2004	Operational
	Firebag Phase 4	√		*in situ*	62,500	--	2011	Construction
	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)	√	96-11-W4M, 97,98-10-W4M	mine	165,000	2001	2005	Approved
	Fort Hills debottleneck	√		mine	25,000	--	--	Approved
	Lewis (Phase 1 and 2)		91-7,8-W4M	*in situ*	80,000	--	--	Application
	MacKay River	√	92, 93-12-W4M	*in situ*	33,000	1998	2000	Operational
	MacKay River Expansion (MR2)	√	92, 93-12-W4M	*in situ*	40,000	2005	--	Application
	Meadow Creek Phase 1/2		84,85-8,9,10-W4M	*in situ*	80,000	2001	--	Approved
Syncrude Canada	Mildred Lake and Aurora North Base Operations (stages 1 & 2)	√	6-93-10-W4M; 96-9,10,11-W4M	mine	290,700	1973	1973	Operational
	Mildred Lake and Aurora North Stage 3 Expansion	√	6-93-10-W4M; 96-9,10,11-W4M	mine	100,000	2001	unknown	Operational
	Aurora South Train 1 and 2	√		mine	200,000	--	2012	Approved
Shell Canada Energy	Muskeg River Mine	√	95-10-W4M	mine	155,000	1997	2000	Operational
	Muskeg River Mine Expansion & Debottlenecking	√	95-8,9-W4M, 94-10-W4M	mine	115,000	2005	2009	Approved
	Jackpine Mine (Phase 1A)	√	95-8-W4, 95-9-W4	mine	100,000	2002	2006	Operational
	Jackpine Mine (Phase 1B)	√		mine	100,000	--	--	Approved
	Jackpine Mine Expansion	√	95,96,97-9,8-W4M	mine	100,000	2007	2017	Application
	Pierre River Mine (Phase 1/2)		97,98,99-10,11-W4M	mine	200,000	2007	2018	Application
Canadian Natural	Horizon Phase 1	√	96-11/12-W4M, 96-13-W4M, 97-11-W4M, 97-12-W4M, 97-13-W4M	mine	110,000	2002	2004	Operational
	Horizon Phase 2A	√		mine	10,000	--	2014	Approved
	Horizon Phase 2B	√		mine	45,000	--	--	Approved
	Horizon Phase 3	√		mine	80,000	--	--	Approved
	Horizon Trache 2	√		mine	135,000	--	2010	Construction
	Kirby North (Phase 1)	√	73,74,75-7,8,9-W4M	*in situ*	40,000	--	2016	Application
	Kirby South (Phase 1)	√		*in situ*	45,000	--	--	Construction

Notes: Information in this table obtained from Dowdeswell *et al*. (2010), Government of Alberta (2011), ERCB (2011), Energy Resources Conservation Board (ERCB) project approvals, project environmental impact assessment (EIA) documents, and company websites.

SAGD is steam-assisted gravity drainage.

[1] Unless otherwise stated, units are in bpd.

Table 2.3-1 (Cont'd.)

2011 RAMP Industry Member	Development	Focal Projects	Location (Township-Range-Meridian)	Type of Operation	Capacity[1]	Year of Application	Year of First Disturbance	2011 Status
Imperial Oil Resources	Kearl Lake Phase 1	√	95,96,97-6,7,8-W4M	mine	110,000	2005	2009	Construction
	Kearl Lake (Phases 2 & 3)	√			200,000			Approved
Nexen	Long Lake Project Phase 1	√	85-6-W4M	*in situ* + upgrader	72,000	2000	2003	Operational
	Long Lake Project Phase 2	√		upgrader	72,000	2000	--	Approved
	Long Lake South Project (Phase 1)	√	84-7-W4M	*in situ*	140,000	2006	--	Approved
	Long Lake South Project (Phase 2)	√						Approved
Total E&P Joslyn	Joslyn, SAGD Phase I	√	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	2011	Approved
	Northern Lights		98,99-5,6,7-W4M	mine	115,000	2006	--	Withdrawn
Husky Energy	Sunrise	√	94-97-6,7-W4M	*in situ*	200,000	2004	2007	Construction
	Phase 1	√			50,000	--	--	Construction
	Phase 2-4	√			150,000	--	--	Approved
	McMullen (Air injection pilot-experimental)	√			755	--	--	Construction
Hammerstone	Muskeg Valley Quarry	√	94,95-10-W4M	quarry	limestone product, 7 million t/yr	2004	2005	Operational
	Hammerstone Quarry	√	94-10-W4M	quarry	limestone product, 18 million t/yr	2006	--	Approved
Cenovus Energy	Christina Lake (Phase 1A and 1B)	√	75,76-5,6-W4M	*in situ*	18,800	--	2002	Operational
	Christina Lake (Phase C)	√		*in situ*	40,000	--	--	Operational
	Christina Lake (Phase D)	√		*in situ*	40,000	--	--	Construction
	Christina Lake (Phase E, F and G)	√		*in situ*	120,000	2009	--	Approved
	Narrows Lake (Phase 1,2 and 3)	√	76,77-6,7W4M	*in situ*	130000	2010	--	Application
ConocoPhillips	Surmont Phase 1	√	81,82,83-5,6,7-W4M	*in situ*	27,000	2001	2004	Operational
	Surmont Phase 2	√		*in situ*	83,000	--	2010	Construction
	Pilot	√		*in situ*	1,200	--	1997	Operational
Devon Energy	Jackfish Phase 1	√	75,76-6,7-W4M	*in situ*	35,000	2003	2005	Operational
	Jackfish Phase 2	√		*in situ*	35,000	2006	2008	Operational
	Jackfish Phase 3	√		*in situ*	35,000	2010	2011	Application
MEG Energy	Christina Lake Phase 1	√	76,78-4,6-W4M	*in situ*	3,000	2004	2005	Operational
	Christina Lake Phase 2A	√		*in situ*	22,000	2005	2007	Operational
	Christina Lake Phase 2B	√		*in situ*	35,000	2007	2007	Construction
	Christina Lake Phase 3A	√		*in situ*	75,000	2008	--	Application
	Christina Lake Phase 3B	√		*in situ*	75,000	2009	--	Application
	Christina Lake Phase 3C	√		*in situ*	50,000	2011	--	Application
JACOS	Hangingstone Pilot	√	84-10,11,12-W4M	*in situ*	11,000	--	1999	Operational
	Hangingstone Expansion	√		*in situ*	35,000	--	2014	Application
Dover Operating Corp.	MacKay	√	92, 93-12-W4M	*in situ*	150,000	2010	2010	Application
	Dover Central	√	87,88,89,90,91-12-W4M	*in situ*	250,000	2010	2010	Application
Teck Resources Ltd.	Frontier	√	99-11, 100,101-9,10,11-W4M	mine	280,000	2011	2020	Application

Notes: Information in this table obtained from Dowdeswell *et al*. (2010), Government of Alberta (2011), ERCB (2011), Energy Resources Conservation Board (ERCB) project approvals, project EIA documents, and company websites.

SAGD is steam-assisted gravity drainage.

[1] Unless otherwise stated, units are in bpd.

- Dewatering releases from four settling ponds in the Fort Hills project, totaling 4.3 million m^3 of water;
- Various withdrawals and releases of water between locations on the Firebag project, totaling 0.18 million m^3; and
- Release of stormwater runoff from ponds totaling 0.01 million m^3 as part of the MacKay River *in situ* project, and withdrawal of 0.01 million m^3 for use in dust suppression.

Table 2.3-2 Approved oil sands projects within the RAMP FSA operated by non-RAMP members, as of 2011.

Operator	Project	Location (Township and Range)	Type of Operation
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). *Note:* Statoil became a member of RAMP in January 2012 (i.e., after the 2011 reporting period).

2.3.2 Syncrude Canada Ltd.

Syncrude's focal projects in 2011 included the Mildred Lake and Aurora North stages 1 and 2, and the Mildred Lake and Aurora North Stage 3 Expansion (Table 2.3-1). Other approved projects, scheduled for construction in 2012, include the Aurora South trains 1 and 2. Syncrude focal project activities' use and discharge of water in 2011 included:

- water withdrawal of 38 million m^3 from the Athabasca River;
- discharge of 0.3 million m^3 of treated domestic wastewater to the Athabasca River;
- discharge of 2.5 million m^3 to Poplar Creek via the Beaver Creek Diversion scheme; and
- discharge of 7.6 million m^3 of water from surface runoff, muskeg dewatering or basal water to Stanley Creek as part of the Aurora Clean Water Diversion system.

2.3.3 Shell Canada Energy

Shell Canada Energy focal projects in 2011 included the Muskeg River Mine, Muskeg River Mine expansion and debottlenecking operations, and the Jackpine Mine (Phase 1A and 1B and expansion); the Pierre River Mine project is still in the application phase (Table 2.3-1). Shell Canada Energy focal project activities' use and discharge of water in 2011 included:

- Muskeg River Mine - water withdrawal from the Athabasca River of 12.6 million m^3, and dewatering and other water releases from the Muskeg River Mine expansion of 1.8 million m^3; and
- Jackpine Mine - water withdrawals of 12.3 million m^3 from the Athabasca River, 1.0 million m^3 from groundwater sources, 0.1 million m^3 from ponds for use in drilling and dust suppression, and 0.05 million m^3 of collected runoff released from various sedimentation ponds.

2.3.4 Canadian Natural Resources Ltd.

As of 2011, the Canadian Natural Horizon project was operational; the Kirby South Phase I project was in the construction stage; and the Kirby North Phase I was in the application stage (Table 2.3-1). Water use and discharge activities in 2011 for the Horizon project included:

- discharge of 0.3 million m^3 from site sedimentation ponds; and
- water withdrawal of 10.3 million m^3 from the Athabasca River, and 0.2 million m^3 of basal water.

2.3.5 Nexen Inc.

The Nexen Inc. Long Lake Phase 1 project was operational in 2011 (Table 2.3-1). Long Lake Phase 1 project activities related to the use and discharge of water in 2011 included:

- water discharge of 0.2 million m^3 to surface ponds and the surrounding environment for dust suppression; and
- water withdrawals of 0.1 million m^3 from surface water sources (e.g., for dust suppression and other uses.

2.3.6 Imperial Oil Resources

The Imperial Oil Resources Kearl Project Phase 1 was under construction in 2011 (Table 2.3-1); Kearl project activities related to water use and discharge in 2011 included:

- muskeg dewatering, with a discharge of approximately 2.9 million m^3 of water to the Muskeg River watershed;
- discharges of 0.7 million m^3 to the Athabasca River; and
- water withdrawals of 11.1 million m^3 from the Athabasca River, and 0.03 million m^3 from various other watersheds.

2.3.7 Total E&P Canada Ltd.

The Total E&P Joslyn North Mine Project received approval in 2011 (Table 2.3-1); preliminary activities for the Joslyn North Mine project in 2011 included withdrawals from the Ells River of approximately 0.002 million m^3, 0.005 million m^3 from Joslyn Creek and its tributaries, 0.002 million m^3 from an unnamed lake in the Tar River watershed, and 0.005 million m^3 from the Athabasca River, for use in project construction.

2.3.8 Husky Energy

The Husky Energy Sunrise project was under construction and not operational in 2011 (Table 2.3-1); project activities included discharges of 0.36 million m^3 of surface runoff from sediment ponds and well pad areas to the Wapasu Creek headwaters.

2.3.9 Hammerstone Corp.

The Hammerstone Muskeg Valley Quarry Project was operational in 2011 (Table 2.3-1) with water discharges of approximately 0.04 million m^3 into an unnamed tributary of the Muskeg River from an interim wetland pond collecting site runoff.

2.3.10 ConocoPhillips Canada

The ConocoPhillips Surmont Phase 1 Project was operational in 2011 (Table 2.3-1) but does not require surface water withdrawals for production and did not discharge into any waterbodies within the lease. The Surmont Phase 2 Project was under construction in 2011.

2.3.11 Devon Energy Canada

The Devon Canada Jackfish Phase 1 and Phase 2 projects were operational in 2011 (Table 2.3-1), but did not require surface water withdrawals for production and has no direct discharges to surface waterbodies. In 2011, the Jackfish Phase 3 Project was in the application phase.

2.3.12 Dover Operating Corp.

The Dover Operating Corp. MacKay and Dover projects were in the application phase in 2011 (Table 2.3-1) and; therefore, no development was occurring during the 2011 monitoring program.

2.3.13 MEG Energy Corp.

MEG Energy became a new member of RAMP in 2011 for monitoring requirements for the Christina Lake Project. The MEG Energy Christina Lake Project Phases 1 and 2A were in the operational phase in 2011 and Phase 2B was under construction (Table 2.3-1). Water withdrawals in 2011 included groundwater withdrawals from OSE (oil sand exploration) wells of approximately 0.075 million m^3, and 0.021 million m^3 from SAGD wells for use in drilling and ice roads.

2.3.14 Japan Canada Oil Sands Limited (JACOS)

Japan Canada Oil Sands Limited (JACOS) became a new member of RAMP in 2011. In 2011, the Hangingstone Pilot Project was operational and the expansion project was in the application phase. No water was being released or withdrawn from surface waters in 2011.

2.3.15 Teck Resources Ltd.

Teck Resources Ltd. (formerly Silverbirch Energy) became a new member of RAMP in 2011 for monitoring requirements for the Frontier Project, which is currently in the application phase.

2.3.16 Cenovus Energy Inc.

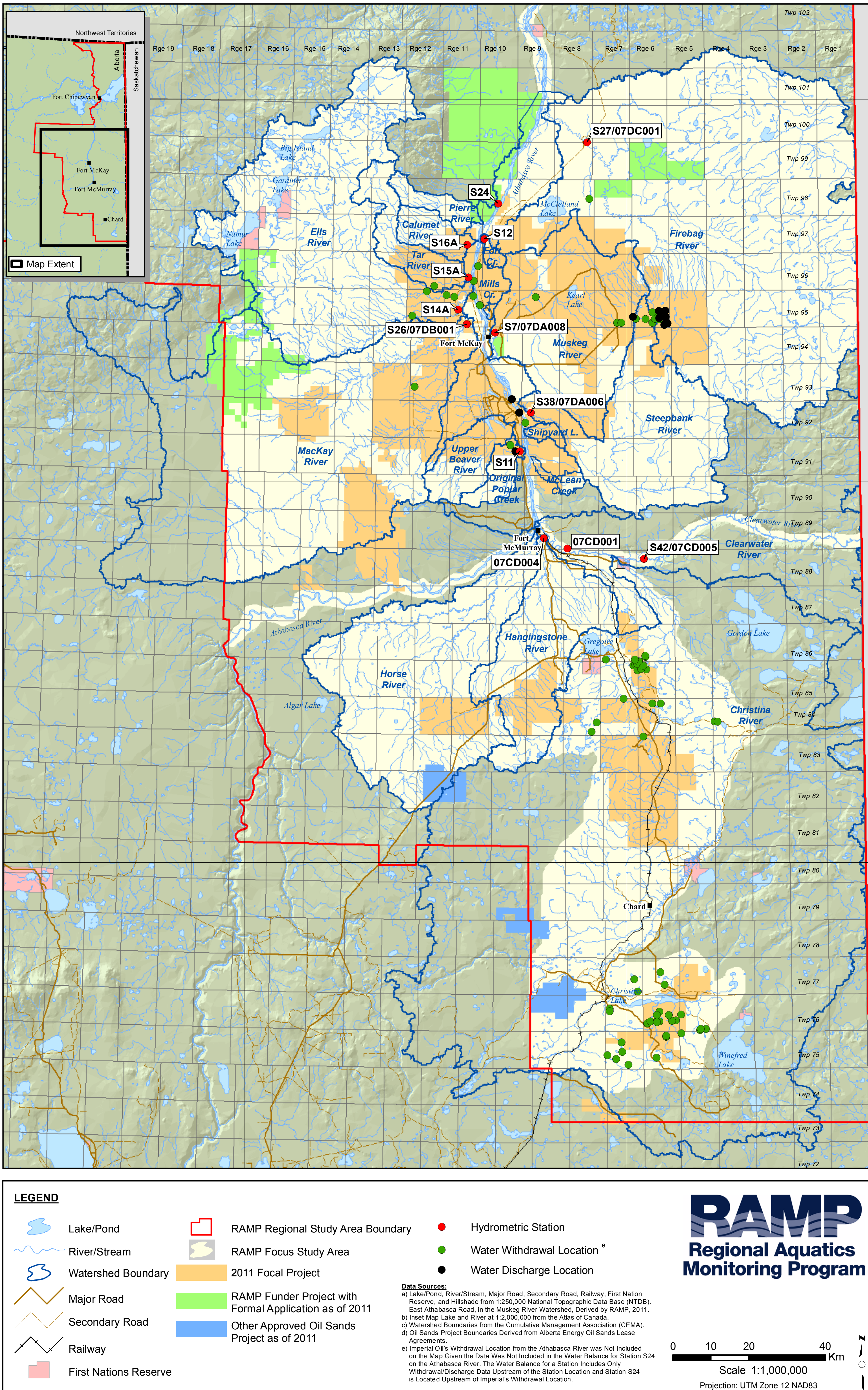
Cenovus Energy Inc. became a new member of RAMP in 2011 to meet monitoring requirements for the Christina and Narrows Lake projects. As of 2011, the Christina Project Phases 1A, 1B and C were operational and Phase 2 was under construction while the Narrows Lake project was still in the application phase. In 2011, water use and discharge requirements for these projects included:

- water withdrawals from various lakes (e.g., Reed Lake, Lard Lake, Bear Lake, and Marvin Lake) and other water sources of 0.12 million m^3; and
- discharges of site runoff between various water bodies located on the plant.

2.4 WATER USE RELATED TO FOCAL PROJECT ACTIVITIES IN 2011

Oil sands developments obtain water for their operations largely from nearby surface waters or groundwater sources. To accurately assess the hydrologic conditions of each watershed for the RAMP Climate and Hydrology Component, water withdrawal and discharge data are collected from RAMP industry members and incorporated into the hydrologic water balance model outlined in Section 3.2.1.4. The hydrologic water balance model incorporates only water that is withdrawn from one waterbody and discharged directly to another waterbody. 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.

Figure 2.4-1 Locations of surface water withdrawals and discharges from focal project activities used in the RAMP water balance calculations, 2011 Water Year.



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2.5 LAND CHANGE AS OF 2011 RELATED TO DEVELOPMENT ACTIVITIES

Land change, as of 2011 related to development activities, was estimated with satellite imagery in conjunction with more detailed maps provided by a number of RAMP industry members. Seven SPOT-5 10 m resolution images (four north of Fort McMurray and four south of Fort McMurray) taken on June 29, June 30, July 4, July 5, July 25, August 8, and August 14, 2011 and two Landsat-5 30 m resolution images (one north and one south of Fort McMurray) taken on May 15, 2011 were obtained. A land change classification protocol was developed and applied to the imagery to identify and delineate two types of land change in 2011 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 2011 land change maps.

Land change area as of 2011 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 2011 within the RAMP FSA is estimated at approximately 93,500 ha for focal projects and over 700 ha for oil sands projects operated by companies who were not members of RAMP in 2011 for a total of approximately 94,300 ha. The land change area for focal projects increased from 88,000 ha in 2010, but the land change area for oil sands projects operated by companies who were not RAMP members has decreased from 2,100 ha in 2010. This decrease reflects the addition of more companies as new members of RAMP in 2011 (i.e., Cenovus, Teck, MEG Energy, and JACOS); therefore, adding the land change from these companies to the total focal project land change area. The total area of land change represents approximately 2.7% of the area of the RAMP FSA. The percentage of the area of watersheds with land change as of 2011 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.

Land change area within the city of Fort McMurray in 2011 is estimated at 4,600 ha. Approximately half of this land change was in watersheds of smaller Athabasca River tributaries with the other half in the Hangingstone and Horse River watersheds. 2011 was the first year that RAMP delineated land change for the town of Fort McMurray; therefore, there are no historical data for comparison.

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Figure 2.5-1 RAMP land change classes derived from SPOT-5 (June and July 2011) satellite imagery, north of Fort McMurray.

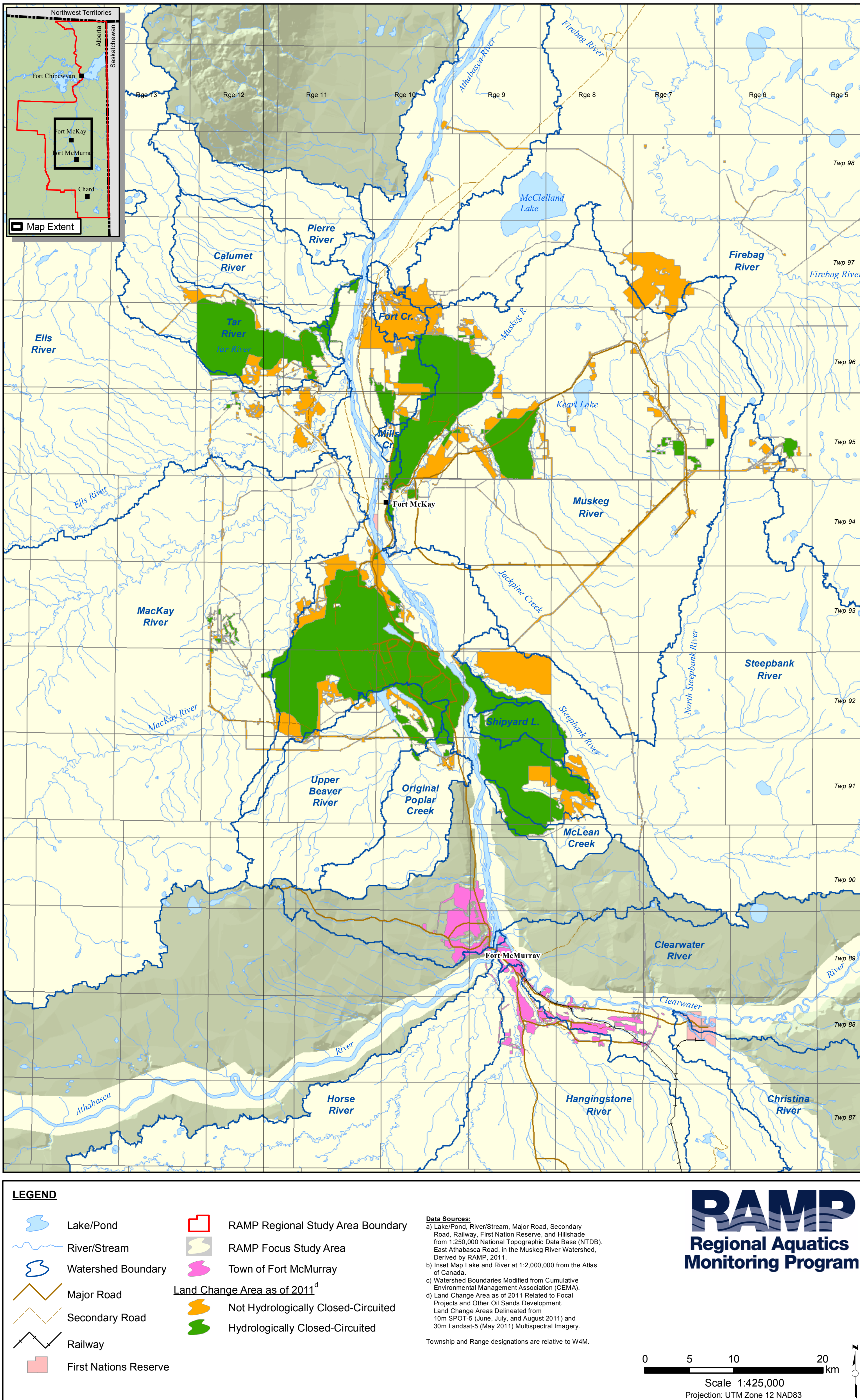

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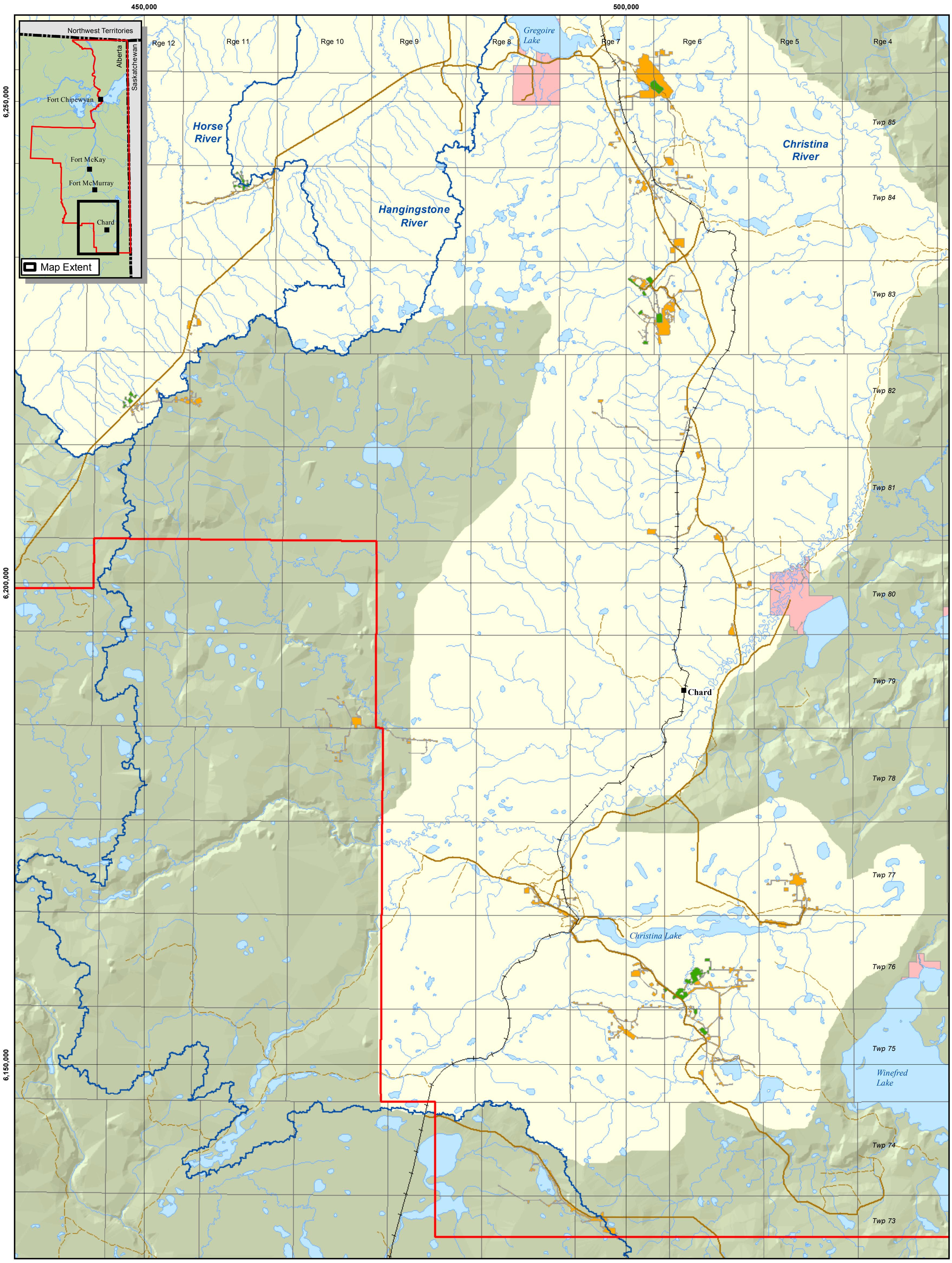
Figure 2.5-2 RAMP land change classes derived from SPOT-5 (June and August 2011) and Landsat-5 (May 2011) satellite imagery, south of Fort McMurray.



LEGEND

Lake/Pond
River/Stream
Watershed Boundary
Major Road
Secondary Road
Railway
First Nations Reserve
RAMP Regional Study Area Boundary
RAMP Focus Study Area
Town of Fort McMurray

Land Change Area as of 2011[d]

Not Hydrologically Closed-Circuited
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). East Athabasca Road, in the Muskeg River Watershed, Derived by RAMP, 2011.
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 Area as of 2011 Related to Focal Projects and Other Oil Sands Development. Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2011) and 30m Landsat-5 (May 2011) 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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Table 2.5-1 Area of watersheds with land change in 2011.

Watershed	Total Watershed Area (ha)	Watershed Area with Land Change (ha)							
		Focal Projects		Other Oil Sands Projects		Total		Watershed Total (ha and %)	
		Not-Closed Circuited (ha)	Closed-Circuited (ha)	Not-Closed Circuited (ha)	Closed-Circuited (ha)	Not-Closed Circuited (ha)	Closed-Circuited (ha)		
Muskeg	146,000	6,898	11,874			6,898	11,874	18,772	12.86
Steepbank	135,491	4,006	488			4,006	488	4,494	3.32
MacKay	557,000	1,275	538			1,275	538	1,813	0.33
Tar	33,261	1,333	7,642			1,333	7,642	8,975	26.98
Calumet	17,354	9	189			9	189	198	1.14
Firebag	568,174	4,282	257			4,282	257	4,539	0.80
Ells	245,000	1,654	164			1,654	164	1,818	0.74
Christina	1,303,805	4,854	680	504		5,358	680	6,038	0.46
Hangingstone	106,641	9	47			9	47	56	0.05
Mills Creek	890	58	235			58	235	293	32.93
Shipyard Lake	4,047	15	3,739			15	3,739	3,754	92.76
Fort Creek	3,193	1,966	33			1,966	33	1,999	62.61
Horse	215,741	115	38	163	66	278	104	382	0.18
McLean	4,712	84	1,103			84	1,103	1,187	25.20
Original Poplar[1]	13,856	182	310			182	310	492	3.55
Upper Beaver[1]	28,711	861	1,928			861	1,928	2,789	9.71
Minor Athabasca River Tributaries[2]	160,730	7,311	29,346			7,311	29,346	36,657	22.81
Total	**3,544,606**	**34,912**	**58,611**	**667**	**66**	**35,579**	**58,677**	**94,257**	**2.66**
Slave[3]	863,473	323				323	0	323	0.04

[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 upstream of Fort McMurray to the mouth of the Firebag River excluding the watersheds explicitly listed in this table.

[3] The Slave watershed was added in 2011 given some of the Canadian Natural Kirby project is located within this watershed. The Slave watershed is not part of the RAMP FSA.

Table 2.5-2 Percent of total watershed areas with land change in 2011.

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 (%)	
Muskeg	146,000	4.72	8.13	-	-	4.72	8.13	12.86
Steepbank	135,491	2.96	0.36	-	-	2.96	0.36	3.32
MacKay	557,000	0.23	0.10	-	-	0.23	0.10	0.33
Tar	33,261	4.01	22.98	-	-	4.01	22.98	26.98
Calumet	17,354	0.05	1.09	-	-	0.05	1.09	1.14
Firebag	568,174	0.75	0.05	-	-	0.75	0.05	0.80
Ells	245,000	0.68	0.07	-	-	0.68	0.07	0.74
Christina	1,303,805	0.37	0.05	0.04	-	0.41	0.05	0.46
Hangingstone	106,641	0.01	0.04	-	-	0.01	0.04	0.05
Mills Creek	890	6.52	26.41	-	-	6.52	26.41	32.93
Shipyard Lake	4,047	0.37	92.39	-	-	0.37	92.39	92.76
Fort Creek	3,193	61.57	1.03	-	-	61.57	1.03	62.61
Horse	215,741	0.05	0.02	0.08	0.03	0.13	0.05	0.18
McLean	4,712	1.78	23.42	-	-	1.78	23.42	25.20
Original Poplar[1]	13,856	1.31	2.24	-	-	1.31	2.24	3.55
Upper Beaver[1]	28,711	3.00	6.72	-	-	3.00	6.72	9.71
Minor Athabasca River Tributaries[2]	533,276	4.55	18.26	-	-	4.55	18.26	22.81
Total	**3,917,152**	**0.98**	**1.65**	**0.02**	**0.00**	**1.00**	**1.66**	**2.66**
Slave[3]	863,473	0.04	-	-	-	0.04	-	0.04

[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 upstream of Fort McMurray to the mouth of the Firebag River excluding the watersheds explicitly listed in this table.

[3] The Slave watershed was added in 2011 given some of the Canadian Natural Kirby project is located within this watershed. The Slave watershed is not part of the RAMP FSA.

2.6 LAND CHANGE RELATED TO FOREST FIRES

Forest fires burned across northern Alberta throughout the spring and summer months of 2011. Large areas within the RAMP FSA were affected by fires including 16% of the Firebag watershed and 13% of the Calumet watershed. As shown in Table 2.6-1, smaller areas of the Ells, Fort Creek, Muskeg, Tar and other Athabasca Tributaries were impacted by fires in 2011.

Table 2.6-1 Percent and area of watersheds with land change resulting from forest fires in 2011.

Watershed	Total Watershed Area (ha)	Area of Watershed Disturbed by Forest Fire (ha)	% of Watershed Disturbed by Forest Fire
Muskeg	143,256	2,669	2.0
Ells	271,380	586	0.2
Minor Athabasca River Tributaries	533,276	25,765	5.0
Tar	33,261	766	2.0
Calumet	17,534	2,338	13.0
Fort Creek	3,193	249	8.0
Firebag	568,174	93,491	16.0
Total	**1,570,075**	**125,865**	**8.0**
Total (all watersheds in FSA)	**3,917,152**		**3.0**

Section 4: Climatic and Hydrologic Characterization of the RAMP Focus Study Area in 2011 – This section of the report describes the 2011 water year (WY) (November 1, 2010 to October 31, 2011) and how the 2011 WY compares with previous years with respect to climatic and hydrologic conditions. This information helps set the context for the results, analyses, and assessments presented in Section 5.

Section 5: Assessment of 2011 Results – This is the main results section of the RAMP 2011 Technical Report, consisting of two major parts:

- Section 5.1 is the report of 2011 findings for the mainstem Athabasca River and the Athabasca River Delta;
- Sections 5.2 to 5.11 are watershed-level reports of the 2011 findings for hydrology, water quality, benthic invertebrate communities and sediment quality, and fish populations; and
- Section 5.12 is the report of 2011 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: Integration Analysis – This section of the report contains the results of an analysis that incorporates the measurement endpoints from all components to explore which key environmental variables could potentially be driving any changes that have been observed in the monitoring results.

Section 8: Conclusions and Recommendations – This section of the report contains a summary of the findings, conclusions, and recommendations from RAMP 2011. The recommendations include proposed changes to the RAMP monitoring network for future years based on the results for 2011.

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

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.

3.0 2011 RAMP MONITORING ACTIVITIES

This section contains a description of RAMP monitoring conducted in 2011 and includes the following for each RAMP component:

- Summary of 2011 monitoring activities and field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, owners and operators of the 2011 focal projects, knowledge obtained from local communities, and other sources);
- Description of changes in the monitoring network from the 2010 program;
- Description of the challenges and issues encountered during 2011 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 2011 were implemented according to the monitoring protocols, field methods, and Standard Operating Procedures (SOPs) 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 2011. Appendix B contains a detailed description of the QA/QC procedures used for RAMP monitoring in 2011.

All 2011 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 2011 RAMP Climate and Hydrology monitoring network includes:

- 17 *baseline* streamflow stations;
- Eight 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;
- 12 stations collecting climate data; and
- an area-wide snowcourse survey program.

The following sections describe the 2011 monitoring activities related to the Climate and Hydrology monitoring network.

3.1.1.1 Overview of 2011 Monitoring Activities

Climate and Hydrology monitoring in 2011 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, Steepbank, Pierre, and Surmont climate stations. The Pierre climate and Surmont climate stations started operation in July and October 2011, respectively;
  - barometric pressure monitoring at five stations;
  - monitoring total precipitation, air temperature, and relative humidity at Kearl Lake and McClelland Lake stations; 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):
  - 17 year-round stations;
  - 17 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 21 of the streamflow stations; and
  - total suspended solids (TSS) 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 2011 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 snowcourse surveys. 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 2011 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.

Table 3.1-1 RAMP climate and hydrometric stations operating in 2011.

RAMP Station	Name	UTM Coordinates[1]		Operating Season	Variables Measured
		Easting	Northing		
C1	Aurora Climate Station	475229	6344053	all year	air temperature, total precipitation, humidity, solar radiation, snow on the ground, wind speed and direction
C2	Horizon Climate Station	443364	6360510	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	air temperature, total precipitation, humidity, solar radiation, snow on the ground, barometric pressure, wind speed and direction
C4	Pierre Climate Station	460898	6378737	all year[3]	air temperature, total precipitation, humidity, solar radiation, snow on the ground, barometric pressure, wind speed and direction
C5	Surmont Climate Station	502542	6230964	all year[4]	air temperature, total precipitation, humidity, solar radiation, snow on the ground, barometric pressure, wind speed and direction
L1	McClelland Lake	483398	6372186	all year	water level, total precipitation, humidity, air temperature, water temperature
L2	Kearl Lake	484815	6351080	all year	water level, total precipitation, humidity, air temperature, water temperature
L3	Isadore's Lake	463297	6342981	all year	water level, water temperature
S2	Jackpine Creek at Canterra Road	474971	6344091	all year	level, discharge, water temperature
S3	Iyinimin Creek above Kearl Lake	489423	6345196	open-water	level, discharge, rainfall, water temperature
S5	Muskeg River above Stanley Creek	479761	6356759	all year	level, discharge, water temperature
S5A	Muskeg River above Muskeg Creek	476042	6351803	all year	level, discharge, barometric pressure, water temperature
S6	Mills Creek at Highway 63	463755	6344927	all year	level, discharge, water temperature
S7	Muskeg River near Fort McKay (07DA008)	465552	6338804	winter[2]	level, discharge, water temperature
S9	Kearl Lake Outlet	483983	6347020	all year	level, discharge, water temperature
S10	Wapasu Creek at Canterra Road	490276	6355968	all year	level, discharge, water temperature
S11	Poplar Creek at Highway 63 (07DA007)	471972	6307825	all year	level, discharge, water temperature
S12	Fort Creek at Highway 63	462620	6363554	open-water	level, discharge, water temperature
S14A	Ells River at the Canadian Natural Bridge	455738	6344944	all year	level, discharge, water temperature
S15A	Tar River near the mouth	458458	6353439	open-water	level, discharge, water temperature

1 UTM coordinate datum is NAD83 Zone 12V. In 2011, a differential GPS was used to increase the accuracy of UTM coordinates. Changes from previous coordinates reflect this increased accuracy and does not reflect a change in physical location of the station. Coordinates for WSC stations were based on WSC values posted for the stations (http://www.wateroffice.ec.gc.ca).

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

3 C4 Pierre Climate Station began operation in August 2011.

4 C5 Pierre Climate Station began operation in October 2011.

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

6 Station began operation in August 2011.

7 Station began operation in May 2011.

8 Daily water temperature data is available on the RAMP website (www.ramp-alberta.org/data).

Table 3.1-1 (Cont'd.)

RAMP Station	Name	UTM Coordinates[1]		Operating Season	Variables Measured
		Easting	Northing		
S16A	Calumet River near the mouth	458096	6362020	open-water[5]	level, discharge, water temperature
S19	Tar River Lowland Tributary near the mouth	457326	6352850	open-water	level, discharge, rainfall
S20	Muskeg River Upland	492107	6355709	open-water	level, discharge
S22	Muskeg Creek near the mouth	480969	6349071	open-water	level, discharge
S24	Athabasca River below Eymundson Creek	466305	6372764	all year	level, discharge, water temperature
S25	Susan Lake Outlet	464513	6368477	open-water	level, discharge
S26	MacKay River near Fort McKay (07DB001)	458019	6341008	winter[2]	discharge
S27	Firebag River near the mouth (07DC001)	487914	6389855	winter[2]	discharge
S29	Christina River near Chard (07CE002)	508211	6187940	winter[2]	discharge
S31	Hangingstone Creek at North Star Road	469812	6236089	open-water	level, discharge, rainfall
S32	Surmont Creek at Highway 31	490250	6254524	open-water	level, discharge, water temperature
S33	Muskeg River at the Aurora North/Muskeg River Mine Boundary	474878	6350204	all year	level, discharge, water temperature
S34	Tar River above Canadian Natural Lake	440745	6361662	all year	level, discharge, water temperature
S36	McClelland Lake Outlet above Firebag River	490635	6384056	open-water	level, discharge, water temperature
S37	East Jackpine Creek near the 1300 m contour	487850	6325416	open-water	level, discharge
S38	Steepbank River near Fort McMurray (07DA006)	475296	6317398	winter[2]	discharge
S39	Beaver River above Syncrude (07DA018)	465560	6311437	winter[2]	discharge
S40	MacKay River at Petro-Canada Bridge	444949	6314178	all year	level, discharge, water temperature, rainfall
S42	Clearwater River above Christina River (07DC005)	504427	6279666	winter[2]	discharge
S43	Firebag River upstream of Suncor Firebag	531704	6354796	open-water	level, discharge, water temperature, rainfall
S44	Pierre River near Fort McKay (Formerly 07DA013)	460769	6369299	open-water	level, discharge, water temperature
S45	Ells River above Joslyn Creek Diversion	440325	6342418	all year	level, discharge, water temperature
S46	Athabasca River near Embarras Airport	470241	6463209	all year[6]	level, discharge, water temperature
S47	Christina River near the mouth	500697	6276412	all year[6]	level, discharge, water temperature
S48	Big Creek	470817	6389113	open-water[7]	level, discharge, water temperature
S49	Eymundson Creek near the mouth	465473	6372694	open-water[6]	level, discharge, water temperature
S50	Red Clay Creek	474954	6396094	open-water[7]	level, discharge, water temperature

[1] UTM coordinate datum is NAD83 Zone 12V. In 2011, a differential GPS was used to increase the accuracy of UTM coordinates. Changes from previous coordinates reflect this increased accuracy and does not reflect a change in physical location of the station. Coordinates for WSC stations were based on WSC values posted for the stations (http://www.wateroffice.ec.gc.ca).

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

[3] C4 Pierre Climate Station began operation in August 2011.

[4] C5 Pierre Climate Station began operation in October 2011.

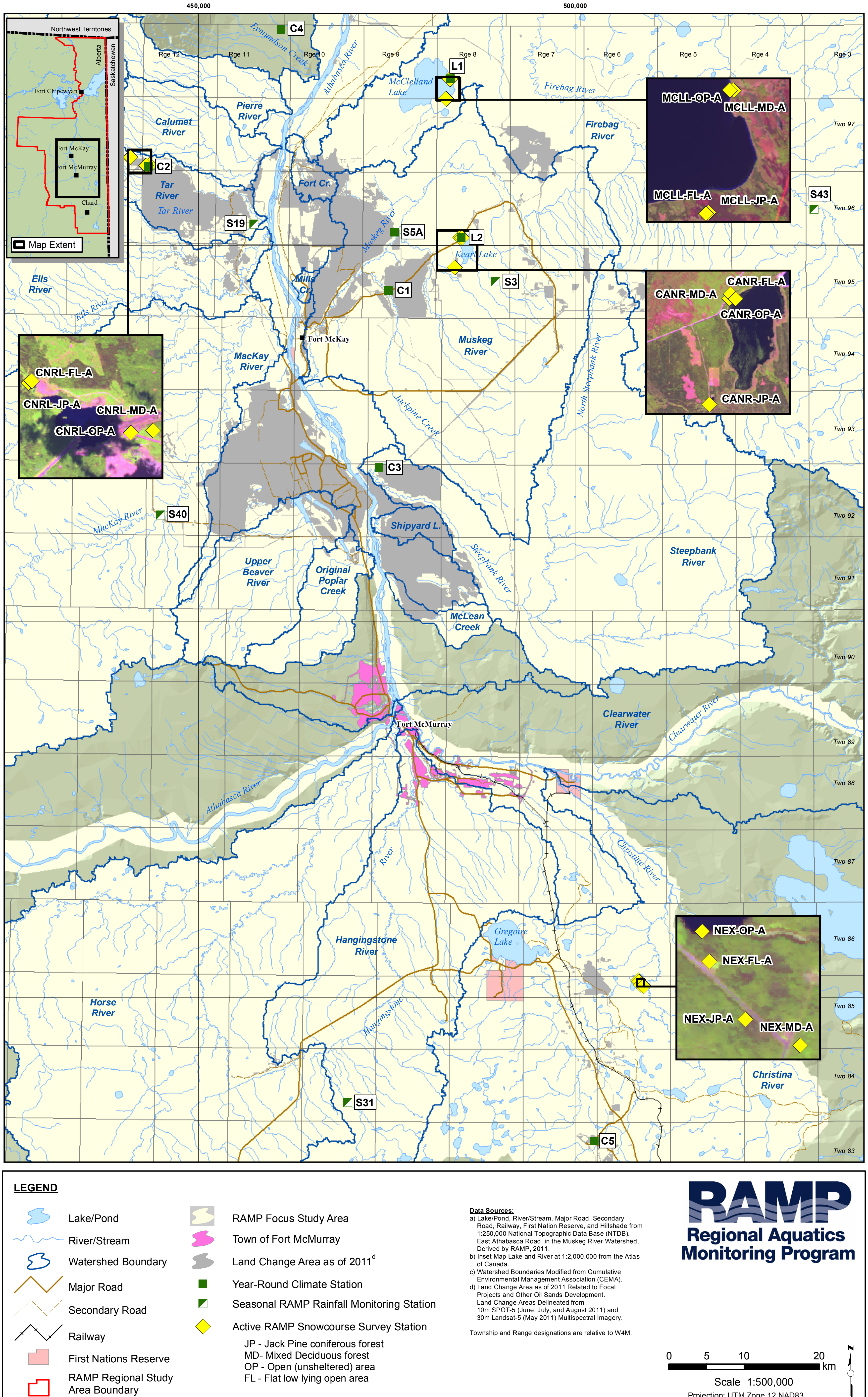
[5] S16A replaced CR-1 (CNRL) and former RAMP S16 which all monitor the Calumet River near the Mouth.

[6] Station began operation in August 2011.

[7] Station began operation in May 2011.

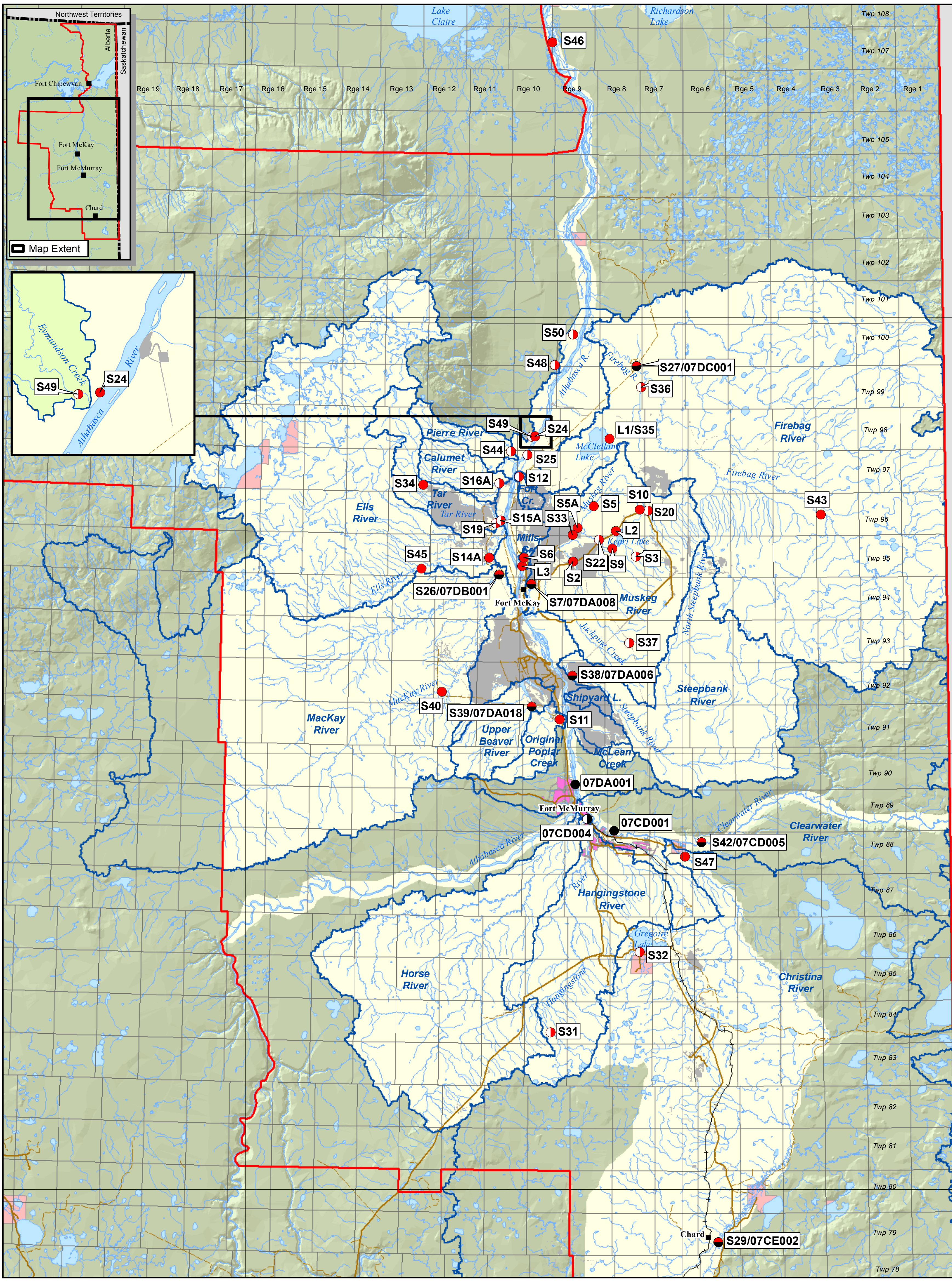
[8] Daily water temperature data is available on the RAMP website (www.ramp-alberta.org/data).

Figure 3.1-1 Locations of RAMP climate stations and snowcourse survey stations, 2011.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_D_Climate_20120423.mxd

Figure 3.1-2 Locations of RAMP and Water Survey of Canada hydrometric stations, 2011.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Town of Fort McMurray
- Land Change Area as of 2011[d]

Hydrometric Station

- Year-Round RAMP
- Seasonal RAMP
- Year-Round RAMP/Water Survey of Canada
- Year-Round Water Survey of Canada
- Seasonal 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). East Athabasca Road, in the Muskeg River Watershed, Derived by RAMP, 2011.

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 Area as of 2011 Related to Focal Projects and Other Oil Sands Development. Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2011) and 30m Landsat-5 (May 2011) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP Regional Aquatics Monitoring Program

0 10 20 40 km

Scale 1:950,000

Projection: UTM Zone 12 NAD83

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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). QA/QC 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 effective depth 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), Ott ADC (Acoustic Digital Current meter) and electromagnetic meters (Marsh McBirney Flo-Mate 2000); and 45 seconds for mechanical meters.

The flow measurements conducted for the RAMP 2011 program utilized a Sontek FlowTracker ADV with the exception of the Athabasca River (Stations S24 and S46) and Christina River (Station S47) measurements that utilized the Ott ADC 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.

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.

GPS Station Location and Elevation Program

As part of the September 2011 RAMP hydrometric field program, updated hydrometric station coordinates were collected using differentially corrected GPS data. This method allowed for sub-metre precision, three-dimensional coordinates of each hydrometric and climate station to be collected using the following methodology:

- The Trimble Geo XT GPS was positioned on a tripod, above an existing benchmark at each hydrometric and climate station;
- X, Y, and Z data were collected using a sampling interval of one second for a period of 30 to 60 minutes; and
- The raw one-second interval data were post-processed using differential correction with data simultaneously collected at a nearby GPS base station to derive an X, Y, and Z coordinate for each station.

Updated UTM coordinates are presented in Table 3.1-1. Benchmark elevation data (reported to the nearest 0.5 metre) are provided in Appendix C to provide a general reference elevation for each station.

3.1.1.3 Changes in Monitoring Network from 2010

New Monitoring Stations

- The Pierre climate station (Station C4) was installed and became fully operational in late July 2011 and includes measurements of air temperature, relative humidity, precipitation, solar radiation, snow depth, wind speed and direction, and barometric pressure. Station C4 measures all standard meteorological variables on the west side of the Athabasca River in the Eymundson Creek watershed north of the Horizon climate station (Station C2).
- To address the lower density of climate stations to the south of Fort McMurray the Surmont climate station (Station C5) was installed and became operational in October 2011. The station measures all standard meteorological variables of air temperature, relative humidity, precipitation, solar radiation, snow depth, wind speed and direction, and barometric pressure. Station C5 is located between Christina Lake and Fort McMurray near Hwy 881.
- With the expansion of oil sands development an additional mainstem Athabasca River station, downstream of the Firebag River, was considered for installation to provide mainstem monitoring below all oil sands development. In response to this monitoring requirement, Station S46, Athabasca River near the Embarras

airport, was installed in August 2011 and monitors water level, discharge, and water temperature near the discontinued Water Survey of Canada station (Station 07DD001).

- Monitoring in the Christina River watershed at the Christina River near Chard (approximately 90 km upstream of the confluence with the Clearwater River) has been ongoing by both WSC and RAMP. This monitoring was enhanced in 2011 with the installation of Station S47, Christina River near the mouth, which began operation in July 2011 and measures water level, discharge, and water temperature on the Christina River approximately 6 km upstream of the confluence with the Clearwater River.
- Due to potential expansion of oil sands development to the northwest of the Athabasca River, new hydrometric stations were established in 2011 to provide *baseline* monitoring of three watersheds draining into the Athabasca River, north of the Pierre River watershed. Stations on Big Creek (Stations S48), Eymundson Creek near the mouth (Station S49), and Red Clay Creek (Station S50) were installed and began operation in 2011 measuring water level, discharge, and water temperature.

Modified Stations

The following modifications and field equipment upgrades were made in 2011 to support station function and data collection reliability:

- Ten stations were upgraded with new data loggers and pressure transducers to proactively replace ageing equipment and improve data collection reliability. These upgraded stations include: Isadore's Lake (Station L3), Jackpine Creek at Canterra Road (Station S2), Iyinimin Creek above Kearl Lake (Station S3), Kearl Lake Outlet (Station S9), Wapasu Creek at Canterra Road (Station S10), Fort Creek at Hwy 63 (Station S12), Ells River at CNRL Bridge (Station S14A), Calumet River near the mouth (Station S16A), McClelland Lake outlet above the Firebag River (Station S36), and Pierre River near Fort McKay (Station S44).
- Seven stations were upgraded with calibrated pressure transducers and sensors based on a two-year exchange cycle for all year-round monitoring stations. These upgraded stations include: Horizon climate station (Station C2), McClelland Lake (Station L1), Kearl Lake (Station L2), Muskeg River at the Muskeg River Mine/Aurora North Boundary (Station S33), MacKay River at Petro-Canada Bridge (Station S40), Firebag River above Suncor Firebag (Station S43), and Ells River above Joslyn Creek Diversion (Station S45).

3.1.1.4 Challenges Encountered and Solutions Applied

Wildfire, Wildlife, and Environmental Challenges

The following wildfire, wildlife and environmental challenges were addressed by the RAMP Climate and Hydrology component in 2011:

- The pressure transducer at McClelland Lake (Station L1) was encased in ice on January 23 due to extreme cold conditions, which affected water level measurements until the ice around the pressure transducer thawed on May 12.
- Station S15A, Tar River near the mouth, was damaged by wildfire on June 23, 2011. The station was reinstalled and became fully operational on August 12.
- Station S16A, Calumet River near the mouth, was damaged by wildfire in spring 2011 (the exact date is unknown given that the logger melted from the fire). The

station was replaced with a new datalogger and pressure transducer on July 27 when field crews were able to access the area.

- A wildfire damaged the pressure transducer at Station S24, Athabasca River below Eymundson Creek, on June 2, 2011. Station function was reinstated during the following station visit on June 18.
- Station S36, McClelland Lake outlet, was damaged on May 8, 2011 by wildfire. The station was repaired on July 27 when field crews were able to access the area.
- The pressure transducer at Station S45, Ells River above Joslyn Creek Diversion, was pulled out of the data logger by wildlife on September 27, 2011. Station function was reinstated on October 28.
- The pressure transducer wiring at Station S48, Big Creek, was pulled from the data logger on June 1, 2011 by an unknown source. The pressure transducer was rewired on July 28 to reinstate the full function of the station.

Data Logger Malfunctions and Attrition

The following data logger malfunctions and equipment challenges were addressed by the RAMP Climate and Hydrology component in 2011:

- A faulty voltage regulator caused Station S10, Wapasu Creek at Canterra Road, to lose power on December 13, 2010. The voltage regulator was replaced on the next station visit on January 15, 2011 and station function was reinstated.
- The pressure transducer at Station S14A, Ells River near the CNRL Bridge, failed on July 24, 2011. A new pressure transducer and datalogger were installed on August 12 to reinstate the station.
- The pressure transducer at Station S31, Hangingstone Creek at Northstar Road, malfunctioned shortly after installation in late April and was replaced with a newly-calibrated pressure transducer on June 20.
- The datalogger malfunctioned at Station S19, Tar River Lowland Tributary near the mouth, after installation on April 19, 2011. Data recording was reinstated on June 24 when a replacement datalogger was installed at the station.

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 Wood Buffalo Environmental Association (WBEA) and Environment Canada (EC) 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 station are used in the RAMP 2011 reporting period.

Table 3.1-2 Summary of RAMP data available for the Climate and Hydrology component, 1997 to 2011. (Page 1 of 2)

see symbol key at bottom

Location	1997				1998				1999				2000				2001			
	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Mainstem																				
Athabasca River below Eymundson Creek (S24)																		2	2	2
Athabasca River near Embarras Airport (S46)																				
Athabasca River East Tributaries																				
Fort Creek at Highway 63 (S12)														2	2	2		2	2	2
Isadore's Lake (L3)													1	1	1	1	1	1	1	1
Mills Creek at Highway 63 (S6)		2	2	2		2	2	2		2	2	2		2d	2d	2d		2	2	2
Susan Lake Outlet (S25)																				
Muskeg River Basin																				
Aurora Climate Station (C1)	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g
Kearl Lake (L2)										1	1	1	1	1	1	1		1	1	1
Alsands Drain (S1)		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
Iyinimin Creek above Kearl Lake (S3)		2	2	2		2a	2a	2a		2a	2a	2a						2a	2a	2a
Blackfly Creek near the Mouth (S4)		2	2	2		2	2	2												
Muskeg River above Stanley Creek (S5)																				
Muskeg River above Muskeg Creek (S5A)		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River near Fort McKay (07DA008, S7)													2	4	4	4	2	4	4	4
Stanley Creek near the Mouth (S8)											1	1		1	1	1		1	1	1
Kearl Lake Outlet (S9)						2	2	2		2e	2e	2e						2	2	2
Wapasu Creek at Canterra Road (S10)		2								2	2	2						2	2	2
Albian Pond 3 Outlet (S13)														2	2	2		2	2	2
Muskeg River Upland (S20)																		2	2	2
Shelley Creek near the Mouth (S21)																		1	1	1
Muskeg Creek near the Mouth (S22)																		2	2	2
Aurora Boundary Weir (S23)																	2	2	2	2
Khahago Creek below Black Fly Creek (S28)																		2	2	2
Muskeg River at the Aurora/Albian Boundary (S33)																				
East Jackpine Creek near the 1300 m Contour (S37)																				
Muskeg River High Water Gauging			3				3				3				3				3	
Jackpine Creek High Water Gauging			3				3												3	
Steepbank River Basin																				
Steepbank Climate Station (C3)																				
Steepbank River near Fort McMurray (07DA006, S38)																				
Firebag River Basin																				
McClelland Lake (L1)			2	2		2	2	2		2	2	2		2	2	2		2	2	2
Firebag River near the Mouth (07DC001, S27)																				
McClelland Lake Outlet at McClelland Lake (S35)																				
McClelland Lake Outlet above Firebag River (S36)																				
Firebag River upstream of Suncro Firebag (S43)																				

Location	2002				2003				2004				2005				2006			
	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
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
Athabasca River near Embarras Airport (S46)																				
Athabasca River East Tributaries																				
Fort Creek at Highway 63 (S12)		2	2	2														2	2	2
Isadore's Lake (L3)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mills Creek at Highway 63 (S6)		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
Susan Lake Outlet (S25)		2	2	2														2	2	2
Muskeg River Basin																				
Aurora Climate Station (C1)	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g
Kearl Lake (L2)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alsands Drain (S1)	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
Iyinimin Creek above Kearl Lake (S3)		2a	2a	2a		2a	2	2		2	2	2		2a	2a	2		2a	2a	2a
Blackfly Creek near the Mouth (S4)																				
Muskeg River above Stanley Creek (S5)						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River above Muskeg Creek (S5A)	2d	2d	2d	2d	2d	2d	2d	2d	2d	2d	2d	2td	2td	2td	2td	2td	2td	2td	2td	2td
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
Stanley Creek near the Mouth (S8)		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
Wapasu Creek at Canterra Road (S10)		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Albian Pond 3 Outlet (S13)		2	2	2																
Muskeg River Upland (S20)		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth (S21)		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
Aurora Boundary Weir (S23)	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
Muskeg River at the Aurora/Albian Boundary (S33)						2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
East Jackpine Creek near the 1300 m Contour (S37)																				
Muskeg River High Water Gauging																				
Jackpine Creek High Water Gauging																				
Steepbank River Basin																				
Steepbank Climate Station (C3)																				
Steepbank River near Fort McMurray (07DA006, S38)																				
Firebag River Basin																				
McClelland Lake (L1)		2a	2a	2a	2a	2a	2a	2	2	2a	2a	2a		2	2	2	1	1b	1b	1bf
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
McClelland Lake Outlet at McClelland Lake (S35)																				
McClelland Lake Outlet above Firebag River (S36)																				
Firebag River upstream of Suncro Firebag (S43)																				

Location	2007				2008				2009				2010				2011				2011
	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	n/a
Athabasca River near Embarras Airport (S46)																			2	2	n/a
Athabasca River East Tributaries																					
Fort Creek at Highway 63 (S12)		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	>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	>5% Land Change
Mills Creek at Highway 63 (S6)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	2t	>5% Land Change
Susan Lake Outlet (S25)		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	Baseline
Muskeg River Basin																					
Aurora Climate Station (C1)	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	g	n/a
Kearl Lake (L2)	1	1	1	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	1th	>5% Land Change
Alsands Drain (S1)																					
Jackpine Creek at Canterra Road (S2)	2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	>5% Land Change
Iyinimin Creek above Kearl Lake (S3)		2	2a	2		2a	2a	2a		2	2	2		2a	2a	2a		2a	2a	2a	>5% Land Change
Blackfly Creek near the Mouth (S4)																					
Muskeg River above Stanley Creek (S5)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2	2	2	2t	>5% Land Change
Muskeg River above Muskeg Creek (S5A)	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	2td	>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	>5% Land Change
Stanley Creek near the Mouth (S8)																					
Kearl Lake Outlet (S9)	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	>5% Land Change
Albian Pond 3 Outlet (S13)																					
Muskeg River Upland (S20)		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	>5% Land Change
Shelley Creek near the Mouth (S21)																					
Muskeg Creek near the Mouth (S22)		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	>5% Land Change
Aurora Boundary Weir (S23)																					
Khahago Creek below Black Fly Creek (S28)	2	2	2	2																	
Muskeg River at the Aurora/Albian Boundary (S33)	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	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		2	2	2	Baseline
Muskeg River High Water Gauging																					
Jackpine Creek High Water Gauging																					
Steepbank River Basin																					
Steepbank Climate Station (C3)											c	c	c	c	c	gd	gd	gd	gd	gd	n/a
Steepbank River near Fort McMurray (07DA006, S38)									2	4	4	4	2	4	4	4	2	4	4	4	<5% Land Change
Firebag River Basin																					
McClelland Lake (L1)	1h	1h	1h	1h	1h	1h	1h	1h	1h	1h	1th	1th	1h	1h	1th	1th	1th	1th	1th	1th	<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	<5% Land Change
McClelland Lake Outlet at McClelland Lake (S35)						2	2	2		2	2	2									<5% Land Change
McClelland Lake Outlet above Firebag River (S36)						2	2	2		2	2	2		2	2	2		2	2	2	<5% Land Change
Firebag River upstream of Suncro Firebag (S43)										2	2	2		2ta	2ta	2ta	2t	2ta	2ta	2ta	Baseline

Legend

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

Location	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008				2009				2010				2011				2011
	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	W	S	S	F	Status
Athabasca River West Tributaries																																																													
Pierre Climate Station (C4)																																																										c	c	n/a
Pierre River near Fort McKay (formerly 07DA013, S44)																																																		2	2	2		2	2	2		2	2	2	Baseline
Big Creek (S48)																																																									2	2	2	Baseline
Eymundson Creek near the Mouth (S49)																																																									2	2	2	Baseline
Red Clay Creek (S50)																																																									2	2	2	Baseline
Ells River Basin																																																													
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	2t	2t	2t	2t	
Ells River above Joslyn Creek Diversion (S45)																																																		2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	Baseline
Mackay River Basin																																																													
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	2	4	4	4	<5% Land Change
MacKay River at Petro-Canada Bridge (S40)																																													2	2t	2t	2t	2t	2t	2t	2t	2t	2ta	2ta	2ta	2ta	2ta	2ta	2ta	<5% Land Change
Tar River Basin																																																													
Horizon Climate Station (C2)																																																g	gd	gd	gd	gd	gd	gd	gd	gd	gd	gd	gd	gd	n/a
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		2t	2t	2t	>5% Land Change
Tar River Upland Tributary (S17)																		2	2	2		2	2	2		2	2	2		1	1	1																													
Tar River Lowland Tributary near the Mouth (S19)																		2	2	2		2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a	b	2b	2b	2b	b	2b	2b	2b	b	2b	2b	2b	b	2b	2b	2		2a	2a	2a		2a	2a	2a	>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	2t	2t	2t	2t	Baseline
Calumet River Basin																																																													
Calumet River near the Mouth (S16)																		2	2	2		2g	2g	2g	be	2tbe	2tbe	2tbe	e	2be	2be	2tbe	be	be	e																										
Calumet River near the Mouth (S16A)																																																						2	2	2		2	2	2	Baseline
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									
Poplar River Basin																																																													
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	2	2t	2t	2t	<5% Land Change
Beaver River above Syncrude (07DA018, S39)																																													2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	Baseline
Clearwater River Tributaries																																																													
Surmont Climate Station (C5)																																																												c	n/a
Christina River near Chard (07CE002, S29)																					2	4a	4a	4a	2	4a	4a	4a	2	4a	4a	4a	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		2a	2a	2a		2a	2a	2a	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		2t	2t	2t	Baseline
Clearwater River above Christina River (07CD005, S42)																																																	2	4	4	4	2	4	4	4	2	4	4	4	Baseline
Christina River near the Mouth (S47)																																																											2t	2t	
Snow Course Surveys																																																													
Muskeg River Basin Snowcourse Survey		c				c				c				c				c																																											
Fort Creek Basin Snowcourse Survey														c																																															
CNRL Area Snowcourse Survey																		c				c				c																																			
Wide-Area Snowcourse Survey																													c				c				c				c				c				c				c				c				n/a

Legend

a = rainfall
b = rainfall and snowfall, or total precipitation
c = snowcourse survey
d = barometric pressure
e = air temperature
f = relative humidity
g = air temperature, relative humidity, rainfall and snowfall or total precipitation, wind speed and direction, solar radiation and snow on the ground
h = 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 2011 Monitoring Activities

Monitoring activities for the Water Quality component were conducted in four sampling campaigns in 2011: winter (March 23 to 25); spring (May 18, 19 and 24); summer (July 13 to 15); and fall (September 6 to 16).

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 Alberta Environment and Water (AEW). Water quality was sampled at 52 RAMP stations in 2011. Table 3.1-3 summarizes the location of 2011 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 2011. Sampling intensity was greatest during the fall campaign, with samples collected from all 2011 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 single grab samples of water from smaller creeks or rivers, 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 total hydrocarbons (oil and grease) sample, which was taken from the surface of the water, to ensure capture of any floating hydrocarbons. The ultra-trace mercury bottle was triple-rinsed prior to the final sample collection, following guidance from the analytical laboratory.

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 in 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 peristaltic pump, which transferred water directly to sampling vessels. Samples were then preserved as required. Any intermediate sampling equipment was triple-rinsed prior to final sample collection; fresh (new) tubing was used in the peristaltic pump for each sample collected.

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 through a disposable, 0.45-µm filter. All water quality samples taken in 2011 were analyzed for the RAMP standard variables (Table 3.1-4) in all sampling seasons, with the addition of CCME fractionated hydrocarbons and PAHs to the spring, summer and fall sampling in 2011. 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 acid-extractable organics (naphthenic acids), which were analyzed by Alberta Innovates Technology Futures (AITF, formerly Alberta Research Council) in Vegreville, Alberta, and PAHs, which were analyzed by AXYS Analytical Services Ltd. in Sidney, BC. Duplicate samples were collected in fall 2011 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 2010

The 2011 monitoring network for the Water Quality component was the same as the 2010 monitoring network with the following exceptions:

- A *baseline* station in lower High Hills River (HHR-1), a tributary to the Clearwater River, was added to the program to increase available *baseline* data;
- Four *baseline* stations were established in the Pierre River area north of the Calumet watershed, including Pierre River (PIR-1), Eymundson Creek (EYC-1), Big Creek (BIC-1), and Red Clay Creek (RCC-1), to acquire *baseline* data in advance of any development in that area associated with the proposed Shell Pierre River project;
- Johnson Lake (*baseline* station JOL-1) was added to provide new *baseline* lake data;
- Muskeg Creek (*test* station MUC-1) was sampled in 2011, following the rotating panel design of the program.

3.1.2.4 Changes in Analytical Chemistry Methods from 2010

Based on discussions of the RAMP Technical Subcommittee in April 2011, and following feedback from the RAMP 2010 Peer Review (AITF 2011), two additional sets of water quality variables were collected from each RAMP station starting in spring 2011, namely:

- Ultra-trace PAHs in water, given improved method detection limits (MDL) of approximately 0.1 ng/L (versus historical PAH detection limits of 20 to 40 ng/L achieved for RAMP from 1997 to 2004) provided a greater likelihood of detecting ambient concentrations of these compounds in regional waters; and
- CCME four-fraction hydrocarbons and BTEX, to provide greater detail and resolution of any hydrocarbons observed in water (this analysis was undertaken in 2011 along with the historical Alberta Environment Protection (AEP) Total Hydrocarbons analysis, with the intent of replacing the older AEP test with the new CCME test in 2012).

Naphthenic acids, a group of alkylated carboxylic acids found in relatively high concentrations in tailings waters of oil sands facilities and in regional groundwaters (Grewer *et al.* 2010), have been analyzed by laboratories for RAMP using different methods. From 1997 to 2008, this analysis was undertaken for RAMP by ALS Environmental, using an analytical method based on Fourier Transform Infrared Spectroscopy (FTIR) developed by the University of Alberta that achieved a MDL) of 1 mg/L. Nearly all ambient waters sampled by RAMP were found to contain non-detectable concentrations of naphthenic acids at this resolution.

Table 3.1-3 Summary of sampling for the RAMP 2011 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)	475122	6298188	1	2	2	2	East bank grab
ATR-DC-W	Athabasca River upstream of Donald Creek (west bank)	474799	6298406	1	2	2	2	West bank grab
ATR-DD-E	Athabasca River downstream of all development (east bank)	463226	6367440	1	2	2	2	East bank grab
ATR-DD-W	Athabasca River downstream of all development (west bank)	463159	6368204	1	2	2	2	West bank grab
ATR-MR-E	Athabasca River upstream of the Muskeg River (east bank)	463465	6332262	-	-	-	2	East bank grab
ATR-MR-W	Athabasca River upstream of the Muskeg River (west bank)	463053	6331931	-	-	-	2	West bank grab
ATR-SR-E	Athabasca River upstream of the Steepbank River (east bank)	471372	6319544	-	-	-	2	East bank grab
ATR-SR-W	Athabasca River upstream of the Steepbank River (west bank)	470902	6319285	-	-	-	2	West bank grab
Tributaries to the Athabasca River (Southern)								
Clearwater River								
CLR-1	Clearwater River upstream of Fort McMurray	479419	6284230	-	-	-	2	Mid-channel grab
CLR-2	Clearwater River upstream of Christina River	496192	6280467	-	-	-	2	Mid-channel grab
Christina River								
CHR-1	Christina River upstream of Fort McMurray	496563	6280114	-	-	-	2	Mid-channel grab
CHR-2	Christina River upstream of Janvier	511752	6192346	-	-	-	2	Mid-channel grab
High Hills Creek								
HHR-1	High Hills River (mouth)	529955	6289304	1	2*	2	2	Mid-channel grab
Tributaries to the Athabasca River (Eastern)								
FOC-1	Fort Creek	461567	6363099	-	-	-	2	Mid-channel grab
MCC-1	McLean Creek (mouth)	474654	6306048	-	-	-	2	Mid-channel grab
Steepbank River								
NSR-1	North Steepbank River	497383	6324562	-	-	-	2	Mid-channel grab
STR-1	Steepbank River (mouth)	470757	6319553	1	-	-	2	Mid-channel grab
STR-2	Steepbank River upstream of Suncor Millennium	485803	6309355	-	-	-	2	Mid-channel grab
STR-3	Steepbank River upstream of North Steepbank River	495009	6300228	-	-	-	2	Mid-channel grab
Muskeg River and Muskeg River Tributaries								
MUR-1	Muskeg River (mouth)	463531	6332456	-	-	-	2	Mid-channel grab
MUR-6	Muskeg River upstream of Wapasu Creek	492109	6355706	-	-	-	2	Mid-channel grab
JAC-1	Jackpine Creek (mouth)	474980	6344051	-	-	-	2	Mid-channel grab
JAC-2	Jackpine Creek (upstream)	480023	6325008	-	-	-	2	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	480966	6349062				2	Mid-channel grab
IYC-1	Iyinimin Creek	489445	6345165	-	-	-	2	Mid-channel grab
STC-1	Stanley Creek (mouth)	477383	6356642	-	-	-	2	Mid-channel grab
WAC-1	Wapasu Creek at Canterra Road crossing	490268	6355933	-	-	-	2	Mid-channel grab
Firebag River								
FIR-1	Firebag River (mouth)	479030	6400123	-	-	-	2	Mid-channel grab
FIR-2	Firebag River upstream of Suncor Firebag	531491	6354835	-	-	-	2	Mid-channel grab

Legend

1 = standard water quality parameters (conventionals, major ions, nutrients, total & dissolved metals, recoverable hydrocarbons and naphthenic acids)

2 = standard water quality + PAHs

3 = AEW routine parameters (conventional parameters, major ions, nutrients and total metals)

4 = AEW routine parameters + RAMP standard parameters

5 = AEW routine parameters + PAHs

6 = standard water quality + chlorophyll-*a*

7 = standard water quality + chlorophyll-*a* + PAHs

* = Sampling was scheduled but didn't occur (station was frozen to depth, dry or couldn't be sampled due to another circumstance)

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)	463646	6330935	-	-	-	2	Mid-channel grab
POC-1	Poplar Creek (mouth)	473016	6308775	-	-	-	2	Mid-channel grab
BER-2	Beaver River (upper)	465482	6311279	-	-	-	2	Mid-channel grab
CAR-1	Calumet River (mouth)	460818	6363194	-	-	-	2	Mid-channel grab
CAR-2	Calumet River (upper river)	454049	6366798	-	-	-	2	Mid-channel grab
ELR-1	Ells River (mouth)	459304	6351517	-	-	-	2	Mid-channel grab
ELR-2	Ells River (upstream)	455554	6345424	-	-	-	2	Mid-channel grab
ELR-2A	Ells River (upstream of Fort McKay Water Intake)	454645	6343655	1	2*	2	2	Mid-channel grab
TAR-1	Tar River (mouth)	458835	6353496	-	-	-	2	Mid-channel grab
TAR-2	Tar River upstream of Canadian Natural Horizon	440357	6361662	-	-	-	2	Mid-channel grab
PIR-1	Pierre River (mouth)	462282	6367456	1*	2	2	2	Mid-channel grab
EYC-1	Eymundson Creek (mouth)	465925	6372242	1*	2	2	2	Mid-channel grab
BIC-1	Big Creek (mouth)	471683	6387689	1*	2	2	2	Mid-channel grab
RCC-1	Red Clay Creek (mouth)	475871	6395030	1*	2	2	2	Mid-channel grab
MacKay River								
MAR-1	MacKay River (mouth)	461540	6336027	-	-	-	2	Mid-channel grab
MAR-2	MacKay River upstream of Suncor MacKay	444836	6314097	-	-	-	2	Mid-channel grab
MAR-2A	MacKay River upstream of Suncor Dover	449271	6319904	1	2*	2	2	Mid-channel grab
Lakes and Wetlands								
ISL-1	Isadore's Lake	463311	6343131	-	-	-	7	Mid-lake grab
KEL-1	Kearl Lake	485270	6348913	-	-	-	7	Mid-lake grab
MCL-1	McClelland Lake	478757	6372046	-	-	-	7	Mid-lake grab
SHL-1	Shipyard Lake	473261	6313030	-	-	-	7	Mid-lake grab
JOL-1	Johnston Lake	537444	6389744	6	7*	7	7	Mid-lake grab
Tributaries to Lakes								
MIC-1	Mills Creek, tributary to Isadore's Lake	463829	6344743	-	-	-	2	Mid-channel grab
QA/QC[1]								
-				2	2	2	2	Trip and field blanks, split,
Government and Industry Monitoring Stations Contributing Data to RAMP								
ATR-UFM	Athabasca River upstream of Fort McMurray (monthly)	474901	6286327	5	3	5	3	AEW sampling
ATR-OF	Athabasca River at Old Fort (monthly)	470205	6474330	4	4	4	4	AEW sampling
ATR-FR-CC	Athabasca River upstream of the Firebag River	478031	6377868	5	5	5	5	AEW sampling

Legend

1 = standard water quality parameters (conventionals, major ions, nutrients, total & dissolved metals, recoverable hydrocarbons and naphthenic acids)

2 = standard water quality + PAHs

3 = AEW routine parameters (conventional parameters, major ions, nutrients and total metals)

4 = AEW routine parameters + RAMP standard parameters

5 = AEW routine parameters + PAHs

6 = standard water quality + chlorophyll-*a*

7 = standard water quality + chlorophyll-*a* + PAHs

* = Sampling was scheduled but didn't occur (station was frozen to depth, dry or couldn't be sampled due to another circumstance)

Figure 3.1-3 Locations of RAMP water quality sampling stations, 2011.

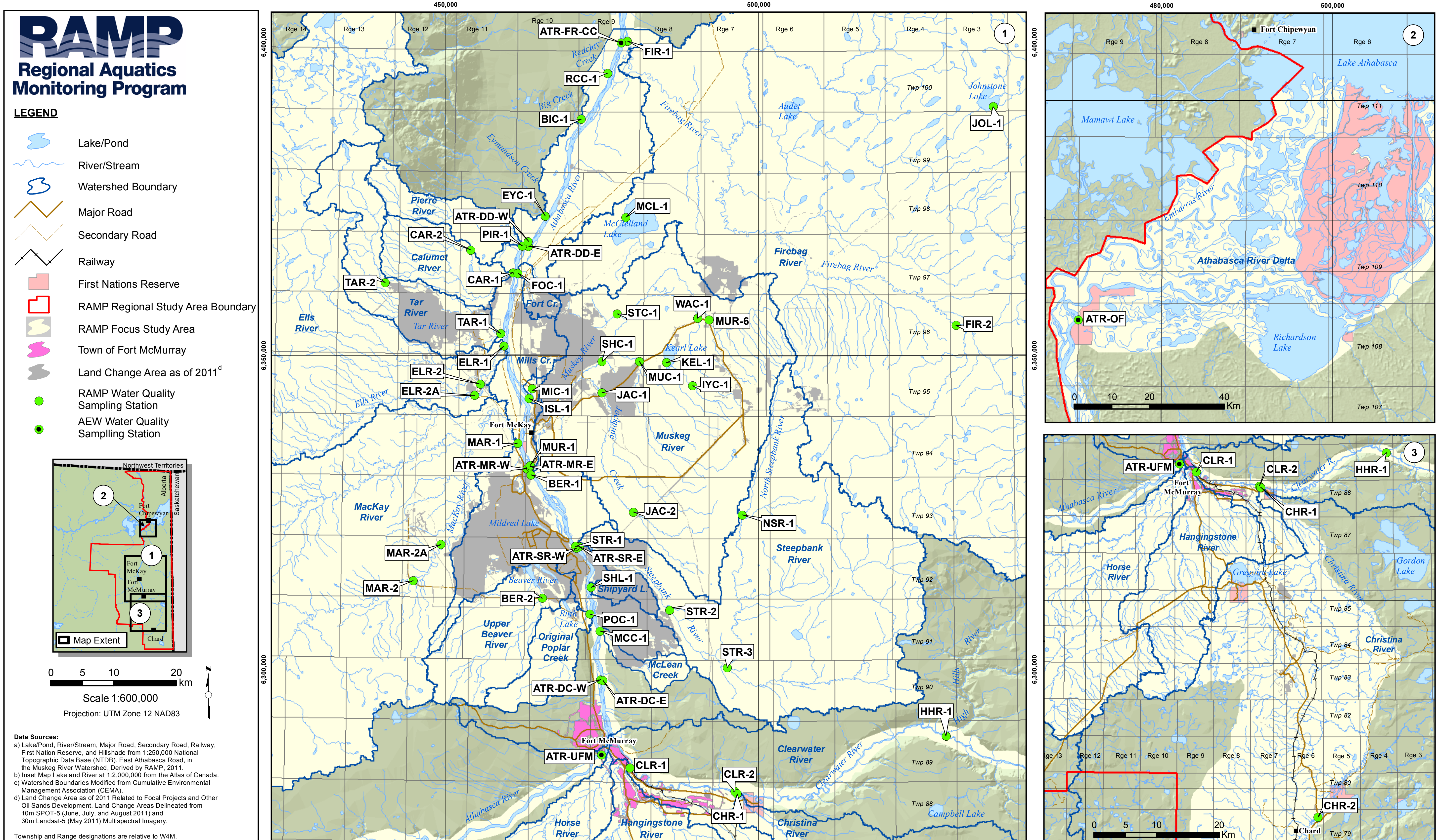


Table 3.1-4 RAMP standard water quality variables.[1]

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 phenolics
	Total recoverable hydrocarbons	Benzene
	Toluene	Ethylbenzene
	Xylenes	CCME Hydrocarbons (F1, F2, F3, F4)
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)
PAHs (ultra-trace)[4]	Acenaphthene	C2-Fluorenes
	Acenaphthylene	C2-Naphthalenes
	Anthracene	C2-Phenanthrenes/Anthracenes
	Benz[a]anthracene	C3-Dibenzothiophenes
	Benzo[a]pyrene	C3-Fluoranthenes/Pyrenes
	Benzo[b,j,k]fluoranthene	C3-Fluorenes
	Benzo[g,h,i]perylene	C3-Naphthalenes
	Biphenyl	C3-Phenanthrenes/Anthracenes
	C1-Acenaphthenes	C4-Dibenzothiophenes
	C1-Benzo[a]anthracenes/Chrysenes	C4-Naphthalenes
	C1-Benzofluoranthenes/Benzopyrenes	C4-Phenanthrenes/Anthracenes
	C1-Biphenyls	Chrysene
	C1-Dibenzothiophenes	Dibenz[a,h]anthracene
	C1-Fluoranthenes/Pyrenes	Dibenzothiophene
	C1-Fluorenes	Fluoranthene
	C1-Naphthalenes	Fluorene
	C1-Phenanthrenes/Anthracenes	Indeno[1,2,3-c,d]-pyrene
	C2-Benzo[a]anthracenes/Chrysenes	Naphthalene
	C2-Benzofluoranthenes/Benzopyrenes	Phenanthrene
	C2-Biphenyls	Pyrene
	C2-Dibenzothiophenes	Retene
	C2-Fluoranthenes/Pyrenes	

[1] Details describing analytical methods and detection limits 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).

[4] PAH species measured with a detection limit of approximately 0.1 ng/L (0.0000001 mg/L). See Section 6.3 for details.

Given improvements in analytical methods, analysis of these compounds was shifted in 2009 to AITF, which used a developmental method based on a GC/MS-ion-trapping method, which provided a method detection limit of 20 µg/L. In spring 2010, AITF modified this 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. However, triplicate samples collected by RAMP in fall 2010 and provided to other laboratories using different methods (i.e., ALS and University of Alberta) found concentrations of naphthenic acids in these samples that were orders of magnitude below those reported by AITF using their method (see Section 6 of RAMP 2011).

In 2011, RAMP samples were again analyzed for naphthenic acids by AITF, to maintain consistency with 2009 and 2010 and with AEW, which also uses AITF for this analysis for their Long-Term Regional Network (LTRN) water samples. Duplicate samples were again collected in September 2011, and provided to Dr. Jon Martin's laboratory at the University of Alberta for comparative analysis.

3.1.2.5 Challenges Encountered and Solutions Applied

During the spring sampling event, three stations and some associated QA/QC samples could not be sampled given that no helicopters required for sampling these locations were available due to extensive forest fires in the region over an extended period during spring 2011. Stations not sampled included JOL-1 (Johnston Lake), HHR-1 (High Hills River), and MAR-2A (mid-MacKay River); QA/QC samples that were not collected included the trip duplicate sample and the field blank. These stations were sampled successfully in the winter, summer and fall 2011 sampling events.

During the fall sampling event, a shipping company used to deliver samples to contract laboratories delivered a total of 11 stations and three QA/QC samples for PAH analysis two days late to AXYS in Sidney, BC, which resulted in recommended holding temperatures being exceeded (i.e., ice packs used to keep samples cool melted). All PAH water quality samples were field preserved, but to ensure these samples were not compromised, a comparative analysis was undertaken using a sample successfully delivered to the lab at proper temperatures. This sample was subsampled to create two duplicates, one of which was analyzed immediately while the other was allowed to gradually warm up to room temperature before analysis (to represent the samples arriving above holding temperatures). These two sets of results were compared against each other and the lab confirmed no obvious bias between the two datasets. The lab concluded that the samples that arrived above holding temperatures were not compromised and the results obtained were accurate.

Shelley Creek (SHC-1) located in the Muskeg River watershed was scheduled to be sampled in fall 2011; however, upon accessing the station, there was no longer water flowing in the channel. Therefore, water samples could not be collected at this station in 2011.

3.1.2.6 Other Information Obtained

All sampling for the Water Quality component in 2011 was conducted by the RAMP implementation team, with the exception of three stations on the mainstem Athabasca River (ATR-UFM, ATR-OF and ATR-FR) that were sampled by AEW, which provided these data to RAMP for inclusion in the analyses contained in this report (Table 3.1-3). The analytical package used by AEW for PAHs and CCME four fraction hydrocarbons and BTEX differed from RAMP analytical procedures, which resulted in higher detection limits in the AEW data. These higher detection limits resulted in all values being below detection, thus eliminating any comparisons between AEW and RAMP CCME hydrocarbon and PAH data.

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 AEW.

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
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
Jackpine Creek (mouth) [g]	JAC-1					13	13	13	11	13	13	13	11,1				1				1
(upper)	JAC-2																				
Shelley Creek (mouth)	SHC-1								11				11,1								
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1
Stanley Creek (mouth)	STC-1								11				11,1								1
Iyinimin Creek (mouth)	IYC-1																				
Wapasu Creek (Canterra Road Crossing)	WAC-1								11,2	1			11,1								

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	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
Muskeg River Tributaries																					
Alsands Drain (mouth) [f g h]	ALD-1	4	10	10	10	4	10	10	10	4	10	10	10								
Jackpine Creek (mouth) [g]	JAC-1				1				1		1	1	1				1				1
(upper)	JAC-2																				
Shelley Creek (mouth)	SHC-1																				1
Muskeg Creek (mouth)	MUC-1				1				1	1	1	1	1				1				1
Stanley Creek (mouth)	STC-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
Iyinimin Creek (mouth)	IYC-1																				
Wapasu Creek (Canterra Road Crossing)	WAC-1												1				1				1

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	2011 W	2011 S	2011 S	2011 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	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	1	3	3	3
(east bank) [b]	ATR-DC-E				1	1			1	1			1	1	1	1	1	1	3	3	3
(middle)	ATR-DC-M																				
Upstream of the Steepbank River (middle)	ATR-SR-M																				
(west bank)	ATR-SR-W				1				1				1				1				3
(east bank)	ATR-SR-E				1				1				1				1				3
Upstream of the Muskeg River (middle)	ATR-MR-M																				
(west bank) [b c]	ATR-MR-W				1				1				1				1				3
(east bank) [b c]	ATR-MR-E				1				1				1				1				3
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	1	3	3	3
(west bank)	ATR-DD-W	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3
Upstream of mouth of Firebag River	ATR-FR-CC				1				1				1				1	12	12	12	12
Upstream of the Embarras River (cross channel)	ATR-ER																				
Embarras River	EMR-1																				
At Old Fort (grab) [d]	ATR-OF	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																					
Big Point Channel [e]	ARD-1																				
Athabasca River tributaries (Eastern)																					
McLean Creek (mouth)	MCC-1				9				1				1				1				3
(100 m upstream)	MCC-2																				
Steepbank River (mouth)	STR-1				1	1			1	1			1	1			1	1			3
(upstream of Project Millennium)	STR-2				1				1				1				1				3
(upstream of Nt. Steepbank)	STR-3	1	1	1	1				1				1				1				3
North Steepbank River (upstream of Suncor Lewis)	NSR-1				1				1				1				1				3
Fort Creek (mouth)	FOC-1				7		6	6	7		6	6	7				1				3
Muskeg River																					
Mouth [f]	MUR-1				1				1				1				1				3
Upstream of Wapasu Creek	MUR-6				7		6	6	7				1				1				3
Muskeg River Tributaries																					
Alsands Drain (mouth) [f g h]	ALD-1																				
Jackpine Creek (mouth) [g]	JAC-1				1				1				1				2				3
(upper)	JAC-2								1				1				2				3
Shelley Creek (mouth)	SHC-1				1								1								3
Muskeg Creek (mouth)	MUC-1				1	1	1	1	1												3
Stanley Creek (mouth)	STC-1				1				1				1				1				3
Iyinimin Creek (mouth)	IYC-1			1	1				1								1				3
Wapasu Creek (Canterra Road Crossing)	WAC-1				1				1				1				1				3

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 (Pseudokirchneriella subcapitata *Ceriodaphnia dubia,* Pimephales promelusfathead minnow)
3 = standard water 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 = AEW routine parameters (conventional parameters, major ions, nutrients and total metals)
12 = AEW routine parameters + RAMP standard parameters
13 = AEW routine parameters + PAHs
14 = AEW routine parameters + DataSonde
15 = standard water quality + chlorophyll-a
16 = standard water quality + chlorophyll-a + PAHs

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)
Sampling was scheduled but didn't occur (station was frozen to depth, dry or couldn't be sampled due to another circumstance)

√ = allowance made for potential TIE

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

See symbol key below.

Waterbody and Location	Station	1997 W	S	S	F	1998 W	S	S	F	1999 W	S	S	F	2000 W	S	S	F	2001 W	S	S	F
Athabasca River tributaries (Western)																					
Poplar Creek (mouth)	POC-1																1				1
Beaver River (mouth)	BER-1																				
(upper)	BER-2																				
MacKay River (mouth)	MAR-1								1								1				1
(upstream of Suncor MacKay)	MAR-2																				
(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			
(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												
(upstream of Canadian Natural Horizon)	TAR-2																				
Calumet River (mouth)	CAR-1																				
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2																				
Firebag River (mouth)	FIR-1																				
(upstream of Suncor Firebag)	FIR-2																				
Pierre River (mouth)	PIR-1																				
Eymundson Creek (mouth)	EYC-1																				
Big Creek (mouth)	BIC-1																				
Red Clay Creek (mouth)	RCC-1																				
Athabasca River tributaries (Southern)																					
Clearwater River (upstream of Fort McMurray)	CLR-1																	3	8	8	8
(upstream of Christina River)	CLR-2																	3	8	8	8
Christina River (upstream of Fort McMurray)	CHR-1																				
(upstream of Janvier)	CHR-2																				
(mid)	CHR-2A																				
Hangingstone River (upstream of Fort McMurray)	HAR-1																				
Horse River (Fish program support)	HOR-1																				
High Hills River (mouth)	HHR-1																				
Lake Tributaries																					
Mills Creek	MIC-1																				
Wetlands (Lakes)																					
Kearl Lake (composite)	KEL-1							15,3	15,3								15,3			15	15
Isadore's Lake (composite)	ISL-1							15									15			15	15
Shipyard Lake (composite)	SHL-1							15			1	15	1			15	1			15	15
McClelland Lake (composite)	MCL-1																16			1	16
Johnston Lake (composite)	JOL-1																				
Additional Sampling (Non-Core Programs)																					
Unnammed Creek north of Ft. Creek (mouth)	UNC-1																1				
Nexen Lakes	-																		5		5
Potential TIE	-																				
QA/QC																					
Field and trip blanks, one split and duplicate	-														1	1	1			1	1

Waterbody and Location	Station	2002 W	S	S	F	2003 W	S	S	F	2004 W	S	S	F	2005 W	S	S	F	2006 W	S	S	F
Athabasca River tributaries (Western)																					
Poplar Creek (mouth)	POC-1				1				1				1				1				1
Beaver River (mouth)	BER-1							1	1			1	1			1	1				1
(upper)	BER-2																				
MacKay River (mouth)	MAR-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
(mid-river, upstream of Suncor Dover)	MAR-2A																				
Dunkirk River (Fish program support)	DUR-1																				
Ells River (mouth)	ELR-1		1	1	2	1	1	1	2	1	1	1	2	1	1	1	2				1
(upstream of Total Joslyn Mine)	ELR-2									1	1	1	2	1	1	1	1	1	1	1	1
(upstream of the Fort MacKay water intake)	ELR-2A																				
Tar River (mouth)	TAR-1		1	1	2	1	1	1	2	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
Calumet River (mouth)	CAR-1		1	1	2	1	1	1	2	1	1	1	2	1	1	1	2				1
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2													1	1	1	2	1	1	1	2
Firebag River (mouth)	FIR-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
(upstream of Suncor Firebag)	FIR-2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
Pierre River (mouth)	PIR-1																				
Eymundson Creek (mouth)	EYC-1																				
Big Creek (mouth)	BIC-1																				
Red Clay Creek (mouth)	RCC-1																				
Athabasca River tributaries (Southern)																					
Clearwater River (upstream of Fort McMurray)	CLR-1	1	7	7	8	1	7	7	8	1	7	7	7	1	7	7	7	1	7	7	7
(upstream of Christina River)	CLR-2	1	7	7	8	1	7	7	8	1	7	7	7	1	7	7	7		6	6	7
Christina River (upstream of Fort McMurray)	CHR-1	1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	1				1
(upstream of Janvier)	CHR-2	1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	1				1
(mid)	CHR-2A																				
Hangingstone River (upstream of Fort McMurray)	HAR-1									1	1	1	1	1	1	1	1	1	1	1	1
Horse River (Fish program support)	HOR-1																				
High Hills River (mouth)	HHR-1																				
Lake Tributaries																					
Mills Creek	MIC-1																				
Wetlands (Lakes)																					
Kearl Lake (composite)	KEL-1				1	1			1			15	15			15	15				15
Isadore's Lake (composite)	ISL-1											15	15			15	15			15	15
Shipyard Lake (composite)	SHL-1			15	15			1	1			15	15			15	15			15	15
McClelland Lake (composite)	MCL-1				1				1												15
Johnston Lake (composite)	JOL-1																				
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

Waterbody and Location	Station	2007 W	S	S	F	2008 W	S	S	F	2009 W	S	S	F	2010 W	S	S	F	2011 W	S	S	F
Athabasca River tributaries (Western)																					
Poplar Creek (mouth)	POC-1				1				1				1				1				3
Beaver River (mouth)	BER-1				1	1			1				1				1				3
(upper)	BER-2						1	1	1	1	1	1	1	1	1	1	1				3
MacKay River (mouth)	MAR-1				1	1	1	1	1	1	1	1	1				1				3
(upstream of Suncor MacKay)	MAR-2				1	1	1	1	1	1	1	1	1				1				3
(mid-river, upstream of Suncor Dover)	MAR-2A									1	1	1	1	1	1	1	1	1	3	3	3
Dunkirk River (Fish program support)	DUR-1												1								
Ells River (mouth)	ELR-1				1				1				1				1				3
(upstream of Total Joslyn Mine)	ELR-2	1	1	1	1				1				1				1				3
(upstream of the Fort MacKay water intake)	ELR-2A																1	1	3	3	3
Tar River (mouth)	TAR-1				1				1		1	1	1				1				3
(upstream of Canadian Natural Horizon)	TAR-2	1	1	1	2				1		1	1	1				1				3
Calumet River (mouth)	CAR-1				1				1				1				1				3
Calumet River (upstrream of Canadian Natural Horizon)	CAR-2	1	1	1	2				1				1				1				3
Firebag River (mouth)	FIR-1				1				1				1				1				3
(upstream of Suncor Firebag)	FIR-2				1				1				1				1				3
Pierre River (mouth)	PIR-1																	1	3	3	3
Eymundson Creek (mouth)	EYC-1																	1	3	3	3
Big Creek (mouth)	BIC-1																	1	3	3	3
Red Clay Creek (mouth)	RCC-1																	1	3	3	3
Athabasca River tributaries (Southern)																					
Clearwater River (upstream of Fort McMurray)	CLR-1		7	7	7				1				1				1				3
(upstream of Christina River)	CLR-2		6		7				1				1				1				3
Christina River (upstream of Fort McMurray)	CHR-1	1			1				1				1				1				3
(upstream of Janvier)	CHR-2	1			1				1				1				1				3
(mid)	CHR-2A	1			1																
Hangingstone River (upstream of Fort McMurray)	HAR-1		1	1	1				1												
Horse River (Fish program support)	HOR-1												1								
High Hills River (mouth)	HHR-1																	1	3	3	3
Lake Tributaries																					
Mills Creek	MIC-1																1				3
Wetlands (Lakes)																					
Kearl Lake (composite)	KEL-1			16	15				15				15				15				16
Isadore's Lake (composite)	ISL-1			15	15			15	15				15				15				16
Shipyard Lake (composite)	SHL-1			15	15			15	15				15				15				16
McClelland Lake (composite)	MCL-1				15				15				1				15				16
Johnston Lake (composite)	JOL-1																	15	16	16	16
Additional Sampling (Non-Core Programs)																					
Unnammed Creek north of Ft. Creek (mouth)	UNC-1																				
Nexen Lakes	-										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

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 (Pseudokirchneriella subcapitata *Ceriodaphnia dubia,* Pimephales promelusfathead minnow)
3 = standard water 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 = standard water quality + chlorophyll-a
16 = standard water quality + chlorophyll-a + PAHs

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)
Sampling was scheduled but didn't occur (station was frozen to depth, dry or couldn't be sampled due to another circumstance)

√ = allowance made for potential TIE

3.1.3 Benthic Invertebrate Communities and Sediment Quality

3.1.3.1 Overview of Benthic Invertebrate Communities Component 2011 Monitoring Activities

Benthic invertebrates were collected from September 3 to 15, 2011. A total of 270 samples were collected from 27 river reaches and five 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 2003a, RAMP 2009b), which were developed from Alberta Environment (1990), Environment Canada (1993), Klemm *et al.* (1990) and Rosenberg and Resh (1993). A Neill-Hess cylinder (0.093-m^2 opening and 210-µm mesh) was used for collection of benthic invertebrates in erosional areas. An Ekman grab (0.023 m^2, 6″ x 6″) was used for benthic invertebrate collections in depositional habitats and was deployed using a rope and messenger in lakes.

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

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

- Wetted and bankfull channel widths – visual estimate (for rivers/streams only); *in situ* water quality measurements – DO, temperature, pH and conductivity 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);
- Current velocity – determined by measuring the time for a semi-submerged object to travel a known distance (2 m);
- Water depth at the benthic sampling location – measured with a graduated device (pole or Hess cylinder);
- Amount of benthic algae at erosional stations (for chlorophyll *a* measurement) – obtained by scraping a 1 cm x 1 cm square from three randomly-selected cobbles and combining these into one composite sample per station;
- Substrate particle size distribution (erosional stations only) – visual estimates of areal coverage by particles in standard size categories using the modified Wentworth classification system (Cummins 1962) and expressed as percentages;
- An additional Ekman grab sample collected at depositional stations for analysis of total organic carbon (TOC, as a dry weight percentage) and particle size (% sand, silt and clay, as dry weight);
- Geographical position – using a hand-held GPS unit; and
- General station appearance.

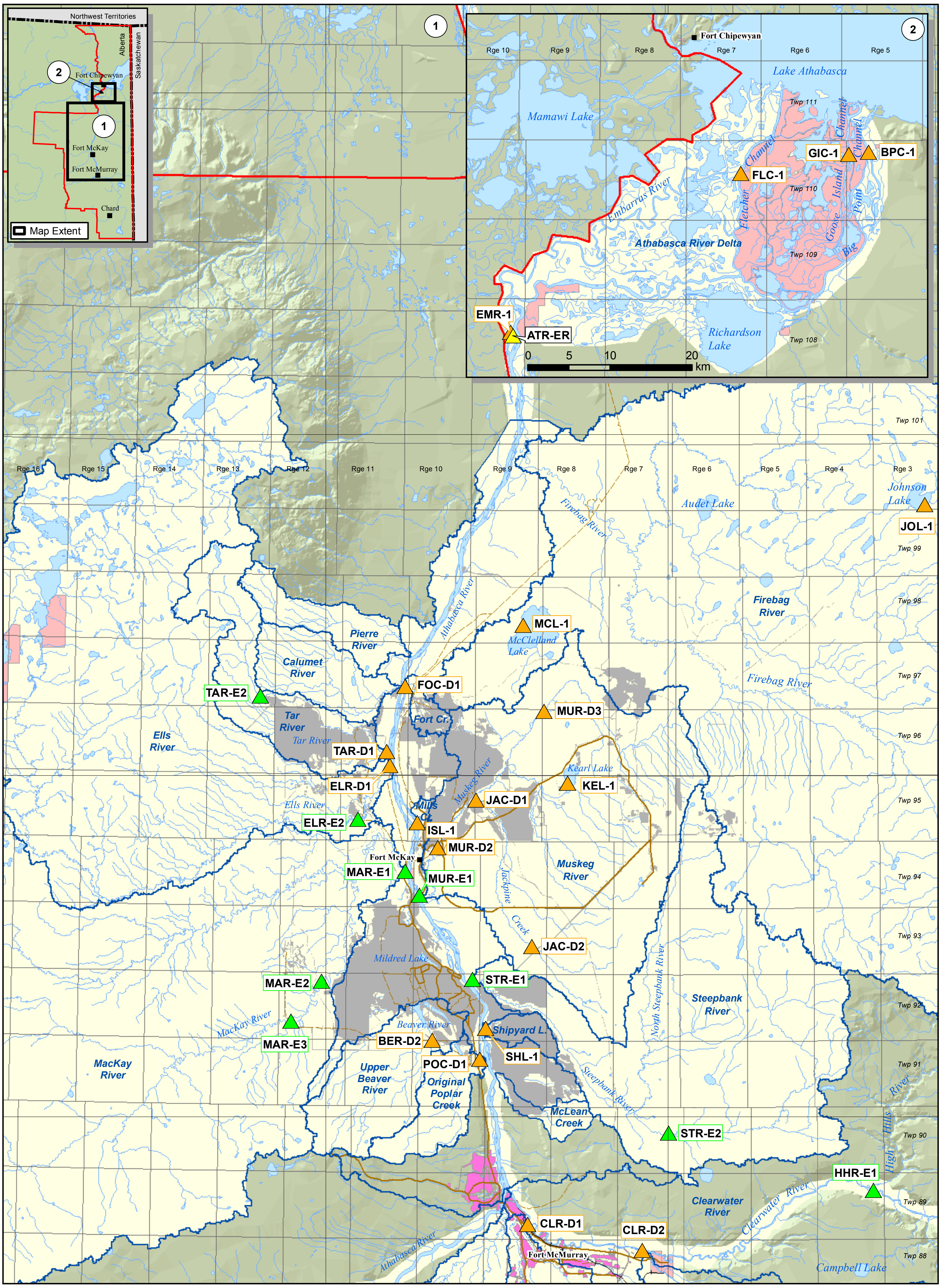
Table 3.1-6 Summary of sampling locations for the RAMP 2011 Benthic Invertebrate Communities component.

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	GIC-1	509622	6494019		
Big Point Channel	depositional	BPC-1	512046	6494274		
Fletcher Channel	depositional	FLC-1	496464	6491687		
Embarras	depositional	EMR-1	468454	6472271		
Steepbank River						
Lower Reach	erosional	STR-E1	471359	6320150	472401	6319883
Upper Reach	erosional	STR-E2	500372	6297491	501111	6297788
Muskeg River						
Lower Reach	erosional	MUR-E1	463643	6332493	464557	6332299
Middle Reach	depositional	MUR-D2	466297	6339500	466608	6340506
Upper Reach	depositional	MUR-D3	481822	6359425	482132	6360101
Jackpine Creek						
Lower Reach	depositional	JAC-D1	471861	6346435	473065	6346315
Upper Reach	depositional	JAC-D2	480023	6325008	480785	6324636
Beaver River						
Upper Reach	depositional	BER-D2	465482	6311279	465221	6311024
Poplar Creek						
Lower Reach	depositional	POC-D1	474426	6308509	473016	6308775
MacKay River						
Lower Reach	erosional	MAR-E1	461540	6336027	460675	6336711
Middle Reach	erosional	MAR-E2	449271	6319904	448743	6318494
Upper Reach	erosional	MAR-E3	444810	6314074	444006	6314215
Tar River						
Lower Reach	depositional	TAR-D1	458852	6353527	458507	6353543
Upper Reach	erosional	TAR-E2	440357	6361662	439870	6362093
Ells River						
Lower Reach	depositional	ELR-D1	459304	6351517	459023	6352010
Upper Reach	erosional	ELR-E2A	454642	6343650	454039	6343851
Clearwater River						
Lower Reach	depositional	CLR-D1	479419	6384230	481566	6283396
Upper Reach	depositional	CLR-D2	499541	6279723	501146	6279686
High Hills River						
Lower Reach	erosional	HHR-E1	529955	6289304		
Fort Creek						
Lower Reach	depositional	FOC-D1	461550	6363107	463658	6363076
Lakes[2]						
Kearl Lake	lake	KEL-1	485270	6348913		
McClelland Lake	lake	MCL-1	478757	6372046		
Shipyard Lake	lake	SHL-1	473261	6313030		
Isadore's Lake	lake	ISL-1	463322	6343131		
Johnson Lake	lake	JOL-1	538744	6389744		

[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, 2011.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Town of Fort McMurray
- Land Change Area as of 2011[d]
- 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). East Athabasca Road, in the Muskeg River Watershed, Derived by RAMP, 2011.

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 Area as of 2011 Related to Focal Projects and Other Oil Sands Development. Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2011) and 30m Landsat-5 (May 2011) 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\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_G_BenthosSed_20120423.mxd

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 sorting 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 2010

The 2011 monitoring network for the Benthic Invertebrate Communities component was the same as the 2011 monitoring network with the following exceptions:

- A *baseline* reach in lower High Hills River (HHR-E1), a tributary to the Clearwater River, was added to the program to increase available *baseline* data;
- Johnson Lake (*baseline* station JOL-1) was added to provide new *baseline* lake data;
- The Clearwater River (*test* reach CLR-D1 and *baseline* reach CLR-D2) was sampled in 2011, following the rotating panel design of the program; and
- The upper Embarras River (*test* reach EMR-1) was sampled for the first time in 2011, whereas *test* reach EMR-2 (lower Embarras River) was sampled in 2010.

A total of nine replicate samples were collected in Fletcher Channel (FLC-1) in 2011 compared to five replicates as in previous years. The additional samples collected were to assess the variability in benthic invertebrate communities in this channel that was observed in 2010 (see Section 6.6).

3.1.3.4 Challenges Encountered and Solutions Applied

All river reaches, and lake sampling stations were accessible, and samples were collected as per the proposed methodology and as scheduled.

3.1.3.5 Other Information Obtained

There was no additional information obtained for the Benthic Invertebrate Communities component in 2011.

3.1.3.6 Summary of Component Data Now Available

As of 2011, 2,796 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 2011 Monitoring Activities

Sediment samples were collected from September 3 to 15, 2011 at the most downstream replicate sampling location in each depositional reach sampled for benthic invertebrate communities (total of 15 depositional reaches), one station in the Athabasca River that was not sampled for benthic invertebrates, and five 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.

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 metals, 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) with the exception of 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 ARD. 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 2011 appears in Appendix E.

3.1.3.9 Changes in Monitoring Network from 2010

Given the three-year sampling rotation for some stations, *test* station CLR-D1 (lower reach on the Clearwater River) and *baseline* station CLR-D2 (upper reach on the Clearwater River), were sampled in 2011 and not in 2010, and station *test* station FIR-D1 (lower reach on the Firebag River) was not sampled in 2011. *Baseline* station JOL-1 (Johnson Lake) was added to the sediment sampling network in 2011. *Test* station EMR-1 (upper Embarras River) was sampled in 2011, whereas *test* station EMR-2 (lower Embarras River) was not sampled in 2011.

In alignment with benthos sampling, sediment chemistry data were collected from four additional replicate locations in Fletcher Channel (FLC-1) in 2011, to assess spatial heterogeneity and allow comparison with the individual sediment-chemistry replicate collected in previous years. Therefore in total, organic content and particle size were measured in nine replicate samples (aligned with benthos) at FLC-1 in 2011, while total metals also were analyzed in a total of five samples collected along Fletcher Channel.

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				2011			
				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	W	S	S	F
Athabasca River Delta																																																													
Athabasca River Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1								1				1				1				1				1
Embarras River	1	depositional	EMR-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												1
Upstream of Christina River	1	depositional	CLR-D2																				1				1				1				1				1												1												1
Ells River																																																												
Lower Reach	1	depositional	ELR-D1																												1				1				1				1				1												1				1
Middle Reach	1	erosional	ELR-E2																												1				1				1				1																				
Upper Reach	2	erosional	ELR-E2A																																																								1				1
Firebag River																																																												
Lower Reach	1	depositional	FIR-D1																												1				1				1				1				1												1				
Upper Reach	1	erosional	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				1
Hangingstone River																																																												
Lower Reach	1	erosional	HAR-E1																																1				1				1				1				1												
High Hills River																																																												
Lower Reach	1	erosional	HHR-E1																																																											1
Jackpine Creek																																																												
Lower Reach	1	depositional	JAC-D1																								1				1				1				1				1				1				1				1				1				1
Upper Reach	1	depositional	JAC-D2																												1				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				1
Middle Reach	1	erosional	MAR-E2																								1				1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	MAR-E3																																																								1				1
Muskeg River																																																												
Lower Reach	1	erosional	MUR-E1																1				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				1
Upper Reach	1	depositional	MUR-D3																								1				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				1
Upper Reach	1	erosional	STR-E2																												1				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*)

[Blue] Test (downstream of focal projects)

[Light green] Baseline (upstream of focal projects)

[Dark green] 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				2004				2005				2006				2007				2008				2009				2010				2011			
				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	W	S	S	F
Tar River																																																															
Lower Reach	1[1]	depositional	TAR-D1																				2				1				1				1				1				1												1				1				1
Historical Upper Reach	1	erosional	TAR-E1																												1				1				1				1																				
Upper Reach	1	erosional	TAR-E2																																																				1				1				1
Beaver River																																																															
Lower Reach	1	depositional	BER-D2																																																1				1				1				1
Poplar Creek																																																															
Lower Reach	1	depositional	POC-D1																																																1				1				1				1
Wetlands and Lakes																																																															
Isadore's Lake	1	lake	ISL-1																																								1				1				1				1				1				1
Johnson Lake	1	lake	JOL-1																																																												1
Kearl Lake	1	lake	KEL-1																				1				1				1				1				1				1				1				1				1				1				1
McClelland Lake	1	lake	MCL-1																								1				1												1				1				1				1				1				1
Shipyard Lake	1	lake	SHL-1																1				1				1				1				1				1				1				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																																																				

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 3.1-8 Summary of sampling for the RAMP Sediment Quality component, September 2011.

Station Identifier and Location		UTM Coordinates (NAD83, Zone12) Easting	Northing	Analytical Package
Athabasca River				
ATR-ER	Athabasca River at Embarras River	468731	6471828	2
Athabasca Delta				
FLC-1	Fletcher Channel	496464	6491687	2
GIC-1	Goose Island Channel	509622	6494019	2
BPC-1	Big Point Channel	512046	6494274	2
Embarras River				
EMR-1	Embarras River	468454	6472271	2
Tributaries to the Athabasca River (Eastern)				
FOC-D1	Fort Creek	461550	6363107	2
Tributaries to the Athabasca River (Western)				
BER-D2	Beaver River (upper reach)	465482	6311279	2
ELR-D1	Ells River (lower reach)	459304	6351517	2
TAR-D1	Tar River (lower reach)	458852	6353527	2
POC-D1	Poplar Creek (lower reach)	472426	6308509	2
Tributaries to the Athabasca River (Southern)				
CLR-D1	Clearwater (lower reach)	479419	6284230	2
CLR-D2	Clearwater (upper reach)	496192	6280467	2
Muskeg River				
MUR-D2	Muskeg River (middle reach)	466297	6339500	1
MUR-D3	Muskeg River (upper reach)	481822	6359425	1
JAC-D1	Jackpine Creek (lower reach)	471861	6346435	2
JAC-D2	Jackpine Creek (upper reach)	480023	6325008	2
Regional Lakes				
KEL-1	Kearl Lake	485270	6348913	2
MCL-1	McClelland Lake	478757	6372046	2
SHL-1	Shipyard Lake	473261	6313030	2
ISL-1	Isadore's Lake	463322	6343131	2
JOL-1	Johnson Lake	537444	6389744	2
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)
2. RAMP standard variables + toxicity (*Chironomus tentans, Hyalella azteca*)

3.1.3.10 Challenges Encountered and Solutions Applied

No challenges were encountered during the Sediment Quality component sampling program in fall 2011.

3.1.3.11 Other Information Obtained

No additional sediment quality information for 2011 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 3.1-9 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				2011			
		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	W	S	S	F
Athabasca River																																																											
Upstream of Fort McMurray (cross channel)	ATR-UFM																								1				2				1																												
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				2				2								1				2				1				2				1																												
(east bank)[a]	ATR-DC-E				2				2								1				2				1				2				1																												
Upstream of Steepbank River (west bank)	ATR-SR-W																1				2				1				2				1																												
(east bank)	ATR-SR-E																1				2				1				2				1																												
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								2								1				2				1				2				1																												
(east bank)[a b]	ATR-MR-E								2								1				2				1				2				1																												
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				2				2								1				2				1				2																																
(east bank)[a b]	ATR-FC-E				2				2								1				2				1				2																																
Testing inter-site variability (3 composite samples)	-																1								1																																				
Downstream of all development (west bank)	ATR-DD-W																								1				2				1																												
(east bank)	ATR-DD-E																								1				2				1																												
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				2				1																												
(east bank)	ATR-FR-E																								1				2				1																												
Upstream of the Embarras River	ATR-ER																3				1				1				2				1				1								1				2				2				2				2
Athabasca Delta / Lake Athabasca																																																											
Delta composite[c]	ARD-1												2																																																
Big Point Channel	BPC-1												2				2				2				2				2								1								1				2				2				2				2
Goose Island Channel	GIC-1																				2				2				2								1								1				2				2				2				2
Fletcher Channel	FLC-1																				2				2				2								1								1				2				2				2				2
Flour Bay	FLB-1																2																																												
Extensive Survey (6 sites)	[d]																																				1																								
Embarras River																																																											
Embarras River	EMR-1																																				1																								2
Embarras River	EMR-2																																				1																				2				
Athabasca River Tributaries (South of Fort McMurray)																																																											
Clearwater River (upstream of Fort McMurray)	CLR-1/CLR-D1																				1				2				2																				2												2
(upstream of Christina River)	CLR-2/CLR-D2																				1				2				2																				2												2
Christina River (upstream of Fort McMurray)	CHR-1																								1				2				2																												
(upstream of Janvier)	CHR-2																								1				2				2																												
(benthic reach at mouth)	CHR-D1																																								2				1								2								
benthic reach at upper Christina River)	CHR-D2																																								2												2								
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																2				2																								
Athabasca River Tributaries (North of Fort McMurray)																																																											
McLean Creek (mouth)	MCC-1												2				2				1				2												2																								
Beaver River	BER-D2																																																2				2				2				2
Poplar Creek (mouth)	POC-1/POC-D1				1																				2								2																2				2				2				2
Steepbank River (mouth)	STR-1				1				1																2												2																								
(upstream of Suncor Project Millennium)	STR-2																								2												2																								
(upstream of North Steepbank)	STR-3																																				2																								
North Steepbank River (upstream of Suncor Lewis)	NSR-1																								2				2				1				1																								
MacKay River (mouth)	MAR-1				1				1												2				2								2																												
(upstream of Suncor MacKay)	MAR-2																				1												2																												

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)

2 = 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

[d] Sites are BEC, BPC-1, CRC-1, EMR-2, JFC-1

[e] In previous RAMP reports, this site was called MUR-D2 (upstream of Stanley Creek) from 2003-2005

[f] In previous RAMP reports, this site was called MUR-2 from 2000-2005

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Table 3.1-10 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006*				2007				2008				2009				2010				2011			
		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	W	S	S	F
Athabasca River Tributaries (North of Fort McMurray) (cont'd)																																																													
Ells River (mouth)	ELR-1								1																2				2				2				1																								
(benthic reach at mouth)	ELR-D1																																								2				2												2				2
(upstream of Total Joslyn Mine)	ELR-2																																2				1																								
Tar River (mouth)	TAR-1								1																2				2				1				1																								
(benthic reach at mouth)	TAR-D1																																								2												2				2				2
(upstream of Canadian Natural Horizon)	TAR-2																																1				1																								
Calumet River (mouth)	CAR-1																								2								2				2																								
(benthic reach at mouth)	CAR-D1																																																				2								
(upstream of Canadian Natural)	CAR-2																																				2																								
(benthic reach at upper Calumet)	CAR-D2																																								2												2								
Fort Creek (mouth)	FOC-1																1								2																																				
(benthic reach at mouth)	FOC-D1																																								2				2				2								2				2
Firebag River (mouth)	FIR-1																								2				2				1																												
(benthic reach at mouth)	FIR-D1																																								2				1												2				
(upstream of Suncor Firebag)	FIR-2																												2				1																												
Muskeg River																																																													
Mouth	MUR-1				1				1				2				1				1				2				2				2				2																								
1 km upstream of mouth	MUR-1b																1												1																																
Upstream of Jackpine Creek	MUR-4				1												1												1																																
Upstream of Muskeg Creek	MUR-5																1												1																																
Upstream of Wapasu Creek	MUR-6																1												1																																
(benthic reach - downstream of Jackpine Creek) [e]	MUR-D2																1												2				2				2				2				2				2				1				1				1
(benthic reach - upstream of Stanley Creek) [f]	MUR-D3																												2				2				2				2				2				2				1				1				1
Muskeg River Tributaries																																																													
Jackpine Creek (mouth)	JAC-1				1																												2																												
(benthic reach at mouth)	JAC-D1																																								2				1				2				2				2				2
(benthic reach at upper Jackpine Creek)	JAC-D2																																								2				1				2				2				2				2
Stanley Creek (mouth)	STC-1																												1																																
Wetlands																																																													
Kearl Lake (composite)	KEL-1																				1												1								2				2				2				1				1				1
Isadore's Lake (composite)	ISL-1																				1																				2				2				2				1				1				1
Shipyard Lake (composite)	SHL-1																				1				2				1				2								2				2				2				1				1				1
McClelland Lake (composite)	MCL-1																								1				1												2				2				2				1				1				1
Johnston Lake (composite)	JOL-1																																																												1
Additional Sampling (Non-Core Programs)																																																													
Potential TIE	-																				√																																								
QA/QC																																																													
One split and one duplicate sample	-																1				1				1				1				1				1				1				1				1				1				1				1

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)

2 = 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

[d] Sites are BEC, BPC-1, CRC-1, EMR-2, JFC-1

[e] In previous RAMP reports, this site was called MUR-D2 (upstream of Stanley Creek) from 2003-2005

[f] In previous RAMP reports, this site was called MUR-2 from 2000-2005

Blue: *Test* (downstream of focal projects)

Green: *Baseline* (upstream of focal projects)

3.1.4 Fish Populations Component

The following monitoring activities were conducted in 2011 for the Fish Populations component:

- Spring, summer, and fall fish inventories on the Athabasca and Clearwater rivers;
- Tissue analyses on target fish (walleye and lake whitefish) on the Athabasca river; and
- Fish Assemblage monitoring (FAM) on tributaries to the Athabasca and Clearwater rivers.

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.

3.1.4.1 Summary of Field Methods

Athabasca River and Clearwater River Fish Inventories

The objectives of the 2011 Athabasca River and Clearwater River inventories were to:

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

In 2011, 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*);
- White sucker (*Catostomus commersoni*); and
- Trout-perch (*Percopis omiscomaycus*).

Spring, summer, and fall sampling was conducted between May 19 and May 26, 2011, July 25 and August 4, 2011, and September 19 and September 29, 2011, respectively. Approximately 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 six areas specifically established for the RAMP fish inventory:

- Upstream of Fort McMurray (Reach -3);
- 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).

With the exception of the area upstream of Fort McMurray, all of the areas have been sampled annually since 1997, and a number of which have been sampled annually since 1987 by Syncrude Canada Ltd. The reach in an area upstream of Fort McMurray, was established in 2011 to provide *baseline* data to the fish inventory program (Table 3.1-11, Figure 3.1-5).

Spring and summer sampling in the Clearwater River was conducted at three reaches (CR1, CR2, and CR3) of the river and fall sampling was limited to one reach (CR3) (Table 3.1-11, 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.

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.

Figure 3.1-5 Locations of RAMP fish monitoring activities for the 2011 Fish Populations component.

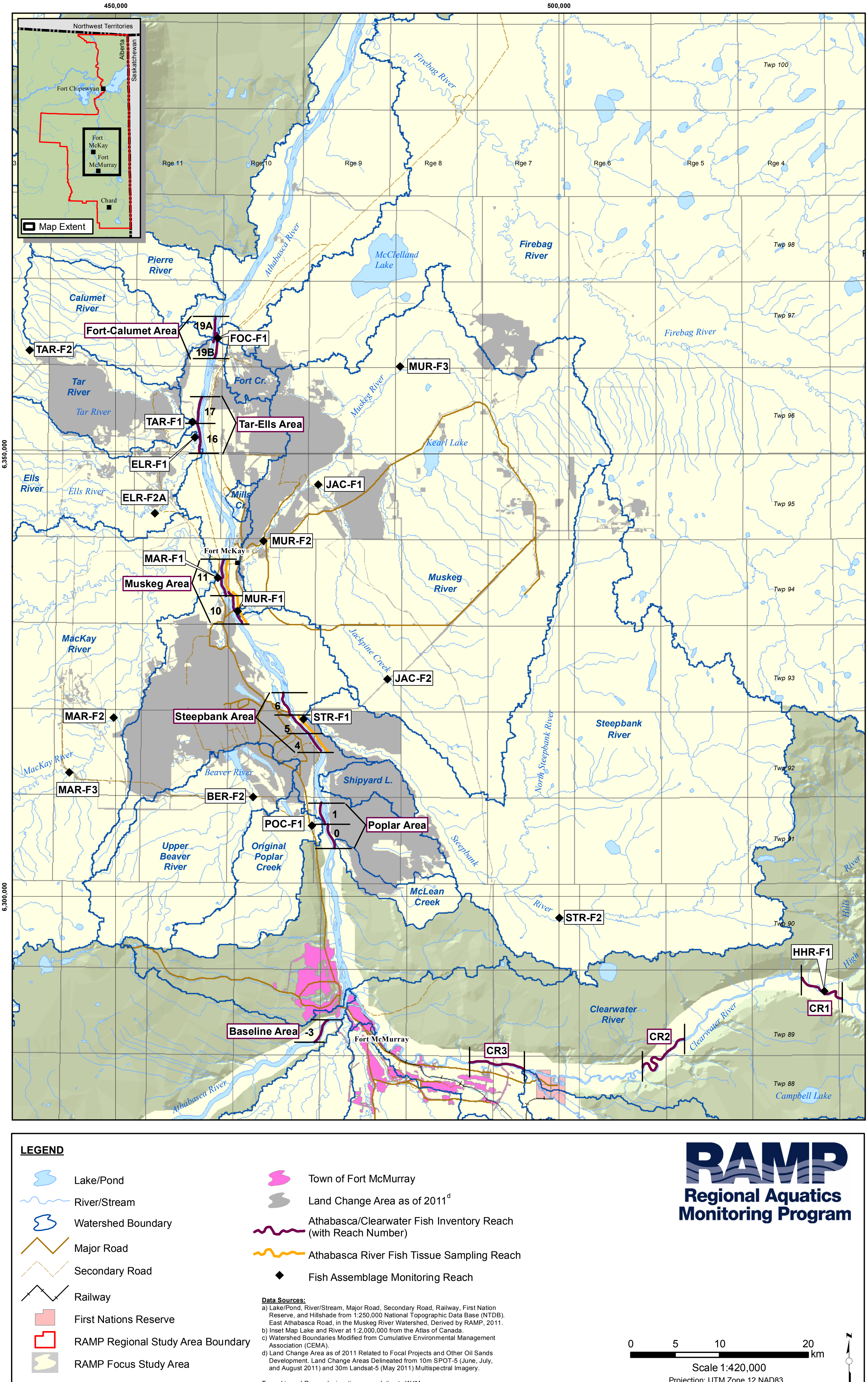


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Table 3.1-11 Fish inventory sampling locations on the Athabasca and Clearwater rivers, 2011.

Area	Reach Number	Subreach Number	UTM Coordinates (NAD 83, Zone 12)	
			Upstream Limit of Reach	Downstream Limit of Reach
Athabasca River				
Upstream of Fort McMurray	-03B		482473 E / 6283525 N	473942 E / 6285983 N
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 -03B, CR1, and CR2 are designated as *baseline*. All other reaches are designated as *test*.

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 Alberta Sustainable Resource Development (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.

Athabasca River Tissue Study

Walleye and lake whitefish were the targeted species for the 2011 fish tissue study on the Athabasca River. Tissue samples were acquired from fish captured in the Muskeg and Steepbank areas of the Athabasca River in September 2011 (Figure 3.1-5). Muscle tissue was collected non-lethally for mercury analysis, and lethal dissections were performed for internal health assessments and the collection of tissue for analyses of tainting compounds (organics) and metals.

During the fall Athabasca fish inventory, captured walleye and lake whitefish, selected for tissue sampling, were stored in cold water and transported back to an indoor facility to minimize contamination from precipitation, wind and debris, where they were sampled for the two types of tissue analyses, using the methods described below.

Non-Lethal Tissue Analysis for Mercury A target of 25 individuals of each species was set for non-lethal mercury tissue analysis, with specific targets of five fish (irrespective of sex) in each of five size classes of 100 mm increments in fork length from 200 mm to 700 mm for walleye and of 50 mm increments in fork length from 200 mm to 450 mm for lake whitefish. These size classes were selected in order to:

- ensure adequate representation of typical size ranges for lake whitefish and walleye observed in the fall during past inventories on the river (RAMP 2004, 2006, 2008, 2009a);
- ensure an even distribution of tissue samples across a wide range of fish sizes and ages; and
- ensure consistency with those size classes targeted in the fall during past tissue programs on the river (RAMP 2004, 2006, 2008, 2009a), and to allow comparisons with historical data.

Prior to tissue sampling, each fish was measured for fork length (± 1 mm) and total weight (± 1 g), and an external assessment was conducted to evaluate general health (e.g., presence of disease, incidence of parasites, and physical abnormalities) based on the external structures including: fins; skin; eyes; opercles; pseudobranchs; gills; and thymus.

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

Following mercury tissue sampling, all walleye and lake whitefish not designated for lethal dissections were released immediately into the calm margins of the river to limit additional handling and confinement stress. All sampling equipment was rinsed using metals-free soap and distilled water, hexane, then acetone, and re-rinsed with deionized water after each fish to avoid cross contamination. Tissue samples were transported in a cooler on dry ice and held in the Hatfield freezer (Fort McMurray) before being shipped on dry ice to Flett Research (Winnipeg) for mercury analysis.

Lethal Dissections and Tissue Analysis for Tainting Compounds and Metals A 2011 target of five fish for each of the two species (target male fork length: 450 mm – 500 mm for walleye and 400 mm – 450 mm for lake whitefish; target female fork length: 500 mm – 550 mm for walleye and 400 – 450 mm for lake whitefish) was set for dissection and comprehensive tissue sampling for tainting compounds (organics) and metals analysis. These sex/length combinations were set as targets in an attempt to minimize potential variability associated with size and age, and to allow for direct comparisons with data from previous tissue surveys conducted by RAMP (RAMP 2004, 2006, 2008, 2009a).

The distribution of fish captured for tissue analysis for tainting compounds is provided in Table 3.1-12. Because of difficulties capturing male walleye within the target size class, female walleye from the "male" target size class were also collected to ensure sufficient tissue for analyses (Table 3.1-12).

Table 3.1-12 Sex/length combinations of walleye and lake whitefish captured for fish tissue analyses of metals and organics, Athabasca River 2011.

Species	Sex	Size Class	Number Captured
Walleye	Male	450-500 mm (target)	3
	Female	500-550 mm (target)	6
		450-500 mm	5
Lake whitefish	Male	400-450 mm	6
	Female	400-450 mm	5

Each captured fish was measured for fork length and weight, given an external health assessment, and sampled for mercury analysis as described above. The fish were then transported to a controlled facility for dissections and comprehensive tissue sampling, as per the methods described below.

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

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

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

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

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

Methods and detection limits used for all chemical analyses, including tainting compounds, metals, and mercury are presented in Table 3.1-13. All remaining tissue samples were archived at the testing laboratory for additional analyses, if required.

Fish Assemblage Monitoring Program

Following a two-year pilot study conducted in 2009 and 2010, fish assemblage monitoring in tributaries to the Athabasca and Clearwater rivers was incorporated into RAMP in 2011. The objective of this monitoring component is to evaluate the fish assemblages in reaches where water quality, sediment quality and benthic invertebrate communities are also assessed. Therefore, fish assemblage monitoring was conducted at all benthic sampling reaches on tributaries in fall 2011 (Table 3.1-14). The FAM study was conducted from September 7 to September 14, 2011 to assess changes in the fish assemblage of rivers that may potentially be influenced by focal projects.

The methods used to develop the FAM program 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 and outline protocols to collect physical habitat, fish, water and sediment chemistry, and benthic invertebrate variables.

Each reach was approximately 40 times the wetted width and divided into five subreaches to assess variability within a reach. Sampling was focused on the shoreline area of the river and 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 (± 1 mm) and weight (± 0.01 g) and an external assessment was conducted for general health.

Table 3.1-13 Methods of analyses and detection limits for mercury, metals, and tainting compounds analyzed in fish tissues from the Athabasca River, 2011.

Variable	Detection Limit (mg/kg)	Method of Analysis
Metals		
Aluminum (Al)	2	EPA 200.3/200.8-ICPMS
Antimony (Sb)	0.05	EPA 200.3/200.8-ICPMS
Arsenic (As)	0.01	APHA 3114 C-AAS – Hydride
Barium (Ba)	0.1	EPA 200.3/200.8-ICPMS
Beryllium (Be)	0.2	EPA 200.3/200.8-ICPMS
Boron (B)	2	EPA 200.3/200.8-ICPMS
Cadmium (Cd)	0.01	EPA 200.3/200.8-ICPMS
Chromium (Cr)	0.1	EPA 200.3/200.8-ICPMS
Cobalt (Co)	0.1	EPA 200.3/200.8-ICPMS
Copper (Cu)	0.05	EPA 200.3/200.8-ICPMS
Iron (Fe)	5	EPA 200.3/200.7-ICPOES
Lead (Pb)	0.02	EPA 200.3/200.8-ICPMS
Lithium (Li)	0.5	EPA 200.3/200.8-ICPMS
Manganese (Mn)	0.5	EPA 200.3/200.7-ICPOES
Mercury (Hg)[1]	0.002	Cold Vapor Atomic Fluorescence Spectraphotometry (CVAFS)
Molybdenum (Mo)	0.05	EPA 200.3/200.8-ICPMS
Nickel (Ni)	0.02	EPA 200.3/200.8-ICPMS
Selenium (Se)	0.002	APHA 3114 C-Auto Continuous Hydride[3]
Silver (Ag)	0.02	EPA 200.3/200.8-ICPMS
Strontium (Sr)	0.05	EPA 200.3/200.8-ICPMS
Thallium (Tl)	0.05	EPA 200.3/200.8-ICPMS
Tin (Sn)	0.1	EPA 200.3/200.8-ICPMS
Titanium (Ti)	0.05	EPA 200.3/200.7-ICP-OES
Vanadium (V)	0.006	EPA 200.3/200.8-ICPMS
Zinc (Zn)	0.5	EPA 200.3/200.8-ICPMS
Tainting Compounds (PAHs)		
1,3,5-Trimethylbenzene	0.01	EPA 5021/8260-Headspace GC/MS
M+P-Xylenes	0.01	EPA 5021/8260-Headspace GC/MS
Naphthalene[2]	0.05	EPA 3540/8270-GC/MS
Thiophene	0.01	EPA 5021/8260-Headspace GC/MS
Toluene	0.01	EPA 5021/8260-Headspace GC/MS

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

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

[3] APHA is the American Public Health Association.

Table 3.1-14 Fish assemblage monitoring locations, September 2011.

Watershed	Reach	Habitat Type	Reach Designation	UTM Coordinates (NAD 83, Zone 12)	
				Upstream Boundary	Downstream Boundary
Beaver River	BER-F2[1]	depositional	*baseline*	465221 E / 6311024 N	465475 E / 6311289 N
Ells River	ELR-F1[2]	erosional	*test*	459277 E / 6351314 N	459318 E / 6351291 N
	ELR-F2A[2]	erosional	*baseline*	454382 E / 6343225 N	454546 E / 6343524 N
MacKay River	MAR-F1[1]	erosional	*test*	460349 E / 6343225 N	461251 E / 6332065 N
	MAR-F2	erosional	*test*	448855 E / 6318837 N	449883 E / 6319957 N
	MAR-F3	erosional	*baseline*	444466 E / 6314020 N	444749 E / 6314040 N
Muskeg River	MUR-F1[1,2]	erosional	*test*	464388 E / 6332064 N	464135 E / 6332065 N
	MUR-F2	depositional	*Test*	466576 E / 6340400 N	466295 E / 6339482 N
	MUR-F3	depositional	*test*	482137 E / 6359826 N	479771 E / 6357033 N
Steepbank River	STR-F1[1,2]	erosional	*test*	471434 E / 6320240 N	471170 E / 6320057 N
	STR-F2	erosional	*baseline*	501116 E / 6297774 N	499961 E / 6297509 N
Tar River	TAR-F1[1]	depositional	*test*	458086 E / 6351314 N	458573 E / 6353573 N
	TAR-F2	erosional	*baseline*	458086 E / 6353579 N	440357 E / 6361662 N
High Hills River	HHR-F1	depositional	*baseline*	529923 E / 6289569 N	529954 E / 6289319 N
Jackpine Creek	JAC-F1[1,2]	depositional	*test*	472846 E / 6346582 N	471705 E / 6346518 N
	JAC-F2[1,2]	depositional	*baseline*	480796 E / 6324615 N	480059 E / 6324905 N
Fort Creek	FOC-F1	depositional	*test*	461666 E / 6363044 N	461539 E / 6363108 N
Poplar Creek	POC-F1[1]	depositional	*test*	472427 E / 6308501 N	473047 E / 6308837 N

[1] Sampled during the first year of the pilot study (RAMP 2010).

[2] Sampled during the second year of the pilot study (RAMP 2011).

Fish Habitat Assessments

Habitat assessments were completed at two transects at the downstream and upstream ends 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 3.1-15);
- 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 3.1-16);
- Substrate (dominant and subdominant particle size) (Table 3.1-17);
- 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, DO, and conductivity were measured using a Hanna hand-held probe (temperature, conductivity, pH) and a LaMotte Winkler titration kit (DO) and collected at the downstream end of each reach.

Table 3.1-15 Habitat type and code used for the fish assemblage monitoring 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
Dry Channel (DR)	No water in the channel or flow is submerged under the substrate.

Table 3.1-16 Percent cover rating for instream and overhead cover at each transect used for the fish assemblage monitoring 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 3.1-17 Substrate size class codes used for the fish assemblage monitoring 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 - not gritty
HP	hardpan - firm consolidated fine substrate

3.1.4.2 Changes in Monitoring Network from 2010

The 2011 Fish Populations component monitoring activities differed from those carried out during 2010 in the following ways:

- Given the three-year sampling rotation, there was fish tissue sampling conducted on the Athabasca river given this program was last completed in 2008;
- Following a two-year pilot study, the fish assemblage monitoring was incorporated into the regular monitoring activities in 2011 following the sampling design of the benthic invertebrate communities component;
- A new reach (-03B) was established for the Athabasca River fish inventory, located upstream of Fort McMurray;
- The regional lakes fish tissue program was not conducted given ASRD did not conduct their Fall Walleye Index Netting (FWIN) program in the oil sands region in fall 2011; and
- A lethal sentinel monitoring program was not conducted in 2011 given the three-year sampling rotation.

3.1.4.3 Challenges Encountered and Solutions Applied

All monitoring activities implemented under the 2011 Fish Populations component were completed successfully without significant difficulties with the exception of:

- low water in the Clearwater River that restricted access to *baseline* reaches CR1 and CR2 during the fall fish inventory program. *Test* reach CR3 was the only reach sampled in the fall season; and
- low numbers of male walleye captured from the 450-500 mm size class for the Athabasca River fish tissue program; therefore, female walleye of that size class were collected to supplement the target sample size.

3.1.4.4 Other Information Obtained

There was no other information obtained to support the Fish Populations component of RAMP.

3.1.4.5 Summary of Component Data Now Available

Fish Populations component data collected to date by RAMP are summarized in Table 3.1-18.

Table 3.1-18 Summary of RAMP data available for the Fish Population component.

WATERBODY AND LOCATION	REACH	1997				1998				1999				2000				2001			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																					
Upstream of Fort McMurray	-3																				
Poplar Area	0/1		1	1,5	1,5		1,6	1,5	1,3,6												
Steepbank Area	4[a]/5[a]/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Muskeg Area	10/11		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7			
Fort-Calumet Area	19[a]																				
CNRL/TrueNorth Area (Fort/Asphalt reaches)																					
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6												
Reference Area - upstream of Fort McMurray[c]			1																		
Radiotelemetry study region[d]					2		2		2						2	2	2	2	2		
Downstream of Suncor's Discharge	ATR-3												1,3								
Below Muskeg River	ATR-4												1,3								
Reference site upstream of Ft. McMurray STP	ATR-1																				
Reference site between STP and Suncor	ATR-2												1,3								
Downstream of Development (near Firebag River)	ATR-5																				
Athabasca River Tributaries (northern)																					
Fort Creek (mouth)	FOC-F1														1,8,5,9	1					
Poplar Creek (mouth)	POC-F1																				
Beaver River (upper)	BER-F2																				
Athabasca River Tributaries (southern)																					
High Hills River (mouth)	HHR-F1																				
Clearwater River Reach	CR1																				
Clearwater River Reach	CR2																				
Clearwater River Reach	CR3																				
Christina River[i]																					
Ells River																					
Upper Ells River[i,h]	ELR-F2A												1,3								
Lower Ells River[i,h]	ELF-F1												1,3								
MacKay River																					
Lower reach (mouth)[j]	MAR-F1		1																		
Mid-River (upstream of Suncor MacKay)	MAR-F2																				
Upper MacKay River reach	MAR-F3																				
Tar River																					
Lower Tar River	TAR-F1												1,3								
Upper Tar River	TAR-F2												1,3								
Muskeg River																					
Lower 35 km below Jackpine Creek confluence	MUR-F2			1			4						1,3		2,8	2	2	2	2	1	6
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1												1,3						4		3
Reference sites (Steepbank, Horse and Dunkirk rivers)	SR-R/HR-R/DR-R																3				3
Upper Muskeg River (near Wapasu Creek Confluence)																					
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	
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			1																	
Vicinity of Steepbank Mine	STR-F1/SR-E												1,3								3
Baseline site in vicinity of Bitumin Heights	SR-R												1,3								
Upstream sentinel site[g]	STR-F2												1,3				3				3
Regionally-Important Lakes																					
Various lakes in water/air emissions pathway																					

WATERBODY AND LOCATION	REACH	2002				2003				2004				2005				2006			
		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	-3																				
Poplar Area	0/1		1								1		1		1		1		1		1
Steepbank Area	4[a]/5[a]/6		1		10,6				6		1		1		1		1,6		1		1
Muskeg Area	10/11		1		10,6				6		1		1		1		1,6		1		1
Tar-Ells Area	16/17		1								1		1		1		1		1		1
Fort-Calumet Area	19[a]																		1		1
CNRL/TrueNorth Area (Fort/Asphalt reaches)			1																		
Reference Area - about 200 km upstream[b]	5/6																				
Reference Area - upstream of Fort McMurray[c]																					
Radiotelemetry study region[d]																					
Downstream of Suncor's Discharge	ATR-3				10,3				10												
Below Muskeg River	ATR-4				10,3				10												
Reference site upstream of Ft. McMurray STP	ATR-1				3				10												
Reference site between STP and Suncor	ATR-2				3				10												
Downstream of Development (near Firebag River)	ATR-5								10,6												
Athabasca River Tributaries (northern)																					
Fort Creek (mouth)	FOC-F1																				
Poplar Creek (mouth)	POC-F1																				
Beaver River (upper)	BER-F2																				
Athabasca River Tributaries (southern)																					
High Hills River (mouth)	HHR-F1																				
Clearwater River Reach	CR1						1		1		1		1,6		1		1		1		1,6
Clearwater River Reach	CR2						1		1		1				1				1		1,6
Clearwater River Reach	CR3						1	10	1		1				1				1		1,6
Christina River[i]													1								
Ells River																					
Upper Ells River[i,h]	ELR-F2A										4		3		4		3				
Lower Ells River[i,h]	ELF-F1										4		3		4		3				
MacKay River																					
Lower reach (mouth)[j]	MAR-F1		1					10			4										
Mid-River (upstream of Suncor MacKay)	MAR-F2																				
Upper MacKay River reach	MAR-F3																				
Tar River																					
Lower Tar River	TAR-F1																				
Upper Tar River	TAR-F2																				
Muskeg River																					
Lower 35 km below Jackpine Creek confluence	MUR-F2			1	6							1	6							1	6
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1		4		4		4						3						4	3	3
Reference sites (Steepbank, Horse and Dunkirk rivers)	SR-R/HR-R/DR-R												3							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			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																				
Vicinity of Steepbank Mine	STR-F1/SR-E												3							3	3
Baseline site in vicinity of Bitumin Heights	SR-R																				
Upstream sentinel site[g]	STR-F2												3							3	3
Regionally-Important Lakes																					
Various lakes in water/air emissions pathway									6				6								

WATERBODY AND LOCATION	REACH	2007				2008				2009				2010				2011			
		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	-3																		1	1	1
Poplar Area	0/1		1		1		1	1	1,6		1	1	1		1	1	1		1	1	1
Steepbank Area	4[a]/5[a]/6		1		1		1	1	1,6		1	1	1		1	1	1		1	1	1,6
Muskeg Area	10/11		1		1		1	1	1,6		1	1	1		1	1	1		1	1	1,6
Tar-Ells Area	16/17		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	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]																					
Downstream of Suncor's Discharge	ATR-3			3	3												3				
Below Muskeg River	ATR-4			3	3												3				
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 Development (near Firebag River)	ATR-5			3	3												3				
Athabasca River Tributaries (northern)																					
Fort Creek (mouth)	FOC-F1																				10
Poplar Creek (mouth)	POC-F1												10								10
Beaver River (upper)	BER-F2												10								10
Athabasca River Tributaries (southern)																					
High Hills River (mouth)	HHR-F1												10								10
Clearwater River Reach	CR1		1		1,6		1		1		1	1	1,6		1	1	1		1	1	
Clearwater River Reach	CR2		1		1,6		1		1		1	1	1,6		1	1	1		1	1	
Clearwater River Reach	CR3		1		1,6		1		1		1	1	1,6		1	1	1		1	1	1
Christina River[i]																					
Ells River																					
Upper Ells River[i,h]	ELR-F2A			3	3												10				10
Lower Ells River[i,h]	ELF-F1			3	3												10				10
MacKay River																					
Lower reach (mouth)[j]	MAR-F1												10								10
Mid-River (upstream of Suncor MacKay)	MAR-F2																				10
Upper MacKay River reach	MAR-F3																				10
Tar River																					
Lower Tar River	TAR-F1												10								10
Upper Tar River	TAR-F2																				10
Muskeg River																					
Lower 35 km below Jackpine Creek confluence	MUR-F2												10								10
Mouth (within 1 km of confluence with Athabasca River)	MR-E/MUR-F1										4	3	3,10				10				10
Reference sites (Steepbank, Horse and Dunkirk rivers)	SR-R/HR-R/DR-R											3	3,10								
Upper Muskeg River (near Wapasu Creek Confluence)																					10
Muskeg River Tributaries																					
Alands Drain																					
Jackpine Creek (upper portion of the creek)	JAC-F2												10				10				10
Jackpine Creek (accessable areas of lower creek)	JAC-F1												10				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	STR-F1/SR-E											3	3,10				10				10
Baseline site in vicinity of Bitumin Heights	SR-R																				
Upstream sentinel site[g]	STR-F2											3	3								10
Regionally-Important Lakes																					
Various lakes in water/air emissions pathway				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 (FAM) program

Blue: *Test* (downstream of focal projects)
Green: *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] Reconnaissance 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 2011 Monitoring Activities

The 2011 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, 2011. 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 3.1-19. The unique identification number listed in Table 3.1-19 is that ascribed to each lake by the NO_xSO_x Management Working Group (NSMWG) lake sensitivity mapping program (WRS 2004). Also included is the current AEW name of each lake.

The sampling design for the ASL component reflects the natural geographic distribution of lakes within the study region, which limits the ability to apply a more statistically robust stratified sampling design. The 50 lakes represent a majority of the major lakes within the RAMP region that are unaffected by oil sands development (except through deposition). There are very few lakes close to the major oil sands developments (e.g., 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 set of ASL component lakes. The lakes include a large number of small ponds that are less than 0.5 km^2 in area. Beaver ponds were not considered to be permanent lakes. 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 in this sampling regime, a seasonal sampling program was conducted for five years by AEW (as recommended in CEMA 2004b) on ten representative lakes scattered around the oil sands region. The results were summarized in the 2008 RAMP technical report (RAMP 2009a). The CEMA/AEW 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 not possible.

Summary of Field Methods

AEW (formerly 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. AEW water quality sampling protocols were used as the basis for the field methods (AENV 2006). Water samples were collected (approximately 10 L of water in total) from the euphotic zone (defined as twice the Secchi disk depth) at a single deep-water site in each major basin of a lake using weighted Tygon tubing. When the euphotic zone extended to the lake bottom, sampling was restricted to depths greater than 1 m above the lake bottom. In shallow lakes (< 3 m deep), composite samples were created from five to ten 1-L grab samples collected at 0.5 m depth along a transect dictated by wind direction (upwind to downwind shore). Samples taken from a given lake were then combined to form a single composite sample.

Vertical profiles of dissolved oxygen, temperature, conductivity and pH were measured at the deepest location using a field-calibrated Hydrolab Minisonde 5 water quality meter. Secchi depth was also recorded. Samples for chemical analysis were stored on ice and were shipped to the Limnology Laboratory, University of Alberta, Edmonton, within 48 hours of collection, and analyzed for the water quality variables listed in Table 3.1-20.

One 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 3.1-20 (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 AEW and the zooplankton samples were sent to Environment Canada for analysis.

Figure 3.1-6 Locations of Acid-Sensitive lakes sampled in 2011.

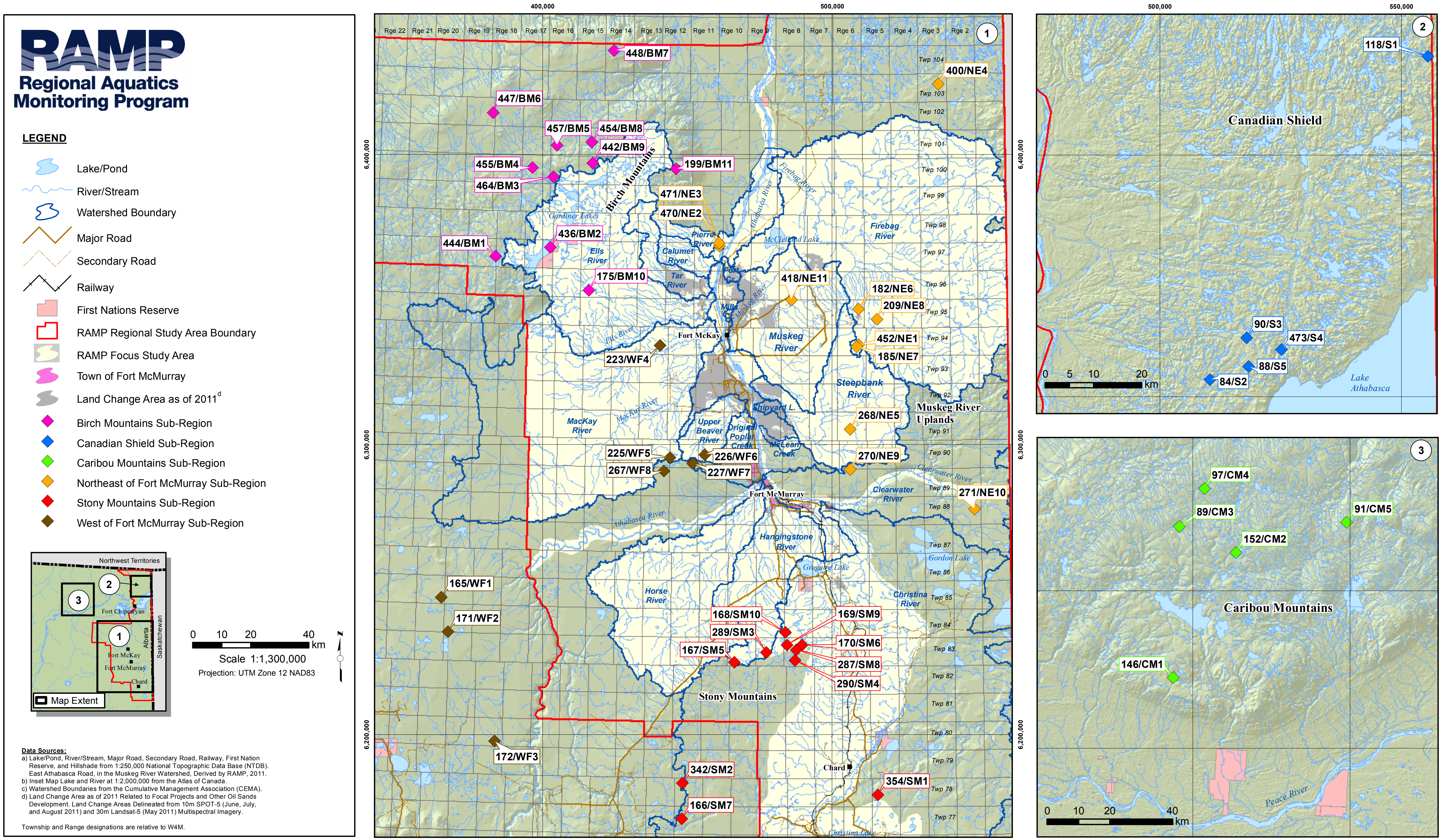


Table 3.1-19 Lakes sampled in 2011 for the Acid-Sensitive Lakes component.

Lake Identification			Lake Area (km²)	UTM Coordinates (NAD83, Zone12)		Sampling Date month/day/year
Unique ID[1]	Original Name	AEW Name		Easting	Northing	
Stony Mountains Sub-Region						
168	A21	SM 10	1.38	483819	6235130	08/29/11
169	A24	SM 9	1.45	484387	6230872	08/29/11
170	A26	SM 6	0.71	489502	6230877	08/29/11
167	A29	SM 5	1.05	466180	6224950	08/29/11
166	A86	SM 7	1.44	448014	6170896	08/29/11
287	25	SM 8	2.18	487594	6229281	08/29/11
289	27	SM 3	1.83	477248	6228400	08/29/11
290	28	SM 4	0.54	487068	6225576	08/29/11
342	82	SM 2	1.97	448271	6183205	08/29/11
354	94	SM 1	2.50	515689	6179207	08/29/11
Birch Mountains Sub-Region						
436	L18/Namur	BM 2	43.39	402704	6368016	08/30/11
442	L23/Otasan	BM 9	3.44	417321	6396959	08/30/11
444	L25/Legend	BM 1	16.80	383849	6364923	08/30/11
447	L28	BM 6	1.30	382996	6414339	08/30/11
448	L29/Clayton	BM 7	0.65	424694	6435790	08/30/11
454	L46/Bayard	BM 8	1.20	416941	6404239	08/30/11
455	L47	BM 4	4.37	396500	6395456	08/30/11
457	L49	BM 5	2.61	404995	6403111	08/30/11
464	L60	BM 3	0.91	403796	6392247	08/30/11
175	P13	BM 10	0.38	416003	6353212	08/17/11
199	P49	BM 11	2.61	446002	6394961	08/17/11
Northeast of Fort McMurray Sub-Region						
452	L4 (A-170)	NE 1	0.61	508990	6334305	09/01/11
470	L7	NE 2	0.33	515029	6327465	09/01/11
471	L8	NE 3	0.56	524390	6322556	09/01/11
400	L39/E9/A-150	NE 4	1.12	536495	6424234	09/01/11
268	E15	NE 5	1.87	506092	6305335	09/01/11
182	P23	NE 6	0.28	509000	6346712	08/17/11
185	P27	NE 7	0.09	508300	6333712	08/17/11
209	P7	NE 8	0.15	515399	6343212	08/17/11
270	4	NE 9	3.44	506113	6291421	09/01/11
271	6	NE 10	4.31	549064	6277789	09/01/11
418	Kearl	NE 11	5.34	485939	6349881	09/01/11
West of Fort McMurray Sub-Region						
165	A42	WF 1	3.20	365015	6247322	08/29/11
171	A47	WF 2	0.47	367321	6235430	08/29/11
172	A59	WF 3	2.06	383467	6197733	08/29/11
223	P94	WF 4	0.03	440557	6334112	08/17/11
225	P96	WF 5	0.21	444002	6295513	08/17/11
226	P97	WF 6	0.16	456002	6296463	08/17/11
227	P98	WF 7	0.08	451762	6293513	08/17/11
267	1	WF 8	2.22	441917	6290884	
Caribou Mountains Sub-Region						
146	E52/ Fleming	CM 1	1.60	243692	6522556	08/31/11
91	O-1/E55	CM 5	2.70	298955	6571856	08/31/11
97	O-2/E67	CM 4	0.56	253582	6582654	08/31/11
152	E59/Rocky I.	CM 2	9.53	263546	6562225	08/31/11
89	E68 Whitesand	CM 3	2.46	245596	6570610	08/31/11
Canadian Shield Sub-Region						
473	A301	S 4	1.40	525150	6559733	09/01/11
118	L107/Weekes	S 1	3.73	555469	6620456	09/01/11
84	L109/Fletcher	S 2	1.29	510321	6553552	09/01/11
88	O-10	S 5	0.70	518279	6556260	09/01/11
90	R1	S 3	0.55	517889	6562197	09/01/11

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

Table 3.1-20 Water quality variables analyzed in 2011 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 2010

All 50 lakes were sampled in 2011. 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 2011.

3.1.5.4 Other Information Obtained

AEW collected additional water samples for metals analyses from each ASL component lake surveyed during the 2011 field season (Table 3.1-19). These water samples were sent to Alberta Innovates Technology Futures (AITF), Vegerville, Alberta for analysis of the total and dissolved fractions of the metals listed in Table 3.1-21. The results of the metals analyses are reported in Appendix G.

Table 3.1-21 Metals analyzed in 2011 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 3.1-22.

Table 3.1-22 Summary of lakes sampled for the Acid-Sensitive Lakes component, 1999 to 2011.

NO_xSO_x GIS No.	Original RAMP Designation	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
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 2011 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, 2011 to October 31, 2011) discharge;
- Mean winter (November 1, 2010 to March 31, 2011) discharge;
- Annual maximum daily (November 1, 2010 to October 31, 2011) 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 2011 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 2011 WY is defined as the period from November 1, 2010 to October 31, 2011. 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.

3.2.1.3 Temporal Comparisons of Climate and Hydrologic Conditions

For each climate and hydrometric station, records for the 2011 WY were assessed in relation to the historical context as available based on past records for the location using 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 (*test*) 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 continue to be collected, this method will provide a more robust analysis of the temporal context and will support the use of other methods that incorporate statistical analyses. 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 2011 WY observations and calculated *baseline* conditions using the EDA approach.

3.2.1.4 Comparison to *Baseline* Conditions

The 2011 hydrologic data were analyzed using a water balance approach consistent with previous analytical methods from 2004 to 2010. The water balance approach is used to develop *baseline* and *test* hydrographs 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 2011 hydrograph. Additional details regarding this analytical approach are found in RAMP (2008) and Appendix C of this report.

The RAMP 2011 hydrology water balance analysis consisted of:

- establishing observed (*test)* hydrographs for all operating stations in 2011 using water level records, associated stage/discharge relationships, and Aquatic Informatics Aquarius software (Aquarius 2.7, Aquatic Informatics ™);
- estimating the 2011 *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 2011 Baseline Hydrograph

The 2011 WY *baseline* hydrographs are defined for this analysis as the hydrographs that would have been observed in the 2011 WY had there been no focal projects in the watershed. Additional influences may be incorporated in the 2011 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 2011 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 2011 WY;

Hyd_O is the *test* hydrograph which was observed in the 2011 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 2011 WY; and

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

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 considerations:

- 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 2011 WY flow records and associated land use and industrial flow data. The water balance approach thereby provides a consistent approach for the 2011 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 2011 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 2011 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 2011 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 – Special Studies of this document, rather than in Section 5);
- *Total hydrocarbons (CCME fractions + BTEX)*: indicators of the total hydrocarbon content in water, including indicators (fractions) capturing hydrocarbon compounds of different molecular weights (specifically, number of carbon atoms), and concentrations of benzene, toluene, ethylbenzene and xylene (collectively called BTEX), based on methods presented by CCME (2001) (added to RAMP water quality in 2011, as an intended replacement for Total Recoverable Hydrocarbons,);
- *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); and
  - *Retene:* an alkylated phenanthrene generated through decomposition of plant materials (i.e., biogenic rather than petrogenic).
- 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**.

Note: RAMP analyzes tainting compounds in fish tissue.

[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 non-seasonal 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 AEW since 1976. Seasonal Mann-Kendall analysis was applied to monthly AEW 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 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 2011), to assess trends potentially related to development between the two stations during this time period.

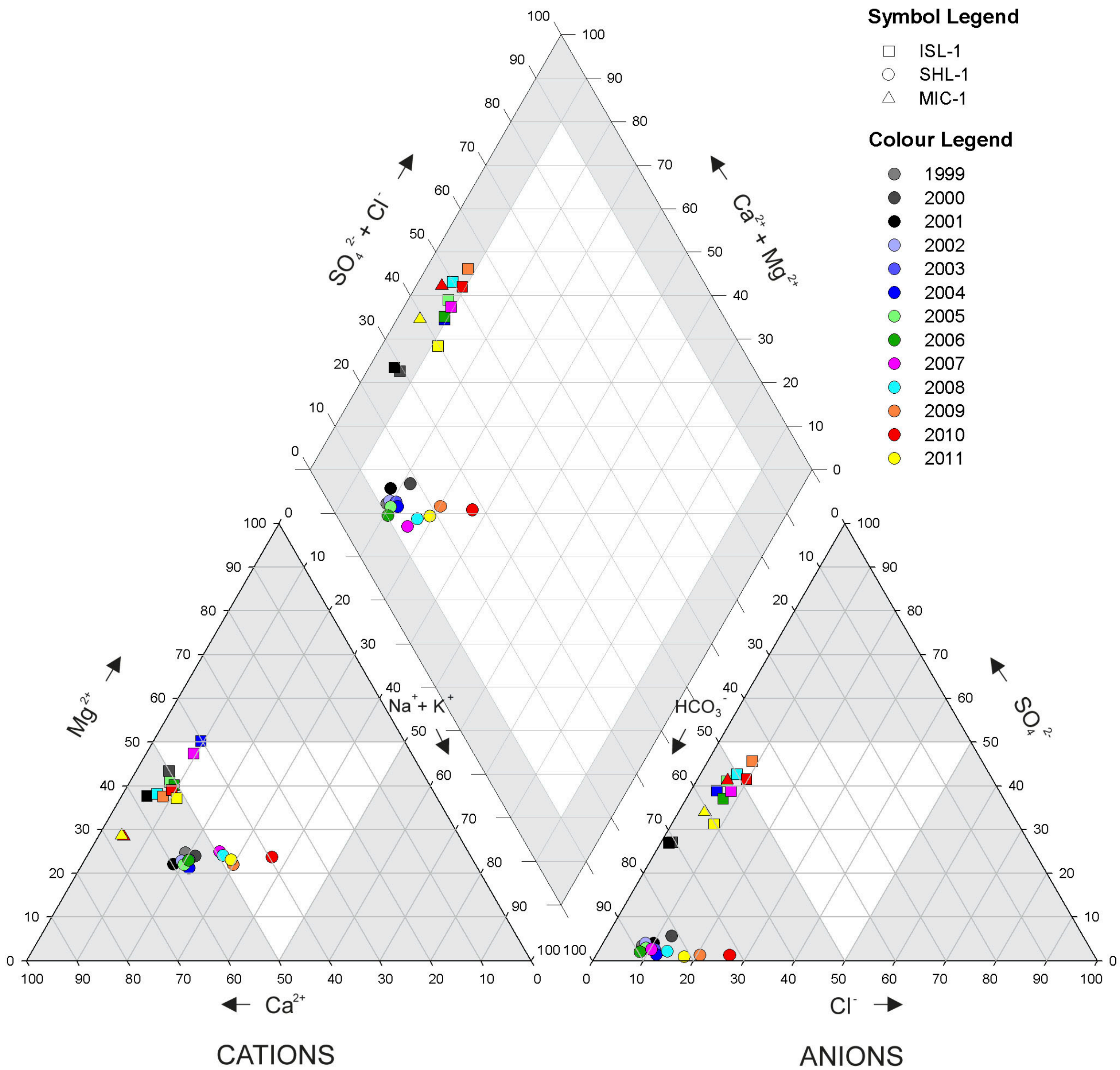
Ion Balance

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 2011 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 2011 (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 (all seasons).

Figure 3.2-1 Example Piper diagram, illustrating relative ion concentrations in waters from Isadore's Lake, Mills Creek and Shipyard Lake, 1999 to 2011.

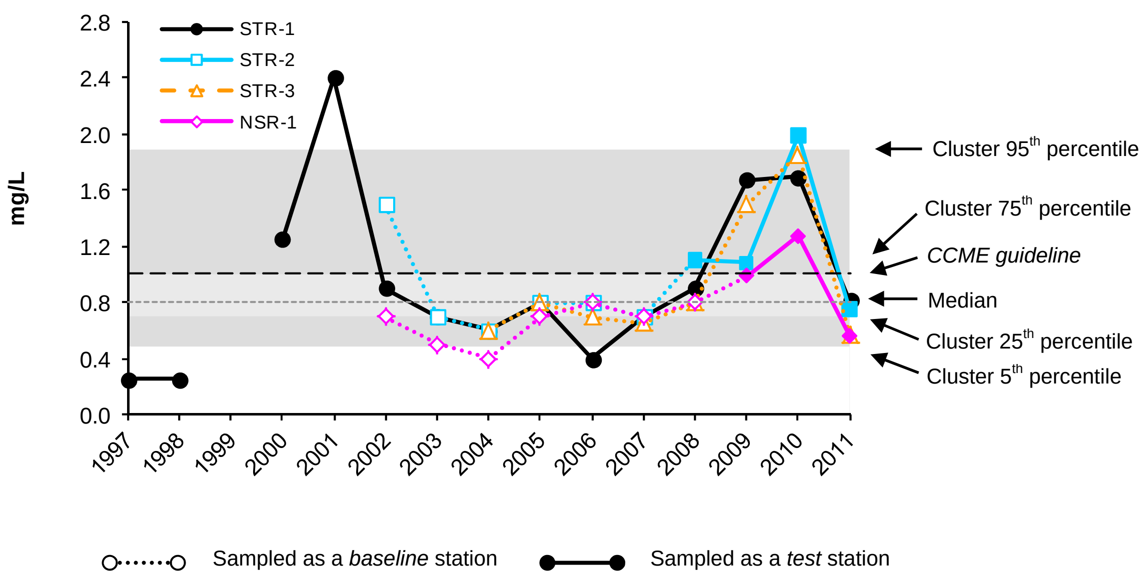


Comparison to Regional Baseline Concentrations

To allow for a regional comparison, untransformed data for 14 of the 21 water quality measurement endpoints from all *baseline* stations sampled by RAMP from 1997 to 2011 (fall only) were pooled from each cluster of similar stations. Descriptive statistics describing *baseline* water quality characteristics for each cluster were calculated including the 5th, 25th, 50th (median), 75th, and 95th percentiles for comparison against station-specific data (Figure 3.2-2, Table 3.2-2, Table 3.2-3, Table 3.2-4). The number of observations varied by cluster for each of the fourteen selected water quality measurement endpoints (Table 3.2-3). 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 2011, 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. Given the limited *baseline* data available for lakes, regional *baseline* ranges were not calculated for lakes.

Data for the fifteen selected water quality measurement endpoints (Section 3.2.2.1) were presented graphically in the context of relevant regional variability by presenting data for each station for all years of sampling by RAMP to allow assessment of any temporal trends (Figure 3.2-2). Where possible, stations located upstream and downstream on specific watersheds were presented together, to allow assessment of any differences in values or trends between upstream/downstream locations.

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



Development of Regional *Baseline* Concentrations Descriptions of regional *baseline* water quality conditions were developed from existing data collected by RAMP since 1997 from *baseline* stations 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 2011, 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 used in the RAMP Benthic Invertebrate Communities component, and incorporates elements of control charting (Morrison 2008), which also is a feature of the 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). This approach of comparing observed data against a defined range of natural variability also aligns with the Alberta Water Council's (2009) definition of a healthy aquatic ecosystem as "…*an aquatic environment that sustains its ecological structure, processes, functions and resilience within its range of natural variability.*"

In previous years, 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 onward were pooled using cluster analysis. 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). Details describing the cluster analysis methodology have been reported in previous RAMP technical reports (e.g., RAMP 2011).

For 2011, cluster analysis confirmed overall patterns previously seen in the data: stations generally group together based on geographical location rather than sampling year. However, results of clustering using 2002 to 2011 data differed somewhat from those using 2002 to 2010 data only, with some station-data combinations "switching clusters" in the 2011 analysis. In addition, rank and scale data transformations of the data produced different cluster memberships for approximately 20% of the stations, suggesting that clustering based on water quality data—especially within tributaries—was based on weak relationships, likely due to the large amount of variability present in the data. To preserve clustering of station-data combinations located within specific watersheds, multivariate analysis was not used exclusively to determine cluster membership. For determination of regional ranges of natural variability, stations were grouped together based on cluster analysis and geographical location. This method incorporated both overall patterns determined from cluster analysis with ecological knowledge of the area. Three "clusters" were determined: 1. Athabasca, 2. Eastern Tributaries, and 3. Western and Southern Tributaries. Stations included in each group of *baseline* data, and those compared against these groups, appear in Table 3.2-2. Ranges of regional *baseline* values calculated for each group of stations and used for comparisons appear in Table 3.2-3 to Table 3.2-5.

Table 3.2-2 Regional *baseline* water quality data groups and station comparisons.

Regional *Baseline* Grouping (Cluster)	*Baseline* Stations Used in Creating Regional Comparison[1]	*Test* Stations (2011) Compared Against Regional *Baseline*
1. Athabasca	ATR-DC-CC, ATR-DC-E, ATR-DC-M, ATR-DC-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, BIC-1, CAR-1, CAR-2, CLR-1, CLR-2, DUR-1, ELR-1, ELR-2, ELR-2A, EYC-1, HHR-1, HAR-1[2], HOR-1, MAR-1, MAR-2, PIR-1, REC-1, TAR-1, TAR-2	BER-1, BER-2, BIC-1, CAR-1, CAR-2, CHR-1, CLR-1, CLR-2, ELR-1, ELR-2, ELR-2A, EYC-1, HHR-1, MAR-1, MAR-2, MAR-2A, PIR-1, POC-1, REC-1, TAR-1, TAR-2
3. Eastern tributaries, Muskeg River and Steepbank River	FIR-2, 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, IYC-1, JAC-1, JAC-2, MCC-1, MIC-1, MUC-1, MUR-1, MUR-6, NSR-1, STC-1, STR-1, STR-2, STR-3, WAC-1

[1] See Table 3.1-5 for classification of station status by year. Where station status changed from *baseline* to *test* during 1997 to 2011, 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.

Table 3.2-3 Regional *baseline* values for water quality measurement endpoints, using data from 1997 to 2011, Group 1 Athabasca River.

Measurement Endpoint	n	Min	Percentiles 5th	25th	Median	75th	95th	Max
Physical variables								
pH	34	7.7	7.8	8.1	8.2	8.2	8.3	8.4
Total suspended solids	34	3	3	10	16	22	84	136
Conductivity	34	202	203	233	269	291	329	366
Nutrients								
Total dissolved phosphorus	34	0.003	0.004	0.007	0.011	0.018	0.027	0.029
Total nitrogen	34	0.25	0.28	0.45	0.5	0.70	0.81	0.90
Nitrate+nitrite	34	0.05	0.05	0.07	0.1	0.10	0.10	0.29
Dissolved organic carbon	34	3.0	4.0	6.0	7.0	9.9	14.7	17.1
Ions								
Sodium	34	8.0	8.9	10.0	11.5	17.0	21.6	28.0
Calcium	34	17.7	19.3	24.4	31.5	33.8	40.1	43.6
Magnesium	34	5.7	6.0	7.2	8.8	9.6	11.4	12.3
Chloride	34	1.9	2.0	3.0	6.0	18.0	25.0	36.0
Sulphate	34	6.4	7.0	11.5	24.1	29.9	39.4	50.2
Potassium	34	0.8	0.8	0.8	1.0	1.2	1.4	1.4
Total dissolved solids	34	40	87	152	168	178	240	282
Total alkalinity	34	63	68	85	100	110	128	145
Selected metals								
Total aluminum	34	0.03	0.14	0.40	0.56	0.93	2.28	3.76
Dissolved aluminum	34	0.006	0.007	0.010	0.011	0.036	0.124	1.100
Total arsenic	34	0.0005	0.0005	0.0006	0.0008	0.0010	0.0013	0.0017
Total boron	34	0.014	0.017	0.021	0.025	0.031	0.040	0.045
Total molybdenum	34	0.0002	0.0002	0.0004	0.0006	0.0007	0.0009	0.0011
Total mercury (ultra-trace)	23	0.6	1.2	1.2	1.2	1.6	5.4	12.9
Total strontium	34	0.09	0.10	0.14	0.20	0.25	0.29	0.30

Table 3.2-4 Regional *baseline* values for water quality measurement endpoints, using data from 1997 to 2011, Group 2 southern/western tributaries.

Measurement Endpoint	n	Percentiles						
		Min	5th	25th	Median	75th	95th	Max
Physical variables								
pH	66	7.2	7.6	7.9	8.1	8.3	8.4	8.4
Total suspended solids	66	2	3	3	7	15	75	208
Conductivity	66	80	156	206	251	446	670	772
Nutrients								
Total dissolved phosphorus	66	0.004	0.008	0.017	0.027	0.054	0.127	0.305
Total nitrogen	66	0.30	0.38	0.51	0.99	1.60	2.65	5.54
Nitrate+nitrite	66	0.05	0.06	0.07	0.10	0.10	0.10	0.10
Dissolved organic carbon	66	6.0	7.0	12.8	20.2	31.5	47.8	54.4
Ions								
Sodium	66	3.0	7.9	11.4	16.0	26.8	69.0	76.0
Calcium	66	10.0	11.6	21.8	28.6	45.4	63.5	68.6
Magnesium	66	2.9	4.0	6.9	8.9	14.2	20.6	26.6
Chloride	66	0.5	0.5	1.0	2.0	16.0	35.5	43.0
Sulphate	66	0.5	3.6	7.8	15.5	34.1	69.2	119.0
Potassium	66	0.5	0.6	0.9	1.1	1.7	3.9	5.0
Total dissolved solids	66	40	111	159	195	305	469	547
Total alkalinity	66	30	43	84	114	189	294	337
Selected metals								
Total aluminum	66	0.02	0.05	0.13	0.24	0.50	1.97	4.24
Dissolved aluminum	66	0.001	0.003	0.007	0.014	0.025	0.043	0.146
Total arsenic	66	0.0003	0.0005	0.0008	0.0010	0.0013	0.0027	0.0050
Total boron	66	0.014	0.022	0.045	0.062	0.089	0.144	0.424
Total molybdenum	66	0.0001	0.0001	0.0002	0.0005	0.0007	0.0015	0.0025
Total mercury (ultra-trace)	56	0.6	0.8	1.2	1.2	1.8	4.9	13.0
Total strontium	66	0.05	0.07	0.11	0.14	0.20	0.29	0.36

Table 3.2-5 Regional *baseline* values for water quality measurement endpoints, using data from 1997 to 2011, Group 3 eastern tributaries.

Measurement Endpoint	n	Min	Percentiles					Max
			5th	25th	Median	75th	95th	
Physical variables								
pH	76	7.2	7.4	7.8	8.1	8.2	8.3	8.5
Total suspended solids	76	3	3	3	4	8	22	39
Conductivity	76	110	136	183	231	318	530	1,172
Nutrients								
Total dissolved phosphorus	77	0.006	0.011	0.014	0.020	0.032	0.060	0.096
Total nitrogen	77	0.30	0.48	0.70	0.80	1.00	1.69	3.90
Nitrate+nitrite	77	0.05	0.05	0.10	0.10	0.10	0.10	0.10
Dissolved organic carbon	76	6.0	10.5	15.0	20.0	24.0	29.0	33.0
Ions								
Sodium	76	2.0	2.8	4.0	8.0	12.0	23.5	96.2
Calcium	76	16.4	18.4	23.1	30.8	45.2	72.4	83.5
Magnesium	76	4.9	5.6	7.1	9.0	14.2	18.3	25.1
Chloride	76	0.5	0.5	1.0	2.0	2.0	4.4	80.2
Sulphate	76	0.5	0.8	1.9	3.0	4.6	8.2	22.6
Potassium	76	0.3	0.5	0.5	0.8	1.0	1.7	3.1
Total dissolved solids	76	109	110	150	183	236	332	500
Total alkalinity	76	55	67	93	117	184	290	354
Selected metals								
Total aluminum	77	0.01	0.01	0.03	0.05	0.09	0.44	0.89
Dissolved aluminum	77	0.001	0.002	0.005	0.009	0.012	0.045	0.170
Total arsenic	77	0.0001	0.0003	0.0005	0.0006	0.0010	0.0010	0.0013
Total boron	77	0.006	0.010	0.015	0.032	0.053	0.118	0.169
Total molybdenum	77	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0064
Total mercury (ultra-trace)	51	0.6	1.1	1.2	1.2	1.2	2.3	2.9
Total strontium	77	0.03	0.05	0.07	0.09	0.12	0.20	0.44

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 2011 data for each of the selected water quality measurement endpoints at a given station were assessed against 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 2011 in any season were screened against Alberta acute and chronic water quality guidelines for the protection of aquatic life (AENV 1999b) and CCME Canadian Water Quality Guidelines (CWQG) (CCME 2007). Variables for which there are no AEW or CCME guidelines were screened against applicable guidelines from other jurisdictions where appropriate (Table 3.2-6). All values that exceeded these guidelines are reported explicitly in Section 5.
- **Comparison to Regional *Baseline* Conditions**: 2011 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 2011 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 95^{th} 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=470) yielded index values ranging from 61.7 to 100.0. It should be noted that historical index values calculated for specific observations may change annually, given 95^{th} 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, Johnson lakes), because of concerns raised by the RAMP Peer Review (AITF 2011) regarding combining lakes and streams in regional *baseline* ranges.

Table 3.2-6 Water quality guidelines used to screen data collected by the RAMP Water Quality Component, 2011.

Water Quality Variable	Units	AENV[b]		CCME[a]	Other Jurisdictions[c]
		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[k]	-
Temperature	°C	-	-	-	-
Suspended Solids	mg/L	-	> 10 mg/L[o]	-	-
Turbidity	NTU	-	-	-	-
Major ions		-	-	-	-
Sulphate	mg/L	-	-	-	100[c]
Sulphide (as H_2S)	mg/L	-	-	-	0.002[c]
Chloride (Cl)	mg/L	-	-	-	230 (BC), 860 (USEPA)
Nutrients		-	-	-	-
Total Kjeldahl Nitrogen (TKN)	mg/L	-	-	-	-
Ammonia	mg/L	-	-	0.043 to 153[j]	-
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	0.0040	0.05[n]
Naphthenic acids	mg/L	-	-	-	-
Total and dissolved metals					
Aluminum (Al)	mg/L	-	-	0.005, 0.1[d]	0.05 (dissolved)[l]
Antimony (Sb)	mg/L	-	-	-	0.023
Arsenic (As)	mg/L	-	-	0.0050	-
Barium (Ba)	mg/L	-	-	-	5[c]
Beryllium (Be)	mg/L	-	-	-	-
Bismuth (Bi)	mg/L	-	-	-	-
Boron (B)	mg/L	-	-	-	1.2[c]
Cadmium (Cd)	mg/L	-	-	0.000017[e]	-
Calcium (Ca)	mg/L	-	-	-	-
Chromium III (Cr^{3+})	mg/L	-	-	0.0089	-
Chromium VI (Cr^{6+})	mg/L	-	-	0.0010	-
Cobalt (Co)	mg/L	-	-	-	0.11[c]
Copper (Cu)	mg/L	-	-	0.002 to 0.004[f]	-
Iron (Fe)	mg/L	-	-	0.300	-
Lead (Pb)	mg/L	-	-	0.001 to 0.007[g]	-
Lithium (Li)	mg/L	-	-	-	0.87
Magnesium (Mg)	mg/L	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	0.8 to 3.8[m]
Mercury (Hg)[h]	mg/L	0.000013	0.000005	-	-
Molybdenum (Mo)	mg/L	-	-	0.073	-
Nickel (Ni)	mg/L	-	-	0.025 to 0.150[i]	-
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	-	-	-	0.1[c]
Uranium (U)	mg/L	0.033	0.15	-	-
Vanadium (V)	mg/L	-	-	-	-
Zinc (Zn)	mg/L	-	-	0.030	-
Polycyclic Aromatic Hydrocarbons (PAHs)					**[BC Chronic]**
Acenaphthene	ng/L	-	-	5800	6000
Anthracene	ng/L	-	-	12	4000
Benzo(a)anthracene	ng/L	-	-	18	100
Benzo(a)pyrene	ng/L	-	-	15	10
Fluoranthene	ng/L	-	-	40	4000
Fluorene	ng/L	-	-	3000	12000
Naphthalene	ng/L	-	-	1100	1000
Phenanthrene	ng/L	-	-	400	300
Pyrene	ng/L	-	-	25	-

a: CCME (2011).

b: AENV (1999b).

c: All from British Columbia (2006), except chloride (USEPA 1999), and sulphide (USEPA 1999)

d: 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

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

f: Hardness-dependant. Guideline = $10^{(0.8545*[\ln(hardness)]-1.465)}/1000$. 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

g: Hardness-dependant. Guideline = $10^{(1.273*[\ln(hardness)]-4.705)}/1000$. 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

h: for inorganic mercury

i: Hardness-dependant. Guideline = $10^{(0.76*[\ln(hardness)]+1.06)}/1000$. 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

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

k: 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.

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

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

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

o: 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 2011 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 (ANOVA) 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; and
- 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

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

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

  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 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-D1) 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 in mean values of measurement endpoints from before to after exposure to oil sands development.

Where a *test* reach can also be compared with an upstream *baseline* reach, evidence of an effect is derived as a change in the difference of a measurement endpoint between *test* and *baseline* reaches, from before to after exposure to oil sands development. 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 the difference between *baseline* and *test* reach mean values of a 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 (SD) (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. The range of variability was used for benchmarks in control charts as part of the assessment of measurement endpoints of benthic invertebrate community.

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 $\bar{x} \pm 1SD$; and (iv) a trend over time in the last six observations (Westgard *et al.* 1981).

In this assessment, the range of operating conditions was estimated using the data obtained from *baseline* reaches unexposed to oil sands development. 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 variation in measurement endpoints of 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 in large measure 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 condition for *baseline* reach means was estimated; therefore, using 1^{st} and 99^{th} percentiles as surrogates for $\bar{x} \pm 3SD$, 5^{th} and 9^{th} percentiles as surrogates for $\bar{x} \pm 2SD$, and 25^{th} and 75^{th} percentiles as surrogates for $\bar{x} \pm 1SD$ (e.g., Figure 3.2-3). For the univariate measures, abundance, richness, Simpson's Diversity and percent EPT, these ranges were developed for the individual measurement endpoints within both erosional and deposition habitat classes. A monotonic increase or decrease in measurement endpoint values 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 based test for time trends, but still considered complimentary). The multivariate CA axis scores were treated somewhat differently. Biplots 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.

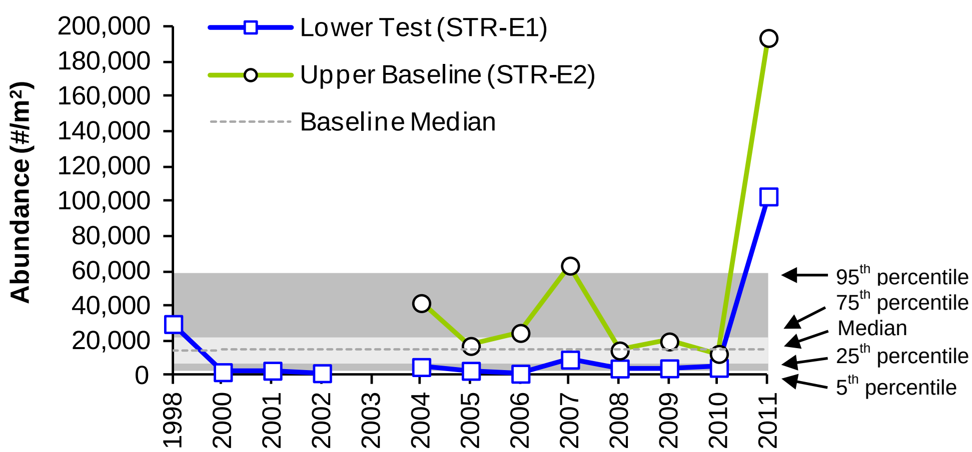
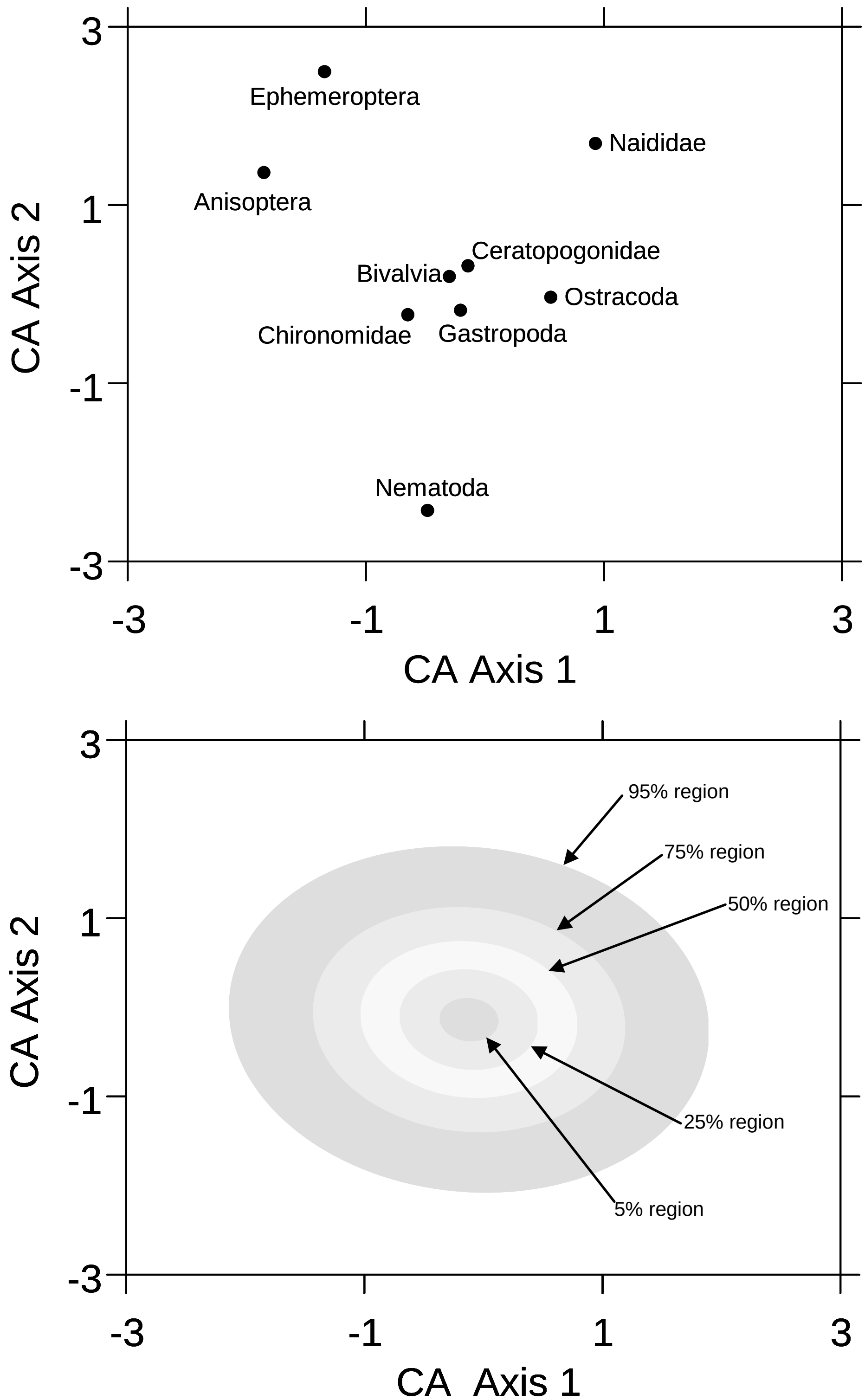


Figure 3.2-4 Example bi-plot showing time trend of benthic invertebrate CA Axis scores in relation to regional *baseline* conditions, in this case, for samples from the Athabasca Delta *test* reaches.



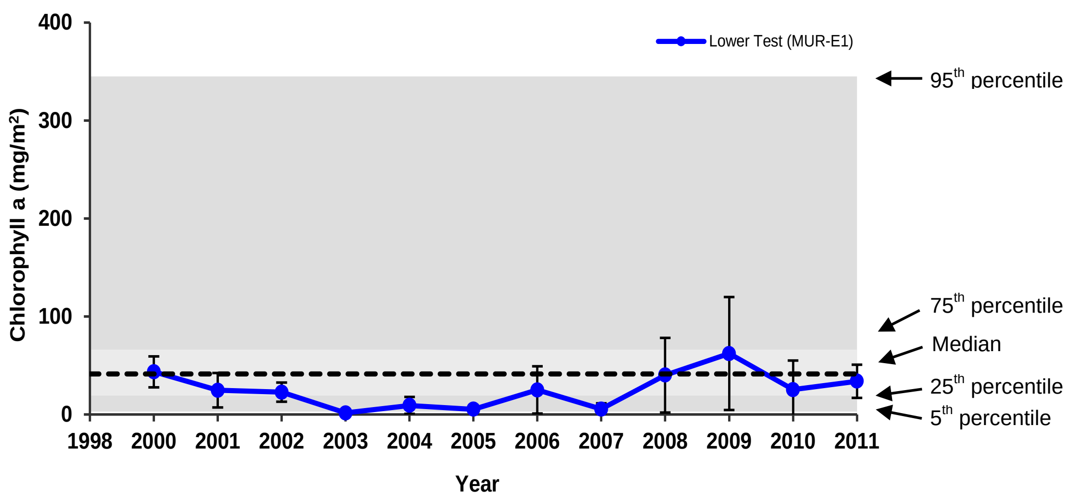
Environmental Variables

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 1999b). Concentrations below this guideline are indicative of potential risks to aquatic life, especially if those concentrations are observed during the day, which is the typical time of sampling for RAMP; and
- Chlorophyll *a*, one of the environmental variables measured in erosional reaches, was identified early in the Alberta Oil Sands Environmental Research Program (AOSERP) studies as a potential indicator of oil sands activity (Barton and Lock 1979) (i.e., removal of cover over a watercourse through development would increase chlorophyll *a* concentrations). The limits of the 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 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 3.2-7). Strong statistical signals are considered 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 3.2-7) 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 five 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 3.2-7 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 2011 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 2011 results, comparing 2011 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 2011 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 3.2-8) was guided by:

- sediment quality measurement endpoints listed in the EIAs 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 3.2-8 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 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 + BTEX)*: indicators of the total hydrocarbon content of sediments, with each indicator (fraction) capturing hydrocarbon compounds of different molecular weights (specifically, number of carbon atoms), and concentrations of benzene, toluene, ethylbenzene and xylene (collectively called BTEX), 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). Sediments with a calculated hazard index value greater than 1.0 have the potential to be toxic to aquatic organisms (USEPA 2004). See Appendix E for further details on the calculation of the predicted PAH toxicity;

- *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), 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 2011 Sediment Quality Results

2011 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 2011. 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 2011 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 2011 (n=302), sediment quality index values of 73.6 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 2011 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 2011 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 2011 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);
- age-frequency distributions;
- size-at-age;
- condition factor; and
- incidence of external health abnormalities.

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) and one small-bodied KIR species [trout-perch]).

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 and spatial comparisons were graphically presented in order to compare species composition and CPUE between 1987 and 2011 for each of the large-bodied KIR species (and lake whitefish in fall only), for each season.

Age-Frequency Distributions Age-frequency distributions (i.e., number of fish per age class) were calculated for large-bodied KIR fish species. Age classes were divided into one year increments for each of the species. Age-frequency distributions were displayed graphically for each year (all seasons combined) in order to evaluate trends in dominant age classes over time.

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 2011) 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 2011) compared to the mean (±2SD) condition of fish captured from 1986 to 1996.

In order to be consistent with past analyses, 2011 analyses of condition 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; white sucker >350 mm; and trout-perch >50 mm.

Spring, summer, and fall condition for each large-bodied KIR species 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 in each season with fin erosion and body wounds; and

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

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 2011.

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 Athabasca River Fish Tissue Study

Selection of Measurement Endpoints

Measurement endpoints used to analyze fish tissue results from the Athabasca River included whole-organism metrics (fork length, body weight, and age), incidence of external/internal health anomalies, and all metals (including mercury) and tainting compounds measured (Table 3.2-12).

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

Temporal Trends and Spatial Comparisons

Whole-organism Metrics Whole-organism metrics (i.e., fork length, body weight, age) were reported along with gender and stage of maturity for walleye and lake whitefish collected during the tissue program on the Athabasca River.

Mercury Mercury results were reported for fish collected from the Athabasca River. Scatterplots were then used to initially assess relationships between mercury concentrations and whole-organism metrics for each species and sex combination. Mercury concentrations among years (2002, 2003, 2005, 2008 and 2011) for the Athabasca River were compared graphically and statistically using ANCOVA (α=0.05), with mercury concentration ($\log_{10}$-transformed) as the dependent variable, year as the independent variable, and fork length ($\log_{10}$-transformed) as the covariate. The first step in the analysis was to compare slopes of length-weight regressions from different populations, and the second step was to compare the intercepts of the regressions.

Total Metals and Organic Compounds Results for total metals and tainting compounds were reported for walleye and lake whitefish collected during the Athabasca River fish tissue program. Temporal comparisons of 2011 results were made with data from walleye and lake whitefish tissue studies previously completed on the Athabasca River (2002, 2003, 2005 and 2008) by RAMP.

Comparison to Published Guidelines

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

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 data were screened against the following criteria:

- Government of Alberta Human Health Risk Assessment for Mercury in Fish in the RAMP area (GOA 2009) (Table 3.2-9);

- Health Canada Guidelines for general fish consumption (Health Canada 2007, last updated July 2007) and subsistence level fish consumption (Health and Welfare Canada 1979, INAC 2003, updated June 2006) (Table 3.2-10);
- Region III USEPA risk-based criteria for consumption of fish tissue for recreational and subsistence fishers (USEPA 2000, updated October 2007) (Table 3.2-10); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000, updated November 2000) (Table 3.2-10).

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, including the Athabasca River.

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 tissue is present as methylmercury (Bloom 1992, 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).

Total arsenic is reported for fish tissue samples collected by RAMP; however, studies have shown that inorganic arsenic should be analyzed rather than total arsenic, which is inclusive of both inorganic and organic forms (EPA 2000). Although both are naturally occurring within the environment, organic arsenic does not appear to bioaccumulate in aquatic organisms (NAS 1977) and has not been considered a significant risk to human health (IRIS 1998). Inorganic arsenic, a minor component of total arsenic, bioaccumulates minimally in finfish (NAS 1977) and has been classified as a human carcinogen (IRIS 1998). Because it is the concentration of inorganic arsenic in fish and shellfish that poses the greatest threat to human health, EPA recommends that inorganic arsenic (not total arsenic) be analyzed in contaminant monitoring programs (EPA 2000).

To assess whether arsenic concentrations in fish may be harmful to human health through consumption, total arsenic concentrations were converted to estimates of inorganic arsenic based on the assumption that inorganic arsenic represented 10% of the total arsenic concentration. This assumption was considered conservative from the perspective of protecting human health as other studies have found that the concentration of inorganic arsenic has been less than 5% of the total arsenic concentration (ATSDR 2009).

Potential Risk to Fish Health To assess potential risk to fish health, fish tissue data were screened against minimum lethal (survival) and non-lethal (growth and reproduction) effects and no-effects thresholds (Table 3.2-11) derived from laboratory-based studies summarized in Jarvinen and Ankley (1999). These criteria were only available for some of the RAMP fish tissue measurement endpoints, including several total metals and mercury, but not for any of the tainting compounds. The thresholds were developed based on ranges of fish tissue residue concentrations linked to both effects and a lack of effects on both sublethal (e.g. growth) and lethal (survival) measurement endpoints; the lowest (i.e., most conservative) concentrations were used to evaluate risk.

Table 3.2-9 Criteria used for evaluating potential risk of fish consumption to human health for watercourses within the RAMP FSA (GOA 2009).

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

* 454 g = 1 lb

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

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

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

Table 3.2-10 Criteria used for evaluating potential risk of fish consumption to human health.

Measurement Endpoint[1]	Units	Health Canada		National USEPA[4]		Region III USEPA[5]
		General[2]	Subsistence[3]	Recreational	Subsistence	Risk-based Criteria
Total Metals						
Antimony (Sb)	mg/kg	nc	nc	nc	nc	0.54
Arsenic (As)[6]	mg/kg	nc	nc	0.026	0.00327	0.0021
Barium (Ba)	mg/kg	nc	nc	nc	nc	270
Beryllium (Be)	mg/kg	nc	nc	nc	nc	2.7
Cadmium (Cd)	mg/kg	nc	nc	nc	nc	1.4
Chromium (Cr)	mg/kg	nc	nc	nc	nc	4.1
Copper (Cu)	mg/kg	nc	nc	nc	nc	54
Iron (Fe)	mg/kg	nc	nc	nc	nc	410
Lithium (Li)	mg/kg	nc	nc	nc	nc	27
Manganese (Mn)	mg/kg	nc	nc	nc	nc	190
Mercury (Hg)[7]	mg/kg	0.5	0.2	0.4	0.049	0.14
Molybdenum (Mo)	mg/kg	nc	nc	nc	nc	6.8
Nickel (Ni)	mg/kg	nc	nc	nc	nc	27
Selenium (Se)	mg/kg	nc	nc	20	2.457	6.8
Silver (Ag)	mg/kg	nc	nc	nc	nc	6.8
Strontium (Sr)	mg/kg	nc	nc	nc	nc	810
Thallium (Tl)	mg/kg	nc	nc	nc	nc	0.095
Tin (Sn)	mg/kg	nc	nc	nc	nc	810
Vanadium (V)	mg/kg	nc	nc	nc	nc	1.4
Zinc (Zn)	mg/kg	nc	nc	nc	nc	410
Tainting Compounds						
Toluene	mg/kg	nc	nc	nc	nc	110

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

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

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

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

5 Last updated June 2011; found at http://www.epa.gov/reg3hwmd/risk/human/pdf/JUNE_2011_FISH.pdf

6 Criterion is for inorganic arsenic.

7 Criteria are for total mercury and methyl-mercury, assuming equivalence.

nc – no criterion

Table 3.2-11 Criteria used for evaluating potential risk to fish health based on concentrations of metals that have lethal, sublethal, or no effects on freshwater fish.

Variable	Endpoint		Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Route	(Days)
Metals								
Aluminum	Survival	no effects	1.0 - 1.15	muscle	rainbow trout, Atlantic salmon	171 g, alevin	oral, water	30 - 42
		effects	20 - 36.8	whole body	Atlantic salmon	alevin	water	30
Antimony	Survival	no effects	5	whole body	rainbow trout	fingerling (1.2 g)	water	30
		effects	9	whole body	rainbow trout	fingerling (1.2 g)	water	30
Arsenic	Survival	no effects	2.6 - 11.4	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	11.2 - 17.9	carcass	rainbow trout	juvenile	oral	56
	Growth	no effects	0.9 - 6.5	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	3.1	carcass	rainbow trout	juvenile	oral	56
Cadmium	Survival	no effects	0.02 - 2.8	muscle	rainbow trout, brook trout	150 -200 g, adult	water, ip injection[2]	210 - 455
		effects	0.14 - 0.7	whole body	rainbow trout, brook trout	5 - 15 g	water	29 - 30
	Growth	no effects	0.09 - 2.8	muscle, whole body	rainbow trout, brook trout	3.1 g, 5 g, adult	water	30 - 455
		effects	0.12 - 0.96	muscle, whole body	rainbow trout, Atlantic salmon	3.1 g, alevin	water	92 - 210
	Reproduction	no effects	0.4	muscle	rainbow trout	adult	water	455
		effects	0.6	muscle	rainbow trout	adult	water	455
Copper	Survival	no effects	0.5 - 3.4	muscle	rainbow trout, brook trout	embryo-adult-juvenile	water	0.33 - 720
		effects	0.5	muscle	rainbow trout	138 g	water	0.33
	Growth	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
	Reproduction	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
Lead	Survival	no effects	4.0	carcass	rainbow trout	under-yearlings (6.5 g)	water	224

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

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

Table 3.2-11 (Cont'd.)

Variable	Endpoint		Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Route	(Days)
Mercury[1]	Survival	no effects	1.91 - 35.0	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, juvenile, fingerling, yearling-adult, adult	ip injection[2], oral, water	15 - 273
		effects	3.7 - 31	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, subadult (100 - 150 g)	ip injection[2], oral	186 - 273
					northern pike	yearling-adult, adult	water	
	Growth	no effects	2.28 - 29.0	whole body, muscle	rainbow trout	fingerling, juvenile	oral, water	24 - 105
		effects	8.6 - 35.0	whole body, muscle	rainbow trout	fingerling	oral	84 - 105
	Reproduction	no effects	9.2	muscle	brook trout	yearling-adult	water	273
		effects	23.5	muscle	brook trout	yearling-adult	water	273
Nickel	Survival	no effects	0.82 - 58.0	muscle	rainbow trout, carp	15 g, 150 - 200 g	water	5 - 180
		effects	118.1	muscle	Carp	15 g	water	4
Selenium	Survival	no effects	0.28 - 3.1	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, egg-juvenile,	water, oral	28 - 308
					largemouth bass	fingerling-juvenile, juvenile		
		effects	0.92 - 2.5	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, .fingerling-juvenile	water, oral	28 - 168
	Growth	no effects	0.08 - 1.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, egg-juvenile	oral	60 - 308
						fingerling-juvenile, juvenile		
		effects	0.32 - 2.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, fingerling-juvenile, juvenile	oral	60 -168
Silver	Survival	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
	Growth	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
Vanadium	Survival	no effects	5.33	carcass	rainbow trout	juvenile	oral	84
	Growth	no effects	0.02	carcass	rainbow trout	juvenile	oral	84
		effects	0.41	carcass	rainbow trout	juvenile	oral	84
Zinc	Survival	no effects	60	whole body	Atlantic salmon	juvenile	water	80
	Growth	no effects	60	whole body	Atlantic salmon	juvenile	water	80

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

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

Classification of Results

Criteria for classifying fish tissue concentrations of mercury were developed for determining risk to human health based on the exceedances of subsistence fisher and general consumer consumption guidelines for mercury. 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 3.2-12 provides the classification of results for risk to human health for subsistence fishers and general consumers. 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 3.2-12 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 Fish Assemblage Monitoring Program

Selection of Measurement Endpoints

Several conventional measurement endpoints of fish assemblages 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 measurement endpoint was computed for each reach following the calculation for Simpson’s Diversity (D):

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

  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 measurement endpoint was computed for each reach following the calculation for evenness (E) as per the EEM Technical Guidance Document (Environment Canada 2010), 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 ATI 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 3.2-13). 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 3.2-13 Tolerance values for fish collected during the 2011 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
Lake whitefish*	LKWH	2.5[1]
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 values for similar species.

Temporal Trends and Spatial Comparisons

Possible changes in fish assemblages were evaluated by comparing measurement endpoints in reaches designated as *test* to upstream *baseline* reaches and/or across years within a reach. Given this is the first year of the fish assemblage monitoring program following a two-year pilot study at a subset of the reaches, statistical analyses were not conducted to assess temporal trends or spatial comparisons. However, as more data are collected over time, ANOVA will be used to test the following hypotheses:

- H_1: No linear time trend in mean values of measurement endpoints during the period of sampling; and
- H_2: No difference in mean values of measurement endpoints between an upstream *baseline* reach and a downstream *test* reach.

Comparison to Published Literature

There are no conventional "guidelines" *per se* against which to judge observed differences in measurement endpoints of fish assemblages given *baseline* ranges of variation tend to depend on local or regional climatic, hydrological, and geological conditions. Consequently, RAMP *baseline* reach data, data for select reaches from the two-year pilot study, and published literature of fish surveys conducted within the region (i.e., Golder [2004]) provide the most appropriate set of regional *baseline* conditions and information against which to assess potential change(s) observed in *test* reaches.

Determination of Regional Baseline Conditions

To allow for a regional comparison, the first step was to determine which fish assemblage reaches were similar in habitat conditions in order to group reaches according to their similarities. A principal components analysis (PCA) of the fish habitat data for each of the 32 reach-year combinations (data collected during the 2009 to 2010 pilot study was included in the PCA) was conducted to determine how habitat variables co-varied and to select a subset of variables that would be used to explore variation in measurement endpoints of fish assemblages. The PCA was conducted using the following variables: average water depth, average flow velocity, bankfull width, wetted width, left bank height, right bank height, left bank angle, right bank angle, concentration of dissolved oxygen, conductivity, pH, water temperature at the time of the sampling, instream cover as attached algae, instream cover as macrophytes, instream cover as large woody debris (LWD), instream cover as small woody debris (SWD), instream cover as live trees, instream cover as overhanging vegetation < 1 m from the water surface, instream cover as undercut banks, instream cover as boulders, canopy cover, understory cover, and sum of LWD. The results of the PCA showed that three PCA axes were considered strong, each explaining greater than 10% of the variation in the habitat data (Jackson 1993). Table 3.2-14 provides the Pearson correlations (i.e., Pearson r-values) between individual habitat variables and the three PCA axes, which explained greater than 10% variation. Habitat variables with correlations to a PCA axis that was greater than $|0.6|$ were considered strongly associated with an axis.

Habitat variables that correlated with the first PCA axis were those that generally described channel width. Channels that were wide tended to have greater flow velocities, and more instream cover as small woody debris and as overhanging vegetation. The second PCA axis correlated with variables associated with cover. Watercourses with more macrophytes tended to have less large woody debris, canopy cover and large woody debris. The third PCA axis was correlated primarily with water depth. Channels that were deeper tended to have deeper banks. Based on the strongest correlations of habitat variables with each PCA axis, channel width (bankfull), water depth, and macrophyte cover are considered good descriptors of habitat conditions.

Table 3.2-14 Principal Component Analysis (PCA) of habitat variables associated with fish assemblage reaches.

Variable	Principal Component		
	1	2	3
Depth	0.20	0.00	**-0.73**
Flow velocity	**-0.78**	-0.14	-0.29
Bankfull width	**-0.86**	0.06	0.08
Wetted width	**-0.78**	0.01	-0.02
Left bank height	0.18	0.37	**-0.72**
Right bank height	0.31	**0.72**	-0.44
Left bank angle	0.01	-0.42	-0.34
Right bank angle	0.46	0.28	-0.21
Dissolved oxygen	-0.59	-0.45	-0.38
Conductivity	**0.68**	0.35	0.45
pH	0.27	-0.37	0.13
Temperature	-0.12	0.58	0.51
Instream cover (algae)	0.38	0.37	0.12
Instream cover (macrophytes)	0.43	**-0.73**	0.13
Instream cover (LWD)	-0.14	**0.64**	0.08
Instream cover (SWD)	**0.76**	0.39	-0.03
Instream cover (live trees)	0.14	-0.28	0.00
Instream cover (overhanging vegetation)	**0.60**	-0.60	-0.22
Instream cover (undercut banks)	0.57	-0.33	0.19
Instream cover (boulders)	-0.32	-0.03	0.30
Canopy cover	-0.51	**0.67**	0.18
Large woody debris	0.19	**0.79**	-0.35
Understory	0.40	-0.15	0.11
% of variance explained	**24**	**20**	**11**

Note: values are Pearson Correlations (*r*); values in bold are > |0.6| and considered strong associations with the PC axis.

Based on the results of the PCA, the three habitat variables with the strongest correlation with the PCA axes (i.e., bankfull width, water depth, and macrophyte cover) were used to explore potential variation in fish assemblage measurement endpoints. In addition to these variables, substrate class (i.e., erosional or depositional), habitat type (i.e., run, pool or riffle) and vegetation class in the riparian zone (deciduous, mixed, coniferous, etc.), which are categorical variables that can't be included in a PCA, were also used to explore potential variation in fish assemblage measurement endpoints. These categorical variables were considered to be important in predicting changes in fish assemblages.

Using only data from *baseline* reaches, variability in measurement endpoints of fish assemblages relative to the five habitat variables, were explored using ANOVA and boxplots. There were no habitat variables that explained a statistically significant amount of variation in any measurement endpoint (p>0.1) with the exception of substrate class (i.e., erosional vs. depositional), which explained a weak statistically significant (i.e., 10%

of the variance) variation in the ATI (p = 0.09), with depositional reaches tending to have fish assemblages with higher ATI scores than erosional reaches (Table 3.2-15). Figure 3.2-7 illustrates the influence of the three habitat variables that were correlated with each PCA axis on measurement endpoints of fish assemblages. Figure 3.2-6 illustrates the influence of the three categorical habitat variables on measurement endpoints of fish assemblages.

Table 3.2-15 Results of ANOVAs testing the influence of various habitat variables on the variation in measurement endpoints of fish assemblages.

Measurement Endpoint	Source	SS	df	MS	F	P-value
Abundance	Substrate Class	0.010	1	0.010	0.158	0.700
	Error	0.570	9	0.063		
	Vegetation Class	0.091	3	0.030	0.433	0.736
	Error	0.489	7	0.070		
	Flow Class	0.100	2	0.050	0.833	0.469
	Error	0.480	8	0.060		
	Bankfull width	0.002	1	0.002	0.038	0.849
	Error	0.578	9	0.064		
	Macrophyte Cover Score	0.031	1	0.031	0.516	0.491
	Error	0.549	9	0.061		
	Depth	0.046	1	0.046	0.782	0.400
	Error	0.534	9	0.059		
Richness	Substrate Class	0.004	1	0.004	0.001	0.970
	Error	22.06	9	2.451		
	Vegetation Class	3.152	3	1.051	0.389	0.765
	Error	18.91	7	2.70		
	Flow Class	0.611	2	0.306	0.114	0.894
	Error	21.45	8	2.68		
	Bankfull width	0.694	1	0.694	0.292	0.602
	Error	21.37	9	2.374		
	Macrophyte Cover Score	0.707	1	0.707	0.298	0.598
	Error	21.35	9	2.373		
	Depth	0.262	1	0.262	0.108	0.750
	Error	21.80	9	2.422		
Diversity	Substrate Class	0.003	1	0.003	0.086	0.776
	Error	0.356	9	0.040		
	Vegetation Class	0.030	3	0.010	0.209	0.887
	Error	0.330	7	0.047		
	Flow Class	0.047	2	0.024	0.606	0.569
	Error	0.312	8	0.039		
	Bankfull width	0.021	1	0.021	0.552	0.476
	Error	0.339	9	0.038		
	Macrophyte Cover Score	0.002	1	0.002	0.049	0.829
	Error	0.357	9	0.040		
	Depth	0.024	1	0.024	0.635	0.446
	Error	0.336	9	0.037		

Note: bold values indicate a significance level (p<0.1).

Table 3.2-15 (Cont'd.)

Measurement Endpoint	Source	SS	df	MS	F	P-value
Evenness	Substrate Class	0.003	1	0.003	0.162	0.697
	Error	0.149	9	0.017		
	Vegetation Class	0.068	3	0.023	1.897	0.219
	Error	0.084	7	0.012		
	Flow Class	0.002	2	0.001	0.04	0.961
	Error	0.150	8	0.019		
	Bankfull width	0.001	1	0.001	0.047	0.833
	Error	0.151	9	0.017		
	Macrophyte Cover Score	0.002	1	0.002	0.094	0.766
	Error	0.150	9	0.017		
	Depth	0.000	1	0.000	0.001	0.982
	Error	0.150	9	0.017		
ATI	Substrate Class	5.75	1	5.752	3.502	**0.094**
	Error	14.78	9	1.643		
	Vegetation Class	6.520	3	2.173	1.085	0.416
	Error	14.02	7	2.002		
	Flow Class	6.060	2	3.028	1.673	0.247
	Error	14.48	8	1.81		
	Bankfull width	0.670	1	0.671	0.304	0.595
	Error	19.87	9	2.207		
	Macrophyte Cover Score	4.30	1	4.3	2.384	0.157
	Error	16.24	9	1.804		
	Depth	2.280	1	2.28	1.124	0.317
	Error	18.26	9	2.028		

Note: bold values indicate a significance level (p<0.1).

Development of Regional *Baseline* Conditions Based on the results of the ANOVA, grouping of *baseline* reaches to create a range of *baseline* variability for which to compare *test* reaches was not required for the abundance, diversity, richness, and evenness measurement endpoints. For the ATI value, *baseline* reaches were grouped by substrate class (depositional and erosional) to develop regional *baseline* conditions. As more data are collected over time, analysis of habitat variables and the influence on fish assemblages will be refined.

The range of variation for each measurement endpoint was calculated for erosional *baseline* reaches and depositional *baseline* reaches as:

$$\overline{X}_r \pm 2SD_r$$

where:

$\overline{X}_r$ is the mean value for a measurement endpoint across all *baseline* reaches within the erosional or depositional groups of reaches; and

SD_r is the standard deviation of the mean value of a measurement endpoint. The range defined by the mean ± 2SD includes approximately 95% of possible observations (Kilgour *et al*. 1998).

The range of variation for *baseline* depositional and erosional reaches is provided in Table 3.2-16. The 5th and 95th percentiles were used to judge whether a reach was consistent with regional *baseline* conditions.

Figure 3.2-6 Scatterplot of measurement endpoints of fish assemblages in relation to bankfull width, water depth, and macrophyte cover in *baseline* reaches.

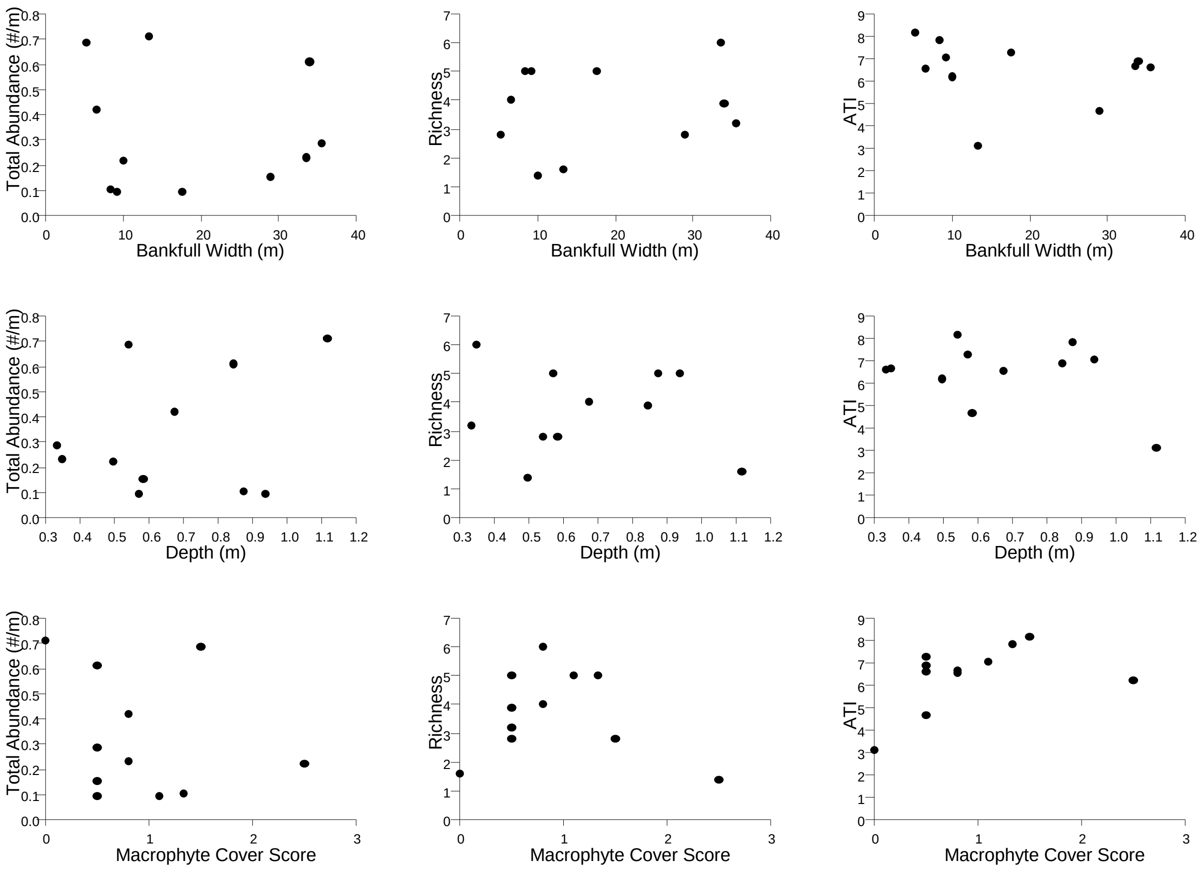
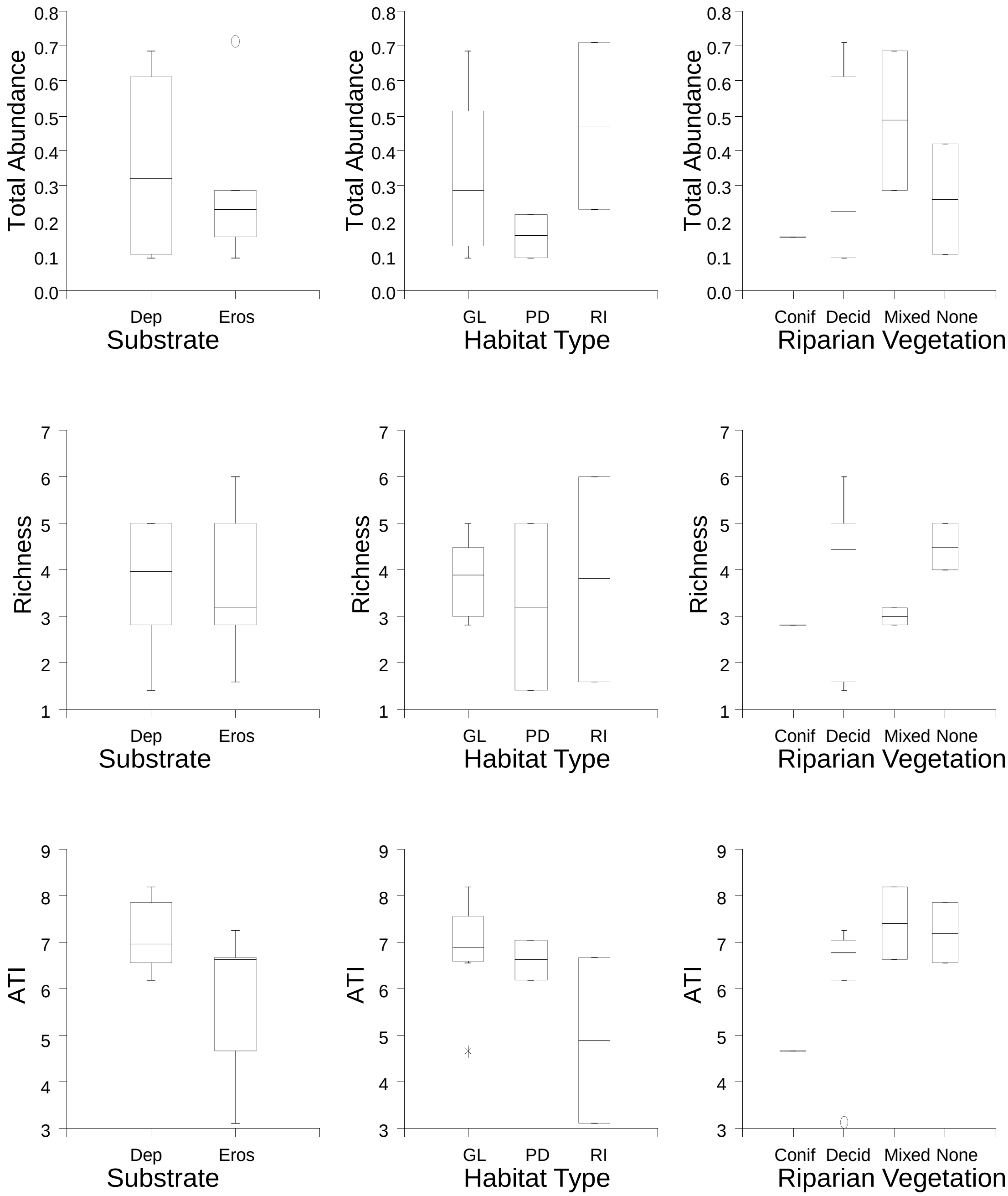


Figure 3.2-7 Comparison of measurement endpoints of fish assemblages in relation to substrate, habitat type, and riparian vegetation in *baseline* reaches.



Note: Dep-depositional; Eros-erosional; GL-run; PD-pool; RI-riffle; Conif-coniferous; Decid-deciduous.

Table 3.2-16 Range of variation for each fish assemblage measurement endpoint within *baseline* reaches.

Habitat Type		Measurement Endpoint				
		Total Abundance	Richness	Simpson's Diversity	Evenness	ATI
Depositional *Baseline* Reaches	Mean	0.36	3.68	0.50	0.63	7.12
	SD	0.26	1.39	0.18	0.11	0.76
	95th percentile	0.87	6.46	0.86	0.86	8.64
	5th percentile	0	0.91	0.15	0.40	5.60
Erosional *Baseline* Reaches	Mean	0.30	3.72	0.47	0.66	5.67
	SD	0.25	1.76	0.22	0.14	1.73
	95th percentile	0.79	7.25	0.92	0.95	9.12
	5th percentile	0	0.19	0.02	0.37	2.22
All *Baseline* Reaches	Mean	0.33	3.70	0.49	0.64	-
	SD	0.24	1.49	0.19	0.12	-
	95th percentile	0.81	6.67	0.87	0.89	-
	5th percentile	0	0.73	0.11	0.40	-

Classification of Results

Criteria used for classifying results of fish assemblages focused on whether or not the core measurement endpoints for fish assemblage at a *test* reach either exceeded regional *baseline* conditions, had significantly changed across years, or was 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 for changes in core measurement endpoints for fish assemblages (Table 3.2-17). There are five core measurement endpoints assessed for fish assemblages (abundance, richness, Simpson's Diversity, evenness, and the assemblage tolerance index). If any one of those measurement endpoints produces a significant 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 assemblage that is important. The second criterion will be considered to be met (producing a "yes" in Table 3.2-17) 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 five measurement endpoints fall outside regional *baseline* conditions within the current year. This is particularly relevant for the assessment of reaches for which there is at least a three-year data record.

Given this is the first year of the fish assemblage monitoring program, the first criterion to classify results cannot be used given there is not enough data to conduct statistical analyses; however, the second criterion can be used to assess the fish assemblage at a given reach designated as *test* by determining whether any of the five measurement endpoints exceed the range of variability in *baseline* reaches.

Table 3.2-17 Classification of results for the Fish Assemblage Monitoring program.

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 are outside of the range of variation in *baseline* reaches.

Note: only the second criterion was used in the 2011 analyses given the limited data available.

3.2.5 Acid-Sensitive Lakes Component

The analytical approach used in 2011 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 2011 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 2011 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, Legge 1988, RAMP 2004). Sulphate has also found to be sequestered and immobilized within the individual catchment basins (Whitfield *et al.* 2010).

3.2.5.2 Temporal Trends

The emphasis in the data analysis was placed on the detection and evaluation of potential trends in the ASL measurement endpoints in the RAMP study lakes that would indicate incipient acidification in the lakes. In this regard, five 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 ten years of monitoring when the all 50 lakes were sampled (2002 to 2011). 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 ANOVA) was applied to detect changes in the median concentrations. Tukey's post-hoc test was used to examine individual differences in mean values among years when the ANOVA indicated significant differences. Any observed changes were discussed in relation 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 An ANOVA using the General Linear Model (GLM) was applied to examine trends in measurement endpoints over time in the study 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 as most likely to undergo acidification (high potential acid input (PAI)/low critical load (CL); see below).

Calculation of Critical Loads of Acidity and Comparison to Modeled Potential Acid Input The 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 2011 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 acid neutralizing capacity (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). In 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, Gibson *et al*. 2010). This technique utilizes a different set of assumptions from traditional hydrometric methods that 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 oil sands (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 G).

2. A study by Whitfield *et al.* (2010) in which the Magic (Model of Acidification of Groundwater in Catchments) 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 PAI to each lake basin summarized in the Teck Frontier EIA (Teck 2011) and CEMA (2010c). In both cases, a maximum emissions scenario was assumed to represent existing emission sources as well as emissions from industrial sources that have been approved but not yet occurring. 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 AEW, 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 on the RAMP study lakes, 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 2011 to the range of chemical characteristics of lakes within the oil sands region;
- Classification of lake chemistry in Piper plots; and
- Analysis of metals in the individual lakes.

Update of the ASL Database, Summary Statistics and Comparisons of RAMP ASL Chemistry to Regional Lake Chemistry The chemical data from 2011 and all previous 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 RAMP 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 study lakes are of lakes within the oil sands region. Comparisons involved:

- examination of the ranges, medians and mean values of key chemical variables for 2011 in the RAMP lakes relative to the regional dataset;
- graphical presentation of both datasets in box-plots; and
- statistical comparison of chemical variables between the RAMP study lakes and the regional dataset.

Classification of the RAMP Study Lakes in Piper Plots Piper plots were used to characterize the waters in each of the study 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, 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^- - $SO_4{}^{2-}$.

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

3.2.5.9 Classification of Results

A summary of the state of the RAMP lakes in 2011 with respect to the potential for acidification was prepared for each physiographic subregion by examining deviations from the mean chemical concentrations of the measurement endpoints for each lake within each subregion. The measurement endpoint and the relevant trend that is indicative of acidification are as follows: Gran alkalinity (downwards); pH (downwards); sum base cations (upwards); nitrates (upwards); dissolved organic carbon (downwards); sulphate (upwards); aluminum (upwards).

For each lake, the mean and standard deviation were calculated for each measurement endpoint over all the monitoring years. The number of lakes in 2011 within each subregion having measurement endpoint values greater than two standard deviations (SD) (above or below the mean as indicated above) was calculated. The number of such endpoint-lake exceedances was expressed as a percentage of the total number of lake-endpoint combinations for each subregion. The results were classified as follows:

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

4.0 CLIMATE AND HYDROLOGIC CHARACTERIZATION OF THE ATHABASCA OIL SANDS REGION IN 2011

The following characterization of the 2011 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 2011 Regional Aquatics Monitoring Program (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 2011 water year (WY), from November 1, 2010 to October 31, 2011.

4.1 PRECIPITATION AND SNOWPACK

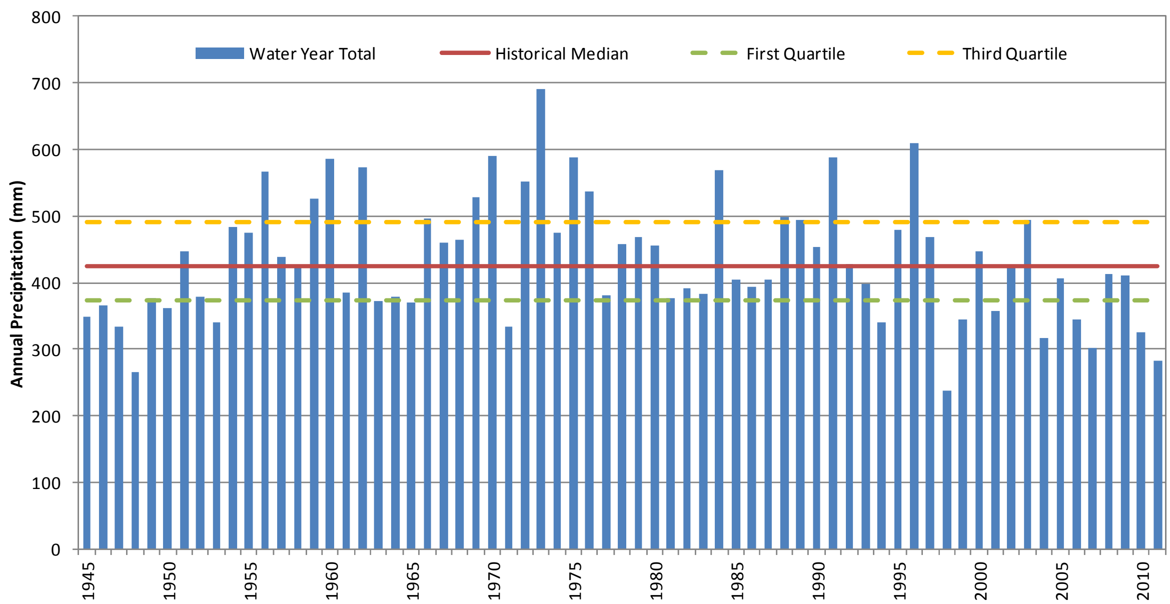
Long-term precipitation records are available for Fort McMurray from the 1945 WY to the 2011 WY with data collected at Environment Canada (EC) Station 3062693, Fort McMurray A, until July 2008 and EC Station 3062700, Fort McMurray AWOS A, thereafter. Total precipitation measured at this station in the 2011 WY was 283.6 mm (Figure 4.1-1), which was 33% lower than the long-term annual median for Fort McMurray (from the 1945 WY to the 2010 WY) of 424 mm, and represented the eighth consecutive year in which precipitation measured at Fort McMurray was below the annual median. Monthly total precipitation values were below average for all months in the 2011 WY (November to October) (Figure 4.1-2). Precipitation falling as snow, from November 1, 2010 to March 31, 2011 was approximately 42% below the historical mean for this period. Precipitation (assumed to be rainfall) from April 1 to October 31, 2011 was 33% lower than the historical mean values for the same period.

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 2011 (Figure 4.1-3). The 2011 WY cumulative precipitation record at all stations was generally below mean historical values for the entire year (Figure 4.1-3) with the exception of values recorded at the C2-Horizon Climate Station, which remained above the mean for the months of December to April. The period from mid-February to mid-June showed little precipitation across the region with all stations recording below the historical mean value. Precipitation for the summer months, mid-June to October, was also below historical mean values for Fort McMurray. No overall spatial pattern was observed in the precipitation record for the 2011 WY. All stations reported similar annual totals and trends with the exception of the C2-Horizon Climate Station, which reported almost 100 mm more precipitation than the other stations characterized in Figure 4.1-3.

Snowpack amounts (in terms of mm snow water equivalent or SWE) were measured at 16 locations during the period of February 8 to 12, March 7 to 14, and March 31 to April 4 2011, 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 mean SWE values recorded for each time period in a category are presented in Figure 4.1-4. The mean of the maximum average SWE values for the period of 2004 to 2010 are included for comparison. SWE values were highest in flat low-lying terrain with a decreasing trend through mixed deciduous, jackpine, and open land/lake terrain. Flat low-lying and mixed deciduous terrain recorded the highest SWE values on record, while jackpine and open land/lake measurements were only slightly greater than the seven-year mean values.

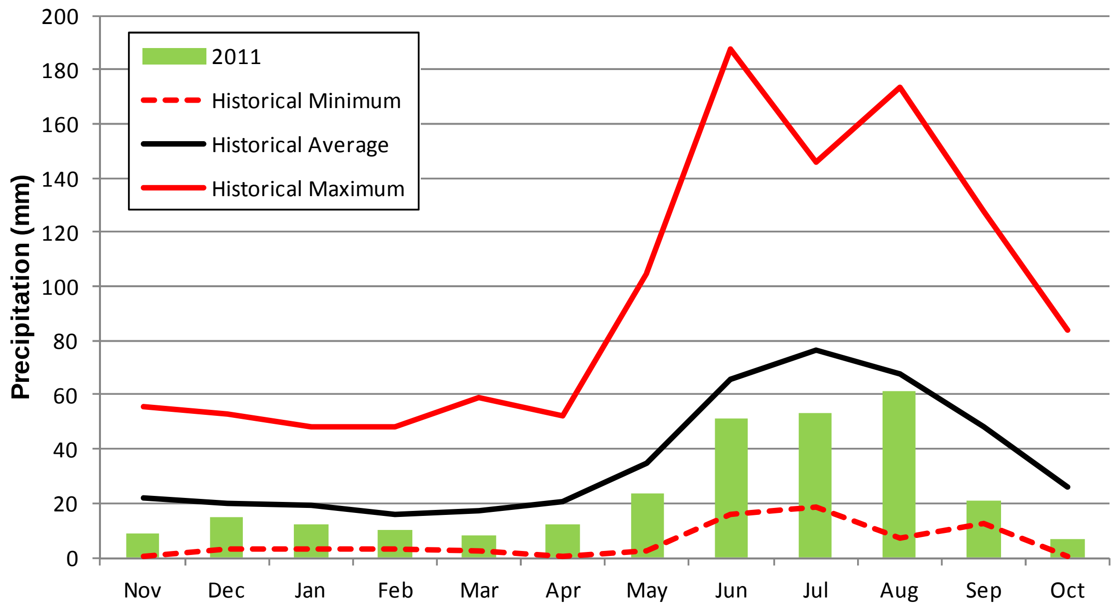
Mean SWE by land category types corresponded well with snow depths measured at the C1-Aurora, C2-Horizon, and C3-Steepbank climate stations. Snow water equivalent measurements were collected at appropriate sampling intervals to characterize the snowpack trend for the 2011 WY. Snow depth in the 2011 WY was greatest in March and melted over a 10-day period from March 28 to April 9, 2011 (see Appendix C).

Figure 4.1-1 Historical annual precipitation at Fort McMurray (1945 WY to 2011 WY).



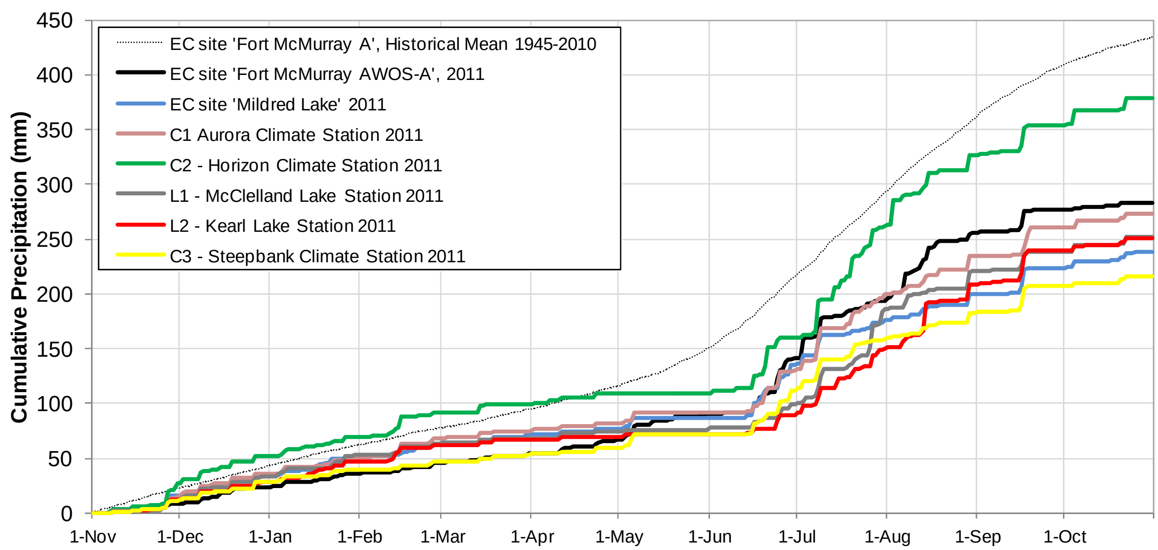
Note: Data recorded at Environment Canada (EC) station 3062693 (Fort McMurray A) from November 1944 until July 2008 and then at EC station 3062700 (Fort McMurray AWOS A) thereafter.

Figure 4.1-2 Monthly precipitation at Fort McMurray in 2011.



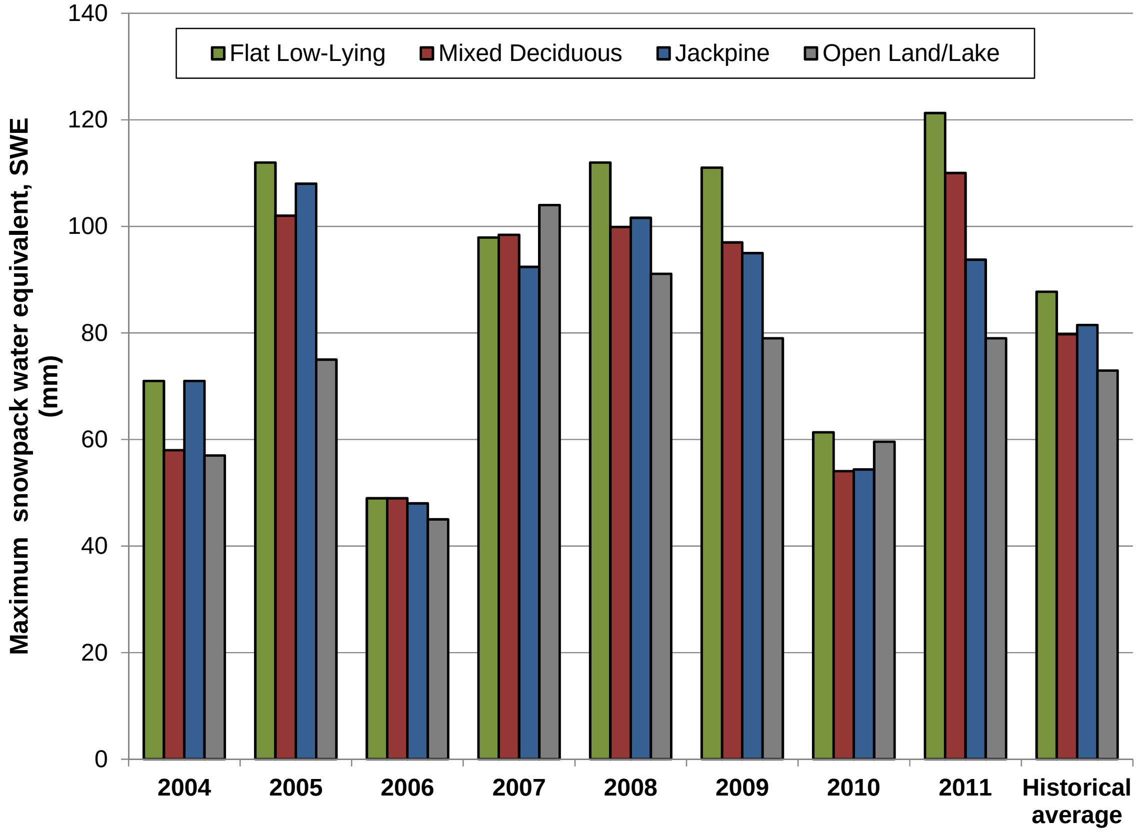
Note: 2011 data recorded at EC Station 3062700 (Fort McMurray AWOS A); historical values based on data from EC station 3062693 (Fort McMurray A) from November 1945 until July 2008, and at AWOS A thereafter.

Figure 4.1-3 Cumulative total precipitation at climate stations in the Athabasca oil sands region in 2011.



Note: Data at Station C2 is missing from August 27 to September 12. The data gap was extrapolated using precipitation data from rainfall collected at Station S19 Tar River Lowland Tributary near the Mouth to complete the cumulative annual record.
Data at Station C3 is missing from July 27 to September 20. The gap was extrapolated using data from EC Mildred Lake to complete the cumulative annual record.

Figure 4.1-4 Historical maximum measured snowpack amounts in the Athabasca oil sands region (2004 to 2011).



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 mean values recorded for each land category and year.

4.2 STREAMFLOW

2011 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 2011 WY hydrologic conditions in four main areas of interest in the RAMP Focus Study Area (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 21,390 million m^3 for the 2011 WY (Table 4.2-1). This is 10% greater than the long-term WY average flow volume of 19,441.7 million m^3 over the station's 54-year recording period (1958 to 2011). The 2011 WY was the fourth year since 1991 to have exceeded the historical average WY runoff volume; the other years were 1996, 1997, and 2005 (Figure 4.2-1).

The flows measured at this station during the 2011 WY were near the historical lower quartile range for the months of November, December, January, February, March, September, and October (Figure 4.2-2). Minimum flow recorded for the open water period, May to October, was more than 100 m^3/s below the historical average minimum and was recorded on October 31 at 323 m^3/s (Table 4.2-1). The spring snowmelt and freshet conditions in the Athabasca River resulted in flows within the historical upper quartile range in the 2011 WY. Flows in late June and July were very high during two separate events, with recorded flows in the historical maximum range. The annual maximum discharge occurred in the later event, on July 13, with a discharge of 4,410 m^3/s. The 2011 WY daily maximum discharge at the Athabasca River below McMurray WSC Station of 4,410 m^3/s was nearly twice the historical mean maximum discharge of 2,478 m^3/s.

The two extreme events observed in June and July in the Athabasca River below McMurray Station were not observed in basins north of Fort McMurray (i.e., Muskeg and MacKay rivers) suggesting that the cause of the peak flows were a result of weather conditions upstream of Fort McMurray.

4.2.2 Muskeg River

The 2011 seasonal (March to October) runoff volume for the Muskeg River watershed recorded at WSC Station 07DA008, Muskeg River near Fort McKay, was 36.9 million m^3 (Table 4.2-1). This was 68% lower than the long-term average seasonal runoff volume of 117 million m^3 and the third lowest runoff volume on record over the station's 37-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 2011 WY followed this pattern. During the freshet period, flow peaked at 9.2 m^3/s on May 10 and was 64% lower than the historical mean maximum flow of 25.7 m^3/s (Table 4.2-1). Streamflow from June to October was between the historical minimum and historical lower quartile daily flow. The 2011 March to October minimum daily flow of 0.21 m^3/s recorded on March 6 was 25% lower than the historical average minimum daily flow of 0.28 m^3/s (Table 4.2-1).

4.2.3 MacKay River

The 2011 seasonal (March to October) runoff volume for the MacKay River watershed recorded at WSC Station 07DB001, MacKay River near Fort McKay, was 288 million m^3 (Table 4.2-1). This was 32% below the long-term average seasonal runoff volume (Figure 4.2-5) based on a 38-year flow record. The spring freshet hydrograph recorded for the MacKay River showed a similar pattern to that of the Muskeg River. The maximum-recorded freshet flow of 49.5 m^3/s occurred on May 10, which was the same date as the freshet peak for the Muskeg River (Figure 4.2-6). Discharge decreased through mid-May into June when discharge was recorded below the historical lower quartile. Flows increased from late June to near historical upper quartile levels by mid-July and remained above or near the historical median for the remainder of the 2011 WY (Figure 4.2-6). Late June flows in the MacKay River was indicative of a regional pattern of generally wetter conditions to the west of the Athabasca River when compared to the Muskeg River (to the east of the Athabasca River) during the early summer period. The 2011 March to October minimum daily flow of 0.38 m^3/s, recorded on March 5, was 8% higher than the historical average minimum daily flow of 0.35 m^3/s (Table 4.2-1).

4.2.4 Christina River

The 2011 seasonal (March to October) runoff volume for the Christina River watershed recorded at WSC station 07CE002, Christina River near Chard, was 499 million m^3 (Table 4.2-1). This was 17% higher than the long-term average seasonal runoff volume of 425 million m^3 over the 28-year recording period and is the eighth consecutive year of above-average seasonal flow volumes recorded at this station (Figure 4.2-7).

The freshet peak of 44.7 m^3/s was recorded on May 7 and was near the historical upper quartile (Figure 4.2-8). The timing of this peak was similar to that of both the Muskeg and MacKay rivers. Following this date, the Christina River hydrograph showed a similar pattern to the MacKay River with flows decreasing to near the historical minimum in mid-June. Discharge increased in late June to the 2011 WY maximum of 107 m^3/s recorded on June 30. This maximum flow value was 30% higher than the historical average maximum for the period of record (Table 4.2-1). Following this peak discharge, flows decreased to the end of October to near the historical lower quartile. The daily minimum discharge in the 2011 WY of 1.45 m^3/s occurred on March 4, which was 40% lower than the historical minimum (Table 4.2-1).

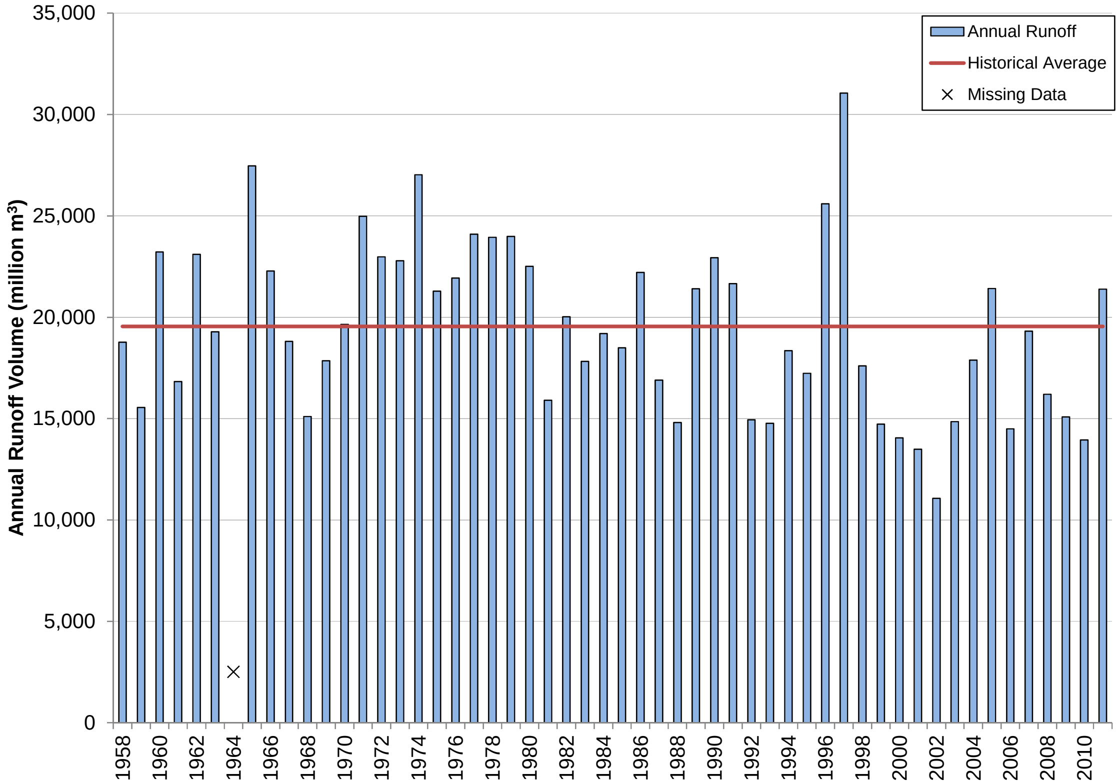
Table 4.2-1 Summary of 2011 streamflow variables compared to historical values measured in the Athabasca oil sands region.

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 - 2011	1974 - 2011	1973 - 2011	1983 - 2011
Runoff Volume[1]				
Historical mean (million m^3)	19,442	117	427	425
2011 (million m^3)	21,390	36.9	288	499
Maximum Daily Discharge[1]				
Historical mean (m^3/s)	2,478	25.7	115	82.4
2011 (m^3/s)	4,410	9.2	49.5	107.0
Minimum Daily Discharge[2]				
Historical mean (m^3/s)	428	0.28	0.35	2.40
2011 (m^3/s)	323	0.21	0.38	1.45

[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.

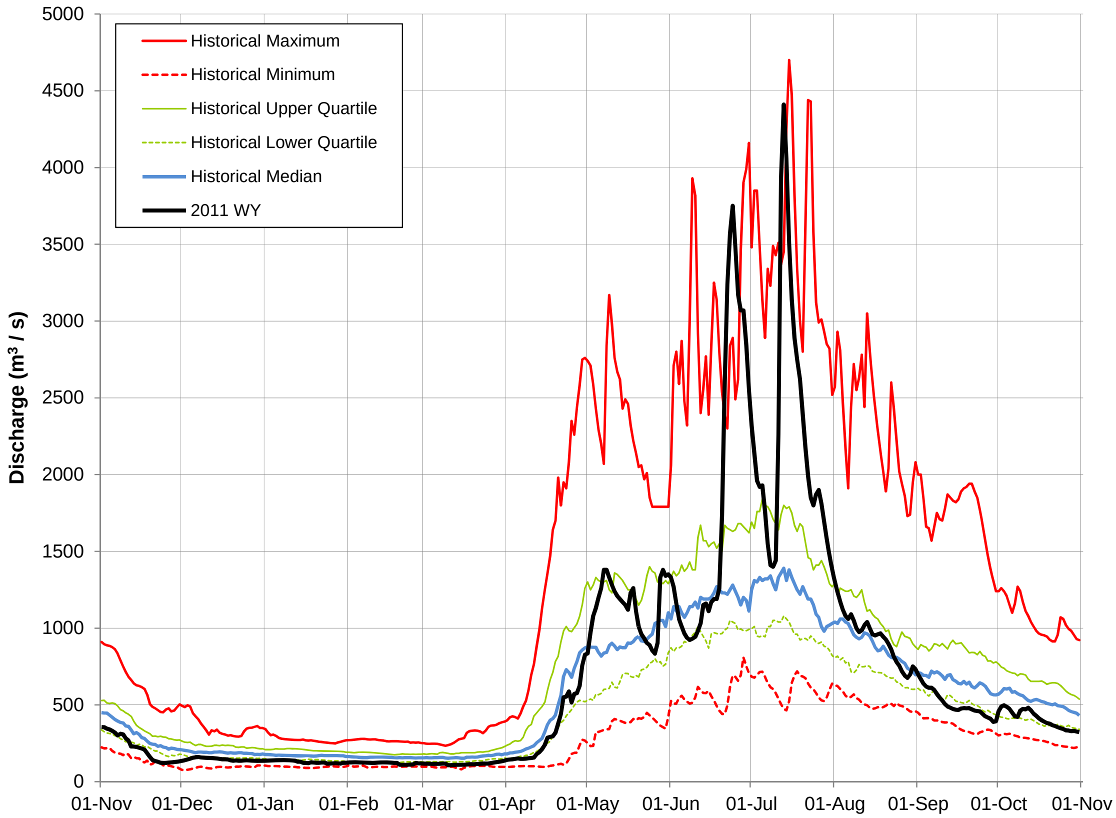
[2] Open-water (May to October) minimum daily discharge provided for the Athabasca River below Fort McMurray (07DA001), while seasonal (March to October) minimum daily discharge are provided for the other three stations.

Figure 4.2-1 Historical annual runoff volume in the Athabasca River basin, 1958 to 2011.



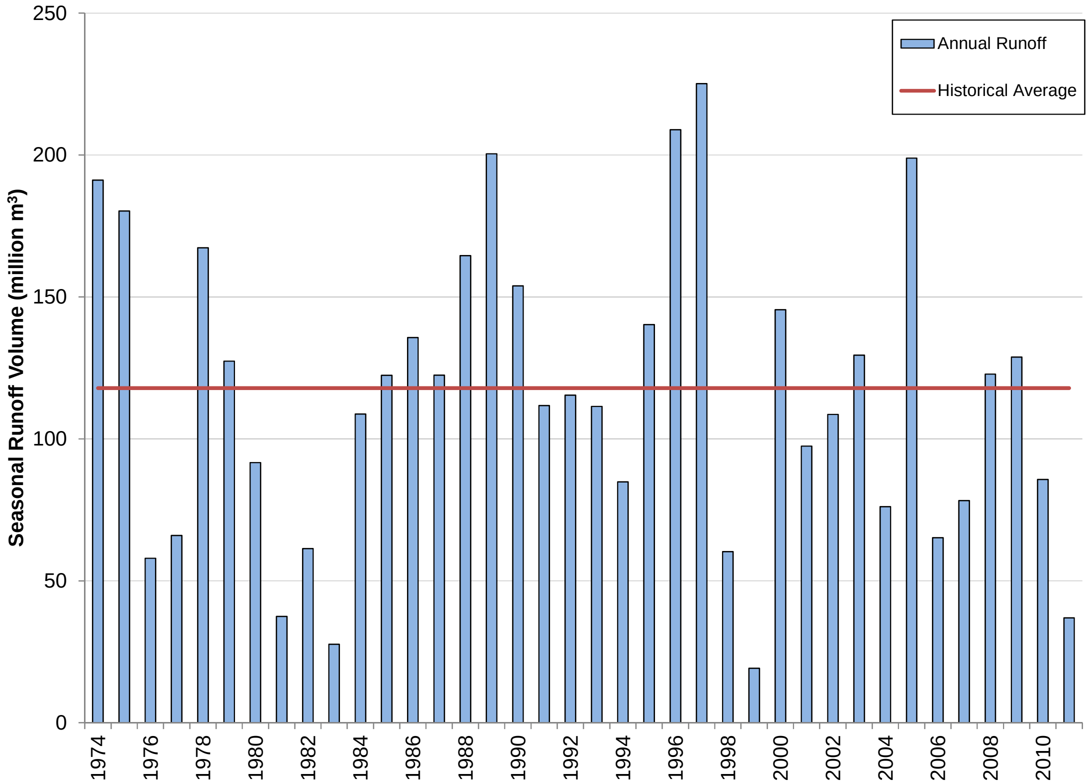
Note: Historical record is based on data recorded from 1958 to 2010 at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2.

Figure 4.2-2 The 2011 WY Athabasca River hydrograph compared to historical values.



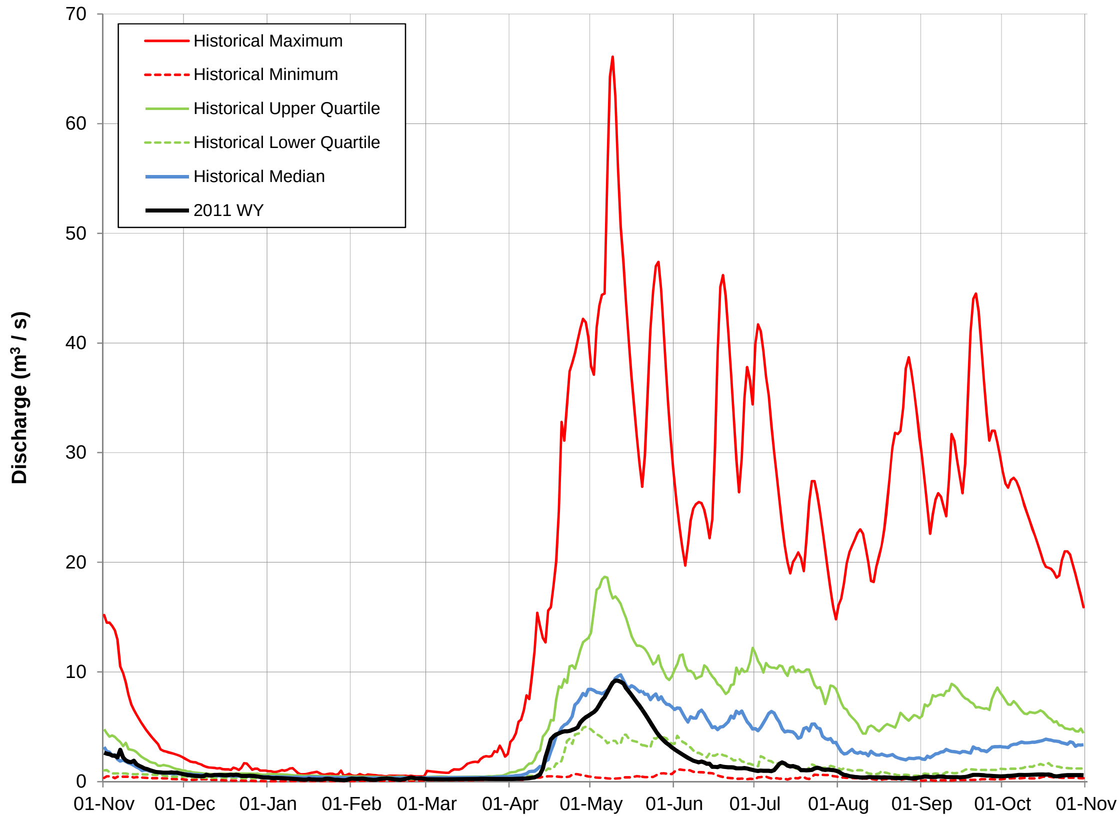
Note: Based on data recorded at WSC Station 07DA001, Athabasca River below Fort McMurray; the upstream drainage area is 132,585 km^2. Historical values were calculated for the period 1958 to 2010.

Figure 4.2-3 Historical seasonal (March to October) runoff volume in the Muskeg River basin, 1974 to 2011.



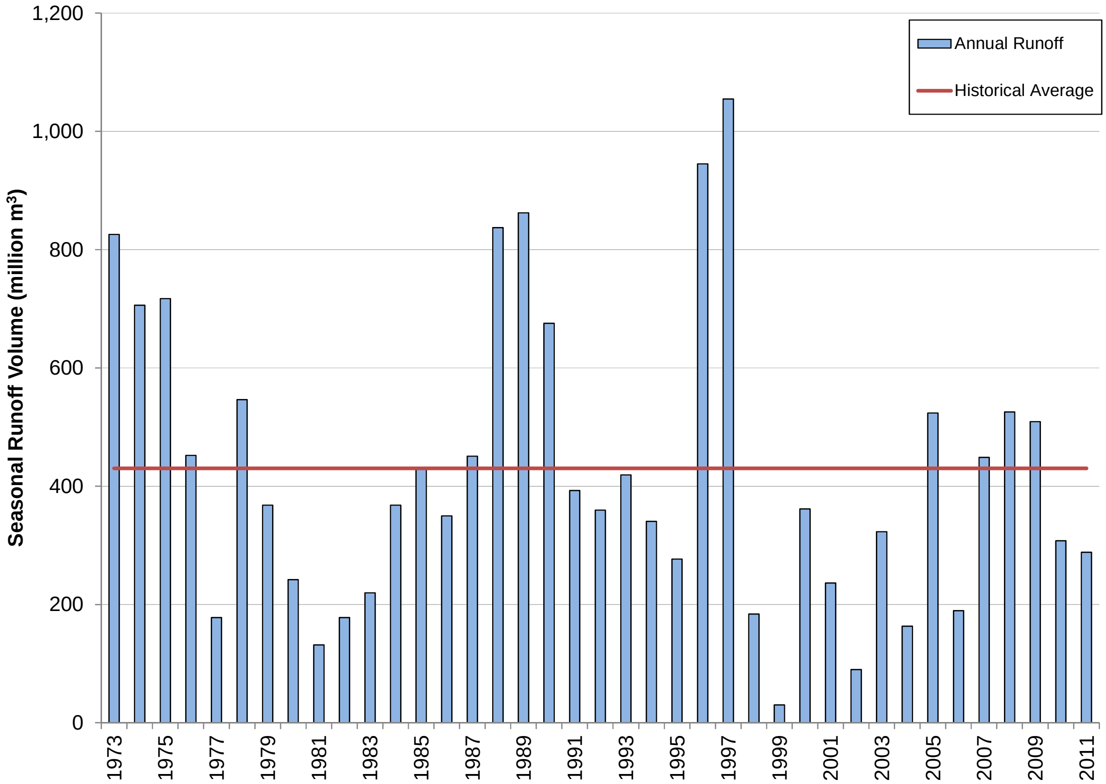
Note: Historical record is based on data recorded from 1974 to 2010 at WSC Station 07DA008, Muskeg River near Fort McKay; the upstream drainage area is 1,457 km^2.

Figure 4.2-4 The 2011 WY Muskeg River hydrograph compared to historical values.



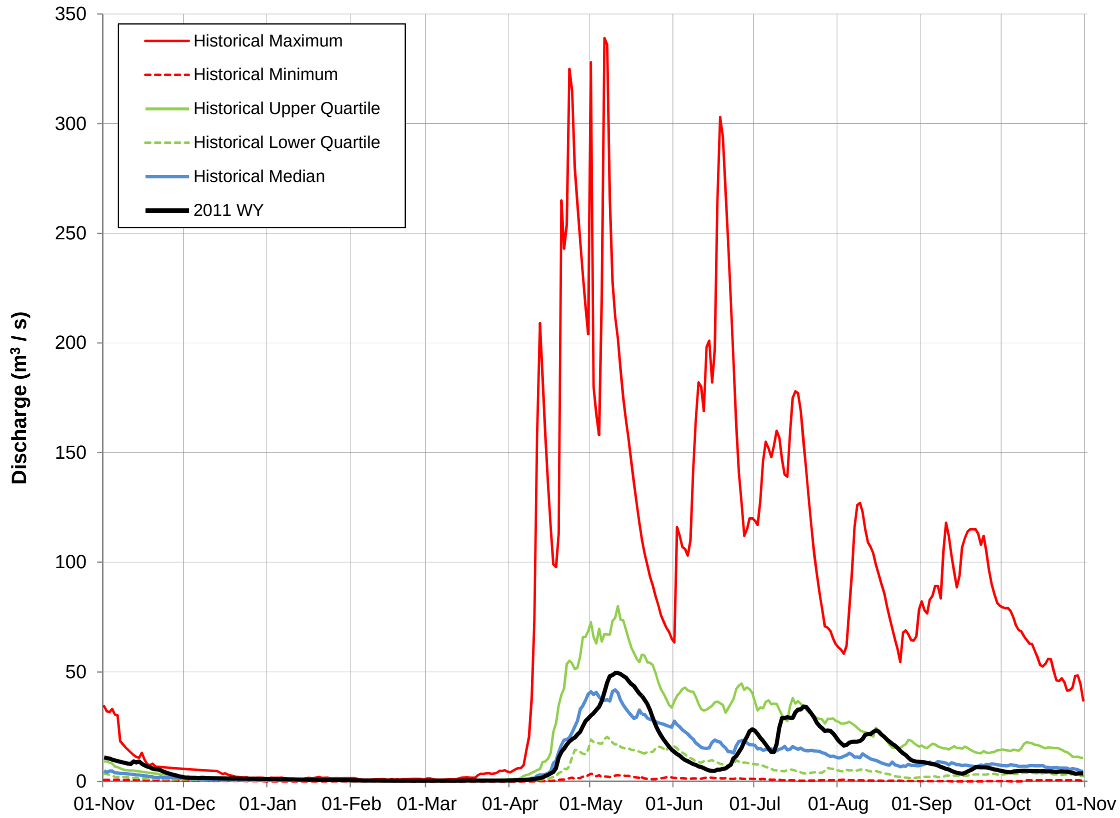
Note: Based on data recorded at WSC Station 07DA008, Muskeg River near Fort McKay; the upstream drainage area 1,460 km^2. Historical values were calculated for the period 1974 to 2010.

Figure 4.2-5 Historical seasonal (March to October) runoff volume in the MacKay River basin, 1973 to 2011.



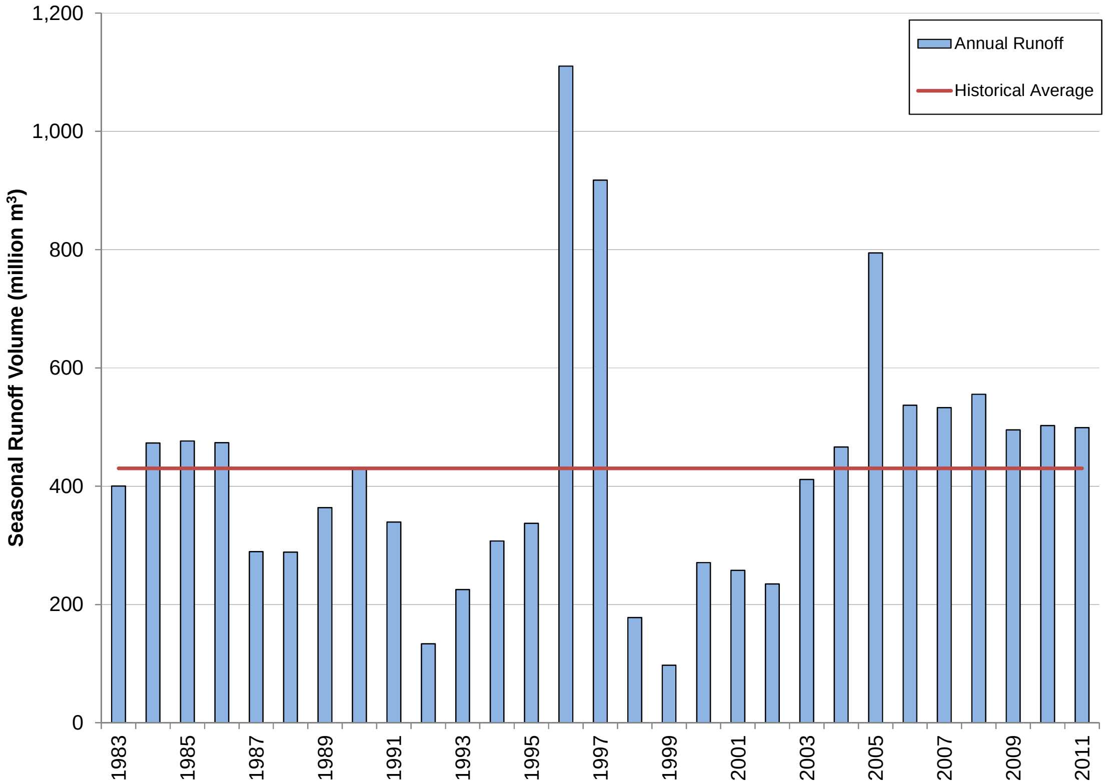
Note: Historical data is based on data recorded from 1973 to 2010 at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2.

Figure 4.2-6 The 2011 WY MacKay River hydrograph compared to historical values.



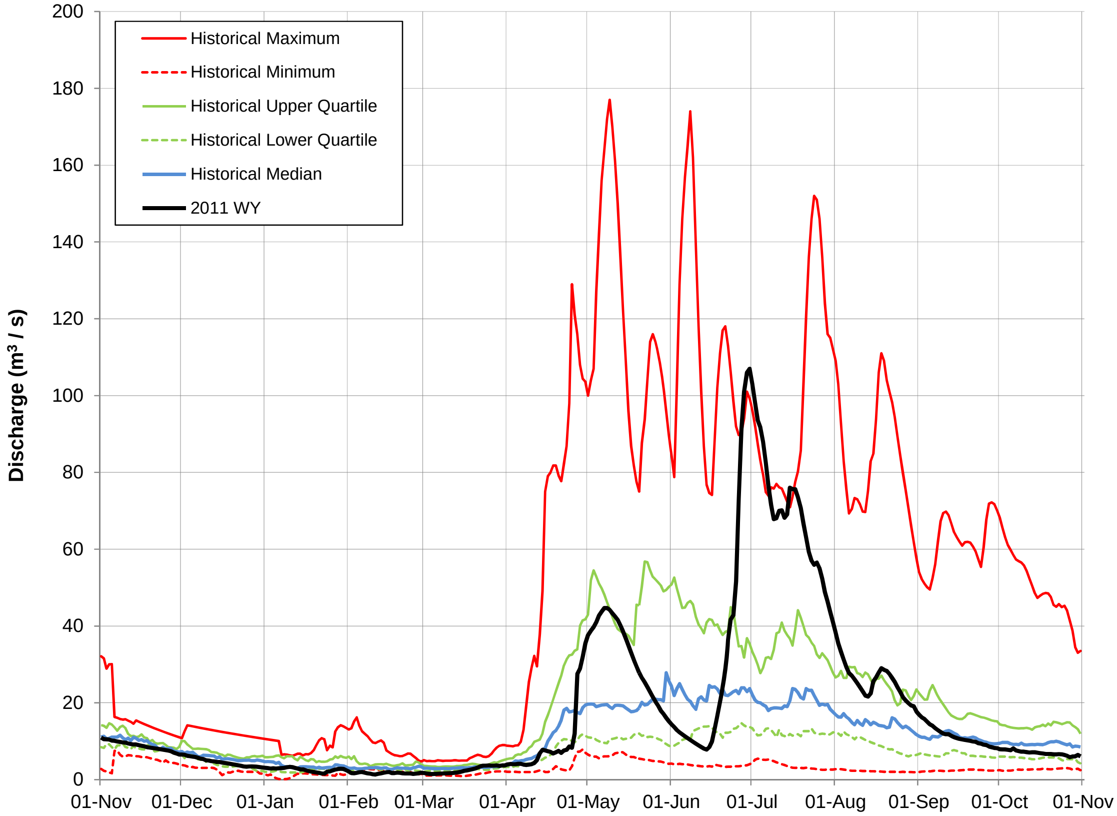
Note: Based on data recorded at WSC Station 07DB001, MacKay River near Fort McKay; the upstream drainage area is 5,569 km^2. Historical values were calculated for the period 1973 to 2010.

Figure 4.2-7 Historical seasonal (March to October) runoff volume in the Christina River basin, 1983 to 2011.



Note: Based on data recorded from 1983 to 2011 at WSC Station 07CE002, Christina River near Chard; the upstream drainage area is 4,863 km^2.

Figure 4.2-8 The 2011 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 2010.

4.3 SUMMARY

In summary, climate and hydrology in the RAMP FSA in the 2011 WY was characterized by the following observations:

1. Annual precipitation measured at Fort McMurray was 33% lower than the historical average, with monthly total precipitation below the long-term average in all months. Winter precipitation was lower than the long-term average at all climate stations with the exception of the C2 Horizon Climate Station where measured precipitation was above the long–term average recorded at Fort McMurray for the months of December to March.

2. The runoff volume for WSC Station 07DA001, Athabasca River below Fort McMurray, recorded above average flows for the fourth year in the last two decades.

3. Seasonal (March to October) runoff volumes were almost 68% and 32% below historical seasonal average values for the Muskeg and MacKay rivers, respectively, but 17% higher for the Christina River.

4. Annual maximum 2011 WY daily flows were rainfall dominated in the Christina River, while spring snowmelt was the predominant factor affecting maximum discharges in the Muskeg and MacKay Rivers.

5.0 2011 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 2011 results for the Athabasca River and the Athabasca River Delta (ARD); Sections 5.2 to 5.10 present 2011 watershed results for the major tributaries of the Athabasca River within the RAMP FSA; and Section 5.11 contains the 2011 results for miscellaneous aquatic systems that were monitored in 2011. 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	5-122	5-209	5-243	5-275	5-307	5-322	5-355	5-390	5-448	5-452	-
Water Quality	5-9	5-123	5-210	5-244	5-276	5-308	5-323	5-356	5-391	-	5-452	-
Benthic Invertebrate Communities	5-13	5-127	5-213	5-245	5-277	5-309	5-325	5-358	5-393	-	5-452	-
Sediment Quality	5-17	5-134	5-215	5-247	5-280	5-309	5-327	5-359	5-396	-	5-452	-
Fish Populations	5-20	5-136	5-215	5-248	5-280	5-309	5-328	5-361	5-397	-	5-452	-

Definitions for Monitoring Status

The RAMP 2011 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 2011) or were (prior to 2011) 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 2011 Conditions													
	Athabasca River									*Athabasca Delta*				
Climate and Hydrology														
Criteria							**S24** below Eymundson Creek			no stations sampled				
Mean open-water season discharge							Negligible-Low							
Mean winter discharge							Negligible-Low							
Annual maximum daily discharge							Negligible-Low							
Minimum open-water season discharge							Negligible-Low							
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	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	Moderate	Negligible-Low	Negligible-Low	Negligible-Low					
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										Moderate	Negligible-Low	Negligible-Low	ns	Negligible-Low
Sediment Quality Index										n/a	n/a	n/a	n/a	n/a
Fish Populations														
Criteria			**Fish Inventory Reaches 4A, 4B, 5A, 5B, 6A, 11A, 10B** Muskeg and Steepbank areas							no sites sampled				
			Sub.[2]		**Gen.**[2]									
Human Health	WALL[1] LKWH[1]		High Negligible-Low		Moderate Negligible-Low									

Legend and Notes

- Negligible-Low
- Moderate
- High

baseline (green shading: ATR-DC-E, ATR-DC-W)
test (blue shading)

n/a – not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches.

ns – not sampled

1 Species (Sp.): WALL=walleye; LKWH=lake whitefish

2 Sub. refers to subsistence fishers; Gen. refers to general consumers as defined by Health Canada

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

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between *baseline* and *test* areas as well as comparison to regional *baselines*; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Fish Populations: Uses various USEPA and Health Canada criteria for risks to human health, fish health, and tainting from fish tissue concentrations of various substances, see Section 3.2.4.2 for a detailed description of the classification methodology.

Figure 5.1-1   Athabasca River and Athabasca River Delta.

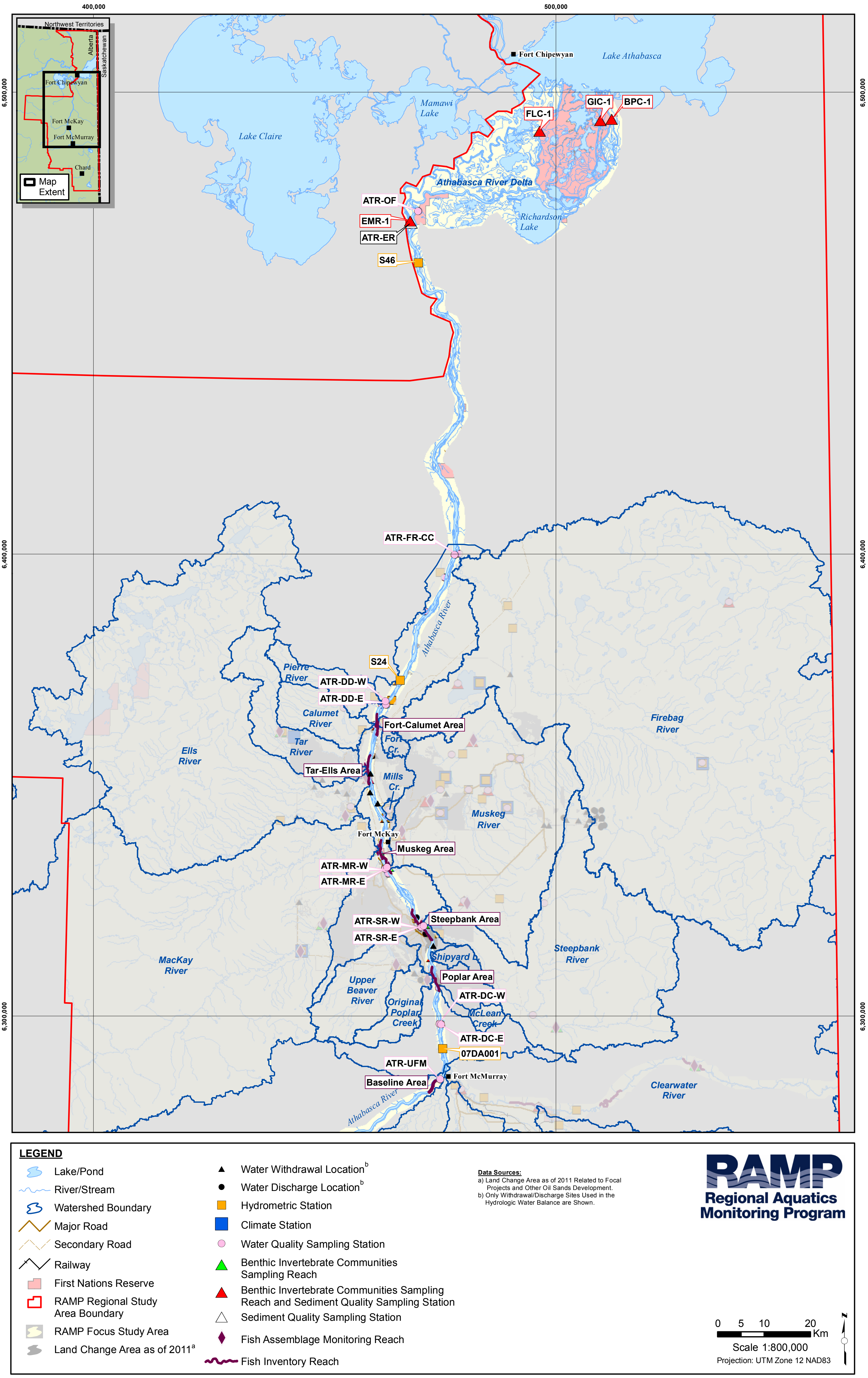


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Figure 5.1-2 Representative monitoring stations of the Athabasca River and Athabasca River Delta, fall 2011.

Hydrology Station (S24): Athabasca River below Eymundson Creek

Benthic and Sediment Quality Station FLC-1: Athabasca River Delta – Fletcher Channel

Water Quality Station ATR-SR-E: Athabasca River upstream of the Steepbank River

Water Quality Station ATR-SR-W: Athabasca River upstream of Steepbank River

Water Quality Station ATR-DC-W: Athabasca River at Donald Creek

Water Quality Station ATR-DD-E: Athabasca River downstream of development

Water Quality Station ATR-MR-W: Athabasca River downstream of Muskeg River

Water Quality Station ATR-MR-E: Athabasca River downstream of Muskeg River

5.1.1 Summary of 2011 Conditions

As of 2011, approximately 2.6% (94,307 ha) of the RAMP FSA had undergone land change from focal projects and other oil sands developments (Table 2.5-2). Approximately 23% (36,657 ha) of the minor Athabasca River tributary watersheds had undergone land change as of 2011 from focal projects and other oil sands developments (Table 2.5-2). For 2011, 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 2011 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 2011. Figure 5.1-2 contains fall 2011 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 were 0.5%, 1.4%, 0.3% and 1.9% lower, respectively, than from the estimated *baseline* hydrograph when only focal projects are considered. These differences were all classified as **Negligible-Low**. The results of the hydrologic assessment are essentially identical to results for the case in which focal projects plus other oil sands developments are considered.

Water Quality Differences in water quality measured in fall 2011 at all *test* and *baseline* stations in the Athabasca River were classified as **Negligible-Low** relative to the regional *baseline* conditions, with the exception of *test* station ATR-MR-W which showed **Moderate** differences from regional *baseline* conditions due to high TSS and associated particulate metals. 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 aluminum and total iron exceeded guidelines at all stations, but no upstream-downstream station trends were observed.

Benthic Invertebrate Communities and Sediment Quality Differences in measurement endpoints for benthic invertebrate communities at *test* reach BPC-1 were classified as **Negligible-Low** because with the exception of the weak significant difference in CA Axis 1 scores, there were no significant time trends in any measurement endpoints for benthic invertebrate communities. All measurement endpoints were within previously-measured values for *test* reach BPC-1.

Differences in measurement endpoints for benthic invertebrate communities at *test* reach FLC-1 were classified as **Moderate** because significant decreases in diversity and evenness accounted for greater than 20% of the variance in annual means. In addition, diversity and evenness in 2011 were lower than the range of previously-measured values for reaches in the delta, while EPT was higher in 2011 than previous years. The high relative abundance of tubificid worms in Fletcher Channel has been consistently observed since sampling began in 2002.

Differences in measurement endpoints for benthic invertebrate communities at *test* reach GIC-1 were classified as **Negligible-Low** because there were no strongly significant time trends in any measurement endpoints for benthic invertebrate communities. Values for all measurement endpoints were within previously-measured values for the reach and for all reaches in the ARD.

Differences in measurement endpoints for benthic invertebrate communities at *test* reach EMR-1 were classified as **Negligible-Low** because measurement endpoints were within previously-measured values for reaches in the ARD. High relative abundances of mayflies and caddisflies at *test* reach EMR-1 indicate that the community is robust and healthy.

Concentrations of sediment quality measurement endpoints at all five stations in the ARD showed low concentrations of hydrocarbons, metals and PAHs, and were generally similar to previously-measured concentrations. Similar to previous years, PAHs at all stations in fall 2011 were dominated by alkylated species indicating a petrogenic origin of these compounds. Sediment fractions at all stations in 2011 showed higher proportions of sand and lower concentrations of silt and clay than measured previously with the exception of *test* station GIC-1, where silt was the dominant substrate. From 1999 to 2010, an increase in concentrations of total PAHs was observed at *test* station BPC-1, although this trend was not evident in concentrations of carbon-normalized total PAHs. In fall 2011, total PAH concentrations at this station were near previously-measured minimum concentrations. With the exception of *test* station GIC-1, all stations in the ARD exhibited a decrease in total PAHs and total organic carbon in fall 2011 relative to fall 2010. The increase in total organic carbon at *test* station GIC-1 relative to 2010 may be related to the historically low proportions of silt and clay in fall 2010. The PAH Hazard Index was higher than previously-measured values at *test* station GIC-1, and above the potential chronic toxicity threshold value of 1.0, while this measurement was lower than previously-measured at *test* station ATR-ER. The increase in the Hazard Index value at *test* station GIC-1 was related to low concentrations of total hydrocarbons, rather than high concentrations of total PAHs, which were historically typical; however, the higher Index suggests greater bioavailability of PAHs in sediments. The decrease in the Hazard Index value at *test* station ATR-ER is likely related to historically low concentrations of total PAH in 2011. Acute and chronic toxicity of sediments were lower than previously-measured for *Hyalella* survival at *test* station ATR-ER, whereas growth for *Hyalella* was higher than previously-measured at *test* stations BPC-1 and FLC-1. Additionally, there was a significant improvement in *Chironomus* survival (68%) compared to 2010 (44%) at *test* station FLC-1. Given there is no *baseline* sediment quality data for the stations in the ARD, SQI values were not calculated.

Fish Populations (fish inventory) The Athabasca River fish inventory is considered to be a community-driven activity, primarily suited for assessing general trends in abundance and populations variables for large-bodied species, rather than detailed community structure.

As of 2011, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, age-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition in some 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 indicated that abnormalities observed in 2011 in all species were within the historical range and consistent with studies done prior to the major oil sands development in the upper Athabasca River, the ARD, and the Peace and Slave rivers.

Fish Populations (fish tissue) Measurement endpoints used in the assessment for the Athabasca River fish tissue program included metals and tainting compounds in fish tissue of both individual and composite samples. Potential human health risks from contaminated fish tissue were predicted from both individual and composite samples. In 2011, the mean concentration of mercury in lake whitefish was lower than previous years, with the exception of 2008 and the mean concentration of mercury in walleye was higher in 2011 compared to previous years, with the exception of 2003. The mean mercury concentration across all size classes of lake whitefish were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. The average mercury concentration in size classes of walleye greater than 300 mm exceeded the subsistence fishers guideline for consumption indicating a **High** risk to subsistence fishers and a **Moderate** risk to general consumers.

5.1.2 Hydrologic Conditions: 2011 Water Year

RAMP Station S24, Athabasca River below Eymundson Creek Continuous annual hydrometric data have been collected for RAMP Station S24 since June 2001. The annual runoff volume recorded at this station in the 2011 water year (WY) was 19,975 million m^3. The open-water period (May to October) runoff volume of 16,539 million m^3 was 22% higher than the historical average open-water runoff volume. Flows steadily decreased in November and December 2010 and remained relatively constant from January to March 2011 (Figure 5.1-3). Flows were near historical median flows from November 2010 to March 2011. Flows increased during the freshet in April and early May 2011 to a peak of 1,373 m^3/s on May 8, which was in the upper quartile of historical values recorded on this date. From June 3 to 17, flows were not recorded due to station malfunction from forest fire damage. Once monitoring resumed on June 18, two extreme flow events were recorded on June 25 and July 14 due to runoff conditions upstream of Fort McMurray. The 2011 WY annual maximum daily discharge of 4,410 m^3/s following the second rain event was 124% higher than the historical mean annual maximum daily flow. Following the peak on July 14, flows decreased until the end of the 2011 WY. The minimum open-water period daily flow of 374 m^3/s recorded on October 31 was 4% higher than the mean historical open-water minimum daily flow.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at Station S24 in the 2011 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 2011 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 2011 in the minor Athabasca River tributaries, McLean Creek, Shipyard Lake, Horse River and Upper Beaver River was estimated to be 362 km^2 (Table 2.5-1). The loss of flow to the Athabasca River that would have otherwise occurred from this land area was estimated at 49.8 million m^3.

2. As of 2011, 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 was estimated to be 84 km^2 (Table 2.5-1). The increase in flow to the Athabasca River that would not have otherwise occurred from this land area was estimated at 2.3 million m^3.

3. Water withdrawals directly from the Athabasca River by focal projects in the 2011 WY were 98.4 million m^3.

4. Water discharges directly to the Athabasca River by focal projects in the 2011 WY were 3.7 million m^3.

5. The 2011 WY discharge into the Athabasca River from major tributaries (i.e., Calumet River, Christina River, Ells River, Firebag River, Fort Creek, Hangingstone River, MacKay River, Mills Creek, Muskeg River, Poplar Creek, Steepbank River, and Tar River) was estimated to be 4.2 million m^3 more than the discharge would have been in the absence of focal projects in those watersheds.

The estimated cumulative effect was a loss of flow of 138.0 million m^3 at Station S24 from what the estimated *baseline* flow would have been in the absence of focal projects. The estimated observed *test* and estimated *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 were 0.5%, 1.4%, 0.3% and 1.9% lower, respectively, than from the estimated *baseline* hydrograph (Table 5.1-3). These differences were 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 and Christina River watersheds. These are the only two watersheds in the RAMP FSA that contained non-focal oil sands developments under construction or operational as of 2011 (Table 2.5-1).

The estimated cumulative effect of focal plus non-focal oil sands developments was a loss of flow of 137.9 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 value was 0.1 million m^3 different from the first case. The values of the hydrologic measurement endpoints were essentially identical for the two cases (Table 5.1-3).

5.1.3 Water Quality

In 2011, 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 2011);

- *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 2011);

- *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 2011); and

- *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 2011).

In addition, monthly water quality sampling of the Athabasca River is undertaken by AEW at their Long-Term Regional Network (LTRN) stations, including stations upstream of Fort McMurray (ATR-UFM) and downstream near the Athabasca Delta at Old Fort (ATR-OF), and a newly established station upstream of the Firebag River (ATR-FR). ATR-FR was previously sampled by RAMP in fall, and was called "ATR-FR-CC" (data available from 2002 to 2010).

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

- Decreasing concentrations of several ions, including calcium, potassium, sodium, chloride, sulphate and total strontium, and increasing concentrations of total suspended solids and total nitrogen at *baseline* station ATR-DC-E;
- Decreasing concentrations of chloride, sulphate and total dissolved phosphorus at *baseline* station ATR-DC-W;
- An increasing concentration of total nitrogen at *test* station ATR-SR-E;
- A decreasing concentration of total dissolved phosphorus at *test* station ATR-SR-W;
- Decreasing concentrations of sodium and sulphate, and increasing concentrations of total suspended solids and total nitrogen at *test* station ATR-MR-E; and
- Increasing concentrations of total arsenic and total boron at *test* station ATR-MR-W.

The trends were generally consistent among stations along the river's east bank (i.e., decreasing ions and increasing TSS and TN) and west bank (i.e., decreasing TDP), and were observed in stations upstream (-DC) and downstream (-SR, -MR, -DD) of watersheds with oil sands development (i.e., McLean, Poplar, and Steepbank, Muskeg, MacKay, Tar rivers). No significant trends from 1998 to 2011 were observed in water quality measurement endpoints at *test* stations ATR-DD-E and ATR-DD-W, which are located downstream of most oil sands development. The increase in concentrations of total arsenic and boron over time at *test* station ATR-MR-W was not observed at other stations. Concentrations of these metals at *test* station ATR–MR-W in fall 2011; however, were within the range of previously-measured concentrations at all stations and similar to concentrations from previous years.

Seasonal water quality data collected by RAMP at ATR-DD (downstream of development) from 1997 to 2011 and by AEW at ATR-UFM and ATR-OF are presented in Figure 5.1-4.

The following significant trends (α=0.05) in concentrations of water quality measurement endpoints were detected from the monthly AEW data for the Athabasca River mainstem over the period of RAMP sampling (1997 to 2010) (Figure 5.1-4):

- Increasing pH and concentrations of total nitrogen and total Kjeldahl nitrogen (indicative of organic nitrogen), and decreasing concentrations of total phosphorous and dissolved organic carbon at *baseline* station ATR-UFM (upstream of Fort McMurray and upstream of oil-sands development); and

- Increasing pH and concentrations of total nitrogen, total Kjeldahl nitrogen, sulphate and total aluminum, and decreasing concentrations of total phosphorous at *test* station ATR-OF (near the Athabasca delta, downstream of oil-sands development).

2011 Results Relative to Historical Concentrations Concentrations of most water quality measurement endpoints in fall 2011 were within the range of historical concentrations at the Athabasca River stations with the following exceptions (Table 5.1-4):

- total aluminum (1.32 mg/L versus previous historical high of 1.10 mg/L), with a concentrations that exceeded the previously-measured maximum concentration at *baseline* station ATR-DC-E;

- dissolved aluminum (0.0074 mg/L vs. previous low of 0.0090 mg/L) and ultra-trace mercury (0.6 vs. <1.2 ng/L), with concentrations that were lower than previously-measured minimum concentrations at *baseline* station ATR-DC-W;

- TSS (117 vs. 97 mg/L) and dissolved aluminum (0.0059 vs. 0.0066 mg/L), with concentrations that exceeded previously-measured concentrations and was lower than previously-measured minimum concentrations, respectively, at *test* station ATR-SR-E;

- pH (7.8 vs. 7.9) and ultra-trace mercury (0.7 vs. <1.2 ng/L), with concentrations that were lower than previously-measured minimum concentrations at *test* station ATR-SR-W;

- pH (8.4 vs. 8.2), with a value that exceeded previously-measured maximum values and ultra-trace mercury (1.1 vs. <1.2 ng/L), with a concentration that was lower than previously-measured minimum concentrations at *test* station ATR-MR-E;

- total aluminum (4.34 vs. 3.13 mg/L), with a concentration that exceeded the previously-measured maximum concentration and ultra-trace mercury (0.6 vs. <1.2 ng/L), with a concentration that was lower than previously-measured minimum concentrations at *test* station ATR-MR-W;

- pH (8.4 vs. 8.3), TSS (13 vs. 15 mg/L), conductivity (294 vs. 267 µS/cm), and total strontium (0.229 vs. 0.213 mg/L), and historically low TDP (0.007 vs. 0.027 mg/L), total nitrogen (0.46 vs. 0.5 mg/L), total aluminum (0.40 vs. 0.581 mg/L), dissolved aluminum (0.0058 vs. 0.0076 mg/L), and ultra-trace mercury (0.7 vs. <1.2 ng/L) at *test* station ATR-DD-E;

- pH (8.4 vs. 8.3), conductivity (285 vs. 275 µS/cm) and total strontium (0.245 vs. 0.2040 mg/L), with concentrations that exceeded previously-measured maximum concentrations and TDP (0.006 vs. 0.027 mg/L), total nitrogen (0.45 vs. 0.5 mg/L), sodium (10.8 vs. 11 mg/L), and dissolved aluminum (0.0064 vs. 77 mg/L), with concentrations that were lower than previously-measured minimum concentrations at *test* station ATR-DD-W; and

- TSS (200 vs. 95 mg/L), conductivity (320 vs. 300 µS/cm), calcium (36 vs. 33.3 mg/L), magnesium (10 vs. 9.5 mg/L), total alkalinity (120 vs. 103 mg/L $CaCO_3$), total molybdenum (0.0071 vs. 0.0070 mg/L) and total strontium (0.264 vs. 0.215 mg/L), with concentrations that exceeded previously-measured maximum concentrations and TDP (0.003 vs. 0.005 mg/L), with a concentration that was lower than the previously-measured minimum concentration at *test* station ATR-FR-CC (sampled in 2011 by AEW, and compared with historical RAMP data collected at this station from 2002 to 2010).

The greater number of historical minimum and maximum concentrations of variables at *test* stations ATR-DD-E/W and ATR-FR-CC may relate to the shorter period of record at these stations (i.e., n=6 at ATR–DD-E/W and n=9 at ATR-FR-CC vs. n=12 at other stations). Differences in analytical or reporting methods (related to reported significant figures, for example) between AEW and RAMP may also have contributed to historically minimum or maximum concentrations observed in 2011 at ATR–FR-CC relative to previous years.

Ion Balance The ionic composition in fall 2011 at all Athabasca River stations was consistent with ionic composition of this area since 1997, and was dominated by calcium and bicarbonate (Figure 5.1-5 to Figure 5.1-8). Water collected from the east bank of the Athabasca River tended to have a greater proportion of sodium and chloride ions compared to the west side of the river, which is most evident at *baseline* station ATR-DC-E. This pattern likely relates to the incomplete mixing of the Clearwater River into the Athabasca River mainsteam 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 2011 (Table 5.1-4), with the exception of total aluminum at all stations on the Athabasca River mainstem.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Athabasca River mainsteam in fall 2011 (Table 5.1-5):

- Dissolved and total silver at *test* station ATR-DD-E;
- Total chromium at *baseline* stations ATR-DC-E and ATR-DC-W, and *test* stations ATR-SR-E, ATR-MR-E and ATR-MR-W;
- Total iron at all stations (dissolved iron was below water quality guidelines at all stations); and
- total phosphorus at *baseline* station ATR-DC-E and *test* stations ATR-SR-E 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.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of the following water quality measurement endpoints exceeded the 95th percentile of regional *baseline* concentrations in fall 2011 (Figure 5.1-9 to Figure 5.1-12):

- sodium at *baseline* station ATR-DC-E;
- total arsenic at *test* station ATR-MR-W;
- total suspended solids at *test* stations ATR-SR-E and ATR-MR-W; and
- potassium at *test* station ATR-FR-CC.

Concentrations of the following water quality measurement endpoints were below the 5th percentile of regional *baseline* concentrations in fall 2011 (Figure 5.1-9 to Figure 5.1-12):

- chloride at *baseline* station ATR-DC-E;
- dissolved phosphorous at *baseline* station ATR-DC-W and *test* stations ATR-SR-W. ATR-MR-E, ATR-MR-W, and ATR-FR-CC; and
- sodium at *baseline* station ATR-DC-W.

Due to the decrease in the analytical detection limit for total mercury in 2010, concentrations in fall 2011 were below the 5th percentile of regional *baseline* concentrations at *baseline* station ATR-DC-W and *test* stations ATR-SR-W, ATR-MR-E, ATR-MR-W and ATR-DD-E.

Water Quality Index The WQI values at all stations in the Athabasca River mainstem in fall 2011 indicated **Negligible-Low** differences from regional *baseline* water quality conditions with the exception of *test* station ATR-MR-W (WQI: 79.5), which indicated a **Moderate** difference from regional *baseline* conditions (Table 5.1-6). The WQI value for all other stations on the Athabasca River ranged from 89.9 to 98.7 (Table 5.1-6). The lower WQI value at *test* station ATR-MR-W was driven primarily by the high concentration of total suspended solids (TSS) and various total metals typically associated with particulates (i.e., Al, As, Ba, Cr, Co, Fe, Pb, Ti, U, V) relative to the historical range of upstream (ATR-DC-E/W) concentrations used to represent regional *baseline* conditions for Athabasca River mainstem stations.

Classification of Results Differences in water quality measured in fall 2011 at all *test* and *baseline* stations in the Athabasca River were classified as **Negligible-Low** relative to the regional *baseline* conditions, with the exception of *test* station ATR-MR-W which showed **Moderate** differences from regional *baseline* conditions due to high TSS and associated particulate metals. 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 aluminum and total iron exceeded guidelines at all stations, but no upstream-downstream station trends were observed.

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 collected at four depositional reaches in the ARD in fall 2011:

- Depositional *test* reach BPC-1 in Big Point Channel, sampled from 2002 to 2005 and 2007 to 2011;
- Depositional *test* reach FLC-1 in Fletcher Channel, sampled from 2002 to 2005 and 2007 to 2011;
- Depositional *test* reach GIC-1 in Goose Island Channel, sampled from 2002 to 2005 and 2007 to 2011; and
- Depositional *test* reach EMR-1 in the Embarras River, sampled for the first time in 2011.

2011 Habitat Conditions Water at *test* reaches BPC-1, GIC-1, FLC-1, and EMR-1 was between 1 and 3 m deep, moderately flowing (between 0.3 and 0.5 m/s), varying conductivity (~170 µS/cm to 300 µS/cm), with neutral pH, high dissolved oxygen (>8.5 mg/L), and an average water temperature of 15°C (Table 5.1-7). Samples were collected near the right bank of the channel (as in previous years), where flows were sufficiently low to allow the Ekman grab to sit vertically on the bottom and obtain an appropriate sediment sample. The substrate in the four channels consisted primarily of sand and silt (Table 5.1-7). The substrate in Goose Island Channel (*test* reach GIC-1) was greater than 50% silt/clay, while the other channels had smaller amounts (Table 5.1-7). Total organic carbon content of sediments was lowest in the Embarras River (*test* reach EMR-1) (0.1 %) and approximately 1% in the other channels (Table 5.1-7).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate communities at *test* reach BPC-1 in fall 2011 were dominated by tubificid worms (75%) with subdominant taxa consisting of Chironomidae (18%) (Table 5.1-8). Dominant chironomids at *test* reach BPC-1 were primarily of the genera *Polypedilum*, *Cryptochironomus*, and *Paracladopelma* with subdominant chironomid taxa including *Monodiamesa* and *Demicryptochironomus*. Bivalves (*Pisidium* and *Sphaerium*), mayflies (*Ametropus neavei*), and caddisflies (*Hydropsyche* and *Neureclipsis)* were found in low relative abundances at *test* reach BPC-1 (Table 5.1-8).

The benthic invertebrate communities at *test* reach FLC-1 in fall 2011 were dominated by tubificid worms (81%, as in 2010) with subdominant taxa consisting of Chironomidae (13%) (Table 5.1-8). Dominant chironomids at *test* reach FLC-1 consisted of eight taxa, primarily of the genera *Polypedilum* and *Paracladopelma*. Mayflies (*Ametropus neavei*) accounted for 2% of the fauna. Two caddisflies (*Hydropsyche* and *Neureclipsis*) and a single stonefly of the genus *Isoperla* were documented. Bivalve clams were of the genus *Sphaerium*.

The benthic invertebrate communities at *test* reach GIC-1 in fall 2011 were dominated by tubificid worms (49%) and chironomids (49%) (Table 5.1-9). Dominant chironomids included *Polypedilum*, *Stempellinella* and *Paracladopelma.* Fingernail clams were present from the genera *Pisidium* and *Sphaerium*. Mayflies (*Ametropus neavei*) and caddisflies (*Neureclipsis*) were present in low relative abundances in some of the replicate samples.

The benthic invertebrate communities at *test* reach EMR-1 in fall 2011 were dominated by Chironomidae (81%), with subdominant taxa consisting of Ephemeroptera (10%), and Nematoda (6%) (Table 5.1-9). Dominant chironomids were primarily from the genera *Rheosmittia*, *Robackia*, *Stempellinella*, and *Paracladopelma*. Bivalves were represented by members of the genera *Pisidium* and *Sphaerium*. Mayflies (Ephemeroptera) were represented by a single species (*Ametropus neavei*).

Big Point Channel

Temporal Comparison Changes in time trends of measurement endpoints for benthic invertebrate communities and changes in 2011 compared to previous sampling years were tested at *test* reach BPC-1 (Hypothesis 1, Section 3.2.3.1). A Spearman rank correlation was used to test for a recent time trend.

There was a significant time trend in CA Axis 1 scores over the data record, explaining less than 20% of the variation in annual means (Table 5.1-10). The trend over the last six years was not significant (r_s=-0.31). There was a significant decrease in diversity and evenness in 2011 relative to the mean of previous years (Table 5.1-10). The CA Axis 1 scores for 2011 were higher than the mean of previous years reflecting an increase in nematodes and a decrease in ostracods and ceratopogonids (Figure 5.1-14).

Comparison to Published Literature The relative abundance of tubificid worms at *test* reach BPC-1 (75%) was high as in previous years (RAMP 2011). Griffiths (1998) has identified that benthic invertebrate communities with greater than 30% worms are known to be potentially indicative of degraded conditions. Hynes (1960) considers samples with greater than 90% worms to be indicative of severe organic enrichment, while samples with greater than 20% worms and greater than 50% chironomids and isopods are considered potentially indicative of mild organic enrichment. Taking this into account, the samples from *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). There were high relative abundances of mayflies (*Ametropus neavei*) and caddisflies (*Hydropsyche* and *Neureclipsis*) in 2011 compared to 2010. Both groups tend to occur only when water and sediment quality is good (Hilsenhoff 1987). Bivalve clams from the genera *Pisidium* and *Sphaerium* were both found at *test* reach BPC-1.

2011 Results Relative to Historical Conditions Values of measurement endpoints of 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 2011 (Figure 5.1-13). Total abundance in 2011 (17,700 per m^2) was approximately equal to the long-term mean for this reach, while the number of taxa (10), diversity, and evenness were below the median values for the delta reaches. The percent of the fauna as EPT taxa in 2011 (4) increased from the previous two years (Figure 5.1-13). The CA Axis 1 and 2 scores were within the range of conditions observed in the Delta (Figure 5.1-14).

Classification of Results Differences in measurement endpoints for benthic invertebrate communities at *test* reach BPC-1 are classified as **Negligible-Low** because with the exception of the weak significant difference in CA Axis 1 scores, there were no significant time trends in any measurement endpoints for benthic invertebrate communities. All measurement endpoints were within previously-measured values for *test* reach BPC-1.

Fletcher Channel

Temporal Comparison Changes in time trends of measurement endpoints for benthic invertebrate communities and changes in 2011 compared to previous sampling years were tested at *test* reach FLC-1 (Hypothesis 1, Section 3.2.3.1). A Spearman rank correlation was used to test for a recent time trend.

There were significant decreases in taxa richness, diversity and evenness over time at *test* reach FLC-1, explaining greater than 20% of the variation in annual means (Table 5.1-11 and Figure 5.1-13). Abundance, richness, diversity, and evenness were also significantly lower in 2011 than the mean of all previous years (Table 5.1-11). Percent EPT taxa were significantly higher in 2011 than the mean of previous years (Table 5.1-11 and Figure 5.1-13). There were no significant trends in any measurement endpoints over the last six years (r_s<0.87) (Table 5.1-11).

Comparison to Published Literature The relative abundance of Tubificidae (81%) was high, which can be indicative of degraded water and substrate (Griffiths 1998). However, Ephemeroptera, Plecoptera and Trichoptera, which were absent in 2010 at *test* reach

FLC-1, were found (in low abundance) in fall 2011 (Table 5.1-8). The presence of these larger fly larvae in 2011 reflects relatively good water quality (Mandaville 2001).

2011 Results Relative to Historical Conditions Diversity and evenness were lower than previously-measured at *test* reach FLC-1 and lower than the range of variation for all Delta reaches; taxa richness was at or near the 5th percentile of the range of historical values for the Delta reaches (Figure 5.1-13). CA Axis 1 and CA Axis 2 scores were within historical ranges for ARD reaches (Figure 5.1-14). Percent of EPT taxa increased and was higher in 2011 than previous years.

Classification of Results Differences in measurement endpoints for benthic invertebrate communities at *test* reach FLC-1 were classified as **Moderate** because significant decreases in diversity and evenness accounted for greater than 20% of the variance in annual means. In addition, diversity and evenness in 2011 were lower than the range of previously-measured values for reaches in the delta, while EPT was higher in 2011 than previous years. The high relative abundance of tubificid worms in Fletcher Channel has been consistently observed since sampling began in 2002.

Goose Island Channel

Temporal Comparison Changes in time trends of measurement endpoints for benthic invertebrate communities and changes in 2011 compared to previous sampling years were tested at *test* reach GIC-1 (Hypothesis 1, Section 3.2.3.1). A Spearman rank correlation was used to test for a recent time trend.

There was a significantly weak time trend in CA Axis 2 scores, and weakly significant variations in CA axes 1 and 2 scores in 2011 (Table 5.1-12). There were no significant differences in the other measurement endpoints over time (r_s<0.87) or in 2011 relative to previous years (Table 5.1-12).

Comparison to Published Literature The relative abundance of Tubificidae (49%) and Chironomidae (49%) were higher than in 2010, but 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 chironomids suggests that organic enrichment is not an issue (Hynes 1960, Griffiths 1998). Mayflies and caddisflies, which were not found in 2010, were present in 2011 (Table 5.1-12), indicating relatively good habitat conditions (Mandaville 2001).

2011 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 (Figure 5.1-13). CA Axis 1 and CA Axis 2 scores were within the range of previously-measured values (Figure 5.1-14).

Classification of Results The differences in measurement endpoints for benthic invertebrate communities at *test* reach GIC-1 were classified as **Negligible-Low** because there were no strongly significant time trends in any measurement endpoints for benthic invertebrate communities. Values for all measurement endpoints were within previously-measured values for the reach and for all reaches in the ARD.

Embarras River

Temporal Comparison Temporal comparisons were not tested at *test* reach EMR-1 because there is only one year of data.

Comparison to Published Literature The benthic invertebrate community at *test* reach EMR-1 was typical for a shifting-sand environment. The relative abundance of tubificid worms was low (<1) and chironomids accounted for just over 80% and Ephemeroptera and Nematoda accounted for the remaining 10% and 6%, respectively. The taxa composition for *test* reach EMR-1 is typical for rivers in good condition (Hynes 1960, Griffiths 1998).

2011 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities at *test* reach EMR-1 were within or exceeded the range of historical values for the other ARD reaches (Figure 5.1-13). The percent of the fauna as EPT increased in 2011 from 2010, and was above the range of historical conditions for the ARD.

Classification of Results The differences in measurement endpoints for benthic invertebrate communities at *test* reach EMR-1 were classified as **Negligible-Low** because measurement endpoints were within previously-measured values for reaches in the ARD. High relative abundances of mayflies and caddisflies at *test* reach EMR-1 indicated that the community is robust and healthy.

5.1.4.2 Sediment Quality

In fall 2011, 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;
- *test* station FLC-1 in Fletcher Channel, sampled from 2001 to 2003, 2005 and 2007 to 2011;
- *test* station GIC-1 in Goose Island Channel, sampled from 2001 to 2003, 2005 and 2007 to 2011;
- *test* station EMR-1 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 2005 and 2007 to 2011.

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

- Decreasing concentrations of total parent PAHs, total metals, and total arsenic at *test* station ATR-ER;
- Increasing concentrations of F4-hydrocarbons at *test* station BPC-1; and
- An increasing PAH Hazard Index at *test* station FLC-1, primarily due to the high value for 2010.

2011 Results Relative to Historical Concentrations Concentrations of sediment quality measurement endpoints at all five stations in fall 2011 were within previously-measured concentrations (Table 5.1-13 to Table 5.1-17, Figure 5.1-15, Figure 5.1-19) with the following exceptions:

- All measurement endpoints for *test* station EMR-1 were low compared to 2005, with the exception of the proportion of sand, and total metals normalized to %silt and clay, which were higher in 2011;

- Substrate at *test* station FLC-1 was dominated by sand in 2011, reversing a general trend towards finer sediments measured at this station from 2001 to 2010;

- Total metals normalized to %silt and clay, with concentrations that exceeded previously-measured maximum concentrations at *test* stations at BPC-1, ATR-ER, and FLC-1;

- Percent sand, which exceeded previously-measured maximum values and fine fractions (silt and clay), which were lower than previously-measured minimum values at *test* stations FLC-1, BPC-1, and ATR-ER. *Test* stations ATR-ER and EMR-1 were nearly entirely sand (99% and 99.5%, respectively);

- Total organic carbon, with concentrations that were relatively low (<1.4%) at all ARD stations and lower than previously-measured minimum concentrations at *test* station ATR-ER;

- Fraction 4-hydrocarbons, with a concentration that was lower than previously-measured minimum concentrations at *test* station ATR-ER;

- Total PAHs, with a concentration that was lower than previously-measured minimum concentrations at *test* station ATR-ER;

- Total parent PAHs and total dibenzothiophenes, with concentrations that were lower than previously-measured minimum concentrations at *test* stations BPC-1 and FLC-1;

- Naphthalene, with concentrations that were lower than previously-measured minimum concentrations at *test* stations ATR-ER and FLC-1;

- Retene, with concentrations that were lower than previously-measured minimum concentrations at *test* stations ATR-ER and BPC-1;

- Potential chronic toxicity of PAHs in sediments, with a value that exceeded previously-measured maximum values at *test* station GIC-1, and exceeded the potential chronic toxicity threshold, while chronic toxicity was lower than previously-measured minimum values at *test* station ATR-ER. Total PAHs at *test* station GIC-1 in fall 2011 were similar to previous years; however, total hydrocarbons, which are used to adjust bioavailability in the equilibrium-partitioning approach used to calculate the potential chronic toxicity, were low. Therefore, a decrease in concentrations of total hydrocarbons rather than an increase in total PAHs caused the increase in the potential chronic toxicity of PAHs at this station. The increase in the chronic toxicity of PAHs at *test* station GIC-1 suggests greater bioavailability of PAHs in sediment pore waters in 2011;

- Direct measures of sediment toxicity to invertebrates indicated good survival (i.e., ≥80%) of the amphipod *Hyalella* at *test* stations FLC-1, BPC-1, and GIC-1, and moderate survival (i.e., ≥68%) at *test* stations EMR-1 and ATR-ER; however, results from *test* station ATR-ER, indicated survival rates lower than previously-measured minimum values (68%). In addition, *test* stations GIC-1, EMR-1, and

ATR-ER indicated good survival (i.e., ≥74%) of the midge *Chironomus* while *test* stations FLC-1 and BPC-1 indicated moderate survival (i.e., 68%). Survival (44%) of the midge *Chironomus* at *test* station FLC-1 in 2010 was historically low; however, in 2011, survival of *Chironomus* increased to 68%, indicating less sediment toxicity at *test* station FLC-1 than in 2010; and

- 14-day growth of the amphipod Hyalella, with growths that were higher than previously-measured values at *test* stations FLC-1 and BPC-1.

As discussed in Section 6.6 of this report, generally coarser sediments present at most delta stations in 2011 (with associated lower TOC, metals and total PAHs) relative to previous years may relate to the sedimentary regime in the delta in 2011, with less fine sediment deposited in 2011 due to high Athabasca River mainstem flows in summer 2011.

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines No hydrocarbon fraction, specific PAHs, or total metals measured at any station exceeded relevant sediment or soil quality guidelines in fall 2011 with the exception of potential chronic toxicity of PAHs in sediments at *test* station GIC-1 (Table 5.1-16), which exceeded the potential chronic toxicity threshold value of 1.0.

2011 Results Relative to Historical Conditions Absolute and carbon-normalized concentrations of total PAHs, total hydrocarbons (i.e., sum of F1-F4), and total metals were similar to previous years, and were 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).

Summary Concentrations of sediment quality measurement endpoints at all five stations in the ARD generally showed low concentrations of hydrocarbons, metals and PAHs relative to previous years. Similar to previous years, PAHs at all stations in fall 2011 were dominated by alkylated species indicating a petrogenic origin of these compounds. Sediment fractions at all stations in 2011 showed higher proportions of sand and lower concentrations of silt and clay than measured previously with the exception of *test* station GIC-1, where silt was the dominant substrate. From 1999 to 2010, an increase in concentrations of total PAHs was observed at *test* station BPC-1, although this trend was not evident in concentrations of carbon-normalized total PAHs. In fall 2011, total PAH concentrations at this station were near previously-measured minimum concentrations. With the exception of *test* station GIC-1, all stations in the ARD exhibited a decrease in total PAHs and total organic carbon in fall 2011 relative to fall 2010. The increase in total organic carbon at *test* station GIC-1 relative to 2010 may be related to the historically low proportions of silt and clay in fall 2010. The PAH Hazard Index was higher than previously-measured values at *test* station GIC-1, and above the potential chronic toxicity threshold value of 1.0, while this measurement was lower than previously-measured at *test* station ATR-ER. The increase in the Hazard Index value at *test* station GIC-1 related to low concentrations of total hydrocarbons, rather than high concentrations of total PAHs; however, suggests greater bioavailability of PAHs in sediments. The decrease in the Hazard Index value at *test* station ATR-ER is likely related to historically low concentrations of total PAHs in 2011. Acute and chronic toxicity of sediments were lower than previously-measured for *Hyalella* survival at *test* station ATR-ER, whereas growth for *Hyalella* was higher than previously-measured at *test* stations BPC-1 and FLC-1. Additionally, there was a significant improvement in *Chironomus* survival (68%) compared to 2010 (44%) at *test* station FLC-1. Given there is no *baseline* sediment quality data for the stations in the ARD, SQI values were not calculated.

5.1.5 Fish Populations

Fish population monitoring in 2011 on the Athabasca River consisted of a spring, summer, and fall fish inventory; a fish tag return assessment; and a fall fish tissue program.

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 (as a measure of relative abundance); age-frequency distributions; size-at-age, and condition factor.

Species Richness A total of 5,546 fish were captured in the 14 standardized reaches in six areas of the Athabasca River (Figure 3.1-5) during the spring, summer, and fall fish inventories in 2011 (Table 5.1-18), of which:

- 1,731 fish representing 15 species were caught in the spring;
- 746 fish representing 16 species were caught in the summer; and
- 3,069 fish representing 18 species were caught in the fall.

A comparison of total catch and species richness in 2011 by season and area is provided in Table 5.1-19 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 both 2011 and 2010, compared to 16 species in 2009 and 22 species in 1997 (i.e., the lowest and highest species richness documented to date). Species richness in 2011 was high compared to the historical range in all seasons. Total catch was higher in 2011 in spring and fall, but lower in summer compared to recent years, (i.e., 2008 to 2010).

Species Composition Key features of the species composition of the Athabasca River in 2011 and comparison to previous years are as follows (Figure 5.1-27):

1. Similar to 2010, the most abundant large-bodied fish species captured in 2011 were white sucker and walleye in spring; walleye and goldeye in summer; and goldeye and lake whitefish in fall. There was a shift in the second most dominant species in fall from walleye in 2010 to lake whitefish in 2011.

2. Similar to 2010, the most abundant small-bodied fish species in each season in 2011 was trout-perch.

3. Until spring 2007, walleye was the most commonly-captured large-bodied KIR fish species and from 2007 to 2011 the dominance has shifted to white sucker. A decrease in goldeye has been observed since 1991; however, in 2011, the number of goldeye capture was higher than all previous years.

4. The composition of large-bodied KIR fish species in summer showed a shift in dominance from goldeye in 2008 and 2009 to walleye in 2010 and 2011.

5. The composition of large-bodied KIR fish species in fall showed a shift in dominance from lake whitefish to goldeye. The high number of lake whitefish captured in fall compared to other seasons is related to the fall spawning migration of lake whitefish from Lake Athabasca to spawning grounds near the town of Fort McMurray, while the other large-bodied species are spring spawners.

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 (i.e., the 14 reaches in the six areas of the Athabasca River). Historically, other reaches in the Athabasca River have been sampled; however, these data were not included for comparisons of CPUE. Comparisons of CPUE over time has focused on KIR fish species given their importance to stakeholders (i.e., lake whitefish, walleye, northern pike, and goldeye) and their suitability to provide an assessment of localized conditions in the river (i.e., white sucker, longnose sucker are bottom feeders, and trout-perch is a non-migratory sentinel species).

A new *baseline* reach, -03B, Upstream of Fort McMurray (U/S of FMM), was added in 2011, to assess the fish assemblage in an area upstream of oil sands development; therefore, only one year of data exists for this reach. Total CPUE for all species combined by area and season is provided in Figure 5.1-28. Mean CPUE for each KIR fish species in 2011 is compared by area and season to three historical sampling periods: 1987 to 1996, designated as pre-RAMP; 1997 to 2004, designated as RAMP prior to standardization of sampling reaches; and 2005 to 2010, designated as RAMP post-reach standardization (Figure 5.1-29 to Figure 5.1-35). From 2005 onwards, RAMP made an effort to target the whole fish assemblage and not just large-bodied fish species; therefore, CPUE has generally been higher during this time period (i.e., 2005 to 2011).

Spatial comparisons were conducted to assess changes in the CPUE of KIR fish species over time between each area of the Athabasca River. Species-specific results for 2011 are as follows:

- Across all *test* areas (i.e., downstream of development), CPUE for goldeye in spring was similar to the *baseline* area (upstream of Fort McMurray), with the exception of the Steepbank and Poplar areas where CPUE for goldeye was higher than the *test* area. In summer, goldeye CPUE in the *test* areas was consistent to the *baseline* area. In fall, goldeye CPUE was higher in the *test* areas than the *baseline* area, with the exception of the Muskeg and Tar-Ells areas (Figure 5.1-29).

- Lake whitefish were only captured in fall when the adult spawning population was in the Athabasca River. In fall, CPUE for lake whitefish is higher in all *test* areas compared to the *baseline* area, with the exception of the Tar-Ells area (Figure 5.1-30).

- CPUE for longnose sucker in 2011 was higher in the *baseline* area compared to the *test* areas in all seasons (Figure 5.1-31).

- There were no northern pike captured in the *baseline* area in spring or fall 2011, which could be due to the habitat conditions in the *baseline* area consisting of faster moving waters, with a rocky bottom and little or no vegetation, which is unsuitable for northern pike (Paetz and Nelson 1970). In spring, CPUE for northern pike was variable between *test* areas and across years; however, CPUE of northern pike in the Poplar *test* area was higher in 2011 compared to previous years. In summer, CPUE for northern pike was within the historical range, with the exception of the Poplar and Steepbank areas where CPUE was historically low and in the Fort-Calumet where no northern pike were captured (Figure 5.1-32).

- Although trout-perch were captured between 1987 and 2004, the focus of the fish inventory program during that period was primarily on large-bodied fish species and not the entire fish assemblage. Given that trout-perch is commonly used as a sentinel species for environmental effects monitoring (RAMP 2010) and it is considered a KIR species for environmental impact assessments (RAMP 2009b), trout-perch has been added as a KIR fish species for the fish inventory program. In spring, CPUE for trout-perch was higher in all *test* areas compared to the *baseline* area. In summer, almost all *test* areas had a higher CPUE for trout-perch compared to the *baseline* area, with the exception of Steepbank *test* area; however, CPUE for trout-perch was generally lower in summer across all areas compared to spring. In fall, CPUE was higher in all *test* areas compared to spring and summer (Figure 5.1-33).

- In spring, CPUE of walleye was higher in the *baseline* area compared to all *test* areas, which could be due to the preferred habitat conditions for spawning (i.e., hard substrate, fast-flowing water; Scott and Crossman 1973) in the *baseline* area. In summer, CPUE of walleye was lower in the *baseline* area compared to the spring. The decrease in walleye CPUE in the *baseline* area from spring to summer could be due to the movement of walleye out of the spawning grounds. In fall, walleye CPUE was lower in the *baseline* area compared to the *test* areas (Figure 5.1-34).

- CPUE of white sucker in spring was lower in the *baseline* area compared to all *test* areas and was highest in the Muskeg, Tar-Ells, and Fort-Calumet areas. White sucker spawn in spring in lakes or in quiet areas of the rivers with gravel bottoms (Scott and Crossman 1973), which can be found in the lower portions of the Muskeg and Ells rivers. The preference of the Muskeg River for spawning was evident from the number of white sucker captured in the RAMP Muskeg River fish fence in 2009 (RAMP 2010). CPUE of white sucker in summer was variable and low across all areas, which is likely because white sucker are in the tributaries following spawning activities. CPUE of white sucker in fall was higher across all areas compared to summer; all *test* areas had a higher CPUE of white sucker compared to the *baseline* area, with the exception of the Tar-Ells area. The increase in CPUE of white sucker in fall is likely due to the migration of white sucker downstream to overwintering habitat (Figure 5.1-35).

Age-Frequency Distributions Age-frequency distributions and size-at-age relationships for large-bodied KIR fish species for all seasons combined are presented in Figure 5.1-36 to Figure 5.1-41. The average relative age-frequency distributions were grouped for the periods: 1987 to 1996 (pre-RAMP); 1996 to 2004 (RAMP prior to standardization); and 2005 to 2010 (RAMP post standardization) and compared to 2011 for each large-bodied KIR fish species. The species-specific results are as follows:

1. The dominant age class of goldeye from 1997 to 2004 was three years. The dominant age class of goldeye in 2011 was four years with a subdominant age class of five years. The relationship between length and age was moderate from 1997 to 2004 and in 2011 (R^2 = 0.64 and 0.60, respectively).

2. The dominant age class of lake whitefish from 1997 to 2004 was six years. The dominant age class in 2011 was eight years with a subdominant age class of ten years. The shift to an older dominant age class over time could be indicative of poor reproductive success of adult individuals or low survival of young individuals. The relationship between length and age from 1997 to 2004 was moderate (R^2 = 0.56), and low (R^2 = 0.39) in 2011. A plateau in growth of lake whitefish was observed at approximately 5 years of age, which is evident across years, but most prominent in 2011.

3. The dominant age class of longnose sucker in 1997 to 2004, 2006, and 2011 was three years, four years, and eight years, respectively. However, the sample size of ageing data collected from 1987 to 1996 and in 2008 was small and may not be representative of the population. The relationship between length and age in 2006 was stronger than previous years (R^2 = 0.82 compared to 0.22 for 1997 to 2004 and 2011), indicating variability in size-at-age of longnose sucker over time.

4. The sample size of ageing data collected for northern pike is too low for most years (e.g., 1987 to 1996, 2005, 2006 and 2008) to determine the dominant age class. With the limited ageing data available for northern pike, there seems to be a slight shift in dominant age class over time from five to seven years. The relationship between length and age for northern pike from 1997 to 2004 and in 2011 and was low and moderate (R^2 = 0.49 and 0.70, respectively).

5. The dominant age classes across years for walleye are as follows: five years from 1987 to 1996; seven years from 1997 to 2004; five years in 2005; five years in 2006; and six years in 2011. Generally, the dominant age class of walleye has remained consistent across years, between five and seven years. The relationship between length and age was moderate for 1997 to 2004, 2005, 2006 and 2011 (R^2 = 0.64, 0.65, 0.75, and 0.59, respectively), and strong for 1987 to 1996 (R^2 = 0.88).

6. The dominant age class of white sucker has shifted from five years for the period of 1997 to 2004 to eight years in 2011. The subdominant age class from 1997 to 2004 was four years and nine years in 2011. The relationship between length and age from 1997 to 2004 was moderate (R^2 = 0.73), and low in 2011 (R^2 = 0.17, Figure 5.1-41).

Condition Factor Mean condition factor for KIR fish species captured in the Athabasca River from 1997 to 2011 in summer and fall were compared to the mean condition of fish from 1987 to 1996 (pre-RAMP) (Figure 5.1-42 to Figure 5.1-48). A comparison of condition of trout-perch was not conducted given that trout-perch captured from 1987 to 1996 were not measured. The species-specific results are as follows:

1. The mean condition of goldeye in summer and fall 2011 was lower than and exceeded the mean condition of goldeye collected from 1987 to 1996, respectively.

2. The mean condition of lake whitefish in 2011 was lower than 2010, but within the historical range and greater than the mean condition of lake whitefish captured from 1987 to 1996.

3. The mean condition of longnose sucker in summer 2011 was similar to the mean condition of longnose sucker captured from 1987 to 1996; the mean condition in fall was lower than previous years (i.e., 2006 to 2010), but greater than the mean condition of longnose sucker captured from 1998 to 1996.

4. The mean condition of northern pike in summer and fall 2011 was slightly lower than 2010 and the mean condition of northern pike captured from 1987 to 1996, but not significantly different.

5. The mean condition of walleye in summer 2010 and 2011 were consistent to the mean condition of walleye captured from 1987 to 1996; however, the mean condition in fall 2011 was higher than 2010, but lower than the mean condition of walleye captured from 1987 to 1996.

6. The mean condition of white sucker in summer 2011 was higher than 2010, but below the mean condition of white sucker captured from 1987 to 1996. The mean condition of white sucker in fall from 1997 to 2011 was higher than the mean condition of fish captured from 1987 to 1996.

Statistical differences between 2011 and all previous sampling years for summer and fall were tested using analysis of covariance (ANCOVA). Fish captured in spring were excluded from the analysis due to the possibility that variability in condition of fish being captured in spring is 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. The same reasoning is applied for lake whitefish in fall during their spawning period. For most species there were no statistically significant differences among years, with the exception of the following:

1. Condition of trout-perch in summer 2011 was significantly lower than 2009 ($n=497$, $p=0.001$). Condition of trout-perch in fall 2011 was also significantly lower compared to 2003, 2005, 2006, and 2009 ($n=2{,}270$, $p<0.001$).

2. There was a significant decrease in condition of walleye across all years in summer ($n=497$, $p<0.001$), with condition being lowest in summer 2010 and 2011 compared to previous years.

3. Condition of white sucker in fall 2011 was significantly lower compared to 1997, 2000, and 2009 ($n=489$, $p=0.01$).

External Health Assessment

Observed abnormalities were primarily associated with minor skin aberrations or wounds, scars, and fin erosion, but infrequent cases of parasites, growth, lesions and body deformities were also observed. In 2011, 1.19%, 0.76%, and 1.19% of fish captured in spring, summer, and fall, respectively, were found to have some type of external abnormality. The incidences of external abnormalities in 2011 were lower in all seasons compared to 2010.

A total of 55 of 5,546 (1.0%) 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 for all seasons combined exhibiting some form of pathology is provided in Table 5.1-20. For each type of external pathology, there has been no increasing trend observed over time (Figure 5.1-49). External pathology is primarily observed in white sucker and longnose sucker accounting for 6.8% and 4.8% of fish with some type of external pathology in 2011, respectively; the percent of external pathology was within the historical range for white sucker (1.7% to 26.4%) and longnose sucker (0.9% to 11.3%). Other species for which pathological abnormalities were recorded, mostly due to their higher catch frequency and relative abundance compared to other species in the river, included emerald shiner, goldeye, lake chub, lake whitefish, northern pike, trout-perch, and walleye.

Similar incidences of fish abnormalities have been documented in previous studies in 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 tumors, lesions, scars or injuries, skin discoloration, 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 collected in all areas of the river is relatively consistent suggesting that increased oil sands development has had little influence on the incidence of external fish abnormalities.

Summary

As outlined in the RAMP Design and Rationale document (RAMP 2009b), the Athabasca River fish inventory is generally considered to be a community-driven activity, primarily suited for assessing general trends in abundance and populations variables for large-bodied species, rather than detailed community structure.

As of 2011, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, age-frequency distributions, and condition of fish among years. The plateau observed in size of lake whitefish at five to six years of age across all years could be due to several reasons. Heikinheimo and Mikkola (2004) observed that changes in temperature regimes, food resources, population density, interspecific competition or fishing could all be contributing factors that would inhibit growth of fish. Statistically significant differences were observed among years for condition in some 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 2011 in all species were within the historical range and consistent with studies done prior to the major oil sands development in the upper Athabasca River, the ARD, and the Peace and Slave rivers (Mill *et al*. 1996, Barton *et al.* 1993, R.L. & L. 1994).

5.1.5.2 Fish Tag Return Assessment

Angler Returns

A total of three RAMP Floy tags from walleye were submitted to the Alberta Sustainable Resource Development (ASRD), Fort McMurray office, by anglers in 2011. A summary of the RAMP tag returns in 2011 during the RAMP fish inventories and from anglers is provided in Table 5.1-21 and a cumulative summary of the RAMP tags returned to date is presented in Table 5.1-22 for comparisons by species. Figure 5.1-50 shows the location of first capture and tagging by RAMP and the location of recapture by angler. Given the location of the initial capture and the tag return are not always on the same river, tag returns for both the Athabasca and Clearwater rivers are provided in this section.

Fish Inventory Returns

Walleye and northern pike are tagged during the RAMP fish inventory programs. During the 2011 Athabasca River fish inventory, five walleye and three northern pike were recaptured that had been previously tagged:

- Two walleye were recaptured in the same river reach where they were originally tagged;
- Two walleye were recaptured just upstream relative to their original capture reach and one walleye was recaptured approximately 30 km downstream from its original capture location;
- Two walleye were originally captured in 2006, one in 2008, one in 2009 and one in 2011;
- Two northern pike were caught further upstream relative to their original capture location and one was captured just downstream from its original capture location; and
- One northern pike was originally captured in 2004, one in 2010 and one in 2011.

During the Clearwater River 2011 fish inventory, eight fish were captured that had been previously tagged during Clearwater River inventories. Of these eight fish, there were two walleye and six northern pike:

- One walleye was recaptured in its original capture reach and one was recaptured just downstream from the original capture reach;
- One walleye was originally captured in 2006 and one in 2011;
- Two northern pike were recaptured in their original capture reach and one northern pike was recaptured just downstream relative to its original capture reach;
- Two northern pike were originally captured in 2007 and one in 2011; and
- Three northern pike had their original floy-tags lost or were not legible to identify the tag number; therefore, the original capture location and year could not be determined.

5.1.5.3 Fish Tissue Analysis Results

Whole-Organism Metrics

A total of 55 walleye (3 males, 12 females, and 16 unsexed) and 24 lake whitefish (9 males, 7 females, and 8 unsexed) were collected from the Athabasca River for fish tissue analysis in conjunction with the 2011 fall fish inventory. The size of walleye captured ranged from 280 mm to 640 mm. The mean length of walleye was 455 mm with females (average length: 493 mm) being larger than males (average length: 471 mm). The size of lake whitefish captured ranged from 430 to 434 mm. The mean length of lake whitefish was 435 mm, with males (average length: 434 mm) being slightly larger than females (average length: 430 mm).

External fish health assessments were conducted on all fish collected for non-lethal mercury analysis and internal fish health assessments were conducted on all 11 lake whitefish and 15 walleye that were sacrificed for metal and organics tissue analyses**.** There were no abnormalities observed in any of the sacrificed fish, or on any of the fish from which tissue was sampled non-lethally.

Mercury

Total mercury concentrations in muscle tissue of lake whitefish and walleye from the Athabasca River in fall 2011 are presented in Table 5.1-23. Concentrations of mercury in lake whitefish ranged from 0.02 to 0.20 mg/kg, with a mean concentration of 0.08 mg/kg. Concentrations of mercury in walleye ranged from 0.10 to 0.75 mg/kg, with a mean concentration of 0.34 mg/kg. Temporal trends in absolute concentrations of mercury and length-normalized concentrations of mercury in lake whitefish and walleye are presented in Figure 5.1-51 and Figure 5.1-52, respectively. Concentrations of mercury in lake whitefish in 2011 were on average higher than 2008, but within the range of previously-measured concentrations. Concentrations of mercury in walleye in 2011 were slightly higher on average than measured in 2008, but within the range of previously-measured concentrations. Mercury concentrations in lake whitefish and walleye from 2002 to 2011 for each size class are presented in Figure 5.1-53. Concentrations of mercury in lake whitefish remained fairly consistent within each size class across years and below the subsistence and general consumer guidelines, with the exception of a few individuals. Concentrations of mercury in walleye greater than 400 mm exceeded the subsistence and general consumer guidelines demonstrating the bioaccumulation of mercury in fish as they grow and that mercury concentrations are greater in walleye given they are piscivores, whereas lake whitefish are generally benthivores (Scott and Crossman 1973).

In 2011, mercury concentrations in muscle tissue of individual lake whitefish were not statistically significant across length or age of fish ($p=0.03$ and $p=0.01$, respectively) and had a weak ($R^2=0.42$) and moderate ($R^2=0.53$) correlation to length and age, respectively (Table 5.1-24 and Figure 5.1-54). A regression of mercury concentrations in fish tissue of individual walleye was statistically significant across length ($p=0.002$, $R^2=0.44$) and age ($p<0.001$, $R^2=0.70$) of fish (Table 5.1-24 and Figure 5.1-54). Differences in mercury concentrations relative to length across sampling years (e.g., 2002, 2003, 2005, 2008 and 2011) were not statistically significant for lake whitefish and walleye ($p=0.27$ and $p=0.38$, respectively) (Figure 5.1-53). Differences in mercury concentrations relative to age across sampling years (e.g., 2002, 2003, 2005, 2008 and 2011) were not statistically significant for lake whitefish and walleye ($p=0.21$ and $p=0.34$, respectively).

Other Chemicals

Composite samples of lake whitefish and walleye were analysed for concentrations of other chemicals and tainting compounds in fish tissue from the Athabasca River: composite samples were collected for females (400 to 450 mm for lake whitefish; 450 to 500 mm and >500 mm for walleye) and males (400 to 450 mm for lake whitefish and walleye) for a total of five composite samples. Fourteen of the 27 metals analysed were below the analytical detection limit for all composite samples with the exception of female lake whitefish (400 to 450 mm) and female walleye (450 to 500 mm), which had fifteen of the 27 variables below the detection limit (Table 5.1-25). In 2011, all tainting compounds were below analytical detection limits for all composite tissue samples (Table 5.1-25).

Potential Risk to Human Health

Mercury In 2011, concentrations of mercury in lake whitefish and walleye were screened against human health criteria for fish consumption established by Health Canada and the United States Environmental Protection Agency (USEPA) (Table 5.1-23). There were no lake whitefish captured in 2011 with concentrations of mercury that exceeded guidelines for human health consumption, with the exception of one lake whitefish, with a mercury concentration of 0.20 mg/kg which is equal to the consumption guideline for subsistence fishers. The mean mercury concentration for walleye (0.34 mg/kg) exceeded the Health Canada consumption guideline for subsistence fishers (0.20 mg/kg); twenty-three of the thirty-one walleye captured exceeded the Health Canada consumption guideline for subsistence fishers (0.2 mg/kg) and of those twenty-three, five exceeded the Health Canada consumption guideline for general consumers (0.5 mg/kg) (Table 5.1-23).

In 2011, 58% of walleye captured were greater than or equal to 908 g in weight. According to the Government of Alberta (2009), the consumption limits for walleye from the Athabasca River with a weight of 908 g or greater are as follows: women at the reproductive age (15 to 49 years) or pregnant should only consume two servings (75 g) per week; a child of one to four years old should only consume half a serving a week; children five to eleven years should only consume one serving a week; and adults (includes adults and children over 12 years) should only consume eight servings a week.

Other Chemicals Concentrations of total arsenic (inclusive of both inorganic and organic) exceeded the USEPA subsistence guideline in all composite samples and the recreational guideline in female lake whitefish (400-450 mm), male walleye (450-500 mm), and female walleye (>500 mm) (Table 5.1-25); however, the guideline is established for inorganic arsenic not total arsenic. To be conservative, the concentration of inorganic arsenic was estimated to be 10% of the total arsenic concentration, although in other studies inorganic arsenic has been documented to be less than five percent of the total arsenic concentration (ATSDR 2009). Estimated concentrations of inorganic arsenic are also provided in Table 5.1-25. Concentrations of inorganic arsenic exceeded the National USEPA guideline for subsistence fishers in male walleye (450 to 500 mm).

Potential Risk to Fish and Fish Health

The following are the results of screening for potential risks of concentrations of chemicals to fish and fish health (Table 5.1-26):

- Concentrations of mercury in lake whitefish and walleye did not exceed any of the effects (or no-effects) thresholds for fish and fish health;

- The concentration of selenium exceeded the lethal no-effects threshold for male and female lake whitefish, and male and female walleye (450 to 500 mm and 400 to 500 mm, respectively); female walleye greater than 500 mm exceeded the lethal effects threshold. From 2008 to 2011, the concentration of selenium has increased in walleye and decreased in lake whitefish.

- The concentration of vanadium in both lake whitefish and walleye exceeded the sublethal no-effects threshold, which was consistent with results recorded in 2008.

The criteria for evaluating potential risk to fish health is subject to further investigation given that sublethal and lethal thresholds are determined in controlled laboratory conditions and may; therefore, not reflect the conditions of the water quality in the Athabasca River as it related to toxicity of metals to fish (RAMP 2009a).

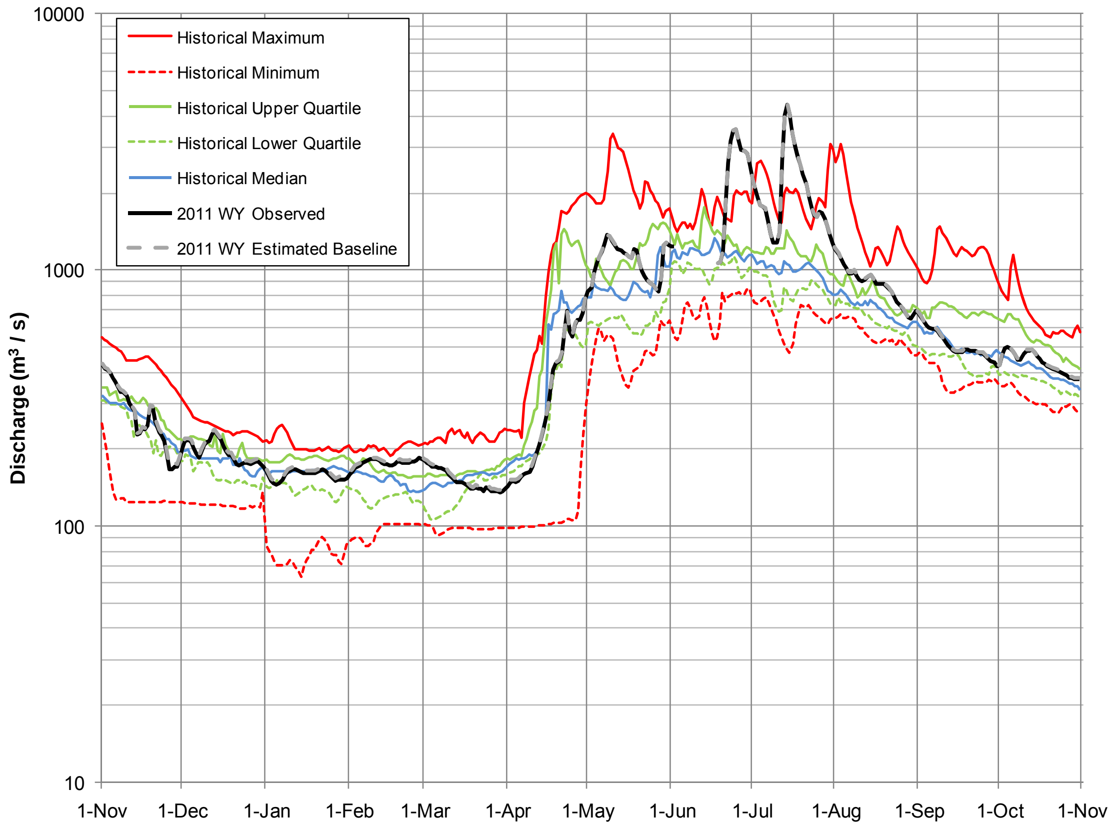
Potential Risk on Fish Palatability

Concentrations of all tainting compounds in lake whitefish and walleye from the Athabasca River were present at concentrations well below the 1 mg/kg threshold for effects on palatability as outlined in Jardine and Hrudey (1998) (Table 5.1-26).

Summary Assessment for Fish Tissue

Measurement endpoints used in the assessment for the Athabasca River fish tissue program included metals and tainting compounds in fish tissue of both individual and composite samples. Potential human health risks from contaminated fish tissue were predicted from both individual and composite samples. In 2011, the mean concentration of mercury in lake whitefish was lower than previous years, with the exception of 2008 and the mean concentration of mercury in walleye was higher in 2011 compared to previous years, with the exception of 2003. The mean mercury concentration across all size classes of lake whitefish were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. The mean mercury concentration in size classes of walleye greater than 300 mm exceeded the subsistence fishers guideline for consumption indicating a **High** risk to subsistence fishers and a **Moderate** risk to general consumers.

Figure 5.1-3 Athabasca River: 2011 WY hydrograph and historical context.



Note: Based on 2011 WY provisional data from Athabasca River below Eymundson Creek, Station S24. The upstream drainage area is 146,000 km^2. Historical data are calculated from nine years of record (June 21, 2001 to October 31, 2010).

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, 2011 WY.

Component	Volume (million m³)		Basis and Data Source
	Focal Projects	Focal Projects Plus Other Oil Sands Developments	
Observed *test* hydrograph (total discharge)	**19975.5**		**Sum of observed daily discharges obtained from Athabasca River below Eymundson Creek, RAMP Station S24**
Closed-circuited area water loss from the observed hydrograph	-49.8	-49.9	362.2km² (361.5 km² focal projects only) of land estimated to have been closed-circuited as of 2011 (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.
Incremental runoff form land clearing (not closed-circuited area)	+2.3	+2.4	85 km² (84 km² focal projects only) of land estimated to have undergone land change as of 2011 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.
Water withdrawals from the Athabasca River watershed from focal projects	-28.1		Withdrawals by Suncor (daily values provided).
	-36.3		Withdrawals by Syncrude (monthly totals provided; constant daily values assumed).
	-23.8		Withdrawals by Shell (daily values provided).
	-10.3		Withdrawals by Canadian Natural (daily values provided).
	-0.02		Withdrawals by Imperial (daily values provided).
	-0.005		Withdrawals by Total (daily values provided)
Water releases in the Athabasca River watershed from focal projects	+0.3		Releases by Syncrude (daily values provided).
	+3.4		Releases by Suncor (daily values provided).
The difference between *test* and *baseline* hydrographs on tributary streams	+4.2	+4.4	Net sum of incremental volume results from the major tributaries as listed in Section 5.2 to Section 5.11[1].
Estimated *baseline* hydrograph (total discharge)	**20,113.5**	**20,113.4**	**Estimated *baseline* discharge at Athabasca River below Eymundson Creek, RAMP Station S24.**
Incremental flow (change in total discharge)	-138.0	-137.9	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-0.69%**	**-0.69%**	**Incremental flow as a percentage of total discharge of estimated *baseline* hydrograph.**

Note: Data and assumptions are discussed in Section 3.2.1.4.

Note: Based on the provisional 2011 WY data for Athabasca River below Eymundson Creek, Station S24.

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 and Christina River watersheds are the only watersheds in the RAMP FSA that contained other oil sands developments under construction or operation as of 2011 (Table 2.5-1).

[3] Due to the absence of observed test data from June 3-17 2011, the company daily values on these dates were removed for water balance calculations. The difference in annual total release and withdrawal by all companies is less than 3.7% different than before the data were removed on these dates. The change in tributary streams was also reduced accordingly.

Table 5.1-3 Calculated change in hydrologic measurement endpoints for the Athabasca River in the 2011 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	1,138	1,133	-0.5%
Mean winter discharge	196	192	-1.9%
Annual maximum daily discharge	4,451	4.438	-0.3%
Open-water season minimum daily discharge	380	374	-1.4%

Note: Based on the provisional 2011 WY data for Athabasca River below Eymundson Creek, Station S24.

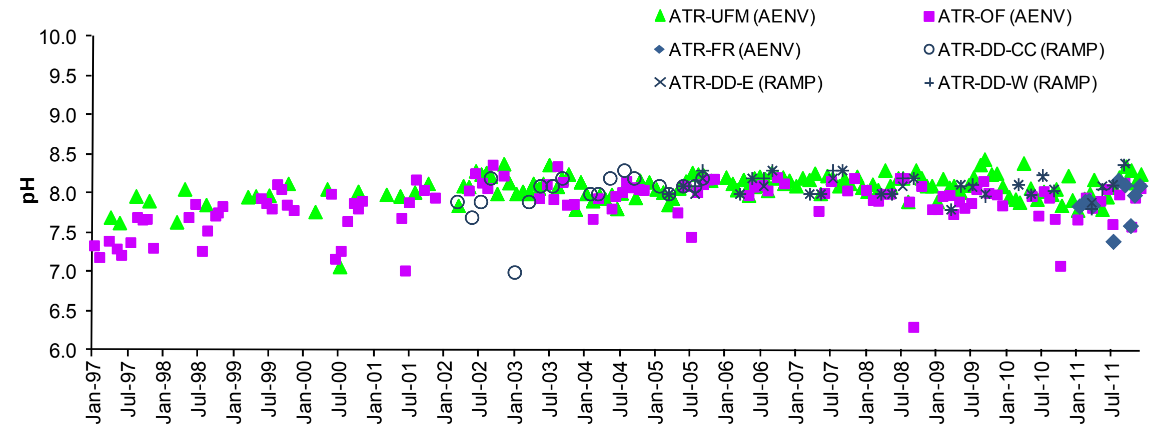
Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to one decimal place.

[1] Assessment results for both cases, focal project and focal project plus other oil sands developments, are essentially the same and only appear different when presented at three decimal places for *baseline* values and relative change values. The values presented in the above table are therefore applicable to both assessment cases.

Figure 5.1-4 Water quality measurement endpoints, 1997 to 2011 AEW and RAMP data for the Athabasca River mainstem.

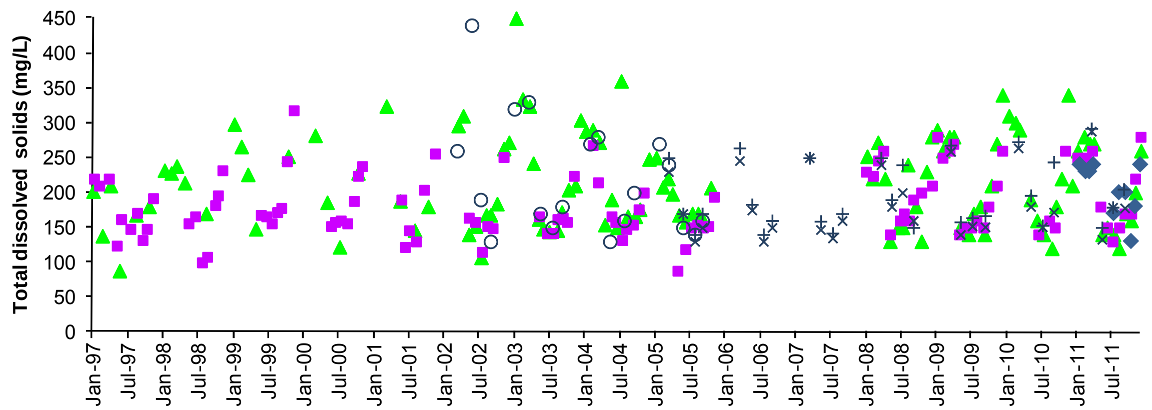
pH

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



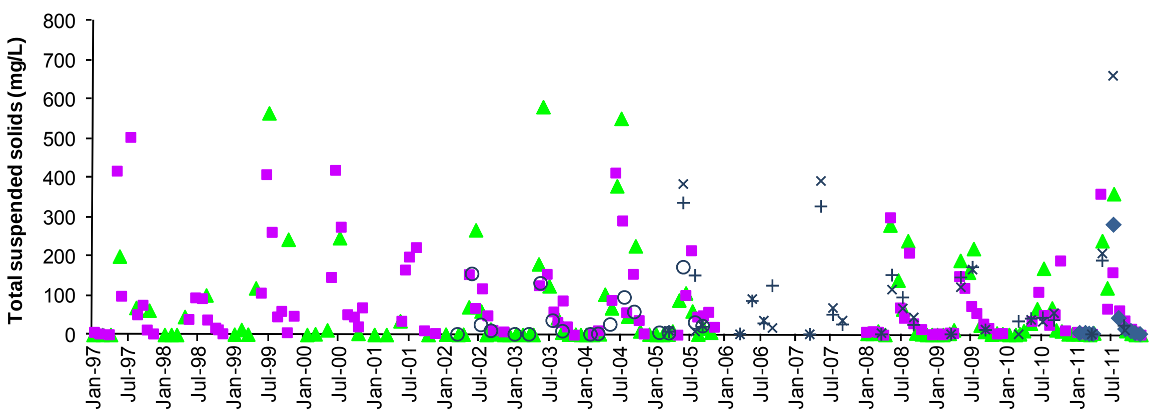
Total dissolved solids

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



Total suspended solids

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

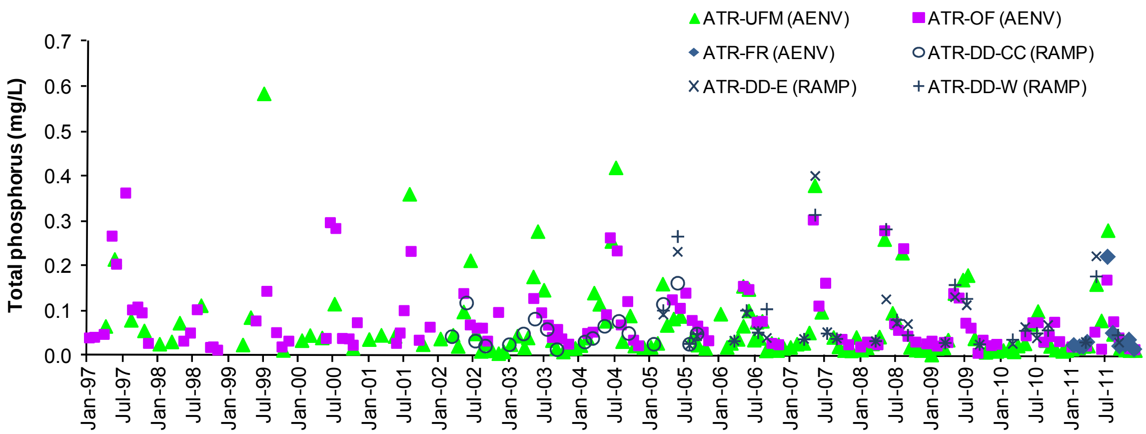


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

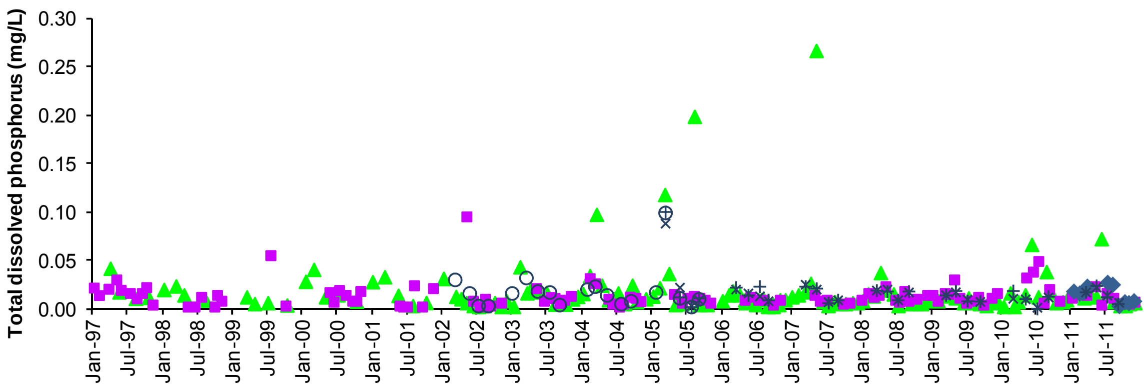
Total phosphorus

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



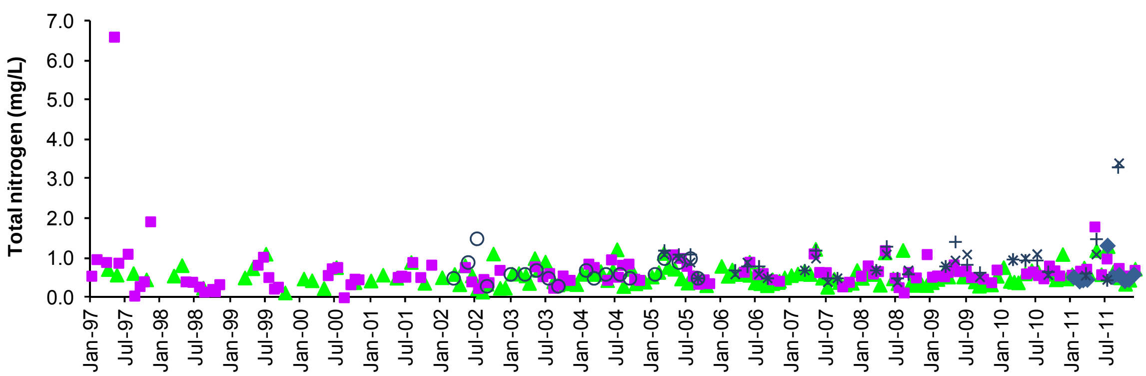
Total dissolved phosphorus

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



Total nitrogen

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

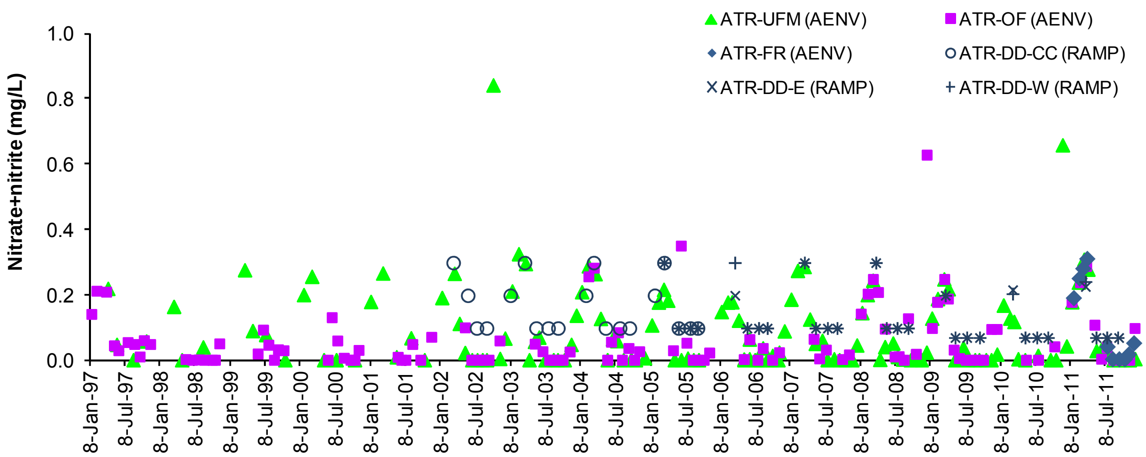


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

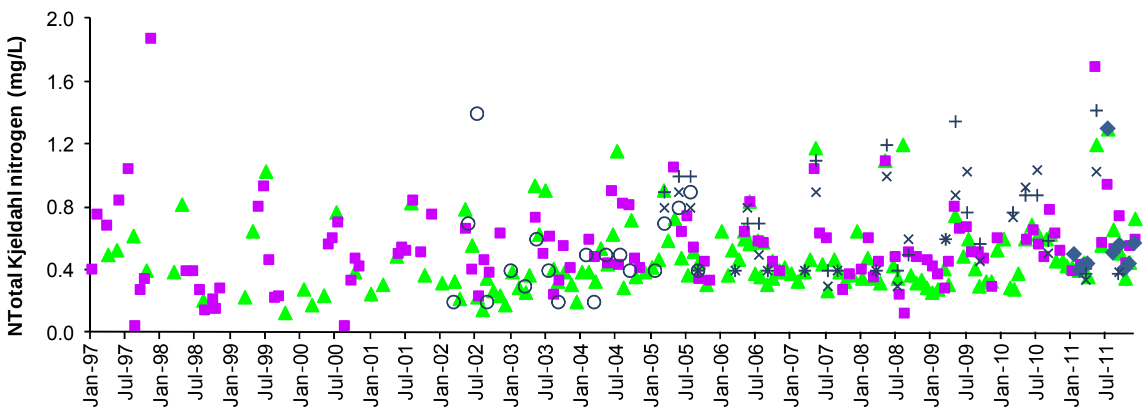
Nitrate + Nitrite

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



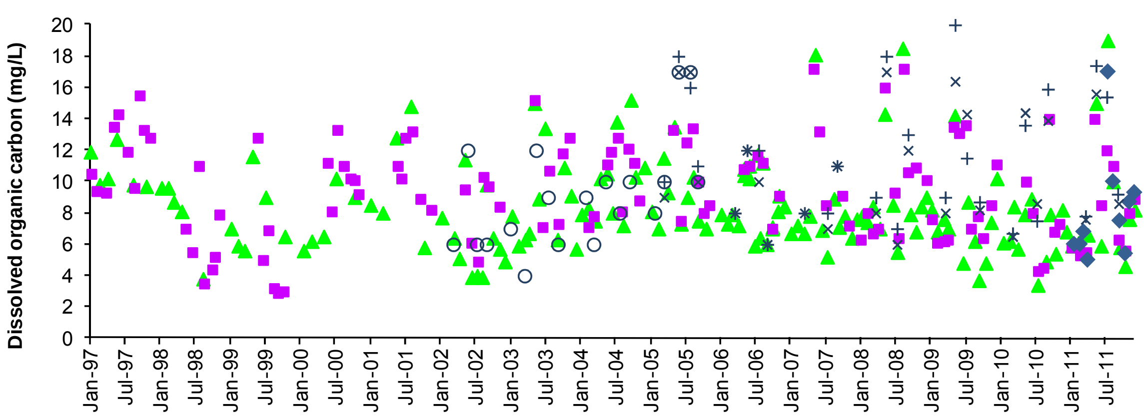
Total Kjeldahl nitrogen

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



Dissolved organic carbon

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

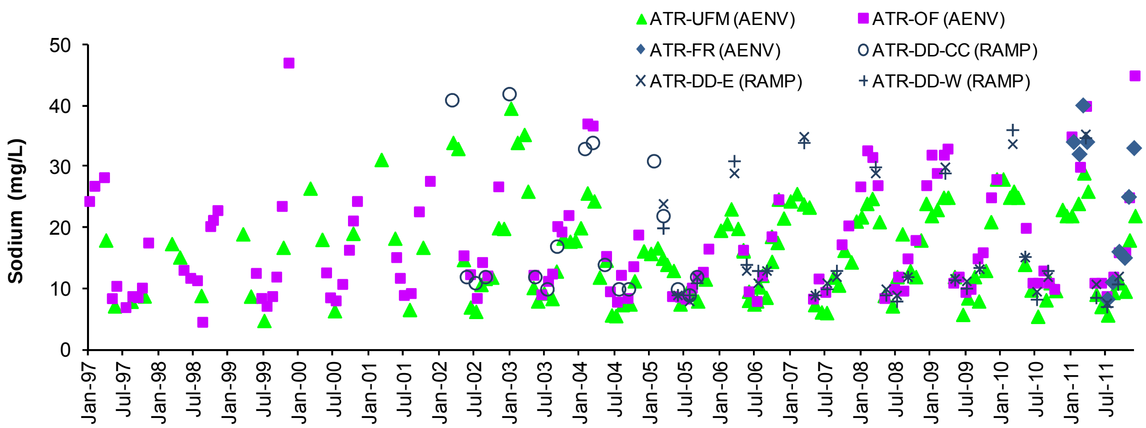


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

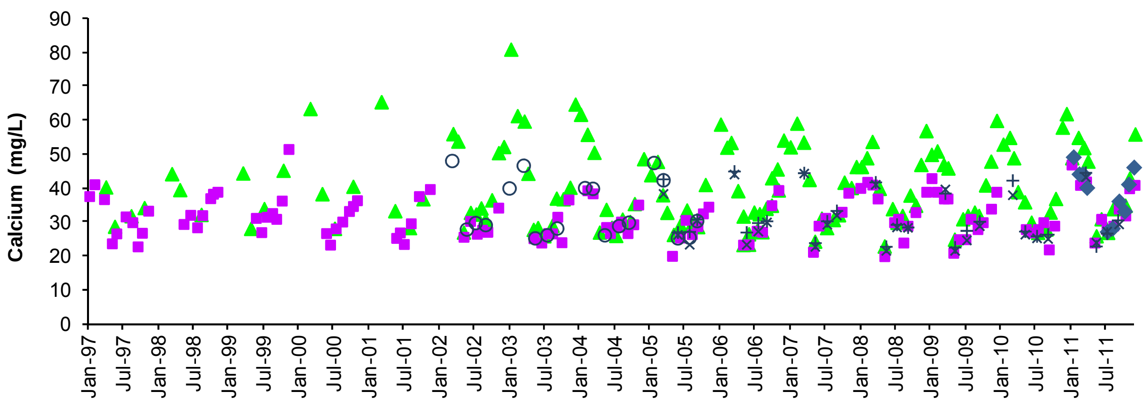
Sodium

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



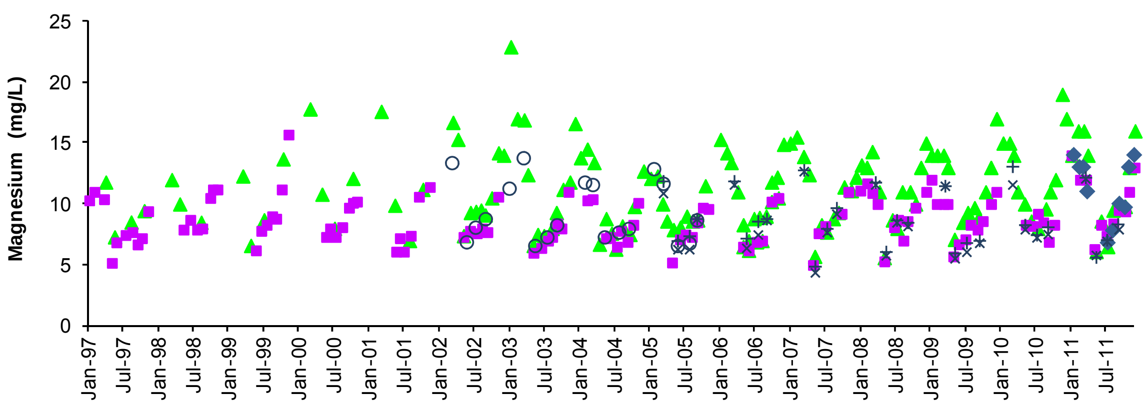
Calcium

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



Magnesium

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

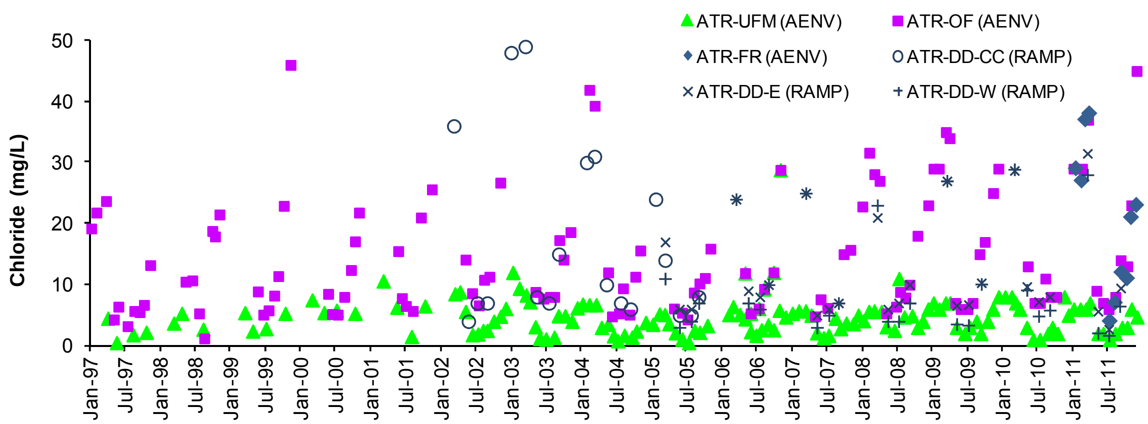


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

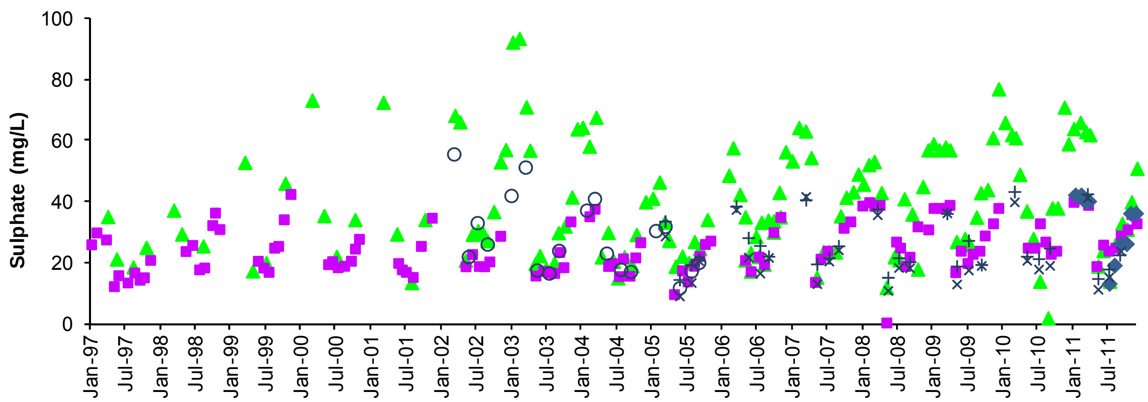
Chloride

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



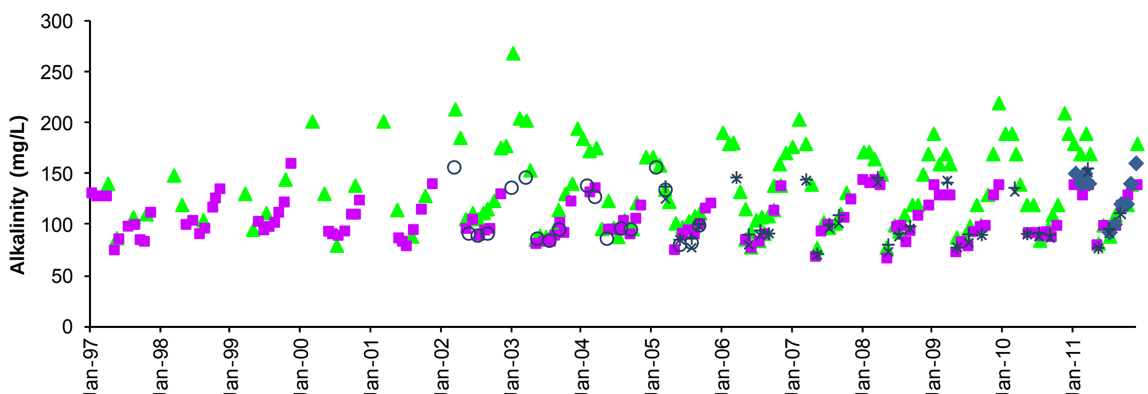
Sulphate

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



Alkalinity (as $CaCO_3$)

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

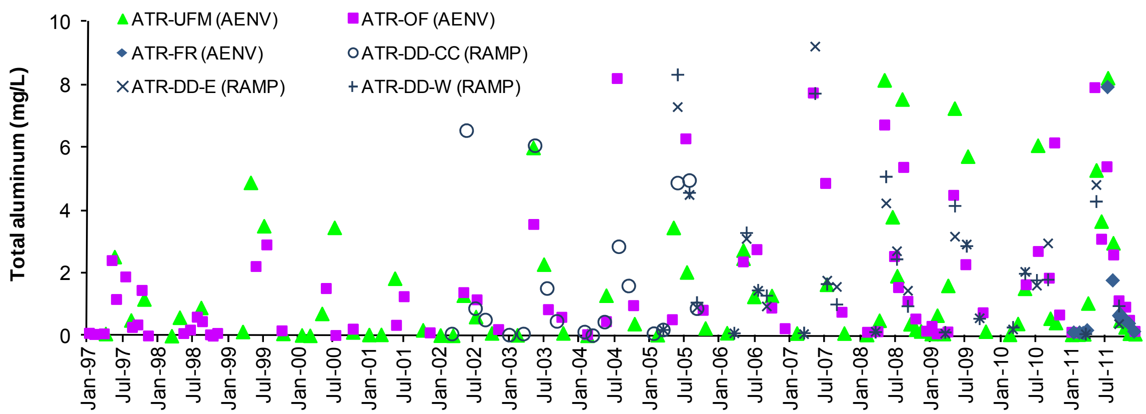


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

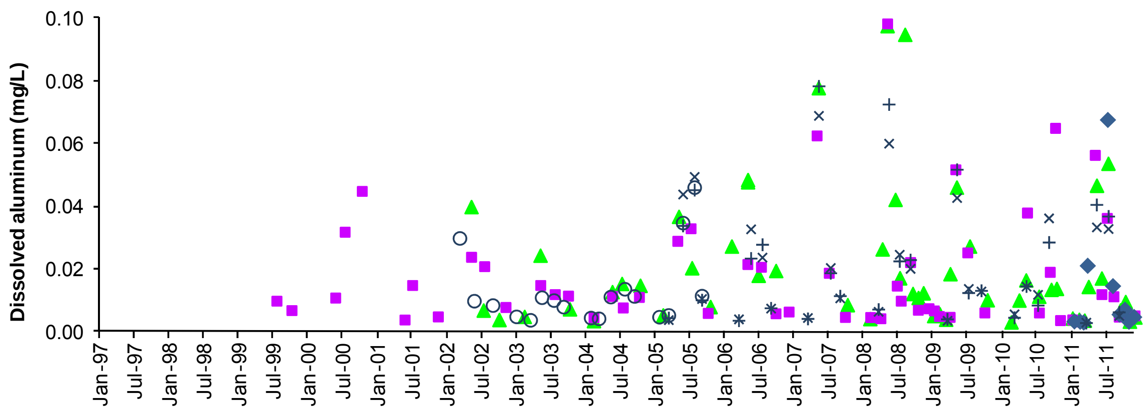
Total aluminum

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



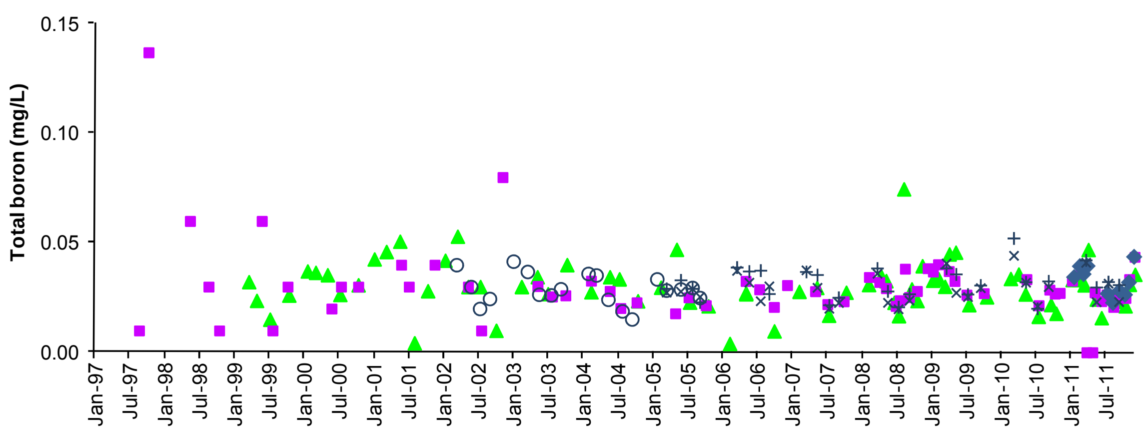
Dissolved aluminum

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



Total boron

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

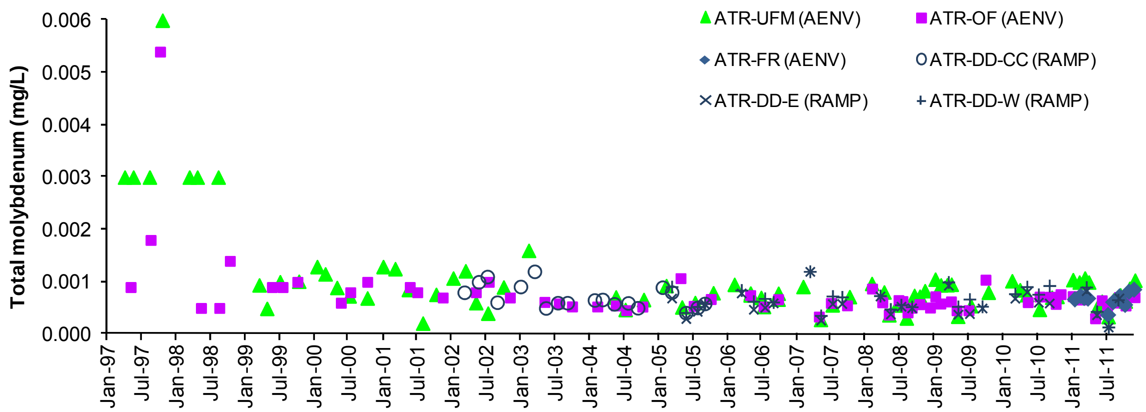


Non-detectable results are shown at the detection limit.

Figure 5.1-4 (Cont'd.)

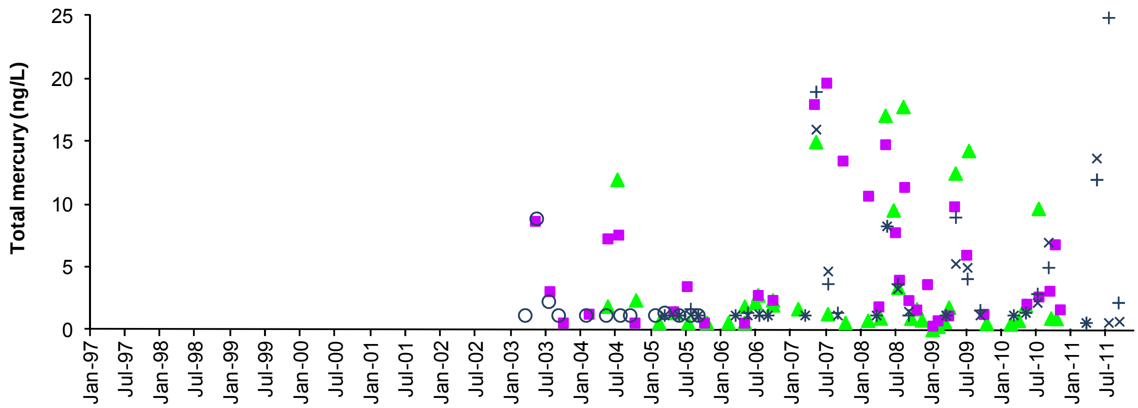
Total molybdenum

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



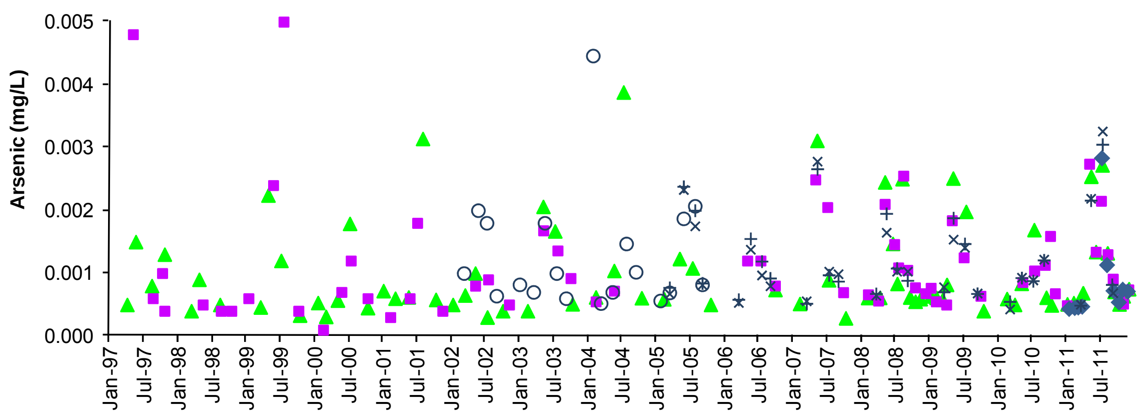
Total mercury (ultra-trace)

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



Total Arsenic

Trend at ATR-UFM: none 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 2011.

Measurement Endpoint	Units	Guideline[a]	Upstream of Fort McMurray (ATR-UFM) Fall AEW data, 1997-2011				Upstream of Donald Creek (ATR-DC-E, ATR-DC-W)[c]		Upstream of Steepbank River (ATR-SR-E, ATR-SR-W)[c]		Upstream of Muskeg River (ATR-MR-E, ATR-MR-W)[c]		Downstream of Development (ATR-DD-E, ATR-DD-W)[d]		Upstream of Firebag River ATR-FR-CC (AEW data)[e]
			n	min	median	max	East	West	East	West	East	West	East	West	Cross-channel
Physical variables															
pH	pH units	6.5-9.0	61	7.3	8.1	8.4	8.3	8.4	8.4	7.8	8.4	8.3	8.4	8.4	8.1
Total suspended solids	mg/L	-	57	<1	7	344	50	16	117	16	23	129	13	25	200
Conductivity	µS/cm	-	58	150	293.5	530	286	273	279	277	279	288	294	285	320
Nutrients															
Total dissolved phosphorus	mg/L	0.05	44	0.003	0.006	0.025	0.011	0.003	0.006	0.003	0.005	0.004	0.007	0.006	0.003
Total nitrogen	mg/L	1.0	56	0.133	0.393	**1.903**	0.45	0.38	0.46	0.37	0.39	0.43	0.46	0.45	0.56
Nitrate+nitrite	mg/L	1.3	62	0.001	<0.003	0.843	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.071	<0.003
Dissolved organic carbon	mg/L	-	57	2.5	7.6	25.0	10.6	6.5	8.4	7.8	8.8	7.5	8.6	9.2	7.5
Ions															
Sodium	mg/L	-	59	4	11	23	22.6	8.6	14.2	9.6	13.0	11.1	12.1	10.8	16
Calcium	mg/L	-	62	19.4	36	58	24.3	33.8	29.7	33.7	31.2	33.8	29.5	30.7	36
Magnesium	mg/L	-	60	5.4	9.9	19	7.6	9.2	8.5	9.3	9.0	9.4	7.9	8.4	10
Chloride	mg/L	230, 860	62	1	3	8	24.3	1.9	11.0	3.3	8.8	5.7	9.5	6.5	12
Sulphate	mg/L	100	61	13	31.8	71	11.3	24.6	19.1	23.7	20.3	26.5	23.9	22.7	26
Total dissolved solids	mg/L	-	53	109	176	340	178	168	167	193	174	173	178	205	180
Total alkalinity	mg/L		62	64	120	210	91	113	105	112	106	113	111	112	120
Selected metals															
Total aluminum	mg/L	0.1	22	0.07	**0.24**	**1.29**	**1.32**	**0.98**	**2.68**	**0.77**	**1.17**	**4.34**	**0.40**	**0.97**	**0.63**
Total arsenic	mg/L	0.1	24	0.0003	0.0006	0.0019	0.0008	0.0007	0.0011	0.0007	0.0008	0.0014	0.0007	0.0008	0.0007
Dissolved aluminum	mg/L	0.1	15	0.0035	0.010	0.020	0.0067	0.0074	0.0059	0.0071	0.0058	0.0057	0.0053	0.0064	0.0054
Total boron	mg/L	1.2	18	0.010	0.025	0.040	0.040	0.020	0.028	0.022	0.026	0.026	0.023	0.031	0.028

Values in **bold** are above the guideline; underlined values are outside historical range of fall observations for station (single line = historical high; double underline = historical low).

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] Non-detectable values treated in summary calculations as 1 x calculated Method Detection Limit.

[c] Historical comparison to 12 years of fall data (1998 to 2010).

[d] Historical comparison to 6 years of fall data (2005 to 2010).

[e] New AEW station in 2011; fall data presented and compared with historical fall ATR-FR-CC data collected by RAMP (2002-2010)

[f] PAHs were analyzed by AENV, but using higher detection limits that are not comparable to RAMP results.

Table 5.1-4 (Cont'd.)

Measurement Endpoint	Units	Guideline[a]	Upstream of Fort McMurray (ATR-UFM) Fall AEW data, 1997-2011				Upstream of Donald Creek (ATR-DC-E, ATR-DC-W)[c]		Upstream of Steepbank River (ATR-SR-E, ATR-SR-W)[c]		Upstream of Muskeg River (ATR-MR-E, ATR-MR-W)[c]		Downstream of Development (ATR-DD-E, ATR-DD-W)[d]		Upstream of Firebag River ATR-FR-CC (AEW data)[e]
			n	min	median	max	East	West	East	West	East	West	East	West	Cross-channel
Selected metals (Cont'd.)															
Total molybdenum	mg/L	0.073	24	0.0006	0.0008	0.0180	0.00033	0.00066	0.00052	0.00071	0.00060	0.00061	0.00069	0.00066	0.00071
Total mercury (ultra-trace)	ng/L	5, 13	10	0.6	0.9	2.4	1.2	0.6	2.6	0.7	1.1	0.6	0.7	2.2	-
Total strontium	mg/L	-	18	0.220	0.288	0.355	0.166	0.262	0.222	0.274	0.232	0.254	0.229	0.245	0.264
Total hydrocarbons															
BTEX	mg/L	-	0	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.01
Fraction 1 (C6-C10)	mg/L	-	0	-	-	-	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.01
Fraction 2 (C10-C16)	mg/L	-	0	-	-	-	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.005
Fraction 3 (C16-C34)	mg/L	-	0	-	-	-	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.02
Fraction 4 (C34-C50)	mg/L	-	0	-	-	-	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.02
Polycyclic Aromatic Hydrocarbons (PAHs)															
Naphthalene	ng/L	-	0	-	-	-	<14.1	<14.1	<14.1	<14.1	<14.1	<14.1	<14.1	<14.1	- [f]
Retene	ng/L	-	0	-	-	-	3.8	<2.1	19.9	2.1	2.4	8.0	<2.1	2.8	- [f]
Total dibenzothiophenes	ng/L	-	0	-	-	-	35.6	7.3	24.1	144.1	31.7	22.1	13.3	20.9	- [f]
Total PAHs[b]	ng/L	-	0	-	-	-	266.6	160.0	275.7	936.0	262.0	242.1	170.8	209.2	- [f]
Total Parent PAHs[b]	ng/L	-	0	-	-	-	23.4	20.2	29.6	94.1	26.5	25.4	20.1	21.8	- [f]
Total Alkylated PAHs[b]	ng/L	-	0	-	-	-	243.1	139.8	246.1	841.9	235.5	216.8	150.7	187.5	- [f]
Other variables that exceeded CCME/AENV guidelines in 2011															
Dissolved silver	mg/L	0.0001	14	<0.0000005	<0.0000005	0.0001	-	-	-	-	-	-	**0.000117**	-	-
Total chromium	mg/L	0.001	26	0.0002	0.0006	0.0070	**0.0012**	**0.0010**	**0.0027**	-	**0.0013**	**0.0041**	-	-	-
Total iron	mg/L	0.3	22	0.14	0.34	3.29	**1.29**	**0.57**	**2.02**	**0.48**	**0.85**	**2.96**	**0.34**	**0.73**	**0.42**
Total phosphorous	mg/L	0.05	60	0.006	0.019	0.350	**0.066**	-	**0.11**	-	-	**0.106**	-	-	-
Total silver	mg/L	0.0001	18	<0.0000005	0.0000048	0.001	-	-	-	-	-	-	**0.000118**	-	-

Values in **bold** are above the guideline; underlined values are outside historical range of fall observations for station (single line = historical high; double underline = historical low).

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] Non-detectable values treated in summary calculations as 1 x calculated Method Detection Limit.

[c] Historical comparison to 12 years of fall data (1998 to 2010).

[d] Historical comparison to 6 years of fall data (2005 to 2010).

[e] New AEW station in 2011; fall data presented and compared with historical fall ATR-FR-CC data collected by RAMP (2002-2010)

[f] PAHs were analyzed by AEW, but using higher detection limits that are not comparable to RAMP results.

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 2011.

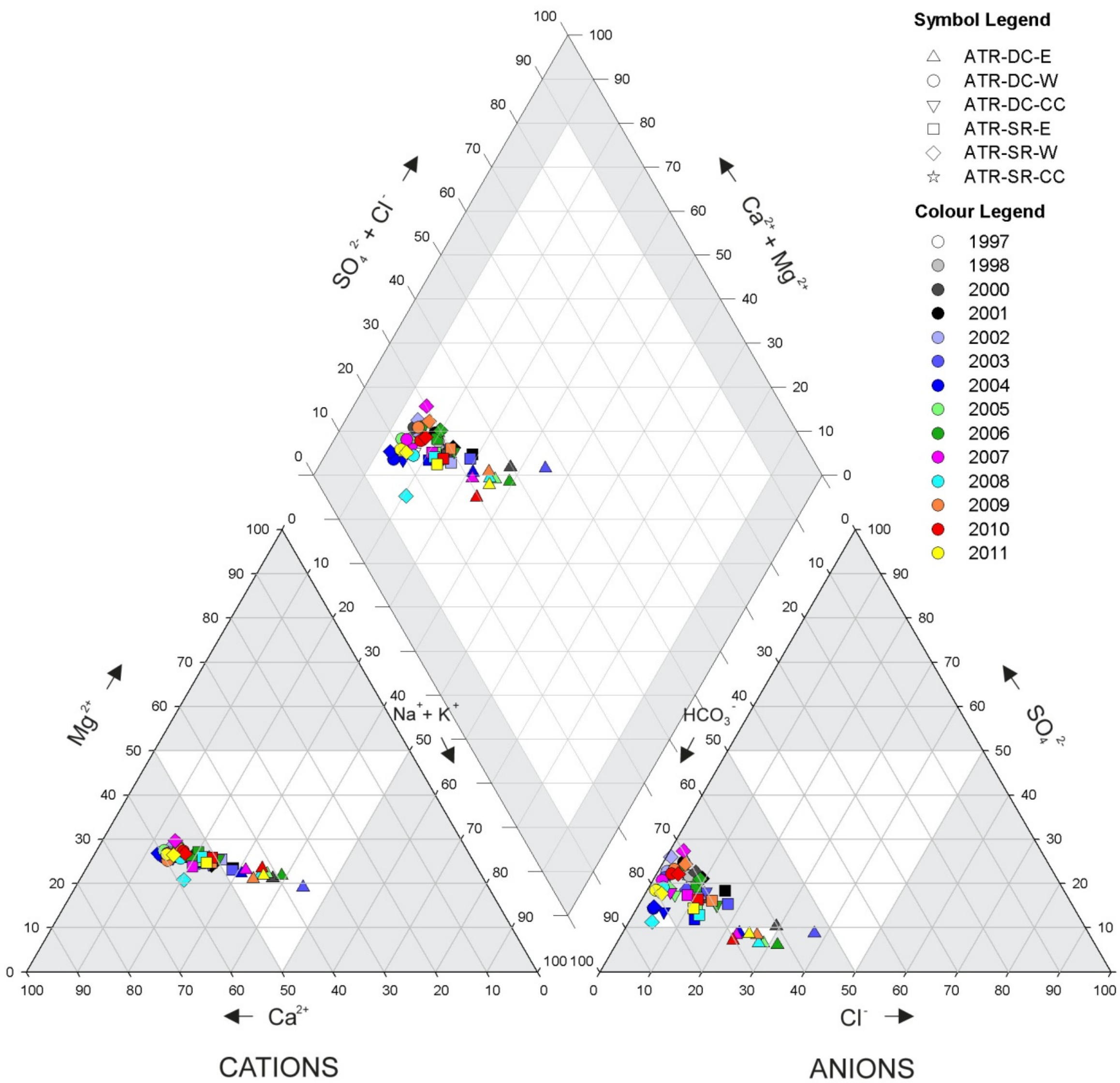


Figure 5.1-6 Piper diagram of ion concentrations in Athabasca River mainstem (*test* stations ATR-MR versus *baseline* stations ATR-DC), fall 1997 to 2011.

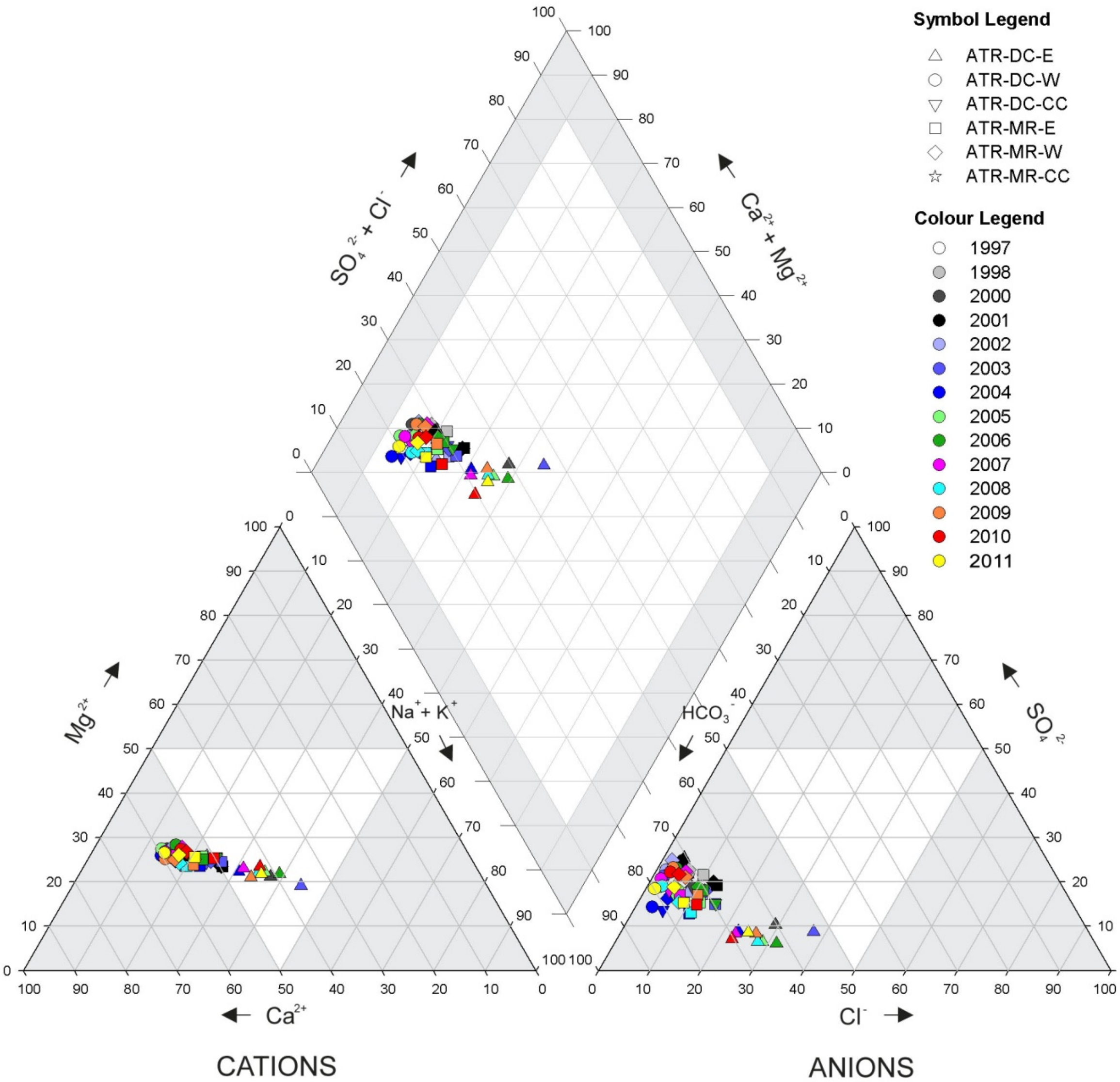


Figure 5.1-7 Piper diagram of ion concentrations in Athabasca River mainstem (*test* stations ATR-FR versus *baseline* stations ATR-DC), fall 1997 to 2011.

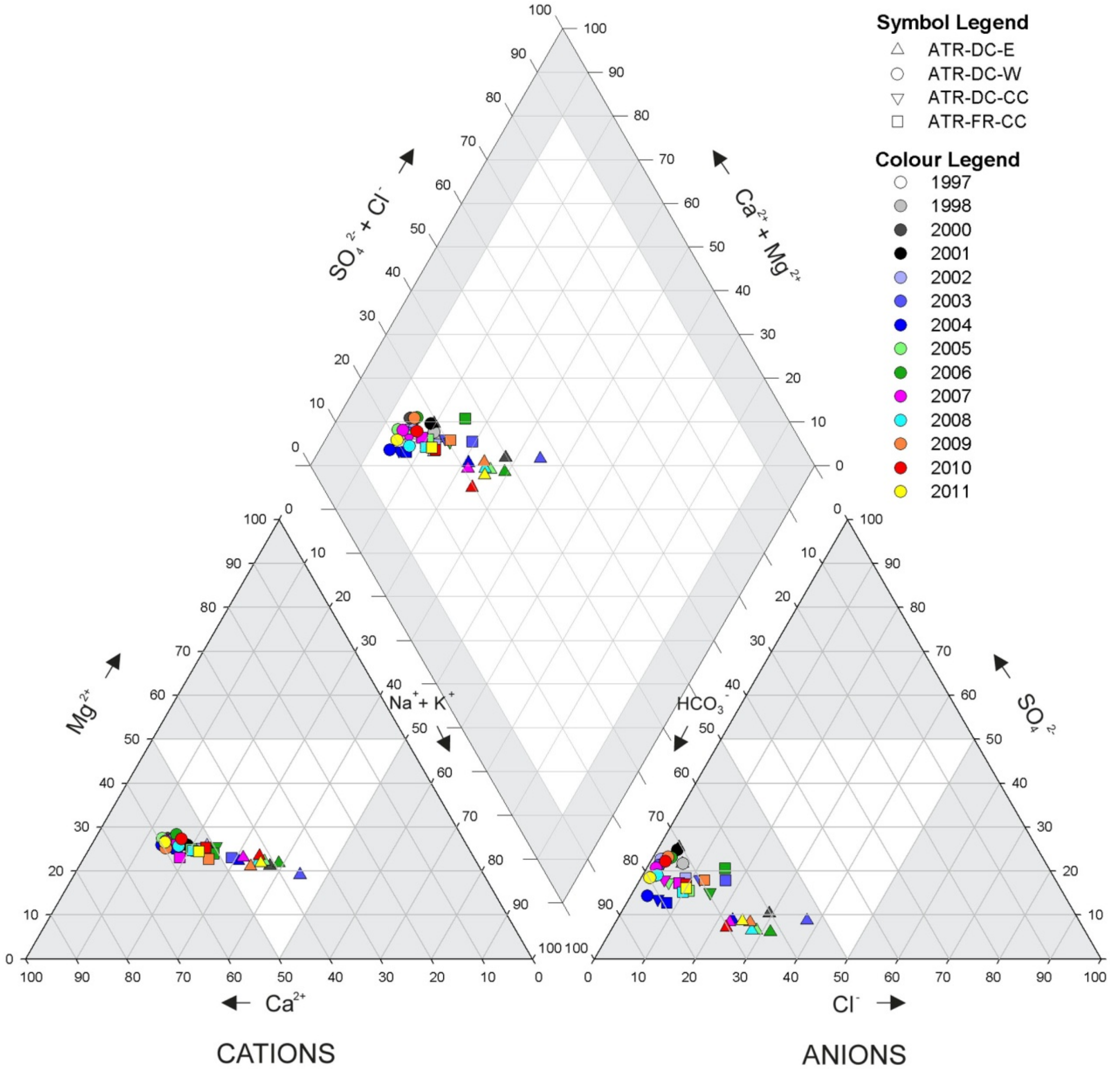


Figure 5.1-8 Piper diagram of ion concentrations in Athabasca River mainstem *test* stations ATR-DD versus *baseline* stations ATR-DC), fall 1997 to 2011.

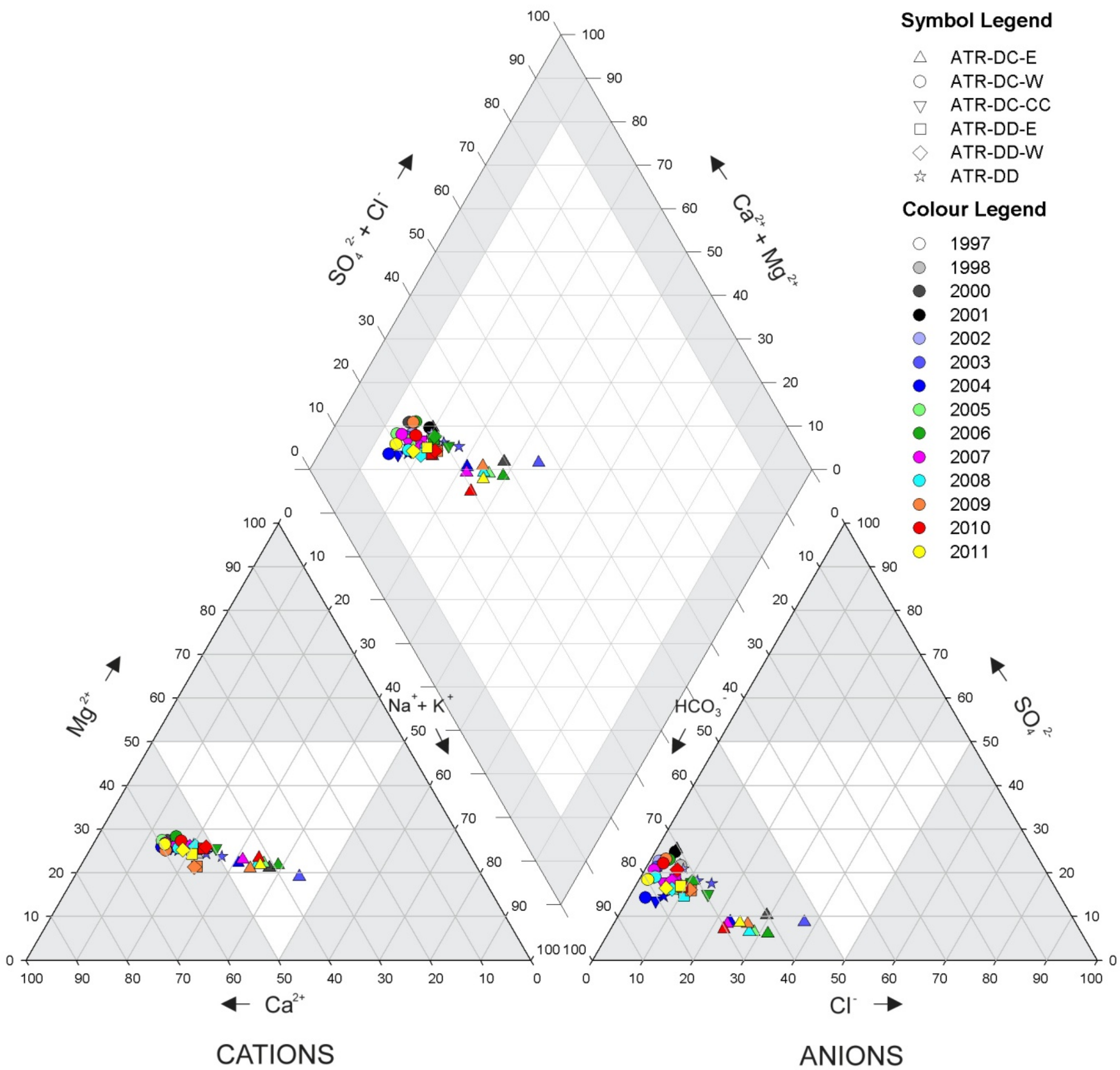


Table 5.1-5 Water quality guideline exceedances in the Athabasca River mainstem, downstream of development (ATR-DD), 2011.

Parameter	Units	Guideline[a]	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	-	0.003	ns	ns	ns	ns	0.004	0.004	-
Total iron	mg/L	0.3	0.64	-	ns	ns	ns	ns	0.34	0.35	0.36
Spring											
Dissolved iron	mg/L	0.3	0.32	-	ns	ns	ns	ns	-	-	-
Sulphide	mg/L	0.002	0.002	0.004	ns	ns	ns	ns	0.007	0.007	-
Total aluminum	mg/L	0.1	2.9	5.5	ns	ns	ns	ns	4.8	4.3	-
Total cadmium	mg/L	0.0001[b]	-	0.0001	ns	ns	ns	ns	-	-	-
Total chromium	mg/L	0.001	0.0040	0.0073	ns	ns	ns	ns	0.0071	0.0065	-
Total iron	mg/L	0.3	3.2	5.3	ns	ns	ns	ns	5.1	4.6	-
Total Kjeldahl nitrogen	mg/L	1	-	-	ns	ns	ns	ns	1.03	1.42	-
Total lead	mg/L	0.0016-0.0026[b]	0.0017	0.0038	ns	ns	ns	ns	0.0033	0.0030	-
Total mercury (ultra-trace)	mg/L	5, 13	5.5	11.5	ns	ns	ns	ns	13.7	12.0	-
Total nitrogen	mg/L	1	-	1.01	ns	ns	ns	ns	1.10	1.49	-
Total phenols	mg/L	0.004	0.009	0.005	ns	ns	ns	ns	0.018	0.005	-
Total phosphorus	mg/L	0.05	0.13	0.21	ns	ns	ns	ns	0.22	0.18	-

ns = not sampled.

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] Guideline is hardness-dependent. See Table 3.2-5 for equation.

Table 5.1-5 (Cont'd.)

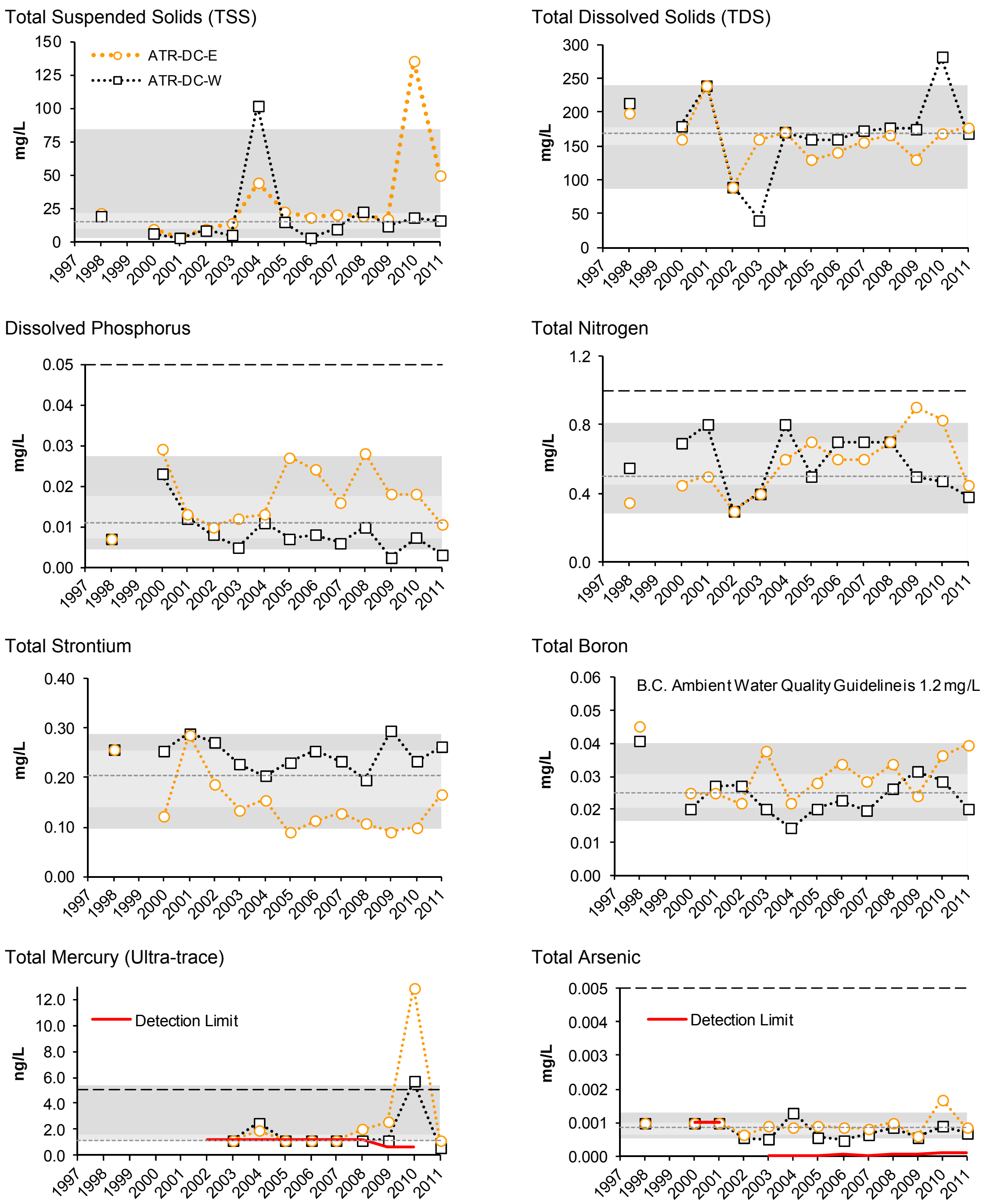
Parameter	Units	Guideline[a]	Upstream of Donald Creek (ATR-DC-E, ATR-DC-W)		Upstream of Steepbank River (ATR-SR-E, ATR-SR-W)		Upstream of Muskeg River (ATR-MR-E, ATR-MR-W)		Downstream of Development (ATR-DD-E, ATR-DD-W)		Upstream of Firebag River ATR-FR-CC
			East[1]	West	East	West	East	West	East	West	Cross-channel
Summer											
Dissolved iron	mg/L	0.3	-	-	ns	ns	ns	ns	-	-	-
Sulphide	mg/L	0.002	0.01	0.01	ns	ns	ns	ns	0.01	0.01	-
Total aluminum	mg/L	0.1	12.3	12.1	ns	ns	ns	ns	15.0	15.1	-
Total cadmium	mg/L	$2.8\text{-}3.2 \cdot 10^{-5}$ [b]	0.000280	0.000354	ns	ns	ns	ns	0.00049	0.00044	-
Total chromium	mg/L	0.001	0.0138	0.0147	ns	ns	ns	ns	0.018	0.018	-
Total copper	mg/L	0.0099-0.012[b]	0.0125	0.0152	ns	ns	ns	ns	0.017	0.017	-
Total iron	mg/L	0.3	12.7	15.2	ns	ns	ns	ns	17.2	17.1	-
Total Kjeldahl nitrogen	mg/L	1	1.72	2.13	ns	ns	ns	ns	2.3	2.4	-
Total lead	mg/L	0.0024-0.0031[b]	0.0106	0.014	ns	ns	ns	ns	0.018	0.016	-
Total mercury (ultra-trace)	mg/L	5, 13	9.2	13.6	ns	ns	ns	ns	-	24.9	-
Total nitrogen	mg/L	1	2.5862	3.1566	ns	ns	ns	ns	3.412	3.308	-
Total phenols	mg/L	0.004	0.0099	0.0082	ns	ns	ns	ns	0.012	0.005	-
Total phosphorus	mg/L	0.05	0.722	0.886	ns	ns	ns	ns	1.00	0.81	-
Total zinc	mg/L	0.03	0.042	0.0483	ns	ns	ns	ns	0.058	0.06	-
Fall											-
Dissolved silver	mg/L	0.0001	-	-	-	-	-	-	0.00012	-	-
Total aluminum	mg/L	0.1	1.32	0.98	2.68	0.77	1.17	4.34	0.40	0.97	-
Total chromium	mg/L	0.001	0.0012	0.0010	0.0027	-	0.0013	0.0041	-	-	-
Total iron	mg/L	0.3	1.29	0.57	2.02	0.481	0.851	2.96	0.34	0.728	-
Total phosphorus	mg/L	0.05	0.066	-	0.11	-	-	0.11	-	-	-
Total silver	mg/L	0.0001	-	-	-	-	-	-	0.00012	-	-

ns = not sampled.

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] Guideline is hardness-dependent. See Table 3.2-5 for equation.

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).



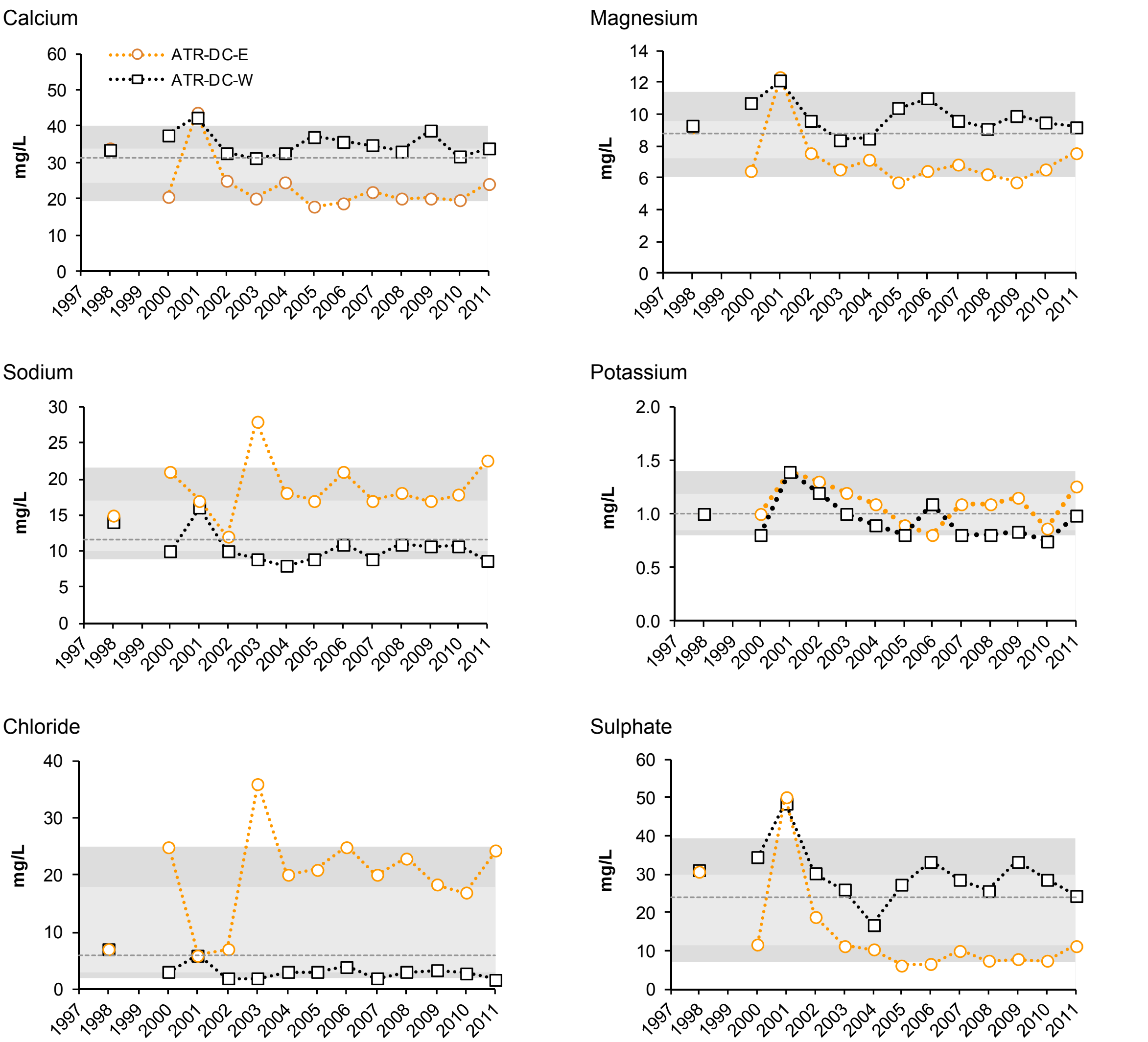
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O⋯⋯O Sampled as a *baseline* station ●━━● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-9 (Cont'd.)



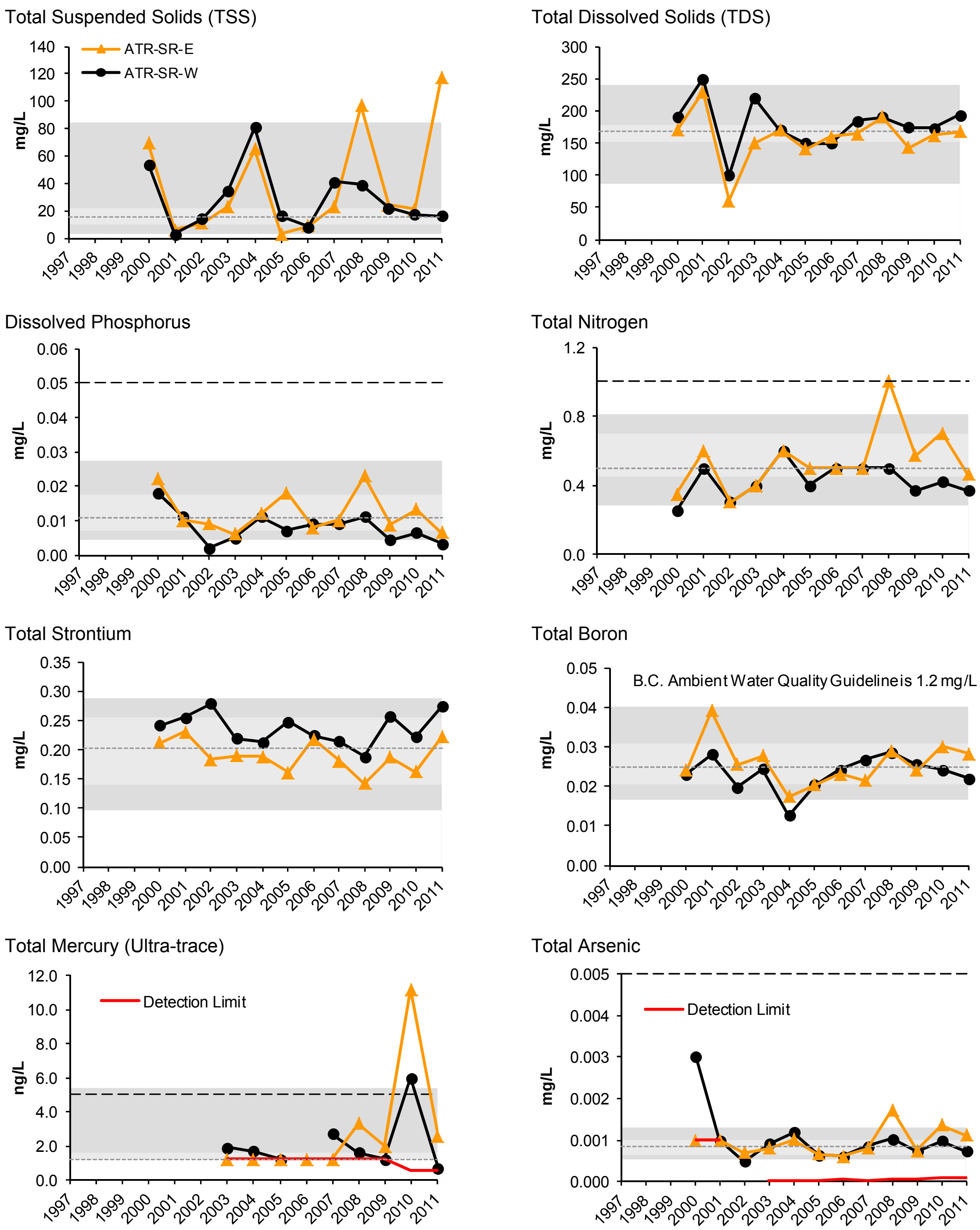
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●━━● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-10 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.

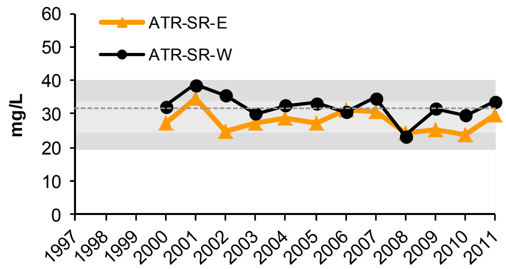
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

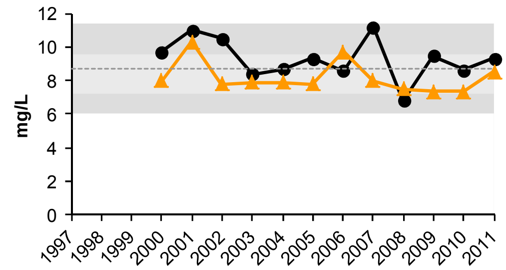
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-10 (Cont'd.)

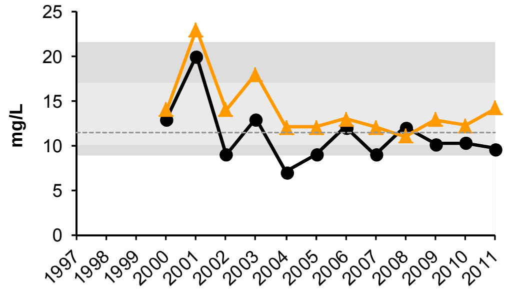
Calcium



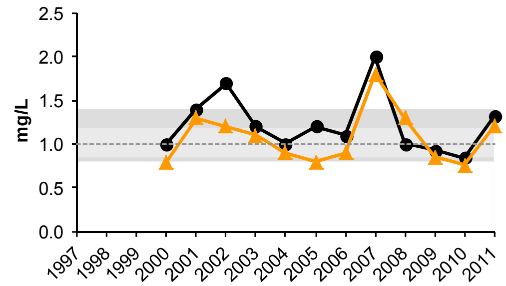
Magnesium



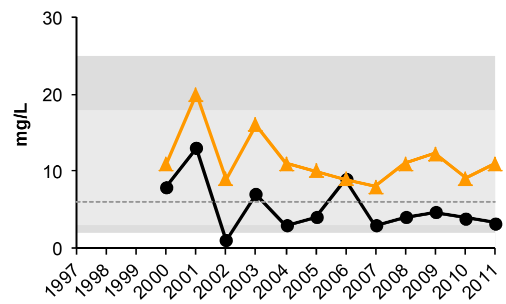
Sodium



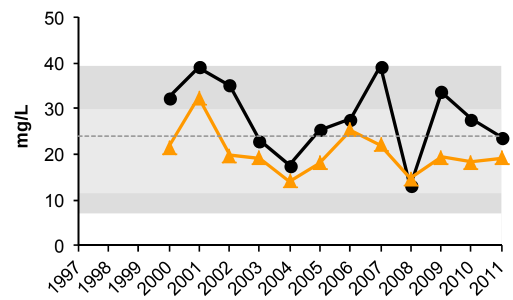
Potassium



Chloride



Sulphate



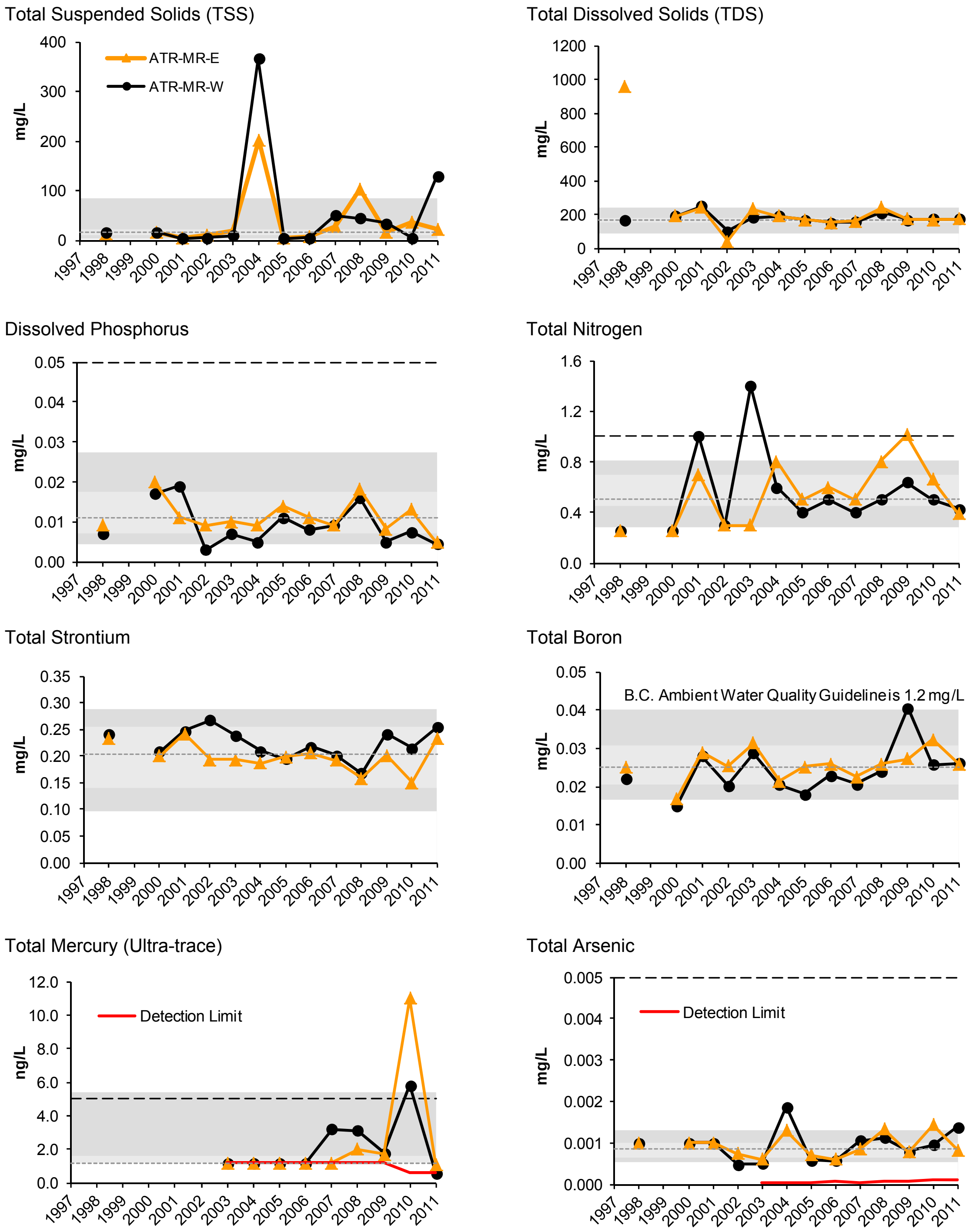
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O••••••O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-11 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).



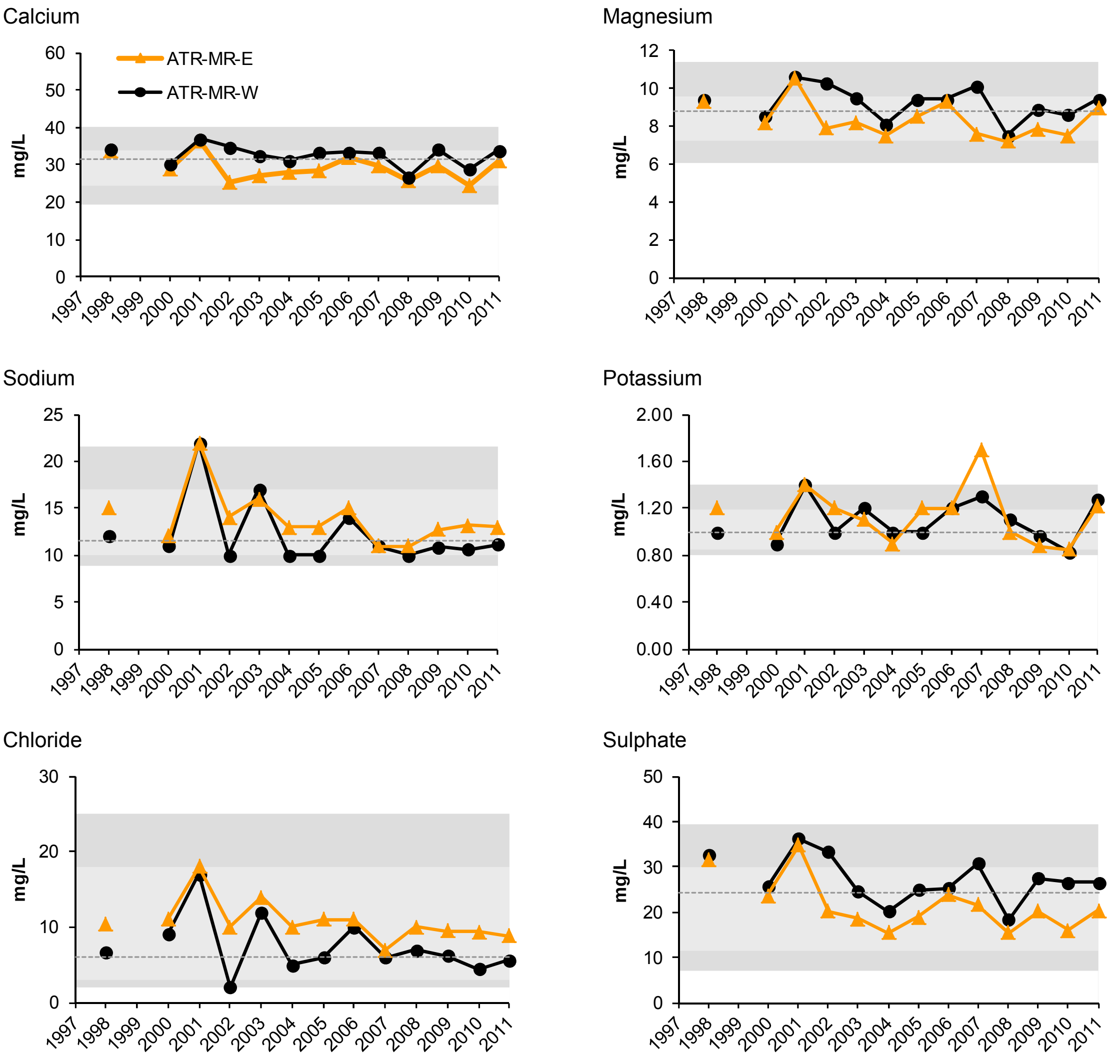
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-11 (Cont'd.)



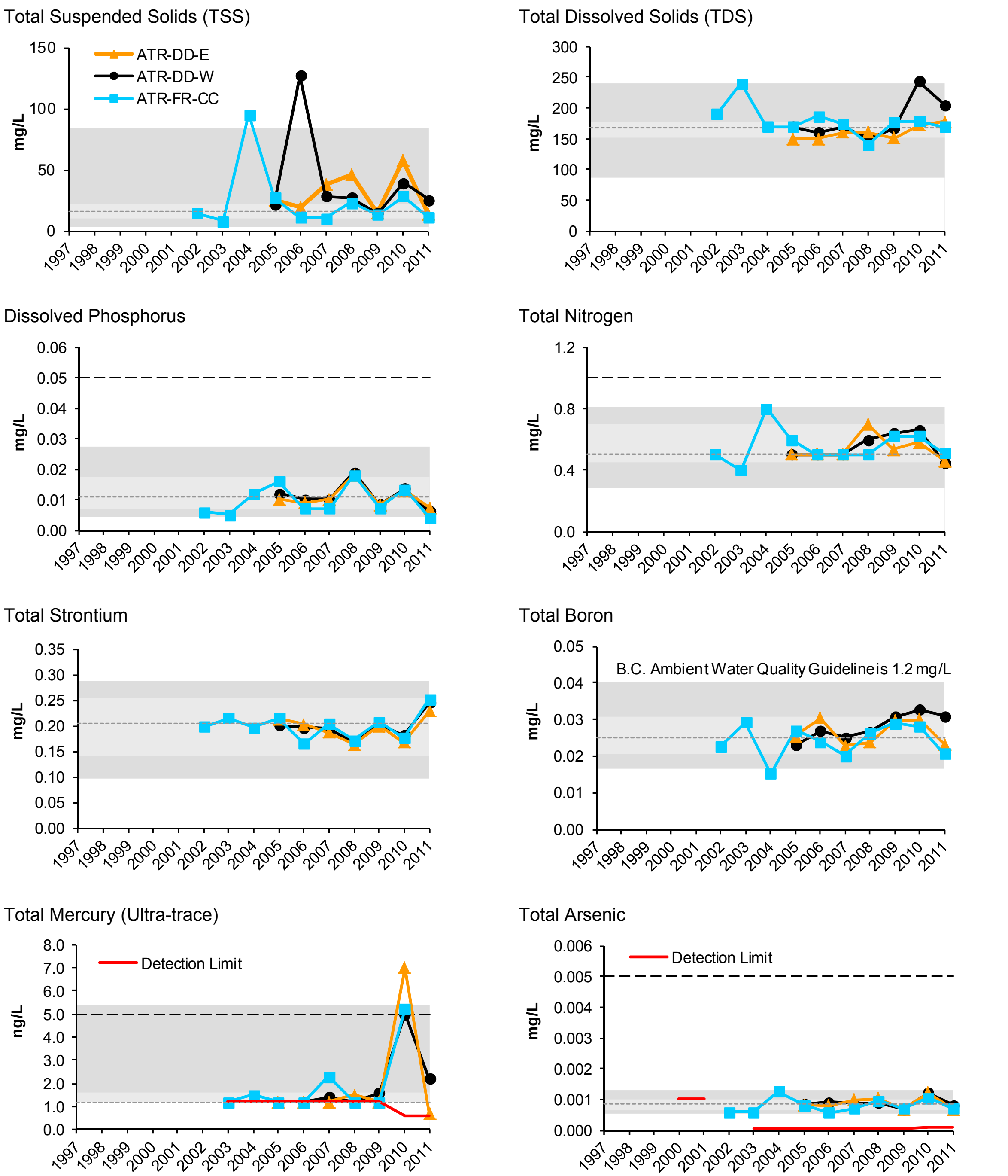
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.1-12 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)[1].



Non-detectable values are shown at the detection limit.

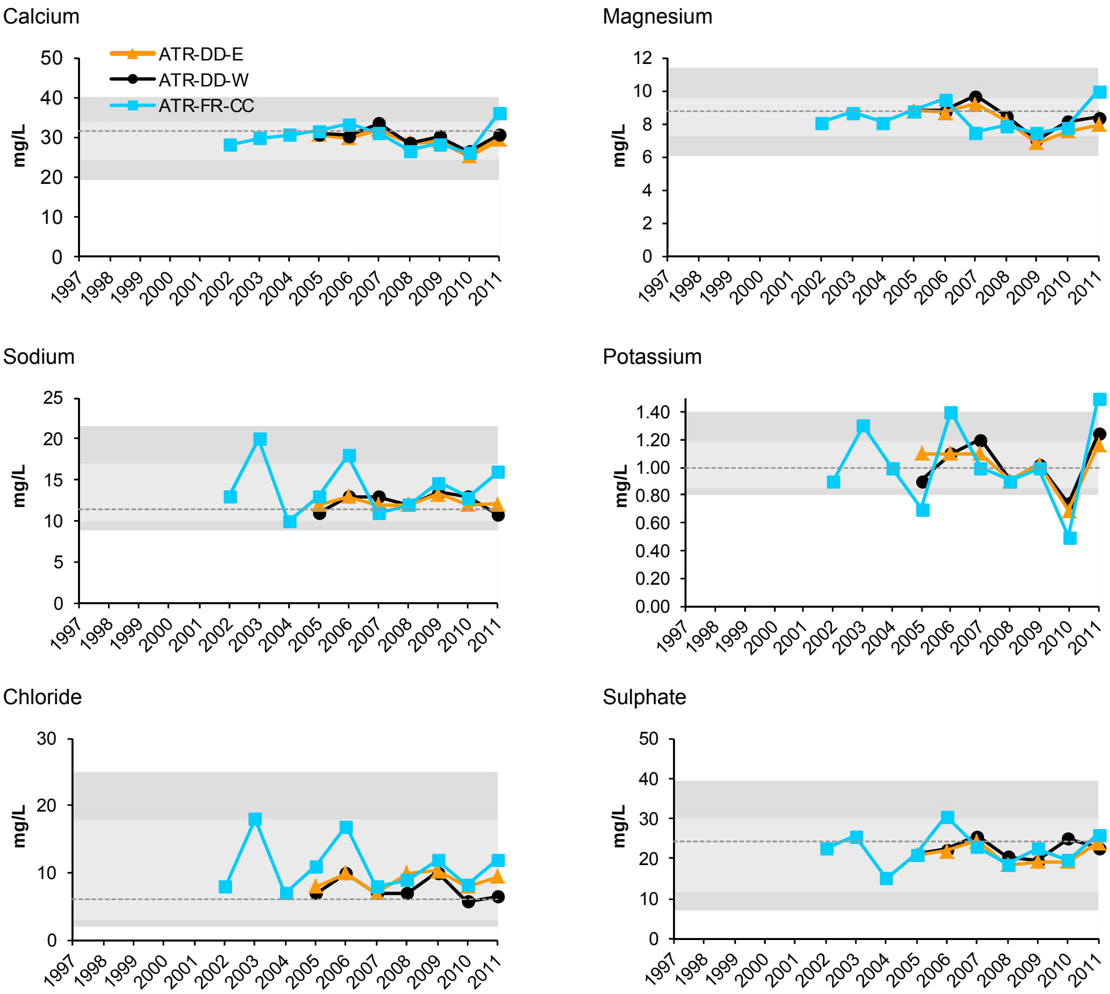
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O••••••O Sampled as a *baseline* station ●━━● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

[1] ATR-FR-CC sampled by RAMP (2003-2010); sampled by AEW from 2011 onward (2011 from AEW).

Figure 5.1-12 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O⋯⋯O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

[1] ATR-FR-CC sampled by RAMP (2003-2010); sampled by AEW from 2011 onward (2011 from AEW).

Table 5.1-6 Water quality index (fall 2011) for Athabasca River mainstem stations.

Station Identifier	Location	2011 Designation	Water Quality Index	Classification
ATR-DC-E	Upstream of Donald Creek, East Bank	*baseline*	94.9	Negligible-Low
ATR-DC-W	Upstream of Donald Creek, West Bank	*baseline*	96.2	Negligible-Low
ATR-SR-E	Upstream of the Steepbank River, East Bank	*test*	89.9	Negligible-Low
ATR-SR-W	Upstream of the Steepbank River, West Bank	*test*	95.0	Negligible-Low
ATR-MR-E	Upstream of the Muskeg River, East Bank	*test*	97.5	Negligible-Low
ATR-MR-W	Upstream of the Muskeg River, West Bank	*test*	79.5	Moderate
ATR-DD-E	Downstream of all development, East Bank	*test*	98.7	Negligible-Low
ATR-DD-W	Downstream of all development, West Bank	*test*	96.2	Negligible-Low

Table 5.1-7 Average habitat characteristics of benthic invertebrate community sampling locations of the Athabasca River Delta.

Variable	Units	Big Point Channel (BPC-1)	Fletcher Channel (FLC-1)	Goose Island Channel (GIC-1)	Embarras River (EMR-1)
Sample date	-	Sept. 3, 2011	Sept. 3, 2011	Sept. 3, 2011	Sept. 3, 2011
Habitat	-	Depositional	Depositional	Depositional	Depositional
Water depth	m	2.2	3.1	1.4	1.2
Current velocity	m/s	0.28	0.54	0.28	0.42
Field Water Quality					
Dissolved oxygen	mg/L	8.6	9.4	9.0	9.0
Conductivity	μS/cm	290	295	169	302
pH	pH units	8.0	6.7	8.0	7.9
Water temperature	°C	15.8	15.2	15.8	15.8
Sediment Composition					
Sand	%	71	78	39	99
Silt	%	20	14	47	<1
Clay	%	9	8	14	<1
Total Organic Carbon	%	0.9	0.7	1.4	0.1

Table 5.1-8 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in *test* reaches BPC-1 and FLC-1 of the Athabasca River Delta.

Taxon	Percent Major Taxa Enumerated in Each Year																
	Reach BPC-1								Reach FLC-1								
	2003	2004	2005	2007	2008	2009	2010	2011	2002	2003	2004	2005	2007	2008	2009	2010	2011
Nematoda	<1	<1	1	1	7	<1	<1	2	5	5	<1	<1	1	22	<1	<1	
Erpobdellidae		<1															
Naididae	1	<1	2	1	<1	7			<1	15	3		2	1	2		
Tubificidae	75	52	46	54	52	49	68	75	2	26	58	81	66	10	72	81	81
Hydracarina	<1				<1		<1					<1					
Amphipoda		<1	2				<1										
Ostracoda	<1	2	2	<1	<1	5	7		3	2	4	4	1	7	4	3	
Macrothricidae									<1			<1					
Copepoda				<1		1	1								<1	<1	
Gastropoda	4	<1	1	2	12	<1	<1		1	14	<1	2	1	1	2	<1	
Bivalvia	10	1	8	37	12	8	4	<1	1	13	3	3	2	1	2	6	<1
Ceratopogonidae	1	<1	7	1	1	2	1	<1	2	10	5	2	8	6	<1	5	<1
Chironomidae	6	40	31	3	11	23	11	18	86	13	27	4	18	52	11	4	13
Empididae					<1	4			<1								
Tabanidae										<1							
Tipulidae	<1							<1									
Ephemeroptera	<1	<1	1	<1			<1	2	<1	1	<1	<1	<1	<1			2
Anisoptera	<1	<1	<1	<1	<1		<1	<1		<1	<1	<1	<1				
Plecoptera				<1	<1		<1					<1					1
Trichoptera	1	2	1	1	4			2		<1	<1	2	1				2
Heteroptera	<1	<1								<1	<1						
Megaloptera		<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	17,760	11,897	8,328	27,207	10,843	13,055	20,696	27,801	118,413	5,874
Richness	11	12	10	15	12	11	14	10	12	11	9	10	11	12	10	12	5
Simpson's Diversity	0.42	0.59	0.63	0.54	0.73	0.68	0.53	0.39	0.53	0.78	0.56	0.33	0.52	0.66	0.47	0.35	0.29
Evenness	0.46	0.64	0.77	0.57	0.81	0.79	0.58	0.44	0.58	0.86	0.63	0.37	0.57	0.74	0.53	0.38	0.34
% EPT	1	2	1	1	19	0	<1	4	1	1	<1	3	<1	<1	0	0	6

Table 5.1-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in *test* reaches GLC-1, EMR-2, and EMR-1 of the Athabasca River Delta.

Taxon	Percent Major Taxa Enumerated in Each Year										
	Reach GIC-1									Reach EMR-2	Reach EMR-1
	2002	2003	2004	2005	2007	2008	2009	2010	2011	2010	2011
Nematoda	5		<1	2	2	1	<1	<1	<1	1	6
Oligochaeta											<1
Naididae			<1	7	2	<1	<1		<1	<1	
Tubificidae	<1	27	27	62	57	36	24	23	49	1	<1
Lumbriculidae		<1	<1								
Hydracarina	<1	<1		<1						<1	
Amphipoda									<1		
Ostracoda	1	9	3	8	9	2	13	39	<1	19	
Macrothricidae	<1	2		2							
Copepoda	<1			1		<1	2		<1	<1	
Gastropoda	5	11	<1	<1	1	24	1	4		<1	
Bivalvia	13	4	2	3	2	4	2	2	<1	29	
Ceratopogonidae	1	17	3	2	2	3	1	2	<1	4	
Chironomidae	74	28	64	13	24	27	55	30	49	41	81
Empididae							<1				
Tipulidae							<1				
Ephemeroptera			<1	<1		1	<1		<1	<1	10
Anisoptera	<1	<1	<1		<1	<1					
Trichoptera	<1				1	2			<1	3	
Heteroptera		<1									
Benthic Invertebrate Community Measurement Endpoints											
Total Abundance (No./m^2)	36,000	2,914	35,776	12,243	15,348	8,270	12,374	2,922	25,395	56,463	1,249
Richness	14	10	11	11	12	11	15	8	12	23	5
Simpson's Diversity	0.54	0.79	0.66	0.61	0.61	0.73	0.79	0.69	0.63	0.86	0.61
Evenness	0.58	0.89	0.73	0.67	0.67	0.84	0.85	0.79	0.69	0.90	0.76
% EPT	<1	0	<1	<1	1	2	<1	0	<1	3	10

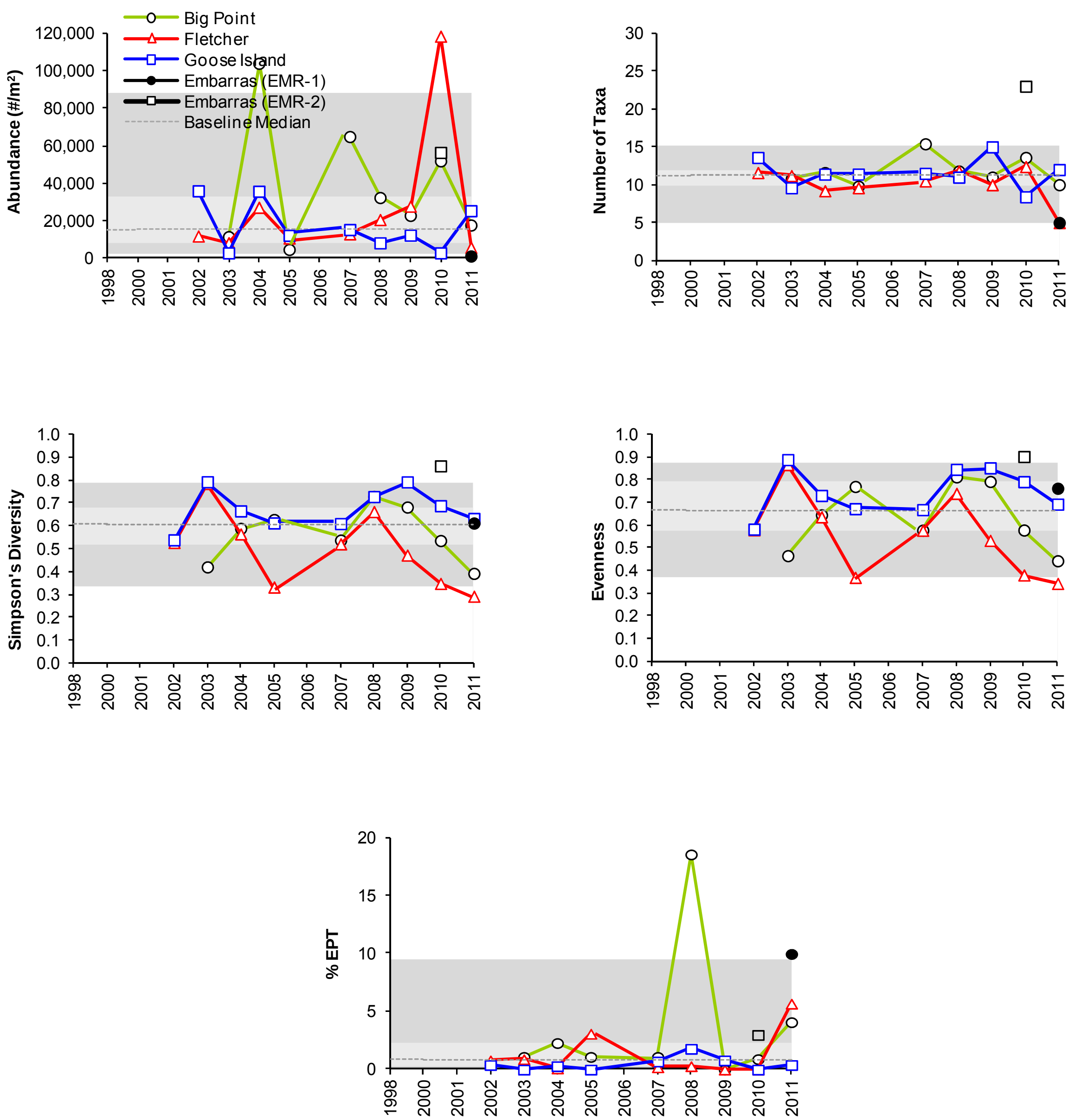
Table 5.1-10 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in Big Point Channel of the Athabasca River Delta.

Variable	P-value		Variance Explained (%)		Nature of Change(s)	Spearman Rank r_s
	Time Trend	2011 vs. Previous Years	Time Trend	2011 vs. Previous Years		
Abundance	0.785	0.236	0	4	No change	0.03
Richness	0.985	0.357	0	11	No change	0.03
Simpson's Diversity	0.859	**0.010**	0	36	Decrease in 2011 relative to average of previous years due to higher values in 2008 and 2009	-0.54
Evenness	0.814	**0.009**	0	30	Decrease in 2011 relative to average of previous years due to higher values in 2008 and 2009	-0.37
EPT	0.948	0.335	0	2	No change	0.06
CA Axis 1	0.957	0.603	0	1	No change	-0.31
CA Axis 2	0.139	0.267	15	8	No change	-0.20

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).

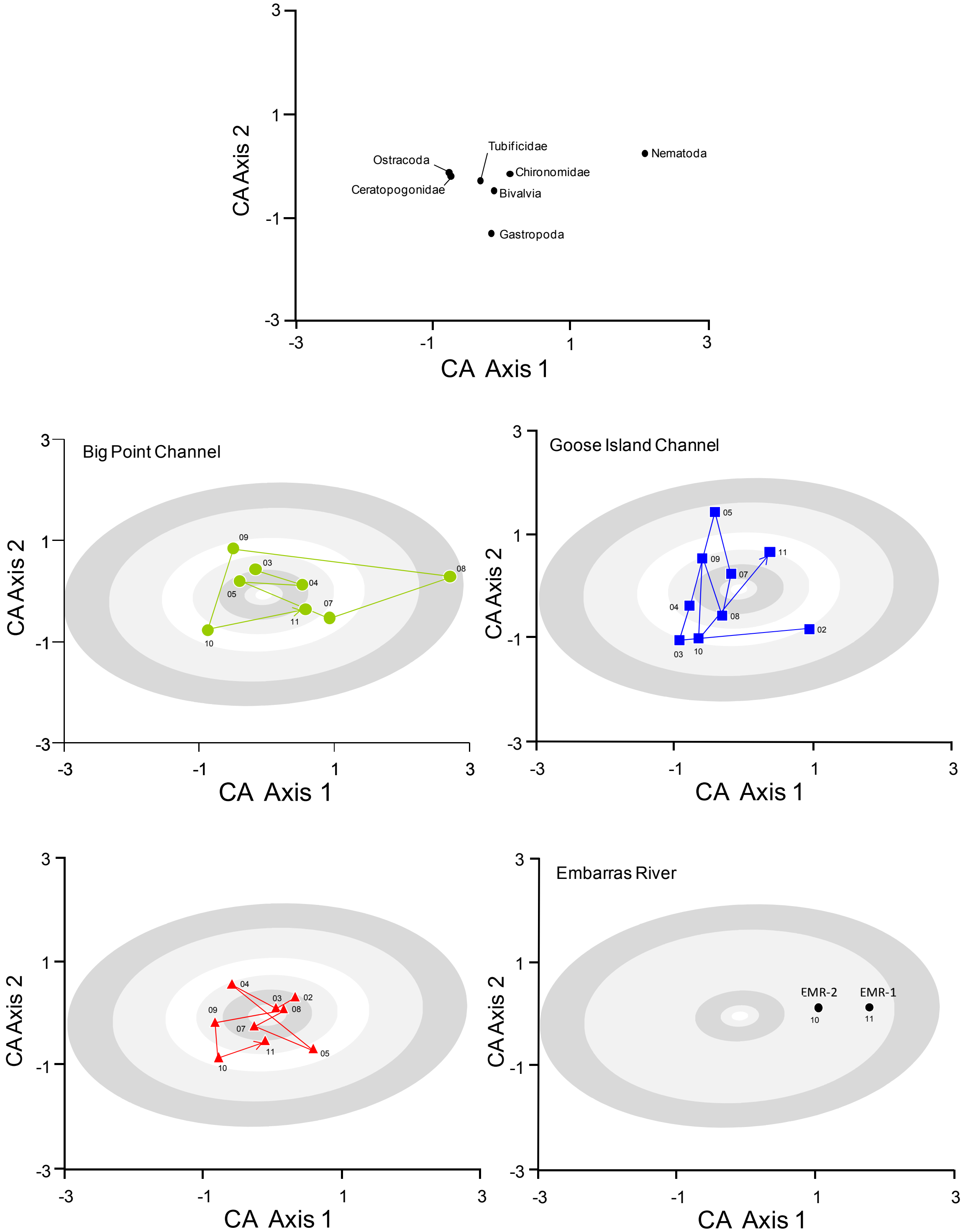
Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Figure 5.1-13 Variation in benthic invertebrate community measurement endpoints in the Athabasca River Delta, 2002 to 2011.



Note: Historical *baseline* values reflect pooled results for all ARD reaches prior to 2011.

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 four panels are the sample scores. The ellipses represent the range of CA axis scores that the four ARD reaches have produced from 1997 to 2010 and serves as a range of values against which to compare the 2011 data.

Table 5.1-11 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 Change(s)	Spearman Rank r_s
	Time Trend	2011 vs. Previous Years	Time Trend	2011 vs. Previous Years		
Abundance	0.344	**<0.001**	2	63	Lower in 2011 than previous years	0.14
Richness	**0.021**	**<0.001**	25	89	Lower in 2011 than previous years	0.14
Simpson's Diversity	**0.001**	**0.008**	36	24	Decreasing over time and 2011 was lower than previous years	0.43
Evenness	**0.001**	**0.010**	34	21	Decreasing over time and 2011 was lower than previous years	0.43
EPT	0.867	**0.022**	0	41	Higher in 2011 than previous years	-0.11
CA Axis 1	0.066	0.882	22	0	No change	0.03
CA Axis 2	0.053	0.387	45	9	No change	-0.26

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Table 5.1-12 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 Change(s)	Spearman Rank r_s
	Time Trend	2011 vs. Previous Years	Time Trend	2011 vs. Previous Years		
Abundance	0.061	0.082	8	7	No change	0.14
Richness	0.596	0.619	2	2	No change	-0.13
Simpson's Diversity	0.327	0.426	5	3	No change	-0.37
Evenness	0.227	0.314	6	4	No change	-0.37
EPT	0.530	0.779	6	1	No change	-0.23
CA Axis 1	0.682	**0.024**	1	17	Significant change in 2011 relative to previous years	-0.49
CA Axis 2	**0.049**	**0.035**	10	11	Significant change over time and in 2011 relative to previous years	-0.26

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Table 5.1-13 Concentrations of sediment quality measurement endpoints, Athabasca River mainstem upstream of Embarras River (ATR-ER).

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	0.5	10	8	13	22
Silt	%	-	0.5	10	8	32	42
Sand	%	-	99	10	36	57	84
Total organic carbon	%	-	<0.1	10	0.6	1.1	1.7
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	6	11	22	39
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	6	76	240	**570**
Fraction 4 (C34-C50)	mg/kg	2800[1]	24	6	72	185	340
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0005	10	0.0046	0.0079	**0.0370**
Retene	mg/kg	-	0.0024	10	0.0165	0.0456	0.0810
Total dibenzothiophenes	mg/kg	-	0.0115	10	0.0915	0.2293	0.7489
Total PAHs	mg/kg	-	0.0753	10	0.6095	1.1410	2.4820
Total Parent PAHs	mg/kg	-	0.0054	10	0.0422	0.0997	0.1561
Total Alkylated PAHs	mg/kg	-	0.0699	10	0.5672	1.0597	2.3550
Predicted PAH toxicity[3]	H.I.	1.0	0.34	10	0.40	0.97	**1.50**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.4	6	3.4	7.7	8.6
Chironomus growth - 10d	mg/organism	-	1.95	6	1.15	2.09	3.50
Hyalella survival - 14d	# surviving	-	6.8	6	7.0	9.3	10.0
Hyalella growth - 14d	mg/organism	-	0.29	6	0.05	0.22	0.288

Values in **bold** indicate concentrations exceeding guidelines.

Values underlined indicate concentrations outside the range of historical observations.

[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 5.1-14 Concentrations of sediment quality measurement endpoints, Big Point Channel (BPC-1).

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	9	9	10	20	32
Silt	%	-	20	9	26	50	58
Sand	%	-	71	9	10	36	64
Total organic carbon	%	-	0.9	9	<0.1	1.2	2.2
Total hydrocarbons							
BTEX	mg/kg	-	<10	5	<5	<5	<21
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	5	<5	<5	<21
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	5	<5	<21	23
Fraction 3 (C16-C34)	mg/kg	300[1]	178	5	110	190	**307**
Fraction 4 (C34-C50)	mg/kg	2800[1]	156	5	33	100	199
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0057	9	0.0050	0.0094	0.0240
Retene	mg/kg	-	0.0346	9	0.0410	0.0527	0.0957
Total dibenzothiophenes	mg/kg	-	0.1610	9	0.1500	0.2714	0.3582
Total PAHs	mg/kg	-	1.0651	9	1.0454	1.3737	2.0275
Total Parent PAHs	mg/kg	-	0.0772	9	0.0963	0.1073	0.2086
Total Alkylated PAHs	mg/kg	-	0.9879	9	0.9448	1.2680	1.8792
Predicted PAH toxicity[3]	H.I.	1.0	0.85	9	0.83	**1.28**	**2.59**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.8	8	3.2	7.3	9.0
Chironomus growth - 10d	mg/organism	-	2.37	8	0.89	1.76	3.60
Hyalella survival - 14d	# surviving	-	8.2	8	6.6	8.0	9.0
Hyalella growth - 14d	mg/organism	-	0.34	8	0.05	0.11	0.21

Values in **bold** indicate concentrations exceeding guidelines.

Values underlined indicate concentrations outside the range of historic observations.

[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 5.1-15 Concentrations of sediment quality measurement endpoints, Fletcher Channel (FLC-1).

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>8</u>	8	10	15	23
Silt	%	-	<u>14</u>	8	18	40	72
Sand	%	-	<u>79</u>	8	11	45	70
Total organic carbon	%	-	0.7	8	0.6	1.3	2.2
Total hydrocarbons							
BTEX	mg/kg	-	<10	5	<5	10	30
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	5	<5	10	30
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	5	<5	23	30
Fraction 3 (C16-C34)	mg/kg	300[1]	106	5	68	290	430
Fraction 4 (C34-C50)	mg/kg	2800[1]	90	5	49	170	280
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0021</u>	7	0.0031	0.0094	0.0156
Retene	mg/kg	-	0.0240	8	0.0197	0.0452	0.1050
Total dibenzothiophenes	mg/kg	-	<u>0.1112</u>	8	0.1324	0.2224	0.5913
Total PAHs	mg/kg	-	0.6893	8	0.5939	1.2468	2.7446
Total Parent PAHs	mg/kg	-	0.0488	8	0.0477	0.1047	0.1596
Total Alkylated PAHs	mg/kg	-	0.6406	8	0.5461	1.1421	2.6147
Predicted PAH toxicity[3]	H.I.	1.0	0.90	8	0.49	0.84	**5.36**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.8	6	3.4	6.0	9.4
Chironomus growth - 10d	mg/organism	-	2.29	6	1.29	2.31	3.60
Hyalella survival - 14d	# surviving	-	8.2	6	8.0	9.0	9.6
Hyalella growth - 14d	mg/organism	-	<u>0.34</u>	6	0.10	0.15	0.29

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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 5.1-16 Concentrations of sediment quality measurement endpoints, Goose Island Channel (GIC-1).

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	14	8	2	18	28
Silt	%	-	47	8	9	49	58
Sand	%	-	39	8	17	31	89
Total organic carbon	%	-	1.4	8	0.5	1.6	2.4
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	<5	17	<20
Fraction 3 (C16-C34)	mg/kg	300[1]	145	5	39	216	**360**
Fraction 4 (C34-C50)	mg/kg	2800[1]	108	5	46	110	200
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0057	8	0.0038	0.0084	0.0146
Retene	mg/kg	-	0.0710	8	0.0058	0.0392	0.0781
Total dibenzothiophenes	mg/kg	-	0.2190	8	0.0426	0.2302	0.4120
Total PAHs	mg/kg	-	1.5190	8	0.2942	1.2376	2.1614
Total Parent PAHs	mg/kg	-	0.1098	8	0.0213	0.1158	0.1771
Total Alkylated PAHs	mg/kg	-	1.4092	8	0.2729	1.1218	1.9843
Predicted PAH toxicity[3]	H.I.	1.0	**<u>1.58</u>**	8	0.80	**1.03**	**1.26**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.6	6	4.0	7.5	8.4
Chironomus growth - 10d	mg/organism	-	2.01	6	1.34	2.13	4.20
Hyalella survival - 14d	# surviving	-	8.0	6	7.0	9.0	10.0
Hyalella growth - 14d	mg/organism	-	0.28	6	0.10	0.14	0.30

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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 5.1-17 Concentrations of sediment quality measurement endpoints, Embarras River (EMR-1).

Variables	Units	Guideline	September 2011	September 2005
			Value	Value
Physical variables				
Clay	%	-	0.1	19
Silt	%	-	0.3	46
Sand	%	-	99.5	35
Total organic carbon	%	-	<0.1	1.7
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]	<20	22
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	360
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	240
Polycyclic Aromatic Hydrocarbons (PAHs)				
Naphthalene	mg/kg	0.0346[2]	0.0003	0.0125
Retene	mg/kg	-	0.0040	0.0729
Total dibenzothiophenes	mg/kg	-	0.0056	0.2892
Total PAHs	mg/kg	-	0.0541	1.5632
Total Parent PAHs	mg/kg	-	0.0043	0.1262
Total Alkylated PAHs	mg/kg	-	0.0498	1.4370
Predicted PAH toxicity[3]	H.I.	1.0	0.26	0.73
Metals that exceed CCME guidelines in 2011				
none	mg/kg			
Chronic toxicity				
Chironomus survival - 10d	# surviving	-	8	-
Chironomus growth - 10d	mg/organism	-	3.91	-
Hyalella survival - 14d	# surviving	-	7.2	-
Hyalella growth - 14d	mg/organism	-	0.29	-

Values in **bold** indicate concentrations exceeding guidelines.

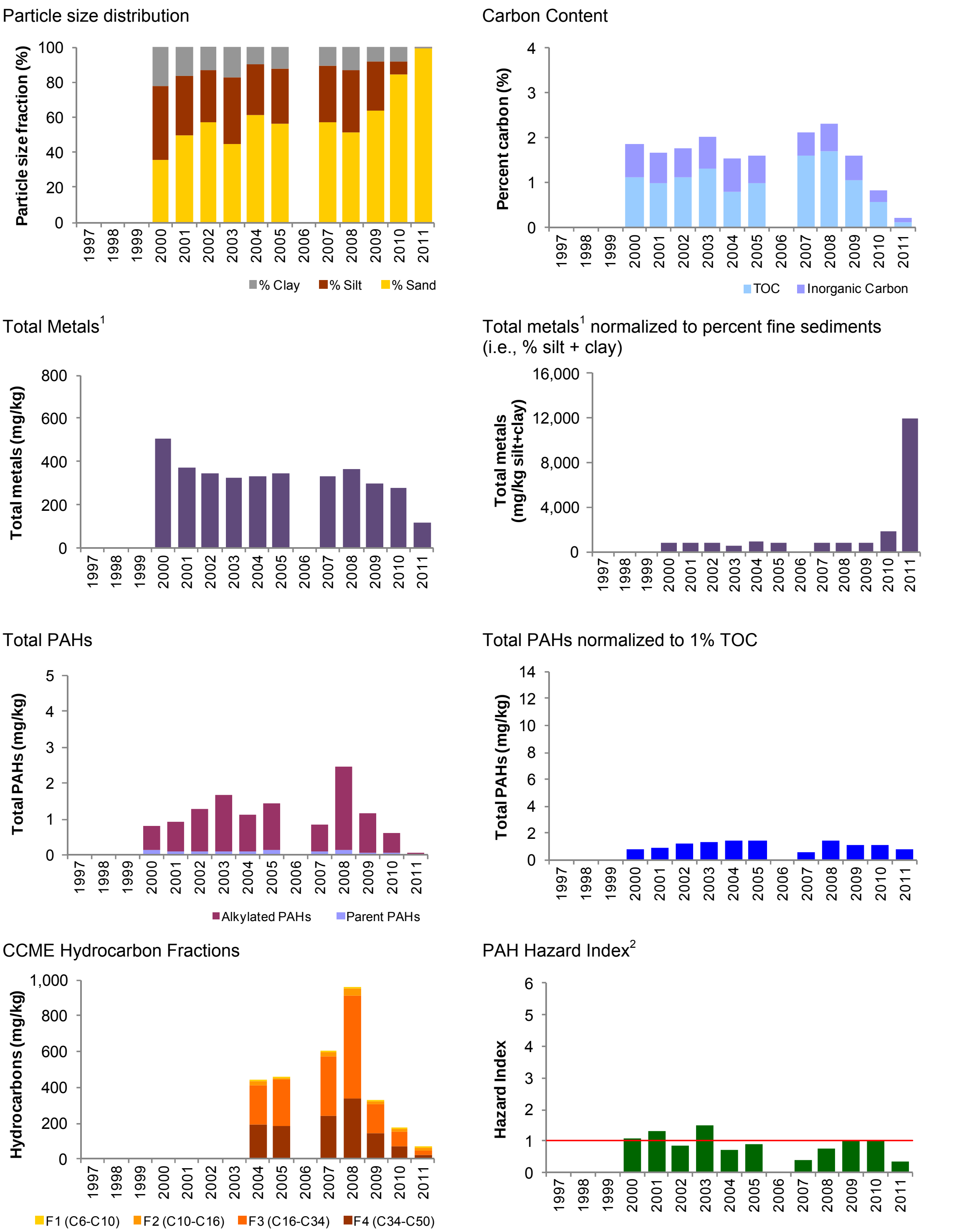
Values underlined indicate concentrations outside the range of historic observations.

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.

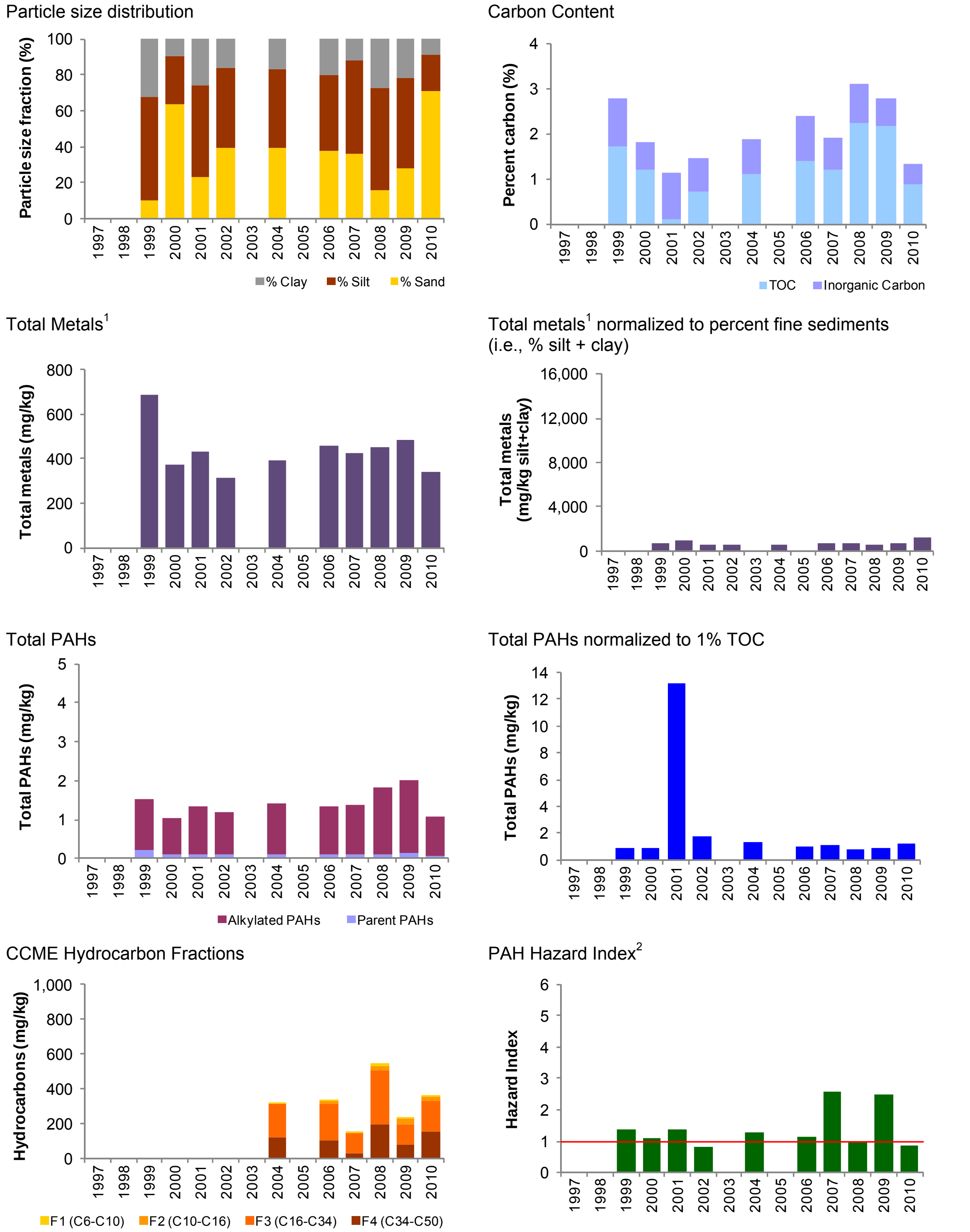
Figure 5.1-15 Characteristics of sediment collected in the Athabasca River upstream of Embarras River (ATR-ER), 2000 to 2011 (fall data only).



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red line indicates potential chronic effects level (HI = 1.0).

Figure 5.1-16 Characteristics of sediment collected in Big Point Channel (BPC-1), 1999-2011 (fall data only).

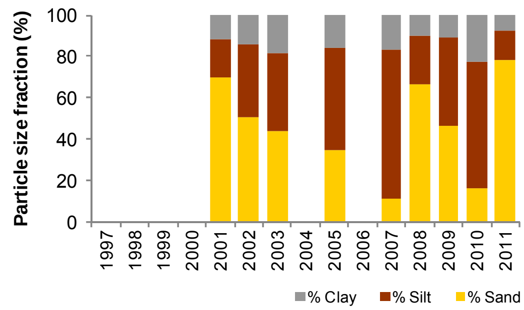


[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

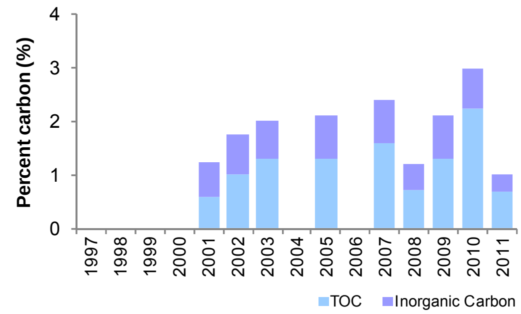
[2] Red line indicates potential chronic effects level (HI = 1.0).

Figure 5.1-17 Characteristics of sediment collected in Fletcher Channel (FLC-1), 2001 to 2011 (fall data only).

Particle size distribution

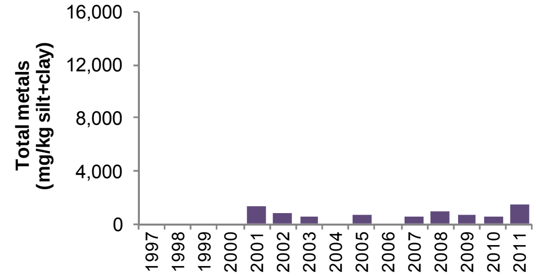


Carbon Content

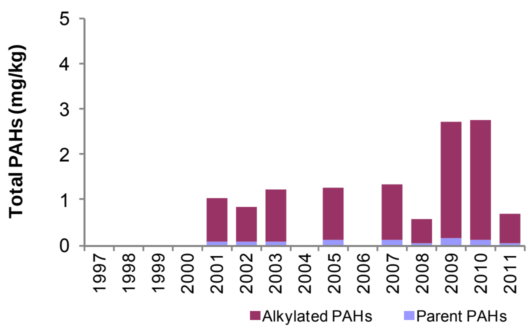


Total Metals[1]

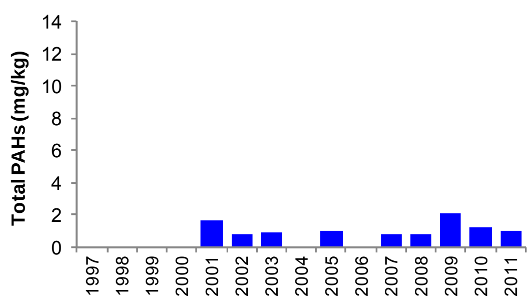
Total metals[1] normalized to percent fine sediments (i.e., % silt + clay)



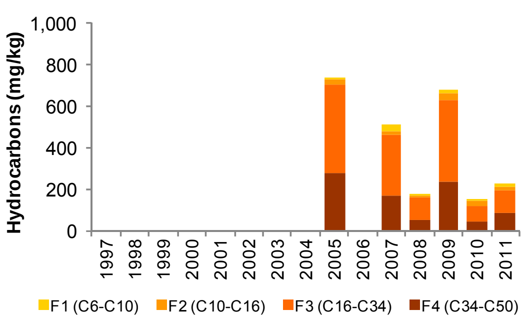
Total PAHs



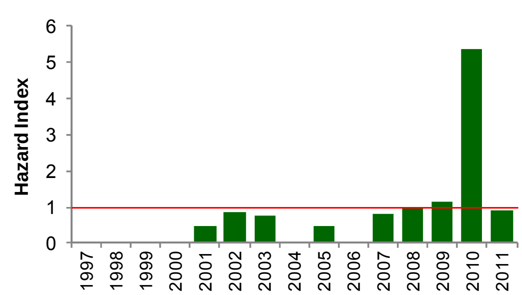
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



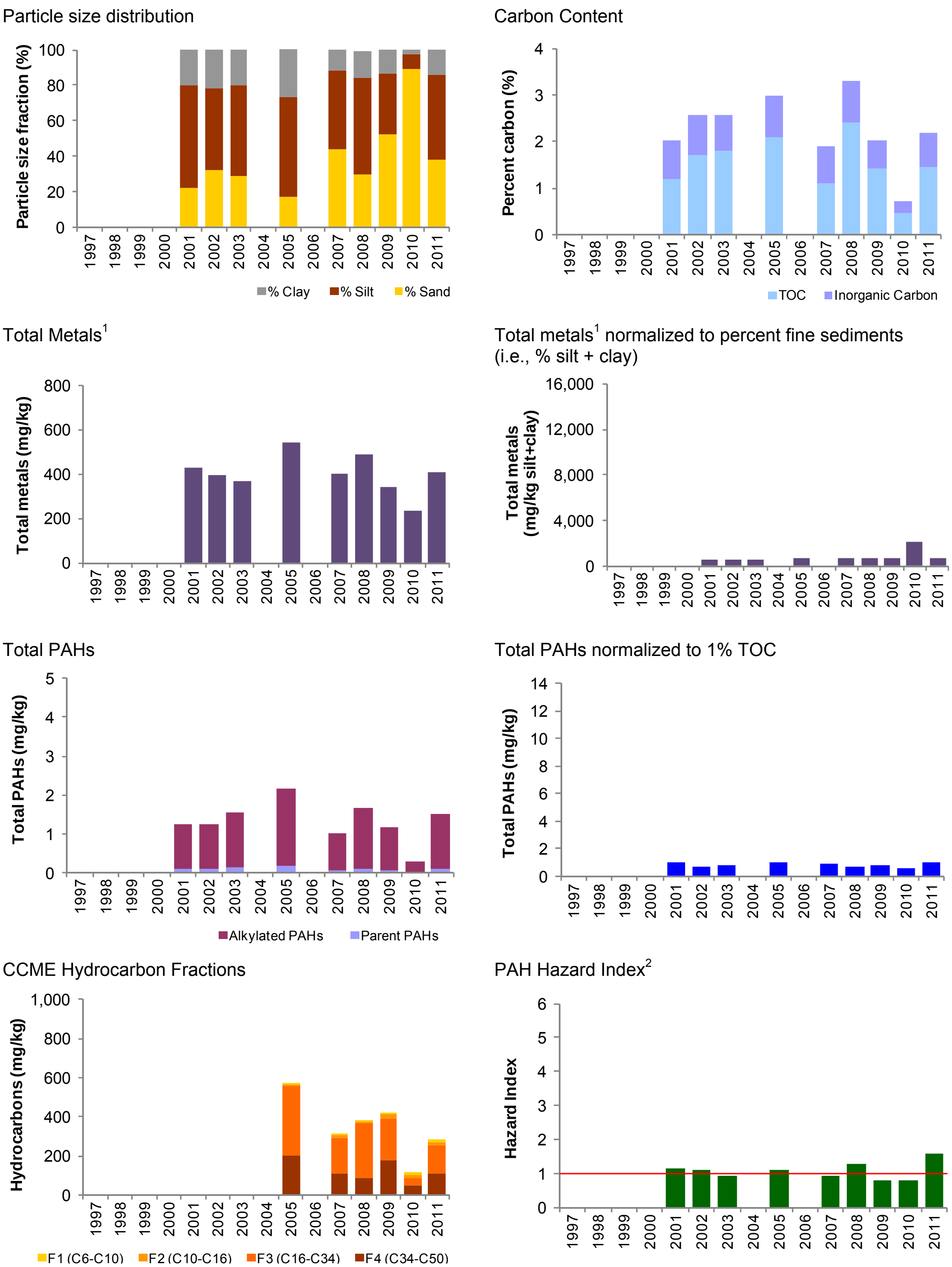
PAH Hazard Index[2]



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red line indicates potential chronic effects level (HI = 1.0).

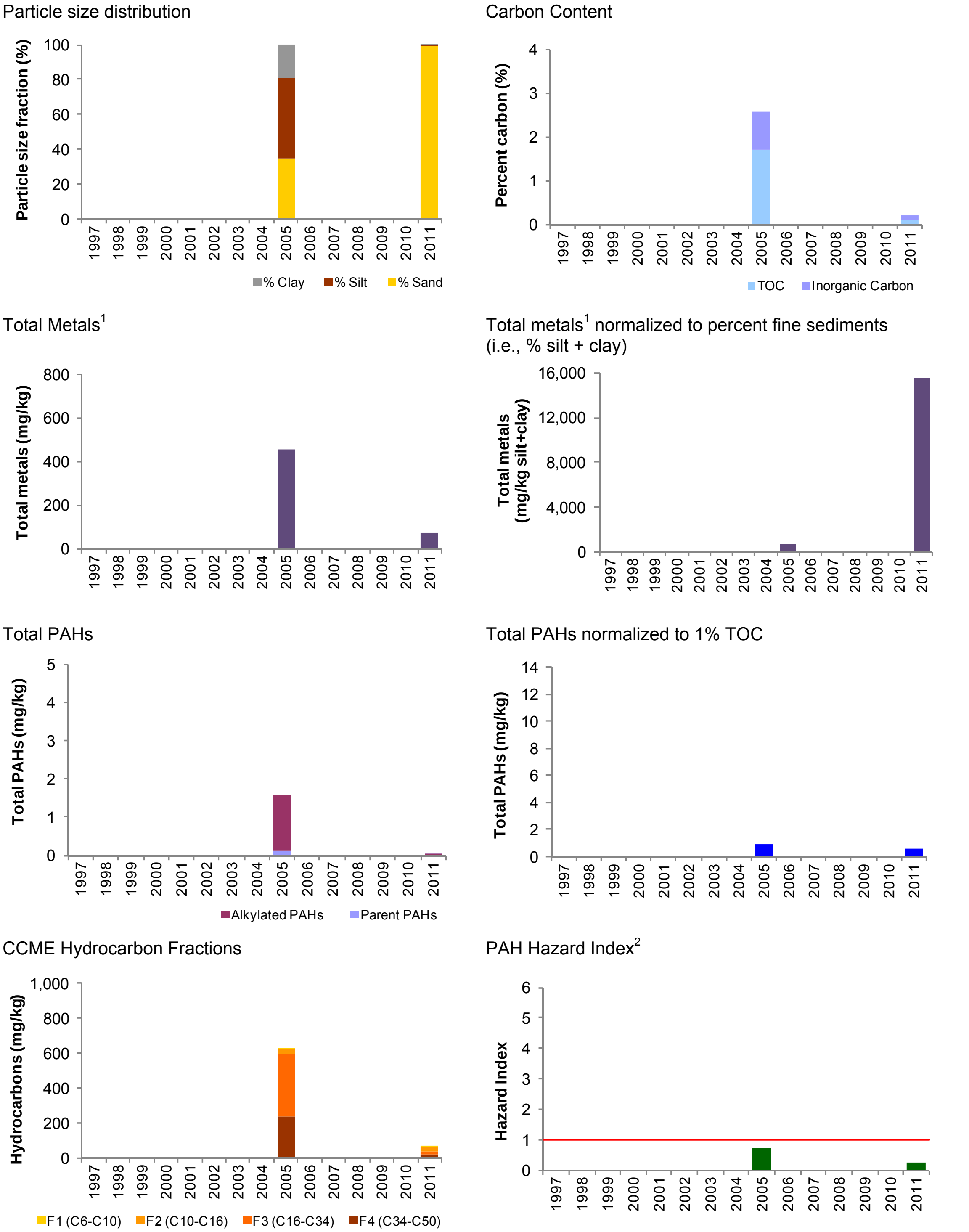
Figure 5.1-18 Characteristics of sediment collected in Goose Island Channel (GIC-1), 2001 to 2011 (fall data only).



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red line indicates potential chronic effects level (HI = 1.0).

Figure 5.1-19 Characteristics of sediment collected in the Embarras River (EMR-1), 2005 and 2011 (fall data only).



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red 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 2011.

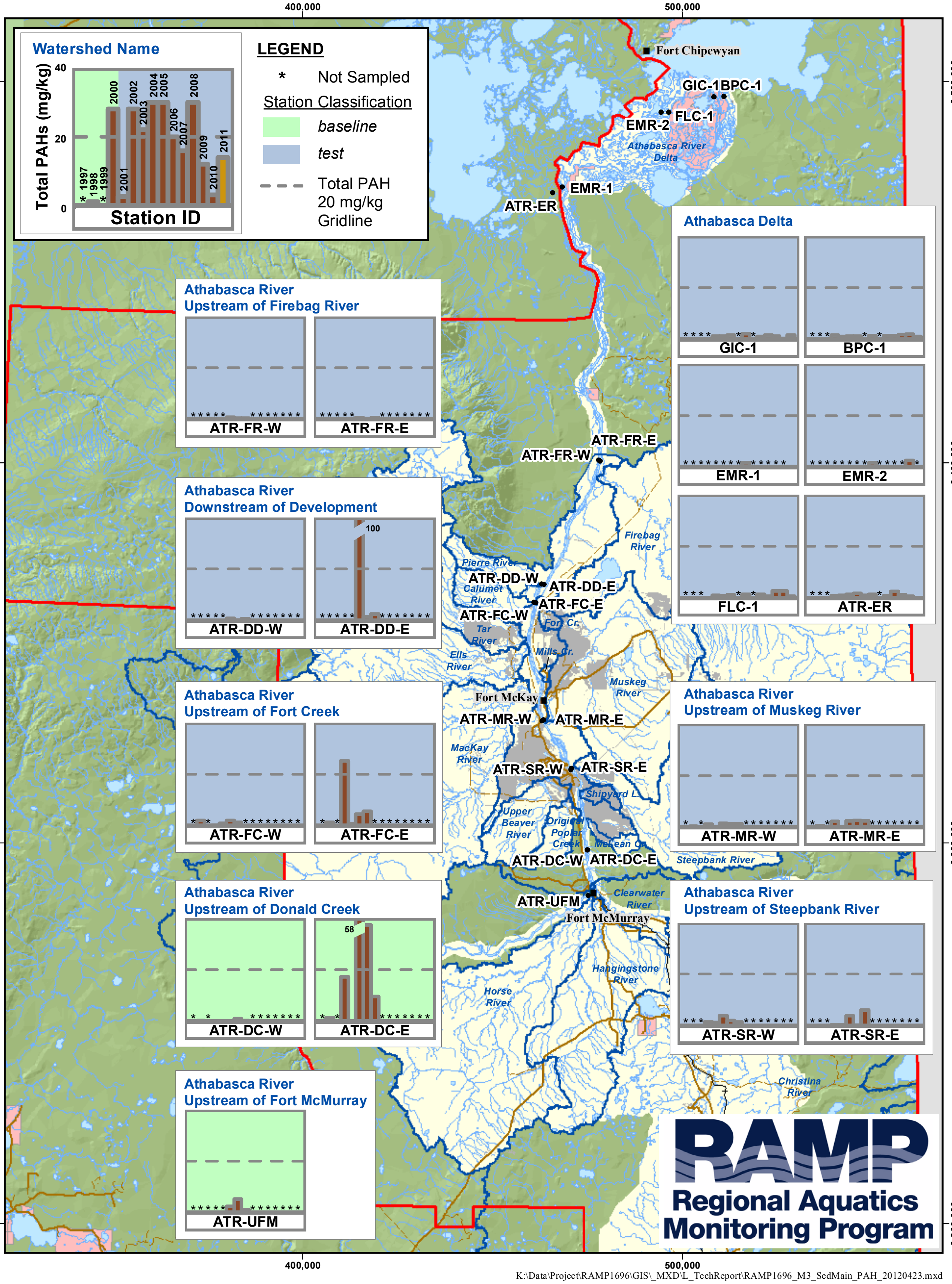


Figure 5.1-21 Carbon-normalized concentrations of total PAHs in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2011.

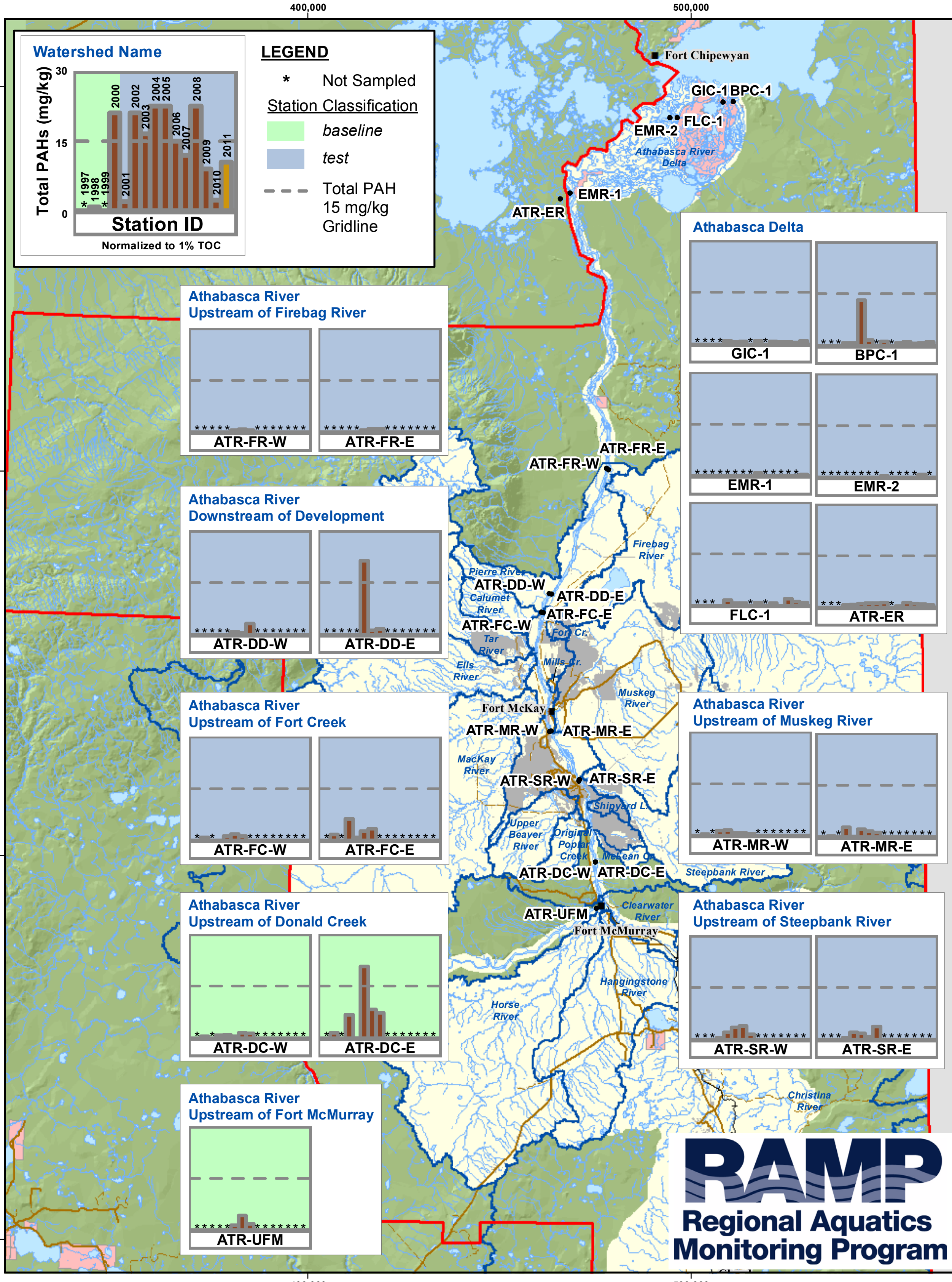


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Figure 5.1-22 Concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2011.

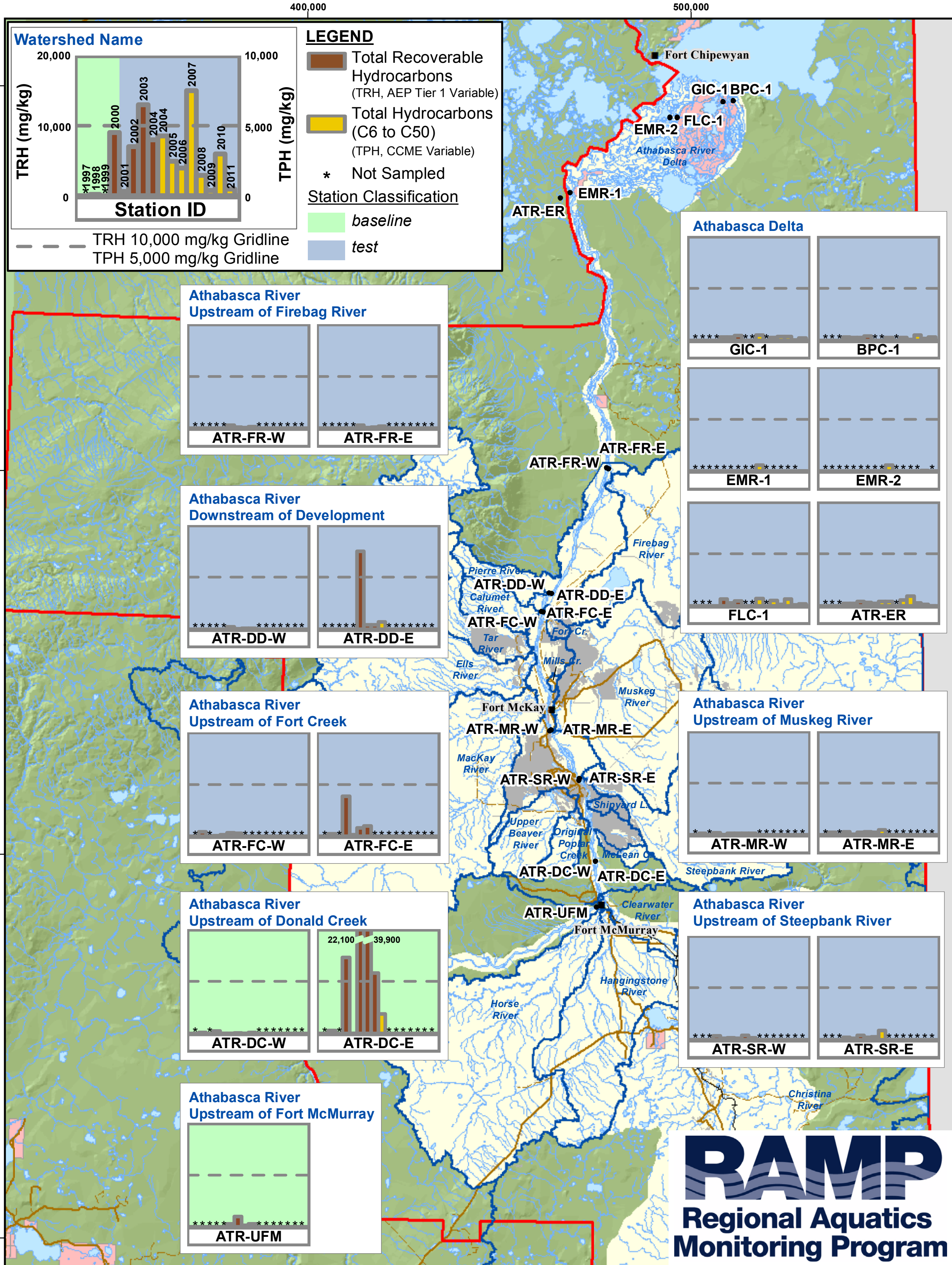

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Figure 5.1-23 Carbon-normalized concentrations of total hydrocarbons in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2011.

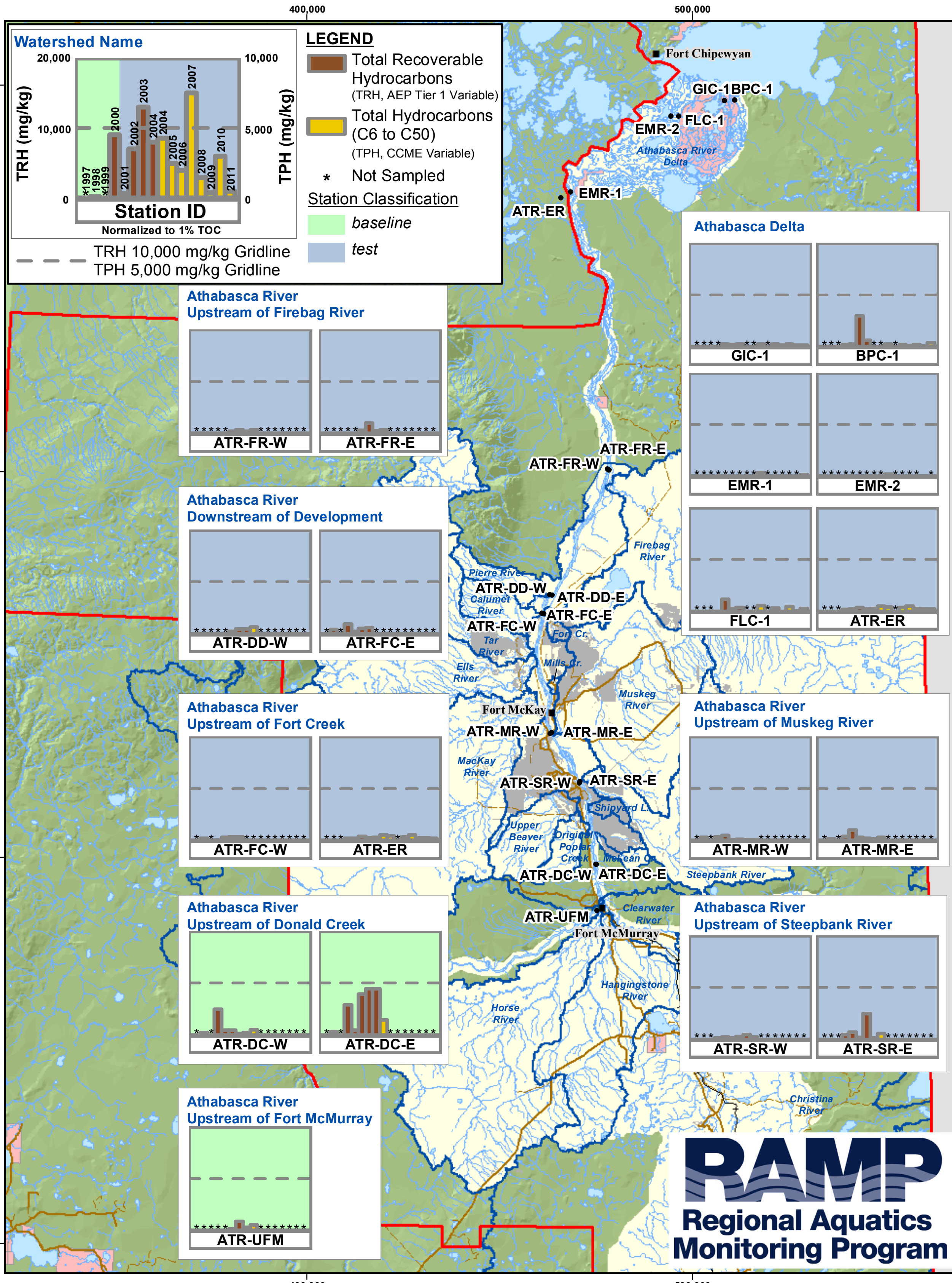

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Figure 5.1-24 Concentrations of total arsenic in sediments sampled by RAMP, Athabasca River mainstem and delta, 1997 to 2011.

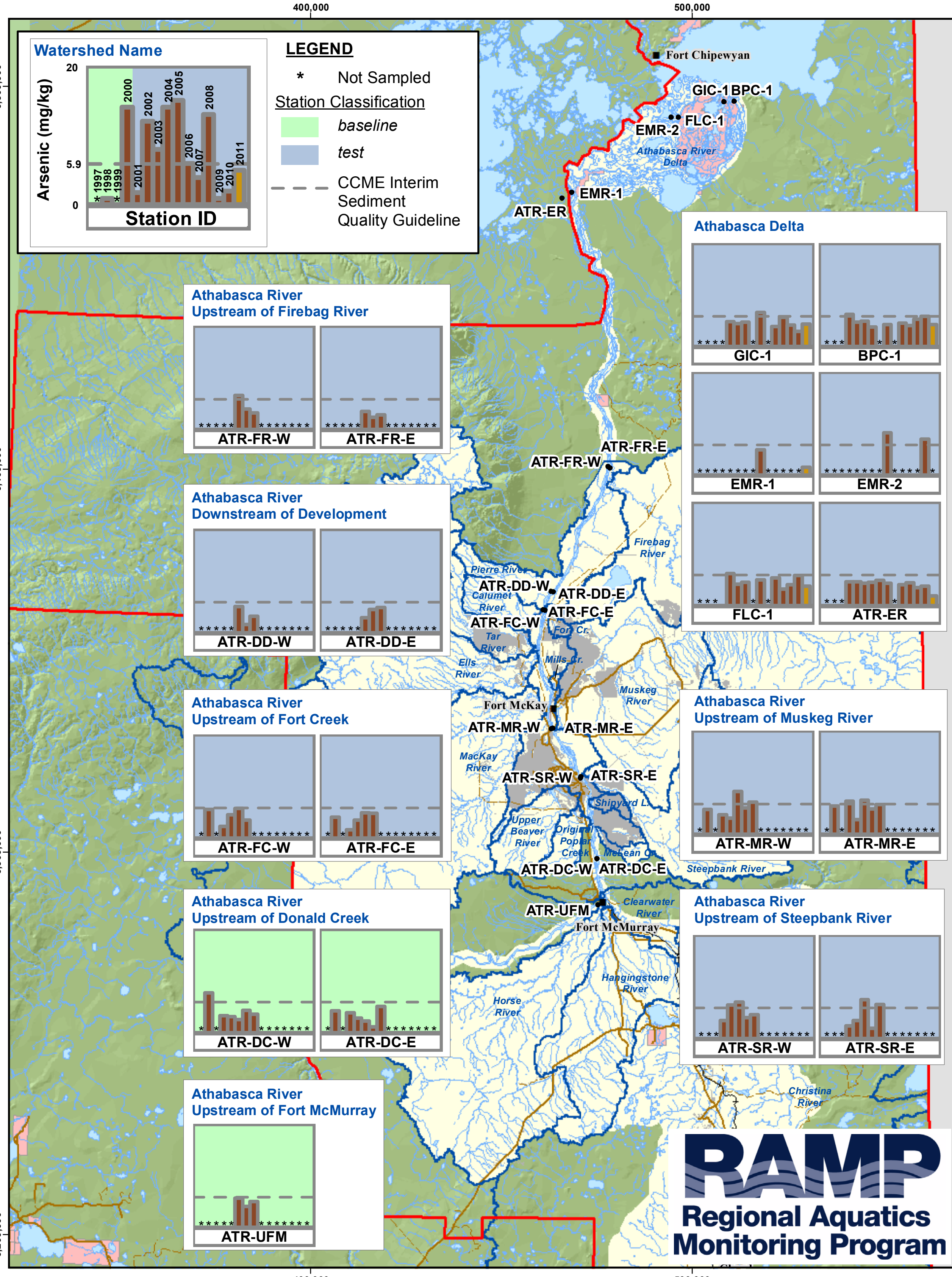

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Table 5.1-18 Total number and percent composition of species in the Athabasca River captured during the spring, summer, and fall fish inventories, 2011.

Species	Spring		Summer		Fall	
	No.	%	No.	%	No.	%
Arctic grayling	-	-	-	-	5	0.16
burbot	7	0.40	5	0.67	1	0.03
emerald shiner	9	0.52	66	8.85	221	7.20
flathead chub	79	4.56	28	3.75	270	8.80
finescale dace	1	0.06	1	0.13	-	-
goldeye*	275	15.89	56	7.51	1,201	39.13
lake chub	1	0.06	36	4.83	6	0.20
lake whitefish*	4	0.23	5	0.67	372	12.12
longnose dace	-	-	2	0.27	-	-
longnose sucker*	37	2.14	42	5.63	66	2.15
mountain whitefish	13	0.75	-	-	5	0.16
northern pike*	27	1.56	13	1.74	26	0.85
pearl dace	2	0.12	-	-	12	0.39
slimy sculpin	9	0.52	1	0.13	2	0.07
spoonhead sculpin	-	-	1	0.13	4	0.13
spottail shiner	-	-	4	0.54	10	0.33
trout-perch*	625	36.11	312	41.82	596	19.42
walleye*	354	20.45	143	19.17	153	4.99
white sucker*	288	16.64	31	4.16	105	3.42
yellow perch	-	-	-	-	14	0.46
Total Count	**1,731**	**100**	**746**	**100**	**3,069**	**100**

* Key Indicator Resource (KIR) species

Table 5.1-19 Percent composition of species in the Athabasca River captured in each area during the spring, summer, and fall fish inventories, 2011.

Species	Spring						Summer						Fall					
	U/S of Fort McMurray	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet	U/S of Fort McMurray	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet	U/S of Fort McMurray	Poplar	Steepbank	Muskeg	Tar-Ells	Fort-Calumet
Arctic grayling	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7	0.3	-	-	-
burbot	2.6	0.3	-	-	0.4	0.5	6.2	-	1.2	-	-	-	-	-	-	0.2	-	-
emerald shiner	-	-	2.4	0.3	-	0.2	-	3.4	11.5	4.9	18.1	12.2	-	0.7	1.7	0.8	7.2	22.6
flathead chub	1.8	2.0	7.7	2.0	4.3	7.0	9.2	3.4	3.5	2.2	1.5	6.1	44.8	10.0	5.8	6.7	10.5	6.1
finescale dace	-	-	-	-	0.4	-	-	-	-	-	-	0.7	-	-	-	-	-	-
goldeye*	10.5	20.5	24.2	18.8	13.3	7.9	6.2	8.0	15.0	7.1	6.0	5.4	26.9	14.8	44.5	47.4	42.4	37.4
lake chub	-	-	-	-	-	0.2	-	-	2.3	4.0	15.0	3.4	0.7	0.3	0.2	0.4	-	-
lake whitefish*	-	0.3	1.0	-	-	-	-	2.3	1.2	-	0.8	0.7	2.1	28.7	9.4	20.5	5.1	8.2
longnose dace	-	-	-	-	-	-	-	2.3	-	-	-	-	-	-	-	-	-	-
longnose sucker*	6.1	3.6	3.0	1.3	0.7	0.9	30.8	4.6	12.6	0.9	1.5	2.0	10.3	2.9	2.5	1.0	0.6	1.30
mountain whitefish	-	0.7	3.0	0.7	-	-	-	-	-	-	-	-	-	0.3	0.2	-	0.6	-
northern pike*	-	4.0	0.7	1.0	0.7	1.9	-	1.1	1.2	2.2	1.5	2.7	0.7	1.6	0.9	0.6	1.5	0.39
pearl dace	-	-	0.3	0.3	-	-	-	-	-	-	-	-	-	0.7	0.3	-	0.6	0.65
slimy sculpin	0.9	-	0.3	0.3	0.4	1.2	-	-	-	-	-	0.7	0.7	-	0.1	-	-	-
spoonhead sculpin	-	-	-	-	-	-	1.5	-	-	-	-	-	-	0.7	0.2	-	-	-
spottail shiner	-	-	-	-	-	-	-	1.1	-	-	2.3	-	-	-	0.4	-	-	0.78
trout-perch*	3.5	39.9	34.2	17.9	40.7	53.4	15.4	34.1	28.7	65.3	30.1	40.5	9.0	27.7	22.8	10.6	23.0	18.16
walleye*	70.2	22.8	21.1	14.0	14.4	13.7	24.6	36.4	16.1	10.2	19.6	21.6	2.8	6.8	5.3	7.3	6.9	1.95
white sucker*	4.4	5.9	2.0	43.5	24.8	13.0	6.2	3.4	6.9	3.1	3.8	4.1	2.1	2.6	5.0	4.4	1.8	2.1
yellow perch	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	0.4	0.2	-	0.5
Total # of species	**8**	**10**	**12**	**11**	**10**	**11**	**8**	**11**	**11**	**9**	**11**	**12**	**10**	**15**	**17**	**12**	**11**	**12**
Total Count	**114**	**303**	**298**	**308**	**278**	**431**	**65**	**88**	**87**	**225**	**133**	**148**	**145**	**310**	**987**	**521**	**335**	**771**

* Key Indicator Resource (KIR) species

Figure 5.1-25 Number of species captured in each sampling area of the Athabasca River captured during the spring, summer and fall fish inventories, 2009 to 2011.

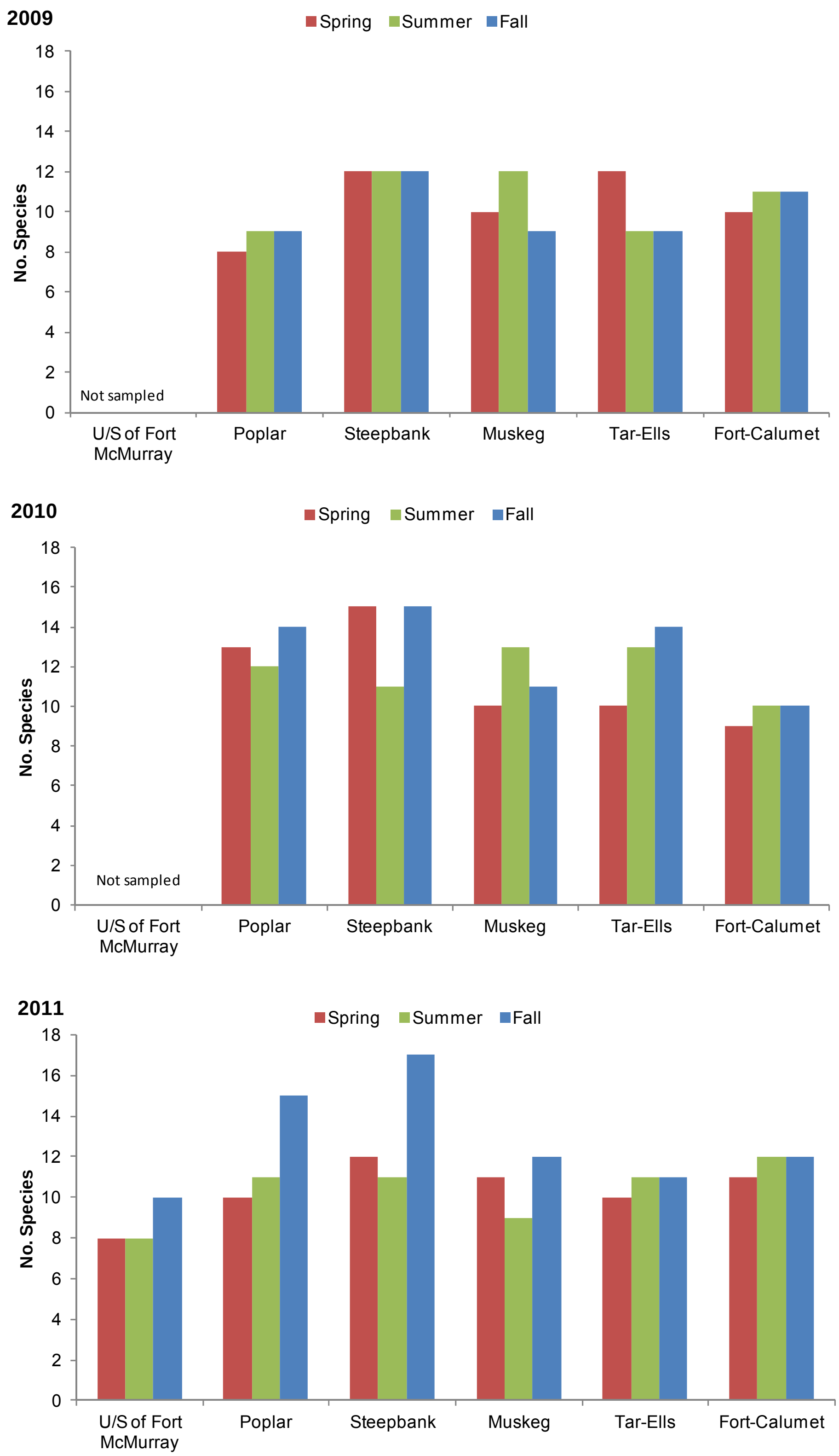


Figure 5.1-26 Species richness and total catch in the Athabasca River during spring, summer and fall fish inventories, 1987 to 2011.

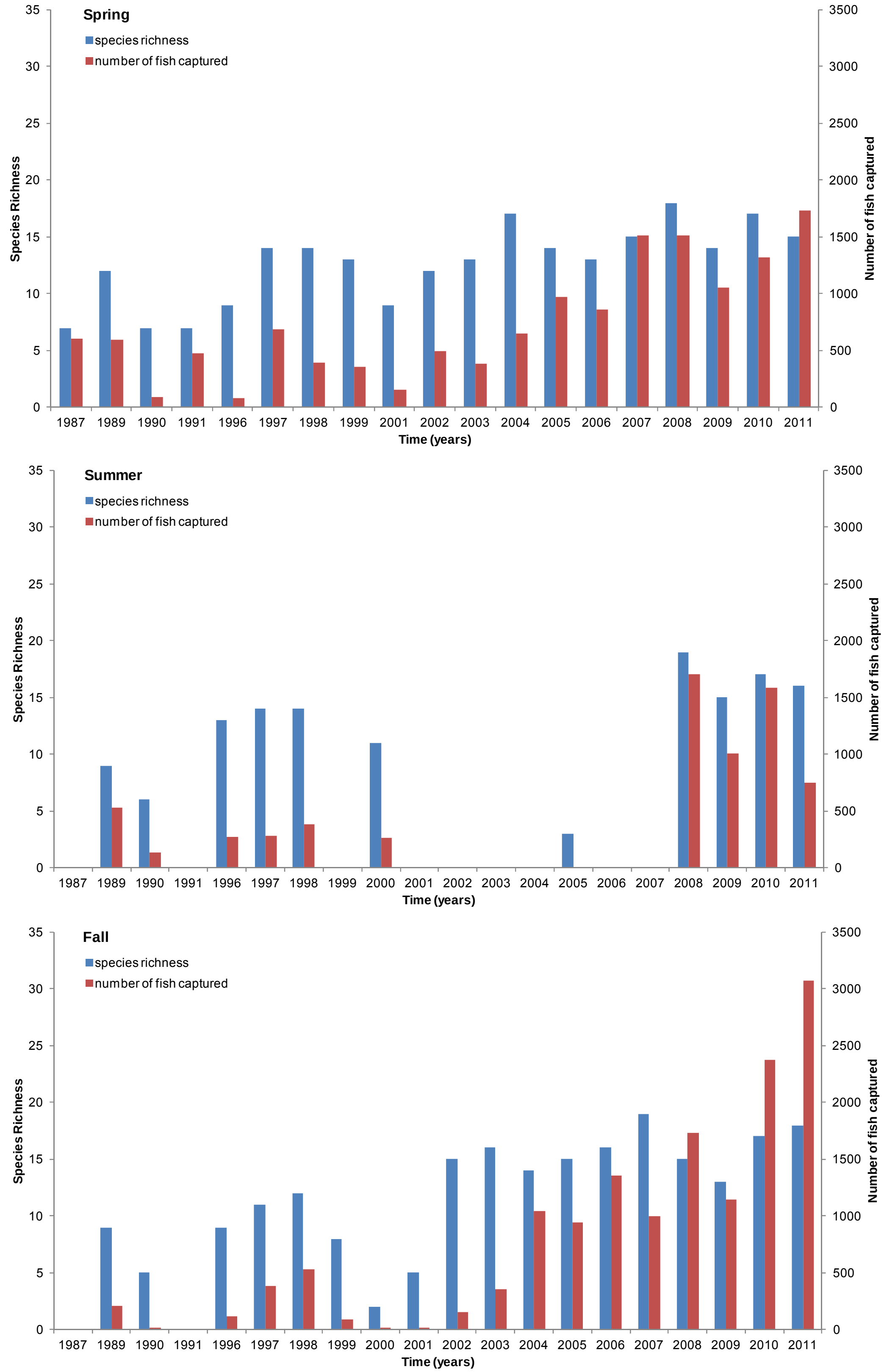


Figure 5.1-27 Percent composition of large-bodied KIR species caught during the Athabasca River spring, summer and fall fish inventories, 1987 to 2011.

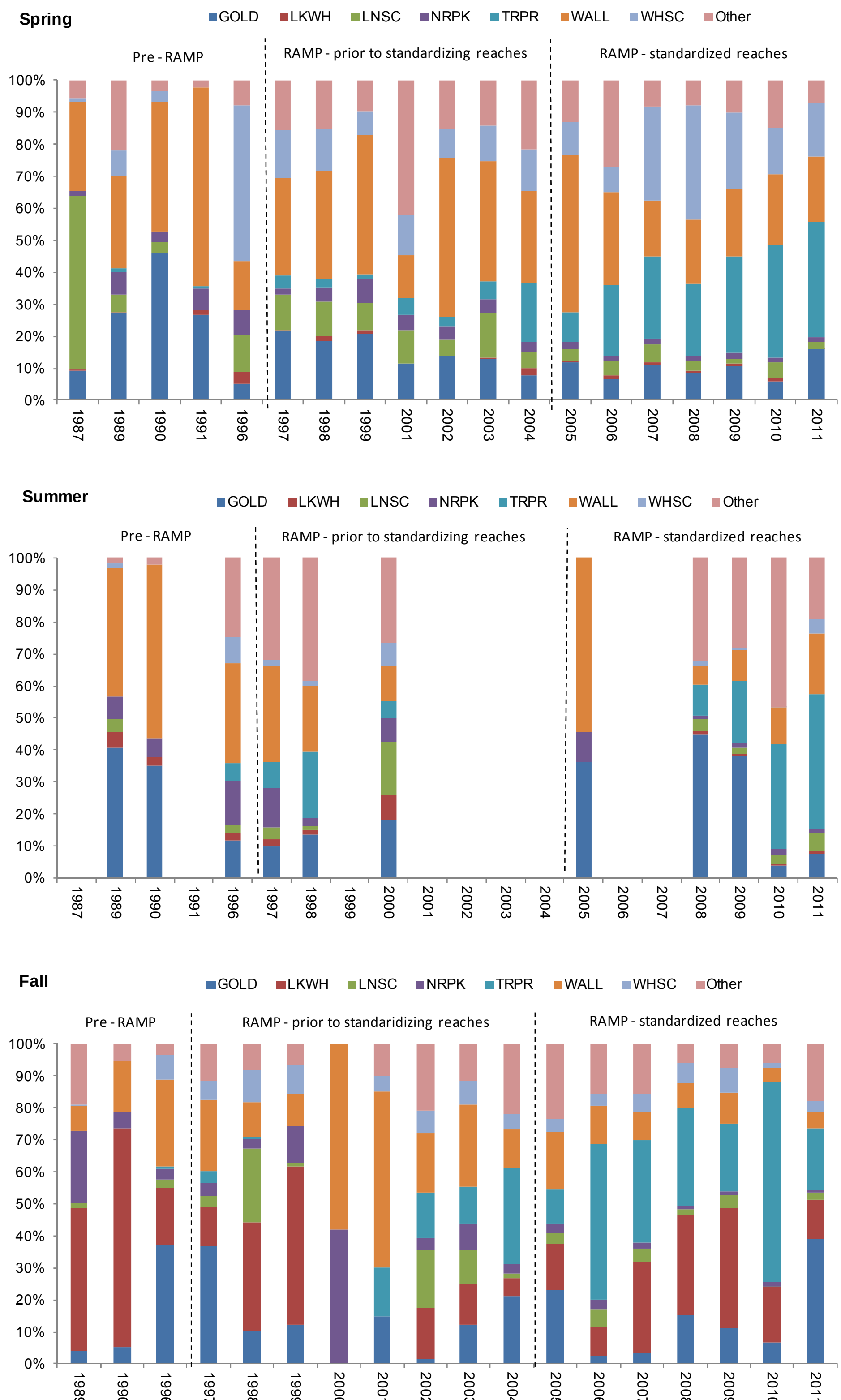


Figure 5.1-28 Total CPUE (±1SD) for KIR fish species in the Athabasca River during spring, summer, and fall fish inventories in 2011.

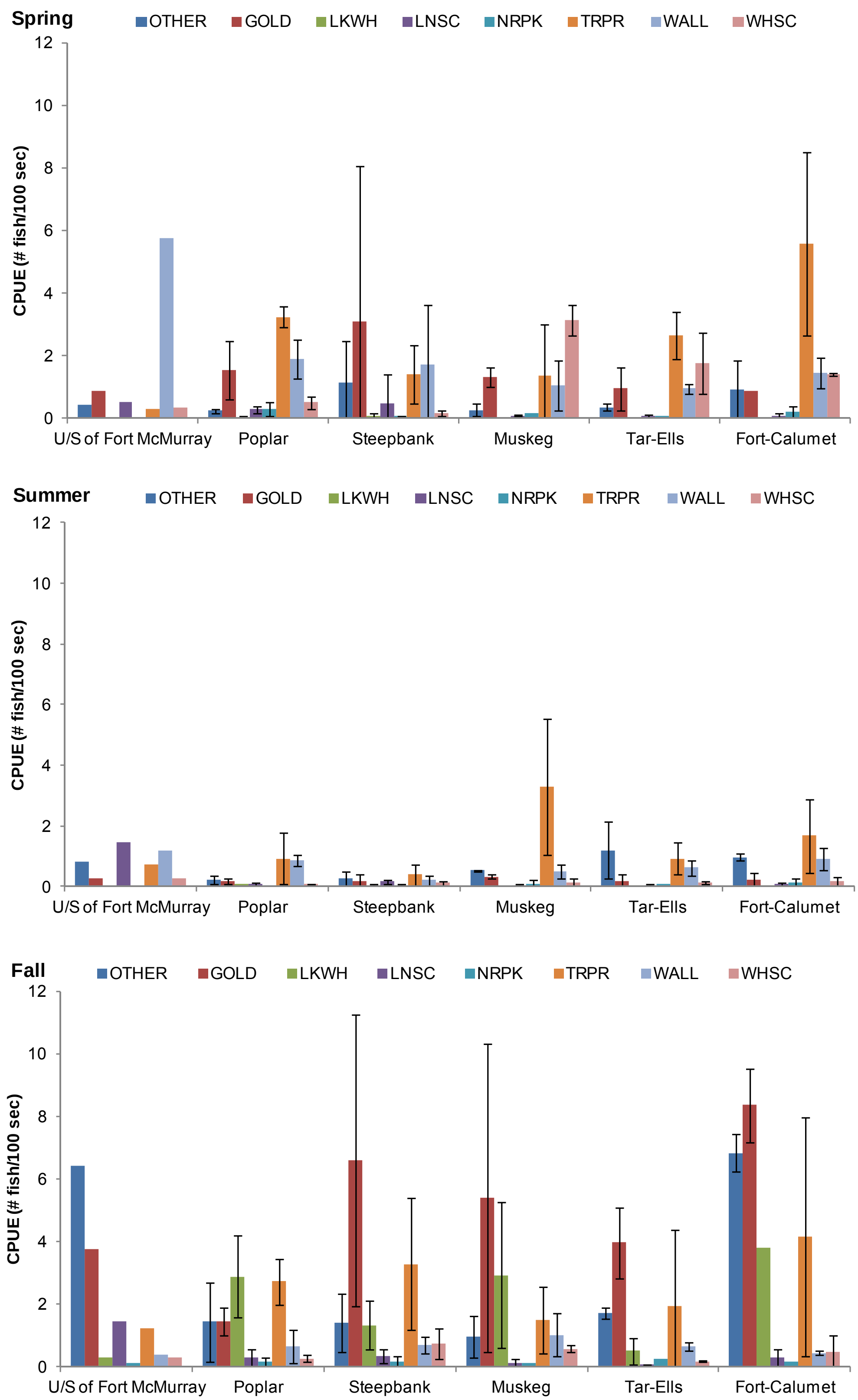


Figure 5.1-29 CPUE (±1SD) for goldeye from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

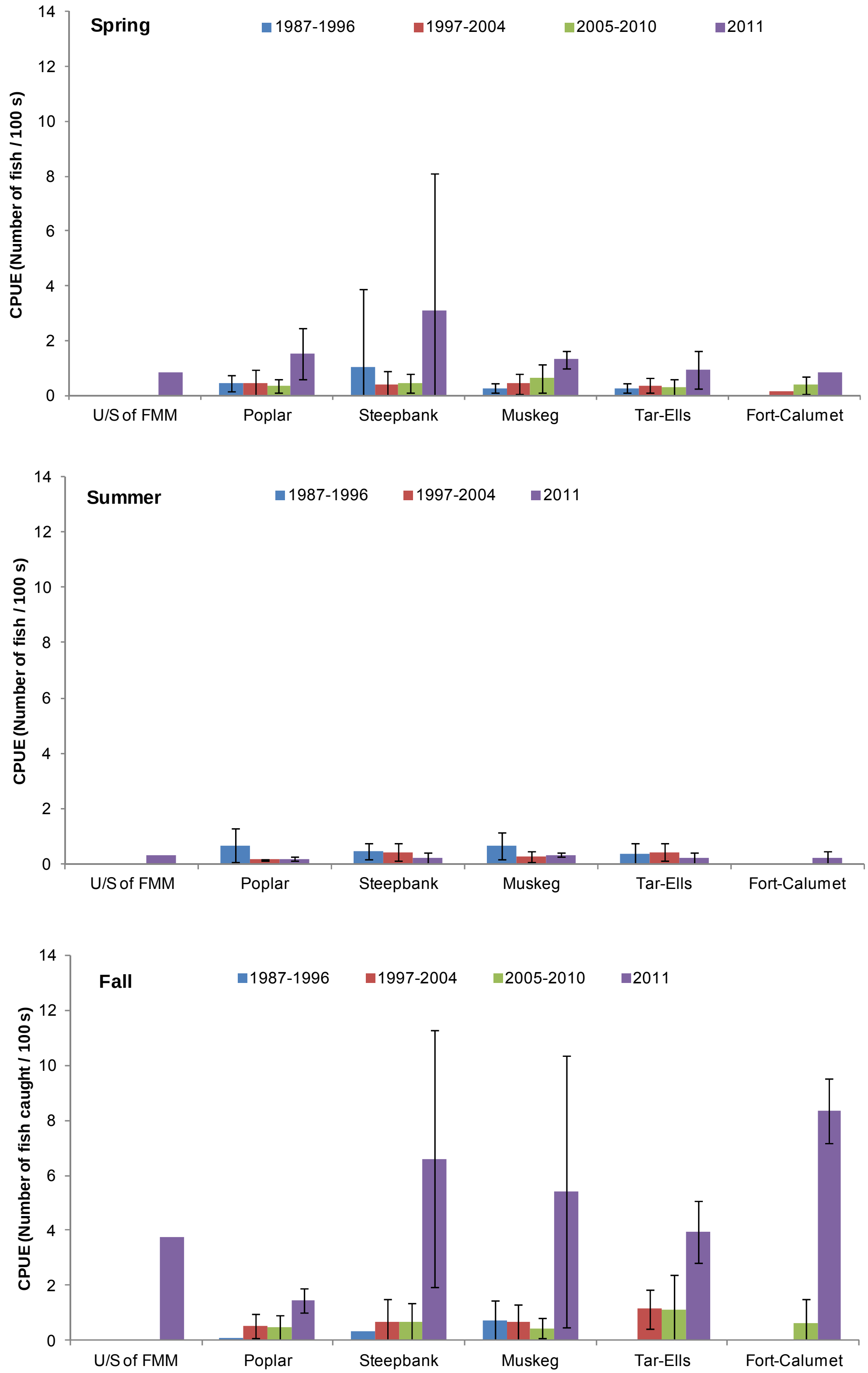


Figure 5.1-30 CPUE (±1SD) for lake whitefish from 1987 to 2011 during the fall fish inventory on the Athabasca River.

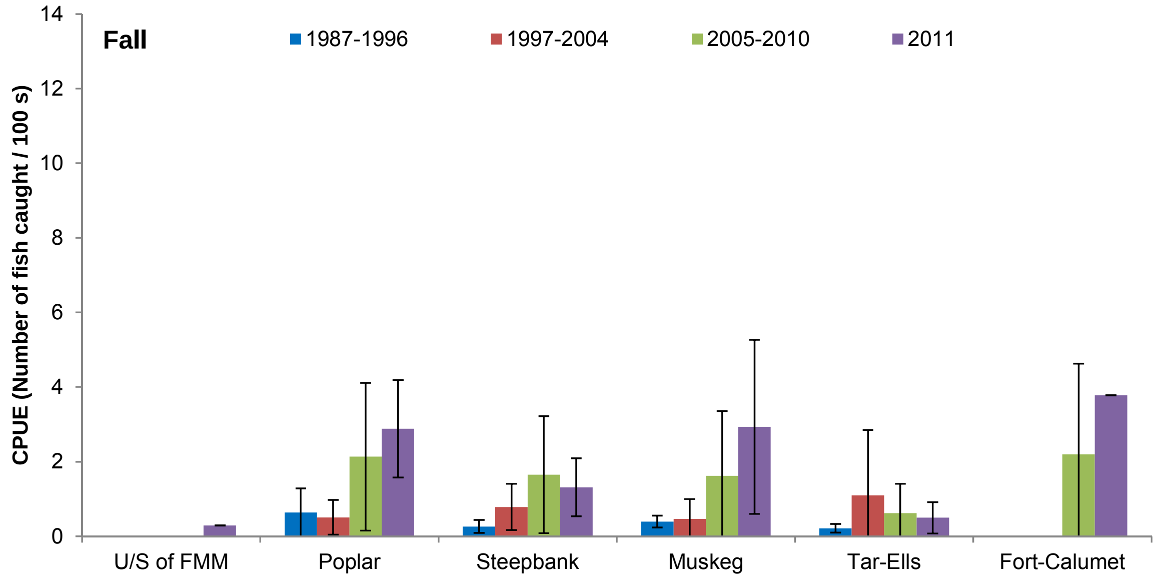


Figure 5.1-31 CPUE (±1SD) for longnose sucker from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

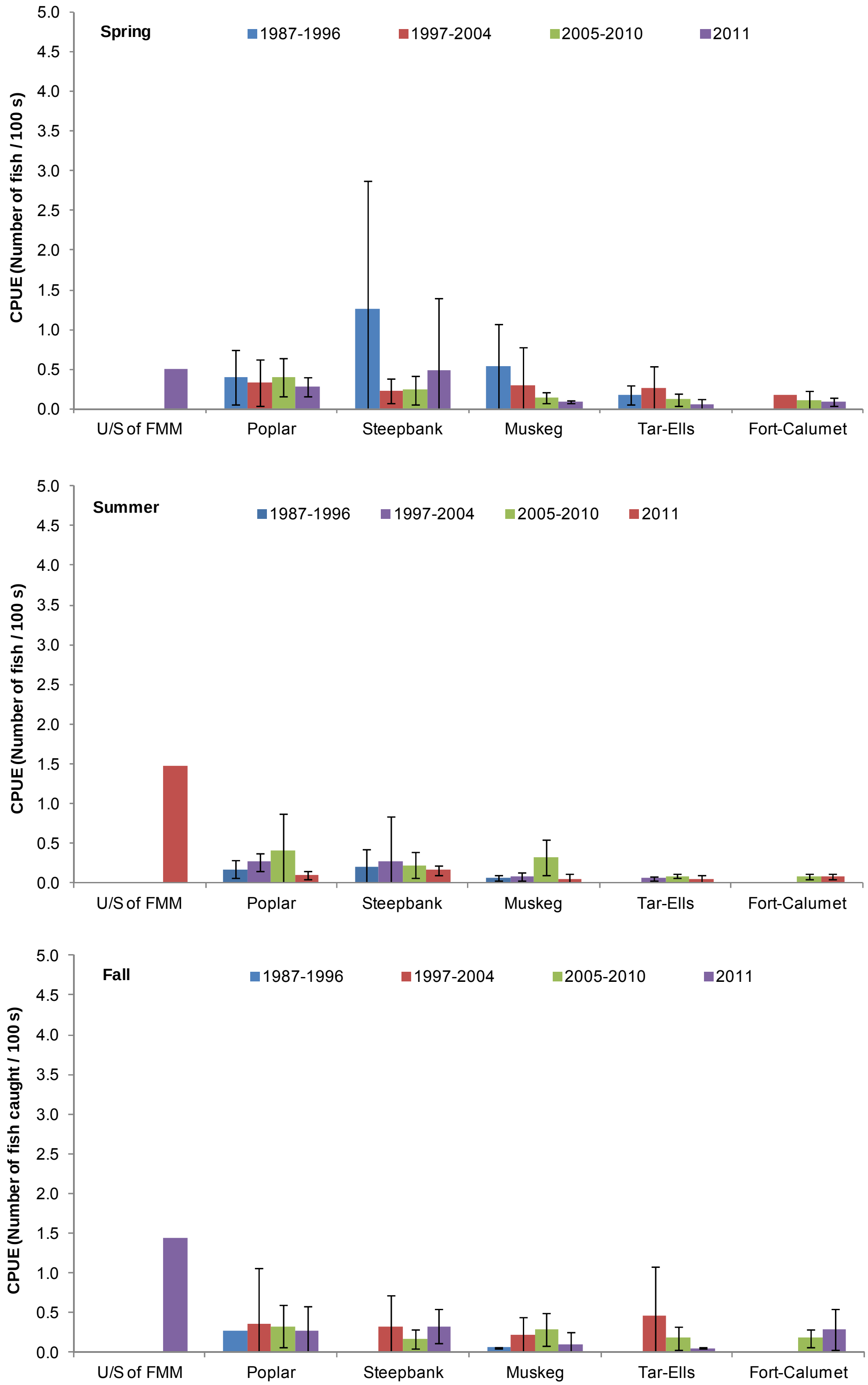


Figure 5.1-32 CPUE (±1SD) for northern pike from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

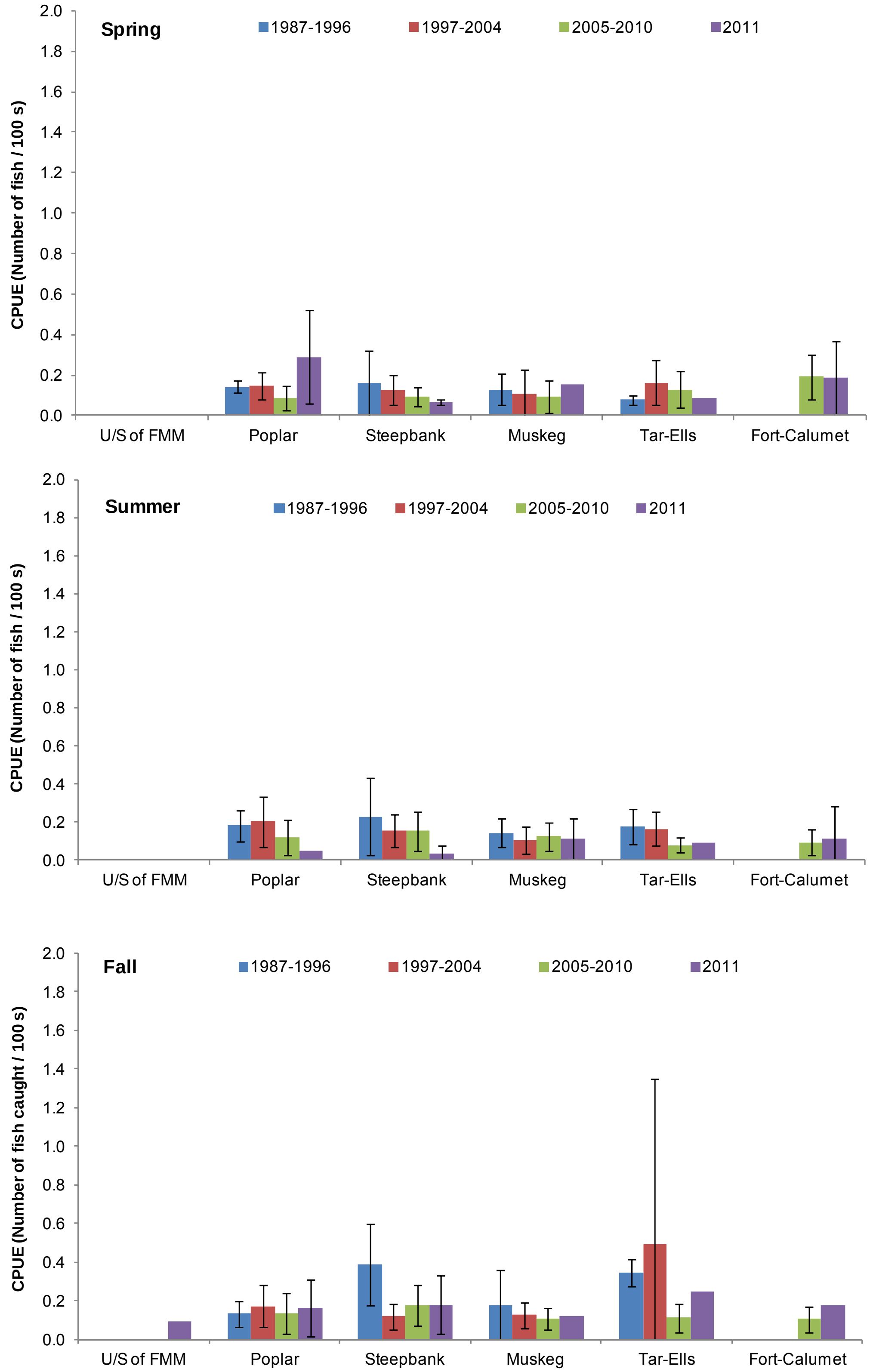


Figure 5.1-33 CPUE (±1SD) for trout-perch from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

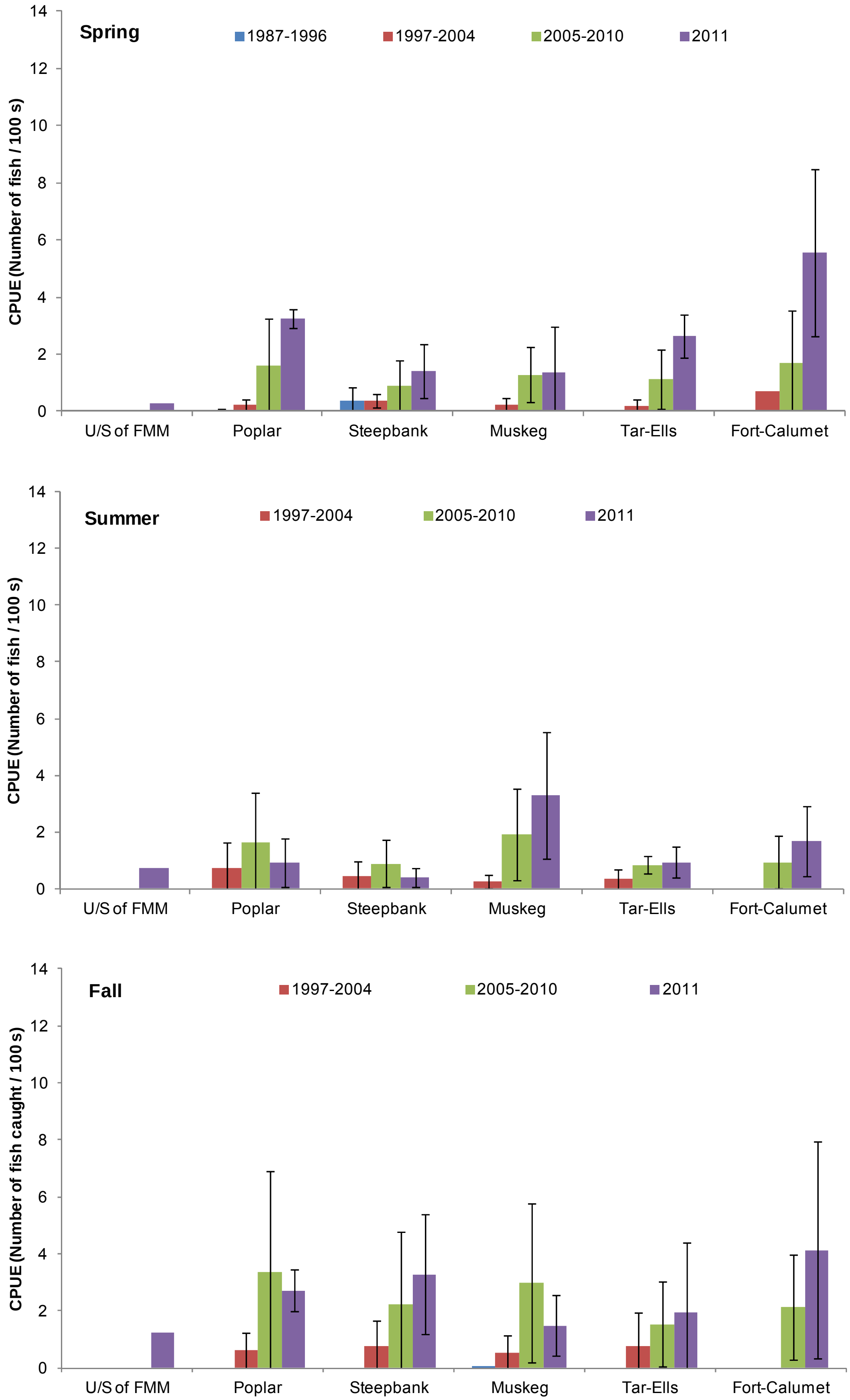


Figure 5.1-34 CPUE (±1SD) for walleye from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

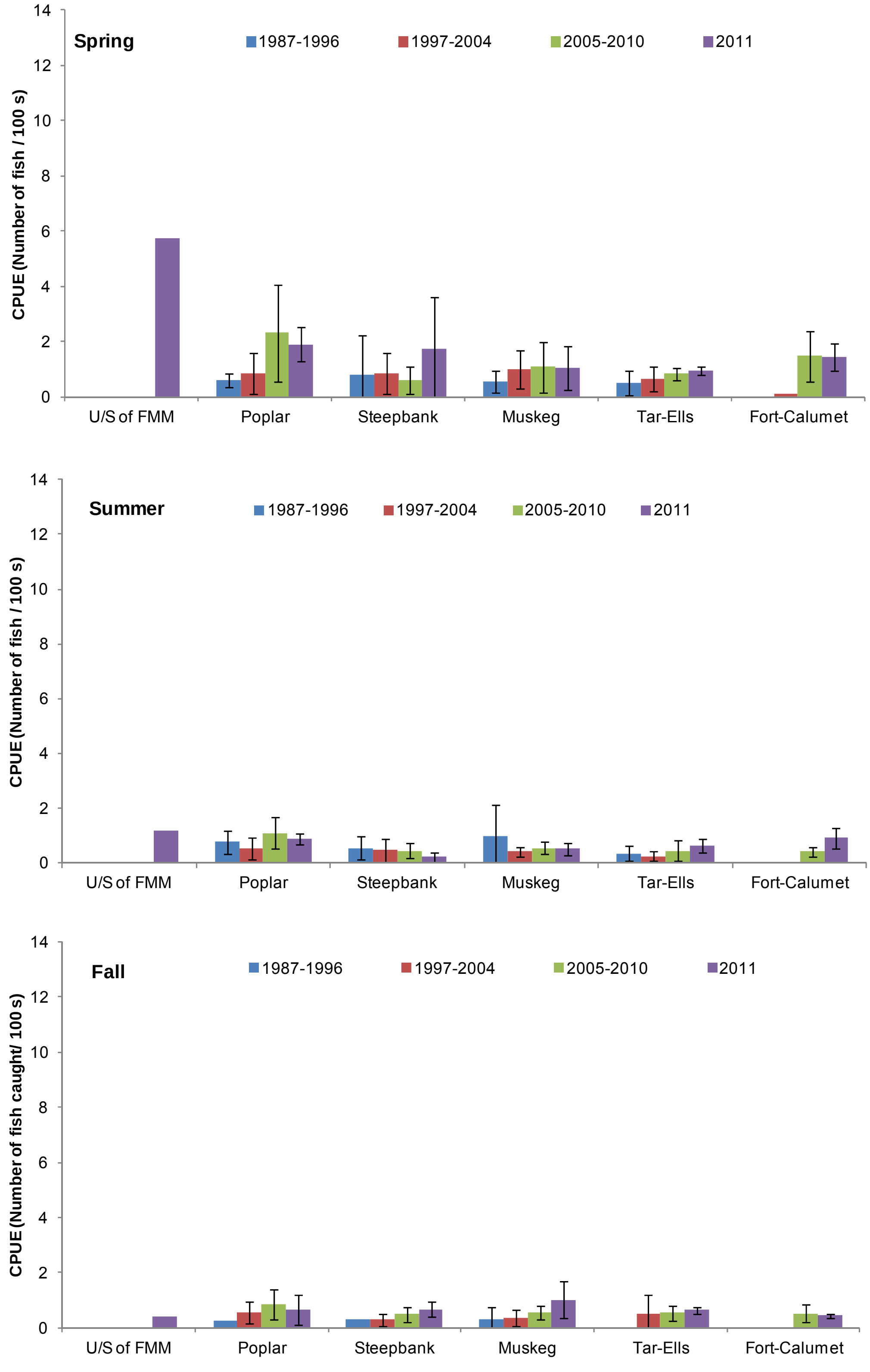


Figure 5.1-35 CPUE (±1SD) for white sucker from 1987 to 2011 during spring, summer, and fall fish inventories on the Athabasca River.

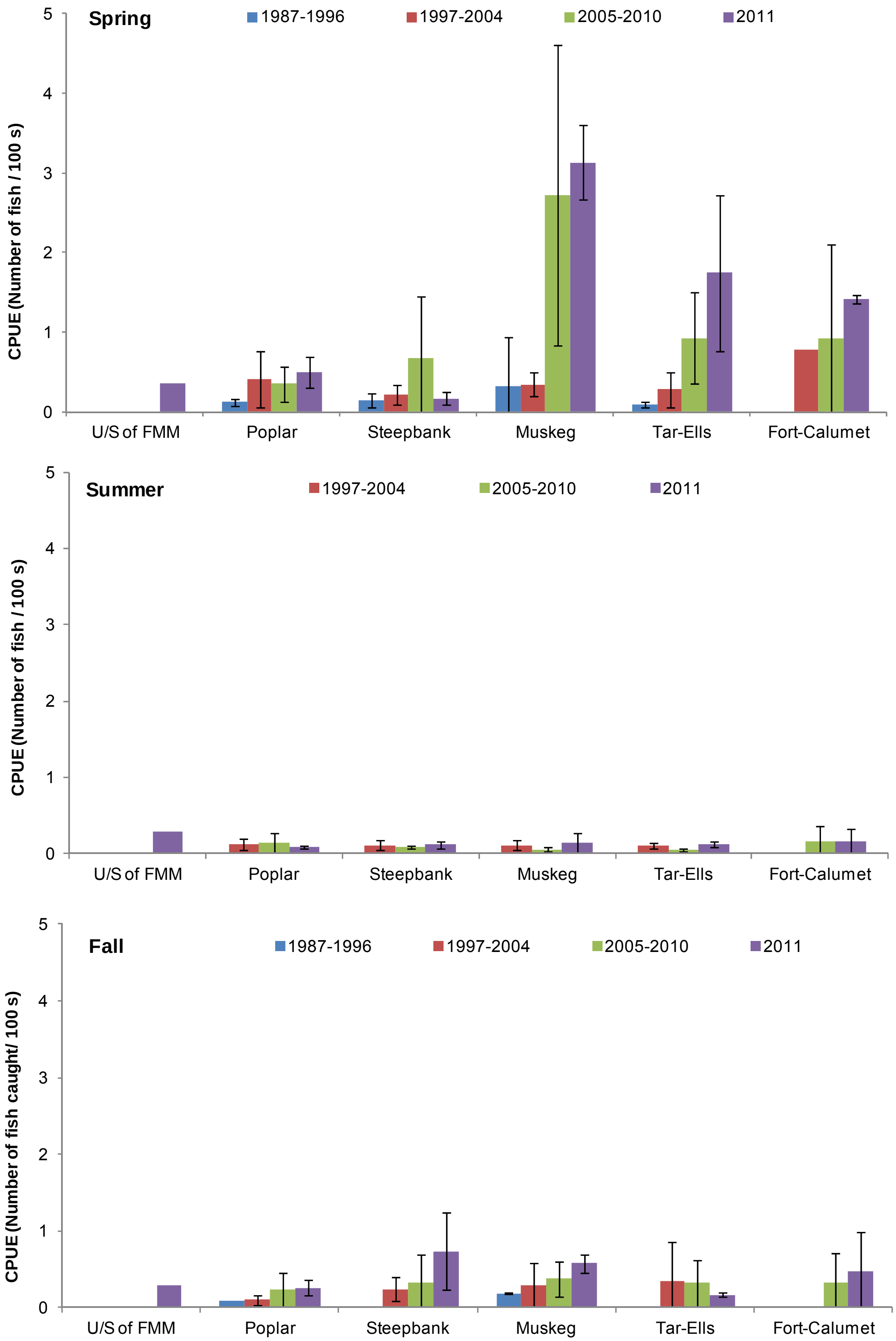
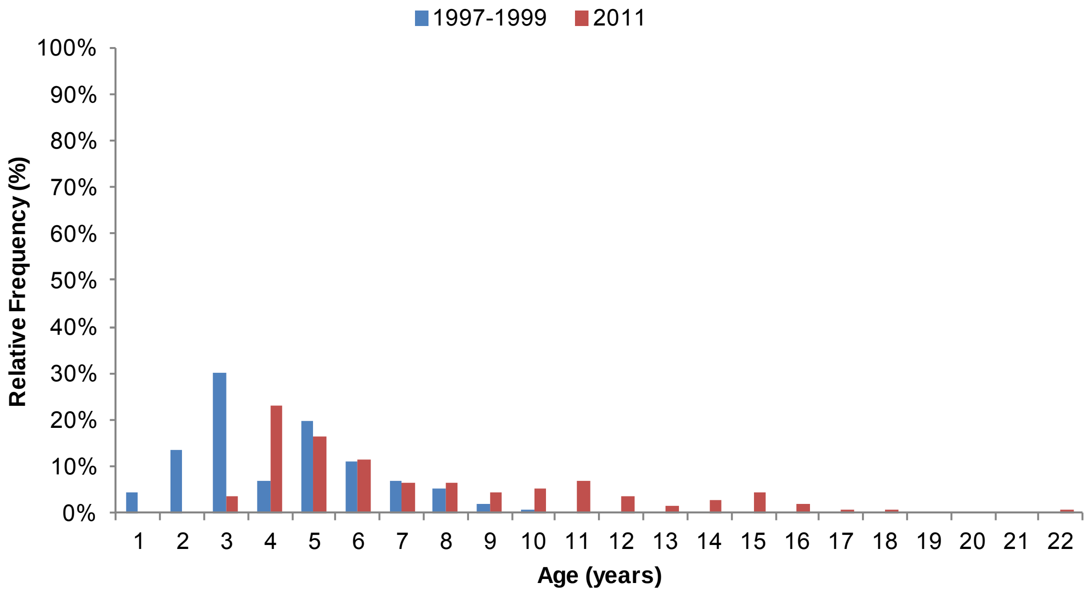


Figure 5.1-36 Relative age-frequency distributions and size-at-age relationship for goldeye captured in the Athabasca River from 1987 to 2011.



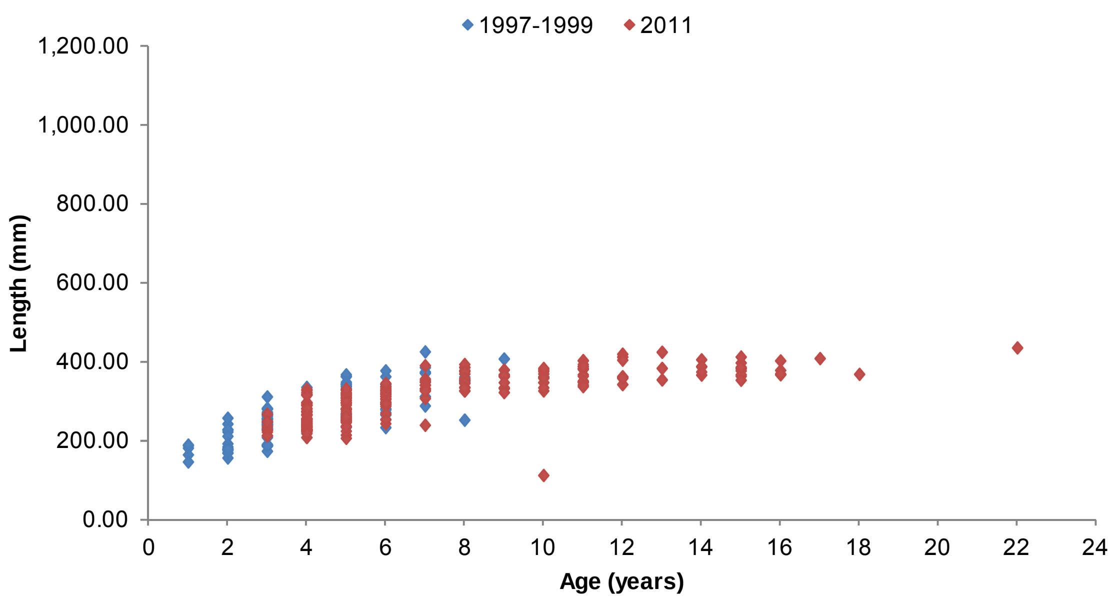
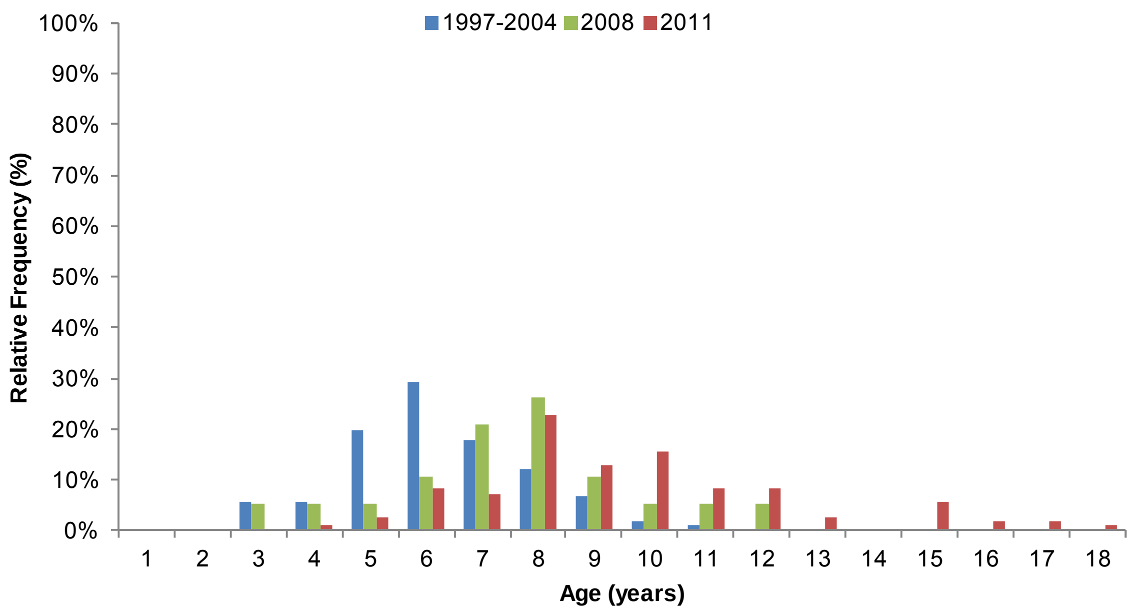


Figure 5.1-37 Relative age-frequency distributions and size-at-age relationship for lake whitefish captured in the Athabasca River from 1987 to 2011.



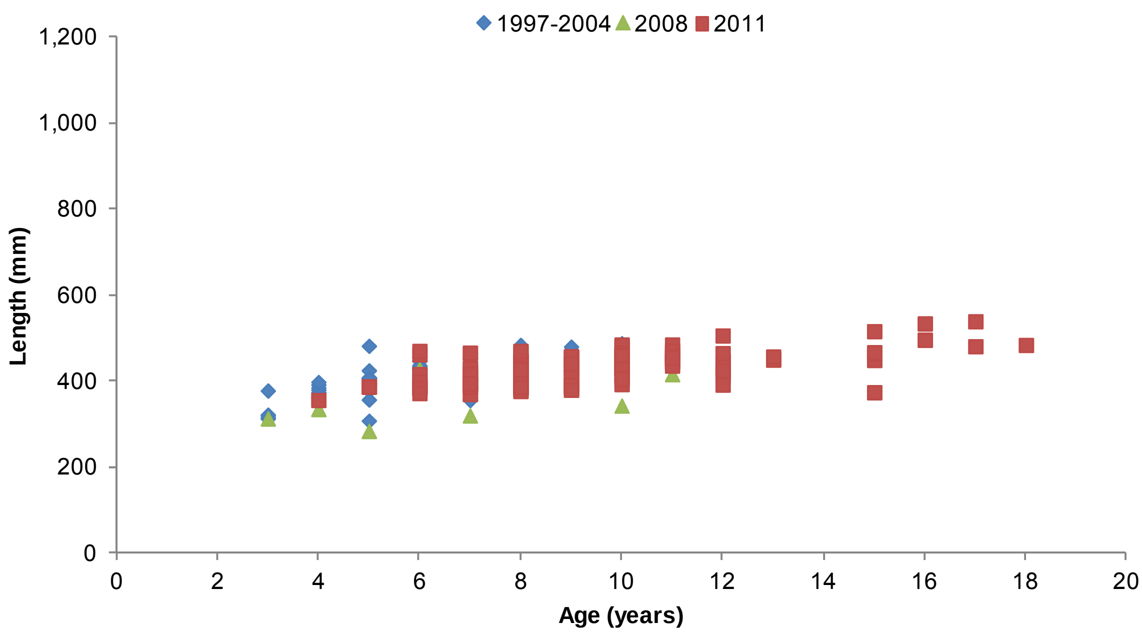
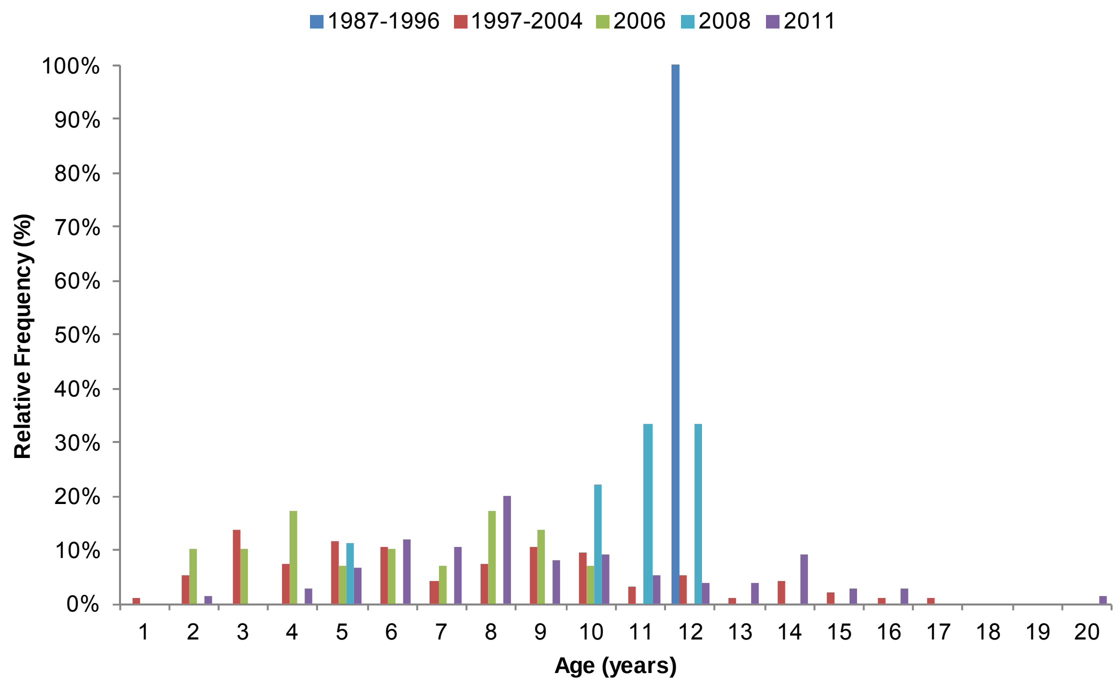


Figure 5.1-38 Relative age-frequency distributions and size-at-age relationship for longnose sucker captured in the Athabasca River from 1987 to 2011.



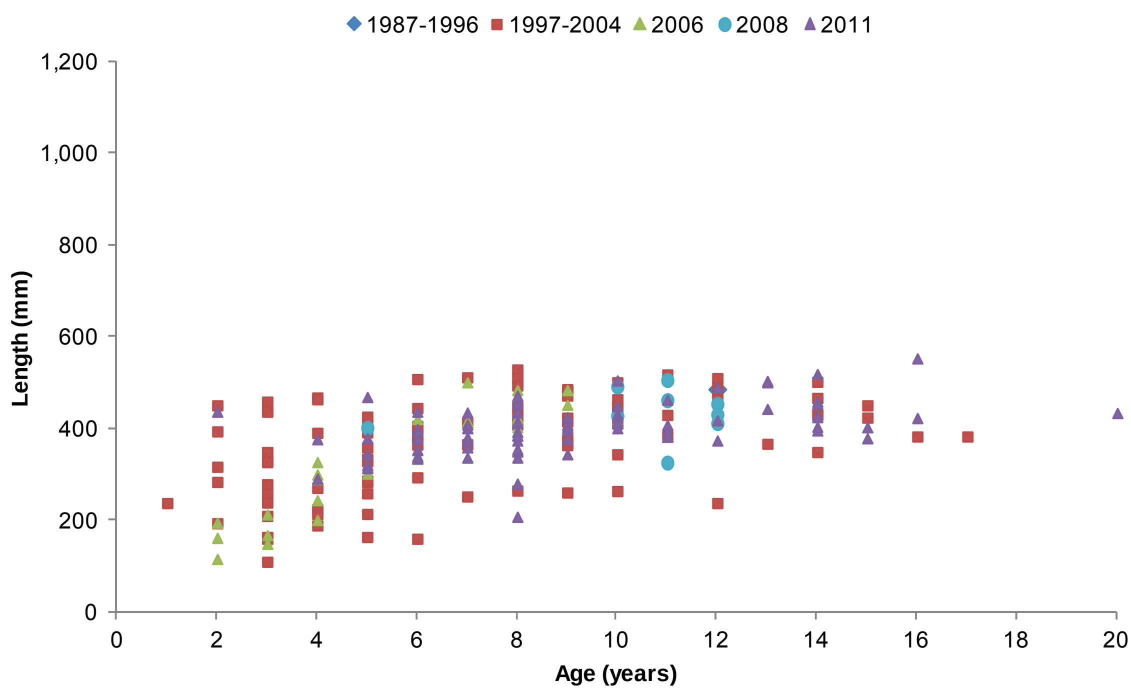
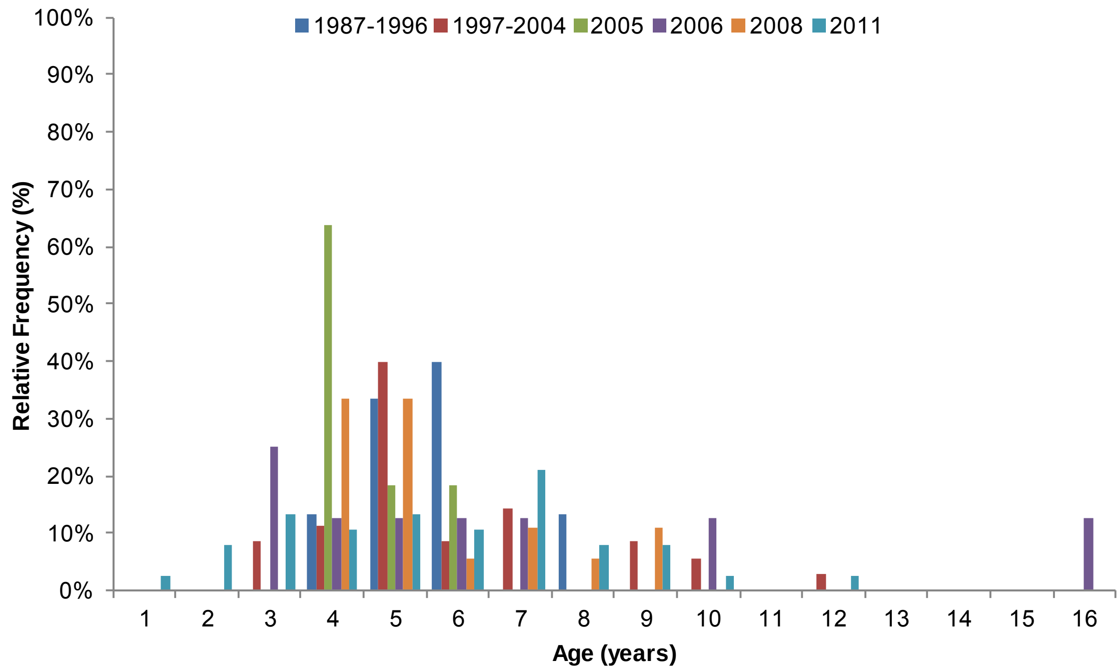


Figure 5.1-39 Relative age-frequency distributions and size-at-age relationship for northern pike captured in the Athabasca River from 1987 to 2011.



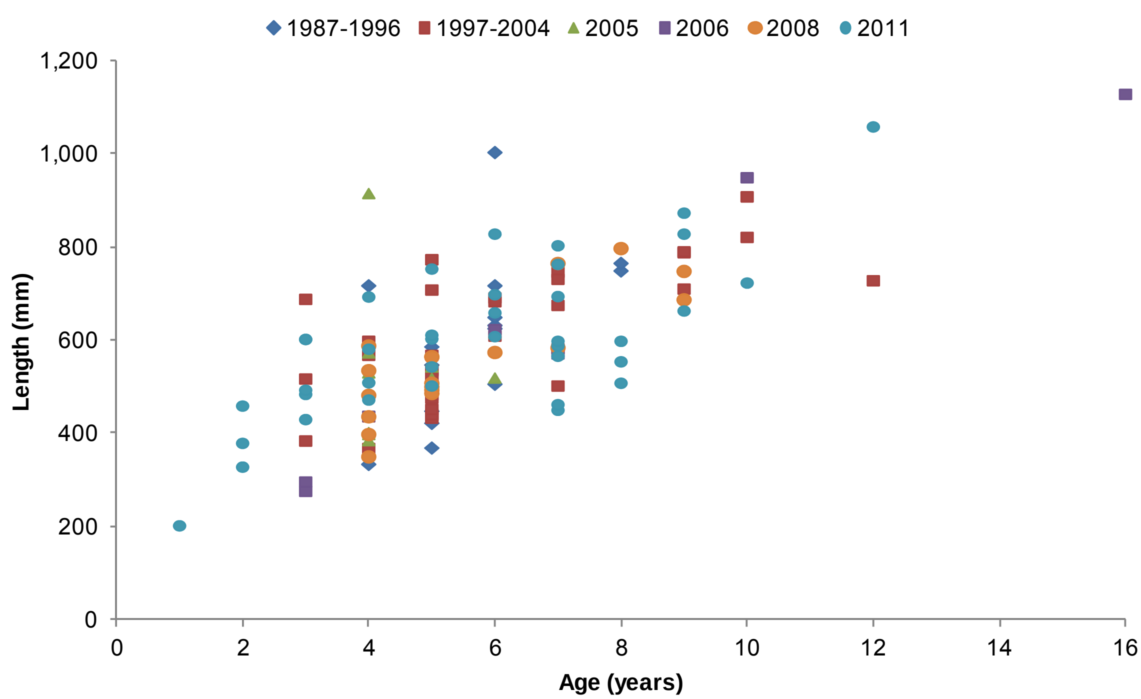
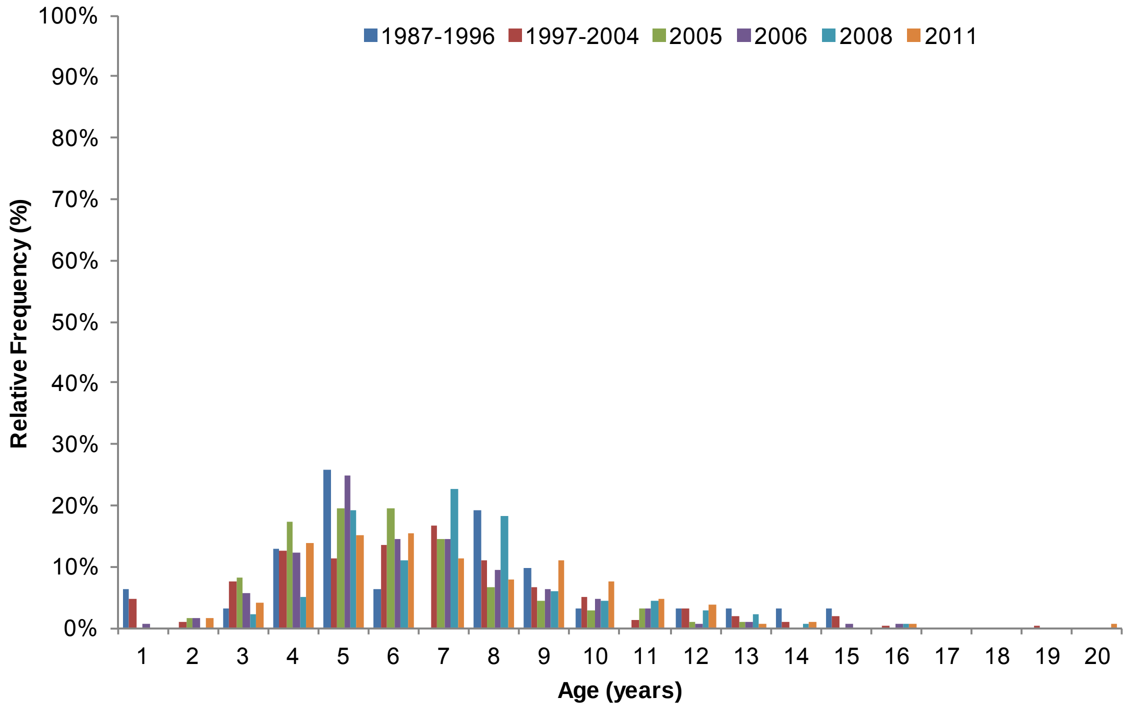


Figure 5.1-40 Relative age-frequency distributions and size-at-age relationship for walleye captured in the Athabasca River from 1987 to 2011.



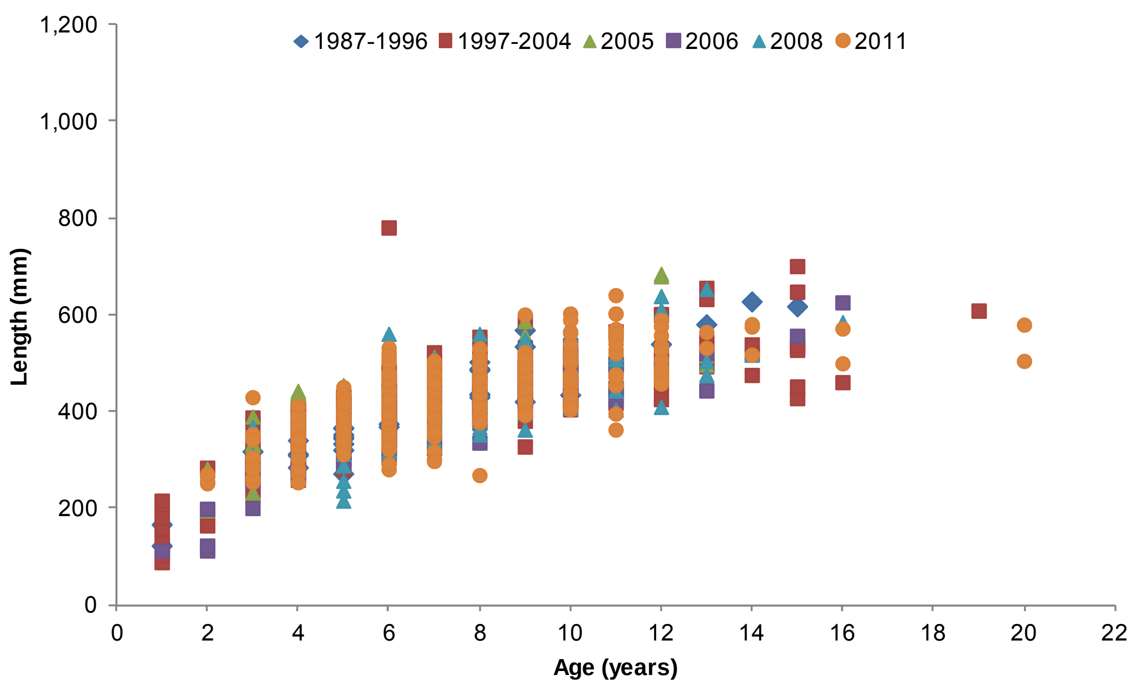
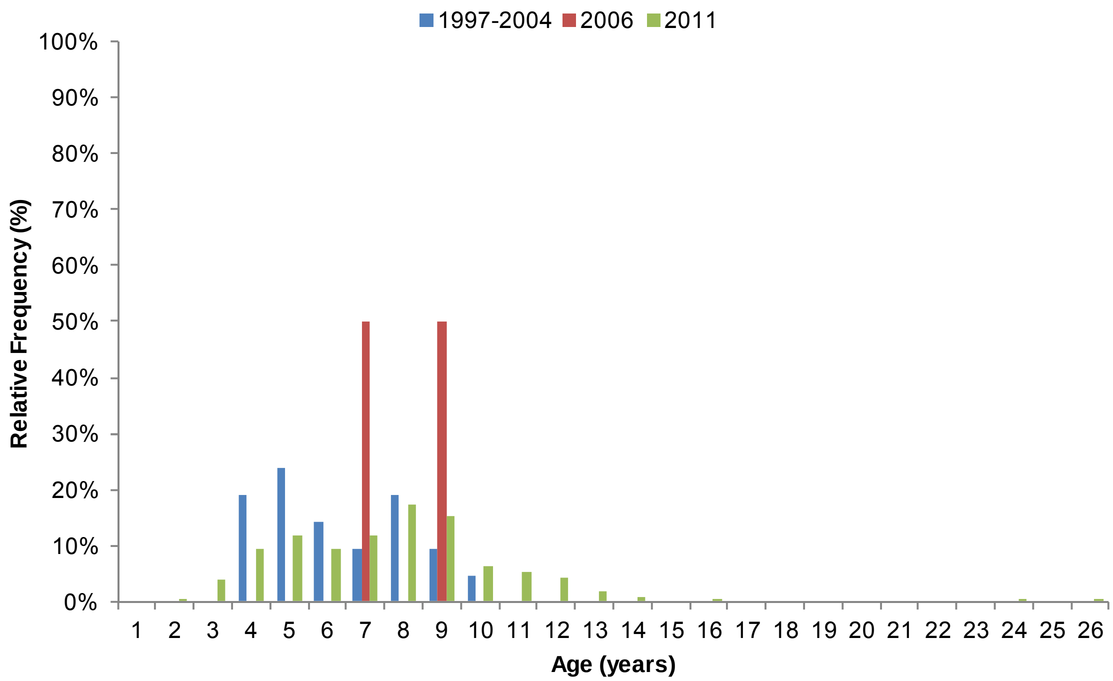


Figure 5.1-41 Relative age-frequency distributions and size-at-age relationship for white sucker captured in the Athabasca River from 1987 to 2011.



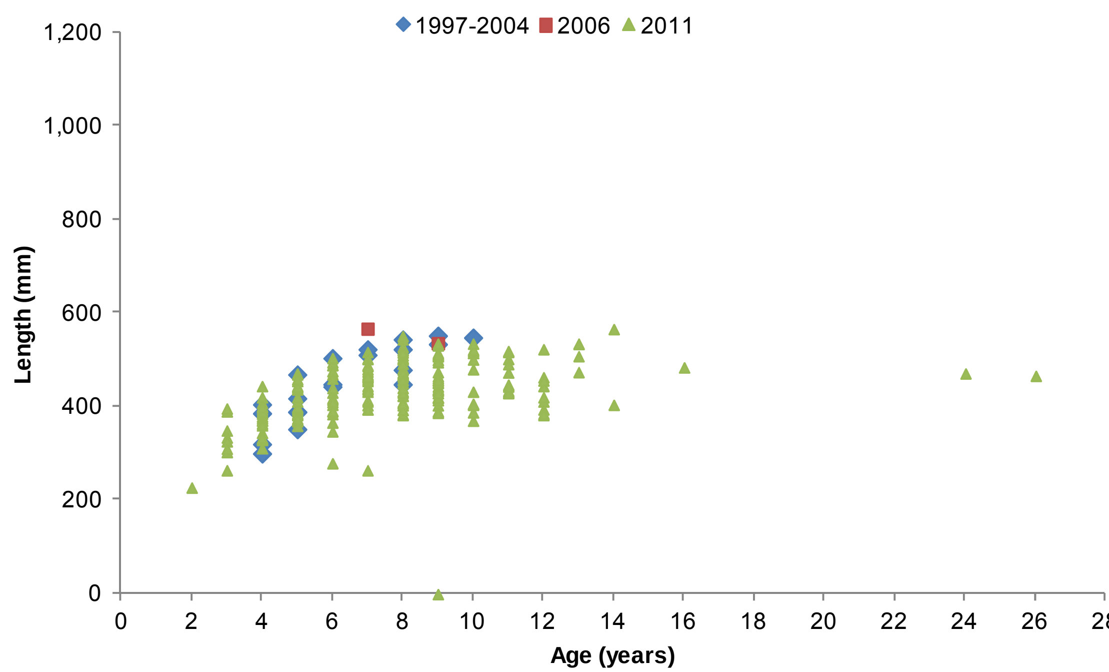


Figure 5.1-42 Mean condition (±2SD) of goldeye captured in summer and fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

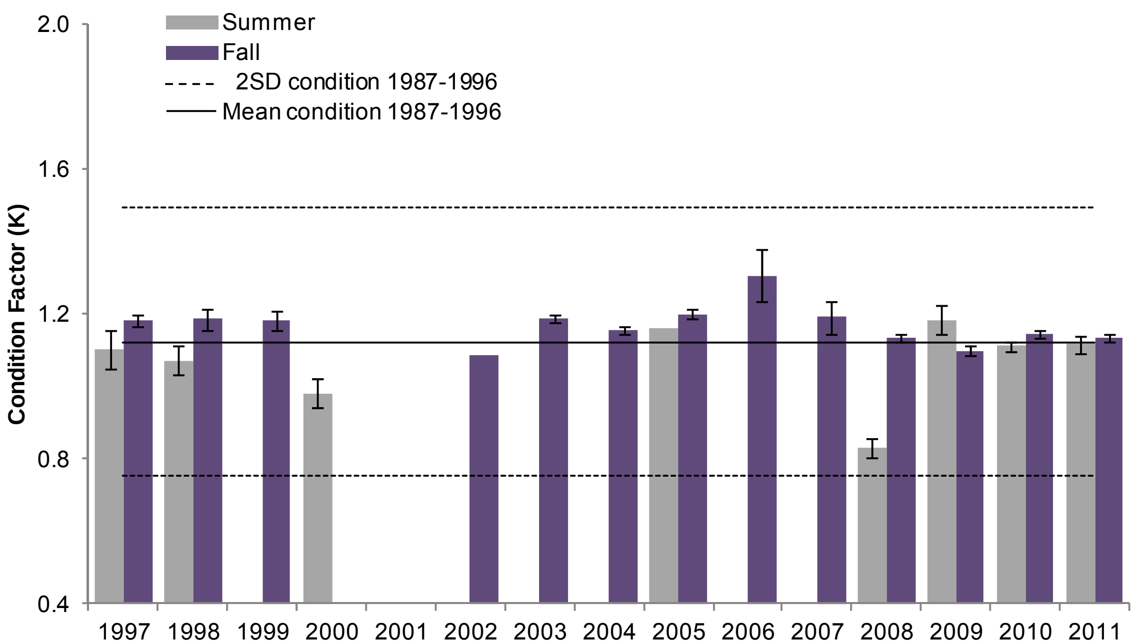


Figure 5.1-43 Mean condition (±2SD) of lake whitefish captured in fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

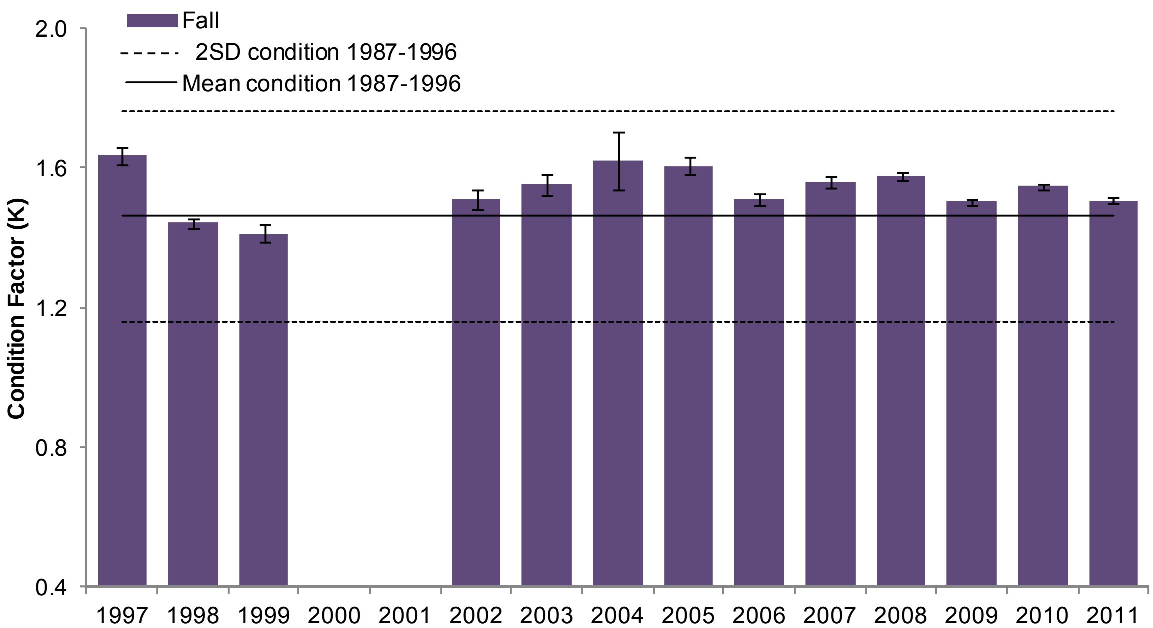


Figure 5.1-44 Mean condition (±2SD) of longnose sucker captured in summer and fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

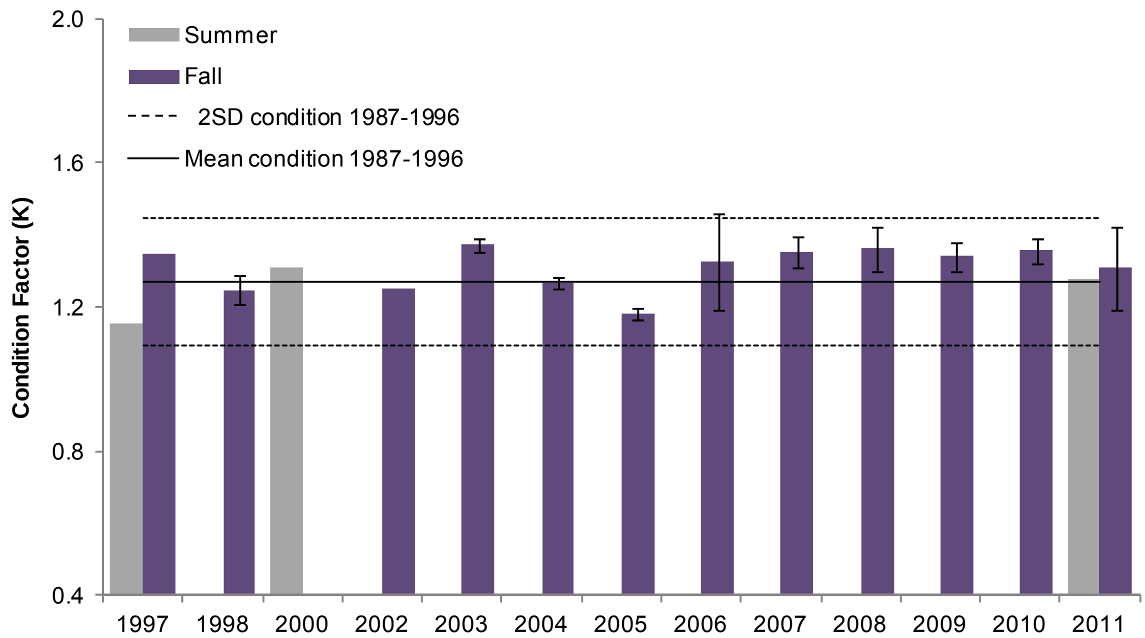


Figure 5.1-45 Mean condition (±2SD) of northern pike captured in summer and fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

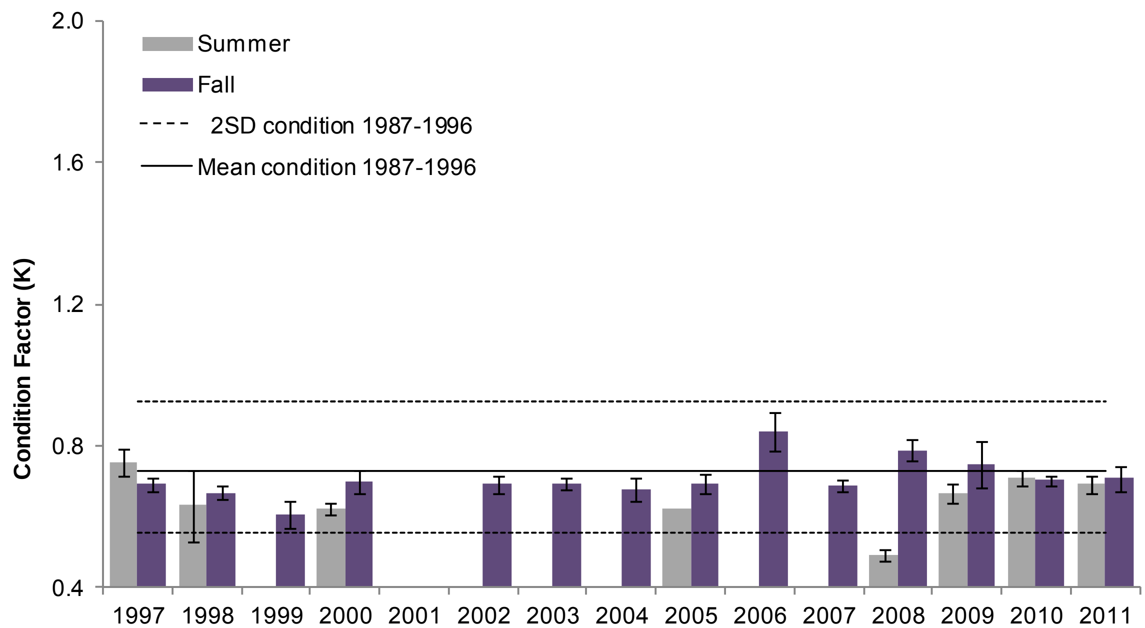
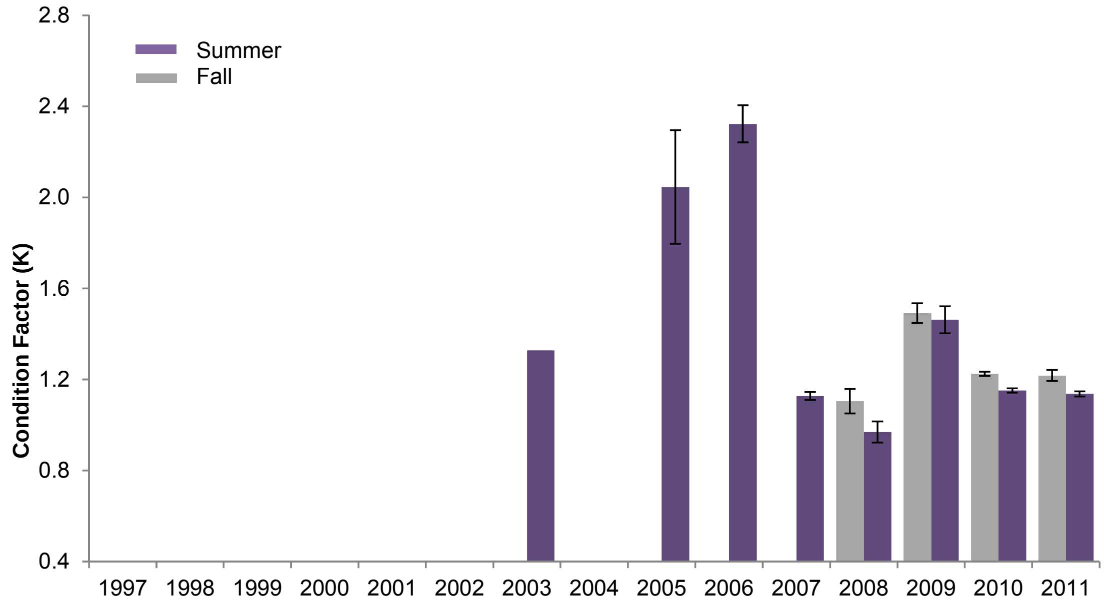


Figure 5.1-46 Mean condition (±2SD) of trout-perch captured in summer and fall from 1997 to 2011 in the Athabasca River.



Note: length and weight data were not collected for trout-perch prior to 1997 to calculate condition of fish during the baseline period.

Figure 5.1-47 Mean condition (±2SD) of walleye captured in summer and fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

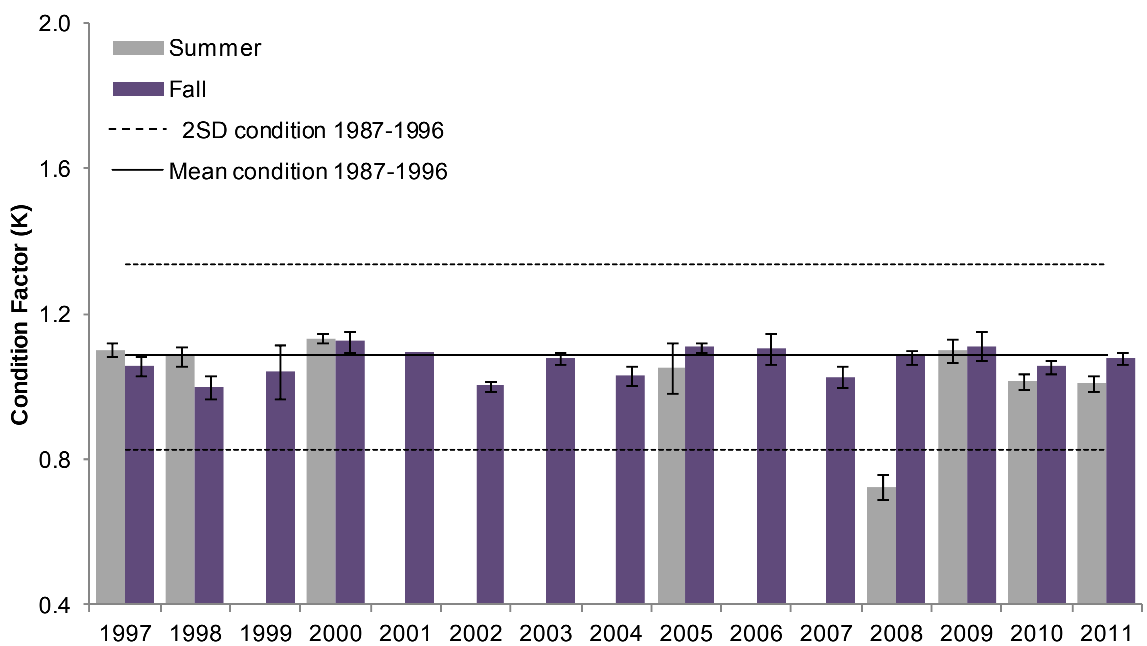


Figure 5.1-48 Mean condition (±2SD) of white sucker captured in summer and fall from 1997 to 2011 in the Athabasca River, relative to pre-RAMP values (1987 to 1996).

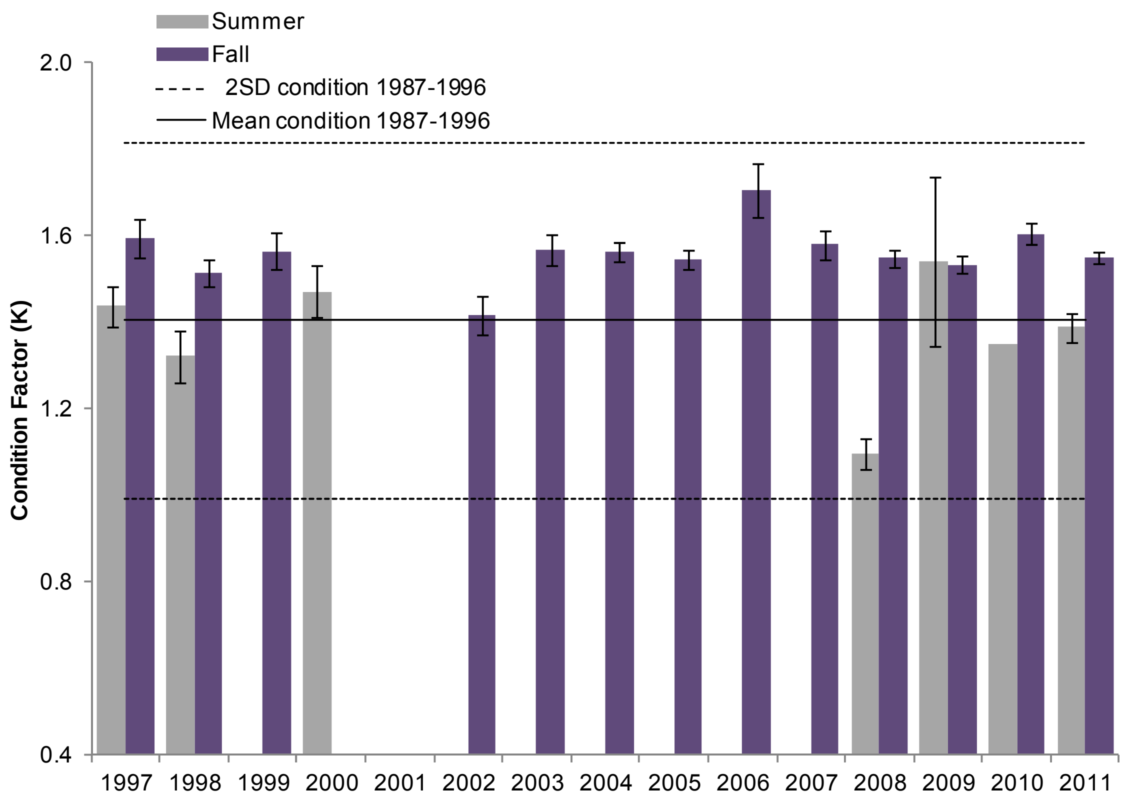


Table 5.1-20 Percent of total fish captured in the Athabasca River with external pathology (growth/session, deformity, parasites), 1987 to 2011.

Year	% Growth/Lesion	% Deformity (body/fins)	% Parasites	% of Total	Total # fish
1987	0.33	0	0	0.33	1,823
1989	1.09	0.42	0.71	2.22	4,237
1990	0.65	0.43	0.22	1.30	921
1991	1.74	0.00	0.83	2.57	1,322
1996	2.65	1.58	2.29	6.51	1,965
1997	2.38	1.14	0.96	4.48	2,187
1998	1.39	0.67	0.88	2.94	2,381
1999	2.01	1.68	1.84	5.53	597
2000	2.43	0.41	0.81	3.65	493
2001	1.24	0.00	0.00	1.24	403
2002	0.45	0.17	0.22	0.84	1,793
2003	0.65	0.18	0.30	1.13	1,680
2004	0.37	0.05	0.69	1.12	1,883
2005	0.88	0.20	0.00	1.08	2,042
2006	0.63	0.05	0.27	0.95	2,222
2007	1.15	0.32	0.12	1.59	2,511
2008	1.43	0.42	0.32	2.18	4,951
2009	0.94	0.59	0.87	2.40	3,207
2010	0.53	0.21	0.64	1.39	5,284
2011	0.34	0.16	0.49	0.99	5,466

Figure 5.1-49 Percent of total fish captured in the Athabasca River with some type of external pathology, 1987 to 2011.

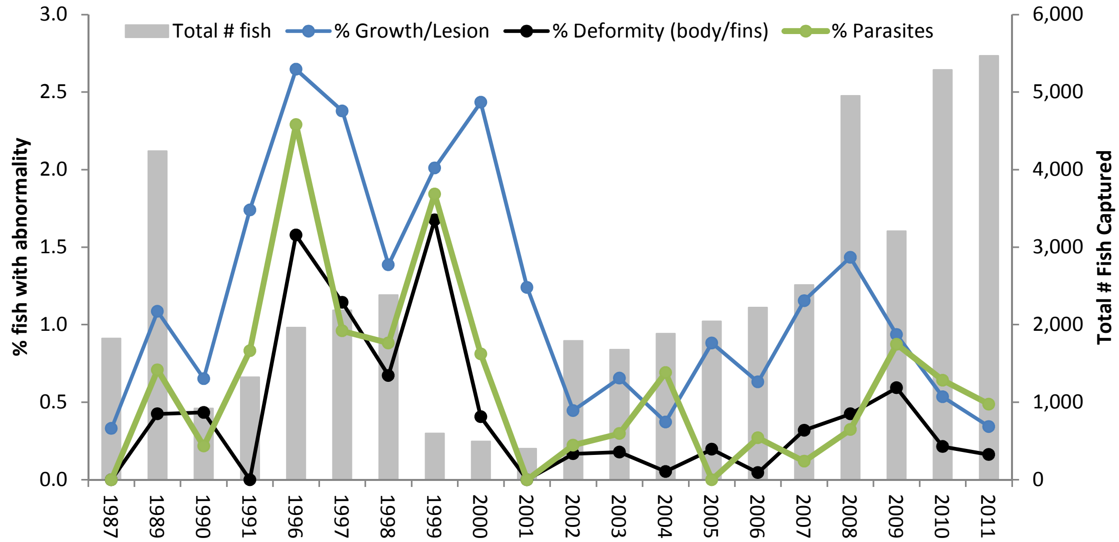


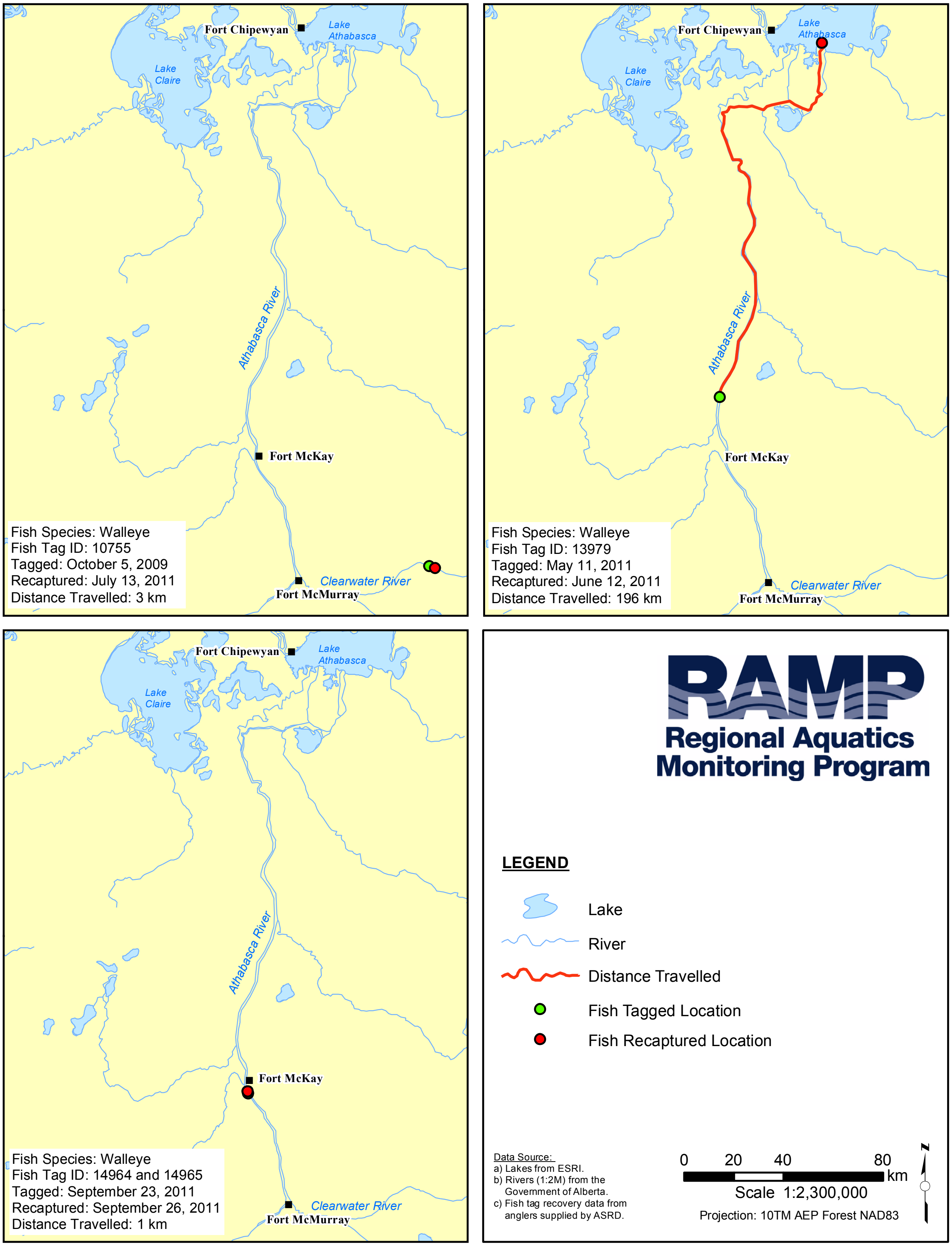
Table 5.1-21 Results of RAMP fish tag returns by anglers and during the Athabasca River and Clearwater River fish inventories, 2011.

Variable	Walleye	Northern Pike
No. of Fish Captured	8	9
Minimum Distance Travelled (km)	1	<1
Maximum Distance Travelled (km)	196	8

Table 5.1-22 Results of RAMP fish tag returns by anglers, Athabasca and Clearwater rivers (1999 to 2011).

Variable	Fish Species				
	Lake Whitefish	Longnose Sucker	Northern Pike	Walleye	White Sucker
No. of Fish Captured	1	2	44	94	4
Minimum Distance Travelled (km)	271	5.3	0	0	<1
Maximum Distance Travelled (km)	271	236	57	715	241

Figure 5.1-50 Location where tagged fish were recaptured by anglers in 2011.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_J_FishTag_20120315.mxd

Table 5.1-23 Mercury concentrations (muscle) and whole-organisms metrics of lake whitefish and walleye collected from the Athabasca River, fall 2011, and screening of concentrations against criteria for fish consumption for the protection of human health.

Species	Sample ID	Sex	Length (mm)	Weight (g)	Age	Hg (mg/kg)
LKWH	LKWH-44-11A	M	471	1,603	11	0.09
LKWH	LKWH-45-11A	M	516	1,714	15	0.09
LKWH	LKWH-67-11A	U	485	1,700	10	0.09
LKWH	LKWH-11-11A	U	397	1,025	8	0.02
LKWH	LKWH-12-11A	F	470	1,778	8	0.02
LKWH	LKWH-03-11A	U	462	1,682	10	0.08
LKWH	LKWH-32-4A	U	393	730	10	0.07
LKWH	LKWH-33-4A	M	370	741	7	0.02
LKWH	LKWH-06-11A	U	539	2,298	17	0.18
LKWH	LKWH-09-11A		481	1,834	17	0.12
LKWH	WALL-06-4A	U	374	826	15	0.05
LKWH	LKWH-30-4A	U	399	927	6	0.04
LKWH	LKWH-31-4A	F	387	932	5	0.08
LKWH	LKWH-4-11A	F	431	1,291	8	0.05
LKWH	LKWH-28-4A	F	409	994	9	0.20
LKWH	LKWH-04-4A	F	435	1,123	8	0.05
LKWH	LKWH-26-4A	F	449	1,247	10	0.11
LKWH	LKWH-07-11A	F	430	1,248	9	0.07
LKWH	LKWH-17-11A	M	436	1,230	11	0.05
LKWH	LKWH-08-11A	M	417	1,102	7	0.07
LKWH	LKWH-13-11A	M	427	1,107	8	0.06
LKWH	LKWH-10-11A	M	405	902	10	0.09
LKWH	LKWH-05-11A	M	415	1,082	10	0.10
LKWH	LKWH-14-11A	M	449	1,300	15	0.16

LKWH – lake whitefish; WALL – walleye; M-Male; F-Female; U-Undetermined

* Refer to Table 3.4-9.

exceeds Health Canada Criterion for subsistence fishers (0.20 mg/kg)

exceeds Health Canada Criterion for general consumers (0.50 mg/kg)

Table 5.1-23 (Cont'd.)

Species	Sample ID	Sex	Length (mm)	Weight (g)	Age	Hg (mg/kg)
WALL	WALL-68-11A	U	280	202	3	0.16
WALL	WALL-02-11A	F	448	1,015*	8	0.46
WALL	WALL-55-11A	U	446	985*	9	0.21
WALL	WALL-56-11A	U	392	602	5	0.23
WALL	WALL-65-11A	U	337	419	5	0.22
WALL	WALL-57-11A	U	370	564	5	0.15
WALL	WALL-64-11A	U	373	491	6	0.27
WALL	WALL-01-11A	U	564	1,832*	10	0.19
WALL	WALL-48-11A	U	434	881	8	0.22
WALL	WALL-49-11A	U	445	950*	9	0.35
WALL	WALL-36-11A	U	355	454	6	0.23
WALL	WALL-41-11A	U	415	719	5	0.10
WALL	WALL-13-5B	U	640	-	11	0.27
WALL	WALL-47-5B	U	291	257	6	0.11
WALL	WALL-29-6A	U	564	2,043*	13	0.58
WALL	WALL-24-4A	U	424	772	5	0.19
WALL	WALL-26-6A	M	472	847	10	0.38
WALL	WALL-173-10B	M	485	1,281*	n/a	0.61
WALL	WALL-58-11A	M	457	1,101*	12	0.33
WALL	WALL-07-4A	F	482	1,243*	n/a	0.46
WALL	WALL-14-5B	F	496	1,707*	9	0.62
WALL	WALL-83-10B	F	481	1,133*	n/a	0.43
WALL	WALL-180-10B	F	468	1,300*	6	0.13
WALL	WALL-36-5B	F	469	1,203*	11	0.72
WALL	WALL-35-6A	F	504	1,418*	10	0.48
WALL	WALL-175-10B	F	517	1,498*	14	0.75
WALL	WALL-15-5B	F	527	1,738*	12	0.32
WALL	WALL-33-6A	F	506	1,575*	8	0.30
WALL	WALL-174-10B	F	516	1,541*	6	0.35
WALL	WALL-84-1-10B	F	500	1,242*	6	0.22
WALL	WALL-02-11A	U	448	-	8	0.46

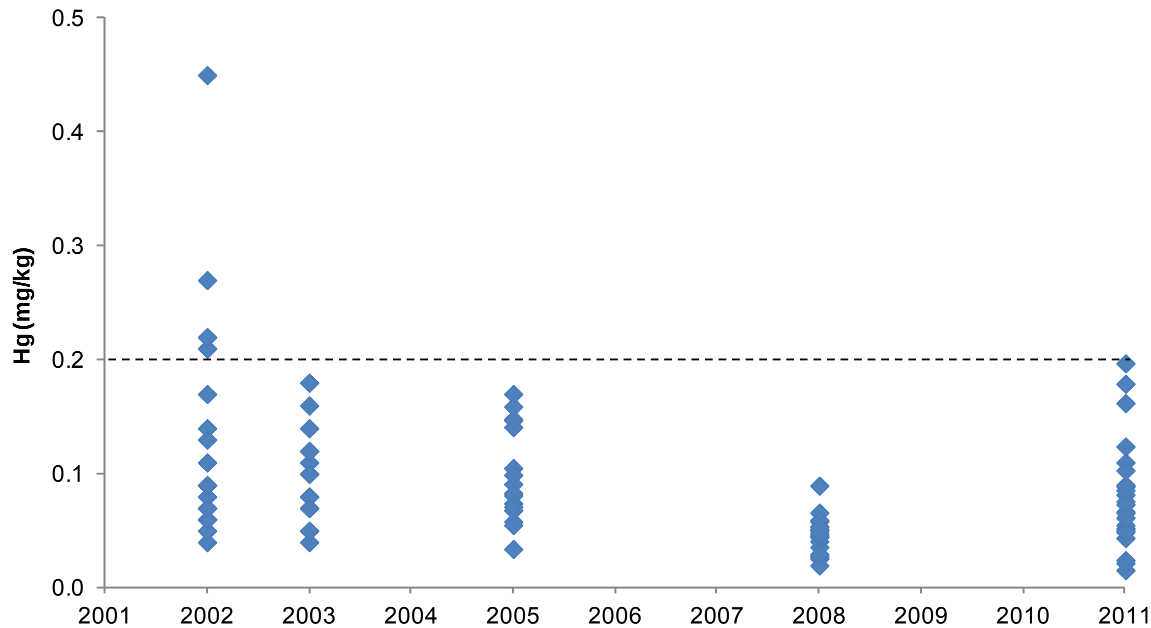
LKWH – lake whitefish; WALL – walleye; M-Male; F-Female; U-Undetermined

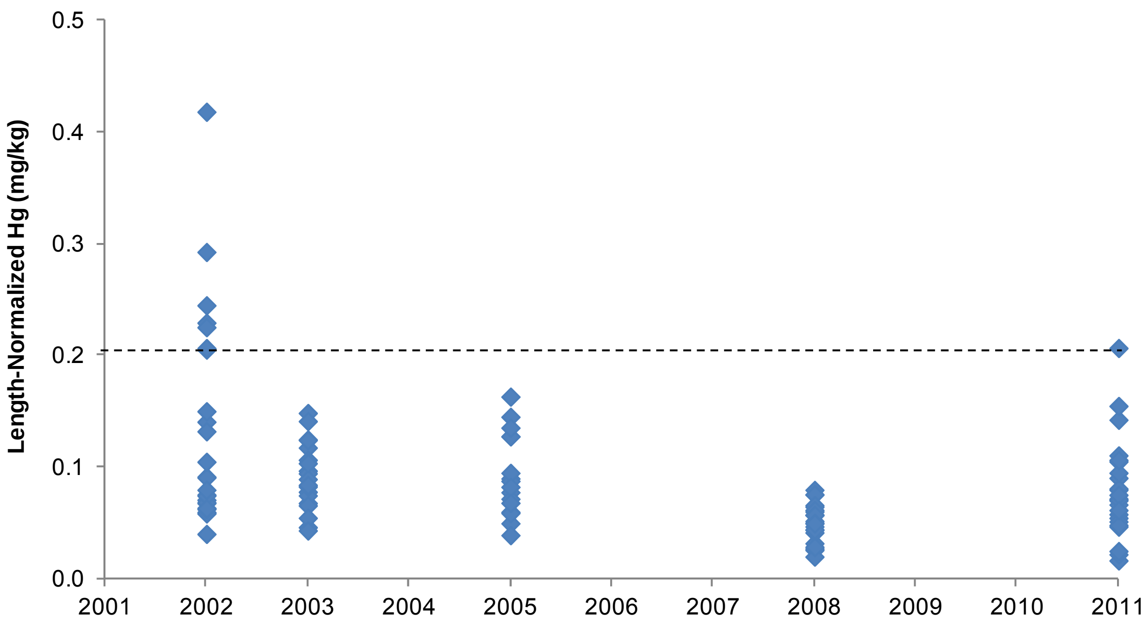
* Refer to Table 3.4-9

exceeds Health Canada Criterion for subsistence fishers (0.20 mg/kg)

exceeds Health Canada Criterion for general consumers (0.50 mg/kg)

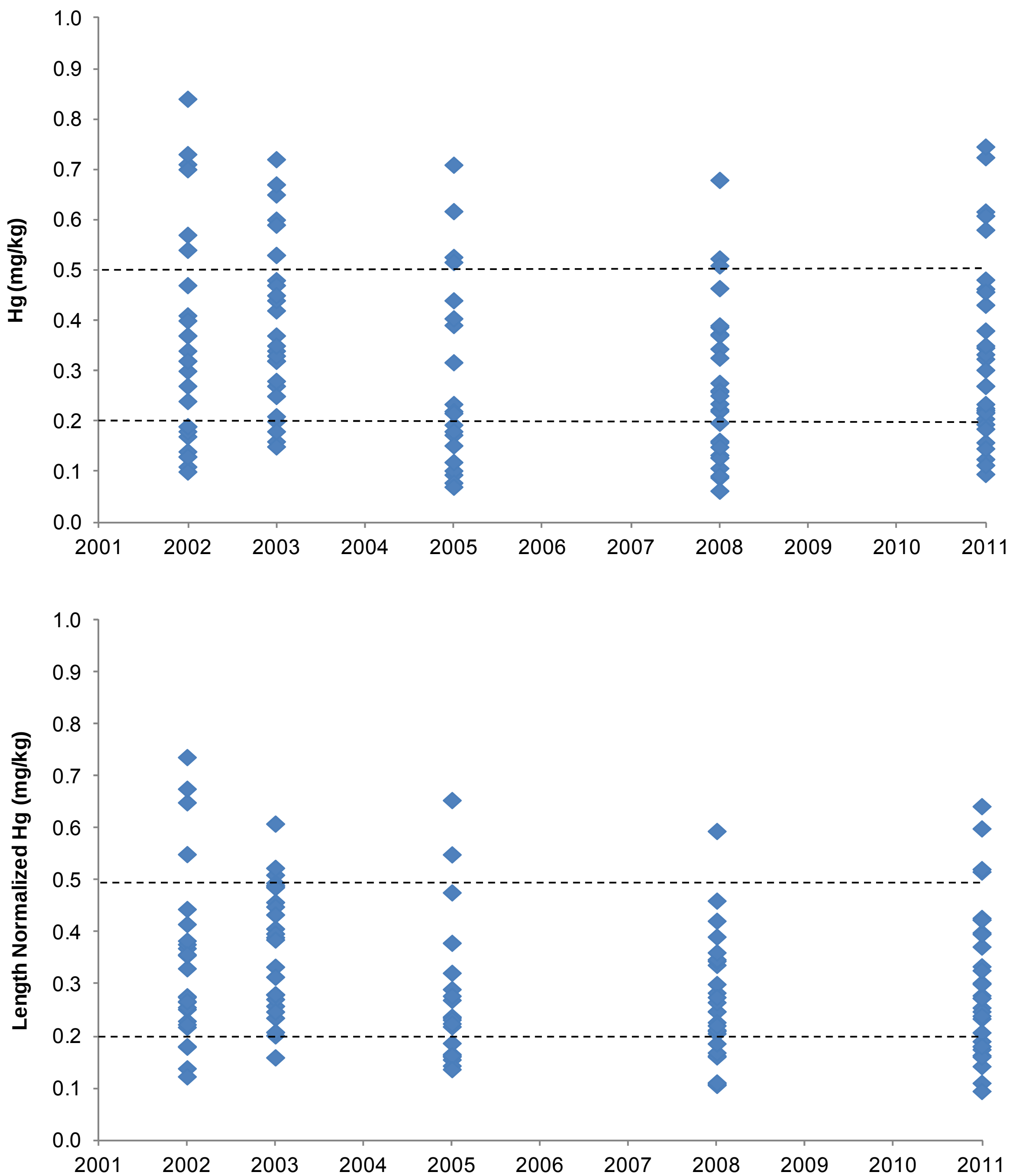
Figure 5.1-51 Temporal comparison of mercury concentrations and length-normalized mercury concentrations in lake whitefish from the Athabasca River, 2002, 2003, 2005, 2008, and 2011.





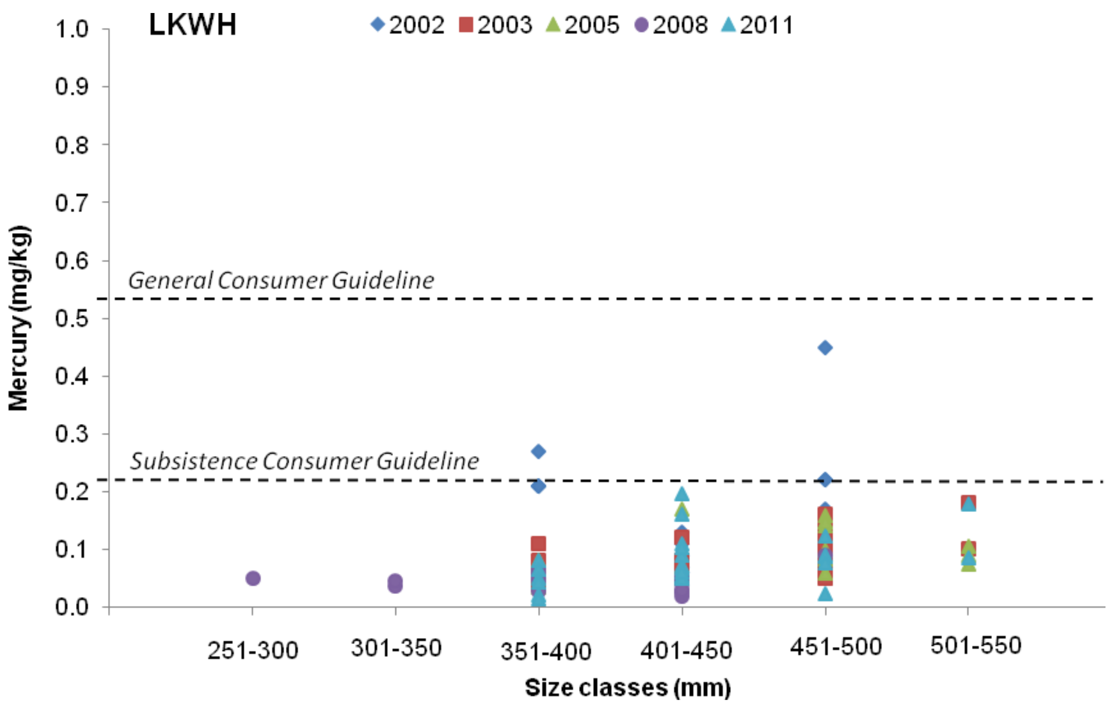
Note: length-normalized mercury concentrations are normalized to the mean length of lake whitefish captured.

Figure 5.1-52 Temporal comparison of mercury concentrations and length-normalized mercury concentrations in walleye from the Athabasca River, 2002, 2003, 2005, 2008, and 2011.



Note: length-normalized mercury concentrations are normalized to the mean length of walleye captured.

Figure 5.1-53 Temporal comparison of mercury concentrations by size class for lake whitefish (LKWH) and walleye (WALL) from the Athabasca River, 2002, 2003, 2005, 2008, and 2011.



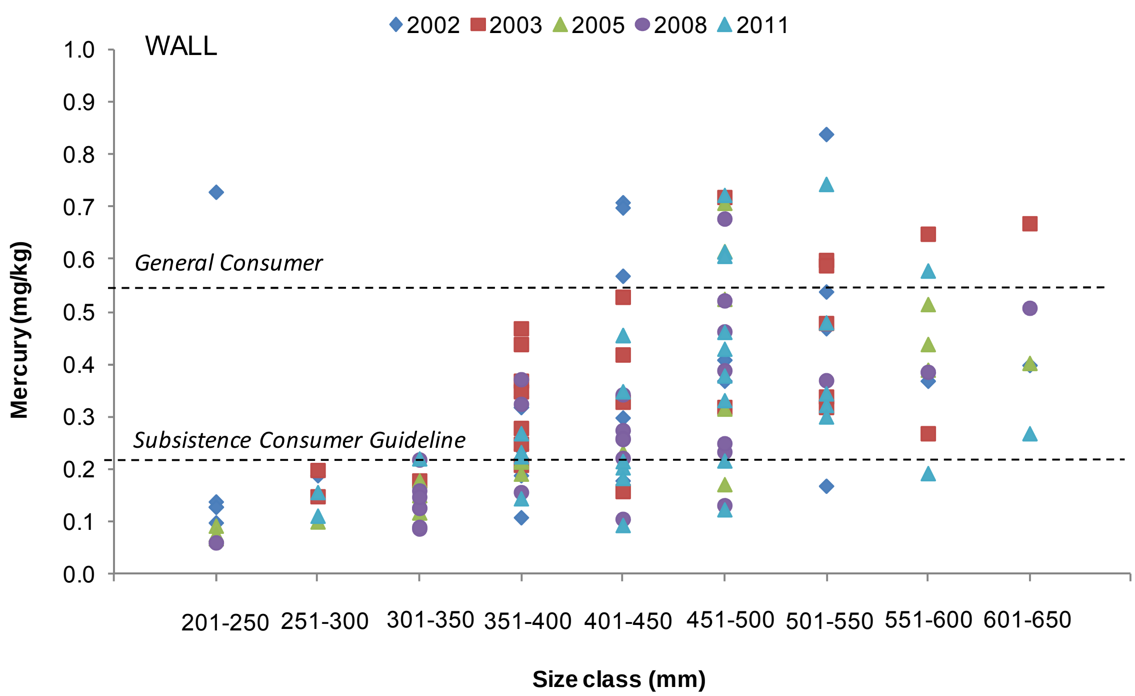


Table 5.1-24 Spearman rank correlations between mercury concentration (muscle) and length and age for walleye and lake whitefish collected from the Athabasca River, September 2011.

Metric	Lake whitefish			Walleye		
	Male	Female	Combined	Male	Female	Combined
	n = 9	n = 7	n = 24	n = 3[1]	n = 12[2]	n = 28[3]
Fork length	0.399	-0.481	0.424	**0.919**	-0.021	0.440
Age	0.684	-0.481	0.525	**-1.000**	0.732	0.700

[1] n = 2 for correlation between age and males

[2] n = 10 for correlation between age and females

[3] n = 12 for correlation between age and both male and females

value = moderate correlation (0.5 < |r| < 0.75)

value = strong correlation (|r| > 0.75)

value = significant correlation (|r| > critical value)

critical values at α=0.1: n=28, |r|=0.317; n=24, |r|=0.344; n=12, |r|=0.503; n=10, |r|=0.564; n=9, |r|=0.600; and n=7, |r|=0.714.

Figure 5.1-54 Mercury concentration in fish muscle versus length and age of lake whitefish (LKWH) and walleye (WALL) from the Athabasca River in 2011.

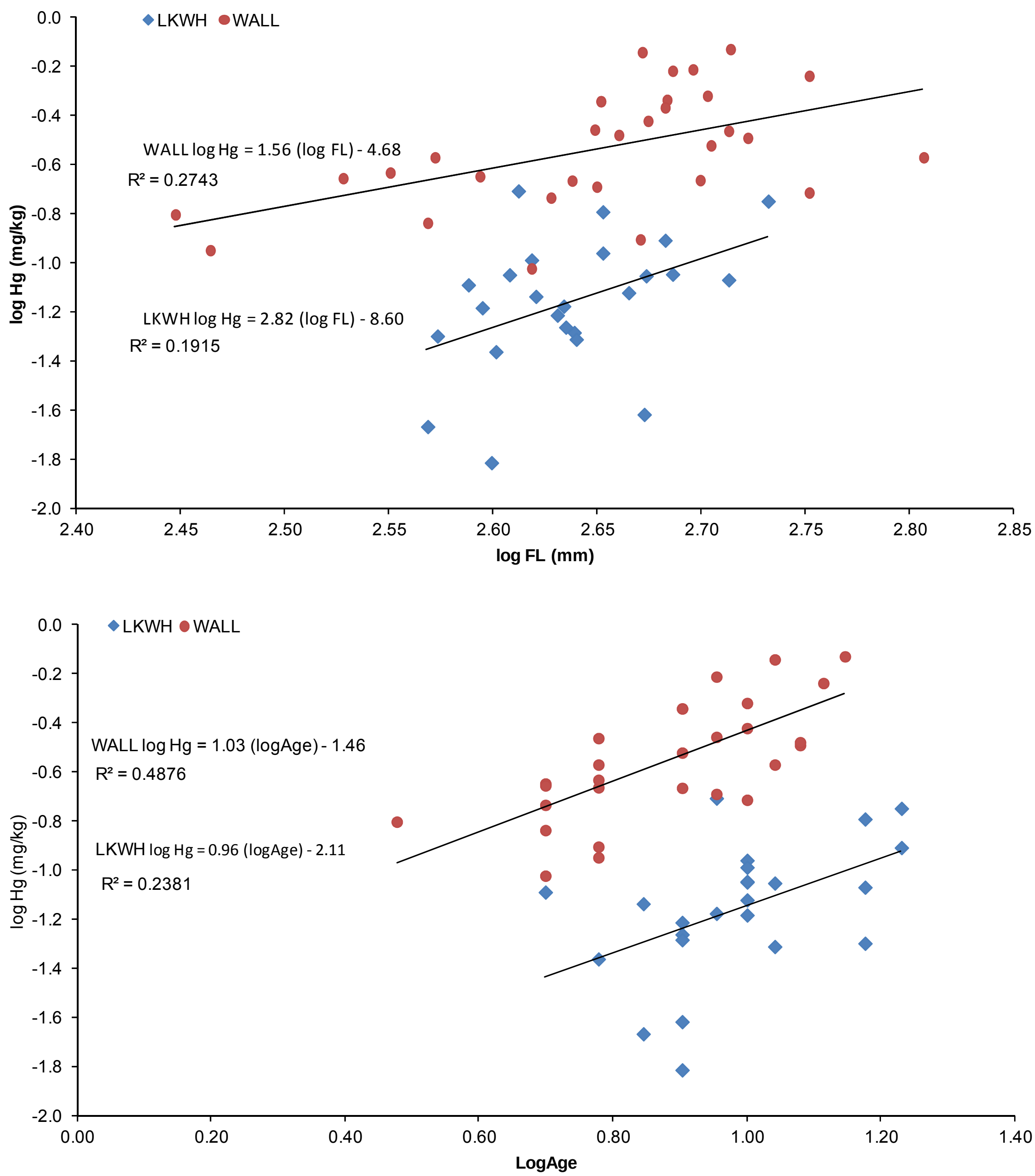


Table 5.1-25 Screening of metals and tainting compounds in lake whitefish and walleye composite samples collected in 2011 from the Athabasca River against fish consumption criteria for the protection of human health.

	Units	DL	Composite Lake whitefish[1]		Composite Walleye[2]			National USEPA[3]		Region III USEPA[4]
			Male (400-450 mm)	Female (400-450 mm)	Male (450-500 mm)	Female (450-500 mm)	Female (>500 mm)	Subsistence	Recreational	Risk-based Criteria
Total Metals										
Aluminum (Al)	mg/kg	2	<2.0	<2.0	<2.0	<2.0	<2.0	nc	nc	nc
Antimony (Sb)	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	0.54
Arsenic (As)[5]	mg/kg	0.01	**0.022**	**0.028**	**0.050**	**0.022**	**0.027**	0.00327	0.026	0.0021
Inorganic Arsenic[6]	mg/kg		0.0022	0.0028	**0.005**	0.0022	0.0027	0.00327	0.026	0.0021
Barium (Ba)	mg/kg	0.02	0.034	0.038	0.038	<0.020	0.022	nc	nc	270
Beryllium (Be)	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	nc	nc	2.7
Cadmium (Cd)	mg/kg	0.006	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	nc	nc	1.4
Calcium (Ca)	mg/kg	20	219	348	241	148	146	nc	nc	nc
Chromium (Cr)	mg/kg	0.1	0.167	0.068	0.169	0.062	0.157	nc	nc	4.1
Cobalt (Co)	mg/kg	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	nc	nc	nc
Copper (Cu)	mg/kg	0.05	0.190	0.151	0.252	0.168	0.187	nc	nc	54
Iron (Fe)	mg/kg	5	2.6	2.0	4.3	1.7	2.4	nc	nc	410
Lead (Pb)	mg/kg	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	nc	nc	nc
Magnesium (Mg)	mg/kg	5	274	267	248	298	297	nc	nc	nc
Manganese (Mn)	mg/kg	0.5	0.172	0.195	0.128	0.085	0.111	nc	nc	190
Molybdenum (Mo)	mg/kg	0.05	0.016	<0.010	0.015	<0.010	0.025	nc	nc	6.8
Nickel (Ni)	mg/kg	0.02	0.122	0.046	0.110	0.049	0.116	nc	nc	27
Phosphorus (P)	mg/kg	20	2140	1860	1850	2340	2240	nc	nc	nc
Potassium (K)	mg/kg	20	3960	3490	3490	4720	4520	nc	nc	nc
Selenium (Se)	mg/kg	0.002	0.294	0.284	0.285	0.391	0.212	2.457	20	6.8
Silver (Ag)	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	nc	nc	6.8
Sodium (Na)	mg/kg	20	320	386	409	241	239	nc	nc	nc
Strontium (Sr)	mg/kg	0.05	0.476	0.815	0.189	0.111	0.070	nc	nc	810
Thallium (Tl)	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	0.095
Tin (Sn)	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	nc	nc	810
Titanium (Ti)	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	nc	nc	nc
Vanadium (V)	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	nc	nc	1.4
Zinc (Zn)	mg/kg	0.5	2.66	2.37	3.62	2.76	2.86	nc	nc	410
Tainting Compounds										
Thiophene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc
Toluene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	110
m+p-Xylenes	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc
1,3,5-Trimethylbenzene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc
Naphthalene[7]	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	nc	nc	nc

value = exceeds Region III USEPA Risk-based Criteria

value = exceeds National USEPA Subsistence fishers

shaded value = exceeds National USEPA Recreational fisher guideline; nc = no criterion

[1] Composite sample taken from lake whitefish target size class (400-450 mm for males and females).

[2] Composite sampled taken from walleye target size class (450-500 mm for males; 450-500 mm and >500 mm for females).

[3] Last updated November 2000: http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/risk/upload/2009_04_23_fish_advice_volume1_v1cover.pdf

[4] Last updated June 2011: http://www.epa.gov/reg3hwmd/risk/human/pdf/JUNE_2011_FISH.pdf

[5] Guidelines refer to inorganic arsenic not total.

[6] Inorganic arsenic was estimated as 10% of total arsenic. This estimate was applied because inorganic arsenic concentrations were not actually evaluated. http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/risk/upload/2009_04_23_fish_advice_volume1_v1cover.pdf

[7] Naphthalene was tested for three target analytes: 1-Methylnaphthalene; 2,6-Dimethylnaphthalene; and 2,3,5-Trimethylnaphthalene all with a detection limit of 0.05 mg/kg.

Table 5.1-26 Screening of metals and tainting compounds in lake whitefish and walleye composite samples collected in 2011 from the Athabasca River against criteria for the protection of fish health.

	Units	DL	Composite Lake whitefish[1]		Composite Walleye[2]			Thresholds for the Protection of Fish[3]			
								Lowest no-effects thresholds		Lowest effects Thresholds	
			Male (400-450 mm)	Female (400-450 mm)	Male (450-500 mm)	Female (400-500 mm)	Female (>500 mm)	Lethal	Sublethal	Lethal	Sublethal
Total Metals											
Aluminum (Al)	mg/kg	2	<2.0	<2.0	<2.0	<2.0	<2.0	1	nc	20	nc
Antimony (Sb)	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	5	nc	9	nc
Arsenic (As)	mg/kg	0.01	0.022	0.028	0.050	0.022	0.027	2.6	0.9	11.2	3.1
Barium (Ba)	mg/kg	0.1	0.034	0.038	0.038	<0.020	0.022	nc	nc	nc	nc
Beryllium (Be)	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	nc	nc	nc	nc
Cadmium (Cd)	mg/kg	0.006	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	0.02	0.09	0.14	0.12
Calcium (Ca)	mg/kg	20	219	348	241	148	146	nc	nc	nc	nc
Chromium (Cr)	mg/kg	0.1	0.167	0.068	0.169	0.062	0.157	nc	nc	nc	nc
Cobalt (Co)	mg/kg	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	nc	nc	nc	nc
Copper (Cu)	mg/kg	0.05	0.190	0.151	0.252	0.168	0.187	0.5	3.4	0.5	0.3
Iron (Fe)	mg/kg	5	2.6	2.0	4.3	1.7	2.4	nc	nc	nc	nc
Lead (Pb)	mg/kg	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	4	nc	nc	nc
Magnesium (Mg)	mg/kg	5	274	267	248	298	297	nc	nc	nc	nc
Manganese (Mn)	mg/kg	0.5	0.172	0.195	0.128	0.085	0.111	nc	nc	nc	nc
Mercury (Hg)[4,5]	mg/kg	0.002	0.0785	0.115	0.673	0.422	0.580	1.91	2.28	3.7	8.6
Molybdenum (Mo)	mg/kg	0.05	0.016	<0.010	0.015	<0.010	0.025	nc	nc	nc	nc
Nickel (Ni)	mg/kg	0.02	0.122	0.046	0.110	0.049	0.116	0.82	nc	118.1	nc
Phosphorus (P)	mg/kg	20	2140	1860	1850	2340	2240	nc	nc	nc	nc
Potassium (K)	mg/kg	20	3960	3490	3490	4720	4520	nc	nc	nc	nc
Selenium (Se)	mg/kg	0.002	**0.294**	**0.284**	**0.285**	**0.391**	0.212	0.28	0.08	0.92	0.32
Silver (Ag)[6]	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	0.003	0.003	nc	nc
Sodium (Na)	mg/kg	20	320	386	409	241	239	nc	nc	nc	nc
Strontium (Sr)	mg/kg	0.05	0.476	0.815	0.189	0.111	0.070	nc	nc	nc	nc
Thallium (Tl)	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc	nc
Tin (Sn)	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	nc	nc	nc	nc
Titanium (Ti)	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	nc	nc	nc	nc
Vanadium (V)[6]	mg/kg	0.1	<0.10	<0.10	<0.10	<0.10	<0.10	5.33	0.02	nc	0.41
Zinc (Zn)	mg/kg	0.5	2.66	2.37	3.62	2.76	2.86	60	60	nc	nc
Tainting Compounds											
Thiophene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc	nc
Toluene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc	nc
m+p-Xylenes	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc	nc
1,3,5-Trimethylbenzene	mg/kg	0.01	<0.010	<0.010	<0.010	<0.010	<0.010	nc	nc	nc	nc
Naphthalene[7]	mg/kg	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	nc	nc	nc	nc

[1] Composite sample taken from lake whitefish target size class (400-450 mm for males and females).
[2] Composite sampled taken from walleye target size class (450-500 mm for males; 500-550 mm for females).
[3] Threshold values were derived from effects data for fish muscle tissue presented in Jarvinen and Ankley (1999).
[4] Threshold values were derived from methylated forms of mercury (Jarvinen and Ankley 1999).
[5] Mercury results are average values from individual samples.
[6] Threshold values are presented for carcass and not muscle tissue (Jarvinen and Ankley 1999).
value = exceeds sublethal lowest no-effects threshold
value = exceeds sublethal lowest effects threshold
value = exceeds lethal lowest no-effects threshold
shaded value = exceeds lethal lowest effects threshold
nc = no criteria
Threshold values were derived from effects data presented in Jarvinen and Ankley (1999).

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5.2 MUSKEG RIVER WATERSHED

Table 5.2-1 Summary of results for the Muskeg River watershed.

Muskeg River Watershed	Summary of 2011 Conditions: Muskeg River			Jackpine Creek		Other						
Climate and Hydrology												
Criteria	**S7** near Fort McKay (test)										**L2** Kearl Lake (baseline)	**S9** Kearl Lake Outlet (baseline)
Mean open-water season discharge	Moderate										not measured	not measured
Mean winter discharge	High										not measured	not measured
Annual maximum daily discharge	Negligible-Low										not measured	not measured
Minimum open-water season discharge	High										not measured	not measured
Water Quality												
Criteria	**MUR-1** at the mouth (test)	no station sampled	**MUR-6** upstream of Wapasu Creek (test)	**JAC-1** at the mouth (test)	**JAC-2** upper station (baseline)	**MUC-1** Muskeg Creek at the mouth (test)	**STC-1** Stanley Creek at the mouth (test)	**SHC-1** Shelley Creek at the mouth (test)	**WAC-1** Wapasu Creek at Canterra Road (test)	**IYC-1** Iyinimin Creek (test)	**KEL-1** Kearl Lake (test)	no station sampled
Water Quality Index	Negligible-Low		Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	ns	Negligible-Low	Negligible-Low	Negligible-Low	
Benthic Invertebrate Communities and Sediment Quality												
Criteria	**MUR-E1** lower reach (test)	**MUR-D2** middle reach (test)	**MUR-D3** upper reach (test)	**JAC-D1** lower reach (test)	**JAC-D2** upper reach (baseline)	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled	**KEL-1** Kearl Lake (test)	no reach sampled
Benthic Invertebrate Communities	Negligible-Low	Negligible-Low	Moderate	Moderate	n/a						Moderate	
Sediment Quality Index	n/a	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low						Negligible-Low	
Fish Populations												
Criteria	**MUR-E1** lower reach (test)	**MUR-D2** middle reach (test)	**MUR-D3** upper reach (test)	**JAC-D1** lower reach (test)	**JAC-D2** upper reach (baseline)	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled
Fish Assemblages	Negligible-Low	Moderate	Negligible-Low	Negligible-Low	n/a							

Legend and Notes

- ○ Negligible-Low
- ● Moderate
- ● High

baseline (green shading)
test (blue shading)

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with *baseline* reaches and/or regional *baseline* conditions.

ns = not sampled given the creek no longer had water due to project development.

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

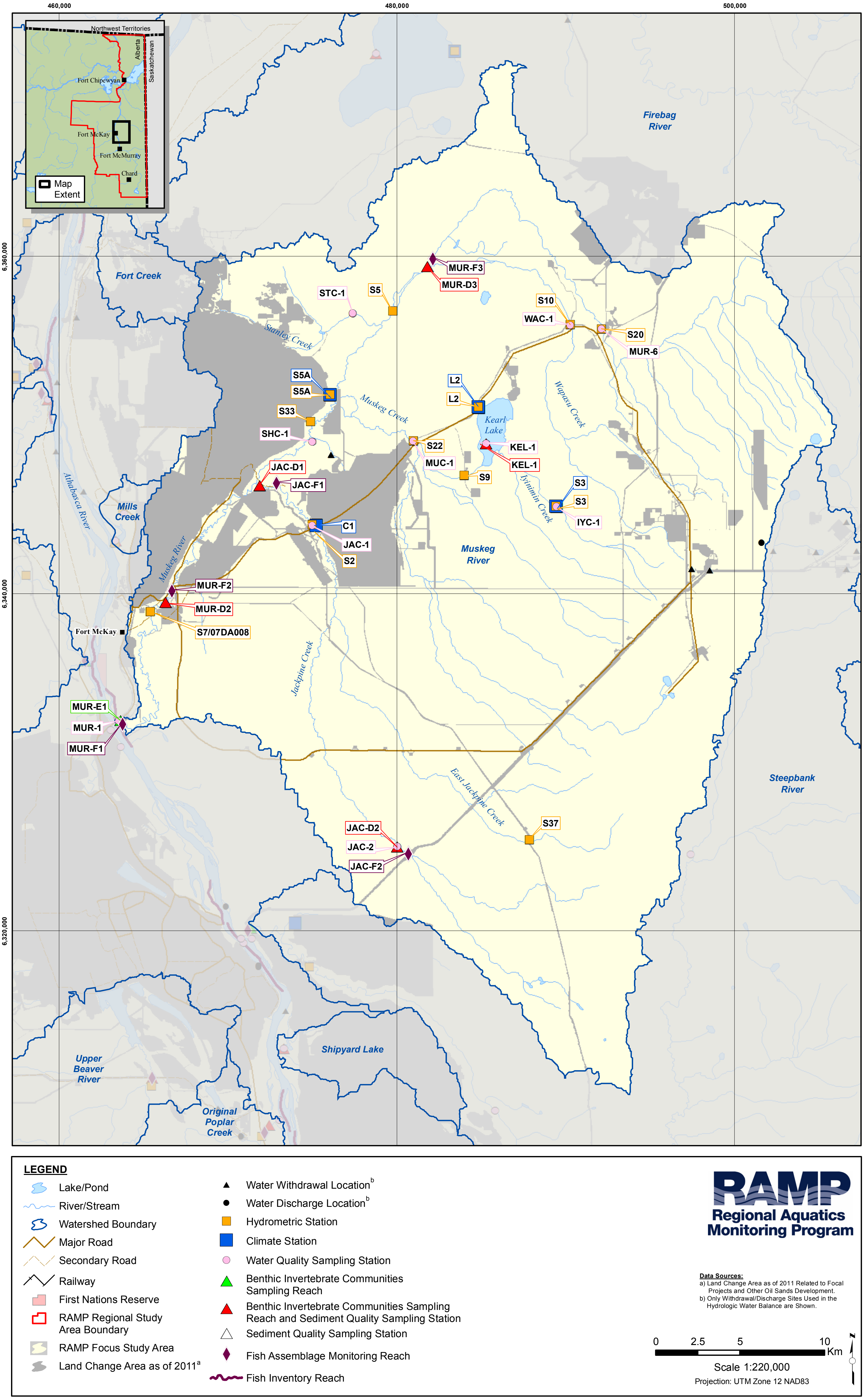
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional baseline conditions; 60 to 80: Moderate difference from regional baseline conditions; Less than 60: High difference from regional baseline conditions.

Benthic Invertebrate Communities: Classification based on statistical differences in measurement endpoints between baseline and test areas as well as comparison to regional baselines; see Section 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional baseline conditions; 60 to 80: Moderate difference from regional baseline conditions; Less than 60: High difference from regional baseline conditions.

Fish Populations: Classification based on differences in measurement endpoints from the range of variation in regional *baseline* conditions; see Section 3.2.4.3 for a description of the classification methodology.

Figure 5.2-1 Muskeg River watershed.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_K02_Muskeg_20120423.mxd

Figure 5.2-2 Representative monitoring stations of the Muskeg River watershed, 2011.

Benthic Invertebrate Reach MUR-E1 (Muskeg River): facing upstream

Water Quality Station IYC-1 (Iyinimin Creek): facing downstream

Benthic and Sediment Quality Reach MUR-D3 (Muskeg Creek): facing upstream

Benthic and Sediment Quality Reach JAC-D2 (Jackpine Creek): facing downstream

Benthic and Sediment Quality Reach JAC-D1 (Jackpine Creek): facing upstream

Water Quality Station STC-1 (Stanley Creek)

Hydrology Station S10 (Wapasu Creek)

Water Quality Station KEL-1: Kearl Lake

5.2.1 Summary of 2011 Conditions

As of 2011, approximately 13% (18,772 ha) of the Muskeg River watershed had undergone land change from focal projects (Table 2.5-2). The designations of specific areas of the Muskeg River 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 the upper portion of Jackpine Creek, is designated as *baseline*.

Monitoring programs were conducted for the Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components of RAMP in the Muskeg River watershed in 2011. Table 5.2-1 is a summary of the 2011 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 2011 in the Muskeg River watershed. Figure 5.2-2 contains fall 2011 photos of monitoring stations in the watershed.

Hydrology The calculated mean open-water discharge was 7.1% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Moderate.** The calculated mean winter discharge and the open-water period minimum daily discharge were 85% and 261% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph, respectively. These differences were classified as **High**. The calculated annual maximum daily discharge was 4.4% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low.**

Water Quality Concentrations of many water quality measurement endpoints in Jackpine Creek were higher than previously-measured maximum concentrations, primarily in dissolved species. Concentrations of water quality measurement endpoints in other portions of the Muskeg River watershed in fall 2011 were mostly within the range of previously-measured concentrations and generally consistent with regional *baseline* conditions. Differences in water quality in fall 2011 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions were classified as **Negligible-Low**. Shelley Creek (*test* station SHL-1) could not be sampled in 2011 because water has been diverted from this creek by approved oil-sands development.

Benthic Invertebrate Communities and Sediment Quality Differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-E1 in fall 2011 were classified as **Negligible-Low** because the significant increase in total abundance in 2011 relative to 2010 and previous years did not coincide with changes in other measurement endpoints that would imply a negative change to the benthic invertebrate community (i.e., richness and diversity were also higher). The increase in total abundance (> 150,000 individuals per m^2 in 2011) could imply a significant increase in available habitat (or nutrients) for the benthic invertebrate community. The benthic invertebrate community at *test* reach MUR-E1; however, appeared to be in good condition given the high relative abundances of mayflies, caddisflies and the presence of stoneflies. The percent of the fauna as worms (tubificids and naidids) was generally consistent with previous years indicating no significant change in the quality of the habitat (i.e., water and sediment quality).

The differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-D2 in fall 2011 were classified as **Negligible-Low** because there was an increase in percent EPT, which did not imply a negative change and all measurement endpoints with the exception richness were within the range of variation for *baseline* depositional reaches. In fall 2011, richness exceeded the 95th percentile of regional *baseline* conditions, which was not indicative of degraded habitat.

The differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-D3 in fall 2011 were classified as **Moderate** because the decrease in taxa richness from the *baseline* period to the *test* period explained 25% of the variation in annual means. In addition, the shift in composition suggested by variations in CA Axis 2 scores reflected an absence of *Hydracarina* in the reach over the last three years, an increase in tubificid worms in 2011, and a decrease in the relative abundance of mayflies. The absence of *Hydracarina* (i.e., water mites) is informative given that mites are not good "indicators" of water or substrate quality and the increase in the relative abundance of tubificid worms may indicate degraded conditions of the water or sediment quality. The percentage of fauna as tubificids has always been higher at *test* reach MUR-D3 than middle *test* reach MUR-D2 despite the fact that *test* reach MUR-D2 has been designated as *test* since RAMP began sampling this reach in 2000. The decrease in the relative abundance of mayflies at *test* reach MUR-D3 may also indicate degraded conditions.

Differences in the benthic invertebrate community at *test* reach JAC-D1 as of fall 2011 were classified as **Negligible-Low** because of the significant increases over time in taxa richness, diversity, and evenness at reach JAC-D1 once the reach became *test* did not imply a negative change in the benthic invertebrate community. In addition, values of some measurement endpoints in fall 2011 for benthic invertebrate communities at both *test* reach JAC-D1 and *baseline* reach JAC-D2 exceeded the range of regional *baseline* conditions, but were not indicative of degraded conditions.

Differences in measurement endpoints for benthic invertebrate communities at *test* station KEL-1 were classified as **Moderate** because of the significant decrease in percent EPT (i.e., mayflies and caddisflies) and the increase in multivariate CA Axis scores compared to the period when Kearl Lake was designated as *baseline*. The benthic invertebrate community of Kearl Lake contained a diverse fauna and included several taxa that are typically associated with relatively good water and sediment quality in lakes (e.g., the mayfly *Caenis* and the caddisfly *Mystacides*). The benthic invertebrate community of Kearl Lake in fall 2011 also contained higher relative abundances of ostracods and mites (totaling over 40% of total numbers) compared to previous years and compared to other lakes in *baseline* condition in the RAMP FSA.

Sediment quality at all Muskeg River watershed stations sampled in fall 2011 was generally consistent with that of previous years and regional *baseline* conditions. Concentrations of total PAHs at all stations were within previously-measured concentrations with a few exceptions where concentrations of PAHs were lower than previously-measured concentrations. Differences in sediment quality in fall 2011 at all four stations in the Muskeg River watershed were assessed as **Negligible-Low** compared to regional *baseline* conditions.

Fish Populations Differences in measurement endpoints for fish assemblages between *test* reaches MUR-F1 and MUR-F3 and regional *baseline* conditions were classified as **Negligible-Low** given that most measurement endpoints were within the regional range of variation of *baseline* reaches. Differences in measurement endpoints for fish assemblages between *test* reach MUR-F2 and regional *baseline* conditions were classified as **Moderate** given all measurement endpoints were lower than the range of variation of *baseline* reaches. Differences in measurement endpoints for fish assemblages between *test* reach JAC-D1 and *baseline* reach JAC-D2 and regional *baseline* conditions were classified as **Negligible-Low** given all measurement endpoints were within the regional range of variation of *baseline* reaches.

5.2.2 Hydrologic Conditions: 2011 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 2011. Seasonal data from March to October have been collected every year since 1974. The 2011 water year (WY) annual runoff volume of 43.5 million m^3 was 61% lower than the historical mean annual runoff volume of 110.9 million m^3. The open-water (May to October) runoff volume of 29.1 million m^3 was 72% lower than the historical mean open-water runoff volume of 103.7 million m^3. Flows decreased from November 2010 to late January 2011 with flows in November and December similar to historical median values and flows from January to the beginning of the freshet in early April generally in the lowest quartile of historical flows (Figure 5.2-3). Flows increased during the spring freshet to a peak of 9.2 m^3/s on May 10, which was the maximum daily flow recorded in the 2011 WY and 59% lower than the historical mean annual maximum daily flow of 22.3 m^3/s. After the freshet, flows generally decreased until the lowest open-water flow of 0.29 m^3/s on August 28. This value was 73% lower than the historical mean open-water minimum daily flow, and in the lowest quartile of historical flows recorded on this date in previous years. Flows then increased slightly until the end of the 2011 WY, but remained within the lowest quartile of historical flows.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07DA008 (RAMP Station S7) for the 2011 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 2011 was estimated to be 118.7 km^2 (Table 2.5-1). The loss of flow to the Muskeg River that would have otherwise occurred from this land area was estimated at approximately 3.10 million m^3.

2. As of 2011, the area of land change in the Muskeg River watershed from focal projects that was not closed-circuited was estimated to be 69.0 km^2 (Table 2.5-1). The increase in flow to the Muskeg River that would not have otherwise occurred from this land area was estimated at 0.36 million m^3.

3. Syncrude discharged 8.95 million m^3 of water into Stanley Creek via the Aurora Clean Water Diversion (CWD). As in previous water balance calculations involving the CWD (e.g., RAMP 2008, RAMP 2009a, RAMP 2010, RAMP 2011), 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. Given that some of the CWD flows are diverted surface water, some proportion of this water likely would have contributed to the Muskeg River naturally; however, this is currently undefined.

   In 2011 WY, the proportional contribution of the water volume released from the CWD to runoff volumes recorded at the mouth of the Muskeg River, was greater than in previous years. Although the CWD volumes were similar (approximately 9 million m^3 in the 2010 and 2011 WYs), the observed runoff at WSC Station 07DA008 (RAMP Station S7) was 43.5 million m^3 in the 2011 WY, which was less than half of the 2010 WY runoff volume (94 million m^3). The CWD volume has also been increasing across years (the CWD volume in 2007 was approximately 2 million m^3). It is recommended that additional information regarding the CWD be provided and incorporated for future analyses.

4. Suncor withdrew 0.01 million m^3 of water to support dust suppression activities, and released 0.001 million m^3 of water for water management activities associated with the Firebag project.

5. Shell withdrew 0.12 million m^3 of water to support drilling and dust suppression activities associated with the Jackpine Mine.

The estimated cumulative effect of land change, water withdrawals, and water releases was an increase in flow of 6.08 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 was 7.1% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Moderate.** The calculated mean winter discharge and the open-water period minimum daily discharge were 85% and 261% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph, respectively (Table 5.2-3). These differences were classified as **High** (Table 5.2-1). The calculated annual maximum daily discharge was 4.4% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.2-3). This difference was classified as **Negligible-Low** (Table 5.2-1).

Kearl Lake

RAMP 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 2011 WY, lake levels showed a gradual decrease from November 2010 to early April 2011 with values similar to the historical median values recorded during this period (Figure 5.2-4). Lake levels increased slightly during the spring freshet, but were much lower than previous years and levels from May 5 to 18 were close to the historical minimum levels recorded during this period. After the freshet, lake levels gradually decreased until the end of the 2011 WY with values consistently below the historical lower quartile. From July 16 to 24 and from August 31 to the end of the 2011 WY, lake levels were below the historical minimum values recorded for these time periods (Figure 5.2-4).

5.2.3 Water Quality

In fall 2011, water quality samples were taken from:

- the Muskeg River near its mouth (*test* station MUR-1, sampled from 1997 to 2011);
- the Muskeg River upstream of Wapasu Creek (*test* station MUR-6, designated as *baseline* from 1998 to 2007 and *test* from 2008 to 2011);
- Jackpine Creek near its mouth (*test* station JAC-1, designated as *baseline* from 1998 to 2005 and *test* from 2006 to 2011);
- upper Jackpine Creek (*baseline* station JAC-2, sampled from 2008 to 2011);
- Muskeg Creek near its mouth (*test* station MUC-1, sampled intermittently from 1998 to 2011, designated as *baseline* from 1998 to 2007 and *test* from 2008 to 2011);
- Stanley Creek near its mouth (*test* station STC-1, designated as *baseline* from 2001 to 2002 and *test* from 2003 to 2011);

- Iyinimin Creek near its mouth (*test* station IYC-1, sampled in 2007, 2008, 2010 and 2011, designated as *baseline* from 2007 to 2008 and *test* from 2010 to 2011);
- Wapasu Creek near its mouth (*test* station WAC-1, sampled intermittently from 1998 to 2011, designated as *baseline* from 1998 to 2006 and *test* from 2007 to 2011); and
- Kearl Lake (*test* station KEL-1, designated as *baseline* from 1998 to 2008 and *test* from 2009 to 2011).

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 boron at *test* station MUR-6;
- A decreasing concentration of total arsenic and an increasing concentration of total boron at *test* station STC-1;
- Decreasing concentrations of total arsenic and sulphate and an increasing concentration of total nitrogen at *test* station WAC-1; and
- Decreasing concentrations of magnesium, sulphate and total dissolved phosphorus, and an increasing concentration of total nitrogen at *test* station KEL-1.

No trends were detected at *test* stations MUR-1 and JAC-1, and trend analyses could not be completed for *baseline* stations JAC-2 or IYC-1 due to an insufficient number of sampling years.

2011 Results Relative to Historical Concentrations Concentrations of water quality measurement endpoints exceeded previously-measured minimum and maximum concentrations at most stations. In particular, many ions and other dissolved fractions were found at high concentrations compared to previous years. Water quality measurement endpoints that were outside previously-measured concentrations were (Table 5.2-4 to Table 5.2-12):

- pH, with a value that exceeded the previously-measured maximum value and dissolved aluminum, with a concentration that was lower than the previously-measured minimum concentration at *test* station MUR-1;
- conductivity with a value that exceeded the previously-measured maximum value, and total and dissolved aluminum and magnesium, with concentrations that were lower than previously-measured minimum concentrations at *test* station MUR-6;
- pH, with a value that exceeded the previously-measured maximum value and total aluminum, with a concentration that was lower than the previously-measured minimum concentration at *test* station MUC-1;
- conductivity, total dissolved solids, total alkalinity, calcium, magnesium, sodium, sulphate, total strontium and total boron, with concentrations that exceeded previously-measured maximum concentrations and total and dissolved aluminum, with concentrations that were lower than previously-measured minimum concentrations at *test* station JAC-1;
- pH, conductivity, total dissolved solids, total alkalinity, calcium, magnesium, sodium, chloride, total strontium total molybdenum, total boron, total suspended solids, total arsenic and total dissolved phosphorus, with

concentrations that exceeded previously-measured maximum concentrations and dissolved aluminum with a concentration that was lower than the previously-measured minimum concentration at *baseline* station JAC-2;

- pH, with a value that exceeded the previously-measured maximum value at *test* station STC-1;
- total dissolved solids, total strontium and total dissolved phosphorus, with concentrations that exceeded previously-measured maximum concentrations and dissolved aluminum, with a concentration that was lower than the previously-measured minimum concentration at *test* station WAC-1;
- pH, conductivity, total dissolved solids, total alkalinity, calcium, magnesium, sodium, sulphate, total boron, total strontium and total molybdenum, with concentrations that exceeded previously-measured maximum concentrations and total and dissolved aluminum and total nitrogen, and dissolved organic carbon, with concentrations that were lower than previously-measured minimum concentrations at *test* station IYC-1; and
- conductivity, total alkalinity, and dissolved organic carbon, with concentrations that exceeded previously-measured maximum concentrations and sulphate, with a concentration that was lower than the previously-measured minimum concentration at *test* station KEL-1.

Generally high conductivity, alkalinity and concentrations of major ions and other dissolved fractions of water quality at all stations likely reflected the very low flows observed in the Muskeg River watershed throughout summer and fall 2011.

Ion balance The ionic composition of water in the Muskeg River watershed in fall 2011 was similar to that measured in previous years (Figure 5.2-5, Figure 5.2-6), despite historically high absolute concentrations of ions measured at many stations. The absence of a shift in relative ionic composition indicates that historically high ion concentrations measured at several stations was related to a lack of ion dilution by surface runoff and a greater influence of shallow groundwater in surface water in these watercourses in fall 2011, which is consistent with the very low precipitation and flow observed from spring to fall in the Muskeg River watershed (Figure 5.2-3).

The ionic composition of water in Stanley Creek (*test* station STC-1) has historically shown the greatest variability of all stations (Figure 5.2-6), indicating influence of site-drainage water from Syncrude's Aurora North project ("Clean Water Diversion"). In the last four years; however, 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 sampling years with anions dominated by calcium bicarbonate and low concentrations of sodium and potassium chloride (Figure 5.2-6).

Comparison of Fall Water Quality Measurement Endpoints to Published Guidelines In fall 2011, concentrations of water quality measurement endpoints at stations in the Muskeg River watershed were below water quality guidelines with the exception of:

- total aluminum at *baseline* station JAC-2 (Table 5.2-8) and *test* station MUR-1 (Table 5.2-4); and
- total nitrogen at *test* stations WAC-1 and KEL-1 (Table 5.2-10 and Table 5.2-12).

Other Water Quality Guideline Exceedances The following other water quality measurement endpoints exceeded water quality guidelines in the Muskeg River watershed in fall 2011 (Table 5.2-13):

- dissolved iron at *baseline* station JAC-2 and *test* stations MUC-1 and IYC-1;
- sulphide at *baseline* station JAC-2 and *test* stations MUC-1 and KEL-1;
- total chromium at *test* station MUR-1;
- total iron at *baseline* station JAC-2 and *test* stations MUR-1, MUC-1, JAC-1, WAC-1 and IYC-1;
- total Kjeldahl nitrogen at *test* station KEL-1; and
- total phenols at all stations.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2011 at *test* stations MUR-1, MUR-6, JAC-1, STC-1, IYC-1, and WAC-1, and *baseline* station JAC-2 were within regional *baseline* concentrations with the exception of (Figure 5.2-7 to Figure 5.2-8; regional *baseline* values are reported in Section 3):

- chloride, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *test* stations MUR-1 and JAC-1;
- dissolved phosphorous, with concentrations that were below the 5th percentile of regional *baseline* concentrations at *test* stations MUR-1 and JAC-1;
- magnesium, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* stations MUR-6 and WAC-1;
- sodium, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station JAC-2 and *test* station IYC-1;
- sulphate, with concentrations that were below the 5th percentile of regional *baseline* concentrations at *test* stations STC-1 and WAC-1, and exceeded the 95th percentile of regional *baseline* concentrations at *test* stations IYC-1 and JAC-1;
- total dissolved solids, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *test* station IYC-1;
- total arsenic, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *baseline* station JAC-2 and was below the 5th percentile of its regional *baseline* concentrations at *test* station STC-1;
- total boron, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station JAC-2 and *test* station IYC-1;
- total mercury, with concentrations that were below the 5th percentile of regional *baseline* concentrations at all stations (in summer 2010, the analytical detection limit for total mercury was reduced resulting in concentrations of total mercury that were lower than previously-measured minimum concentrations);
- total nitrogen, with a concentration that was below the 5th percentile of its regional *baseline* concentrations at *test* station STC-1; and
- total strontium, with a concentration that exceeded the 95th percentile of its regional *baseline* concentrations at *test* station JAC-1.

Concentrations of water quality measurement endpoints in Kearl Lake (Figure 5.2-9) 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. A range of regional *baseline* conditions was not calculated for lakes that are sampled by RAMP due to the limited *baseline* data available.

Water Quality Index The WQI values for all stations in the Muskeg River watershed in fall 2011 indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.2-14).

Classification of Results Concentrations of many water quality measurement endpoints in Jackpine Creek were higher than previously-measured maximum concentrations, primarily in dissolved species. Concentrations of water quality measurement endpoints in other portions of the Muskeg River watershed in fall 2011 were mostly within the range of previously-measured concentrations and generally consistent with regional *baseline* conditions. Differences in water quality in fall 2011 at all stations in the Muskeg River watershed compared to regional *baseline* water quality conditions were classified as **Negligible-Low**.

5.2.4 Benthic Invertebrate Communities and Sediment Quality

5.2.4.1 Benthic Invertebrate Communities

Muskeg River Mainstem

Benthic invertebrate communities were sampled in fall 2011 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, designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2011.

2011 Habitat Conditions Water at *test* reach MUR-E1 in fall 2011 was shallow (0.3 m), fast flowing (1.12 m/s), alkaline (pH: 8.2), with high conductivity (426 µS/cm) (Table 5.2-14). The substrate was dominated by small cobble (36%) and large gravel (30%) with small amounts of gravel (11%) and large cobble (11%). Periphyton chlorophyll *a* biomass averaged 34 mg/m^2, which was within regional *baseline* conditions (Figure 5.2-10).

Water at *test* reach MUR-D2 in fall 2011 was moderately deep (1.4 m), slow flowing (0.07 m/s), weakly alkaline (pH: 7.4), with high conductivity (440 µS/cm) (Table 5.2-14). The substrate was dominated by sand (72%) with a moderate amount of silt (22%) and low total organic carbon content (3.3%).

Water at *test* reach MUR-D3 in fall 2011 was deep (1.6 m), alkaline (pH: 7.9), with negligible flow, moderate conductivity (248 µS/cm) and low dissolved oxygen (5.5 mg/L) (Table 5.2-15). The substrate was dominated by sand (82%) with small amounts of silt and clay and a moderate level of organic carbon (10%).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach MUR-E1 in fall 2011 was dominated by Ephemeroptera (34%) and chironomids (27%) with subdominant taxa consisting of Hydracarina (10%) and naidid worms (11%) (Table 5.2-16). Chironomids were diverse, consisting of many common forms (Wiederholm 1983) including *Micropsectra*, *Tanytarsus, Cricotopus*, *Orthocladius*, *Corynoneura*, *Ablabesmyia* and *Thienemannimuia gr.* Mayfly taxa included the common forms (Merritt and Cummins 1996) *Acerpenna* and *Baetis,* as well as other forms that require good water quality (i.e., *Heptagenia*) (Mandaville 2001). Caddisflies (Trichoptera; *Protoptila* and *Psychomyia)* and stoneflies (Plecoptera; Chloroperlidae and *lsoperla*) were present in low relative abundances. Fingernail and pea clams (*Pisidium* and *Sphaerium*) and the Gastropod limpet (*Ferrissia rivularis*) were also present at this reach (Table 5.2-16).

The benthic invertebrate community at *test* reach MUR-D2 in fall 2011 was dominated by chironomids (58%) with subdominant taxa consisting of Cladocera (8%), Ephemeroptera (6%) and nematodes (5%) (Table 5.2-17). Chironomids were diverse and included *Cladotanytarsus*, *Pagastiella*, *Tanytarsus*, *Larsia*, and *Parametriocnemus.* Mayfly genera (Ephemeroptera) included *Caenis, Callibaetis,* and *Acerpenna.* Caddisflies (Trichoptera; *Polycentropus* and *Lepidostoma)* were present in lower relative abundance.

The benthic invertebrate community at *test* reach MUR-D3 was dominated by chironomids (30%) and tubificid worms (26%), with subdominant taxa consisting of fingernail clams (17%) and ostracods (9%) (Table 5.2-19). Dominant chironomids included the common forms (Wiederholm 1983) *Procladius*, *Polypedilum Micropsectra,* and *Tanytarsus.* Mayflies (Ephemeroptera; *Leptophlebia)* were present in low relative abundance and caddisflies and stoneflies (Plecoptera) were absent.

Temporal Comparisons Changes in time trends 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. In addition, based on a visual assessment of the differences in results from 2011 compared to previous years, the variation in measurement endpoints in 2011 were tested against previous years to quantify the percent of variation in annual means accounted for by the changes. A Spearman rank correlation was used to test the significance of time trends in the last six years of the data record.

Total abundance significantly increased and CA Axis 2 scores decreased significantly over time at lower *test* reach MUR-E1 (Table 5.2-19, Figure 5.2-11, Figure 5.2-11). The time trends for both of these measurement endpoints explained only 7% of the variation in the annual means for *test* reach MUR-E1 (Table 5.2-19). Total abundance was much higher in 2011 than previous years, explaining 49% of the variation in annual means (Table 5.2-19). The difference in CA Axis 2 in 2011 compared to previous years only explained 7% of variance in annual means (Table 5.2-19). Although the CA Axis 2 score was below the mean in 2011, it was greater than fall 2010 (Figure 5.2-12). The increase in total abundance over the past six years was also shown by the Spearman rank correlation (r_s = 0.89) (Table 5.2-19).

Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for middle *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*. In addition, based on a visual assessment of the differences in results from 2011 compared to previous years, the variation in measurement endpoints in 2011 were tested against previous years to quantify the percent of variation in annual means accounted for by the changes. A Spearman rank correlation was used to test the significance of time trends in the last six years of the data record.

There were significant increases in taxa richness, diversity and percent EPT, and significant decreases in CA Axes 1 and 2 over time at *test* reach MUR-D2 (Table 5.2-20, Figure 5.2-13, and Figure 5.2-14). The change in percent EPT and CA Axis 2; however, were the only changes that explained more than 20% of the variation in annual means (Table 5.2-20). The decrease in CA Axis 2 reflected an increase in the relative abundance of Gastropoda (Figure 5.2-14). There were also significant increases in abundance, taxa richness, diversity, and percent EPT, and a significant decrease in CA Axis 2 in 2011 compared to previous years; however, the variation in annual means was greater than 20% for only percent EPT (Table 5.2-20). There were no significant trends over the past six years in any measurement endpoint; however, taxa richness has increased significantly over the past eight years (r_s=0.85) (Table 5.2-20).

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, explaining 25% of the variation in annual means (Table 5.2-21, Figure 5.2-15, and Figure 5.2-16).

Second, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that reach MUR-D3 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). There were significant decreases in percent EPT and CA Axis 1 scores, and a significant increase in CA Axis 2 scores over time during the period when reach MUR-D3 was designated as *test* (Table 5.2-21). The decrease in percent EPT explained 15% of the variation in annual means while the increase in CA Axis 2, explained more than 20% of the variation in annual means and reflected a decrease in the relative abundance in *Hydracarina* over time (Figure 5.2-16).

Comparison to Published Literature The benthic invertebrate community at *test* reach MUR-E1 in fall 2011 had a very high total abundance (> 150,000 individuals per m^2). Benthic invertebrate communities with abundances that high are generally degraded, often due to nutrient enrichment effects (Burt *et al.* 1991, Diggins and Snyder 2003). The benthic invertebrate community at *test* reach MUR-E1; however, remained diverse with an average of 36 taxa per sample and contained a number of taxa that are considered sensitive including the mayfly *Heptagenia*, the caddisflies *Protoptila* and *Psychomyia*, and the stonefly *Isoperla* (Hynes 1960, Mandaville 2001, Griffiths 1998). The percentage of the community as worms (especially tubificids) was low (i.e., 2% for tubificids) indicating that concentrations of dissolved oxygen were high enough (~ 8 mg/L at the time of sampling) to sustain the diversity of fauna. The density of periphyton chlorophyll *a* was consistent with previous years.

The benthic invertebrate community at *test* reach MUR-D2 was diverse with a mean of approximately 25 taxa per sample. The benthic invertebrate community included a number of taxa that are considered relatively sensitive including the mayflies *Caenis*, *Callibaetis* and *Acerpenna*, and the caddisflies *Polycentropus* and *Lepidostoma*. Tubificid worms were less than 5% of the total fauna (Table 5.2-17), indicating good habitat quality (Hynes 1960, Griffiths 1998).

The benthic invertebrate community at *test* reach MUR-D3 reflected the depositional nature of the river. The benthic invertebrate community was dominated by chironomids (30%) and tubificid worms (26%). Tubificids accounted for a high relative abundance of greater than 30%, which can indicate degradation or the addition of nutrients (Hynes 1960, Griffiths 1998). The benthic invertebrate community at *test* reach MUR-D3; however, also contained a high relative abundance of fingernail clams (*Pisidium/Sphaerium*, 17%), and other sensitive (Mandaville 2001) forms including the mayfly *Leptophlebia*.

2011 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints for benthic invertebrate communities in fall 2011 at *test* reach MUR-E1, with the exception of abundance, were within the range of regional *baseline* erosional conditions (Figure 5.2-12). Abundance was three times greater than the 95th percentile of regional *baseline* conditions and five times greater than the abundance recorded in 2010.

Values of measurement endpoints for benthic invertebrate communities for abundance, richness and diversity in fall 2011 at *test* reach MUR-D2 exceeded the 95th percentile of regional *baseline* conditions (Figure 5.2-13). These measurement endpoints also exceeded values observed in 2010 and all previously-measured values for this reach (Figure 5.2-13). Evenness and percent EPT were both within the ranges for regional *baseline* depositional reaches. CA Axis 2 scores have shifted negatively over time from regional *baseline* conditions; however, both CA Axes scores were still within regional *baseline* conditions (Figure 5.2-14).

Values of all measurement endpoints for benthic invertebrate communities in fall 2011 at *test* reach MUR-D3 were within the range of regional *baseline* conditions for depositional reaches (Figure 5.2-15 and Figure 5.2-16).

Classification of Results Differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-E1 in fall 2011 were classified as **Negligible-Low** because the significant increase in total abundance in 2011 relative to 2010 and previous years did not coincide with changes in other measurement endpoints that would imply a negative change to the benthic invertebrate community (i.e., richness and diversity were also higher). The increase in total abundance (> 150,000 individuals per m^2 in 2011) could imply a significant increase in available habitat (or nutrients) for the benthic invertebrate community (Perrin and Richardson 1997). The benthic invertebrate community at *test* reach MUR-E1; however, appears to be in good condition given the high relative abundances of mayflies, caddisflies and the presence of stoneflies. The percent of the fauna as worms (tubificids and naidids) was generally consistent with previous years indicating no significant change in the quality of the habitat (i.e., water and sediment quality).

The differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-D2 in fall 2011 were classified as **Negligible-Low** because there was an increase in percent EPT, which does not imply a negative change and all measurement endpoints with the exception richness were within the range of variation for *baseline* depositional reaches. In fall 2011, richness exceeded the 95th percentile of regional *baseline* conditions, which is not indicative of degraded habitat.

The differences in measurement endpoints of benthic invertebrate communities at *test* reach MUR-D3 in fall 2011 were classified as **Moderate** because the decrease in taxa richness from *baseline* to *test* periods explained 25% of the variation in annual means. In addition, the shift in composition suggested by variations in CA Axis 2 scores reflected an absence of *Hydracarina* in the reach over the last three years, an increase in tubificid worms in 2011, and a decrease in the relative abundance of mayflies. The absence of *Hydracarina* (i.e., water mites) is informative given that mites are not good “indicators” of water or substrate quality (Mandaville 2001) and the increase in the relative abundance of tubificid worms may indicate degraded conditions of the water or sediment quality. The percentage of fauna as tubificids has always been higher at *test* reach MUR-D3 than *test* reach MUR-D2 despite the fact that *test* reach MUR-D2 has been designated as *test* since RAMP began sampling this reach in 2000. The decrease in the relative abundance of mayflies at *test* reach MUR-D3 may also indicate degraded conditions.

Jackpine Creek

Benthic invertebrate communities were sampled in fall 2011 at:

- depositional *test* reach JAC-D1, near the mouth of Jackpine Creek (designated as *baseline* from 2002 to 2005 and *test* from 2006 to 2011); and
- depositional *baseline* reach JAC-D2 (designated as *baseline* from 2006 to 2011).

2011 Habitat Conditions Water at *test* reach JAC-D1 in fall 2011 was moderately deep (0.9 m), basic (pH: 7.8), with negligible flow, with high conductivity (497 µS/cm) (Table 5.2-22). The substrate was dominated by sand (98%). Water at *baseline* reach JAC-D2 was also relatively deep (0.7 m), slow flowing (0.21 m/s), basic (pH: 8.1), with moderate conductivity (268 µS/cm) (Table 5.2-22). The substrate was also dominated by sand (70%).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach JAC-D1 had a high abundance, with over 100,000 individuals per m^2, a value that was approximately five times higher than previously reported for this reach (Table 5.2-23). The benthic invertebrate community was dominated by chironomids (51%) (Table 5.2-23). There were 37 genera of chironomid observed, with the most common being the Tanytarsini followed by *Stempellina*, *Stempellinella*, and *Micropsectra*. A variety of orthoclads were present, in particular the sensitive genera *Parakiefferiella* (Bode *et al.* 1996). A variety of Tanypodinae were also present, as were several Chironomini. Mayflies (Ephemeroptera) included *Baetis*, *Caenis*, *Siphloplecton* and *Leptophlebia*. Caddisflies (Trichoptera) included *Oxyethira*, *Hydroptila* and *Oecetis*. Stoneflies (Plecoptera) were also present. Gastropods included the limpet *Ferrissia rivularis* and the snails *Physa* and *Gyraulus*. Bivalve clams included sphaeriids (*Pisidium* and *Sphaerium*).

The benthic invertebrate community at *baseline* reach JAC-D2 had a higher abundance (26,000 individuals per m^2) than previously reported for this reach. The benthic invertebrate community was diverse and dominated by chironomids (32%) belonging to 31 genera, primarily *Parakiefferiella, Tanytarsus*, *Stempellinella* and *Pagastiella* (Table 5.2-24). Subdominant taxa consisted of ceratopogonids (10%), Ephemeroptera (19%, *Acerpenna*, *Callibaetis*, *Leptophlebia*, *Caenis*), and Trichoptera (3%; *Lepidostoma*, *Polycentropus*).

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 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 community measurement endpoints were tested between *test* reach JAC-D1 and *baseline* reach JAC-D2 from before to after reach JAC-D1 was designated as *test* in 2006 (Hypothesis 3, Section 3.2.3.1).

There were no significant differences in mean values of measurement endpoints from *baseline* to *test* periods between the *baseline* and *test* reaches (Table 5.2-25). There was a significant increase in taxa richness, diversity and evenness during the period that reach JAC-D1 was designated as *test,* while these measurement endpoints have remained more stable in *baseline* reach JAC-D2 during the same period (Table 5.2-25, Figure 5.2-17). The increases over time in these measurement endpoints explained less than 20% in the variance of the annual mean, indicating a weak signal in the changes. CA Axes 1 and 2 scores produced by the fauna at both reaches have been generally consistent across time (Figure 5.2-18).

Comparison to Published Literature The benthic invertebrate community at *test* reach JAC-D1 had a composition that would be expected in a depositional river. The community was numerically dominated by chironomids, which is typical (Griffiths 1998, Barton and Smith 1984). The reach contained both mayflies and caddisflies, snails, clams and various other flies. The reach did not have any amphipods, which were last reported in 2004, but in low relative abundances at that time (i.e., < 1%). Naidid and tubificid worms were present, but in relatively low abundances (< 20% combined), which indicates that the reach is in good condition (Hynes 1960, Griffiths 1998). The single unusual observation in the 2011 collection was the finding that abundances were in excess of 100,000 individuals per m^2, which is normally an indication of a degraded condition (e.g., Burt *et al.* 1991, Diggins and Snyder 2003).

The benthic invertebrate community at *baseline* reach JAC-D2 was similar to *test* reach JAC-D1 consisting of relatively typical fauna for depositional rivers. Chironomids were dominant, including the genera of Tanytarsini that have a general preference for depositional habitats. The benthic invertebrate community was diverse with mayflies and caddisflies present in relatively high abundances as well as snails and clams. Naidid and tubificid worms accounted for a relatively small portion (13% combined) of the total numbers of organisms. The fauna observed at *baseline* reach JAC-D2 are consistent with fauna observed in rivers with good water and sediment quality (Hynes 1960, Griffiths 1998).

2011 Results Relative to Regional *Baseline* Conditions Values of measurement endpoints for benthic invertebrate communities at *test* reach JAC-D1 exceeded the range of *baseline* conditions for total abundance, taxa richness, and diversity (Figure 5.2-17). Taxa richness has been greater than the 75^{th} percentile of regional *baseline* conditions since 2007, while diversity and evenness have been in the top 25% of *baseline* values since 2008. Values of measurement endpoints for benthic invertebrate communities at *baseline* reach JAC-D2 exceeded the range of *baseline* conditions for percent EPT and diversity (Figure 5.2-17).

Classification of Results Differences in the benthic invertebrate community at *test* reach JAC-D1 as of fall 2010 were classified as **Negligible-Low** because the significant increases over time in taxa richness, diversity, evenness at reach JAC-D1 once the reach became *test* did not imply a negative change in the benthic invertebrate community. In addition, values of some measurement endpoints in fall 2011 for benthic invertebrate communities at both *test* reach JAC-D1 and *baseline* reach JAC-D2 exceeded the range of regional *baseline* conditions, but was not indicative of conditions that were degraded.

Kearl Lake

Benthic invertebrate communities were sampled in fall 2011 in Kearl Lake at depositional *test* station KEL-1 (designated as *baseline* from 2001 to 2008, and *test* from 2009 and 2011).

2011 Habitat Conditions Water in Kearl Lake was alkaline (pH = 8.1) with moderate conductivity (175 µS/cm) (Table 5.2-26). The substrate of Kearl Lake was dominated by sand (53%) and silt (45%). Organic material, which have been a major component of the substrate of Kearl Lake in previous years, were low in fall 2011 (5% TOC).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of Kearl Lake in fall 2011 were dominated by ostracods (25%), Copepoda (19%), and Hydracarina (16%), with subdominant taxa consisting of Chironomidae (14%) and amphipods (12%) (Table 5.2-27). Dominant chironomids included *Procladius, Glyptotendipes,* and *Paratanytarsus*, which are commonly distributed in holarctic lakes (Widerholm 1983). Trichoptera (*Mystacides*) and Ephemeroptera (*Caenis*) were present in low relative abundances (<1%). Clams were present in low abundance (~4%) and were principally of the genus *Pisidium*. Amphipods were dominated by *Hyalella azteca*, but also included *Gammarus lacustris*.

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 station was designated as *test* (Hypothesis 2, Section 3.2.3.1). There was a significant decrease in percent EPT in the *test* period, explaining 31% of the variance in annual means (Table 5.2-28, Figure 5.2-19). CA axis 2 scores were higher during the *test* period; however, this increase accounted for only 19% of the variance in annual means.

Given that there are three years of data for the *test* period at station KEL-1, differences in time trends of measurement endpoints after station KEL-1 was designated *test* was tested (Hypothesis 4, Section 3.2.3.1). There was a significant increase in CA Axis 1 and CA Axis 2 scores during the *test* period in Kearl Lake explaining greater than 20% of the variance in annual means (Table 5.2-28). The increase over time in both CA axis scores reflect a decrease in the relative abundance of chironomids, amphipods and bivalves and an increase in the relative abundance of Ostracoda (seed shrimp) and Hydracarina (water mites) (Table 5.2-27, Figure 5.2-20).

Comparison to Published Literature The benthic invertebrate community of Kearl Lake contained fauna that would be considered typical of benthos from a shallow lake. The percent of the fauna that were worms was low (tubificid worms were not found in 2011, while naidid worms accounted for 4%) indicating generally good water and sediment quality (O'Toole *et al.* 2008). Chironomids accounted for 14% of the total fauna and species present in the lake tended to be a combination of sensitive and tolerant taxa (Broderson and Lindegaard 1999). The benthic invertebrate community also contained a combination of permanent aquatic forms such as amphipods, bivalves and gastropods, as well as flying insects (chironomids, Ephemeroptera, Trichoptera) indicating favourable long-term water quality (Resh and Unzicker 1975, Niemi *et al.* 1990). The most unusual aspect of the benthic invertebrate community of Kearl Lake was the slightly higher relative abundance of ostracods and water mites, which collectively accounted for approximately 40% of the total numbers of organisms. Lakes in the RAMP FSA generally do not contain ostracods and mites in the relative abundances observed in Kearl Lake in fall 2011 (e.g., Parsons *et al.* 2010); however, in 2005, similar relative abundances of mites and ostracods were observed in McClelland Lake when it was still designated as *baseline* (see Section 5.7).

2011 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities were within the range of values reported for Kearl Lake during the *baseline* period, with the exception of the CA Axis 2 scores, which was higher than *baseline* values in fall 2011 reflecting higher relative abundances of ostracods and water mites.

Classification of Results Differences in measurement endpoints for benthic invertebrate communities at *test* station KEL-1 were classified as **Moderate** because of the significant decrease in percent EPT (i.e., mayflies and caddisflies) compared to the period when

Kearl Lake was designated as *baseline* and the increase in multivariate CA Axis scores. The benthic invertebrate community of Kearl Lake contained a diverse fauna and included several taxa that are typically associated with relatively good water and sediment quality in lakes (e.g., the mayfly *Caenis* and the caddisfly *Mystacides*). The benthic invertebrate community of Kearl Lake in fall 2011 also contained higher relative abundances of ostracods and mites (totaling over 40% of total numbers) compared to previous years and compared to other lakes in *baseline* condition in the RAMP FSA.

5.2.4.2 Sediment Quality

Sediment quality was sampled in depositional reaches and lakes of the Muskeg River watershed in the same locations as benthic invertebrate communities were sampled in fall 2011:

- *test* station MUR-D2 on the Muskeg River (sampled in 2000, and 2003 to 2011);
- *test* station MUR-D3 on the Muskeg River (designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2011);
- *test* station JAC-D1 on Jackpine Creek near its mouth (designated as *baseline* in 1997 and *test* from 2006 to 2011);
- *baseline* station JAC-D2 on Jackpine Creek (sampled from 2006 to 2011); and
- *test* station KEL-1 in Kearl Lake (designated as *baseline* from 2001 to 2008 and as *test* from 2009 to 2011).

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

- A decreasing concentration of total arsenic at *test* station KEL-1; however, when results from 1998 to 2001, when detection limits for arsenic were significantly higher than presently measured, were removed, no significant trend in concentrations of arsenic concentrations was detected; and
- Decreasing concentrations of F1 hydrocarbons at *test* station MUR-D2 and *test* station KEL-1.

Trend analysis was not completed for *baseline* station JAC-D2 because insufficient data exists (n=4).

2011 Results Relative to Historical Concentrations Sediments sampled in 2011 from all stations in the Muskeg River watershed were taken from the same locations as those reaches sampled from 2006 to 2010. Prior to the integration of the Sediment Quality component with the Benthic Invertebrate Communities component in 2006, benthic invertebrate community at *test* reaches MUR-D2 and MUR-D3 corresponded to pre-2006 sediment-quality *test* stations MUR-2 and MUR-D2 respectively, and *test* reach JAC-D1 corresponded 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). All stations were dominated by sand with the exception of *test* station KEL-1, which exhibited similar proportions of both sand and clay in fall 2011 (53% and 45%, respectively). The proportion of silt was above the previously-measured maximum value at *baseline* station JAC-D2, while proportions of clay were below the previously-measured minimum value at *test* station JAC-D1. Concentrations of total organic carbon were relatively low (≤10%) at all five stations; sediments exhibited much lower total organic carbon than previously-measured at *test* station KEL-1 (Table 5.2-33). The concentration of total organic carbon exceeded previously-measured maximum concentrations at *baseline* station JAC-D2 (Table 5.2-32).

Concentrations of volatile, low-molecular-weight hydrocarbons (i.e., CCME fraction 1 and BTEX – benzene, toluene, ethylene and xylene) in fall 2011 were undetectable at all stations. Concentrations of heavier hydrocarbon fractions in fall 2011 were within previously-measured concentrations, with the exception of *test* station JAC-D1 where hydrocarbon fractions 3 and 4 were lower than previously-measured minimum concentrations (Table 5.2-31). The concentration of total parent PAHs was lower than previously-measured minimum concentrations at *test* station JAC-D1 (Table 5.2-31); however, total PAHs (both absolute and carbon-normalized) were within the range of previously-measured concentrations at this station. Concentrations of naphthalene were lower than previously-measured minimum concentrations at *test* station JAC-D1 and *baseline* station JAC-D2 (Table 5.2-31, Table 5.2-32). The concentration of retene was below previously-measured minimum concentrations at *test* station MUR-D3, and was only slightly above the previously-measured minimum concentration at *test* station MUR-D2 (Table 5.2-29 and Table 5.2-30). Similar to previous years, concentrations of total PAHs in sediments generally increased from upstream to downstream in tributaries, with lowest concentrations in *baseline* station JAC-D2 (Table 5.2-32 and Figure 5.2-24) and *test* station MUR-D3 (Table 5.2-30, Figure 5.2-22) and highest concentrations at *test* station MUR-D2 (Table 5.2-29, Figure 5.2-21).

In fall 2010, potential PAH toxicity in sediments was higher than previously-measured maximum values at *baseline* station JAC-D2 and *test* stations MUR-D2, and MUR-D3. In fall 2011, potential PAH toxicity of sediments at these stations returned to within the range of previously-measured values, with the exception of *test* station MUR-D2, where chronic toxicity was lower than the previously-measured minimum value. The change in PAH toxicity was most notable at *test* station MUR-D2, where values decreased from 4.00 in fall 2010 to 0.73 in fall 2011 (Figure 5.2-21). The decrease in potential PAH toxicity is likely related to lower concentrations of total PAHs at each of these stations. The notable change in toxicity at *test* station MUR-D2 may also be related to an increase in CCME hydrocarbon fractions in sediments, which complex with PAHs, thereby reducing the bioavailability in pore water.

Survival of the midge *Chironomus* at *test* station JAC-D1 and growth of the amphipod *Hyalella* at *baseline* station JAC-D2 were higher than previously-measured maximum values (Table 5.2-31, Table 5.2-32). *Chironomus* survival at *test* station KEL-1 was lower than previously-measured minimum values; however, both *Hyalella* growth and survival at *test* station KEL-1 were greater than previously-measured minimum values (Table 5.2-33).

Spatial comparisons The following comparisons of sediment quality measurement endpoints among stations in the Muskeg River watershed in fall 2011 are noted:

- Percent sand and total organic carbon were higher at *test* station MUR-D3 (82% and 10.4%, respectively) than *test* station MUR-D2 (72% and 3.3%, respectively). Percent sand was higher at *test* station JAC-D1 (98.3%) than *baseline* station JAC-D2 (70%).

- Concentrations of hydrocarbons (including PAHs) were higher at *test* station MUR-D2 than all other stations in the Muskeg River watershed; *baseline* station JAC-D2 exhibited the lowest concentrations of hydrocarbons.
- Survival and growth of *Chironomus*, and survival of *Hyalella* were similar between *test* station JAC-D1 and *baseline* station JAC-D2; *Hyalella* growth was higher at *baseline* station JAC-D2 (0.56 mg/organism) than *test* station JAC-D1 (0.27 mg/organism).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines Concentrations of Fraction-1, -2, and -3 hydrocarbons exceeded relevant CCME soil-quality guidelines at *test* station KEL-1 (Table 5.2-33). The concentration of Fraction-1 hydrocarbons exceeded the CCME soil-quality guideline at *test* station MUR-D3 (Table 5.2-30), and the concentration of Fraction-3 hydrocarbons exceeded CCME guidelines at *test* station MUR-D2 (Table 5.2-29).

Sediment Quality Index The SQI values for all stations in the Muskeg River watershed in fall 2011 indicated **Negligible-Low** differences in sediment quality conditions from regional *baseline* conditions (Table 5.2-34). A SQI was not calculated for *test* station KEL-1 because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

Classification of Results Sediment quality at all Muskeg River watershed stations sampled in fall 2011 was generally consistent with that of previous years and regional *baseline* conditions. Concentrations of total PAHs at all stations were within previously-measured concentrations with a few exceptions where concentrations of PAHs were lower than previously-measured concentrations. Differences in sediment quality in fall 2011 at all four stations in the Muskeg River watershed were assessed as **Negligible-Low** compared to regional *baseline* conditions.

5.2.5 Fish Populations

Muskeg River Mainstem

Fish assemblages were sampled in fall 2011 at:

- erosional *test* reach MUR-F1, near the mouth of the Muskeg River, sampled in 2009 and 2010 as part of the Fish Assemblage Pilot Study (this reach is at the same location as the benthic invertebrate community *test* reach MUR-E1);
- depositional *test* reach MUR-F2, sampled for the first time in 2011 (this reach is at the same location as the benthic invertebrate community *test* reach MUR-D2); and
- depositional *test* reach MUR-F3, sampled for the first time in 2011 (this reach is at the same location as the benthic invertebrate community *test* reach MUR-D2).

2011 Habitat Conditions *Test* reach MUR-F1 was comprised of run and shallow riffle habitat with a wetted width of 14.8 m and a bankfull width of 21.3 m (Table 5.2-35). The substrate was dominated by coarse gravel with small amounts of cobble and silt/clay. Water at *test* reach MUR-F1 in fall 2011 was shallow (average depth: 0.31 m), moderately flowing (average: 0.28 m/s), alkaline (pH: 7.96), with high conductivity (470 µS/cm), and a temperature of 18.9°C. Instream cover was comprised primarily of boulders with small amounts of filamentous algae and small and large woody debris (Table 5.2-35).

Test reach MUR-F2 was comprised entirely of run habitat with a wetted width of 14 m and a bankfull width of 14.5 m (Table 5.2-35). The substrate was dominated by sand with small amounts of cobble and coarse gravel. Water at *test* reach MUR-F2 was deeper (average depth: 0.88 m) and faster flowing (average flow: 0.44 m/s) than *test* reach MUR-F1, neutral (pH: 7.0), with high conductivity (497 µS/cm), moderate dissolved oxygen (7 mg/L) and a temperature of 10˚C. Instream cover was comprised primarily of small woody debris, with small amounts of filamentous algae, undercut banks, and boulders.

Test reach MUR-F3 was comprised entirely of run habitat with a wetted width of 11.25 m and a bankfull width of 12 m (Table 5.2-35). The substrate was dominated by slit/clay/fines. Water at *test* reach MUR-F3 had little flow, was slightly alkaline (pH: 7.08), with high conductivity (524 µs/cm), dissolved oxygen of 6.4 mg/L and a temperature of 10.3˚C.

Temporal and Spatial Comparisons Sampling was initiated at *test* reach MUR-F1 in 2009 during the RAMP Fish Assemblage Pilot Study; therefore, temporal comparisons were conducted from 2009 to 2011. *Test* reaches MUR-F2 and MUR-F3 were first sampled in 2011; therefore, temporal comparisons were not conducted. Spatial comparisons were not conducted for *test* reach MUR-F1 because there is no upstream *baseline* erosional reach on the Muskeg River. Spatial comparisons for *test* reaches MUR-F2 and MUR-F3 were not conducted because there is no upstream *baseline* depositional reach on the Muskeg River.

There was an increase in abundance and CPUE from 2009 to 2011 at *test* reach MUR-F1 (Table 5.2-36). Species richness, diversity, evenness and the ATI were lower in 2011 compared to 2010, but higher than values measured in 2009 (Table 5.2-37). The decrease in ATI value at *test* reach MUR-F1 compared to fall 2010 was likely related to the presence of more sensitive fish species (e.g., burbot, slimy sculpin, lake chub, etc.). *Test* reach MUR-F1 was dominated by longnose sucker. Northern pike and brook stickleback were the dominant species at *test* reaches MUR-D2 and MUR-D3, respectively (Table 5.2-36).

Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important baseline data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, 21 species have been documented in the Muskeg River; whereas RAMP found only thirteen fish species from 2009 to 2011 in addition to finescale dace and spoonhead sculpin, which have not been previously documented. Past fish inventory studies in the Muskeg River used a variety of capture techniques (e.g., fish fence, trapping, electrofishing) targeting a broad range of life stages. Conversely, the RAMP fish assemblage monitoring program collected fish by means of a standardized protocol using backpack electrofishing, which targeted small-bodies fish species and juvenile large-bodied fish species. These differences in fishing techniques may explain some of the observed variation in species richness reported by RAMP versus historical studies. In addition, Golder (2004b) documents fish inventory studies throughout the entire Muskeg River, whereas RAMP samples smaller, defined reach lengths.

Golder (2004b) has documented similar habitat conditions in the portion of the Muskeg River where *test* reach MUR-F1 is located, consisting of slow riffles, and infrequent pools dominated by cobble and gravel substrate with some boulder and fine sediment. Golder (2004b) reported that this area of the river had low spawning potential, but provided excellent rearing habitat for young fish moving down from upstream spawning areas, as well as excellent resting areas for migratory fish coming from the Athabasca River (Bond and Machniak 1979). The low species richness observed at *test* reaches MUR-F2 and MUR-F3 could be attributed to the habitat conditions in these portions of the Muskeg River. Golder (2004b) documented similar habitat conditions consisting of deep slow pools and runs, with substrate of primarily fines with very small amounts of gravel, cobble and boulders. This portion of the river has low habitat diversity and minimum spawning areas and food supply for most fish species (Golder 2004b).

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at *test* reach MUR-F1 were within regional *baseline* conditions for erosional reaches in the region (Figure 5.2-26). Median values of all measurement endpoints in fall 2011 at *test* reach MUR-F2 were lower than regional *baseline* conditions, which is likely due to the absence of fish in three of the five sub-reaches (Figure 5.2-26). Median values of all measurement endpoints in fall 2011 at *test* reach MUR-F3 were within regional *baseline* conditions for depositional reaches, with the exception of the ATI value, which exceeded regional *baseline* conditions, indicating the presence of more tolerant species compared to other *baseline* reaches in the region (Figure 5.2-26).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reaches MUR-F1 and MUR-F3 and regional *baseline* conditions were classified as **Negligible-Low** given most measurement endpoints were within the regional range of variation of *baseline* reaches. Differences in measurement endpoints for fish assemblages between *test* reach MUR-F2 and regional *baseline* conditions were classified as **Moderate** given all measurement endpoints were lower than the range of variation of *baseline* reaches.

Jackpine Creek

Fish assemblages were sampled in fall 2011 at:

- depositional *test* reach JAC-F1, near the mouth of Jackpine Creek, sampled in 2009 and 2010 as part of the Fish Assemblage Pilot Study (this reach is at the same location as the benthic invertebrate community *test* reach JAC-D1); and
- depositional *baseline* reach JAC-F2, sampled in 2009 and 2010 as part of the Fish Assemblage Pilot Study (this reach is at the same location as the benthic invertebrate community *baseline* reach JAC-D2).

2011 Habitat Conditions *Test* reach JAC-F1 was comprised of run habitat with few pools and a wetted width of 6.0 m and bankfull width of 8.0 m (Table 5.2-38). The substrate was dominated by fines with moderate amounts of gravel (Table 5.2-38). Water at *test* reach JAC-F1 in fall 2011 was deep (maximum depth: >2 m), slow flowing (average flow: 0.04 m/s), alkaline (pH: 8.2) with high conductivity (488 µS/cm), moderate dissolved oxygen (5.2 mg/L) and a temperature of 13ºC. Instream cover was comprised primarily of small woody debris, overhanging vegetation with smaller proportions of large woody debris and undercut banks.

Baseline reach JAC-F2 was comprised entirely of run habitat and a wetted 4.1 m and a bankfull width of 5.2 m. The substrate was dominated by fines and small cobble with a smaller amount of gravel. Water at *baseline* reach JAC-F2 in fall 2011 was shallow (maximum depth: 0.73 m), slow flowing (average flow: 0.01 m/s), slightly alkaline (pH: 7.5) with high conductivity (372 µS/cm), high dissolved oxygen (8.7 mg/L) and a temperature of 10.8°C. Instream cover was comprised primarily of undercut banks, overhanging vegetation, and macrophytes with some small woody debris.

Temporal and Spatial Comparisons Sampling was initiated in Jackpine Creek in 2009 during the RAMP Fish Assemblage Pilot Study; therefore, temporal comparisons were conducted from 2009 to 2011; spatial comparisons were conducted between lower *test* reach JAC-F1 and upper *baseline* reach JAC-F2.

There was an increase in abundance and CPUE of fish from 2009 to 2011 in *test* reach JAC-F1 and *baseline* reach JAC-F2 (Table 5.2-36, Table 5.2-37, Figure 5.2-27). There was a decrease in diversity over time at *test* reach JAC-F1; however, the assemblage tolerance index (ATI) has also decreased over time indicating a presence of more sensitive species, including a greater proportion of lake chub, which has a lower tolerance value relative to other small-bodied fish species (Whittier *et al.* 2007a) (Table 5.2-36). *Test* reach JAC-F1 was dominated by lake chub while *baseline* reach JAC-D2 was dominated by pearl dace with a relatively high abundance of brook stickleback (Table 5.2-36). Species richness was consistent across years and between reaches from 2009 to 2011, with the exception of *test* reach JAC-F1 in 2010, which had a higher species richness relative to other years at both reaches.

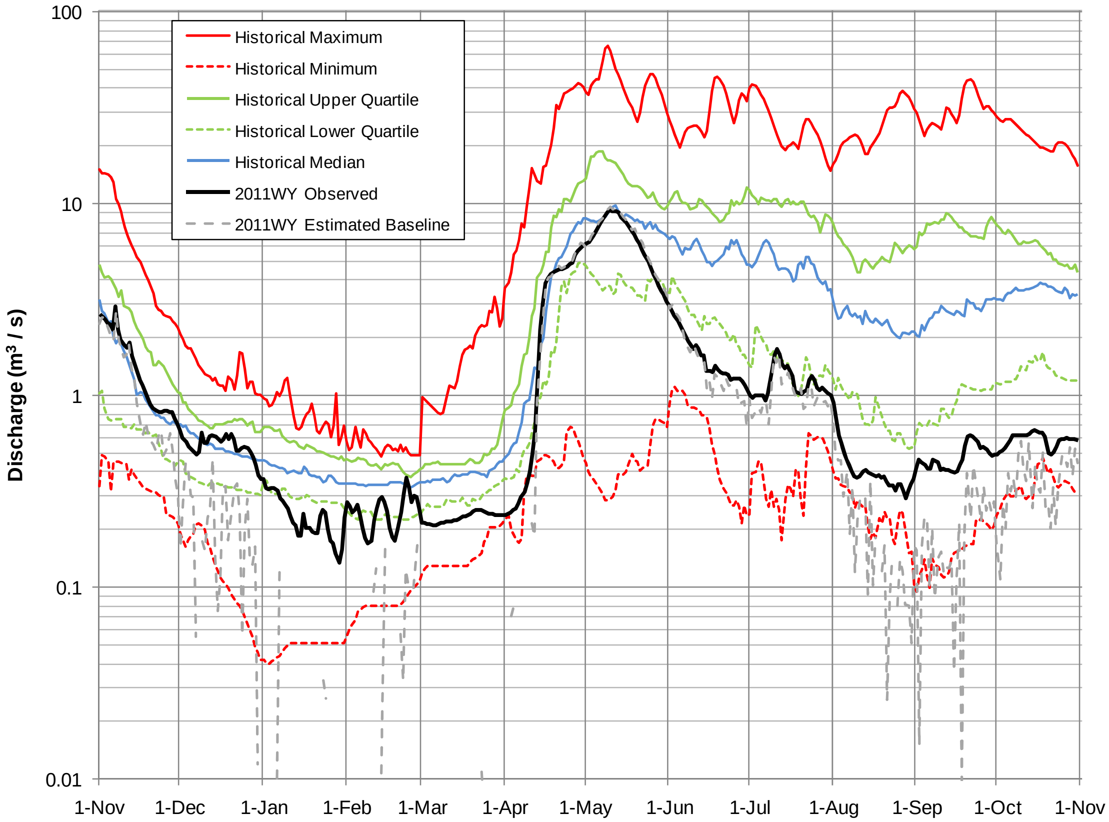
Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of 15 fish species were recorded in Jackpine Creek; whereas RAMP found only 11 species from 2009 to 2011, with the exception of Arctic grayling, fathead minnow, flathead chub, and spoonhead sculpin. Two additional fish species were observed by RAMP from 2009 to 2011, including finescale dace and trout-perch (Table 5.2-36). As noted in the Muskeg River section, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

The lower species richness at *test* reach JAC-F1 and *baseline* reach JAC-F2 observed in recent years compared to historical studies is likely due to the habitat conditions in the portions of the creek where these reaches are located. Golder (2004b) documented similar habitat conditions to what have been observed by RAMP, consisting of runs and small pools with sand/fine substrate and slow flowing water. These conditions are likely not suitable for most fish species in the region that require harder substrate and faster flowing water for spawning activities (e.g., sculpin sp., Arctic grayling, and sucker sp.) (Bond and Machniak 1977).

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at *test* reach JAC-F1 and *baseline* reach JAC-F2 were within the range of regional *baseline* conditions for depositional reaches (Figure 5.2-27).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reach JAC-F1 and *baseline* reach JAC-F2 and regional *baseline* conditions were classified as **Negligible-Low** given all measurement endpoints were within the regional range of variation of *baseline* reaches.

Figure 5.2-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Muskeg River in the 2011 WY, compared to historical values.



Note: Based on provisional 2011 WY data from Muskeg River near Fort MacKay, WSC Station 07DA008 (RAMP Station S7). The upstream drainage area is 1,457 km^2. Historical values from March 1 to October 31 calculated from data collected from 1974 to 2010, and values for other months calculated from data collected from 1974 to 1986 and 1999 to 2010.

Note: In some cases observed flows at WSC Station 07DA008 (RAMP Station S7) minus the net flow releases from focal projects resulted in negative estimated *baseline* values that were set to zero. These values 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, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**43.52**	**Observed discharge at Muskeg River near Fort MacKay, WSC Station 07DA008 (RAMP Station S7)**
Closed-circuited area water loss from the observed *test* hydrograph	-3.10	Estimated 118.7 km^2 of the Muskeg River watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.36	Estimated 69.0 km^2 of the Muskeg River watershed with land change from focal projects as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Muskeg River watershed from focal projects	-0.13	Water withdrawn by Shell and Suncor Firebag (all values provided daily)
Water releases into the Muskeg River watershed from focal projects	0.001	Water released by Suncor Firebag (all values provided daily)
Diversions into or out of the watershed	8.95	Syncrude Aurora Clean Water Diversion discharges to Stanley Creek
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)	**38.04**	**Estimated *baseline* discharge at Muskeg River near Fort MacKay, WSC Station 07DA008 (RAMP Station S7)**
Incremental flow (change in total discharge)	+6.08	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+14.4%**	**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 2011 WY data from Muskeg River near Fort MacKay, WSC Station 07DA008 (RAMP Station S7).

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: In some cases observed flows at WSC Station 07DA008 (RAMP Station S7) minus the net flow releases from focal projects resulted in negative estimated *baseline* values that were set to zero.

Table 5.2-3 Calculated changes in hydrologic measurement endpoints for the Muskeg River watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	1.71	1.83	7.1%
Mean winter discharge	0.30	0.55	85%
Annual maximum daily discharge	9.63	9.21	-4.4%
Open-water season minimum daily discharge	0.08	0.29	261%

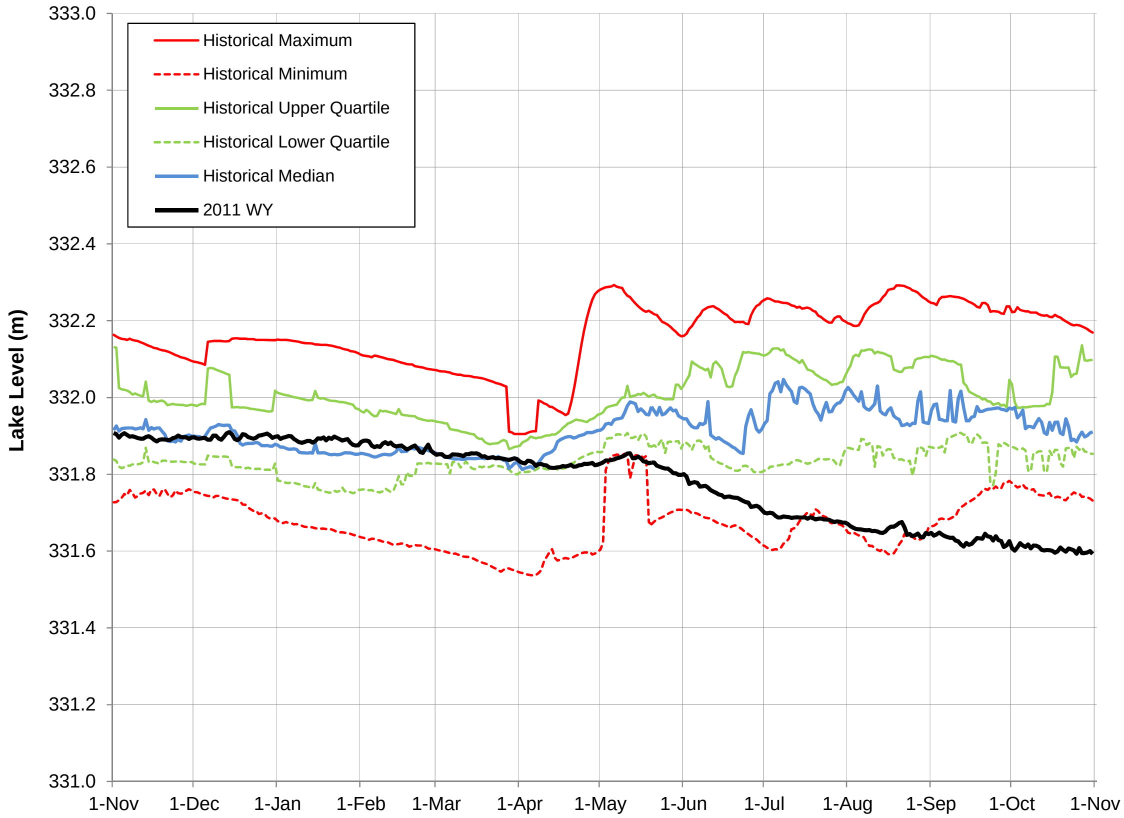
Note: Based on provisional the 2010 WY data from Muskeg River near Fort MacKay, WSC Station 07DA008 (RAMP Station S7).

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: In some cases observed flows at WSC Station 07DA008 (RAMP Station S7) minus the net flow releases from focal projects resulted in negative estimated *baseline* values that were set to zero.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two and one decimal places, respectively.

Figure 5.2-4 Observed lake levels for Kearl Lake in the 2011 WY, compared to historical values.



Note: Observed 2011 WY lake levels based on the 2011 WY provisional data for Kearl Lake, RAMP Station L2. Historical values calculated from 1999 to October 2010, 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 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.6</u>	14	7.4	8.2	8.4
Total suspended solids	mg/L	-	21	14	<3	3	70
Conductivity	µS/cm	-	462	14	220	327	671
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.006	14	0.004	0.014	0.030
Total nitrogen	mg/L	1	0.70	14	0.40	0.90	**1.62**
Nitrate+nitrite	mg/L	1.3	<0.071	14	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	19.1	14	15.0	21.5	29.0
Ions							
Sodium	mg/L	-	16.9	14	8.0	12.5	64.0
Calcium	mg/L	-	64.9	14	28.8	45.7	108
Magnesium	mg/L	-	15.1	14	7.1	12.2	18.9
Chloride	mg/L	230, 860	8.1	14	1.0	3.0	36.0
Sulphate	mg/L	100	4.8	14	0.6	5.3	91.0
Total dissolved solids	mg/L	-	311	14	170	260	405
Total alkalinity	mg/L		240	14	105	167	313
Selected metals							
Total aluminum	mg/L	0.1	**0.72**	14	0.03	0.07	**1.20**
Dissolved aluminum	mg/L	0.1	<u>0.0016</u>	14	0.0019	0.0051	0.0300
Total arsenic	mg/L	0.005	0.00043	14	0.00025	0.00045	0.00100
Total boron	mg/L	1.2	0.067	14	0.032	0.043	0.150
Total molybdenum	mg/L	0.073	0.00011	14	0.00007	0.00010	0.00030
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	3
Total strontium	mg/L	-	0.18	14	0.09	0.12	0.30
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	2.2	0	-	-	-
Total dibenzothiophenes	ng/L	-	10.2	0	-	-	-
Total PAHs	ng/L	-	181.5	0	-	-	-
Total Parent PAHs	ng/L	-	20.7	0	-	-	-
Total Alkylated PAHs	ng/L	-	160.8	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total chromium	mg/L	0.001	**0.0011**	14	0.0002	0.0004	**0.0032**
Total iron	mg/L	0.3	**0.46**	14	0.29	**0.66**	**1.81**
Total phenols	mg/L	0.004	**0.005**	14	<0.001	0.003	**0.011**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-5 Concentrations of selected water quality measurement endpoints, Muskeg River upstream of Wapasu Creek (*test* station MUR-6), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	13	7.2	8.1	8.4
Total suspended solids	mg/L	-	5	13	<3	3	25
Conductivity	µS/cm	-	<u>524</u>	13	233	303	441
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.014	13	0.011	0.014	0.029
Total nitrogen	mg/L	1	0.63	13	0.30	0.90	**1.93**
Nitrate+nitrite	mg/L	1.3	<0.071	13	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	16.9	13	13.0	19.0	31.9
Ions							
Sodium	mg/L	-	3.6	13	3.0	3.4	7.0
Calcium	mg/L	-	66.7	13	31.3	43.5	67.4
Magnesium	mg/L	-	<u>24.0</u>	13	11.6	15.8	21.4
Chloride	mg/L	230, 860	0.7	13	<0.5	1.0	3.0
Sulphate	mg/L	100	2.4	13	1.5	3.0	6.3
Total dissolved solids	mg/L	-	307	13	180	225	320
Total alkalinity	mg/L		<u>292</u>	13	120	166	235
Selected metals							
Total aluminum	mg/L	0.1	<u><0.003</u>	13	0.009	0.020	**0.110**
Dissolved aluminum	mg/L	0.1	<u>0.0015</u>	13	0.0017	0.0051	0.0100
Total arsenic	mg/L	0.005	0.00030	13	0.00026	0.00037	<0.001
Total boron	mg/L	1.2	0.019	13	0.006	0.011	0.016
Total molybdenum	mg/L	0.073	<0.0001	13	0.0000685	0.0001	0.0003
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	0.8	<1.2	<1.2
Total strontium	mg/L	-	0.11	13	0.06	0.08	0.16
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	7.1	0	-	-	-
Total PAHs	ng/L	-	154.9	0	-	-	-
Total Parent PAHs	ng/L	-	19.8	0	-	-	-
Total Alkylated PAHs	ng/L	-	135.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total phenols	mg/L	0.004	**0.0043**	13	<0.001	**0.0050**	**0.0310**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-6 Concentrations of selected water quality measurement endpoints, Muskeg Creek (*test* station MUC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.3</u>	11	7.4	7.9	8.2
Total suspended solids	mg/L	-	<3	11	<3	4	9
Conductivity	µS/cm	-	428	11	184	251	671
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.019	11	0.012	0.014	0.034
Total nitrogen	mg/L	1	0.96	11	0.40	1.00	**1.20**
Nitrate+nitrite	mg/L	1.3	<0.071	11	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	27.1	11	12.0	23.0	29.0
Ions							
Sodium	mg/L	-	17.8	11	7.0	17.0	64.0
Calcium	mg/L	-	50.8	11	20.8	29.7	71.1
Magnesium	mg/L	-	15.9	11	6.5	9.7	17.3
Chloride	mg/L	230, 860	1.5	11	<1	2.0	36.0
Sulphate	mg/L	100	2.1	11	2.0	3.6	8.0
Total dissolved solids	mg/L	-	303	11	140	200	378
Total alkalinity	mg/L		232	11	93	123	313
Selected metals							
Total aluminum	mg/L	0.1	<u>0.021</u>	11	0.022	0.050	**0.142**
Dissolved aluminum	mg/L	0.1	0.0032	11	0.0029	0.0078	0.0300
Total arsenic	mg/L	0.005	0.00051	11	0.00020	0.00052	0.00100
Total boron	mg/L	1.2	0.070	11	0.024	0.053	0.150
Total molybdenum	mg/L	0.073	<0.0001	11	0.000045	0.000096	0.0064
Total mercury (ultra-trace)	ng/L	5, 13	0.6	6	<1.2	<1.2	1.8
Total strontium	mg/L	-	0.17	11	0.07	0.09	0.30
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	9.6	0	-	-	-
Total PAHs	ng/L	-	160.3	0	-	-	-
Total Parent PAHs	ng/L	-	19.3	0	-	-	-
Total Alkylated PAHs	ng/L	-	141.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.30**	11	0.18	0.27	**1.02**
Sulphide	mg/L	0.002	**0.004**	11	0.002	**0.012**	**0.068**
Total iron	mg/L	0.3	**0.65**	11	0.29	**0.63**	**1.81**
Total phenols	mg/L	0.004	**0.006**	11	<0.001	**0.005**	**0.017**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-7 Concentrations of selected water quality measurement endpoints, Jackpine Creek (*test* station JAC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	12	7.8	8.1	8.3
Total suspended solids	mg/L	-	<3	12	<3	<3	8
Conductivity	µS/cm	-	<u>483</u>	12	183	237	413
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.011	12	0.006	0.014	0.026
Total nitrogen	mg/L	1	0.74	12	0.70	0.90	**1.62**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	23.7	12	18.6	23.5	30.0
Ions							
Sodium	mg/L	-	<u>18.8</u>	12	10.0	12.0	18.0
Calcium	mg/L	-	<u>65.6</u>	12	22.2	29.1	56.6
Magnesium	mg/L	-	<u>16.3</u>	12	6.6	8.2	14.2
Chloride	mg/L	230, 860	5.4	12	0.9	2.0	5.6
Sulphate	mg/L	100	<u>9.8</u>	12	<0.5	2.7	4.3
Total dissolved solids	mg/L	-	<u>322</u>	12	110	199	234
Total alkalinity	mg/L		<u>249</u>	12	93	120	227
Selected metals							
Total aluminum	mg/L	0.1	<u>0.016</u>	12	0.018	0.068	**0.197**
Dissolved aluminum	mg/L	0.1	<u>0.0016</u>	12	0.0033	0.0080	**0.1700**
Total arsenic	mg/L	0.005	0.00043	12	0.00030	0.00055	<0.00100
Total boron	mg/L	1.2	<u>0.071</u>	12	0.033	0.044	0.066
Total molybdenum	mg/L	0.073	0.00010	12	0.00007	0.00010	0.00020
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	1.7
Total strontium	mg/L	-	<u>0.21</u>	12	0.09	0.11	0.17
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	3.4	0	-	-	-
Total dibenzothiophenes	ng/L	-	15.3	0	-	-	-
Total PAHs	ng/L	-	180.1	0	-	-	-
Total Parent PAHs	ng/L	-	20.4	0	-	-	-
Total Alkylated PAHs	ng/L	-	159.8	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**0.60**	12	**0.38**	**0.59**	**1.57**
Total phenols	mg/L	0.004	**0.0048**	12	<0.001	**0.0065**	**0.0190**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.
Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-8 Concentrations of selected water quality measurement endpoints, upper Jackpine Creek (*baseline* station JAC-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.3</u>	3	8.0	8.0	8.2
Total suspended solids	mg/L	-	<u>21</u>	3	3	6	13
Conductivity	µS/cm	-	<u>346</u>	3	202	213	216
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.023</u>	3	0.012	0.014	0.017
Total nitrogen	mg/L	1	0.86	3	0.90	**1.06**	**2.63**
Nitrate+nitrite	mg/L	1.3	<0.071	3	<0.071	<0.071	<0.1
Dissolved organic carbon	mg/L	-	23.7	3	22.6	25.0	29.1
Ions							
Sodium	mg/L	-	<u>25.5</u>	3	10.0	10.4	11.0
Calcium	mg/L	-	<u>36.8</u>	3	22.1	26.9	30.5
Magnesium	mg/L	-	<u>11.5</u>	3	7.2	8.6	8.6
Chloride	mg/L	230, 860	<u>1.6</u>	3	<0.5	<0.5	1.0
Sulphate	mg/L	100	0.92	3	0.67	1.95	2.00
Total dissolved solids	mg/L	-	<u>264</u>	3	150	160	173
Total alkalinity	mg/L		<u>187</u>	3	103	110	113
Selected metals							
Total aluminum	mg/L	0.1	**0.60**	3	**0.14**	**0.20**	**0.70**
Dissolved aluminum	mg/L	0.1	<u>0.0057</u>	3	0.0088	0.0104	0.0137
Total arsenic	mg/L	0.005	<u>0.0013</u>	3	0.0007	0.0007	0.0008
Total boron	mg/L	1.2	<u>0.14</u>	3	0.05	0.06	0.06
Total molybdenum	mg/L	0.073	<u>0.00024</u>	3	0.00011	0.00014	0.00014
Total mercury (ultra-trace)	ng/L	5, 13	1	3	<1.2	<1.2	2.9
Total strontium	mg/L	-	<u>0.20</u>	3	0.10	0.10	0.12
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	7.1	0	-	-	-
Total PAHs	ng/L	-	154.1	0	-	-	-
Total Parent PAHs	ng/L	-	19.6	0	-	-	-
Total Alkylated PAHs	ng/L	-	134.5	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**<u>0.50</u>**	3	0.24	**0.41**	**0.45**
Sulphide	mg/L	0.002	**0.0058**	3	**0.0047**	**0.0070**	**0.0081**
Total iron	mg/L	0.3	**<u>1.21</u>**	3	**0.69**	**0.70**	**0.82**
Total phenols	mg/L	0.004	**0.0059**	3	**0.0058**	**0.0120**	**0.0124**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-9 Concentrations of selected water quality measurement endpoints, Stanley Creek (*test* station STC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.3</u>	10	7.6	8.0	8.2
Total suspended solids	mg/L	-	6	10	<3	<3	6
Conductivity	µS/cm	-	420	10	271	386.5	760
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.022	11	0.010	0.019	0.033
Total nitrogen	mg/L	1	0.35	11	0.30	0.40	**2.10**
Nitrate+nitrite	mg/L	1.3	<0.071	11	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	10.5	10	6.0	8.5	12.2
Ions							
Sodium	mg/L	-	6.4	10	2.0	4.2	26.0
Calcium	mg/L	-	58.9	10	45.4	61.8	112.0
Magnesium	mg/L	-	13.2	10	11.1	12.7	20.5
Chloride	mg/L	230, 860	1.4	10	<0.5	1.5	14.0
Sulphate	mg/L	100	<0.5	10	<0.5	5.2	126.0
Total dissolved solids	mg/L	-	275	10	200	254	480
Total alkalinity	mg/L		229	10	157	206	260
Selected metals							
Total aluminum	mg/L	0.1	0.0087	11	<0.002	0.0070	0.0200
Dissolved aluminum	mg/L	0.1	<0.001	11	<0.001	0.001	0.020
Total arsenic	mg/L	0.005	0.00013	11	0.00010	0.00014	<0.00100
Total boron	mg/L	1.2	0.058	11	0.018	0.025	0.087
Total molybdenum	mg/L	0.073	<0.0001	11	<0.000008	0.000077	0.000200
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<0.6	<1.2	<1.2
Total strontium	mg/L	-	0.17	11	0.08	0.14	0.25
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	8.2	0	-	-	-
Total PAHs	ng/L	-	173.6	0	-	-	-
Total Parent PAHs	ng/L	-	19.6	0	-	-	-
Total Alkylated PAHs	ng/L	-	154.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total phenols	mg/L	0.004	**0.010**	11	<0.001	0.003	**0.052**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-10 Concentrations of selected water quality measurement endpoints, Wapasu Creek (*test* station WAC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	9	7.4	8.0	8.2
Total suspended solids	mg/L	-	6	9	<3	<3	23
Conductivity	µS/cm	-	469	9	207	247	524
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.023</u>	9	0.009	0.014	0.022
Total nitrogen	mg/L	1	**1.06**	9	0.50	1.00	**1.84**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	23.6	9	11.0	18.0	33.2
Ions							
Sodium	mg/L	-	7.1	9	6.0	7.0	9.0
Calcium	mg/L	-	59.5	9	26.7	33.1	71.7
Magnesium	mg/L	-	19.5	9	8.6	11.1	25.1
Chloride	mg/L	230, 860	1.0	9	0.8	2.0	3.0
Sulphate	mg/L	100	<0.5	9	1.6	2.5	7.6
Total dissolved solids	mg/L	-	<u>312</u>	9	160	199	300
Total alkalinity	mg/L		258	9	99.1	124	292
Selected metals							
Total aluminum	mg/L	0.1	0.014	9	0.014	0.018	0.074
Dissolved aluminum	mg/L	0.1	<u>0.0025</u>	9	0.0037	0.0064	0.0500
Total arsenic	mg/L	0.005	0.00048	9	0.00025	0.00034	<0.00100
Total boron	mg/L	1.2	0.023	9	0.014	0.021	0.081
Total molybdenum	mg/L	0.073	<0.0001	9	0.0000328	0.0000504	0.0004
Total mercury (ultra-trace)	ng/L	5, 13	0.6	7	<0.6	<1.2	3.3
Total strontium	mg/L	-	<u>0.15</u>	9	0.06	0.08	0.13
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	20.4	0	-	-	-
Total PAHs	ng/L	-	228.9	0	-	-	-
Total Parent PAHs	ng/L	-	20.4	0	-	-	-
Total Alkylated PAHs	ng/L	-	208.5	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**0.87**	9	0.18	**0.39**	**2.07**
Total phenols	mg/L	0.004	**0.0065**	9	0.0020	**0.0080**	**0.0160**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-11 Concentrations of selected water quality measurement endpoints, Iyinimin Creek (*baseline* station IYC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.5</u>	3	7.9	8.0	8.2
Total suspended solids	mg/L	-	<3	3	<3	17	29
Conductivity	µS/cm	-	<u>535</u>	3	134	143	202
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.021	3	0.017	0.018	0.031
Total nitrogen	mg/L	1	<u>0.58</u>	3	0.90	0.90	**1.93**
Nitrate+nitrite	mg/L	1.3	<0.071	3	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	<u>17.1</u>	3	27.0	33.0	33.9
Ions							
Sodium	mg/L	-	<u>40.1</u>	3	4.9	7.0	9.0
Calcium	mg/L	-	<u>51.0</u>	3	18.0	18.8	24.0
Magnesium	mg/L	-	<u>18.0</u>	3	6.2	6.5	8.3
Chloride	mg/L	230, 860	1.5	3	<0.5	1.0	2.0
Sulphate	mg/L	100	<u>12.3</u>	3	2.2	2.7	3.9
Total dissolved solids	mg/L	-	<u>359</u>	3	134	141	172
Total alkalinity	mg/L		<u>284</u>	3	64	72	104
Selected metals							
Total aluminum	mg/L	0.1	<u>0.055</u>	3	**0.115**	**0.889**	**0.902**
Dissolved aluminum	mg/L	0.1	<u>0.0084</u>	3	0.0215	0.0350	0.0439
Total arsenic	mg/L	0.005	0.00075	3	0.00072	0.00077	0.00083
Total boron	mg/L	1.2	<u>0.23</u>	3	0.02	0.03	0.05
Total molybdenum	mg/L	0.073	<u>0.00047</u>	3	0.00011	0.00013	0.00019
Total mercury (ultra-trace)	ng/L	5, 13	0.6	3	<1.2	2.4	2.8
Total strontium	mg/L	-	<u>0.19</u>	3	0.05	0.05	0.07
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	27.3	0	-	-	-
Total PAHs	ng/L	-	221.2	0	-	-	-
Total Parent PAHs	ng/L	-	22.9	0	-	-	-
Total Alkylated PAHs	ng/L	-	198.3	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.47**	3	0.28	0.30	**0.71**
Total iron	mg/L	0.3	<u>**0.84**</u>	3	**0.96**	**1.05**	**1.15**
Total phenols	mg/L	0.004	<u>**0.0047**</u>	3	**0.0086**	**0.0090**	**0.0160**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.2-12 Concentrations of selected water quality measurement endpoints, Kearl Lake (*test* station KEL-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	12	7.6	8.0	8.3
Total suspended solids	mg/L	-	8	12	<3	4	19
Conductivity	µS/cm	-	<u>187</u>	12	133	174	183
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.0039	12	0.0020	0.0075	0.0130
Total nitrogen	mg/L	1	**1.24**	12	0.45	**1.41**	**1.92**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	<u>24.4</u>	12	9.8	21.0	24.0
Ions							
Sodium	mg/L	-	10.8	12	8.0	10.0	11.3
Calcium	mg/L	-	19.8	12	16.5	19.4	20.6
Magnesium	mg/L	-	7.5	12	5.7	6.8	7.6
Chloride	mg/L	230, 860	<0.5	12	<0.5	<1.0	3
Sulphate	mg/L	100	<u>2.0</u>	12	2.2	4.7	5.7
Total dissolved solids	mg/L	-	175	12	94	153	220
Total alkalinity	mg/L		<u>94.3</u>	12	72.0	87.5	93.0
Selected metals							
Total aluminum	mg/L	0.1	0.011	12	0.007	0.022	**0.130**
Dissolved aluminum	mg/L	0.1	0.0013	12	<0.001	0.0017	0.0300
Total arsenic	mg/L	0.005	0.00031	12	0.00029	0.00037	<0.00100
Total boron	mg/L	1.2	0.046	12	0.012	0.047	0.052
Total molybdenum	mg/L	0.073	<0.0001	12	0.0000288	0.000102	0.0009
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<0.6	<1.2	1.3
Total strontium	mg/L	-	0.063	12	0.056	0.067	0.215
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	7.0	0	-	-	-
Total PAHs	ng/L	-	161.2	0	-	-	-
Total Parent PAHs	ng/L	-	20.7	0	-	-	-
Total Alkylated PAHs	ng/L	-	140.5	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Sulphide	mg/L	0.002	**0.0028**	12	0.0020	**0.0049**	**0.0100**
Total Kjeldahl Nitrogen	mg/L	1	**1.17**	12	0.40	**1.33**	**1.85**
Total phenols	mg/L	0.004	**0.010**	12	0.001	**0.005**	**0.012**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.2-5 Piper diagram of fall ion concentrations in the Muskeg River.

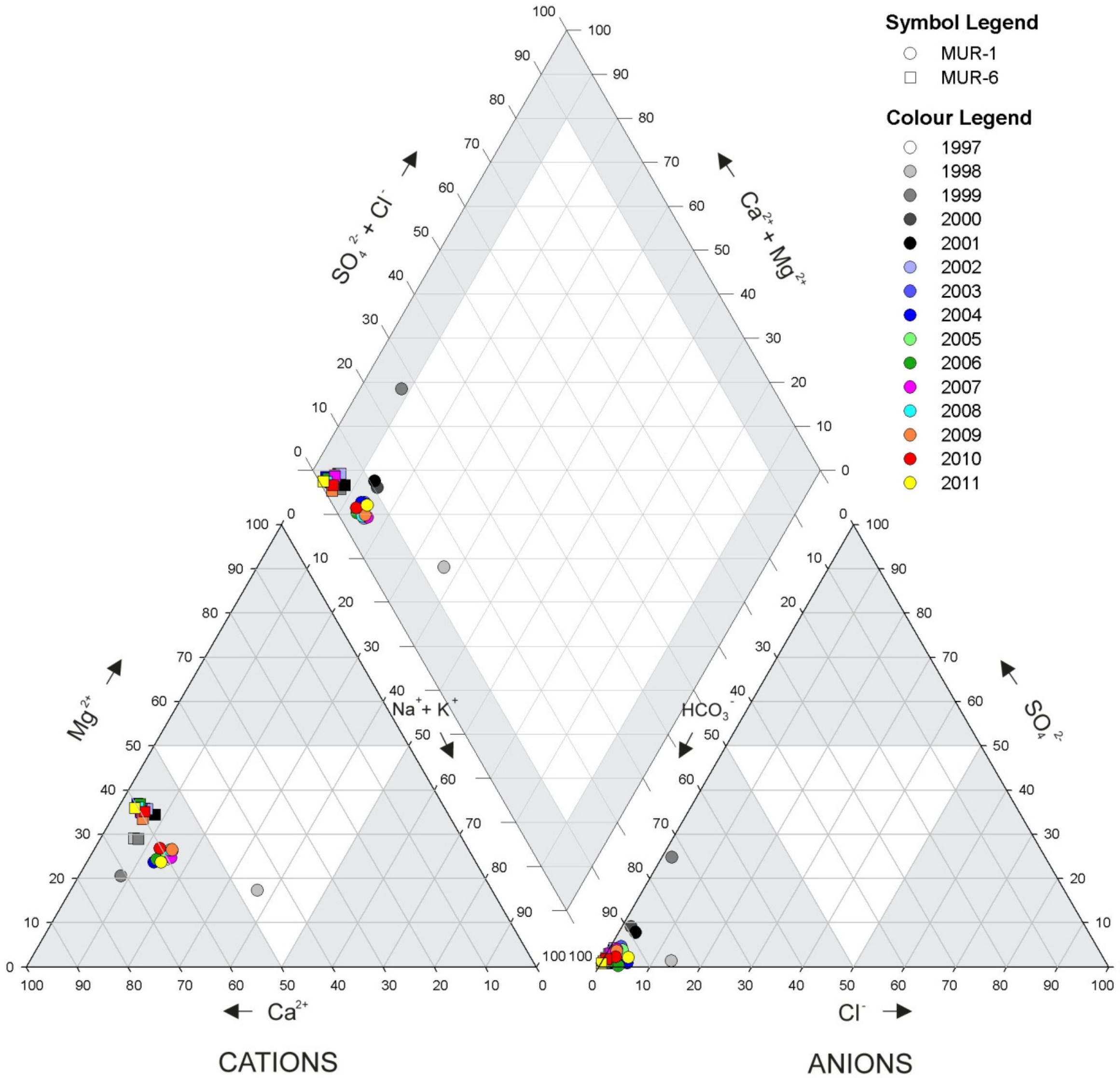


Figure 5.2-6 Piper diagram of fall ion concentrations in tributaries to the Muskeg River and Kearl Lake.

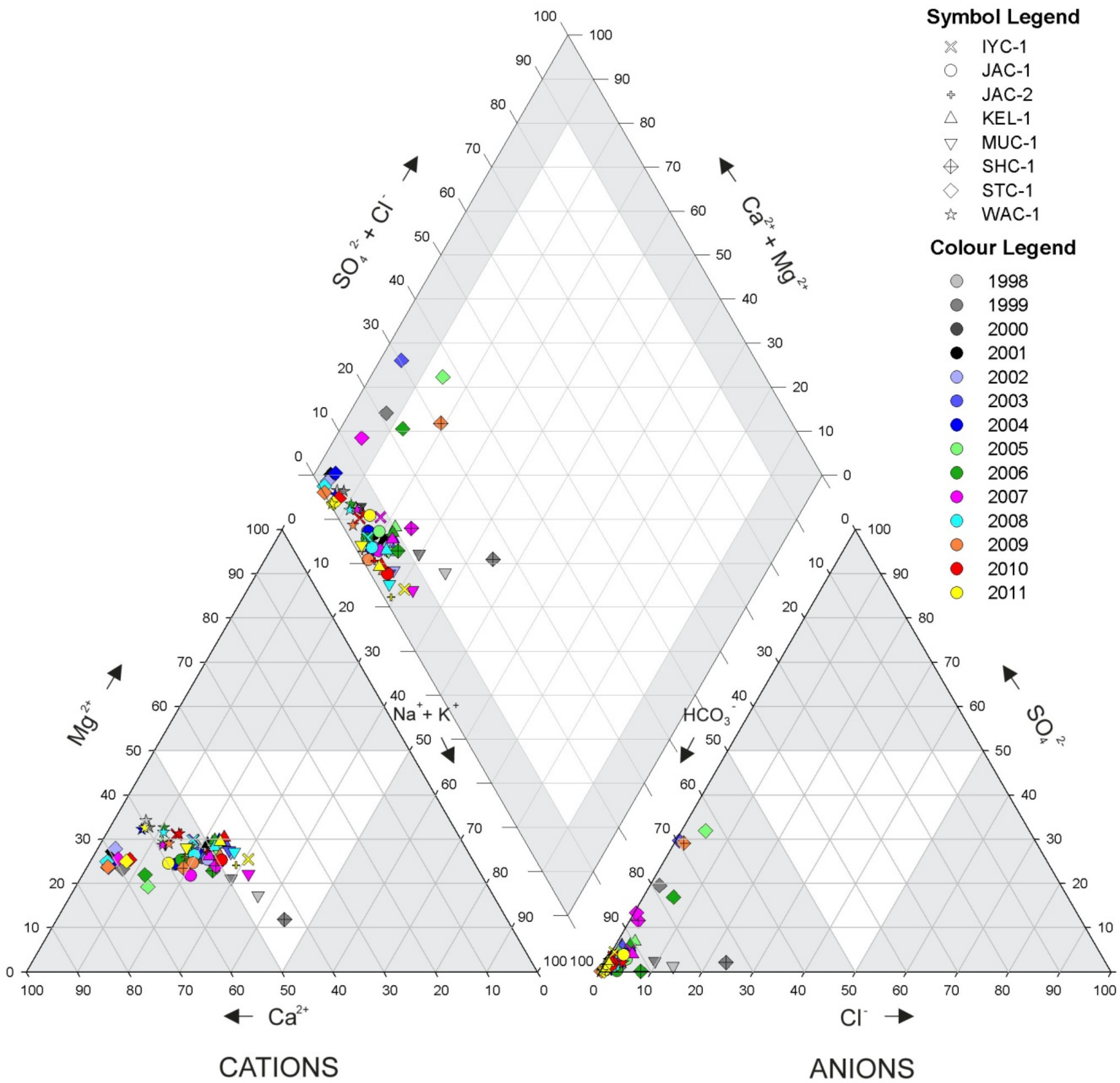
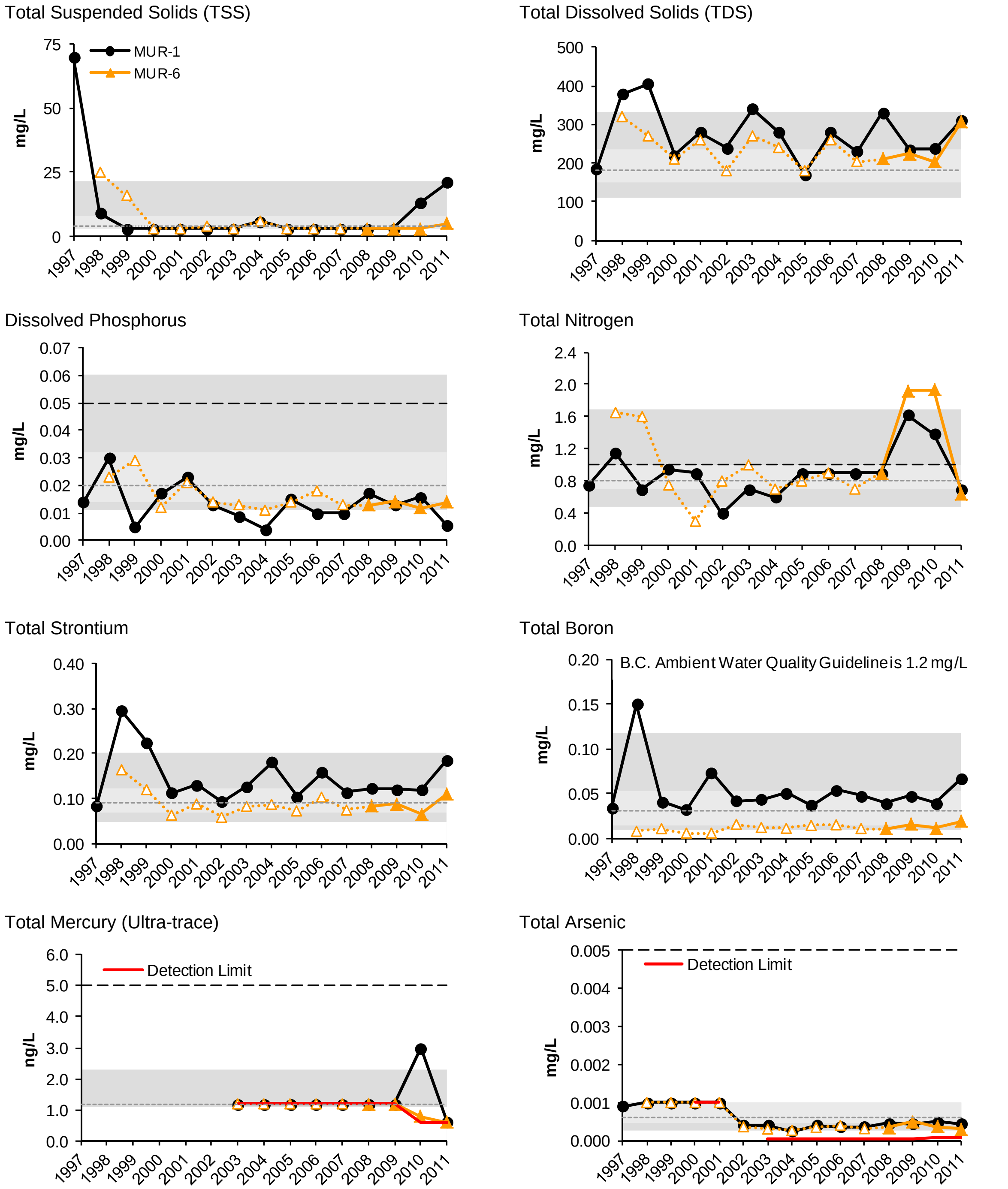


Table 5.2-13 Water quality guideline exceedances, Muskeg River watershed, fall 2011.

Variable	Units	Guideline[a]	MUR-1	MUR-6	MUC-1	JAC-1	JAC-2	STC-1	WAC-1	IYC-1	KEL-1
Fall											
Dissolved iron	mg/L	0.3	-	-	0.30	-	0.50	-	-	0.47	-
Sulphide	mg/L	0.002	-	-	0.0044	-	0.0058	-	-	-	0.0028
Total aluminum	mg/L	0.1	0.72	-	-	-	0.60	-	-	-	-
Total chromium	mg/L	0.001	0.0011	-	-	-	-	-	-	-	-
Total iron	mg/L	0.3	0.46	-	0.65	0.60	1.21	-	0.87	0.84	-
Total Kjeldahl Nitrogen	mg/L	1	-	-	-	-	-	-	-	-	1.17
Total nitrogen	mg/L	1	-	-	-	-	-	-	1.061	-	1.24
Total phenols	mg/L	0.004	0.0051	0.0043	0.0060	0.0048	0.0059	0.0097	0.0065	0.0047	0.0102

[a] Sources for all guidelines are outlined in Table 3.2-5.

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 data) relative to historical concentrations and regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

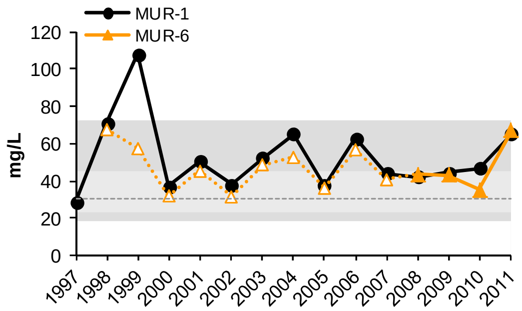
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

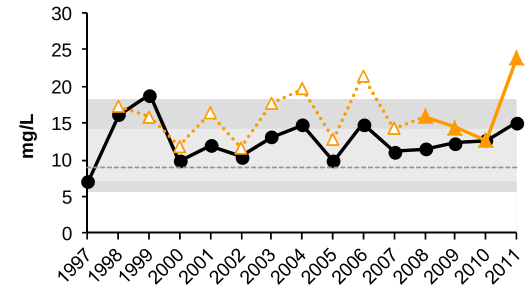
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-7 (Cont'd.)

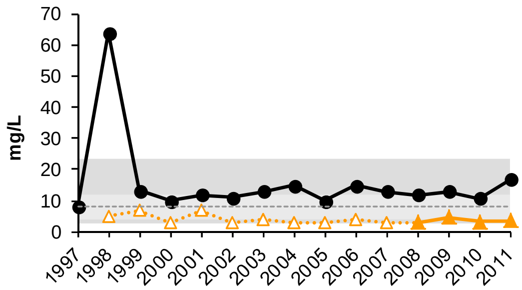
Calcium



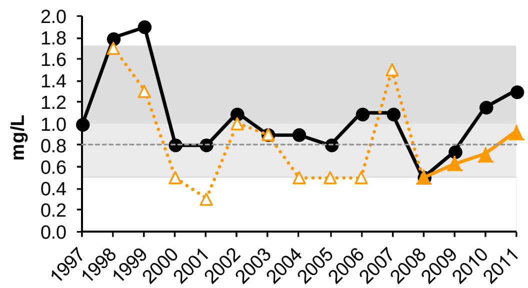
Magnesium



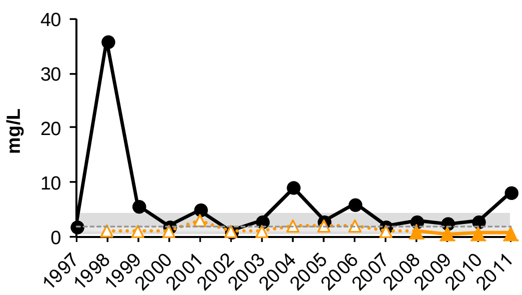
Sodium



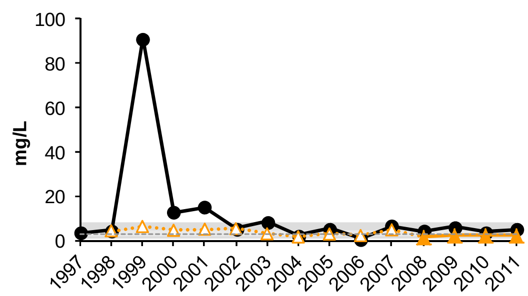
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

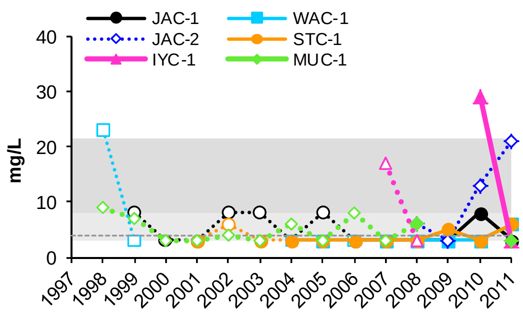
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

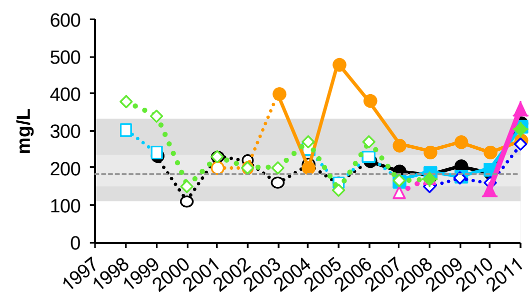
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-8 Selected water quality measurement endpoints in Muskeg River tributaries (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

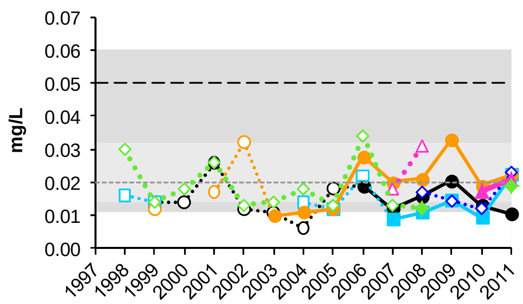
Total Suspended Solids (TSS)



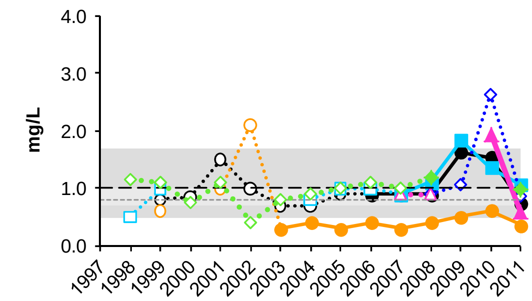
Total Dissolved Solids (TDS)



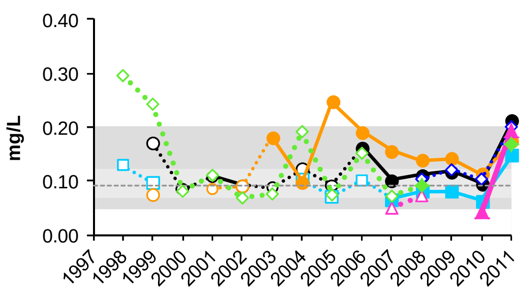
Dissolved Phosphorus



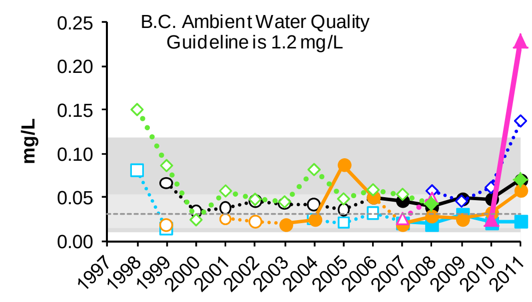
Total Nitrogen



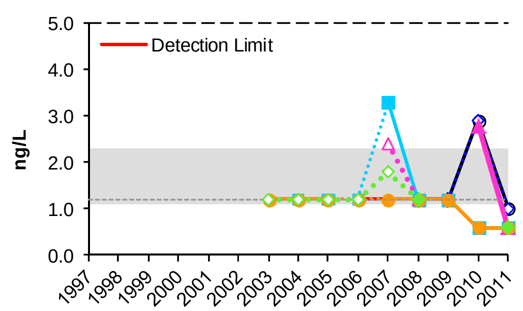
Total Strontium



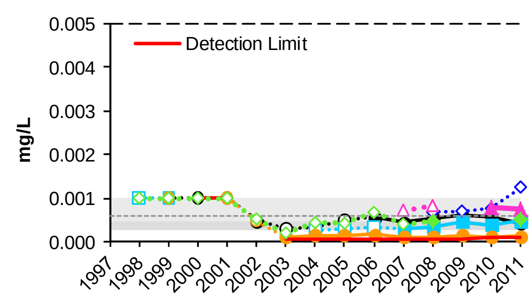
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



Non-detectable values are shown at the detection limit.

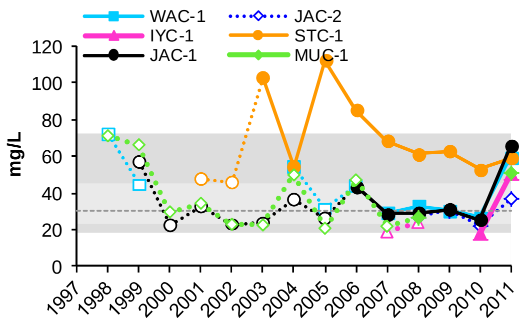
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O⋯⋯O Sampled as a *baseline* station ●——● Sampled as a *test* station

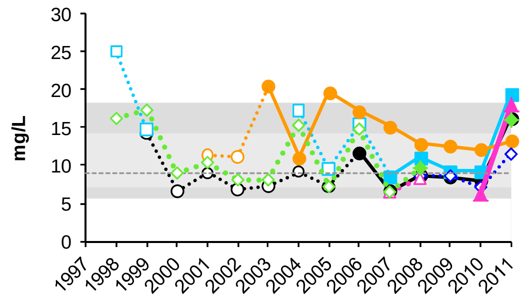
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-8 (Cont'd.)

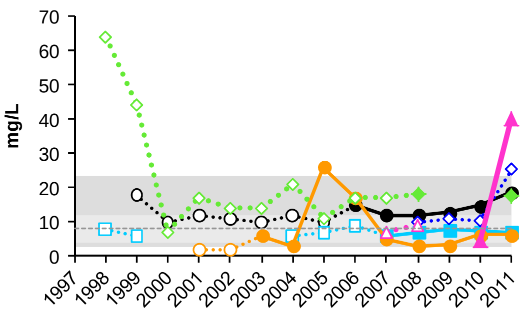
Calcium



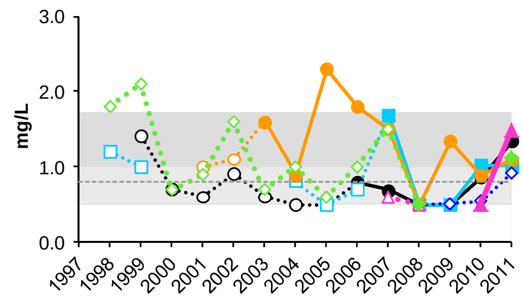
Magnesium



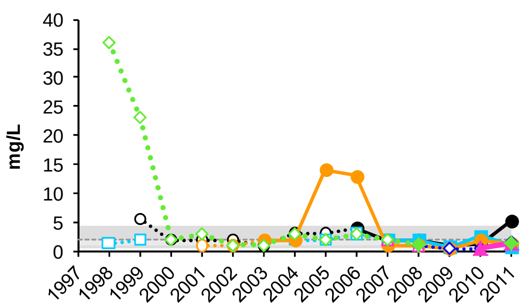
Sodium



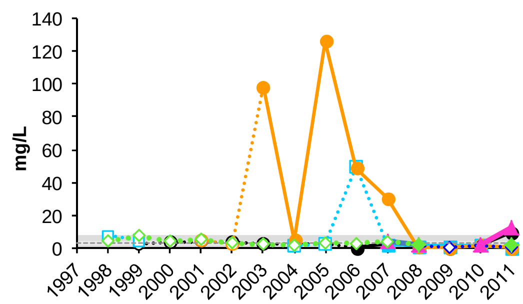
Potassium



Chloride



Sulphate



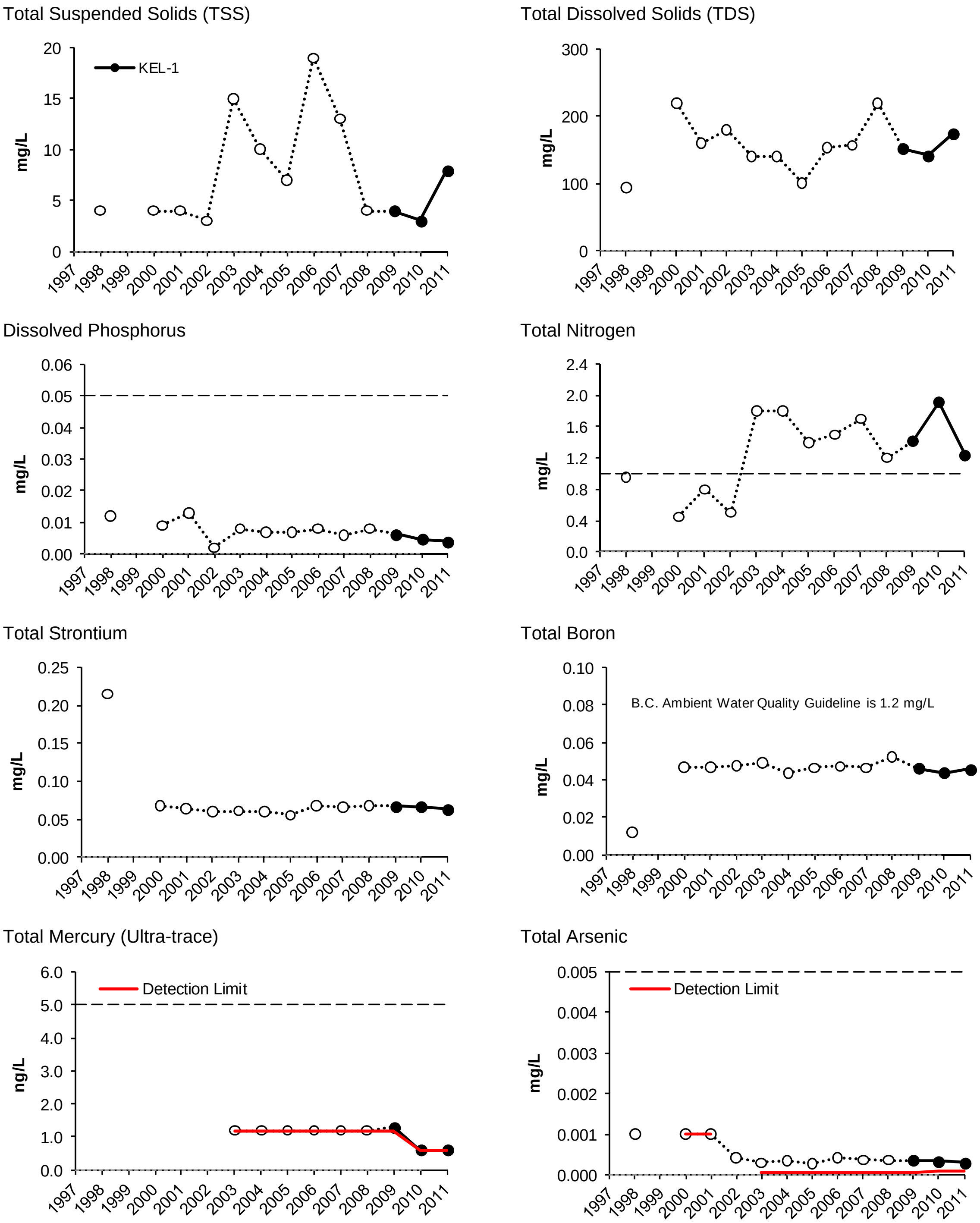
Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.2-9 Selected water quality measurement endpoints in Kearl Lake (fall data) relative to historical concentrations.

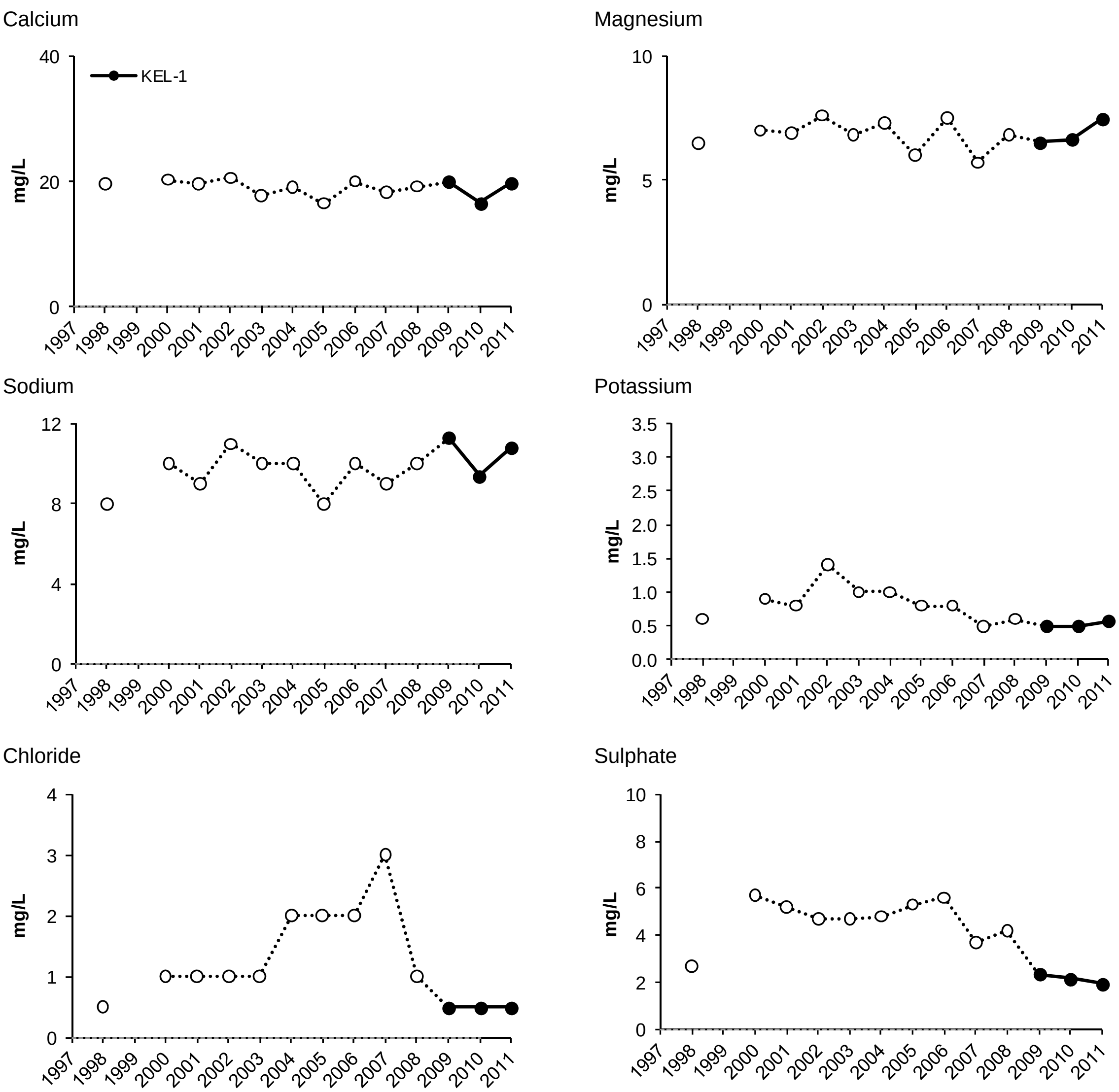


Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Figure 5.2-9 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Table 5.2-14 Water quality index (fall 2011) for Muskeg River watershed stations.

Station Identifier	Location	2011 Designation	Water Quality Index	Classification
MUR-1	lower Muskeg River	*test*	93.5	Negligible-Low
MUR-6	upstream of Wapasu Creek	*test*	93.7	Negligible-Low
MUC-1	near mouth of Muskeg Creek	*test*	96.0	Negligible-Low
JAC-1	near mouth of Jackpine Creek	*test*	92.4	Negligible-Low
JAC-2	upper Jackpine Creek	*baseline*	91.1	Negligible-Low
STC-1	near mouth of Stanley Creek	*test*	100.0	Negligible-Low
IYC-1	near mouth of Iyinimin Creek	*test*	82.2	Negligible-Low
WAC-1	near mouth of Wapasu Creek	*test*	97.5	Negligible-Low

Table 5.2-15 Average habitat characteristics of benthic invertebrate sampling locations of the Muskeg River.

Variable	Units	MUR-E1 Lower *Test* Reach of Muskeg River	MUR-D2 Middle *Test* Reach of Muskeg River	MUR-D3 Upper *Test* Reach of Muskeg River
Sample date	-	Sept. 7, 2011	Sept. 15, 2011	Sept. 10, 2011
Habitat	-	Erosional	Depositional	Depositional
Water depth	m	0.3	1.4	1.6
Current velocity	m/s	1.1	0.07	Neg.
Field Water Quality				
Dissolved oxygen	mg/L	7.9	6.4	5.5
Conductivity	µS/cm	426	440	248
pH	pH units	8.2	7.4	7.9
Water temperature	°C	18.7	9.6	15.6
Sediment Composition				
Sand	%	3	72	82
Silt	%	3	22	11
Clay	%	3	6	7
Small Gravel		11		
Large Gravel		30		
Small Cobble		36		
Large Cobble		11		
Boulder		3		
Total Organic Carbon	%		3.3	10

Figure 5.2-10 Periphyton chlorophyll *a* biomass at *test* reach MUR-E1 of the Muskeg River.

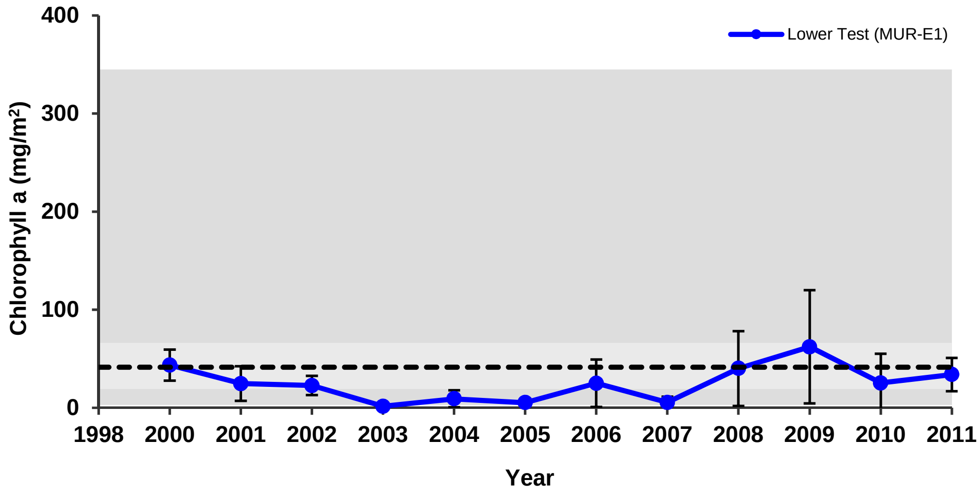


Table 5.2-16 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the lower Muskeg River (*test* reach MUR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year												
	Reach MUR-E1												
	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Hydra		<1	<1	<1									
Nematoda	2	<1	4	2	3	5	2	1	1	<1	1	1	5
Oligochaeta													<1
Erpobdellidae				<1									
Glossiphoniidae				<1									
Naididae	5	1	6	14	3	3	1	4	3	30	3	4	11
Tubificidae	5	<1	<1	1	1	13	5		7	7	<1	26	2
Enchytraeidae	<1	<1	1	<1	<1	1	1	<1		1	<1	<1	<1
Lumbriculidae				<1	<1	<1				<1			
Hydracarina	14	6	15	13	13		10	11	17	8	3	10	10
Amphipoda		<1		<1	<1								
Ostracoda	3	1	<1	3	<1			<1	2	1	<1	15	1
Cladocera													<1
Copepoda	<1	<1	<1	2	<1	<1	1		<1	<1	2	1	<1
Gastropoda	3	<1	<1	<1	<1				7	2		5	<1
Bivalvia	6	1	3	5	1	3	2		5	4	1	4	1
Coleoptera	5	1	2	1	3	10	5	3	2	1	1	1	<1
Ceratopogonidae	1	<1	<1	1		<1	<1	1	2	<1	<1	1	<1
Chironomidae	32	31	23	37	58	37	20	31	25	15	52	15	27
Empididae	4	<1	2	2	3	6	22	1	<1	<1	1	<1	<1
Tipulidae	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1	<1	
Tabanidae	0	<1	<1			<1							
Simuliidae	<1							<1	<1				<1
Ephemeroptera	12	50	28	5	5	9	21	24	20	25	29	10	34
Anisoptera	<1	<1	2	1	1	2	<1	<1	1	2	<1	<1	1
Plecoptera	4	6	5	5	3	8	8	5	3	2	2	2	<1
Trichoptera	2	1	8	5	4	4	2	16	3	2	4	1	4
Collembola													<1
Benthic Invertebrate Community Measurement Endpoints													
Total Abundance (No./m^2)	68,374	9,983	4,953	7,754	11,343	18,757	2,849	11,131	12,296	11,223	27,783	20,987	151,193
Richness	60	32	29	39	32	31	32	30	36	39	43	40	36
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	0.82
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	0.84
% EPT	18	57	39	16	14	21	31	44	25	30	34	17	39

Table 5.2-17 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**	**2011**
Hydra	<1	<1				<1	<1	1	<1		4	<1
Nematoda	2	1	6	3	3	6	1	6	5	2	3	5
Erpobdellidae	<1	<1	<1	<1		<1		<1				
Glossiphoniidae	<1	<1	<1	<1			<1	<1	<1	<1	1	<1
Naididae	2	1	<1	2	1	11	1	4	4	6	4	4
Tubificidae	10	<1	3	2	8	10	31	5	3	21	11	3
Enchytraeidae	<1	1	2	2	3	3	<1	6	1		1	
Lumbriculidae	1	<1	<1	1		<1	<1	<1		7		<1
Hydracarina	1	1	2	1	<1	<1	2	<1	3	1	<1	<1
Amphipoda		<1	<1	1	<1	<1	<1	2			<1	<1
Ostracoda	1	2	5		<1	10	<1	3	<1	1	1	3
Cladocera												8
Copepoda	<1	1	<1	<1	1	<1	<1	2	<1	3	2	2
Gastropoda	<1	3	1	<1		<1	1	2	4	1	4	1
Bivalvia	4	1	3	1	1	<1		2	4	5	3	3
Coleoptera	<1	<1	<1		<1	1	<1	<1		<1	<1	<1
Ceratopogonidae	1	1	2	3	7	4	2	28	11	3	5	5
Chironomidae	75	84	69	81	74	44	55	32	56	48	53	58
Empididae	<1	<1	<1	<1	1	1	1		4		<1	<1
Tipulidae	1	<1			<1		<1	<1	1		<1	
Tabanidae	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1
Simuliidae						1						
Ephemeroptera	<1	1	2	1	<1	6	1	2	1	1	3	6
Anisoptera	<1	<1	<1	<1		<1		<1	<1	<1	<1	<1
Zygoptera												<1
Plecoptera	<1	<1	<1	<1		<1	<1		<1			
Trichoptera	<1	<1	<1	<1	<1	1	<1	<1	<1		<1	<1
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	66,707
Richness	26	30	21	14	10	17	24	20	23	23	27	32
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	0.87
Evenness	0.78	0.87	0.91	0.77	0.77	0.83	0.69	0.90	0.95	0.81	0.86	0.90
% EPT	<1	1	2	2	<1	5	1	2	1	1	<1	6

Table 5.2-18 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	2011
Hydra				<1	1	<1				
Nematoda	1	2	6	3	4	5	2	<1		3
Erpobdellidae	<1	<1	<1	<1	<1	<1		<1		
Glossiphoniidae	<1	1	1	<1	3	<1	<1			<1
Naididae	<1	1	1	2	2	7	2	2	<1	5
Tubificidae	<1	2	15	2	15	16	9	23	7	26
Enchytraeidae		<1	1	<1		<1	<1		1	
Lumbriculidae		<1	1		1	<1		2		
Hydracarina	<1	1	<1	<1		<1	15			
Amphipoda	<1	1	5	<1	1	<1	<1	1	<1	<1
Ostracoda	4	1	7	1		2	3	2	7	9
Cladocera										2
Copepoda		1	3	1		<1	2	3	1	5
Gastropoda	<1	1	2	<1	<1	<1	<1		<1	
Bivalvia	28	17	18	8		5	7	12	10	17
Coleoptera		<1	<1			1	1		<1	
Ceratopogonidae	<1	2	2	1	1	1	1		<1	<1
Chironomidae	66	65	27	79	54	60	48	42	70	30
Tabanidae	<1	<1	<1	<1	<1	1	<1			<1
Tipulidae								2		
Simuliidae				<1						
Ephemeroptera		5	5	2	3	3	7	<1	<1	<1
Anisoptera		<1	<1				<1			
Plecoptera						1				
Trichoptera	<1	<1	<1	1		<1	<1	<1	1	
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	13,796
Richness	12	17	9	11	15	16	14	10	12	12
Simpson's Diversity	0.64	0.78	0.71	0.75	0.84	0.82	0.77	0.68	0.67	0.79
Evenness	0.71	0.85	0.81	0.83	0.86	0.89	0.85	0.78	0.78	0.87
% EPT	<1	6	5	2	3	4	9	<1	<1	0.72

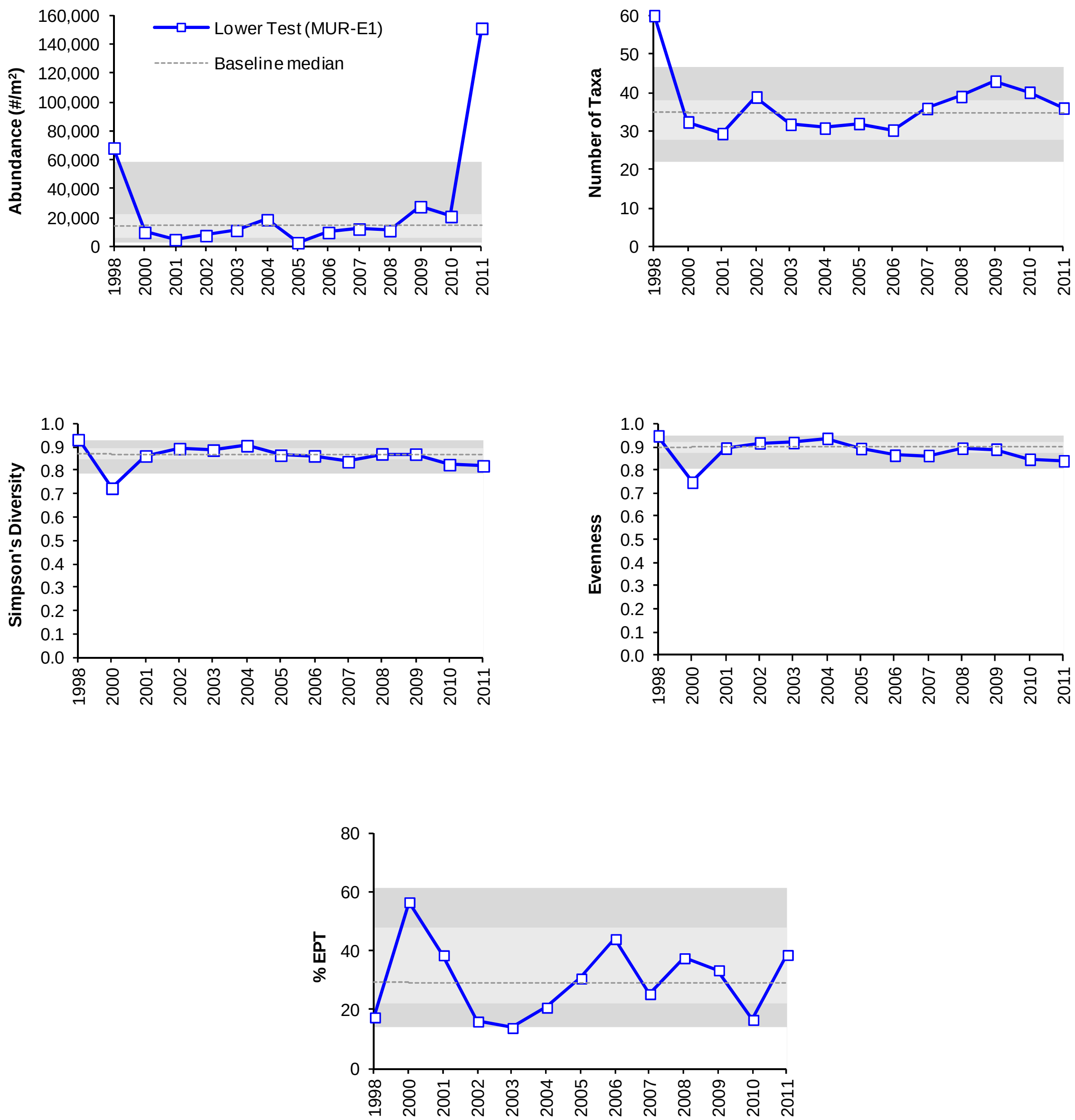
Table 5.2-19 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, *test* reach MUR-E1.

Variable	P-value		Variance Explained (%)		Nature of Change(s)	Spearman Rank r_s
	Time Trend	2011 vs. Previous Years	Time Trend	2011 vs. Previous Years		
Abundance	**<0.001**	**<0.001**	7	49	Increasing over time and higher in 2011 than the mean of previous years	**0.89**
Richness	0.665	0.528	0	1	No change	0.60
Simpson's Diversity	0.416	0.142	1	4	No change	-0.54
Evenness	0.363	0.161	1	3	No change	-0.54
EPT	0.997	0.087	0	2	No change	-0.26
CA Axis 1	0.163	0.097	1	2	No change	-0.14
CA Axis 2	**<0.001**	**<0.001**	7	7	Decreasing over time and lower in 2011 lower than mean of previous years	-0.71

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).

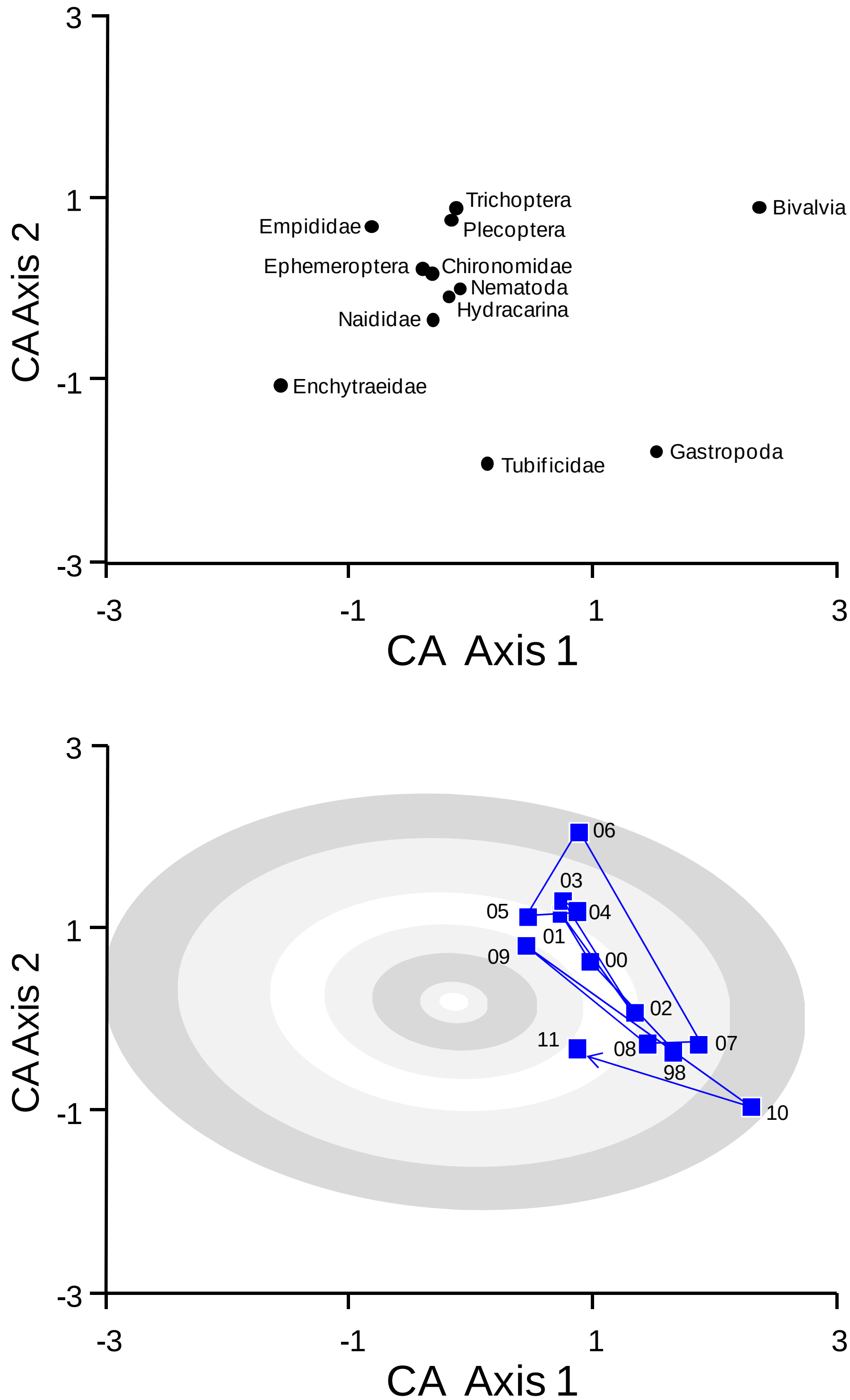
Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Figure 5.2-11 Variation in benthic invertebrate community measurement endpoints in the Muskeg River (*test* reach MUR-E1).



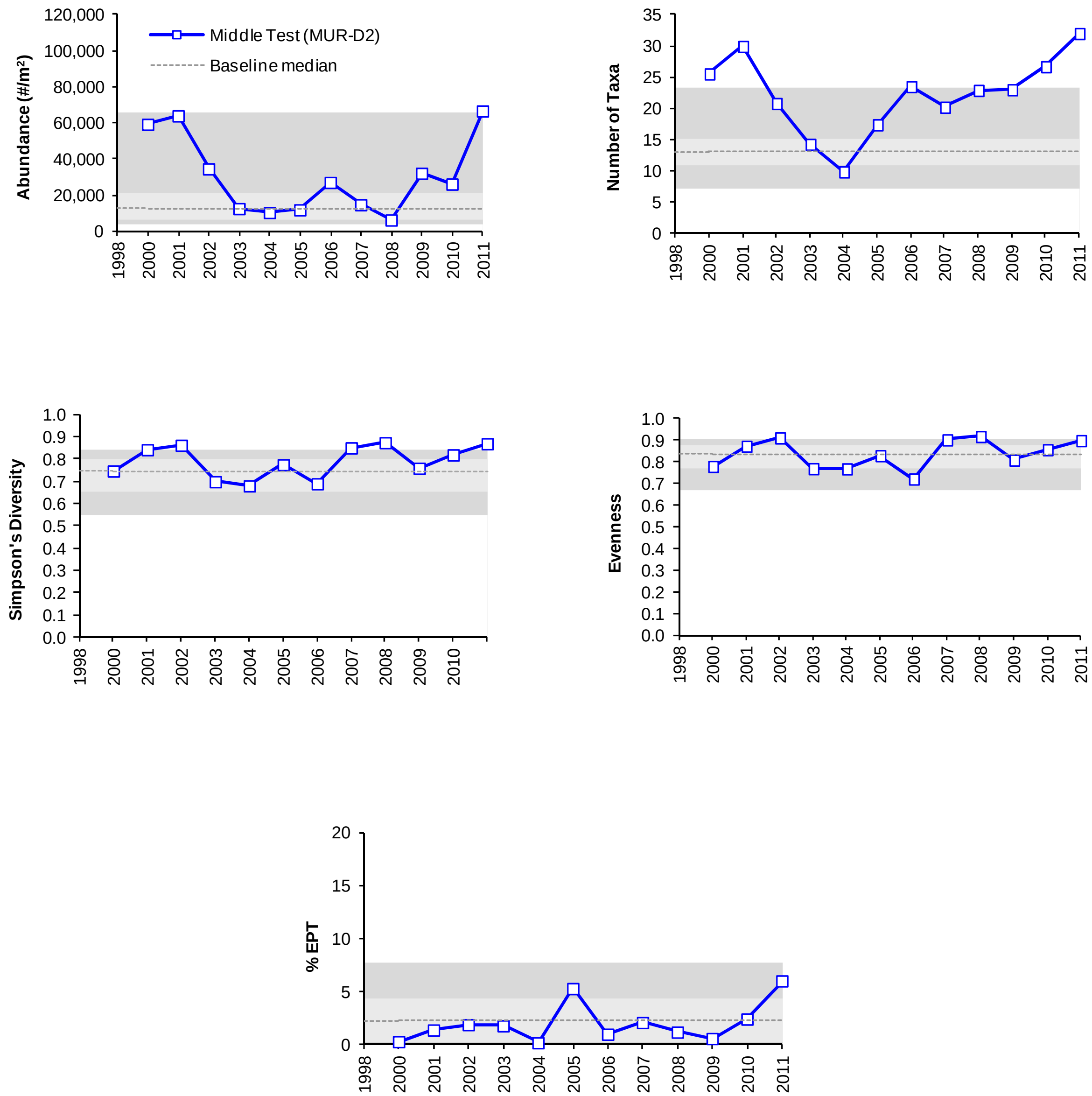
Note: Regional *baseline* values reflect pooled results for all *baseline* erosional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.2-12 Ordination (Correspondence Analysis) of benthic invertebrate communities in the Muskeg River (*test* reach MUR-E1).



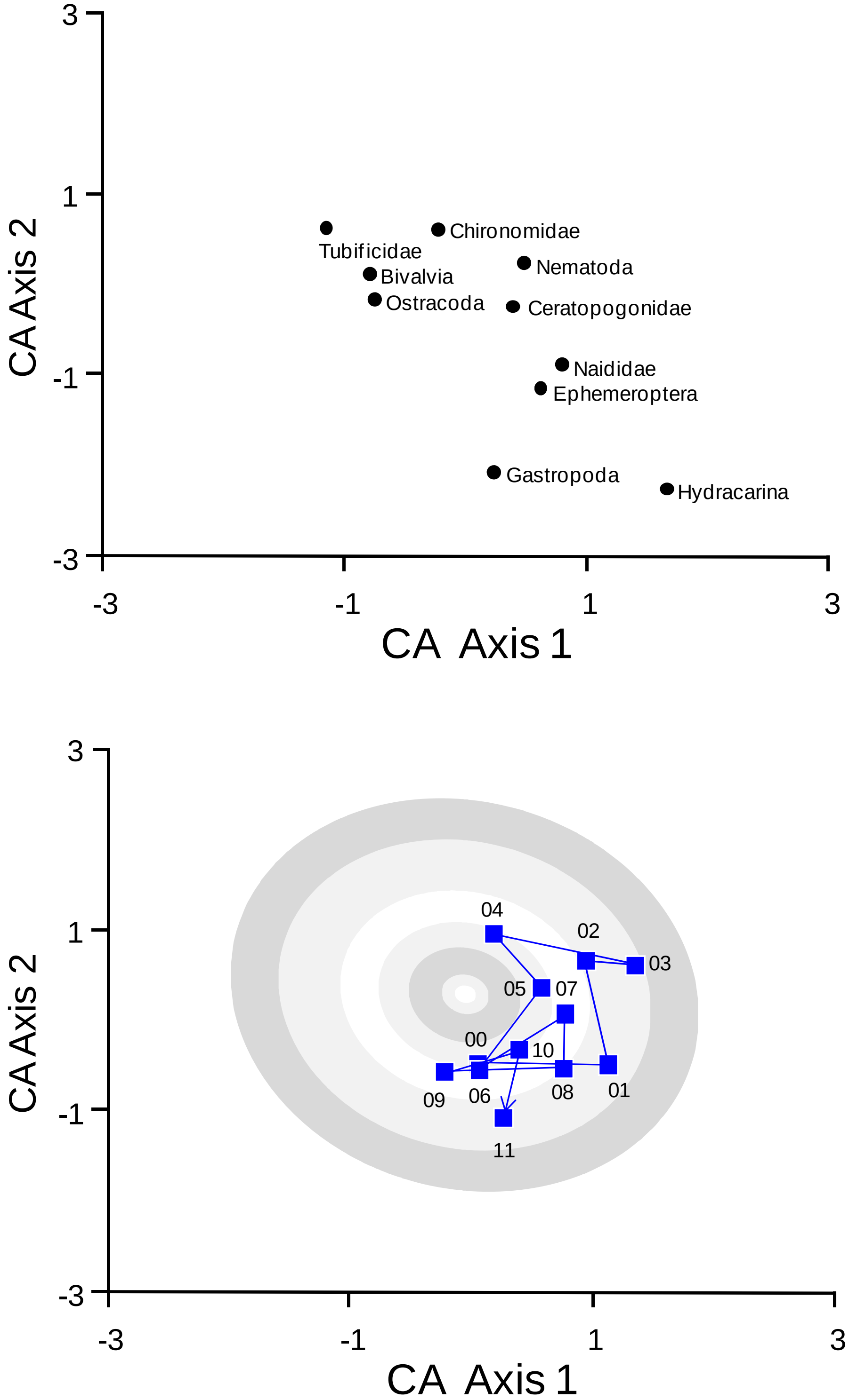
Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores. The ellipse in the lower panel is for the *baseline* erosional reaches in the RAMP FSA.

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.

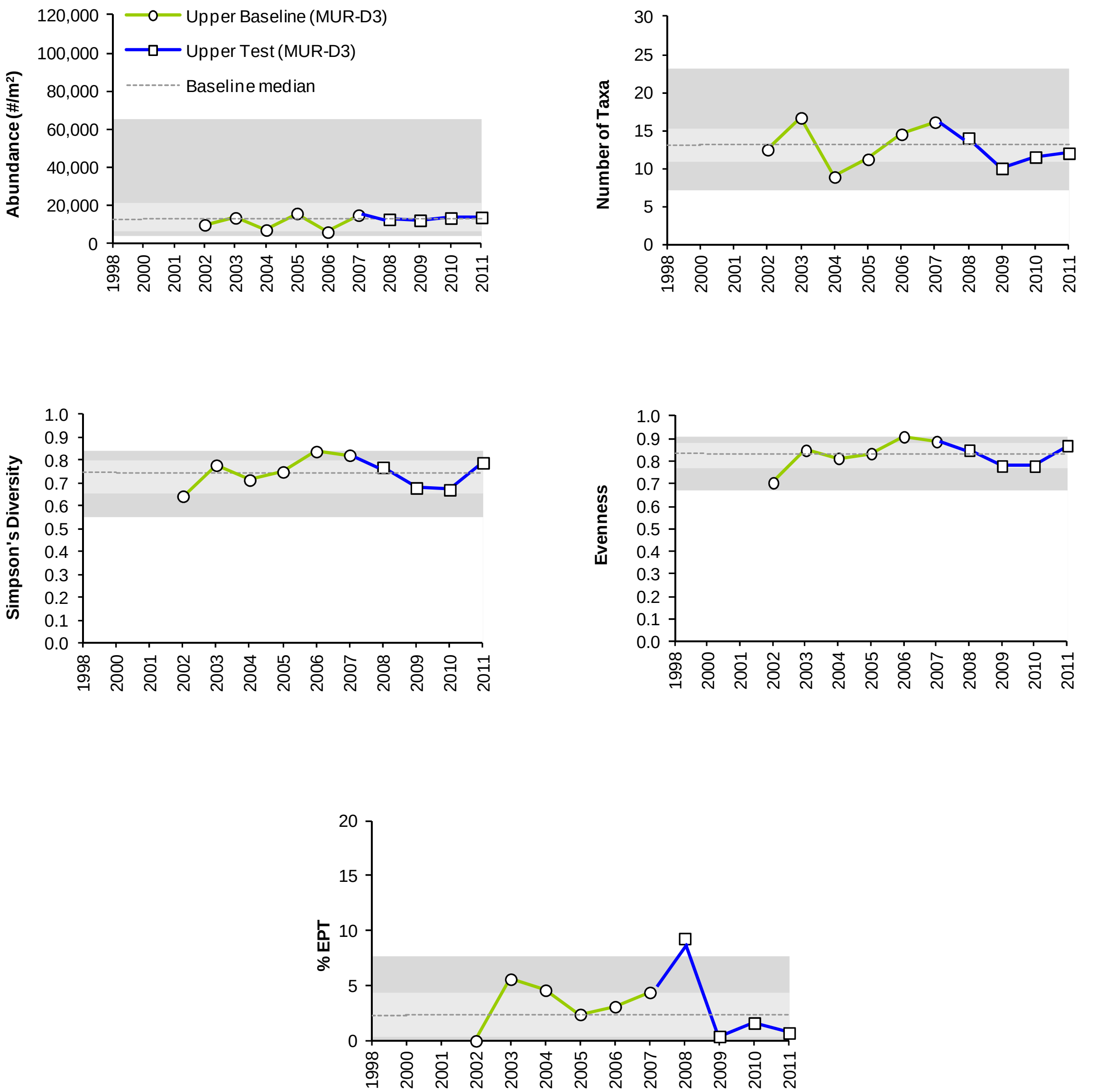
Table 5.2-20 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in the Muskeg River, *test* reach MUR-D2.

Variable	P-value		Variance Explained (%)		Nature of Change(s)	r_s
	Time Trend	2011 vs. Previous Years	Time Trend	2011 vs. Previous Years		
Abundance	0.199	<0.001	2	18	Higher in 2011 than mean of previous years	0.49
Richness	**0.038**	<0.001	4	12	Higher in 2011 than mean of previous years	0.66
Simpson's Diversity	**0.034**	**0.024**	9	10	Increasing over time and higher in 2011 than mean of previous years	0.37
Evenness	0.068	0.061	7	7	No change	0.14
EPT	**<0.001**	**<0.001**	21	39	Increasing over time and higher in 2011 than mean of previous years	0.60
CA Axis 1	**0.019**	0.314	13	2	Decreasing over time	-0.14
CA Axis 2	**<0.001**	**<0.001**	20	19	Decreasing over time and lower in 2011 than mean of previous years.	-0.43

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

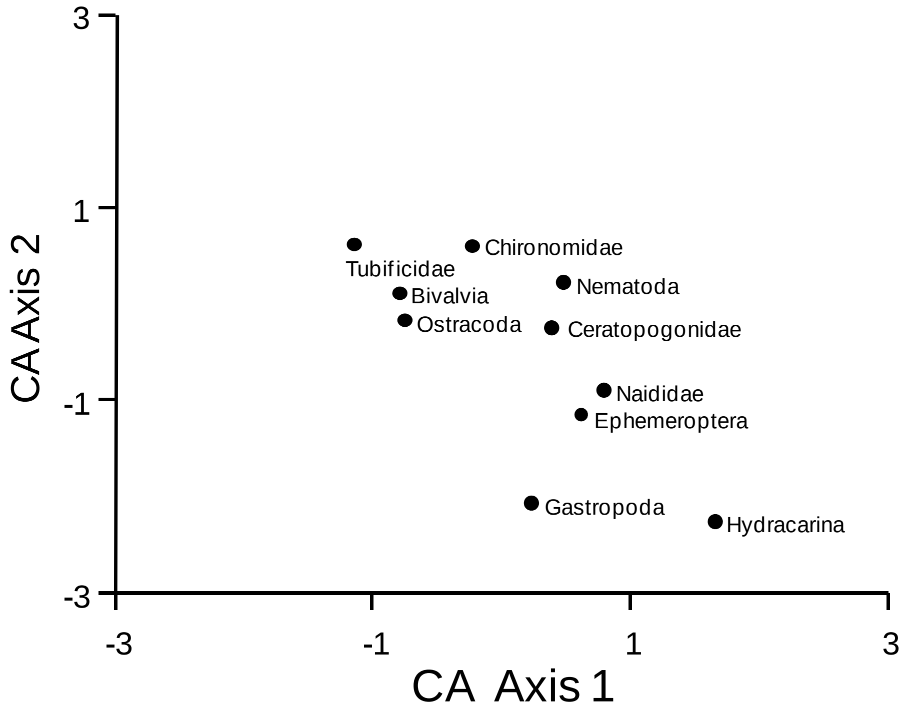
Figure 5.2-15 Variation in benthic invertebrate community measurement endpoints in the upper Muskeg River (*test* reach MUR-D3).

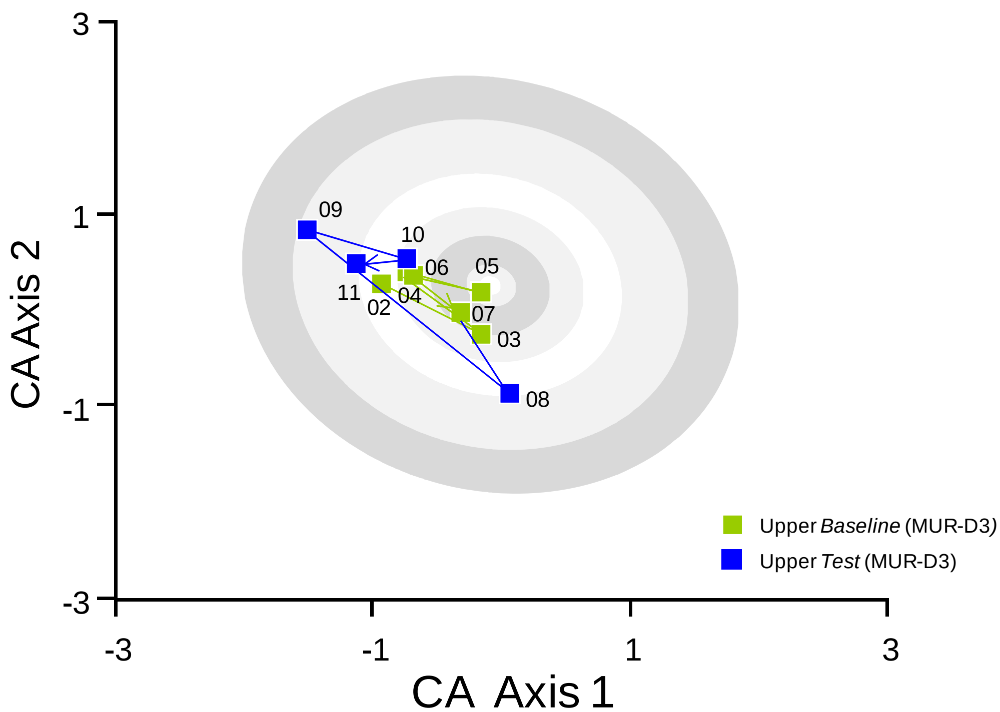


Note: Regional *baseline* values reflect pooled results for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Note: *Test* reach MUR-D3 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 5.2-21 Results of 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 Change(s)
	Before vs. After	Time Trend (*test* period)	Before vs. After	Time Trend (*test* period)	
Abundance	0.548	0.736	3	1	No change
Richness	**0.025**	0.699	25	1	Lower in *test* period compared to *baseline* period
Simpson's Diversity	0.137	0.616	9	1	No change
Evenness	0.433	0.515	3	2	No change
EPT	0.183	**0.049**	7	15	Decreasing over time after reach was designated as *test*
CA Axis 1	**0.029**	**0.010**	12	18	Lower in *test* period compared to *baseline* period and decreasing over time after reach was designated as *test*
CA Axis 2	0.553	**<0.001**	1	33	Increasing over time after reach was designated as *test*

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 Average habitat characteristics of benthic invertebrate sampling locations in Jackpine Creek.

Variable	Units	JAC-D1 Lower *Test* Reach of Jackpine Creek	JAC-D2 Upper *Baseline* Reach of Jackpine Creek
Sample date	-	Sept. 14, 2011	Sept. 9, 2011
Habitat	-	Depositional	Depositional
Water depth	m	0.9	0.7
Current velocity	m/s	Neg.	0.21
Field Water Quality			
Dissolved oxygen	mg/L	7.0	8.1
Conductivity	µS/cm	497	268
pH	pH units	7.8	8.1
Water temperature	°C	9.7	14.1
Sediment Composition			
Sand	%	98	70
Silt	%	1	23
Clay	%	1	7
Total Organic Carbon	%	0.3	2

Table 5.2-23 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Jackpine Creek (*test* reach JAC-D1).

Taxon	Percent Major Taxa Enumerated in Each Year									
	Reach JAC-D1									
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Hydra			<1						1	<1
Nematoda	5	6	1	4	2	2	6	1	2	1
Glossiphoniidae		<1								
Naididae	<1	2	2		1	<1	1	1	8	6
Tubificidae	<1	<1	1	5	<1	17	8	1	7	11
Enchytraeidae	<1	4	<1			<1	1		<1	<1
Hydracarina	1	1	1	8	1	5	4	3	1	7
Amphipoda		<1	<1							
Ostracoda	<1		2	4		1	<1	<1	1	<1
Cladocera			8		<1	2	<1	<1	4	15
Copepoda	<1	1	6	1		1		4	1	1
Gastropoda	<1		<1			2	1	<1	4	1
Bivalvia	1	3	<1	<1		<1	1	<1	<1	<1
Coleoptera		<1	<1				<1		<1	<1
Ceratopogonidae	2	2	4		5	2	9	4	13	2
Chironomidae	88	66	69	69	86	66	57	80	53	51
Empididae	<1	2	2	4	2	1	1	2	1	1
Tipulidae	<1	2	1	1	1	<1	<1		<1	
Tabanidae	<1	<1	<1	<1	<1	<1	1	<1	1	<1
Ephemeroptera	<1		2	1	1	1	7	1	3	2
Anisoptera	<1	<1	<1		1	<1	<1	<1	<1	<1
Zygoptera										<1
Plecoptera					1		<1			
Trichoptera	<1	<1	<1	3	<1	<1	2	1	<1	<1
Benthic Invertebrate Community Measurement Endpoints										
Total Abundance (No./m^2)	28,172	4,017	9,230	7,417	9,561	9,644	8,913	31,371	16,427	105,500
Richness	15	11	15	7	12	16	20	27	16	31
Simpson's Diversity	0.79	0.76	0.81	0.58	0.72	0.72	0.79	0.87	0.80	0.87
Evenness	0.85	0.88	0.88	0.73	0.73	0.78	0.82	0.91	0.86	0.9
% EPT	<1	<1	2	3	<1	1	2	2	<1	2

Table 5.2-24 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Jackpine Creek (*baseline* reach JAC-D2).

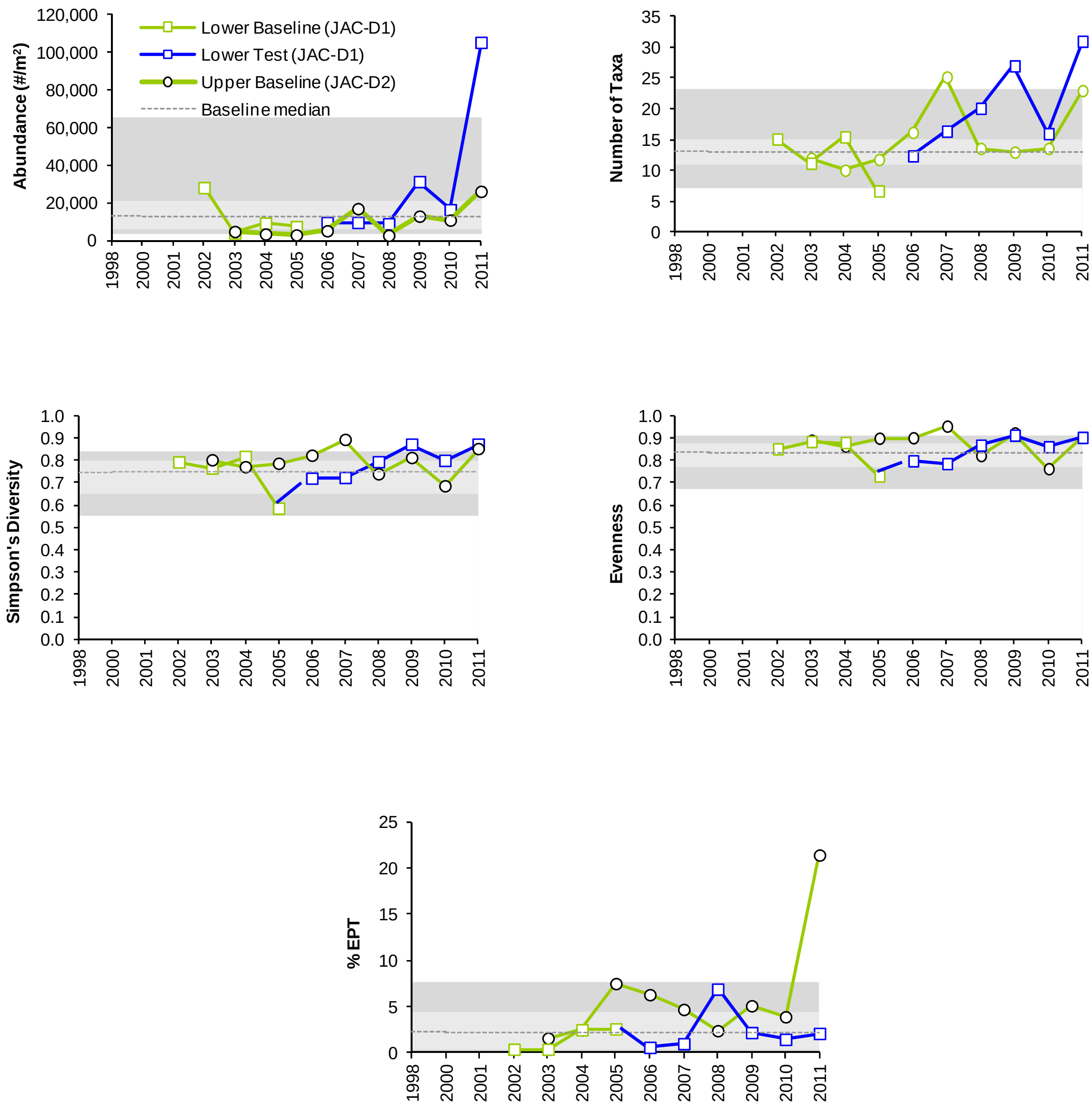
Taxon	Percent Major Taxa Enumerated in Each Year								
	Reach JAC-D2								
	2003	2004	2005	2006	2007	2008	2009	2010	2011
Hydra					<1				
Nematoda	6	4	2	4	5	3	<1	2	1
Glossiphoniidae						<1			
Naididae	3	1	1	2	8	2		5	9
Tubificidae	2	5	1	2	5	2	1	2	4
Enchytraeidae	1	1	1	2	<1	<1	<1	1	<1
Hydracarina	<1	<1	18	1	2	<1		1	6
Ostracoda	<1	1	3	1	<1	<1		1	<1
Cladocera		<1			<1				7
Copepoda		2	3		<1	<1		2	3
Gastropoda			<1	<1	<1	<1	1	1	<1
Bivalvia	<1	<1	<1		<1	2	1	<1	3
Coleoptera	6	3	6	1	2	3	6	5	3
Ceratopogonidae	1	31	4	2	5	19	11	12	10
Chironomidae	67	34	44	63	66	60	69	59	32
Empididae	1	<1	3	3	1		<1	1	<1
Tipulidae	1	13	4	2	<1	<1	2	1	
Tabanidae	1	2	<1	<1	<1	<1	<1	<1	<1
Ephemeroptera	<1	2	1	6	4	3	7	6	19
Anisoptera			<1				<1		<1
Plecoptera	<1					<1	<1		
Trichoptera	<1	1	7	1	2	1	1	<1	3
Benthic Invertebrate Community Measurement Endpoints									
Total Abundance (No./m^2)	4,787	3,448	2,957	5,174	16,966	2,752	12,952	10,879	26,179
Richness	12	10	12	16	25	14	13	14	23
Simpson's Diversity	0.8	0.77	0.78	0.82	0.89	0.74	0.81	0.68	0.85
Evenness	0.89	0.86	0.9	0.86	0.95	0.87	0.92	0.84	0.90
% EPT	2	2	7	6	5	6	5	<1	21

Table 5.2-25 Results of 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 Change(s)
	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	0.063	0.231	3	1	No change
Richness	0.080	0.007	4	9	Increasing in *test* reach more quickly than in *baseline* reach
Simpson's Diversity	0.214	**0.018**	4	16	Increasing in *test* reach more quickly than in *baseline* reach
Evenness	0.808	**0.035**	0	15	Increasing in *test* reach more quickly than in *baseline* reach
EPT	0.414	0.534	1	0	No change
CA Axis 1	0.440	0.325	2	3	No change
CA Axis 2	0.699	0.088	0	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).

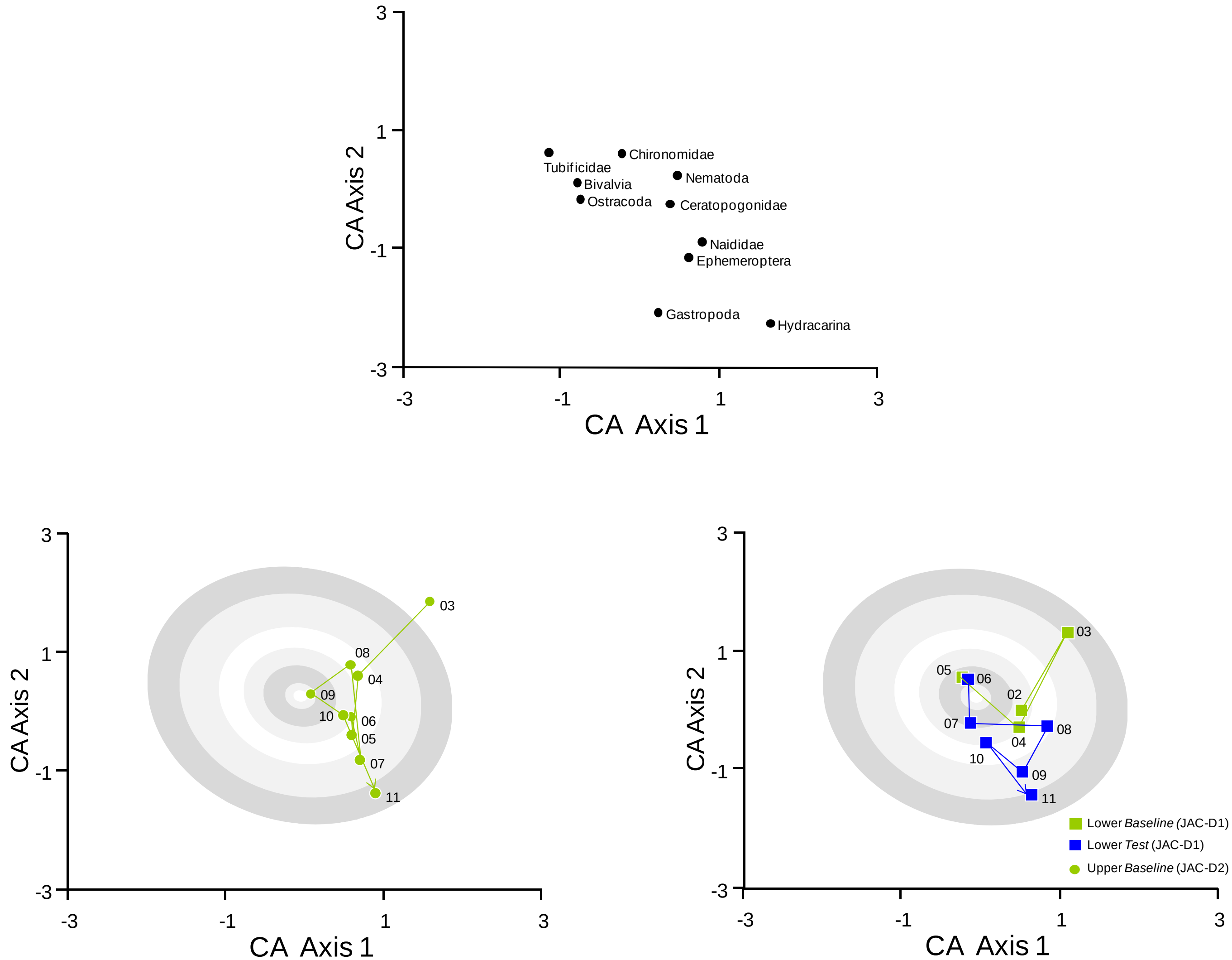
Figure 5.2-17 Variations in benthic invertebrate community measurement endpoints in *test* reach JAC-D1 and *baseline* reach JAC-D2 of Jackpine Creek.



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-D1 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.

Variable	Units	Kearl Lake (KEL-1)
Sample date	-	Sept. 10, 2011
Habitat	-	Depositional
Water depth	m	1.7
Field Water Quality		
Dissolved oxygen	mg/L	8.4
Conductivity	µS/cm	175
pH	pH units	8.1
Water temperature	°C	19
Sediment Composition		
Sand	%	53
Silt	%	45
Clay	%	2
Total Organic Carbon	%	5

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										
	Kearl Lake										
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Nematoda					1	1	3	5		3	
Erpobdellidae					<1	<1		<1	<1	<1	
Glossiphoniidae	<1	1	1	<1				<1			<1
Naididae		<1	6	5	1	3	2	5	5	20	4
Tubificidae					1	2	1	<1	2		
Lumbriculidae						<1					
Hydracarina	<1		<1				2	7		1	16
Amphipoda	13	46	36	58	25	23	27	2	8	7	12
Ostracoda	7	7	4	4	1	<1	1		<1	2	25
Cladocera	1		<1	1	7	<1		1	<1	14	4
Copepoda	<1	<1		2	15	<1	31	38	56	30	19
Gastropoda	1	<1				<1		1	<1	<1	<1
Bivalvia	4	4	6	9	4	23	7	11	6	7	4
Ceratopogonidae		1	1			<1		<1	<1	<1	
Chaoboridae	1						<1	<1	<1	<1	<1
Chironomidae	6	42	46	20	45	42	24	28	21	13	14
Ephemeroptera	<1	1				2	1			<1	<1
Anisoptera						<1				<1	
Trichoptera	2	1	1	<1	<1	1	2	1		<1	<1
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	5,313
Richness	7	9	8	7	12	17	8	7	10	13	10
Simpson's Diversity	0.73	0.64	0.63	0.6	0.76	0.76	0.71	0.49	0.61	0.67	0.75
Evenness	0.92	0.72	0.79	0.71	0.83	0.76	0.84	0.62	0.72	0.78	0.85
% EPT	3	2	1	<1	<1	2	2	<1	0	<1	<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		Variance Explained (%)		Nature of Change(s)
	Before vs. After	Time Trend (*test* period)	Before vs. After	Time Trend (*test* period)	
Abundance	0.210	0.686	3	0	No change
Richness	0.327	0.763	3	0	No change
Simpson's Diversity	0.797	0.053	0	14	No change
Evenness	0.835	0.071	0	13	No change
EPT	**0.003**	0.259	31	4	Lower in *test* period
CA Axis 1	0.595	**0.005**	1	37	Increasing during *test* period
CA Axis 2	**0.004**	**0.001**	19	29	Lower in *baseline* period and increasing during *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).

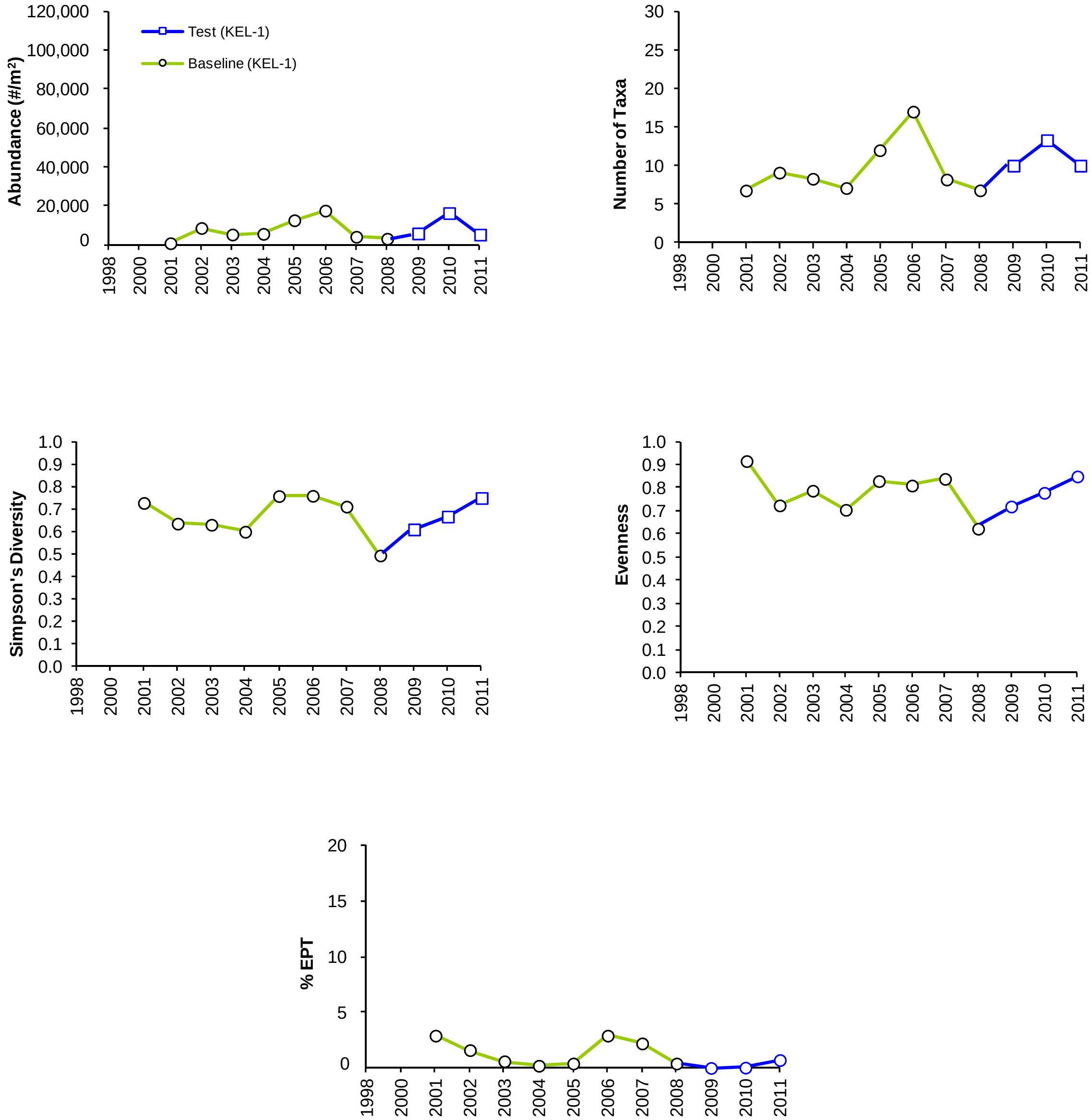
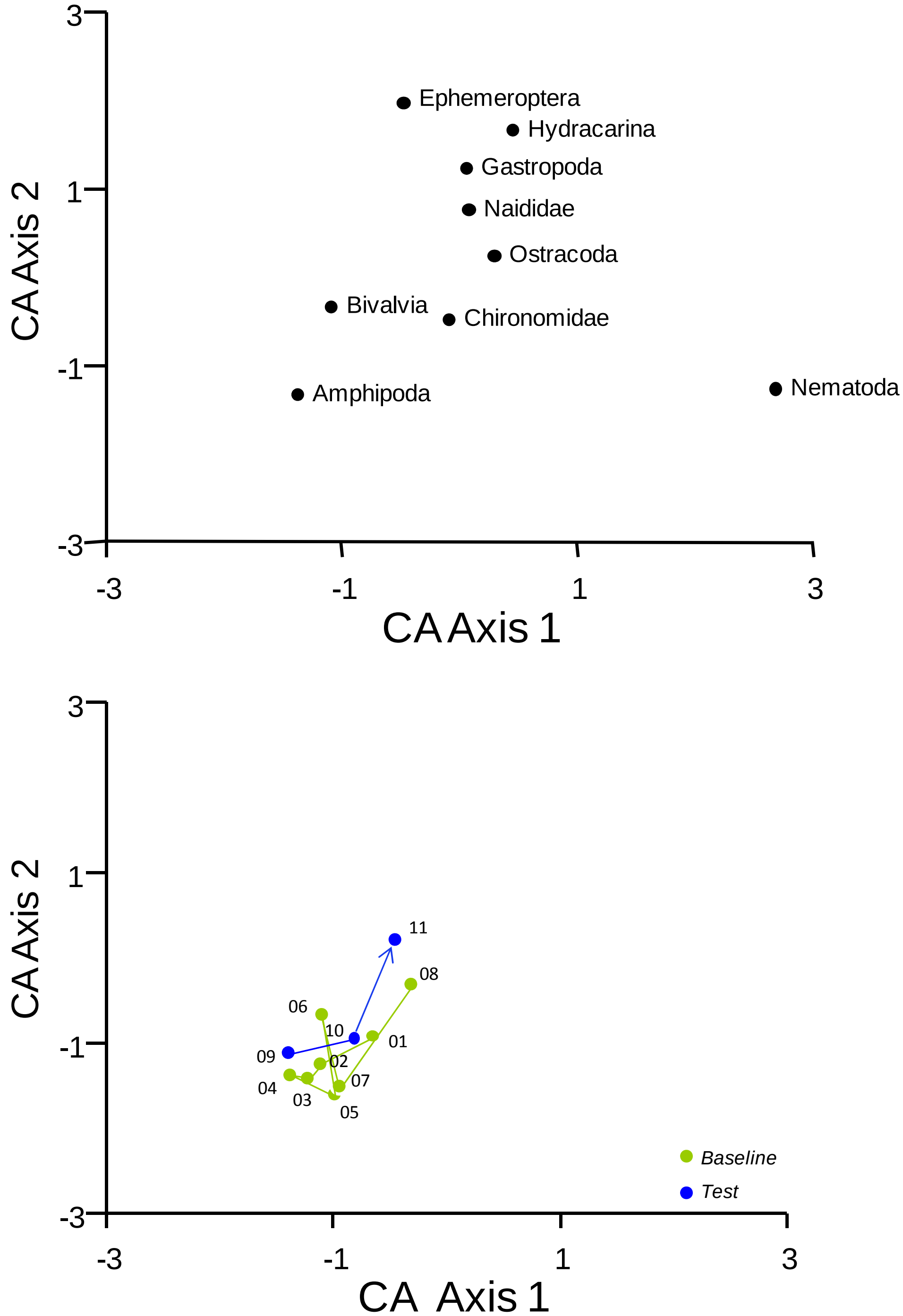


Figure 5.2-20 Ordination (Correspondence Analysis) of benthic invertebrate communities in Kearl Lake (KEL-1).



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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	6	7	1	8	12
Silt	%	-	22	7	8	19	32
Sand	%	-	72	7	60	74	88
Total organic carbon	%	-	3.3	8	1.1	3.2	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<20	7	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<20	7	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	44	7	<5	71	**180**
Fraction 3 (C16-C34)	mg/kg	300[1]	**1080**	7	110	**1200**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	1170	7	62	1100	2100
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0016	9	0.0013	0.0025	0.0200
Retene	mg/kg	-	0.0614	9	0.0116	0.1830	0.3140
Total dibenzothiophenes	mg/kg	-	1.4004	9	0.2871	5.3306	11.0401
Total PAHs	mg/kg	-	5.7989	9	0.9035	15.3275	30.4399
Total Parent PAHs	mg/kg	-	0.1632	9	0.0286	0.3641	0.6761
Total Alkylated PAHs	mg/kg	-	5.6357	9	0.8749	15.0141	29.7638
Predicted PAH toxicity[3]	H.I.	1.0	<u>0.73</u>	9	0.93	**1.50**	**4.00**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	-	7	2.6	7.0	8.6
Chironomus growth - 10d	mg/organism	-	-	7	0.7	2.1	2.5
Hyalella survival - 14d	# surviving	-	-	7	8.0	8.0	9.2
Hyalella growth - 14d	mg/organism	-	-	7	0.1	0.2	0.4

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	7	7	5	7	47
Silt	%	-	12	7	6	14	29
Sand	%	-	82	7	26	79	85
Total organic carbon	%	-	10.4	8	1.7	23.1	29.6
Total hydrocarbons							
BTEX	mg/kg	-	<50	7	<5	<5	<73
Fraction 1 (C6-C10)	mg/kg	30[1]	**<50**	7	<5	<5	**<73**
Fraction 2 (C10-C16)	mg/kg	150[1]	<70	7	<5	27	130
Fraction 3 (C16-C34)	mg/kg	300[1]	111	7	52	**740**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	74	7	71	326	1800
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<0.0075	8	0.0031	0.0074	0.0145
Retene	mg/kg	-	<u>0.0155</u>	8	0.1310	0.3735	2.3300
Total dibenzothiophenes	mg/kg	-	0.0832	8	0.0478	0.1284	0.1899
Total PAHs	mg/kg	-	0.4223	8	0.3786	1.1905	3.1058
Total Parent PAHs	mg/kg	-	0.0346	8	0.0300	0.0500	0.3397
Total Alkylated PAHs	mg/kg	-	0.3877	8	0.3486	1.0221	3.0537
Predicted PAH toxicity[3]	H.I.	1.0	0.45	8	0.03	0.28	0.79
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	-	6	3.0	6.5	8.8
Chironomus growth - 10d	mg/organism	-	-	6	1.3	1.6	2.2
Hyalella survival - 14d	# surviving	-	-	6	7.0	8.2	9.2
Hyalella growth - 14d	mg/organism	-	-	6	0.1	0.2	0.3

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>0.7</u>	7	1.0	4.0	18.7
Silt	%	-	1.0	7	0.3	11.0	13.0
Sand	%	-	98.3	7	81.0	84.0	99.0
Total organic carbon	%	-	0.3	7	0.2	1.1	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	6	13	23	71
Fraction 3 (C16-C34)	mg/kg	300[1]	<u>101</u>	6	150	**480**	**790**
Fraction 4 (C34-C50)	mg/kg	2800[1]	<u>137</u>	6	210	632	820
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0003</u>	7	0.0007	0.0016	0.0030
Retene	mg/kg	-	0.0117	6	0.0072	0.0395	0.9510
Total dibenzothiophenes	mg/kg	-	0.1379	7	0.1047	0.4909	1.6392
Total PAHs	mg/kg	-	0.6048	7	0.4129	1.5525	4.4924
Total Parent PAHs	mg/kg	-	<u>0.0155</u>	7	0.0218	0.0471	0.1360
Total Alkylated PAHs	mg/kg	-	0.5893	7	0.3911	1.5054	4.3754
Predicted PAH toxicity[3]	H.I.	1.0	0.68	7	0.21	0.33	**1.33**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>8.8</u>	5	5.6	7.2	8.6
Chironomus growth - 10d	mg/organism	-	2.29	5	1.15	3.10	3.40
Hyalella survival - 14d	# surviving	-	9.8	5	7.0	9.4	9.8
Hyalella growth - 14d	mg/organism	-	0.27	5	0.14	0.27	0.31

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	7	4	1	8	13
Silt	%	-	<u>23</u>	4	<1	18	22
Sand	%	-	70	4	66	74	98
Total organic carbon	%	-	<u>2.1</u>	5	0.1	1.4	1.9
Total hydrocarbons							
BTEX	mg/kg	-	<20	5	<5	<10	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<20	5	<5	<10	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	<26	5	<5	8	<27
Fraction 3 (C16-C34)	mg/kg	300[1]	58	5	10	74	190
Fraction 4 (C34-C50)	mg/kg	2800[1]	57	5	<5	53	160
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0005</u>	4	0.0008	0.0017	0.0041
Retene	mg/kg	-	0.0152	4	0.0010	0.0220	0.0331
Total dibenzothiophenes	mg/kg	-	0.0121	4	0.0019	0.0059	0.0164
Total PAHs	mg/kg	-	0.1624	4	0.0143	0.1086	0.2002
Total Parent PAHs	mg/kg	-	0.0156	4	0.0037	0.0136	0.0203
Total Alkylated PAHs	mg/kg	-	0.1468	4	0.0106	0.0948	0.1803
Predicted PAH toxicity[3]	H.I.	1.0	0.31	4	0.14	0.21	0.35
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	8.2	4	4.6	7.9	9.6
Chironomus growth - 10d	mg/organism	-	2.11	4	0.80	2.31	3.05
Hyalella survival - 14d	# surviving	-	9.4	4	8.0	8.7	9.8
Hyalella growth - 14d	mg/organism	-	<u>0.56</u>	4	0.29	0.32	0.34

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	2	5	1	16	58
Silt	%	-	45	5	4	28	62
Sand	%	-	53	5	9	56	93
Total organic carbon	%	-	<u>5.0</u>	7	31.1	34.4	38.1
Total hydrocarbons							
BTEX	mg/kg	-	<160	6	<5	<9	<220
Fraction 1 (C6-C10)	mg/kg	30[1]	**<160**	6	<5	<9	**<220**
Fraction 2 (C10-C16)	mg/kg	150[1]	**<213**	6	<5	22	**530**
Fraction 3 (C16-C34)	mg/kg	300[1]	**487**	6	230	**578**	**3600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	366	6	81	355	2500
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0194	3	0.0120	0.0159	**0.0361**
Retene	mg/kg	-	0.0485	7	0.0156	0.0499	0.1130
Total dibenzothiophenes	mg/kg	-	0.0437	7	0.0281	0.0443	0.0839
Total PAHs	mg/kg	-	0.9486	7	0.7229	0.9175	1.4596
Total Parent PAHs	mg/kg	-	0.1385	7	0.0783	0.1249	0.3449
Total Alkylated PAHs	mg/kg	-	0.8101	7	0.6424	0.7237	1.3436
Predicted PAH toxicity[3]	H.I.	1.0	0.24	7	0.03	0.40	0.92
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>8.4</u>	3	8.8	8.8	9.0
Chironomus growth - 10d	mg/organism	-	<u>1.16</u>	3	1.22	1.29	1.45
Hyalella survival - 14d	# surviving	-	<u>9.2</u>	3	7.6	9.0	9.0
Hyalella growth - 14d	mg/organism	-	<u>0.31</u>	3	0.12	0.22	0.27

Values in **bold** indicate concentrations exceeding guidelines.

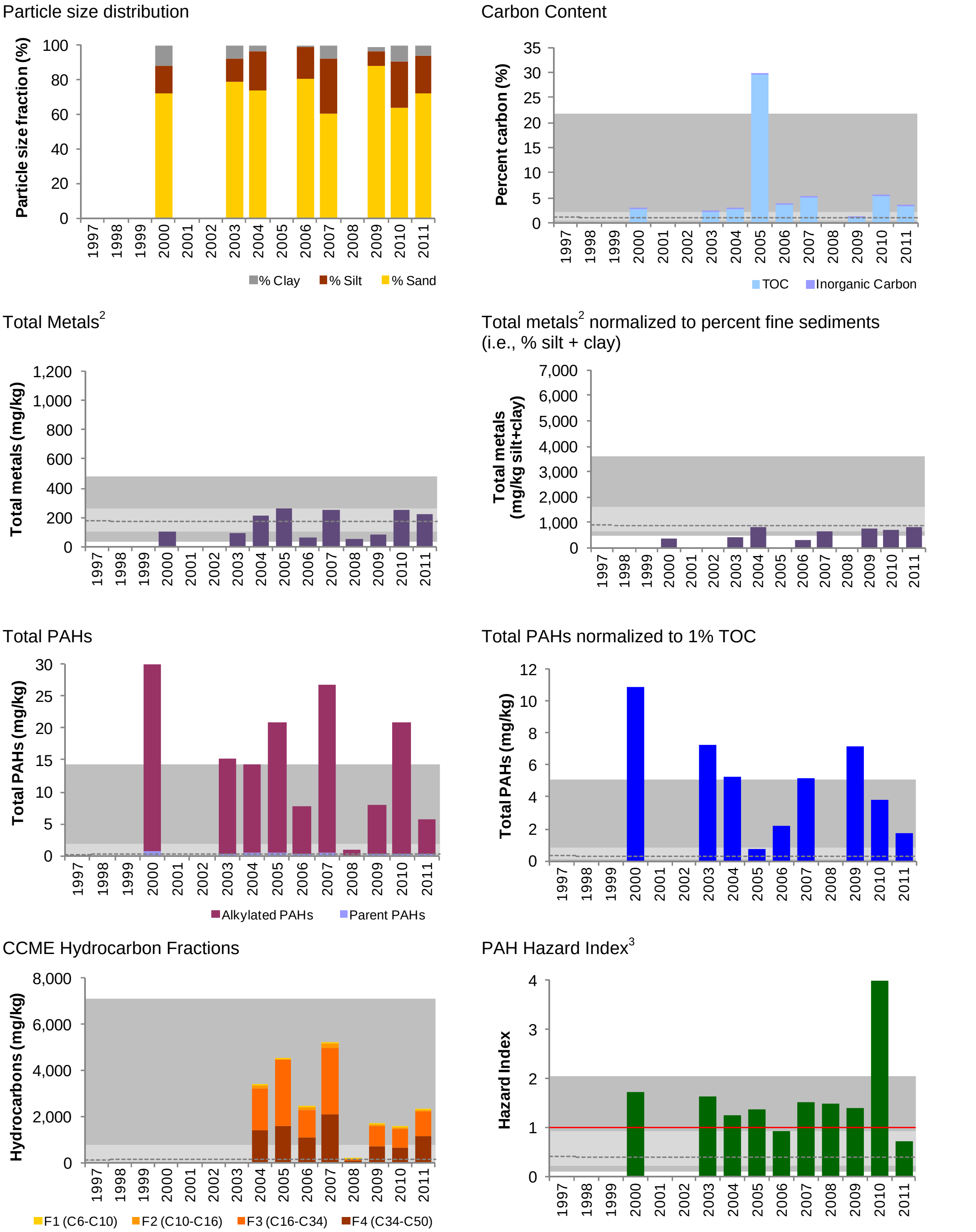
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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.



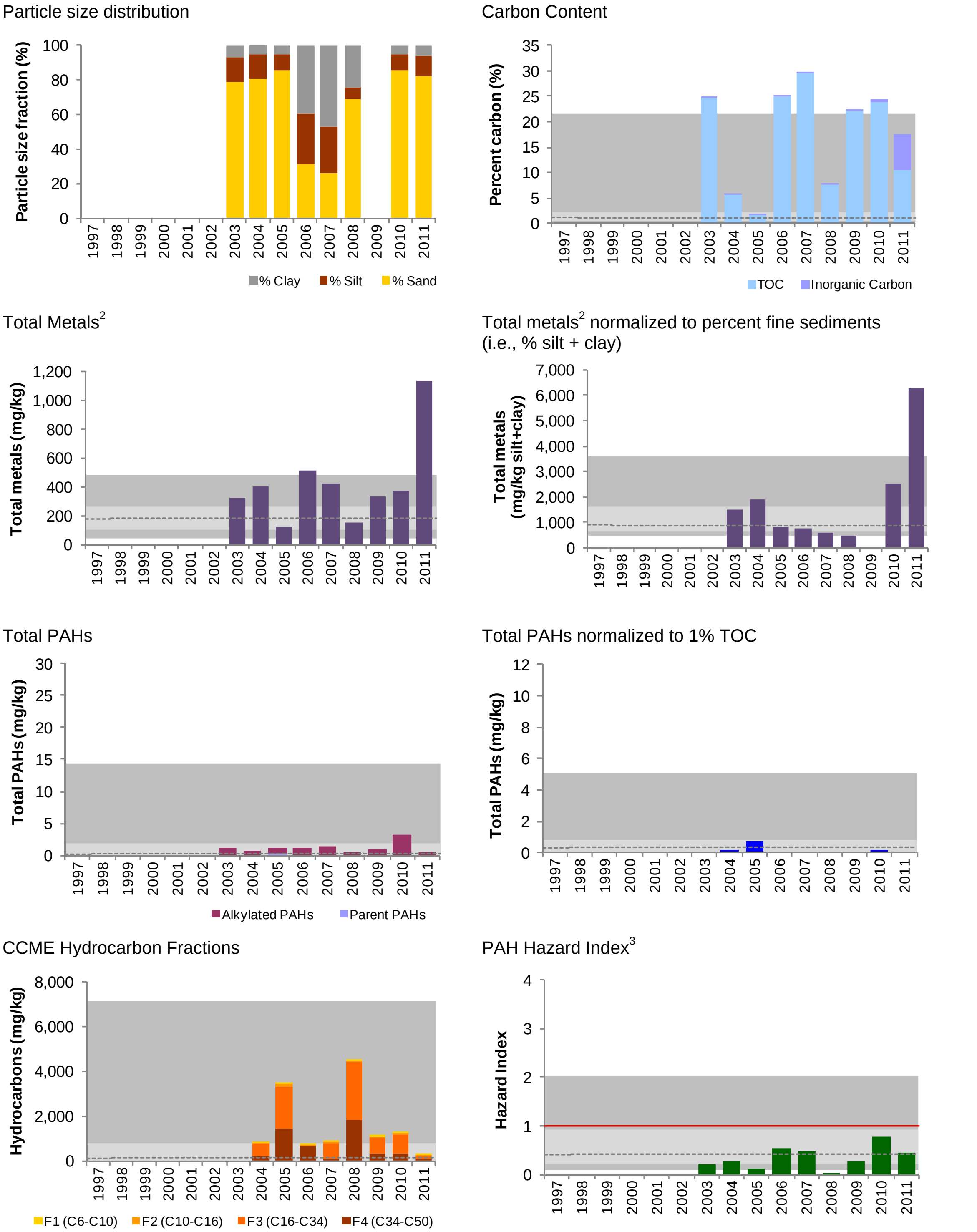
Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

1 Regional *baseline* values represent "total" values for multi-variable data.

2 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

3 Red 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.



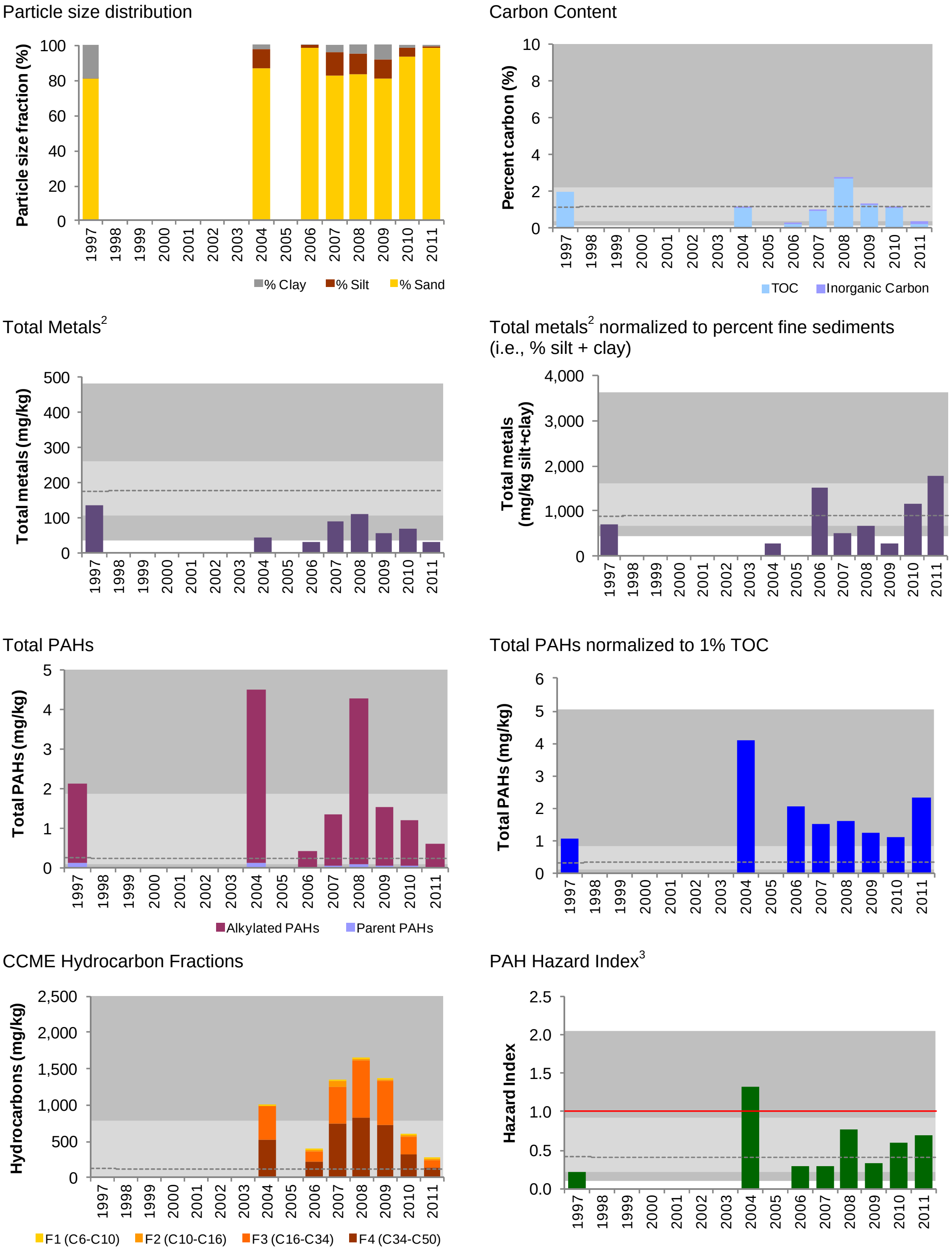
Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

1 Regional *baseline* values represent "total" values for multi-variable data.

2 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

3 Red 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.



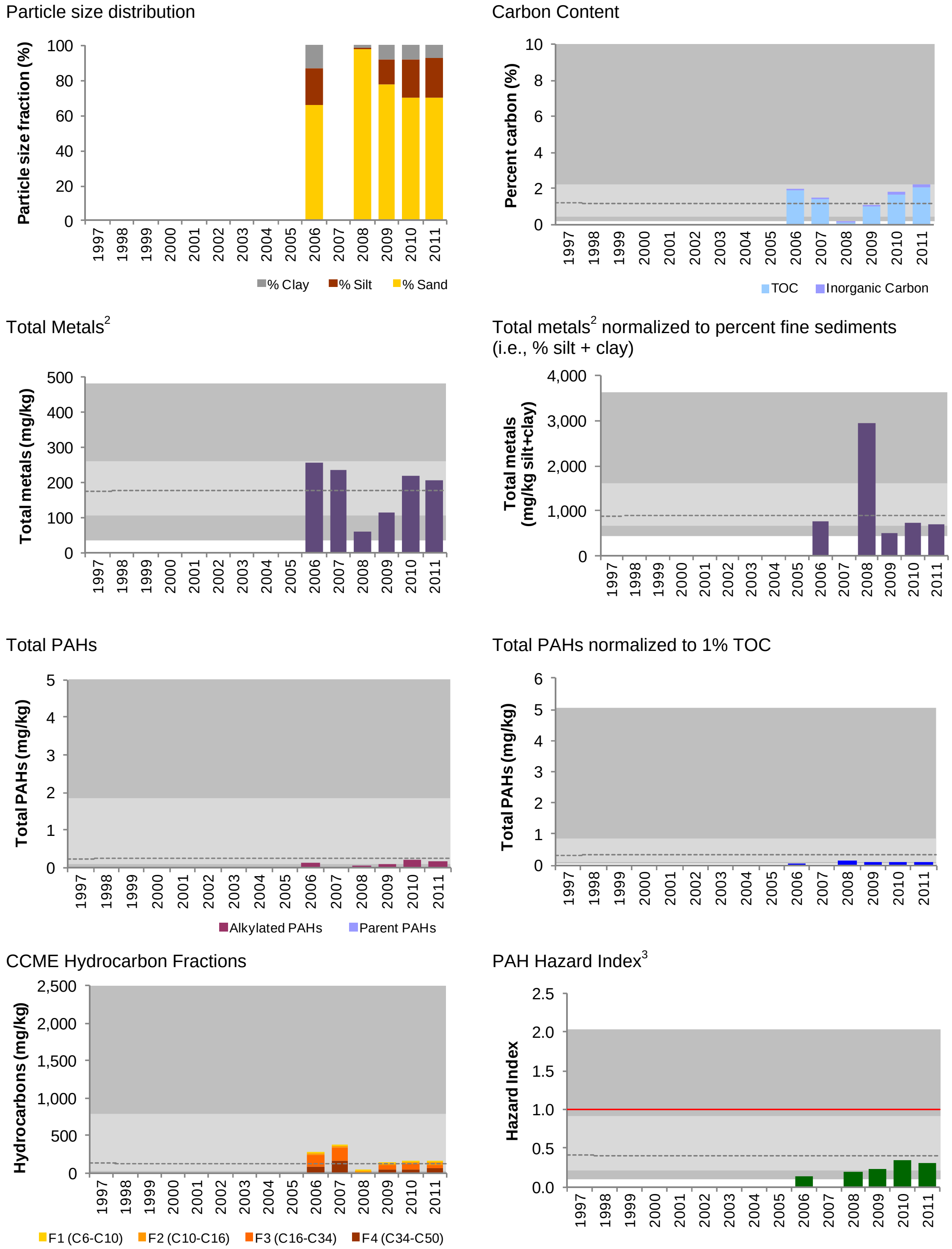
Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

1 Regional *baseline* values represent "total" values for multi-variable data.

2 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

3 Red 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.



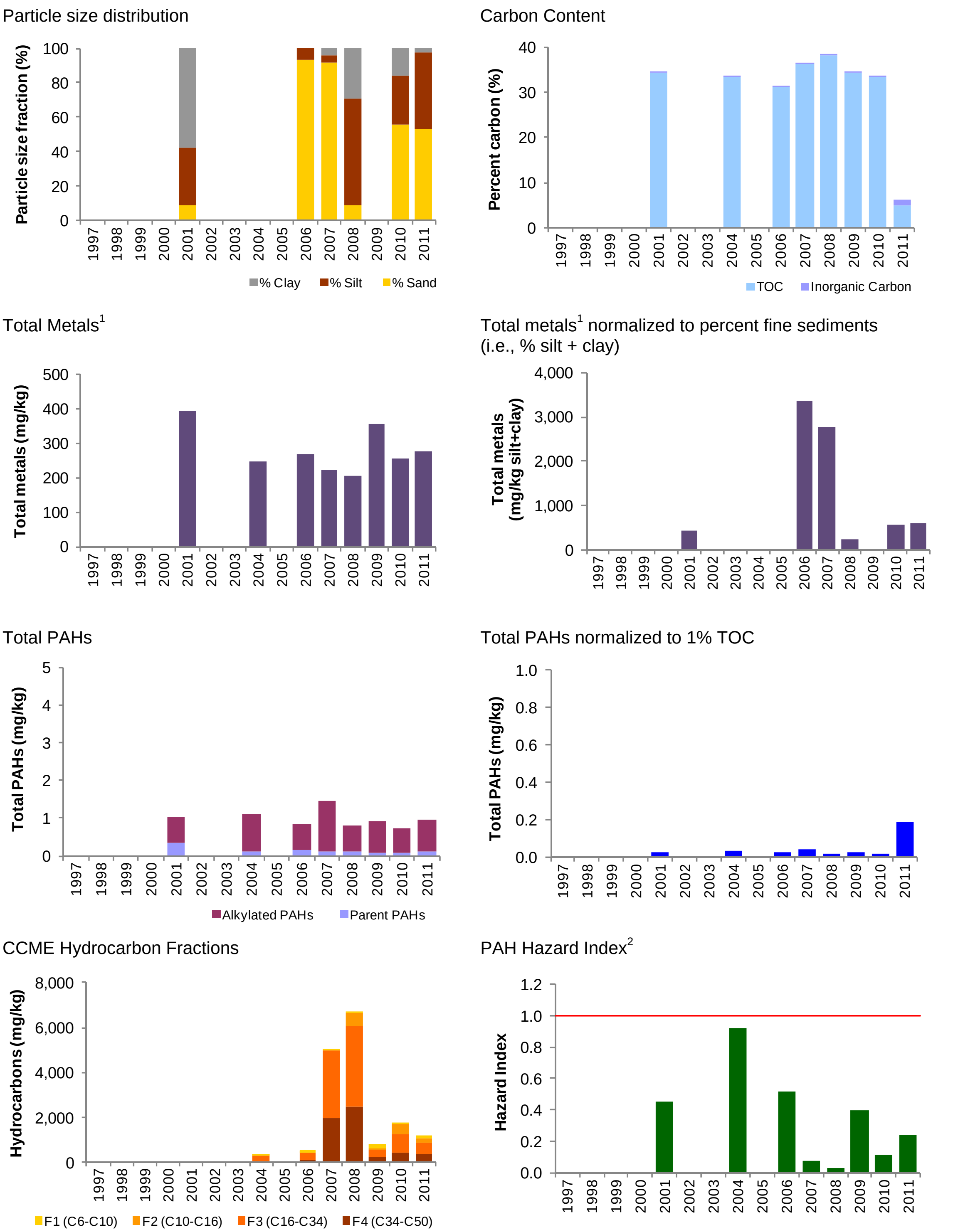
Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red 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.



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.2-34 Sediment quality index (fall 2011) for Muskeg River watershed stations.

Station Identifier	Location	2011 Designation	Sediment Quality Index	Classification
JAC-D1	mouth of Jackpine Creek	*test*	100	Negligible-Low
JAC-D2	upper Jackpine Creek	*baseline*	98.9	Negligible-Low
MUR-D2	Muskeg River at Canterra Road	*test*	95.4	Negligible-Low
MUR-D3	upper Muskeg River	*test*	87.7	Negligible-Low

Table 5.2-35 Average habitat characteristics of fish assemblage monitoring locations of the Muskeg River.

Variable	Units	MUR-F1 Lower *Test* Reach of Muskeg River	MUR-F2 Middle *Test* Reach of Muskeg River	MUR-F3 Upper *Test* Reach of Muskeg River
Sample date		Sept. 10, 2011	Sept. 13, 2011	Sept. 13, 2011
Habitat type	-	run/riffle	deep run	deep run
Maximum depth	m	0.31	0.89	0.31
Average bankfull channel width	m	21.3	14.5	12.0
Average wetted channel width	m	14.8	14.0	11.3
Substrate				
Dominant	-	coarse gravel	sand	silt/clay
Subdominant	-	cobble/fines	cobble/coarse gravel	-
Instream cover				
Dominant	-	boulders	small woody debris	macrophytes
Subdominant	-	filamentous algae, small and large woody debris	filamentous algae, undercut banks, and boulders	small woody debris
Field water quality				
Dissolved oxygen	mg/L	-	7	6.4
Conductivity	µS/cm	470	497	524
pH	pH units	7.96	7.00	7.08
Water temperature	°C	14.6	10.0	10.3
Water velocity				
Left bank velocity	m/s	0.13	0.02	0.00
Left bank water depth	m	0.35	0.60	>1.5
Centre of channel velocity	m/s	0.12	0.07	0.00
Centre of channel water depth	m	0.48	0.87	>1.5
Right bank velocity	m/s	0.12	0.36	0.00
Right bank water depth	m	0.47	0.76	>1.5
Riparian cover- understory (<5 m)				
Dominant	-	woody shrubs and samplings	woody shrubs and samplings	woody shrubs and samplings
Subdominant	-	overhanging vegetation	overhanging vegetation	overhanging vegetation

Table 5.2-36 Percent composition and mean CPUE of fish species in reaches of the Muskeg River and Jackpine Creek, 2009 to 2011.

Common Name	Code	Total Species											Percent of Total Catch										
		JAC-F1			JAC-F2			MUR-F1			MUR-F2	MUR-F3	JAC-F1			JAC-F2			MUR-F1			MUR-F2	MUR-F3
		2009	2010	2011	2009	2010	2011	2009	2010	2011	2011	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011	2011	2011
Arctic grayling	ARGR	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
brook stickleback	BRST	-	19	2	14	29	36	3	5	1	-	33	0	11.4	1.3	23.7	47.5	35.0	5.2	5.4	1.4	0	84.6
burbot	BURB	-	-	-	-	-	-	1	-	-	-	-	0	0	0	0	0	0	1.7	0	0	0	0
fathead minnow	FTMN	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
finescale dace	FNDC	-	75	-	-	12	-	-	15	-	-	-	0	44.9	0	0	19.7	0	0	16.1	0	0	0
lake chub	LKCH	1	-	138	40	10	-	4	8	1	-	-	14.3	0	89.6	67.8	16.4	0.0	6.9	8.6	1.4	0	0
lake whitefish	LKWH	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
longnose dace	LNDC	-	-	-	-	-	-	-	10	7	-	-	0	0	0	0	0	0	0	10.8	9.9	0	0
longnose sucker	LNSC	2	3	5	-	-	-	5	4	49	-	-	28.6	1.8	3.2	0	0	0	8.6	4.3	69.0	0	0
northern pike	NRPK	-	1	-	-	-	-	-	-	-	2	-	0	0.6	0	0	0	0	0	0	0	66.7	0
northern redbelly dace	NRDC	-	-	-	-	-	2	-	-	-	-	-	0	0	0	0	0	1.9	0	0	0	0	0
pearl dace	PRDC	-	21	-	3	9	50	-	35	2	-	2	0	12.6	0	5.1	14.8	48.5	0	37.6	2.8	0	5.1
slimy sculpin	SLSC	-	23	2	-	-	-	43	11	5	-	-	0	13.8	1.3	0	0	0	74.1	11.8	7.0	0	0
spoonhead sculpin	SPSC	-	-	-	-	-	-	1	3	-	-	-	0	0	0	0	0	0	1.7	3.2	0	0	0
spottail shiner	SPSH	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0
trout-perch	TRPR	-	9	5	-	-	-	-	-	-	-	-	0	5.4	3.2	0	0	0	0	0	0	0	0
walleye	WALL	-	-	-	-	-	-	-	-	1	-	-	0	0	0	0	0	0	0	0	1.4	0	0
white sucker	WHSC	4	16	2	2	1	15	-	2	5	1	-	57.1	9.6	1.3	3.4	1.6	14.6	0	2.2	7.0	33.3	0
yellow perch	YLPR	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0.0	0	0	0
sucker sp. *		-	-	-	-	-	-	1	-	-	-	-	0	0	0	0	0	0	1.7	0	0	0	0
unknown sp. *		-	-	-	-	-	-	-	-	-	-	4	0	0	0	0	0	0	0	0	0	0	10.3
Total Count		**7**	**167**	**154**	**59**	**61**	**103**	**58**	**93**	**71**	**3**	**39**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Total Species Richness		**3**	**8**	**6**	**4**	**5**	**4**	**7**	**9**	**8**	**2**	**3**	**3**	**8**	**6**	**4**	**5**	**4**	**6**	**9**	**8**	**2**	**2**
Electrofishing effort (secs)		**2,221**	**3,863**	**1,052**	**1,352**	**4,183**	**973**	**2,051**	**4,623**	**1,267**	**1,178**	**1,297**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
CPUE (#/100secs)		**0.32**	**4.32**	**14.6**	**4.36**	**1.46**	**10.6**	**2.78**	**2.01**	**5.6**	**0.25**	**3.01**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

* Not included in total species richness count.

Table 5.2-37 Summary of fish assemblage measurement endpoints in reaches of the Muskeg River and Jackpine Creek, 2009 to 2011.

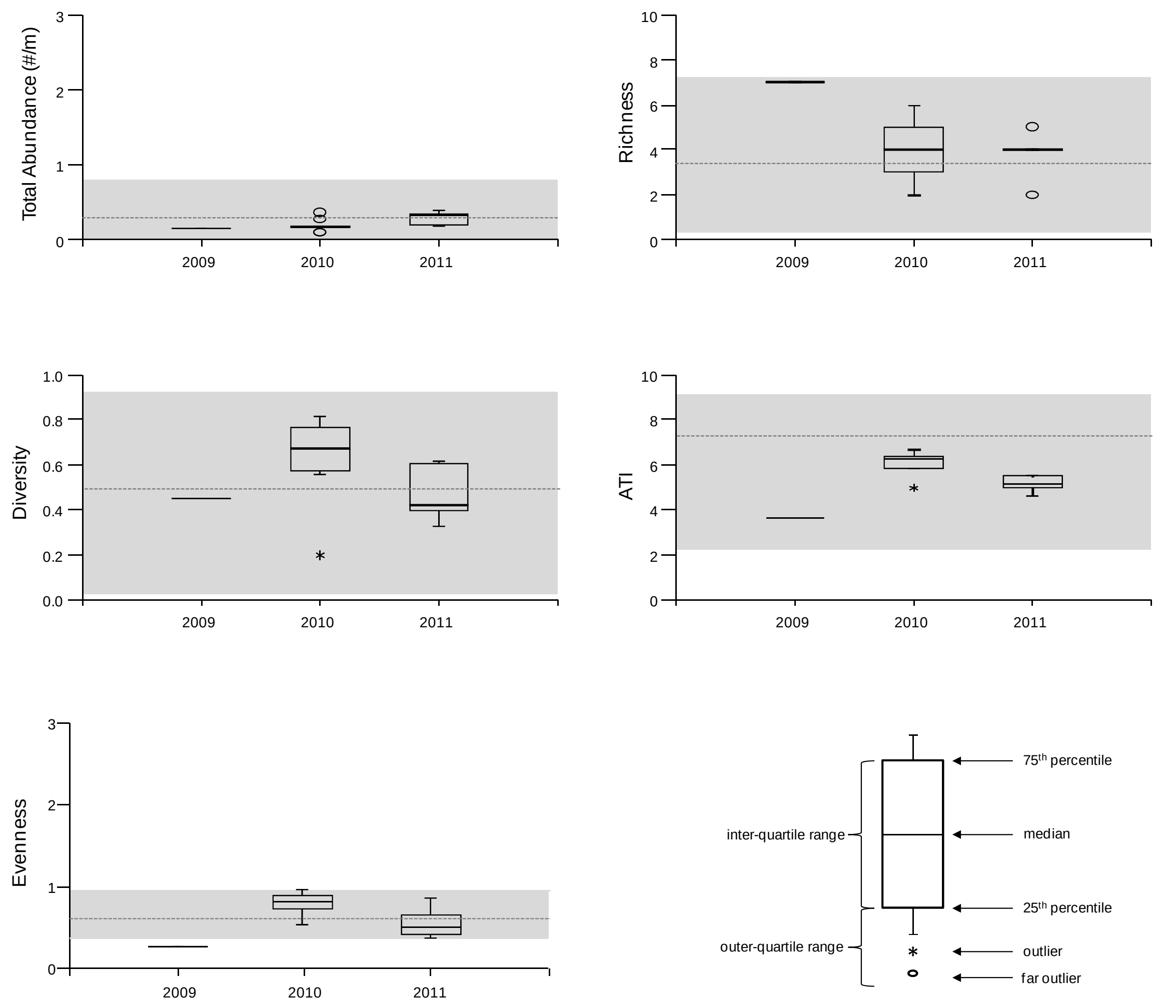
Reach	Year	Abundance		Richness*			Diversity*		Evenness*		ATI*	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
JAC-F1	2009	0.02		3		-	0.57	-	0.78	-	6.41	-
	2010	0.65	0.59	8	4	2.38	0.53	0.29	0.54	0.33	6.18	3.29
	2011	1.03	1.04	6	3	0.84	0.20	0.20	0.64	0.34	5.74	0.35
JAC-F2	2009	0.42		4	-	-	0.48	-	0.48	-	6.56	-
	2010	0.10		5	-	-	0.69	-	0.65	-	7.85	-
	2011	0.69	0.62	4	3	0.84	0.50	0.16	0.79	0.12	8.18	0.61
MUR-F1	2009	0.15		7	-	-	0.43	-	0.29		3.65	-
	2010	0.19	0.08	9	4	2.38	0.64	0.29	0.79	0.33	6.10	3.29
	2011	0.28	0.09	8	4	1.10	0.47	0.13	0.56	0.20	5.15	0.39
MUR-F2	2011	0.01	0.02	2	1	0.89	0.30	0.45	0.40	0.55	3.10	4.24
MUR-F3	2011	0.14	0.10	3	1	0.55	0.14	0.22	0.93	0.16	9.06	0.58

* Unknown species not included in the calculation.

SD=standard deviation across sub-reaches within a reach.

Figure 5.2-26 Box-plots showing variation in fish assemblage measurement endpoints in reaches of the Muskeg River, 2009 to 2011.

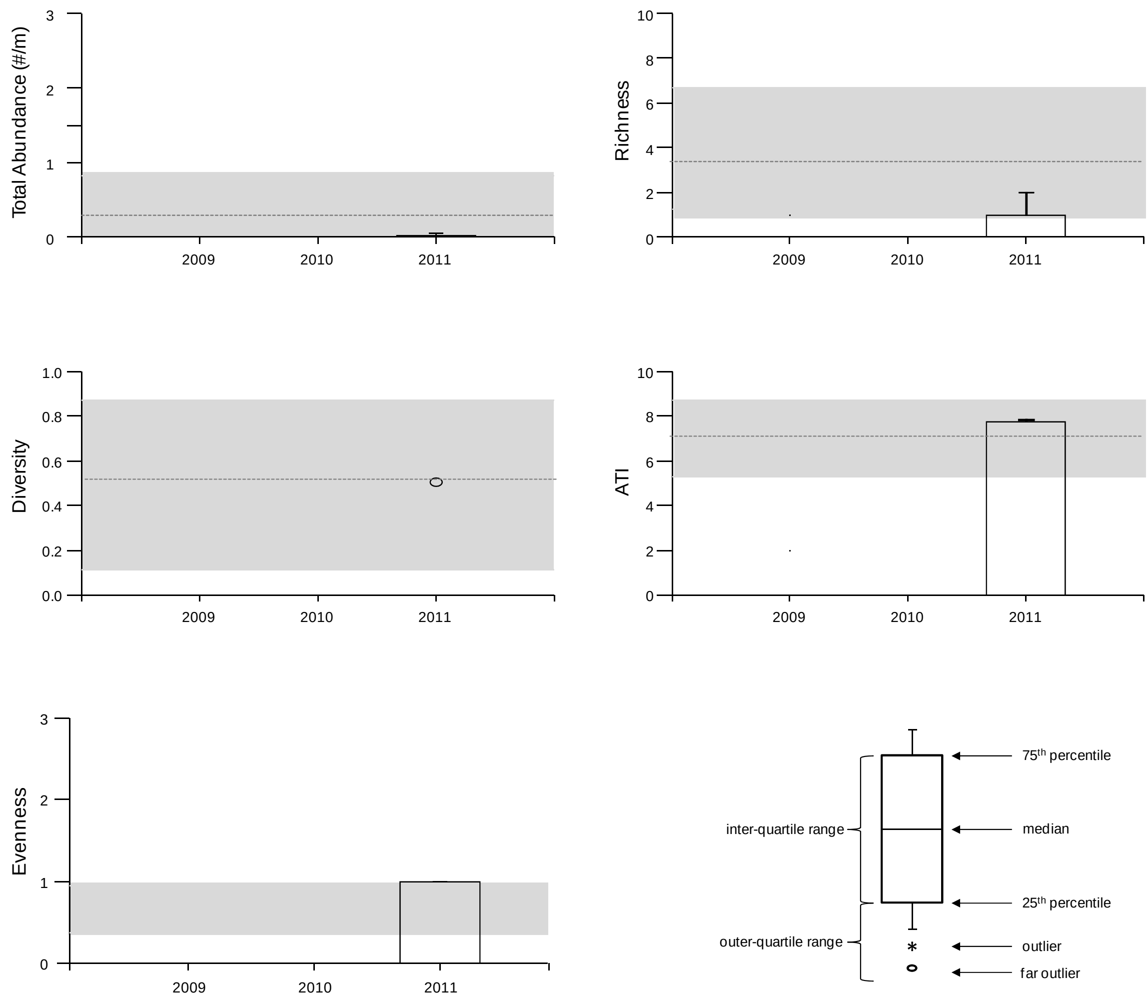
Erosional *Test* Reach MUR-F1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

Figure 5.2-26 (Cont'd.)

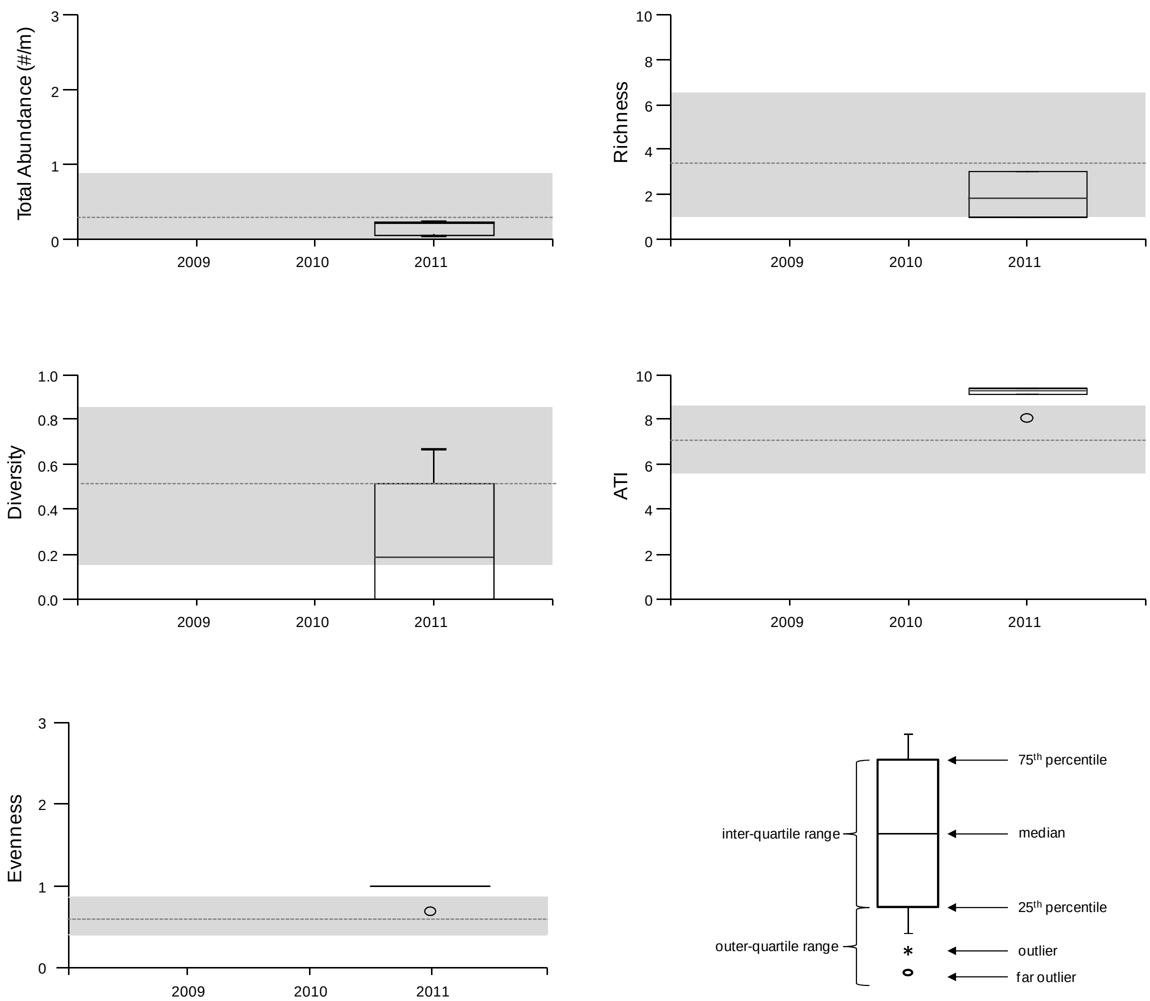
Depositional *Test* Reach MUR-F2



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

Figure 5.2-26 (Cont'd.)

Depositional *Test* Reach MUR-F3



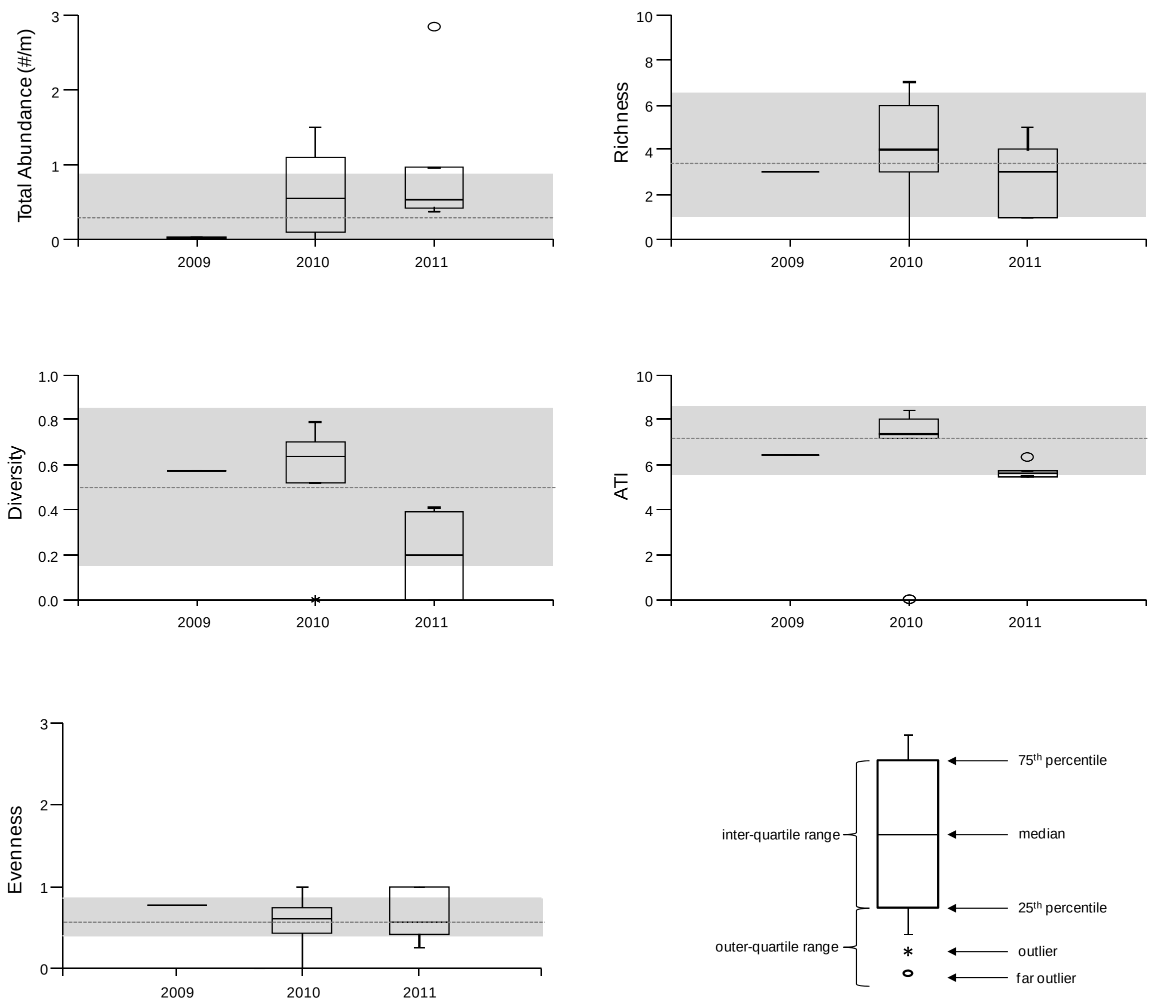
Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

Table 5.2-38 Average habitat characteristics of fish assemblage monitoring locations of Jackpine Creek.

Variable	Units	JAC-F1 Lower *Test* Reach of Jackpine Creek	JAC-F2 Upper *Baseline* Reach of Jackpine Creek
Sample date	-	Sept. 12, 2011	Sept. 12, 2011
Habitat type	-	run	run
Maximum depth	m	1.75	0.58
Average bankfull channel width	m	8.0	5.2
Average wetted channel width	m	6.0	4.1
Substrate			
Dominant	-	silt/clay	silt/clay
Subdominant	-	sand	cobble/coarse gravel
Instream cover			
Dominant	-	small woody debris	macrophytes, overhanging vegetation and undercut banks
Subdominant	-	overhanging vegetation and filamentous algae	overhanging vegetation, filamentous algae and boulders
Field water quality			
Dissolved oxygen	mg/L	5.2	8.7
Conductivity	µS/cm	488	372
pH	pH units	8.19	7.49
Water temperature	°C	13.0	10.8
Water velocity			
Left bank velocity	m/s	0.07	0.01
Left bank water depth	m	-	0.44
Centre of channel velocity	m/s	0.01	0.01
Centre of channel water depth	m	0.30	0.57
Right bank velocity	m/s	0.00	-
Right bank water depth	m	-	0.56
Riparian cover- understory (<5 m)			
Dominant	-	woody shrubs and saplings	overhanging vegetation
Subdominant	-	overhanging vegetation	woody shrubs and saplings

Figure 5.2-27 Box-plots showing variation in fish assemblage measurement endpoints in reaches of Jackpine Creek, 2009 to 2011.

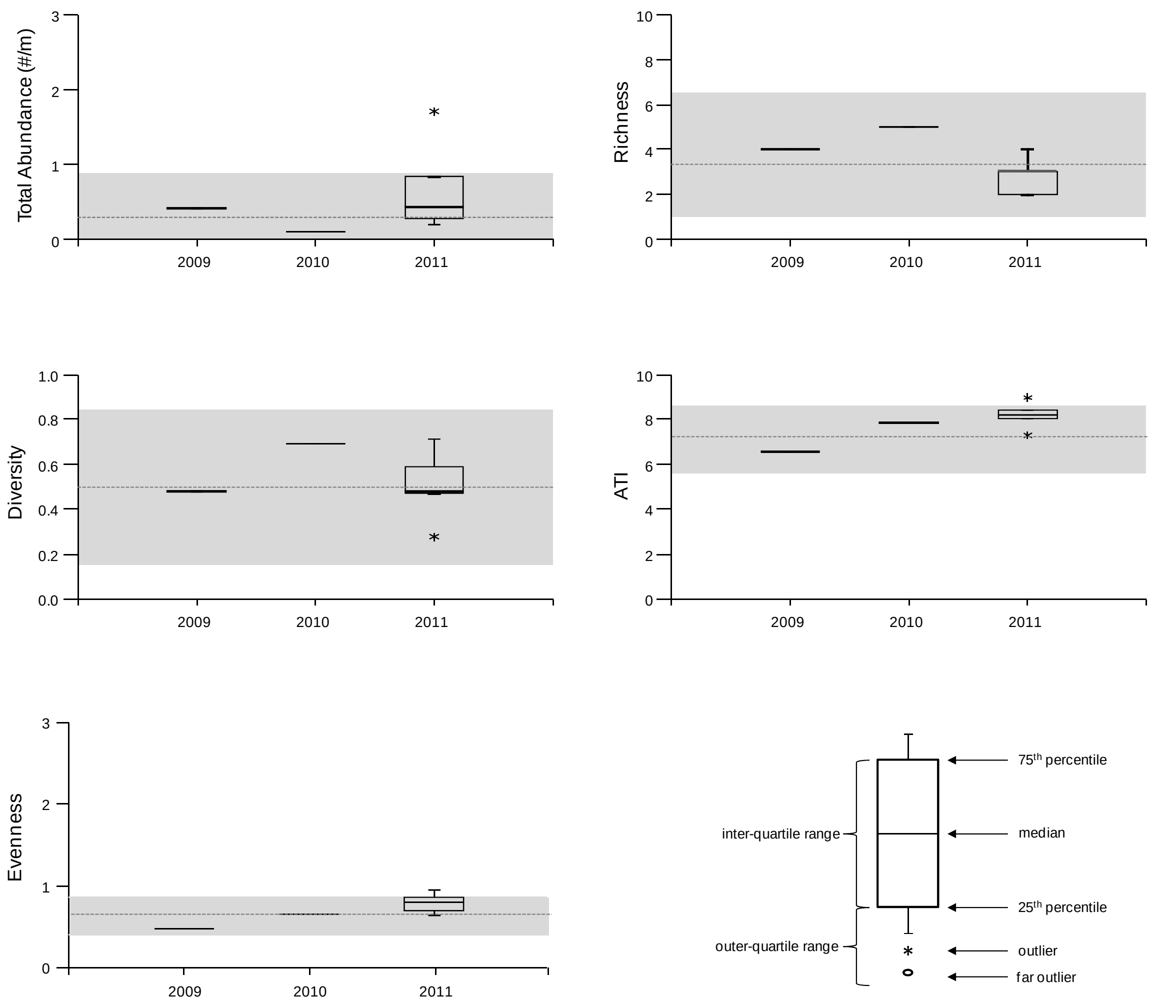
Depositional *Test* Reach JAC-D1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

Figure 5.2-27 (Cont'd.)

Depositional *Baseline* Reach JAC-D2



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

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5.3 STEEPBANK RIVER WATERSHED

Table 5.3-1 Summary of results for the Steepbank River watershed.

Steepbank River Watershed	**Summary of 2011 Conditions**			
	Steepbank River			***North Steepbank River***
Climate and Hydrology				
Criteria	**S38** near Fort McMurray			
Mean open-water season discharge	Negligible-Low			
Mean winter discharge	Negligible-Low			
Annual maximum daily discharge	Negligible-Low			
Minimum open-water season discharge	Negligible-Low			
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	Moderate	Negligible-Low	Negligible-Low	Negligible-Low
Benthic Invertebrate Communities and Sediment Quality				
Criteria	**STR-E1** lower reach	no reach sampled	**STR-E2** upper reach	no reach sampled
Benthic Invertebrate Communities	Moderate		n/a	
No Sediment Quality component activities conducted in 2011				
Fish Populations				
Criteria	**STR-F1** lower reach	no reach sampled	**STR-F2** upper reach	no reach sampled
Fish Assemblages	Negligible-Low		n/a	

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 and/or regional *baseline* conditions.

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.

Fish Populations: Classification based on exceedances of measurement from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.3-1 Steepbank River watershed.

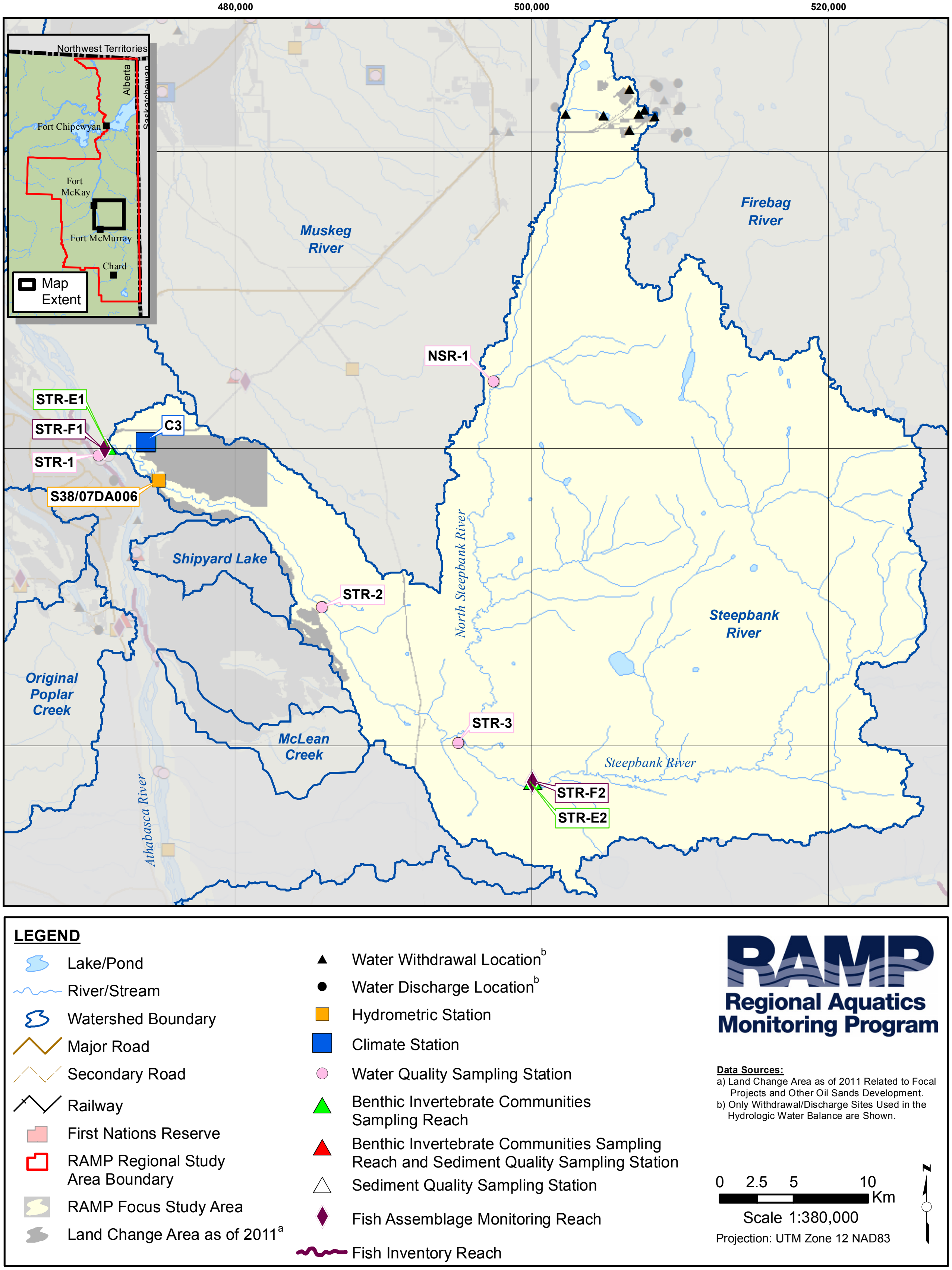

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Figure 5.3-2 Representative monitoring stations of the Steepbank River, fall 2011.

Benthic Invertebrate and Fish Assemblage Reach STR-E1/STR-F1: Left Downstream Bank

Benthic Invertebrate and Fish Assemblage Reach STR-E2/STR-F2: Right Downstream Bank

Water Quality Station STR-3: facing upstream

Water Quality Station NSR-1: North Steepbank River, facing downstream.

5.3.1 Summary of 2011 Conditions

Approximately 3.3% (4,500 ha) of the Steepbank River watershed had undergone land change as of 2011 from focal projects (Table 2.5-1); much of this land change is concentrated in the lower portion of the watershed. The designations of specific areas of the watershed for 2011 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities, and Fish Populations components of RAMP in the Steepbank River watershed in 2011. Table 5.3-1 is a summary of the 2011 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 2011. Figure 5.3-2 contains photos of monitoring stations in the watershed taken in fall 2011.

Hydrology The calculated mean open-water discharge, mean winter discharge, annual maximum daily discharge, and open-water minimum daily discharge were 0.37%, 0.46%, 0.25% and 0.24% greater, respectively, in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality Concentrations of many water quality measurement endpoints in the Steepbank River watershed in fall 2011 were higher than previously-measured concentrations, particularly at *test* stations STR-2 and NSR-1 and *baseline* station STR-3. Although several ions were near previously-measured maximum concentrations at *test* station STR-1, there were few variables that exceeded previously-measured maximum concentrations, perhaps due to the longer period of record at this station. When compared with regional *baseline* conditions for fall (1997 to 2011), concentrations of water quality measurement endpoints were generally consistent. The ionic composition at all water quality monitoring stations in the Steepbank River watershed in fall 2011 was consistent with previous years, despite historically high concentrations of ions at several stations. Differences in water quality in fall 2011 at water quality monitoring stations compared to regional *baseline* water quality conditions were classified as **Negligible-Low** for *test* stations STR-2 and NSR-1 and *baseline* station STR-3. *Test* station STR-1 showed a **Moderate** difference from regional *baseline* conditions due to regionally high concentrations of some ions, suspended solids and some metals, although nearly all measurement endpoints were within previously-measured concentrations for this station.

Benthic Invertebrate Communities Differences in measurement endpoints of the benthic invertebrate community at *test* reach STR-E1 were classified as **Moderate** because total abundance, richness, percent EPT, and CA Axis scores were significantly lower at *test* reach STR-E1 than *baseline* reach STR-E2. The benthic invertebrate community; however, was diverse at *test* reach STR-E1, and although it was numerically dominated by tolerant naidids, many other taxa that require cool, clean water, were documented indicating that there hasn't been an increase in degraded conditions at *test* reach STR-E1 over time. With the exception of total abundance, all values of measurement endpoints of benthic invertebrate communities were within the range of *baseline* conditions at both reaches of the Steepbank River.

Fish Populations Differences in fish assemblages observed in fall 2011 between *test* reach STR-F1 and regional *baseline* conditions were **Negligible-Low** with all median values of measurement endpoints within the range of regional *baseline* variability.

5.3.2 Hydrologic Conditions: 2011 Water Year

WSC Station 07DA006 (RAMP Station S38), Steepbank River near Fort McMurray Continuous annual hydrometric data have been collected for WSC Station 07DA006 (RAMP Station S38) from 1974 to 1986 and more recently from 2009 to 2011, 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 2011 water year (WY) was 48 million m^3. This value is 65% lower than the historical mean open-water runoff volume of 136 million m^3 based on the period of record. In the 2011 WY, flows decreased from November 2010 to February 2011 and values were generally between historical upper quartile and maximum values recorded during this period (Figure 5.3-3). Flows increased in April and early May during freshet to a peak of 13.5 m^3/s on May 8. This value was the maximum daily flow recorded in the 2011 WY and was 60% lower than the historical mean annual maximum daily flow. Flows decreased until June 17, followed by small increases due to rainfall events in July and August. Flows generally continued to decrease until the end of the 2011 WY. All flows recorded from May 14 to

October 31 were below historical median values but above historical minimum values. The minimum open-water daily flow of 0.80 m^3/s on October 26 was 52% 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 the Steepbank River near Fort McMurray is provided in Table 5.3-2 and described below:

1. The closed-circuited land area from focal projects as of 2011 was estimated to be 4.9 km^2 (Table 2.5-1). The loss of flow to the Steepbank River that would have otherwise occurred from this land area was estimated at 0.25 million m^3.

2. As of 2011, the area of land change in the Steepbank watershed that was not closed-circuited was estimated to be 40.1 km^2 (Table 2.5-1). The increase in flow to the Steepbank River that would not have otherwise occurred from this land area was estimated at 0.41 million m^3.

3. In the 2011 WY, Suncor withdrew 0.01 million m^3 of water from a source in the northern area of the Steepbank River watershed to support activities including dust suppression.

4. 0.11 million m^3 of water was released by Suncor to the Steepbank River watershed to support various water management activities.

Classification of Results The estimated cumulative effect of land change, water withdrawals, and water releases was an increase in flow of 0.26 million m^3 in the 2011 WY for WSC Station 07DA006 (RAMP Station S38), Steepbank River near Fort McMurray. 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 were 0.37%, 0.46%, 0.25% and 0.24% greater, respectively, in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.3-3). These differences were classified as **Negligible-Low** (Table 5.3-1).

5.3.3 Water Quality

In fall 2011, water quality samples were taken from:

- the Steepbank River near its mouth (*test* station STR-1, sampled from 1997 to 2011);
- the Steepbank River downstream of the confluence with the North Steepbank River (*test* station STR-2, designated as *baseline* from 2002 to 2007 and *test* from 2008 to 2011);
- the Steepbank River upstream of the confluence with the North Steepbank River (*baseline* station STR-3, sampled from 2004 to 2011); and
- the North Steepbank River (*test* station NSR-1, designated as *baseline* from 2002 to 2008 and *test* from 2009 to 2011).

Winter water quality sampling was also conducted at *test* station STR-1 in 2011.

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 2011);
- Decreasing concentrations of chloride and sulphate at *baseline* station STR-3 (2004 to 2011) and *test* stations STR-2 (2002 to 2011) and NSR-1 (2002 to 2011); and
- An increasing concentration of total arsenic at *test* station NSR-1 (2002 to 2011), although the increase over time has been small.

2011 Results Relative to Historical Concentrations Concentrations of water quality measurement endpoints in fall 2011 often exceeded previously-measured maximum concentrations at all stations in the Steepbank River watershed (Table 5.3-4 to Table 5.3-7). Many of these exceedances were in dissolved analytes, specifically:

- pH with a value that exceeded previously-measured maximum values at *test* station STR-1;
- pH, conductivity, total dissolved solids, total alkalinity, magnesium, sodium, total boron, and total dissolved phosphorus with concentrations that exceeded previously-measured maximum concentrations at *test* station STR-2;
- pH, conductivity, total alkalinity, total dissolved solids, sodium, magnesium, total dissolved phosphorus, total boron, total nitrogen with concentrations that exceeded previously-measured maximum concentrations and total aluminum with a concentration that was lower than the previously-measured minimum concentration at *baseline* station STR-3; and
- pH, conductivity, total dissolved solids, sodium, calcium, magnesium, total arsenic, total boron, total molybdenum, and total strontium with concentrations that exceeded previously-measured maximum concentrations and total and dissolved aluminum with concentrations that were lower than previously-measured minimum concentrations at *test* station NSR-1.

Ion Balance In fall 2011, the ionic composition of all stations in the Steepbank River watershed was dominated by calcium and bicarbonate ions (Figure 5.3-4). Despite many historically high ion concentrations at all Steepbank-watershed stations in fall 2011, the ion balance at all stations was comparable with previous years, suggesting that the observed increases in ion concentrations was related to the very low river flows (and associated dilutant surface runoff) observed in the watershed in 2011 (Figure 5.3-3).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints measured in the Steepbank River in fall 2011 were below water quality guidelines with the exception of total aluminum at *test* station STR-1; however, the concentration of dissolved aluminum, the bioavailable form of aluminum, was near previously-measured minimum concentrations at this station in fall 2011 and approximately two orders of magnitude below the relevant water quality guideline (Table 5.3-4).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Steepbank River watershed in 2011 (Table 5.3-8):

- Total iron at *test* station STR-1 in winter 2011;
- Total chromium at *test* station STR-1 in fall 2011;

- Sulphide at *test* stations STR-1 and STR-2 and *baseline* station STR-3 in fall 2011; and
- Dissolved iron, total phenols, and total phosphorus at *test* stations STR-1, STR-2 and NSR-1, and *baseline* station STR-3 in fall 2011.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2011 at *test* stations STR-1, STR-2, and NSR-1 and *baseline* station STR-3 were within regional *baseline* concentrations with the following exceptions (Figure 5.3-5):

- Chloride, sodium, and total suspended solids with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-1;
- Sulphate with a concentration that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-1 and a concentration that was lower than the 5th percentile of regional *baseline* concentrations at *test* station NSR-1;
- Total arsenic with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* stations STR-1 and NSR-1;
- Total boron with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station STR-2 and *baseline* station STR-3; and
- Total strontium with a concentration that exceeded the 95th percentile of regional *baseline* concentrations at *test* station NSR-1.

Due to a decrease in the analytical detection limit for total mercury in 2010, concentrations in fall 2011 were lower than the 5th percentile of regional *baseline* concentrations for *test* stations STR-2 and NSR-1 and *baseline* station STR-3.

Water Quality Index The WQI values for all stations in the Steepbank River watershed indicated **Negligible-Low** differences from regional *baseline* water quality conditions with the exception of *test* station STR-1, which had a **Moderate** difference from regional *baseline* conditions due to concentrations of pH, sodium, chloride, sulphate, TSS, and some particulate-associated metals (e.g., aluminum, iron, lead, vanadium) that were higher than regional *baseline* concentrations. The WQI for *test* station STR-1 was 74.1, while the other stations had WQI values ranging from 90.3 to 96.2.

Classification of Results Concentrations of many water quality measurement endpoints in the Steepbank River watershed in fall 2011 were higher than previously-measured concentrations, particularly at *test* stations STR-2 and NSR-1 and *baseline* station STR-3. Although several ions were near previously-measured maximum concentrations at *test* station STR-1, there were few variables that exceeded previously-measured maximum concentrations, perhaps due to the longer period of record at this station. When compared with regional *baseline* conditions for fall (1997 to 2011), concentrations of water quality measurement endpoints were generally consistent. The ionic composition at all water quality monitoring stations in the Steepbank River watershed in fall 2011 was consistent with previous years, despite historically high concentrations of ions at several stations. Differences in water quality in fall 2011 at water quality monitoring stations compared to regional *baseline* water quality conditions were classified as **Negligible-Low** for *test* stations STR-2 and NSR-1 and *baseline* station STR-3 and **Moderate** at *test* station STR-1 due to regionally high concentrations of some ions, suspended solids and some metals.

5.3.4 Benthic Invertebrate Communities and Sediment Quality

5.3.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 at the upper and lower 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.

2011 Habitat Conditions Water at *test* reach STR-E1 in fall 2011 was shallow (0.2 m), slow flowing (0.4 m/s) with high conductivity (404 µS/cm), high dissolved oxygen (11.8 mg/L) and basic pH (pH: 8.7) (Table 5.3-10). Periphyton biomass averaged 236 mg/m^2, which was greater than 2010 but within the range of regional *baseline* conditions (Figure 5.3-6).

Water at *baseline* reach STR-E2 was shallow (0.2 m), slow flowing (0.4 m/s) with moderately high conductivity (304 µS/cm), moderately high dissolved oxygen (9.2 mg/L) and basic pH (8.5). Periphyton biomass averaged 280 mg/m^2, which was greater than 2010, but within the range of regional *baseline* conditions (Figure 5.3-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach STR-E1 was dominated by Naididae worms (42%), with subdominant taxa consisting of Ephemeroptera (mayflies; 19%) and chironomids (24%) (Table 5.3-11). The chironomids were diverse, consisting of many common forms such as *Rheotanytarsus*, *Thienemannimyia* and *Potthastia*, as well as other forms that are more restricted to clean cold water including *Tvetenia*. The mayfly assemblage was also diverse and included the widely distributed *Baetis*, as well as forms restricted to fast flowing waters such as *Ephemerella*. Other sensitive taxa included the Plecopteran stonefly *Nemoura* and the Trichopteran caddisfly *Hydropsyche*.

The benthic invertebrate community at *baseline* reach STR-E2 was dominated by Trichoptera (24%) and chironomids (29%) with subdominant taxa consisting of Ephemeroptera (14%), and Cladocera (6%) (Table 5.3-12). Similar to the lower *test* reach, the chironomids were diverse consisting of both widely distributed forms such as *Cricotopus* and *Rheotanytarsus*, as well as those more typically associated with clean and cold water including *Tvetenia* (Mandaville 2001). Other sensitive taxa included the mayflies *Ephemerella*, and *Drunella grandis*, the stonefly *Zapada*, and the caddisfleis *Brachycentrus*, *Lepidostoma*, *Hydroptila*, and *Micrasema*.

Values of measurement endpoints of benthic invertebrate communities in fall 2011 at both reaches were similar to 2009 and 2010. *Test* reach STR-E1 had a mean of 41 taxa per sample, a diversity of 0.76 and a mean of 21% EPT taxa per sample. *Baseline* reach STR-E2 had a mean of 37 taxa per sample, a diversity of 0.85 and an average of 44% EPT taxa per sample. Total abundance in both reaches; however, was considerably higher in 2011 than in any previous sampling years with a total abundance of approximately 103,000 individuals per m^2 at *test* reach STR-E1 and a total abundance of 194,000 individuals per m^2 at *baseline* reach STR-E2 (Figure 5.3-7).

Temporal and Spatial Comparisons For spatial comparisons, changes in mean values of measurement endpoints for benthic invertebrate communities over time were tested between *baseline* reach STR-E2 and *test* reach STR-E1 (Hypothesis 3, Section 3.2.3.1). There was a significant decrease in total abundance, richness, %EPT, and CA Axis 1 and 2 scores at *test* reach STR-E1 compared to *baseline* reach STR-E2, with the statistical signal explaining greater than 20% of the variation in the annual means (Table 5.3-13 and Figure 5.3-7). The higher CA Axis 1 and 2 scores at *baseline* reach STR-E2 reflected a higher relative abundance of sensitive taxa such as Trichoptera, Plecoptera, and Ephemeroptera, and water mites (Hydracarina), and Empidid flies (Table 5.3-12 and Figure 5.3-8). Lower *test* reach STR-E1 tended to be more abundant in Tubificidae and Enchytraeidae worms (Figure 5.3-8), while still maintaining a high relative abundance of Ephemeroptera (19%), and presence of both caddisflies and stoneflies (~1%).

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 *test* reach STR-E1 and *baseline* reach STR-E2. There was a strong significant increase in diversity and evenness at *baseline* reach STR-E2 over time, explaining greater than 20% of the variation in annual mean values (Table 5.3-13). Diversity and evenness increased at *baseline* reach STR-E2, while remaining comparatively stable at *test* reach STR-E1. Significant differences were also observed for abundance, %EPT, and the CA axis 1 and 2 scores; however the differences explained less than 20% of the variation in the annual means (Table 5.3-13).

Comparison to Published Literature The benthic invertebrate community at *test* reach STR-E1 had a high total abundance (> 100,000 individuals per m^2), numerically dominated by naidid worms in fall 2011. Naidids can tolerate degraded conditions (Mandaville 2001). The benthic invertebrate community; however, was diverse with a mean of 41 taxa per sample and contained taxa that require colder and cleaner water including the chironomids *Tvetenia* and *Potthastia*, the mayfly *Ephemerella*, and the stonefly *Nemoura* (Mandaville 2001). Periphyton chlorophyll *a* biomass was higher at *test* reach STR-E1 in fall 2011 (236 mg/m^2) compared to previous years, which may have been related to the higher total abundance of benthic invertebrates and a higher relative abundance of naidid worms.

The benthic invertebrate community at *baseline* reach STR-E2 was diverse and contained a benthic fauna that reflected high water and substrate quality. The percent of the community as worms was very low (<1% Tubificidae, 4% Naididae), while chironomids accounted for 29% of the fauna. The percentage of the fauna as EPT taxa was also high at 43%. These values are generally indicative of the presence of a robust community, reflecting high water and substrate quality (Hynes 1960, Griffiths 1998). Similar to *test* reach STR-E1, total abundance at *baseline* reach STR-E2 was much higher than previous years (nearly 200,000 individuals per m^2); abundance of this magnitude typically coincides with communities dominated by few very tolerant organisms (e.g., Burt *et al.* 1991, Diggins and Snyder 2003).

2011 Results Relative to Regional *Baseline* Conditions The values of measurement endpoints for benthic invertebrate communities, including the CA Axis scores, were within the range of *baseline* conditions as defined by *baseline* erosional river reaches in the RAMP FSA with the exception of total abundance at both reaches. Total abundance at *test* reach STR-E1 and *baseline* reach STR-E2 was higher in 2011 than the 95^{th} percentile of the range of *baseline* conditions.

Total abundance and taxa richness at *test* reach STR-E1 have been lower than the long-term median for *baseline* reaches since 2000, indicating that *test* reach STR-E1 previously has had unusually low abundance and richness over this period, relative to *baseline* reaches in the RAMP FSA until fall 2011.

Classification of Results The values of measurement endpoints of the benthic invertebrate community at *test* reach STR-E1 were classified as **Moderate** because total abundance, richness, %EPT, and CA Axis scores were significantly lower at *test* reach

STR-E1 than *baseline* reach STR-E2. The benthic invertebrate community; however, was diverse at *test* reach STR-E1, and although it was numerically dominated by tolerant naidids, many other taxa that require cool, clean water, were documented indicating that there hasn't been an increase in degraded conditions at *test* reach STR-E1 over time. With the exception of total abundance, all values of measurement endpoints of benthic invertebrate communities were within the range of *baseline* conditions at both reaches of the Steepbank River.

5.3.4.2 Sediment Quality

No sediment quality sampling was conducted in the Steepbank River in 2011 because both reaches of the Steepbank River where benthic invertebrate communities were sampled are erosional and sediment quality is only sampled in depositional reaches in which benthic invertebrate communities are sampled.

5.3.5 Fish Populations

Fish assemblages were sampled in fall 2011 at erosional *test* reach STR-F1, near the mouth of Steepbank River and erosional *baseline* reach STR-F2. The lower *test* reach STR-F1 has been sampled since 2009 while the upper *baseline* reach STR-F2 was first sampled in 2011. The locations of these reaches are consistent with the benthic invertebrate community reaches STR-F1 and STR-F2.

2011 Habitat Conditions *Test* reach STR-F1 was comprised of riffle habitat with a wetted width of 10.5 m and a bankfull width of 23.0 m. The substrate was dominated by coarse gravel with a small amount of cobble. Water at *test* reach STR-F1 in fall 2011 was an average of 0.65 m in depth, moderately flowing (average flow: 0.42 m/s), alkaline (pH: 8.12), with low conductivity (195 µS/cm), high dissolved oxygen (9.6 mg/L), and a temperature of 10.5°C. Instream cover consisted primarily of macrophytes and boulders with smaller amounts of filamentous algae and small and large woody debris (Table 5.3-14).

Baseline reach STR-F2 was comprised of riffle and run habitat with a wetted width of 13 m and a bankfull width of 15.5 m. The substrate was dominated by cobble with a smaller proportion of small boulders. Water at *baseline* reach STR-F2 in fall 2011 was an average of 1.05 m in depth, moderate flowing (average flow: 0.35 m/s), alkaline (pH: 8.36), with high conductivity (357 µS/cm), high dissolved oxygen (9.8 mg/L) and a temperature of 6.7°C. Instream cover consisted primarily of boulders and small and large woody debris, with smaller proportions of filamentous algae, overhanging shrubs and undercut banks (Table 5.3-14).

Temporal and Spatial Comparisons Sampling was initiated in the Steepbank River in fall 2009 at *test* reach STR-F1 during the RAMP Fish Assemblage Pilot Study; therefore, temporal comparisons were conducted from 2009 to 2011. *Baseline* reach STR-F2 was sampled for the first time in 2011; therefore, spatial comparisons were conducted only in 2011 between lower *test* reach STR-F1 and upper *baseline* reach STR-F2.

There was a decrease in abundance, species richness, and total CPUE from 2009 to 2011 at *test* reach STR-F1 (Table 5.3-15 and Table 5.3-16). White sucker was the dominant species in 2011 with slimy sculpin as the subdominant species. The assemblage tolerance index also decreased over time reflecting a larger proportion of more sensitive fish species (e.g., burbot, slimy sculpin, and lake chub). Mean values of all measurement endpoints at *test* reach STR-F1 in fall 2011 were lower than *baseline* reach STR-F2 with the exception of evenness (Table 5.3-16). The lower species richness at *test* reach STR-F1 in fall 2011 compared to previous years could be attributed to the low water levels in 2011, which did not encompass habitat along the shoreline where suitable habitat cover is located for most small-bodied species (i.e., vegetation, slower flows). Accordingly, sampling occurred in the deeper, faster flowing sections of the river where habitat is less suitable for most small-bodied fish species.

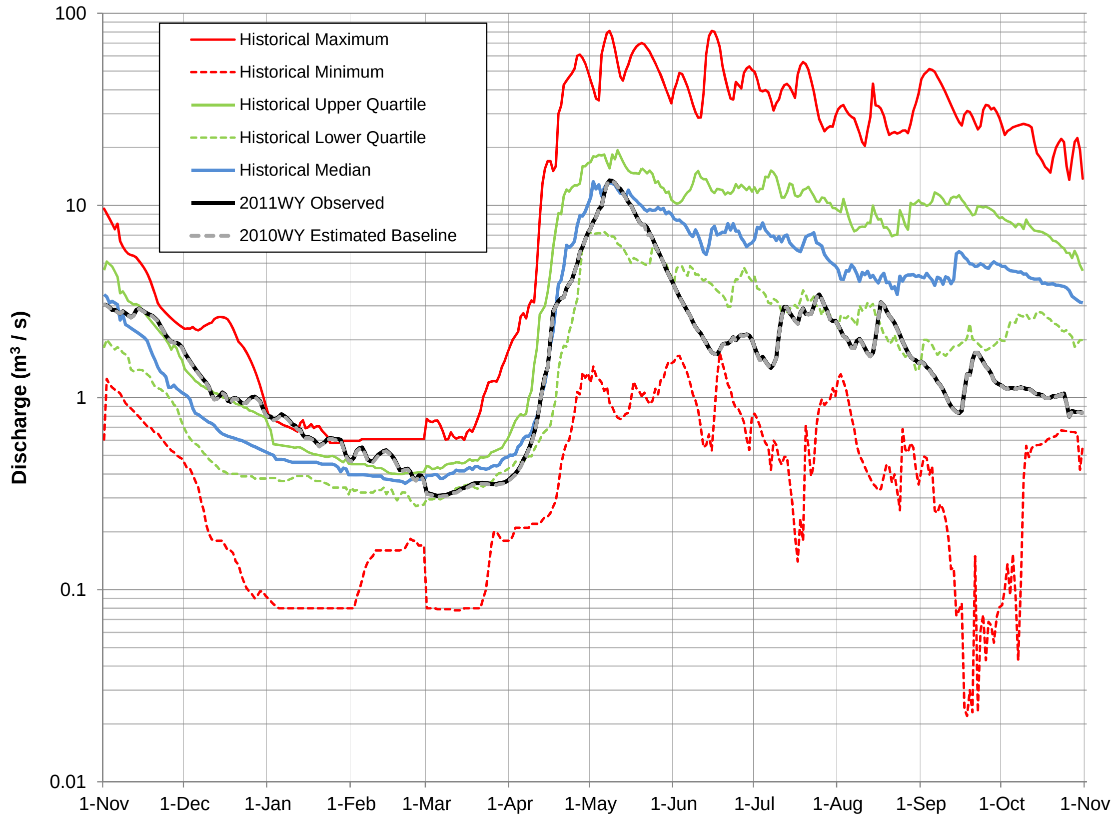
Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of 24 fish species were recorded in the Steepbank River; whereas RAMP found only 14 species from 2009 to 2011. As noted in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Habitat conditions documented in Golder (2004b) were different than what has been observed by RAMP from 2009 to 2011. Historically, habitat conditions in the lower Steepbank River were poor due to beaver activity, low habitat heterogeneity and predominance of fine substrate (Golder 2004b). In more recent years, RAMP has documented habitat conditions at *test* reach STR-F1 consisting of riffles primarily dominated by coarse gravel substrate with smaller proportions of cobble and riffle, and run habitat with cobble and smaller proportions of small boulders at *baseline* reach STR-F2. Beaver impoundments have not been documented during fish assemblage monitoring by RAMP in the Steepbank River.

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at both *test* reach STR-F1 and *baseline* reach STR-F2 were within the range of regional *baseline* conditions for (Figure 5.3-9).

Classification of Results Differences in the fish assemblage observed in fall 2011 between *test* reach ELR-F1 and regional *baseline* conditions were classified as **Negligible-Low** with all values of measurement endpoints within the range of regional *baseline* variability.

Figure 5.3-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Steepbank River in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on Steepbank River near Fort McMurray, WSC Station 07DA006 (RAMP Station S38) provisional data from March 1 to October 31, 2011 and RAMP Station S38 from November 1, 2010 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 2010, 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, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**67.69**	**Observed discharge from Steepbank River near Fort McMurray, WSC Station 07DA006 (RAMP Station S38)**
Closed-circuited area water loss from the observed *test* hydrograph	-0.25	Estimated 4.9 km^2 of the Steepbank River watershed is closed-circuited as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.41	Estimated 40.1 km^2 of the Steepbank River watershed with land change as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Steepbank River watershed from focal projects	-0.01	Approximately 0.01 million m^3 of water withdrawn by Suncor from various water sources (daily values provided)
Water releases into the Steepbank River watershed from focal projects	+0.11	Approximately 0.11 million m^3 of water released by Suncor for water management activities (daily values provided)
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)	**67.43**	**Estimated *baseline* discharge at Steepbank River near Fort McMurray, WSC Station 07DA006 (RAMP Station S38)**
Incremental flow (change in total discharge)	+0.26	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+0.39%**	**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 Steepbank River near Fort McMurray, WSC Station 07DA006 provisional data from March 1 to October 31, 2011 and RAMP Station S38 from November 1, 2010 to February 28, 2011. 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, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	3.00	3.01	0.37%
Mean winter discharge	1.02	1.03	0.46%
Annual maximum daily discharge	13.47	13.50	0.25%
Open-water period minimum daily discharge	0.80	0.80	0.24%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Based on Steepbank River near Fort McMurray, WSC Station 07DA006 provisional data from March 1 to October 31, 2011 and RAMP Station S38 from November 1, 2010 to February 28, 2011.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two decimal places.

Table 5.3-4 Concentrations of water quality measurement endpoints in the Steepbank River (*test* station STR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.6</u>	13	7.7	8.2	8.5
Total suspended solids	mg/L	-	49	13	<3	8	60
Conductivity	µS/cm	-	395	13	141	210	516
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.015	13	0.006	0.0192	0.032
Total nitrogen	mg/L	1	0.81	13	0.25	0.80	**2.40**
Nitrate+nitrite	mg/L	1.3	<0.071	13	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	22.7	13	10	20	30
Ions							
Sodium	mg/L	-	26.9	13	6.0	10.0	38.0
Calcium	mg/L	-	41.4	13	17.2	27.5	50.3
Magnesium	mg/L	-	12.9	13	5.4	8.3	16.2
Chloride	mg/L	230, 860	5.1	13	<1	2.0	8.4
Sulphate	mg/L	100	8.4	13	2.5	4.6	12.3
Total dissolved solids	mg/L	-	263	13	120	180	320
Total alkalinity	mg/L		202	13	63	105	263
Selected metals							
Total aluminum	mg/L	0.1	**1.69**	13	0.04	**0.164**	**2.79**
Dissolved aluminum	mg/L	0.1	0.0048	13	<0.004	0.0148	0.0987
Total arsenic	mg/L	0.005	0.0011	13	<0.001	0.0008	0.00128
Total boron	mg/L	1.2	0.16	13	0.03	0.05	0.20
Total molybdenum	mg/L	0.073	0.00040	13	0.00015	0.00020	0.00050
Total mercury (ultra-trace)	ng/L	5, 13	2.3	8	<1.2	<1.2	2.9
Total strontium	mg/L	-	0.19	13	0.06	0.10	0.25
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	9.4	0	-	-	-
Total dibenzothiophenes	ng/L	-	114.1	0	-	-	-
Total PAHs	ng/L	-	529.8	0	-	-	-
Total Parent PAHs	ng/L	-	32.3	0	-	-	-
Total Alkylated PAHs	ng/L	-	497.5	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.31**	13	0.19	**0.37**	**0.60**
Sulphide	mg/L	0.002	**0.004**	13	<0.003	**0.006**	**0.041**
Total chromium	mg/L	0.001	**0.0021**	13	0.0004	0.0006	**0.0083**
Total iron	mg/L	0.3	**1.89**	13	**0.47**	**0.834**	**2.28**
Total phenols	mg/L	0.004	**0.0055**	13	<0.001	**0.006**	**0.013**
Total phosphorus	mg/L	0.05	**0.059**	13	0.008	0.039	**0.070**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.3-5 Concentrations of water quality measurement endpoints in the Steepbank River (*test* station STR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.4</u>	9	7.8	8.1	8.3
Total suspended solids	mg/L	-	5	9	<3	4	28
Conductivity	µS/cm	-	<u>329</u>	9	121	191	274
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.048</u>	9	0.014	0.022	0.038
Total nitrogen	mg/L	1	0.75	9	0.60	0.80	**1.99**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	0.1
Dissolved organic carbon	mg/L	-	22	9	14	25	30
Ions							
Sodium	mg/L	-	<u>18.5</u>	9	5.0	8.1	16.0
Calcium	mg/L	-	34.0	9	16.8	25.5	35.9
Magnesium	mg/L	-	<u>11.4</u>	9	5.3	7.4	10.8
Chloride	mg/L	230, 860	<0.5	9	<0.5	2.0	3.0
Sulphate	mg/L	100	1.4	9	<0.5	2.9	5.5
Total dissolved solids	mg/L	-	<u>249</u>	9	139	160	200
Total alkalinity	mg/L		<u>178</u>	9	61	98	155
Selected metals							
Total aluminum	mg/L	0.1	0.035	9	0.018	**0.160**	**0.536**
Dissolved aluminum	mg/L	0.1	0.0098	9	0.0023	0.0146	0.0294
Total arsenic	mg/L	0.005	0.00057	9	0.00050	0.00067	0.00075
Total boron	mg/L	1.2	<u>0.16</u>	9	0.02	0.05	0.10
Total molybdenum	mg/L	0.073	0.00022	9	0.00010	0.00016	0.00030
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	1.4	3.4
Total strontium	mg/L	-	0.15	9	0.05	0.10	0.17
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	4.0	0	-	-	-
Total dibenzothiophenes	ng/L	-	6.4	0	-	-	-
Total PAHs	ng/L	-	188.0	0	-	-	-
Total Parent PAHs	ng/L	-	20.6	0	-	-	-
Total Alkylated PAHs	ng/L	-	167.4	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.54**	9	0.27	**0.45**	**0.60**
Sulphide	mg/L	0.002	**0.0048**	9	<0.003	**0.0060**	**0.0120**
Total iron	mg/L	0.3	**0.78**	9	**0.73**	**0.81**	**1.07**
Total phenols	mg/L	0.004	**0.0064**	9	<0.001	**0.0070**	**0.0111**
Total phosphorus	mg/L	0.05	<u>**0.064**</u>	9	0.035	0.037	0.047

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.3-6 Concentrations of water quality measurement endpoints in the Steepbank River (*baseline* station STR-3), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.5</u>	7	7.9	8.1	8.3
Total suspended solids	mg/L	-	6	7	<3	<3	7
Conductivity	µS/cm	-	<u>346</u>	7	128	229	317
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.046</u>	7	0.024	0.034	0.042
Total nitrogen	mg/L	1	<u>0.57</u>	7	0.60	0.80	**1.85**
Nitrate+nitrite	mg/L	1.3	<0.071	7	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	19.6	7	14.0	25.0	32.4
Ions							
Sodium	mg/L	-	<u>22.8</u>	7	5.4	11.0	17.0
Calcium	mg/L	-	38.7	7	17.1	30.0	40.7
Magnesium	mg/L	-	<u>13.2</u>	7	5.4	9.1	12.4
Chloride	mg/L	230, 860	0.7	7	<0.5	1.0	2.0
Sulphate	mg/L	100	1.50	7	0.83	3.00	3.40
Total dissolved solids	mg/L	-	<u>234</u>	7	140	186	220
Total alkalinity	mg/L		<u>186</u>	7	63.6	121	170
Selected metals							
Total aluminum	mg/L	0.1	<u>0.015</u>	7	0.021	0.041	**0.233**
Dissolved aluminum	mg/L	0.1	0.0066	7	0.0040	0.0137	0.0301
Total arsenic	mg/L	0.005	0.00055	7	0.00046	0.00067	0.00075
Total boron	mg/L	1.2	<u>0.13</u>	7	0.03	0.06	0.11
Total molybdenum	mg/L	0.073	0.00027	7	0.00014	0.00018	0.00028
Total mercury (ultra-trace)	ng/L	5, 13	0.6	7	<1.2	<1.2	2.1
Total strontium	mg/L	-	0.15	7	0.06	0.11	0.15
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	2.6	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.9	0	-	-	-
Total PAHs	ng/L	-	171.7	0	-	-	-
Total Parent PAHs	ng/L	-	20.0	0	-	-	-
Total Alkylated PAHs	ng/L	-	151.7	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.52**	7	**0.34**	**0.59**	**0.75**
Sulphide	mg/L	0.002	**0.0043**	7	**0.0040**	**0.0060**	**0.0110**
Total iron	mg/L	0.3	**0.76**	7	**0.70**	**0.93**	**1.04**
Total phenols	mg/L	0.004	**0.0072**	7	<0.001	**0.0050**	**0.0190**
Total phosphorus	mg/L	0.05	<u>**0.061**</u>	7	0.043	**0.051**	**0.060**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.3-7 Concentrations of water quality measurement endpoints in the North Steepbank River (*test* station NSR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.4</u>	9	7.5	8.0	8.1
Total suspended solids	mg/L	-	<3	9	<3	<3	8
Conductivity	µS/cm	-	<u>311</u>	9	110	143	191
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.03	9	0.02	0.02	0.04
Total nitrogen	mg/L	1	0.56	9	0.40	0.70	**1.27**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	16.7	9	13.0	20.0	23.1
Ions							
Sodium	mg/L	-	<u>6.1</u>	9	2.0	3.0	4.0
Calcium	mg/L	-	<u>42.9</u>	9	16.5	23.1	31.0
Magnesium	mg/L	-	<u>12.5</u>	9	4.9	6.5	8.8
Chloride	mg/L	230, 860	<0.5	9	<0.5	1.0	2.0
Sulphate	mg/L	100	<0.5	9	<0.5	1.2	5.2
Total dissolved solids	mg/L	-	<u>219</u>	9	109	139	160
Total alkalinity	mg/L		<u>169</u>	9	55	73	106
Selected metals							
Total aluminum	mg/L	0.1	<u>0.018</u>	9	0.028	0.054	**0.129**
Dissolved aluminum	mg/L	0.1	<u>0.0030</u>	9	0.0050	0.0111	0.0148
Total arsenic	mg/L	0.005	<u>0.0014</u>	9	0.0005	0.0008	0.0013
Total boron	mg/L	1.2	<u>0.050</u>	9	0.01020	0.01310	0.02010
Total molybdenum	mg/L	0.073	<u>0.00080</u>	9	0.00013	0.00020	0.00036
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<0.6	<1.2	1.2
Total strontium	mg/L	-	<u>0.25</u>	9	0.05	0.07	0.11
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.9	0	-	-	-
Total PAHs	ng/L	-	178.5	0	-	-	-
Total Parent PAHs	ng/L	-	19.5	0	-	-	-
Total Alkylated PAHs	ng/L	-	159.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.42**	9	0.23	**0.50**	**0.77**
Total iron	mg/L	0.3	**0.98**	9	**0.51**	**0.79**	**1.29**
Total phenols	mg/L	0.004	**0.0047**	9	<0.001	**0.0062**	<0.010
Total phosphorus	mg/L	0.05	**0.053**	9	0.027	0.032	**0.059**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.3-4 Piper diagram of fall ion concentrations in the Steepbank River, fall 2011.

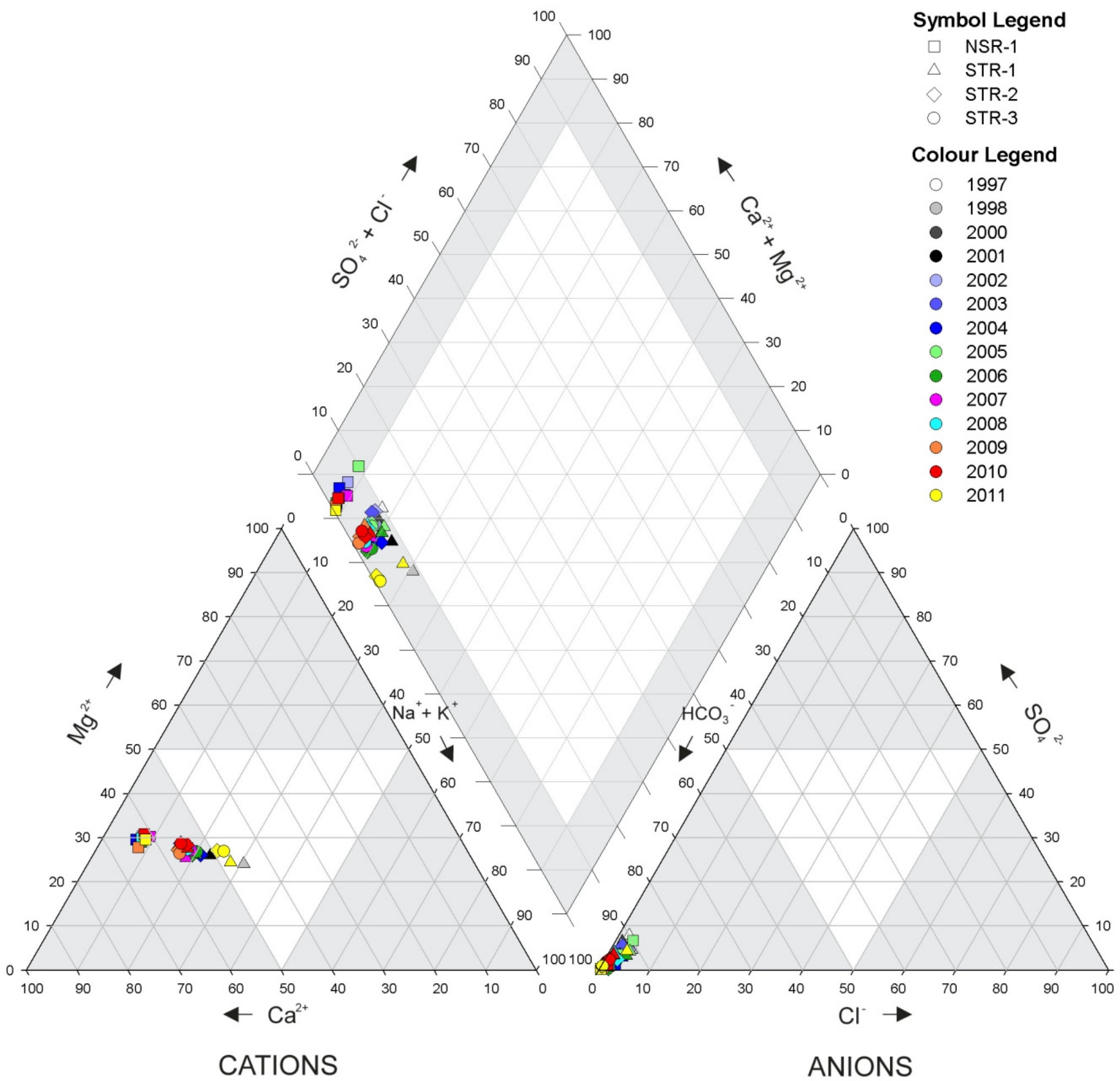


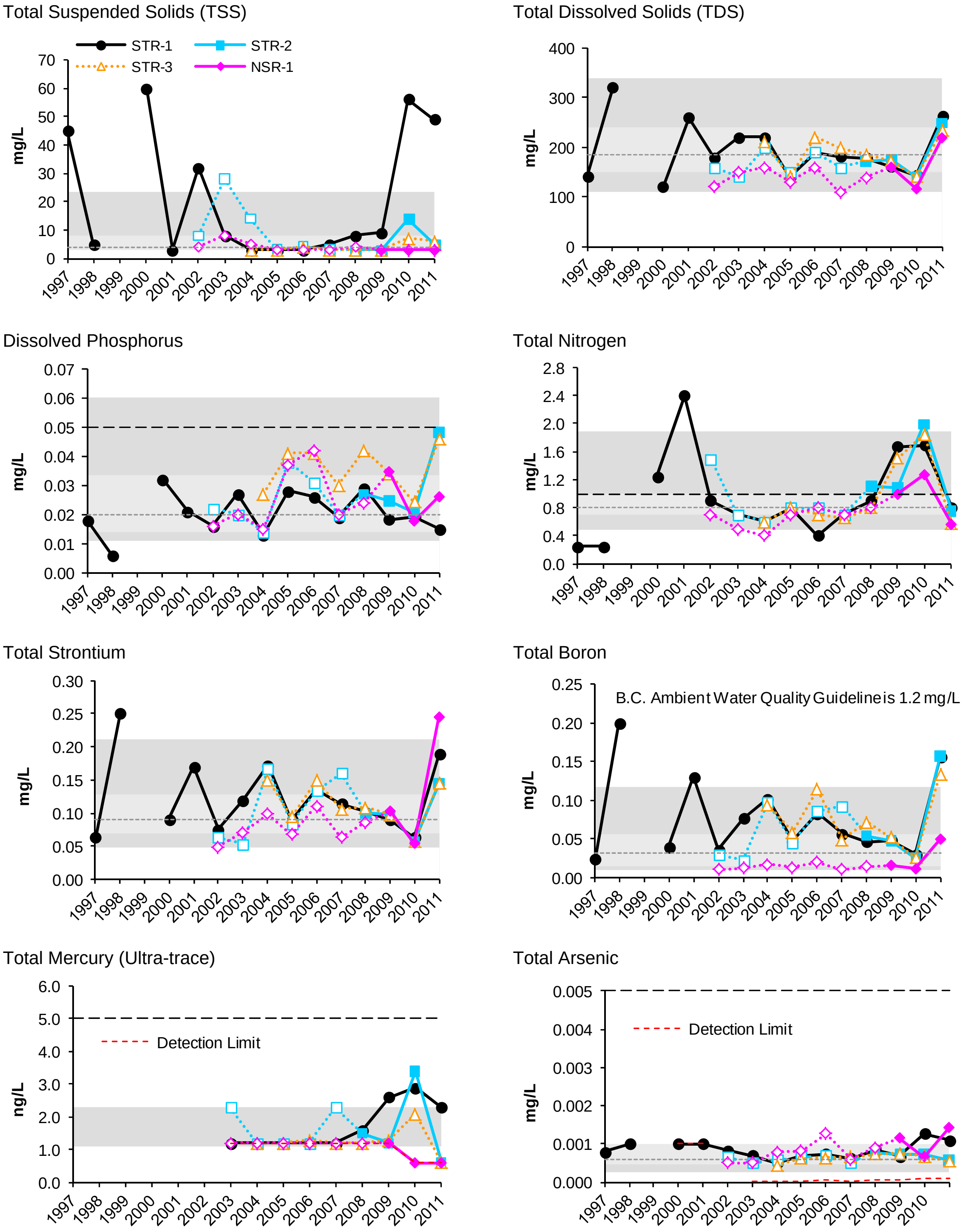
Table 5.3-8 Water quality guideline exceedances, Steepbank River watershed, 2011.

Variable	Units	Guideline[a]	STR-1	STR-2	STR-3	NSR-1
Winter						
Total iron	mg/L	0.3	0.653	ns	ns	ns
Fall						
Dissolved iron	mg/L	0.3	0.31	0.54	0.52	0.42
Sulphide	mg/L	0.0	0.0040	0.0048	0.0043	-
Total aluminum	mg/L	0.1	1.69	-	-	-
Total chromium	mg/L	0.001	0.0021	-	-	-
Total iron	mg/L	0.3	1.89	0.78	0.76	0.98
Total phenols	mg/L	0.004	0.0055	0.0064	0.0072	0.0047
Total phosphorus	mg/L	0.05	0.059	0.064	0.061	0.053

[a] Sources for all guidelines are outlined in Table 3.2-5.

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.



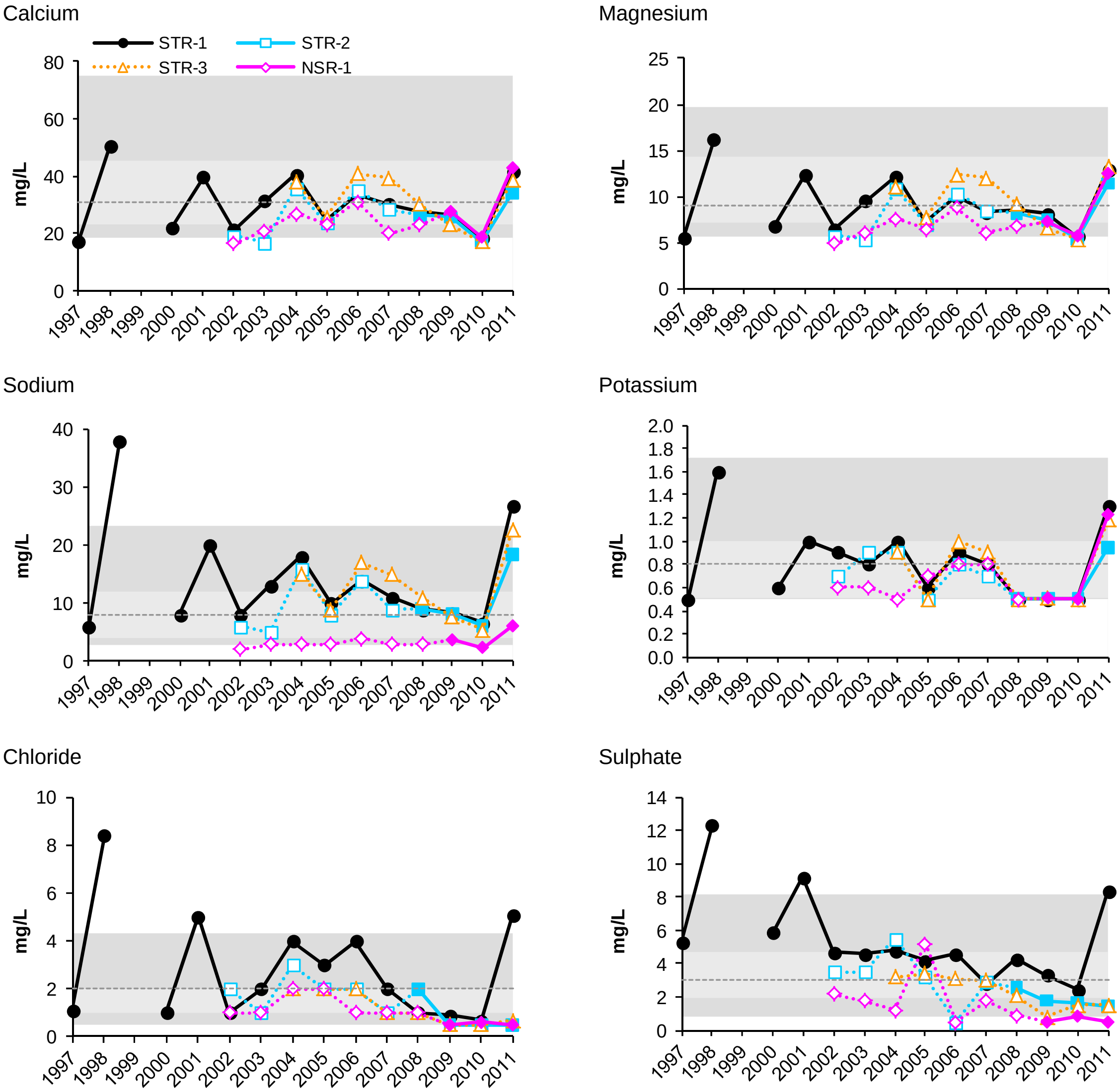
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O⋯⋯O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.3-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.3-9 Water quality index (fall 2011) for Steepbank River watershed stations.

Station Identifier	Location	2011 Designation	Water Quality Index	Classification
STR-1	Lower Steepbank River	*test*	74.1	Moderate
STR-2	Upstream of Project Millennium	*test*	96.2	Negligible-Low
STR-3	Upstream of North Steepbank River	*baseline*	96.2	Negligible-Low
NSR-1	North Steepbank River	*test*	90.3	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. 13, 2011	Sept. 11, 2011
Habitat	-	Erosional	Erosional
Water depth	m	0.2	0.2
Current velocity	m/s	0.40	0.40
Field Water Quality			
Dissolved oxygen	mg/L	11.8	9.2
Conductivity	µS/cm	404	304
pH	pH units	8.7	8.5
Water temperature	°C	8.2	12.3
Sediment Composition			
Sand/Silt/Clay	%	5	25
Small Gravel	%	7	6
Large Gravel	%	34	1
Small Cobble	%	42	24
Large Cobble	%	12	23
Boulder	%	2	22
Bedrock	%	0	0

Figure 5.3-6 Periphyton chlorophyll *a* biomass in the Steepbank River.

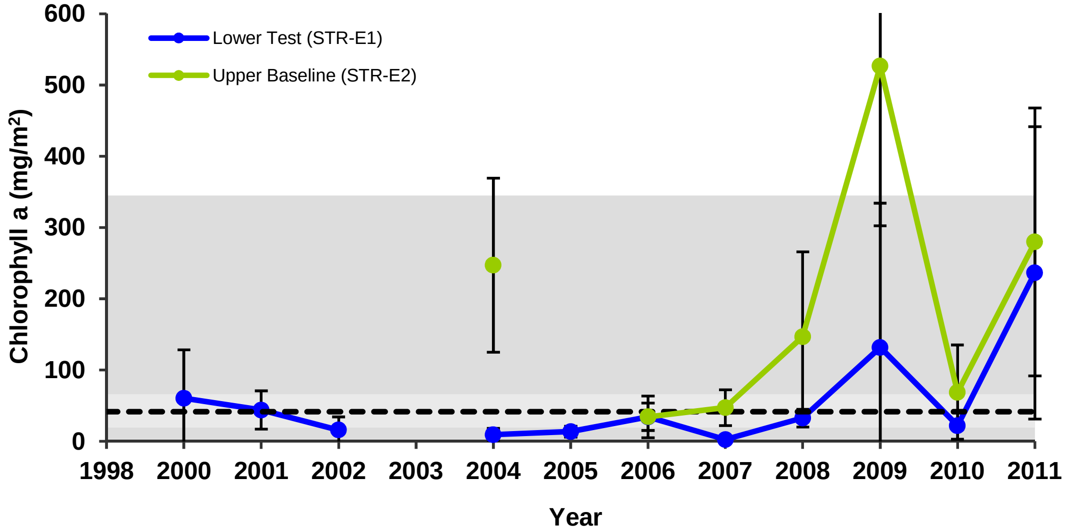


Table 5.3-11 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the lower Steepbank River (*test* reach STR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year											
	Reach STR-E1											
	1998	2000	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011
Nematoda	1	2	2	2	1	<1	1	1	1	2	<1	1
Oligochaeta												<1
Naididae	2	21	2	2	21	5	13	4	17	7	10	41
Tubificidae	2	1	<1	1	<1	1	1	10	19	1	1	<1
Enchytraeidae	1	11	1	9	6	9	15	6	9	3	4	2
Hydracarina	6	3	6	4	4	9	15	14	20	11	10	6
Ostracoda	1	<1	<1	<1			<1	5				<1
Cladocera	1	<1								<1	1	<1
Copepoda	<1	<1	<1	<1		<1		1	<1	<1	<1	<1
Gastropoda	<1	<1	<1	<1	<1		1	6	2		<1	2
Bivalvia				<1				<1	<1		<1	
Coleoptera												<1
Ceratopogonidae	<1		<1	<1	<1		<1	3	1	<1	1	<1
Chironomidae	31	15	25	43	38	25	29	36	17	41	22	24
Athericidae		<1	<1	<1	<1	<1	<1	1	1	<1	<1	<1
Empididae	2	1	2	6	4	9	7	<1	1	2	2	<1
Tipulidae	<1	<1						<1			<1	<1
Tabanidae	<1	<1			<1			<1				
Simuliidae	3	<1	<1	1	<1	3	1	<1	<1	1	<1	<1
Ephemeroptera	51	42	51	19	23	38	15	1	11	30	26	19
Anisoptera	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
Plecoptera	<1	1	<1	1	1	<1	<1	1	<1	<1	<1	<1
Trichoptera	1	<1	<1	1	1	1	<1	2	1	2	2	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	102,882
Richness	41	23	21	17	20	17	23	31	21	28	28	41
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	0.76
Evenness	0.78	0.87	0.83	0.9	0.9	0.87	0.89	0.91	0.80	0.90	0.90	0.78
% EPT	47	39	47	23	24	34	15	13	10	33	35	21

Table 5.3-12 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the upper Steepbank River (*baseline* reach STR-E2).

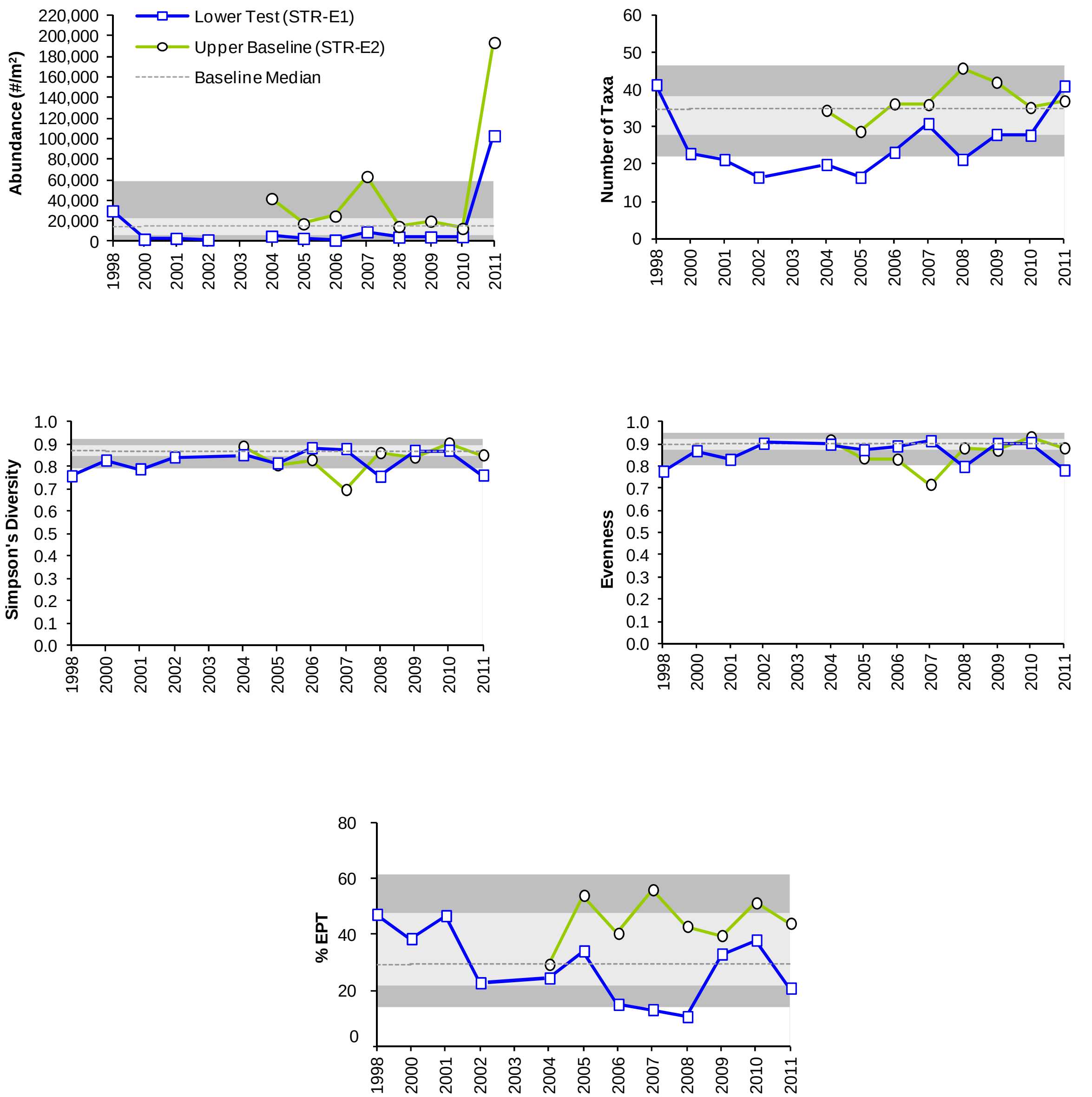
Taxon	Percent Major Taxa Enumerated in Each Year							
	Reach STR-E2							
	2004	2005	2006	2007	2008	2009	2010	2011
Hydra								<1
Nematoda	3	1	1	1	3	2	<1	2
Naididae	2	2	24	16	2	1	3	4
Tubificidae	<1		1	1	<1	<1	<1	<1
Enchytraeidae	<1	1			1	1		<1
Hydracarina	7	3	5	8	12	6	6	5
Ostracoda	1			18	<1	<1	<1	
Cladocera	4		<1	1		<1		7
Copepoda	4	<1	1		<1	<1	<1	2
Gastropoda			<1	<1	<1	<1	<1	<1
Bivalvia		<1		1	4	2	1	<1
Coleoptera								<1
Ceratopogonidae				7	<1		<1	
Chironomidae	46	32	24	52	24	41	29	29
Athericidae	<1	3	1	1	2	<1	<1	<1
Empididae	2	6	2	<1	3	3	8	3
Tipulidae	1	1	1	<1	1	<1	<1	2
Tabanidae	<1	<1		<1	<1		<1	<1
Simuliidae	<1	1	1	<1		1	<1	<1
Ephemeroptera	18	23	17	6	35	30	14	18
Anisoptera	<1	<1	<1	<1	<1		<1	<1
Plecoptera	2	4	2	1	2	2	1	1
Trichoptera	9	24	22	6	10	9	34	24
Hemiptera								<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	193,600
Richness	34	29	36	36	46	42	35	37
Simpson's Diversity	0.89	0.81	0.83	0.70	0.86	0.84	0.9	0.85
Evenness	0.92	0.83	0.83	0.72	0.88	0.87	0.93	0.88
% EPT	29	54	40	56	31	40	51	44

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 Change(s)
	Difference in Time Trend Between Reaches	*Baseline* Reach vs. *Test* Reach	Difference in Time Trend between Reaches	*Baseline* Reach vs. *Test* Reach	
Abundance	**0.003**	**<0.001**	1	42	Higher in *baseline* reach. Decreasing in *baseline* reach and stable in *test* reach.
Richness	0.071	**<0.001**	1	47	Higher in *baseline* reach
Simpson's Diversity	**<0.001**	0.999	33	0	Increasing in *baseline* reach and stable in *test* reach
Evenness	**<0.001**	0.292	31	1	Increasing in *baseline* reach and stable in *test* reach
EPT	**0.026**	**<0.001**	3	52	Higher in *baseline* reach and increasing in *baseline* reach.
CA Axis 1	**0.008**	**<0.001**	2	30	Higher in *baseline* reach and increasing in *test* reach
CA Axis 2	**0.001**	**<0.001**	2	64	Higher in *baseline* reach and decreasing in test reach

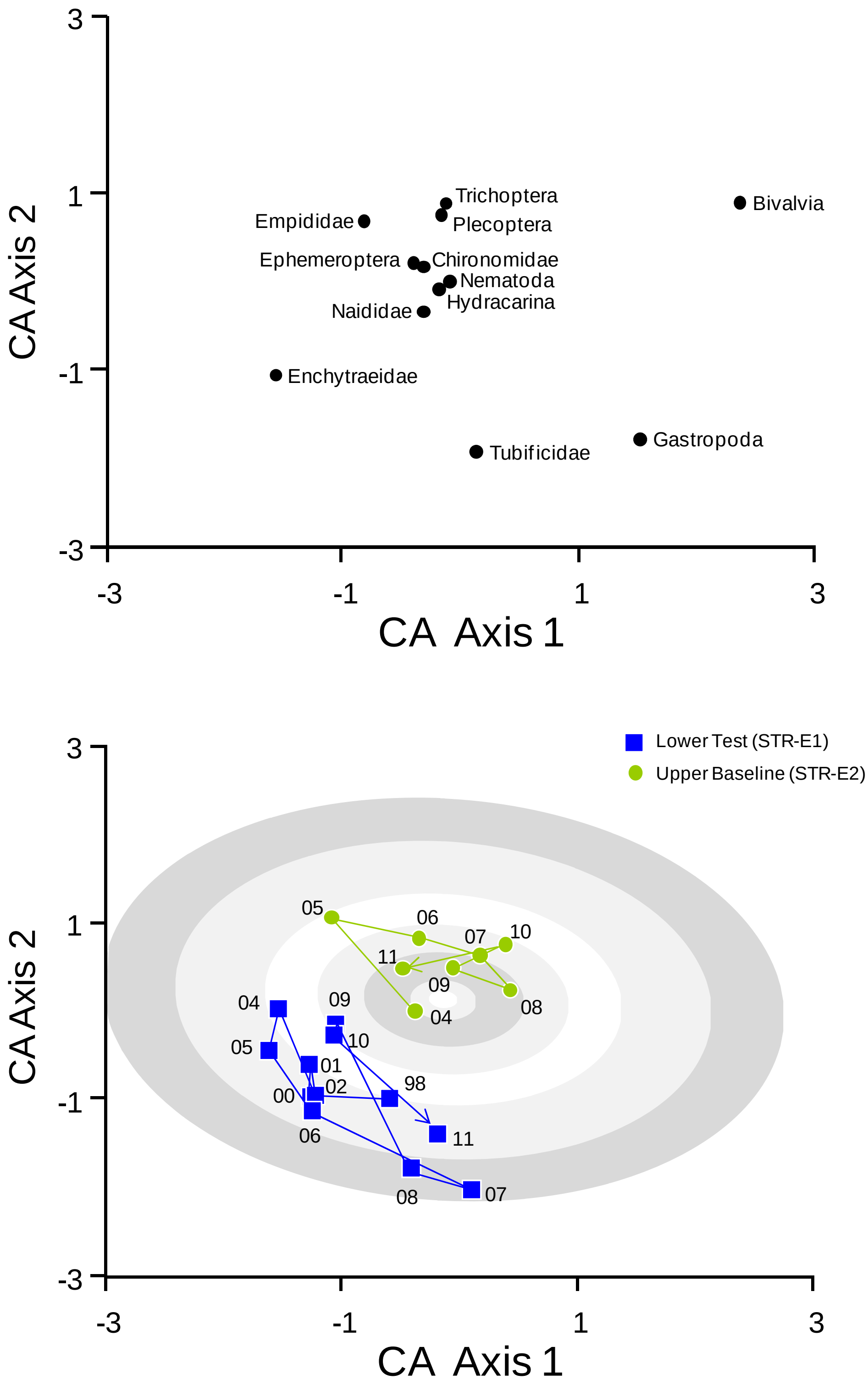
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low, Moderate, or High (Table 3.2-6).

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.

Table 5.3-14 Average habitat characteristics of fish assemblage monitoring locations in the Steepbank River.

Variable	Units	STR-F1 Lower *Test* Reach of Steepbank River	STR-F2 Upper *Baseline* Reach of Steepbank River
Sample date	-	Sept. 12, 2011	Sept. 13, 2011
Habitat type	-	riffle	riffle/run
Maximum depth	m	0.65	1.05
Average bankfull channel width	m	23.0	15.5
Average wetted channel width	m	10.5	13.0
Substrate			
Dominant	-	coarse gravel	cobble
Subdominant	-	cobble	small boulder
Instream cover			
Dominant	-	macrophytes and boulders	boulders and small and large woody debris
Subdominant	-	filamentous algae and small and large woody debris	filamentous algae, overhanging vegetation and undercut banks
Field water quality			
Dissolved oxygen	mg/L	9.6	9.8
Conductivity	µS/cm	195	357
pH	pH units	8.12	8.36
Water temperature	°C	10.5	6.7
Water velocity			
Left bank velocity	m/s	0.36	0.04
Left bank water depth	m	0.45	0.53
Centre of channel velocity	m/s	0.54	0.14
Centre of channel water depth	m	0.43	0.57
Right bank velocity	m/s	0.52	0.20
Right bank water depth	m	0.24	0.60
Riparian cover – understory (<5 m)			
Dominant	-	woody shrubs and saplings	woody shrubs and saplings
Subdominant	-	overhanging vegetation	overhanging vegetation

Table 5.3-15 Percent composition and mean CPUE of fish species at *test* reach STR-F1 and *baseline* reach STR-F2 of Steepbank River, 2009 to 2011.

Common Name	Code	Total Species				Percent of Total Catch			
		STR-F1			STR-F2	STR-F1			STR-F2
		2009	2010	2011	2011	2009	2010	2011	2011
Arctic grayling	ARGR	-	-	-	-	0	0	0	0
brook stickleback	BRST	-	-	-	5	0	0	0	6.3
burbot	BURB	-	8	-	-	0	3.8	0	0
fathead minnow	FTMN	-	-	-	-	0	0	0	0
finescale dace	FNDC	-	-	-	-	0	0	0	0
lake chub	LKCH	2	-	-	5	6.1	0	0	6.3
lake whitefish	LKWH	-	-	-	1	0	0	0	1.3
longnose dace	LNDC	1	63	2	9	3.0	30.0	7.7	11.4
longnose sucker	LNSC	2	-	1	3	6	0	3.8	3.8
northern pike	NRPK	-	-	-	-	0	0	0	0
northern redbelly dace	NRDC	16	-	-	1	48.5	0	0	1.3
pearl dace	PRDC	2	64	-	-	6.1	30.5	0	0
slimy sculpin	SLSC	2	60	8	35	6.1	28.6	30.8	44.3
spoonhead sculpin	SPSC	-	3	3	-	0	1.4	11.5	0
spottail shiner	SPSH	-	-	-	-	0	0	0	0
trout-perch	TRPR	1	7	-	20	3.0	3.3	0	25.3
walleye	WALL	1	-	-	-	3.0	0	0	0
white sucker	WHSC	1	4	12	-	3.0	1.9	46.2	0
yellow perch	YLPR	-	1	-	-	0	0.5	0	0
unknown sp. *		5	-	-	-	15.2	0	0	0
Total Count		**33**	**210**	**26**	**79**	**100**	**100**	**100**	**100**
Total Species Richness		**9**	**8**	**5**	**8**	**9**	**8**	**5**	**8**
Electrofishing effort (secs)		**3,652**	**4,977**	**1,326**	**1,309**	**-**	**-**	**-**	**-**
CPUE (#/100secs)		**0.9**	**4.22**	**1.96**	**6.04**	**-**	**-**	**-**	**-**

* not included in total species richness count.

Table 5.3-16 Summary of fish assemblage measurement endpoints in reaches of the Steepbank River watershed, 2009 to 2011.

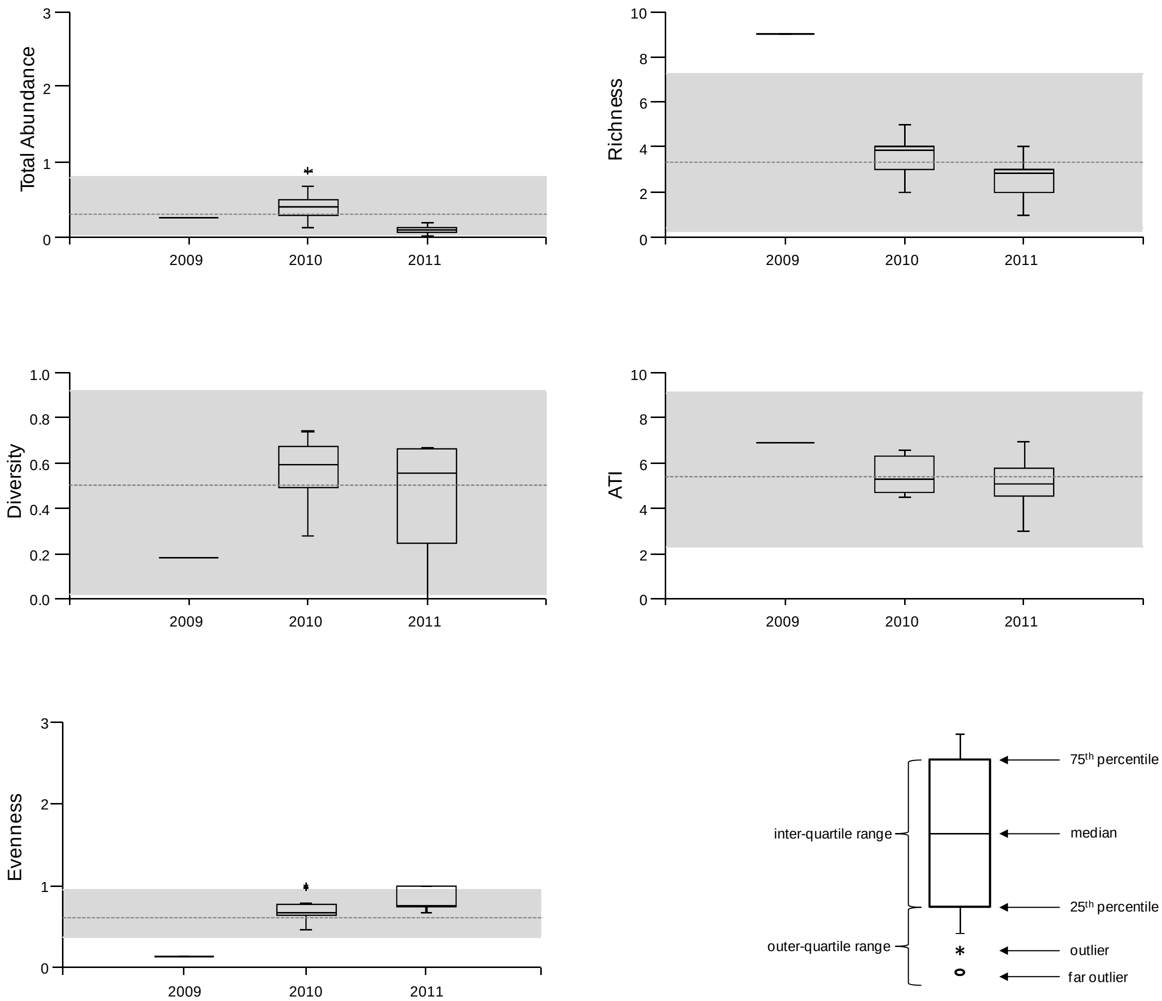
Reach	Year	Abundance		Richness*			Diversity*		Evenness*		ATI*	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
STR-F1	2009	0.25		10	9		0.18		0.14		6.92	
	2010	0.42	0.23	8	4	0.95	0.57	0.13	0.69	0.14	5.42	0.81
	2011	0.10	0.07	5	3	1.14	0.43	0.29	0.83	0.16	5.07	1.46
STR-F2	2011	0.32	0.18	8	4	1.30	0.59	0.09	0.64	0.18	6.02	2.08

* Unknown species not included in the calculation.

SD=standard deviation across sub-reaches within a reach.

Figure 5.3-9 Box-plots showing variation in fish assemblage measurement endpoints in reaches of the Steepbank River, 2009 to 2011.

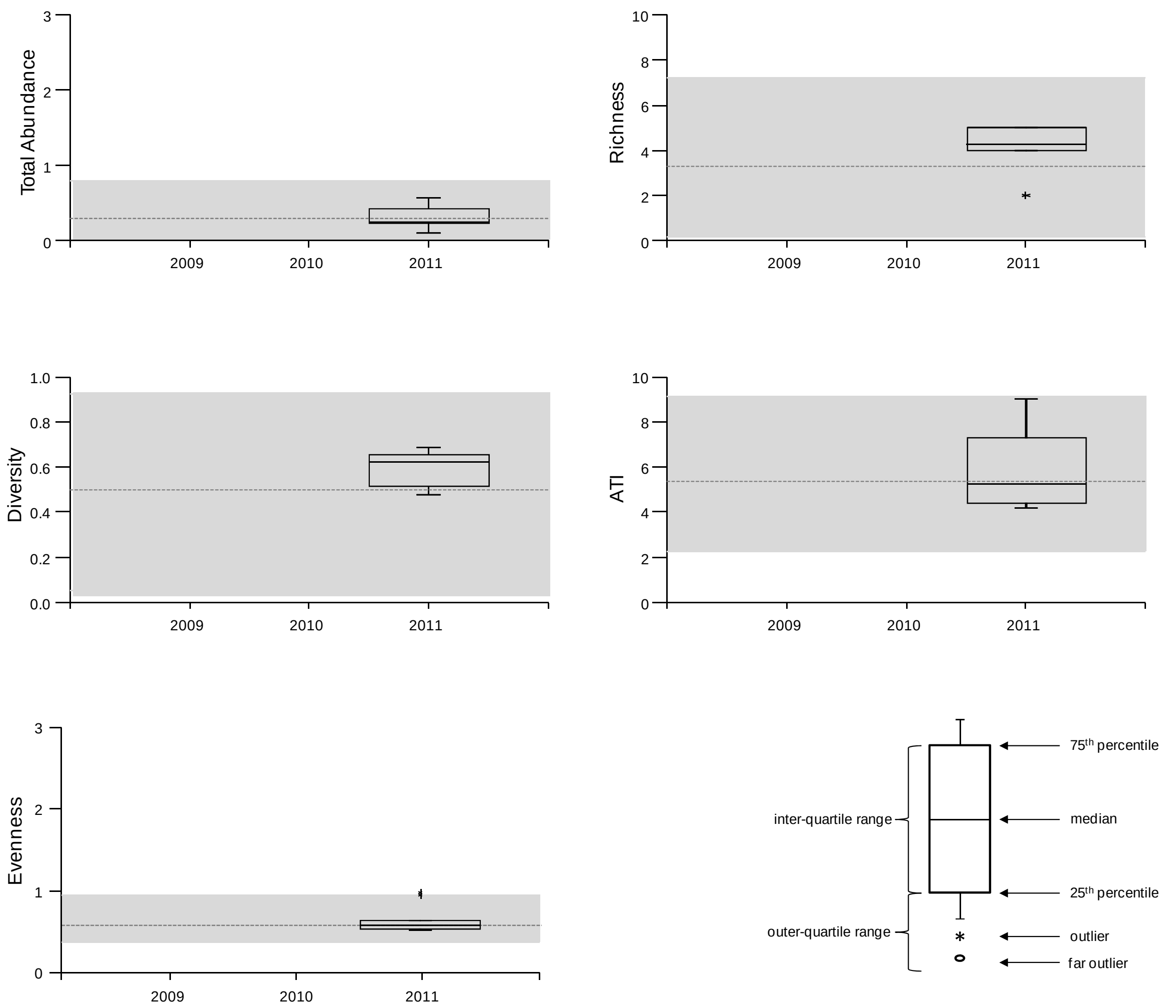
Erosional *Test* Reach STR-F1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

Figure 5.3-9 (Cont'd.)

Erosional *Baseline* Reach STR-F2



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

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5.4 TAR RIVER WATERSHED

Table 5.4-1 Summary of results for the Tar River watershed.

Tar River Watershed	Summary of 2011 Conditions	
Climate and Hydrology		
Criteria	**S15A** near the mouth	no station sampled
Mean open-water season discharge	High	
Mean winter discharge	not measured	
Annual maximum daily discharge	High	
Minimum open-water season discharge	High	
Water Quality		
Criteria	**TAR-1** at the mouth	**TAR-2** upstream of Canadian Natural Horizon
Water Quality Index	Negligible-Low	Negligible-Low
Benthic Invertebrate Communities and Sediment Quality		
Criteria	**TAR-D1** lower reach	**TAR-E2** upper reach
Benthic Invertebrate Communities	Moderate	n/a
Sediment Quality Index	Moderate	not sampled
Fish Populations		
Criteria	**TAR-F1** lower reach	**TAR-F2** upper reach
Fish Assemblages	Negligible-Low	n/a

Legend and Notes

○ (yellow)	Negligible-Low
● (orange)	Moderate
● (brown)	High
(green)	*baseline*
(blue)	*test*

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches and/or regional *baseline* conditions.

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.

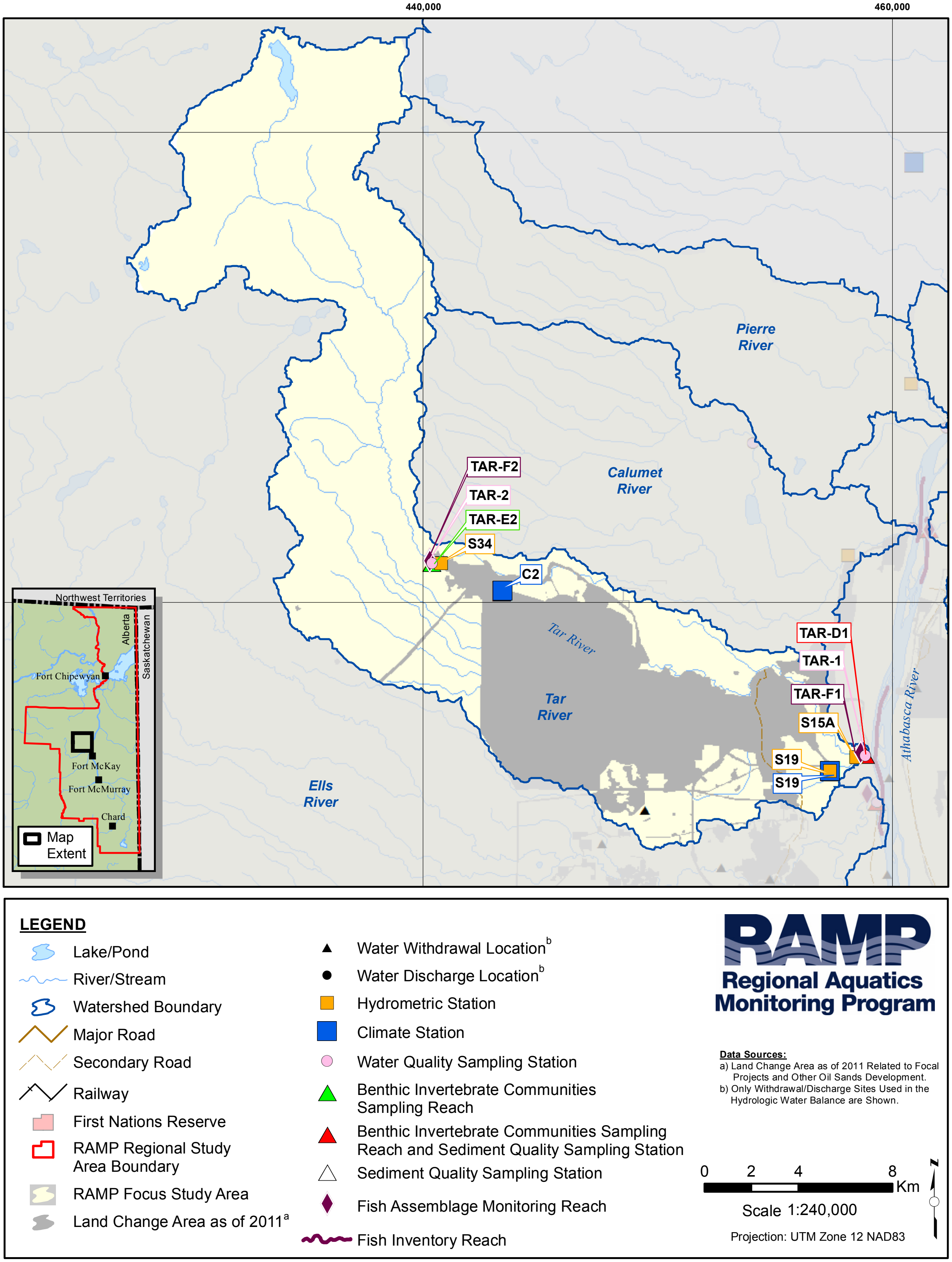
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* 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: Classification based on exceedances of measurement endpoints from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.4-1 Tar River watershed.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_K04_Tar_20120423.mxd

Figure 5.4-2 Representative monitoring stations of the Tar River, fall 2011.

Benthic Invertebrate and Fish Assemblage Reach TAR-D1/TAR-F1: facing upstream

Benthic Invertebrate and Fish Assemblage Reach TAR-D1/TAR-F1: facing downstream

Hydrology Station S34 (above Horizon Lake): facing downstream

Benthic Invertebrate and Fish Assemblage Reach TAR-E2/TAR-F2: facing upstream

5.4.1 Summary of 2011 Conditions

As of 2011, approximately 27% (8,980 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components of RAMP in the Tar River watershed in 2011. Table 5.4-1 is a summary of the 2011 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 2011. Figure 5.4-2 contains fall 2011 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 were 17.6% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **High**.

Water Quality Differences in water quality observed in fall 2011 between the Tar River and regional *baseline* fall conditions were classified as **Negligible-Low**. All water quality measurement endpoints at *baseline* station TAR-2 and *test* station TAR-1 in fall 2011 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 of the benthic invertebrate communities at *test* reach TAR-Dl were 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* and because two of the five measurement endpoints were outside the range of variation for *baseline* depositional reaches. Percent EPT and CA axes scores 1 and 2 also varied over time (linearly) during the *test* period. In addition, the statistical signal in all of these differences explained more than 20% of the variance in the values of these measurement endpoints. The benthic fauna of the lower *test* reach was dominated numerically by tubificid worms, indicating that the reach is potentially exhibiting degrading conditions.

Differences in sediment quality observed in fall 2011 between *test* station TAR-D1 and regional *baseline* conditions were classified as **Moderate**, primarily because of high metal concentrations relative to *baseline* data. These high metal concentrations are likely related to the relatively high percent-fines measured in fall 2011 at *test* station TAR-D1, given similar metal concentrations were observed in TAR-1 in 2004, when percent-fines was similar to that observed in 2011. With the exception of total metals, concentrations of most other sediment quality measurement endpoints were within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although CCME Fraction-4 and total hydrocarbons represented historical minimum concentrations.

Fish Populations Differences in measurement endpoints for fish assemblages at *test* reach TAR-F1 and regional *baseline* conditions were classified as **Negligible-Low** given there were no measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

5.4.2 Hydrologic Conditions: 2011 Water Year

RAMP Station S15A, Tar River near the mouth Continuous hydrometric data have been collected during the open-water runoff period (May to October) for Station S15A since 2001. Data were also collected during the open-water period at Station S15 (2001 to 2006) and WSC Station 07DA015 (1975 to 1977) (RAMP 2009b). In the 2011 WY, data from June 20 to August 11 could not be recorded due to damage of station equipment by forest fires. When monitoring began in the 2011 WY, on April 18, flows were below the historical minimum flows until May 1 (Figure 5.4-3). Flows increased during freshet to a peak value of 5.3 m^3/s on May 6, which was the highest flow recorded from available data in the 2011 WY and was in the upper quartile of flows recorded for May 6 in previous years. Flows continued to decrease until monitoring ceased on June 19. Flows continued to decrease when monitoring resumed on August 12 to a minimum value of 0.15 m^3/s on September 15, which was in the lower quartile of flows recorded on September 15 in previous years, as were the majority of flow values recorded for the remainder of the 2011 WY.

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 2011 was estimated to be 63.6 km^2 (Table 2.5-1). The loss of flow to the Tar River that would have otherwise occurred from this land area was estimated at 2.5 million m^3.
2. As of 2011, the area of land change in the Tar River watershed from focal projects that was not closed-circuited was estimated to be 26.3 km^2 (Table 2.5-1). The increase in flow to the Tar River that would not have otherwise occurred from this land area was estimated at 0.21 million m^3.

The estimated cumulative effect of this land change was a decrease in flow of 2.30 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 were 17.6% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.4-3). These differences were classified as **High** (Table 5.4-1).

5.4.3 Water Quality

In fall 2011, water quality samples were taken from:

- the Tar River near its mouth (*test* station TAR-1, designated as *baseline* from 1998 to 2003, and *test* from summer 2004 to 2011); and
- the upper Tar River (*baseline* station TAR-2, sampled since 2004).

Temporal Trends There were no significant trends (α=0.05) in any measurement endpoints at *test* station TAR-1 (1998, 2002 to 2011). There was a significant decreasing trend in the fall concentration of chloride (α=0.05) at *baseline* station TAR-2 (2004 to 2011).

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within previously-measured concentrations at *test* station TAR-1 and *baseline* station TAR-2 in fall 2011 (Table 5.4-4 and Table 5.4-5).

Ion Balance In fall 2011, the ionic compositions of water at *baseline* station TAR-2 and *test* station TAR-1 were consistent with previous years. *Test* station TAR-1 has shown much greater variability since sampling was initiated in 1998. In fall 2011, the ionic composition of water at *test* station TAR-1 showed calcium-bicarbonate composition similar to conditions observed from 1998 to 2006 and 2009 to 2010, 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 the water quality guideline at *test* station TAR-1 and *baseline* station TAR-2 in fall 2011 (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 2011 (Table 5.4-6).

- concentrations of dissolved iron, total chromium, total iron, total phenols and total phosphorous at *test* station TAR-1; and
- concentrations of dissolved iron, total iron, total phenols and total phosphorous at *baseline* station TAR-2.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints at *test* station TAR-1 and *baseline* station TAR-2 in fall 2011 were within regional *baseline* concentrations (Figure 5.4-5).

Water Quality Index The WQI values for both stations in the Tar River watershed (*test* station TAR-1: 97.2, *baseline* station TAR-2: 100) indicated **Negligible-Low** differences from regional *baseline* fall conditions. The calculated WQI value for *test* station TAR-1 continued to remain high in 2011 and consistent to 2010 and 2009 following a low WQI value of 59.8 observed in 2008.

Classification of Results Differences in water quality observed in fall 2011 between the Tar River and regional *baseline* fall conditions were classified as **Negligible-Low**. All water quality measurement endpoints at *baseline* station TAR-2 and *test* station TAR-1 in fall 2011 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 2011 at:

- depositional *test* reach TAR-D1, designated as *baseline* from 2002 to 2003 and as *test* from 2004 to 2011 (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.

2011 Habitat Conditions Water at *test* reach TAR-D1 in fall 2011 was shallow (0.2 m), slow flowing (0.43 m/s), mildly alkaline (pH: 7.9), with high conductivity (336 µS/cm) (Table 5.4-7). The substrate was dominated by silt (50%) with small amounts of sand and clay. Water at *baseline* reach TAR-E2 was shallow (0.2 m), moderately flowing (0.60 m/s), very mildly alkaline (pH: 7.3), with moderately high conductivity (297 µS/cm) (Table 5.4-7). The substrate was dominated by a combination of gravel, cobble, and boulder. Periphyton biomass at *baseline* reach TAR-E2 averaged 99 mg/m^2, which was within the range of previously-measured concentrations (Figure 5.4-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach TAR-D1 was dominated by tubificid worms (55%), chironomids (27%), and ostracods (10%), with subdominant taxa consisting of ceratopogonids, gastropods and bivalves (Table 5.4-8). Mayflies (Ephemerella) and caddisflies were present in very low relative abundance. Dominant chironomids included the *Tanytarsus*, *Paralauterborniella*, *Polypedilum* and *Stempellinella*, all of which are ubiquitous (Wiederholm 1983).

The benthic invertebrate community at *baseline* reach TAR-E2 was dominated by chironomids (32%), mayflies (Ephemeroptera, 26%), and water mites (Hydracarina, 13%) with subdominant taxa consisting of caddisflies (Trichoptera), empidid fly larvae, and enchytraeids (Table 5.4-9). In addition to enchytraeids, a variety of other worms (i.e., nadids, nematodes, tubificids) were present in lower relative abundance (2% each). *Cricotopus*, a common chironomid in north-temperate climates (Wiederholm 1983) was the most dominant chironomid. Caddisflies included the net spinner *Hydropsyche*, and the scraper *Glossosoma*, which are both very common in north-temperate regions

(Wiggins 1977). Mayflies included taxa from Heptageneiidae and Baetidae, while stoneflies were represented by Capniidae, Chloroperlidae, *Skwala* and *Isoperla*, all of which are commonly distributed in Alberta (Clifford 1991).

Temporal and Spatial Comparisons Two temporal comparisons were conducted for *test* reach TAR-D1 (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 of benthic invertebrate communities were tested between the years before and after reach TAR-D1 was 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* compared to the period it was designated as *baseline*, while there was a weak significant difference in percent EPT (i.e., slightly higher during the *test* period) (Figure 5.4-7). There was a weak significant difference in CA Axis 2 scores between the two periods (Table 5.4-10 and Figure 5.4-8). Greater than 20% of the variance in the values of total abundance, taxa richness, diversity, and evenness was accounted for by the differences between the two periods (Table 5.4-10).

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 were small but significant increases in percent EPT and CA Axis 2 scores at reach TAR-D1 during the *test* period (Table 5.4-10). There was also a statistically strong decrease in CA Axis 1 over the *test* period. There was a significant but weak increase in total abundance, explaining less than 20% of the variance in values of total abundance (Table 5.4-10). Time trends in the other three measurement endpoints at *test* reach TAR-D1 during the period the reach has been designated as *test* were not statistically significant (Table 5.4-10).

Comparison to Published Literature The percent of the benthic invertebrate community as Tubificidae at *test* reach TAR-D1 during the period it has been designated as *test* was higher compared to the period it was designated as *baseline*. With tubificids accounting for >50% of the fauna, there is some indication that the Tar River is subject to nutrient enrichment (Hynes 1960, Griffiths 1998). *Test* reach TAR-D1 in fall 2011; however, contained a high diversity of benthic invertebrate fauna including sphaeriid bivalves, gastropods, Ephemeroptera and some stoneflies (Plecoptera), all of which indicated a relatively robust benthic invertebrate community.

2011 Results Relative to Regional *Baseline* Conditions The values of the benthic invertebrate community measurement endpoints at *test* reach TAR-D1 in fall 2011, including total abundance, taxa richness, and percent EPT, 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 was designated as *test* or *baseline* (Figure 5.4-7). Diversity and evenness were below the range of *baseline* reaches in 2011, which was also observed in 2005 and 2006 (Figure 5.4-7). These measurement endpoints had returned to values within the range of *baseline* reaches in 2009 following the decrease in 2005 and 2006, but have decreased over the past two years to below the 5th percentile of regional *baseline* conditions. Ordination axis scores were within the range of variation for *baseline* depositional reaches, but not consistent with previously-measured values for this reach (Figure 5.4-8).

Classification of Results Differences in measurement endpoints of the benthic invertebrate communities at *test* reach TAR-Dl were 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* and because two of the seven measurement endpoints were outside the range of variation for *baseline* depositional reaches. Percent EPT and CA axes scores 1 and 2 also varied over time (linearly) during the *test* period. In addition, the statistical signal in all of these differences explained more than 20% of the variance in the values of these measurement endpoints. The benthic fauna at the lower *test* reach was dominated numerically by tubificid worms, indicating that the reach is potentially exhibiting degrading conditions.

5.4.4.2 Sediment Quality

Sediment quality was sampled in fall 2011 in the Tar River, near its mouth at *test* station TAR-D1 in the same location as the benthic invertebrate community *test* reach TAR-D1. This station was designated as *baseline* from 1998 to 2003 and as *test* from 2004 to 2011.

Temporal Trends No statistically significant trends (α=0.05) in concentrations of sediment quality measurement endpoints were observed for *test* station TAR-D1 in fall 2011.

2011 Results Relative to Historical Conditions 2011 sediment quality data from *test* reach TAR-D1 was compared directly to the data collected at this reach in 2006 and 2009 to 2010. 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 finer in 2011 than in recent years, with concentrations of silt and clay more similar to sediment composition observed in 2004 (Table 5.4-11 and Figure 5.4-9). In fall 2011, concentrations of all other sediment quality measurement endpoints were within previously-measured concentrations at *test* station TAR-D1 with the exception of Fraction-4 CCME hydrocarbons and total hydrocarbons, which were below previously-measured minimum concentrations. Concentrations of Fraction-1 and Fraction-2 hydrocarbons and BTEX (benzene, toluene, ethylene and xylene) were not detectable (Table 5.4-11). Similar to previous years, concentrations of hydrocarbons in the sediments at *test* station TAR-D1 in fall 2011 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, both absolute and carbon normalized, was within previously-measured concentrations and similar to concentrations observed in 2009. The predicted PAH toxicity in fall 2011 was within the range of historical values and lower than 2010, but continued to exceed the potential chronic toxicity threshold of 1.0, which has been observed during most of the sampling record for this station (Table 5.4-11 and Figure 5.4-9). However, total metal concentrations exceeded previously-measured maximum concentrations, and were most similar to historical data from 2004, when this sample also was dominated by fine sediments. When total metals were normalized to percent fines, they were within the range of historical values for this station (Figure 5.4-9).

Direct tests of sediment toxicity to invertebrates at *test* station TAR-D1 showed 88% survival in test organisms of both the amphipod *Hyalella* and the midge *Chironomus.* Ten-day growth of *Chironomus* was within the range of previous observations. Both survival of *Chironomus* and 14-day growth of *Hyalella* exceeded previously-measured maximum values (Table 5.4-11).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines No sediment quality measurement endpoints in fall 2011 had concentrations that exceeded the relevant CCME sediment quality guidelines at *test* station TAR-D1 (Table 5.4-11).

Sediment Quality Index A SQI of 75.9 was calculated for *test* station TAR-D1 for fall 2011, indicating a **Moderate** 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 also indicated a **Moderate** difference from regional *baseline* conditions, and also contained a relatively high proportion of fines and relatively high metal concentrations.

Classification of Results Differences in sediment quality observed in fall 2011 between *test* station TAR-D1 and regional *baseline* conditions were classified as **Moderate**, primarily because of high metal concentrations relative to *baseline* data. These high metal concentrations are likely related to the relatively high percent-fines measured in fall 2011 at *test* station TAR-D1, given similar metal concentrations were observed in TAR-1 in 2004, when percent-fines was similar to that observed in 2011. With the exception of total metals, concentrations of most other sediment quality measurement endpoints were within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although CCME Fraction-4 and total hydrocarbons represented historical minimum concentrations.

5.4.5 Fish Populations

Fish assemblages were sampled in fall 2011 at:

- depositional *test* reach TAR-F1, sampled in 2009 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is in the same location as the benthic invertebrate community *test* reach TAR-D1); and
- erosional *baseline* reach TAR-F2, sampled for the first time in 2011 (this reach is in the same location as the benthic invertebrate community *baseline* reach TAR-E2).

2011 Habitat Conditions *Test* reach TAR-F1 was comprised of deep riffle and run habitat and a wetted width of 6.9 m and a bankfull width of 10.4 m (Table 5.4-12). The substrate was comprised entirely of sand. Water at *test* reach TAR-F1 in fall 2011 was 0.94 m deep, slow flowing (average flow: 0.25 m/s), alkaline (pH: 7.86) with moderate conductivity (353 µS/cm), moderate dissolved oxygen (7.8 mg/L), and a temperature of 15.6°C. Instream cover was comprised primarily of small and large woody debris with small amounts of overhanging vegetation and undercut banks (Table 5.4-12).

Baseline reach TAR-F2 was comprised of riffle and pool habitat and a wetted width of 4.6 m and a bankfull width of 13.4 m (Table 5.4-12). The substrate was primarily cobble with small portions of coarse gravel, silt, and clay. Water at *baseline* reach TAR-F2 in fall 2011 was 0.68 m deep, slow flowing (average flow: 0.29 m/s), alkaline (pH: 8.10) with low conductivity (357 µS/cm), high dissolved oxygen (8.8 mg/L), and a temperature of 12.7°C. Instream cover was comprised primarily of small woody debris and overhanging vegetation with small amounts of large woody debris, live trees/roots, undercut banks, and boulders (Table 5.4-12).

Temporal and Spatial Comparisons Temporal comparisons were conducted at *test* reach TAR-F1 between 2009 and 2011 (spatial comparisons were not conducted because *test* reach TAR-F1 is depositional and *baseline* reach TAR-F2 is erosional, providing different habitat conditions for fish assemblages). *Baseline* reach TAR-F2 was sampled for the first time in 2011; therefore, no temporal comparisons were conducted.

There was an increase in abundance, taxa richness and total CPUE from 2009 to 2011 at *test* reach TAR-F1 (Table 5.4-13, Table 5.4-14 and Figure 5.4-10). There was a decrease in diversity over time at *test* reach TAR-F1; however, the ATI value also decreased since 2009 indicating a presence of more sensitive species (e.g., lake chub) and a greater abundance of fish. *Test* reach TAR-F1 was dominated by lake chub, while *baseline* reach TAR-F2 was dominated by slimy sculpin (Table 5.4-13).

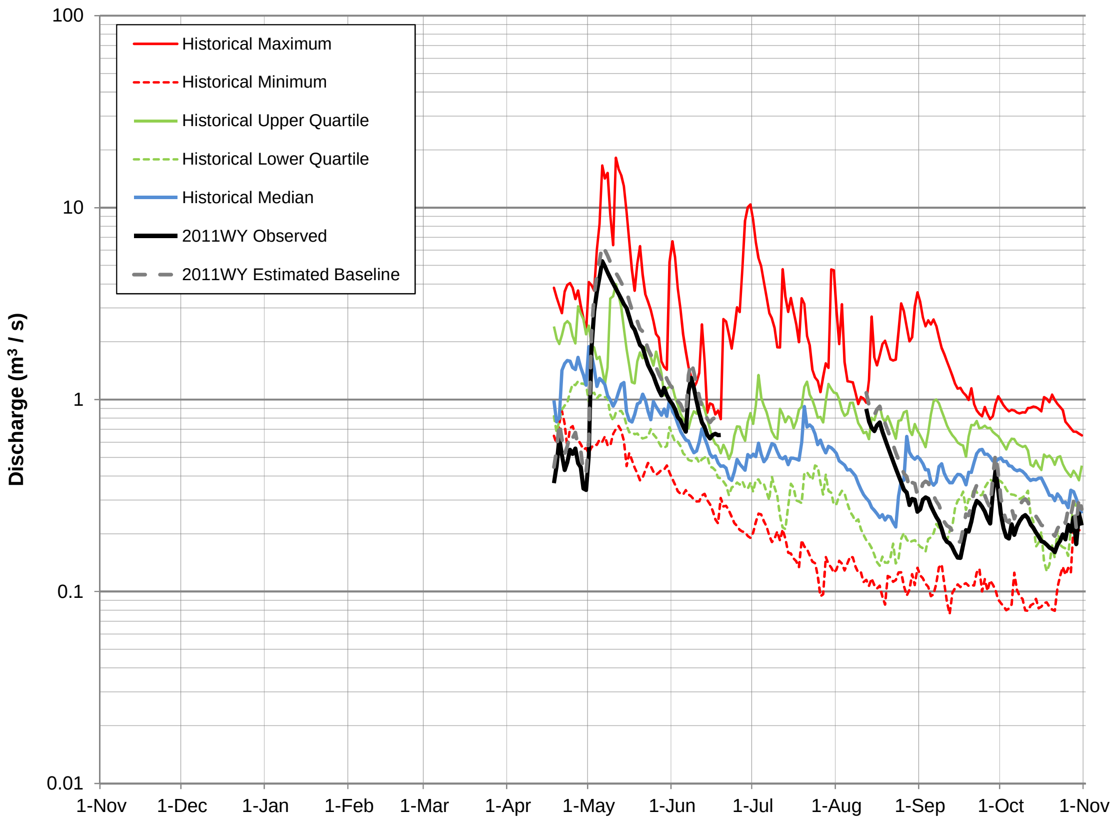
Comparison to Published Literature A summary of fish sampling activities within watersheds in the oil sands region was prepared in Golder (2004b). This document provides a thorough assessment of fish species presence in watersheds prior to major oil sands development to capture historical *baseline* fish assemblages for comparison to results reported by RAMP. Historically, 11 fish species have been documented along the entire length of the Tar River (Golder 2004b). From 2009 to 2011, RAMP has observed seven of these fish species at *test* reach TAR-F1, as well as three additional species that were not previously documented including finescale dace, longnose dace, and northern pike (Table 5.4-14). The number of species previously-documented is from various methods of sampling (i.e., fish fence, trapping, and electrofishing), which target all life-stages of fish while backpack electrofishing used for the RAMP fish assemblage monitoring targets only small-bodied fish or juvenile large-bodied fish, which likely explains the difference in documented species between historical results and results reported by RAMP.

Habitat conditions documented by Golder (2004b) were similar to conditions observed by RAMP from 2009 to 2011 at *test* reach TAR-F1. Golder (2004b) documented low habitat diversity and relatively homogenous substrate (90% sand) in the location of *test* reach TAR-F1 and better fish habitat with a combination of riffles, runs and pools and a higher proportion of coarser substrate in the location of *baseline* reach TAR-F2.

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints of fish assemblages at *test* reach TAR-F1 and *baseline* reach TAR-F2 in fall 2011 were within the range of variation for regional *baseline* conditions (Figure 5.4-10).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reach TAR-F1 and regional *baseline* conditions were classified as **Negligible-Low** given there were no measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

Figure 5.4-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Tar River in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on Tar River near the mouth, Station S15A, provisional data for April 18 to June 19 and August 12 to October 31. The upstream drainage area is 333 km^2. Historic values from 1975 to 1977 calculated for the open-water period at WSC Station 07DA015 (1975 to 1977), RAMP Station S15 (2001 to 2006) and RAMP Station S15A (2007 to 2010).

Table 5.4-2 Estimated water balance at RAMP Station S15A, Tar River near the mouth, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**10.80**	**Observed discharge, obtained from Tar River near the Mouth, Station S15A**
Closed-circuited area water loss from the observed *test* hydrograph	-2.51	Estimated 63.6 km^2 of the Tar River watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.21	Estimated 26.3 km^2 of the Tar River watershed with land change from focal projects as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Tar River watershed from focal projects	0	None reported during the periods of monitoring at Station S15A
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)	**13.10**	**Estimated *baseline* discharge at Tar River near the Mouth, RAMP Station S15A**
Incremental flow (change in total discharge)	-2.30	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**-17.6%**	**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 18 to June 19 and August 12 to October 31, 2011 for Tar River near the Mouth, RAMP Station S15A.

Note: Volumes presented to two decimal places.

Table 5.4-3 Calculated change in hydrologic measurement endpoints for the Tar River watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	1.10	0.91	-17.6%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	6.37	5.25	-17.6%
Open-water period minimum daily discharge	0.18	0.15	-17.6%

Note: Values are calculated from provisional data for April 18 to June 19 and August 12 to October 31, 2011 for Tar River near the Mouth, RAMP Station S15A.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two and one decimal places, respectively.

Table 5.4-4 Concentrations of water quality measurement endpoints, mouth of the Tar River (*test* station TAR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	10	8.1	8.2	8.5
Total suspended solids	mg/L	-	18	10	6	14	214
Conductivity	µS/cm	-	360	10	302	460	875
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.030	10	0.012	0.017	**0.125**
Total nitrogen	mg/L	1	0.62	10	0.50	**1.01**	**4.30**
Nitrate+nitrite	mg/L	1.3	<0.071	10	<0.05	<0.1	**3.5**
Dissolved organic carbon	mg/L	-	18.2	10	12.0	16.8	22.6
Ions							
Sodium	mg/L	-	14.6	10	15.0	29.5	50.0
Calcium	mg/L	-	39.0	10	38.0	50.8	88.5
Magnesium	mg/L	-	11.4	10	11.3	16.0	24.3
Chloride	mg/L	230, 860	2.3	10	1.7	4.5	50.0
Sulphate	mg/L	100	40.6	10	20.4	43.8	173.0
Total dissolved solids	mg/L	-	259	10	170	315	590
Total alkalinity	mg/L		142	10	121	175	221
Selected metals							
Total aluminum	mg/L	0.1	**0.95**	10	**0.17**	**0.52**	**3.95**
Dissolved aluminum	mg/L	0.1	0.023	10	0.005	0.009	0.026
Total arsenic	mg/L	0.005	0.0019	10	0.0009	0.0016	0.0022
Total boron	mg/L	1.2	0.074	10	0.053	0.087	0.145
Total molybdenum	mg/L	0.073	0.0012	10	0.0004	0.0010	0.0020
Total mercury (ultra-trace)	ng/L	5, 13	1.7	8	<1.2	<1.2	**5.6**
Total strontium	mg/L	-	0.19	10	0.14	0.21	0.44
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	3.7	0	-	-	-
Total dibenzothiophenes	ng/L	-	68.3	0	-	-	-
Total PAHs	ng/L	-	440.4	0	-	-	-
Total Parent PAHs	ng/L	-	36.8	0	-	-	-
Total Alkylated PAHs	ng/L	-	403.6	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.436**	10	<0.004	**0.314**	**0.947**
Total chromium	mg/L	0.001	**0.0011**	10	0.0006	0.0009	**0.0059**
Total iron	mg/L	0.3	**1.70**	10	**1.40**	**1.86**	**7.03**
Total phenols	mg/L	0.004	**0.0061**	10	<0.001	**0.0055**	**0.0196**
Total phosphorus	mg/L	0.05	**0.074**	10	0.028	**0.084**	**0.232**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.4-5 Concentrations of water quality measurement endpoints, upper Tar River (*baseline* station TAR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	7	8.0	8.3	8.4
Total suspended solids	mg/L	-	3	7	<3	5	7
Conductivity	µS/cm	-	341	7	233	331	393
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.035	7	0.022	0.039	**0.058**
Total nitrogen	mg/L	1	0.42	7	0.40	0.50	**1.43**
Nitrate+nitrite	mg/L	1.3	<0.071	7	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.8	7	8.0	13.0	14.6
Ions							
Sodium	mg/L	-	11.5	7	6.0	12.0	16.0
Calcium	mg/L	-	37.5	7	31.4	45.6	53.0
Magnesium	mg/L	-	12.1	7	8.8	13.5	14.3
Chloride	mg/L	230, 860	0.5	7	<0.5	1	2
Sulphate	mg/L	100	40.1	7	20.0	37.2	49.0
Total dissolved solids	mg/L	-	233	7	160	234	280
Total alkalinity	mg/L		137	7	100	157	162
Selected metals							
Total aluminum	mg/L	0.1	**0.15**	7	0.07	**0.17**	**0.71**
Dissolved aluminum	mg/L	0.1	0.036	7	0.008	0.025	0.052
Total arsenic	mg/L	0.005	0.0013	7	0.0008	0.0012	0.0014
Total boron	mg/L	1.2	0.072	7	0.035	0.056	0.074
Total molybdenum	mg/L	0.073	0.0014	7	0.0008	0.0013	0.0015
Total mercury (ultra-trace)	ng/L	5, 13	0.8	7	<1.2	<1.2	3.4
Total strontium	mg/L	-	0.17	7	0.10	0.16	0.19
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.8	0	-	-	-
Total PAHs	ng/L	-	157.0	0	-	-	-
Total Parent PAHs	ng/L	-	19.2	0	-	-	-
Total Alkylated PAHs	ng/L	-	137.8	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.45**	7	0.11	**0.40**	**0.82**
Total iron	mg/L	0.3	**0.93**	7	**0.72**	**1.07**	**1.59**
Total phenols	mg/L	0.004	**0.0052**	7	0.0020	0.0040	**0.0210**
Total phosphorus	mg/L	0.05	**0.067**	7	0.045	**0.065**	**0.100**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.4-4 Piper diagram of fall ion concentrations, Tar River.

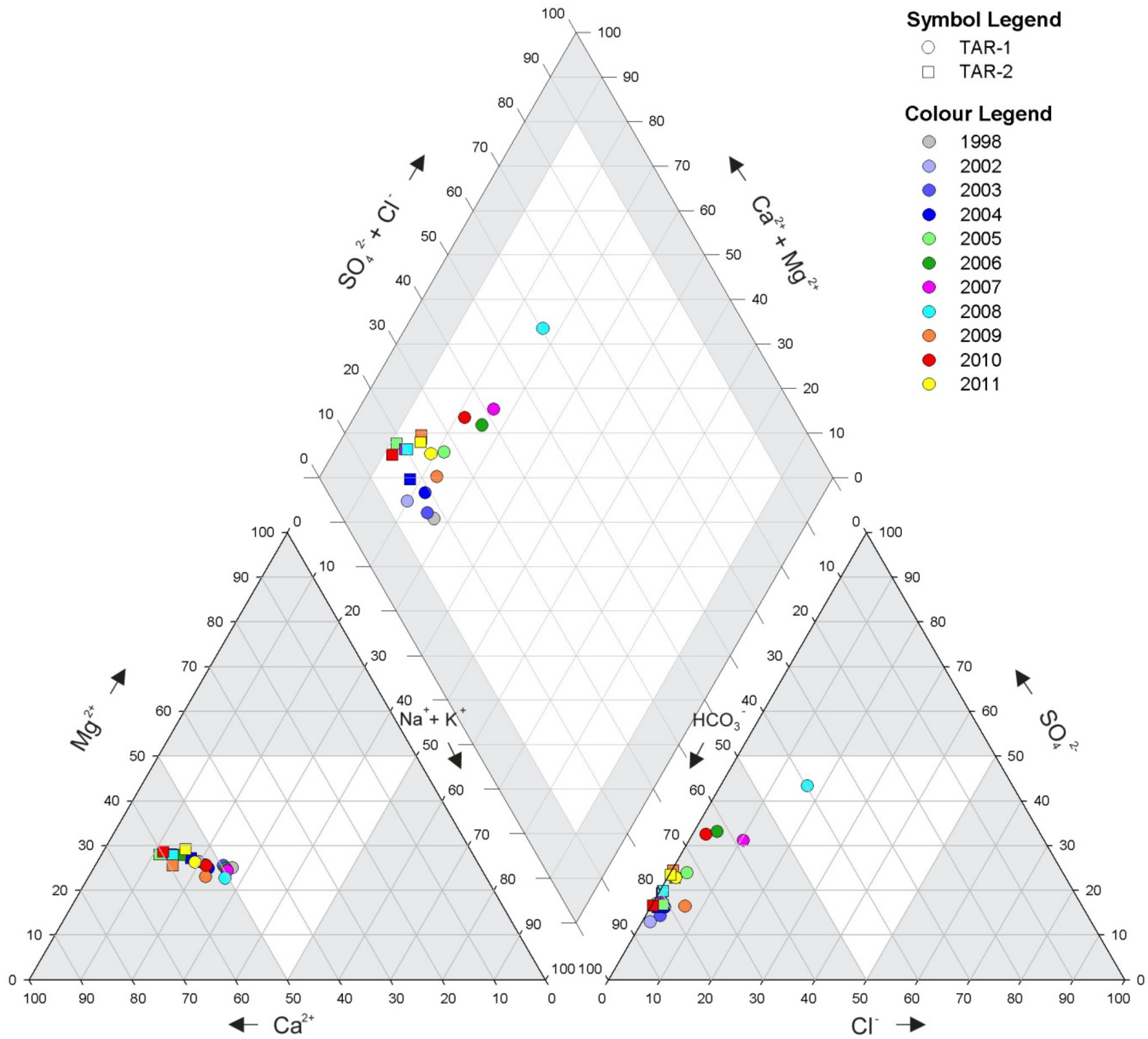
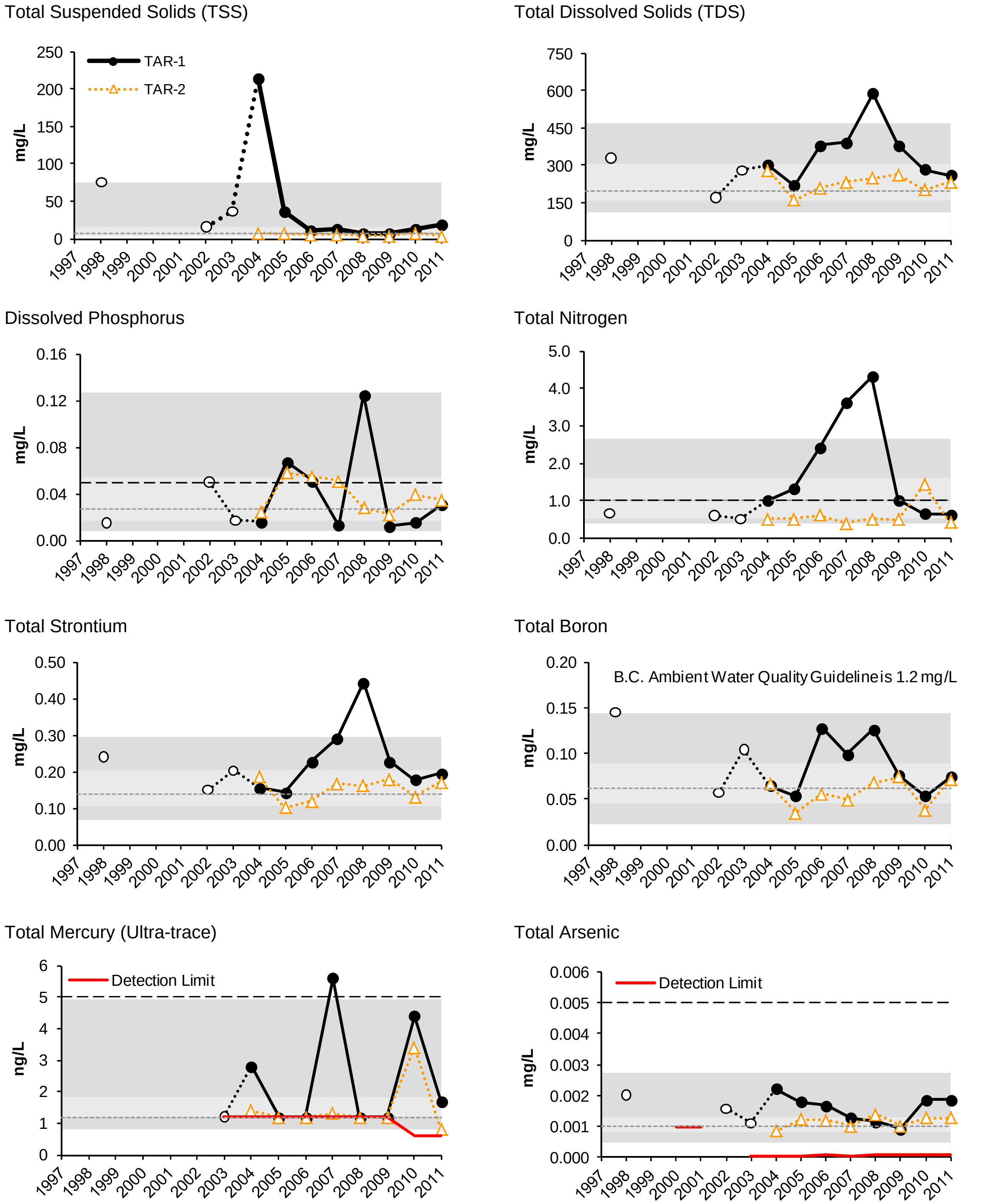


Table 5.4-6 Water quality guideline exceedances, Tar River, 2011.

Variable	Units	Guideline[a]	TAR-1	TAR-2
Fall				
Dissolved iron	mg/L	0.3	0.44	0.45
Total aluminum	mg/L	0.1	0.95	0.15
Total chromium	mg/L	0.001	0.0011	-
Total iron	mg/L	0.3	1.70	0.93
Total phenols	mg/L	0.004	0.0061	0.0052
Total phosphorus	mg/L	0.05	0.074	0.067

[a] Sources for all guidelines are outlined in Table 3.2-5.

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.



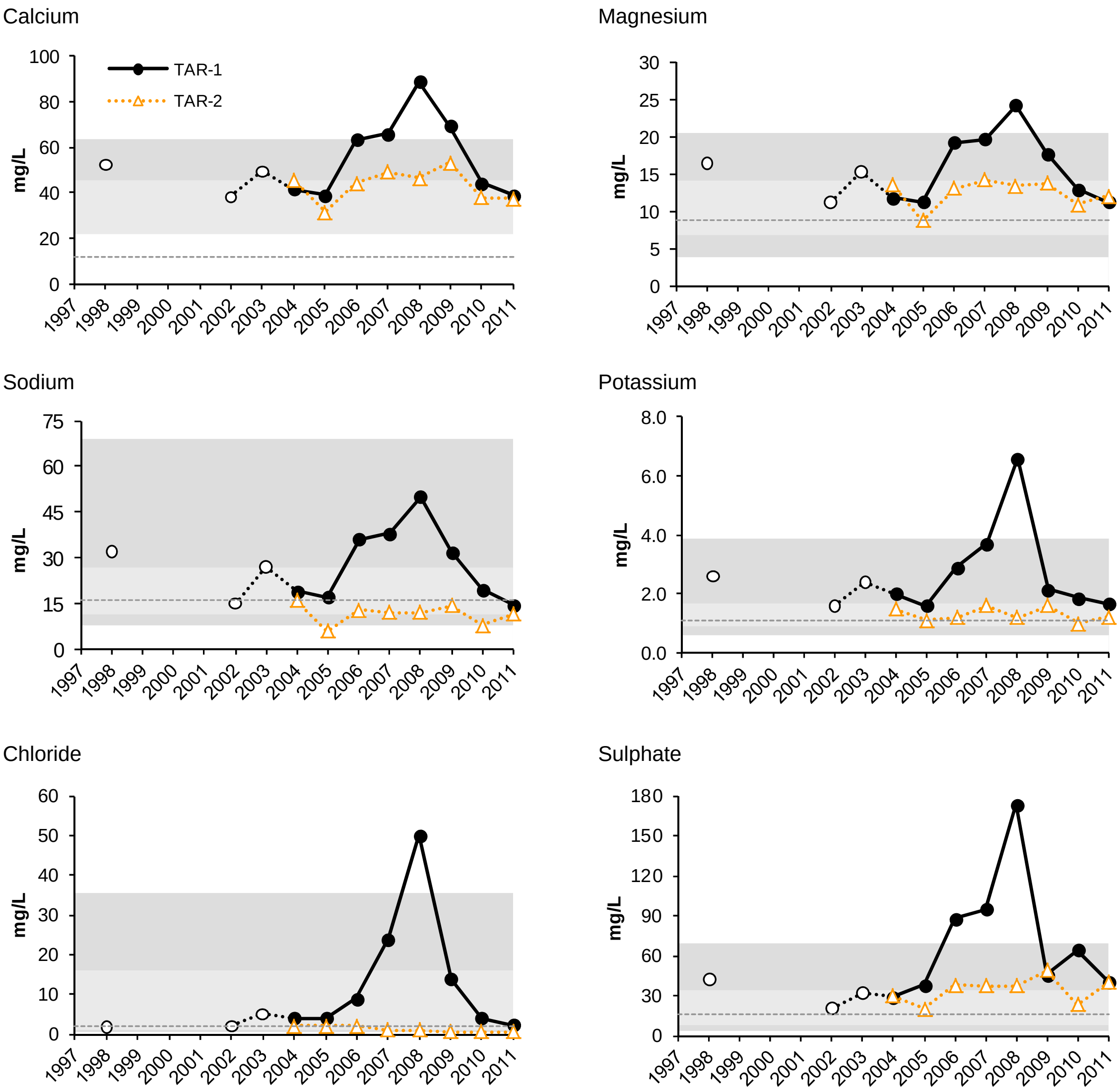
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.4-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.4-7 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 Tar River
Sample date	-	Sept. 13, 2011	Sept. 12, 2011
Habitat	-	Depositional	Erosional
Water depth	m	0.2	0.2
Current velocity	m/s	0.43	0.60
Field Water Quality			
Dissolved oxygen	mg/L	8.4	8.3
Conductivity	µS/cm	336	297
pH	pH units	7.9	7.4
Water temperature	°C	18.4	8.6
Sediment Composition			
Sand	%	21	-
Silt	%	50	-
Clay	%	29	-
Total Organic Carbon	%	2	-
Sand/Silt/Clay	%	-	13
Small Gravel	%	-	3
Large Gravel	%	-	12
Small Cobble	%	-	31
Large Cobble	%	-	31
Boulder	%	-	12
Bedrock	%	-	0

Figure 5.4-6 Periphyton chlorophyll *a* biomass in *baseline* reach TAR-E2 of the Tar River.

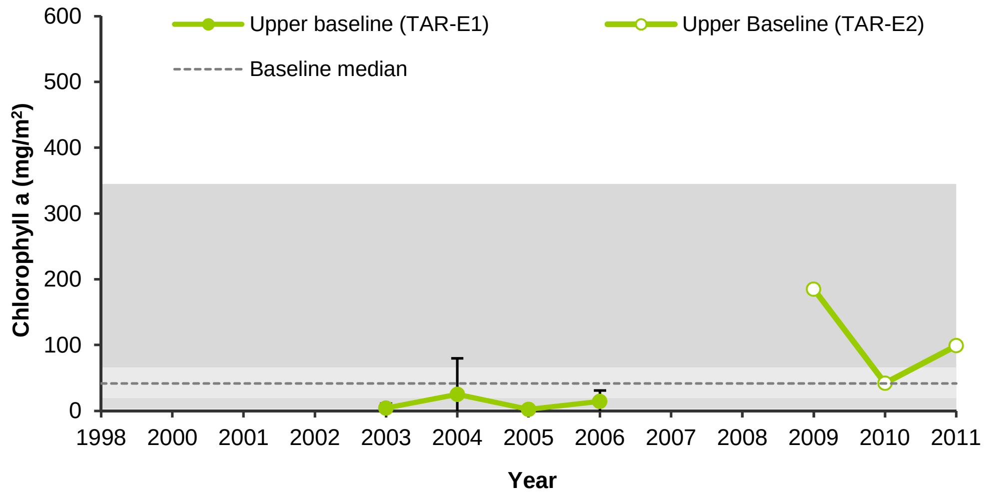


Table 5.4-8 Summary of major taxa abundances and benthic invertebrate community measurement endpoints in the lower Tar River (*test* reach TAR-D1).

Taxon	Percent Major Taxa Enumerated in Each Year							
	Reach TAR-D1							
	2002	2003	2004	2005	2006	2009	2010	2011
Nematoda	2	<1	4	1	<1	1	1	
Erpobdellidae	<1	<1	<1					
Naididae	<1	4	2			2	3	<1
Tubificidae	7	1	6	28	1	28	32	55
Enchytraeidae			5	2				
Hydracarina	<1	1	1			<1	2	<1
Amphipoda	<1							
Ostracoda	2	<1	25	37		5	22	10
Chydoridae	<1	<1	<1					
Copepoda	<1	<1	2			11	1	<1
Gastropoda	<1		1				<1	2
Bivalvia	1	<1	<1	1		<1	<1	2
Coleoptera	<1		<1			<1	<1	
Ceratopogonidae	1	1	16	8		5	4	2
Chironomidae	86	90	33	20	<1	43	31	27
Dolichopodidae			1					
Empididae	1	1	1		<1	<1	<1	
Tipulidae	<1	<1	<1	3	<1	<1	<1	
Tabanidae	<1	<1	<1	1		<1	1	<1
Simuliidae								<1
Ephemeroptera	<1	<1	1			1	1	<1
Anisoptera	<1							<1
Plecoptera	<1	<1	<1				<1	<1
Trichoptera	<1	<1	<1			<1		<1
Collembola		<1						
Benthic Invertebrate Community Measurement Endpoints								
Total Abundance (No./m^2)	69,759	20,805	3,489	657	5,534	14,218	13,387	11,992
Richness	22	16	11	4	4	18	13	9
Simpson's Diversity	0.80	0.74	0.67	0.50	0.33	0.70	0.62	0.53
Evenness	0.84	0.85	0.75	0.87	0.33	0.75	0.70	0.63
% EPT	<1	<1	2	0	0	1	<1	<1

Table 5.4-9 Summary of major taxa abundances and benthic invertebrate community measurement endpoints in the upper Tar River (*baseline* reaches TAR-E1 and TAR-E2).

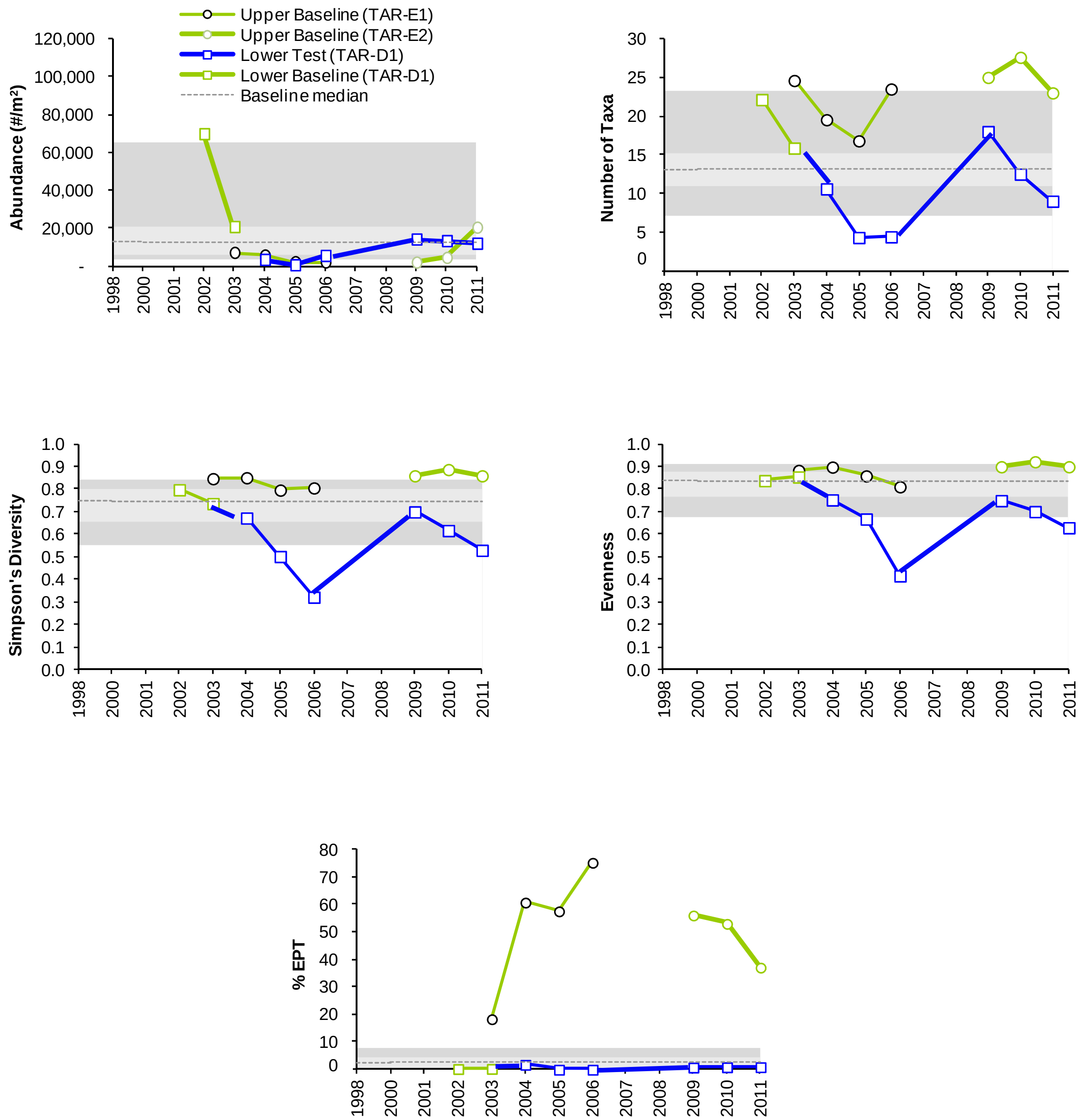
Taxon	Percent Major Taxa Enumerated in Each Year						
	Reach TAR-E1				Reach TAR-E2		
	2003	2004	2005	2006	2009	2010	2011
Nematoda	2	<1	<1	<1	<1	<1	2
Erpobdellidae		<1					
Naididae	6	<1	<1	1	<1	<1	2
Tubificidae	1	1	1	<1	<1	1	2
Enchytraeidae	2	<1	<1	2	6	1	4
Lumbriculidae							<1
Hydracarina	1	2	<1	2	4	9	13
Ostracoda					<1	1	<1
Copepoda	1		<1		<1	<1	<1
Coleoptera		<1		<1			
Ceratopogonidae	<1	<1				<1	
Chironomidae	67	21	33	8	28	26	32
Dolichopodidae		<1					
Empididae	2	1	2	8		1	5
Ephydridae	<1				26		
Tipulidae	1	<1	<1	1	1	1	<1
Tabanidae						<1	
Simuliidae		13	2	1	<1	2	<1
Ephemeroptera	5	38	45	48	1	18	26
Plecoptera	8	13	12	8	15	21	3
Trichoptera	2	10	3	19	16	17	8
Benthic Invertebrate Community Measurement Endpoints							
Total Abundance (No./m^2)	7,166	5,781	2,263	21,54.8	2,037	4,512	20,470
Richness	25	20	17	24	25	28	23
Simpson's Diversity	0.85	0.85	0.8	0.8	0.86	0.89	0.86
Evenness	0.88	0.9	0.86	0.8	0.9	0.92	0.90
% EPT	18	61	58	7	56	5	37

Table 5.4-10 Results of analysis of variance (ANOVA) *test*ing for differences in benthic invertebrate community measurement endpoints at *test* reach TAR-D1.

Variable	P-value		Variance Explained (%)		Nature of Change(s)
	Before vs. After	Time Trend (*test* period)	Before vs. After	Time Trend (*test* period)	
Abundance	**<0.001**	**0.002**	46	11	Lower during *test* period versus *baseline* period and increasing during *test* period
Richness	**<0.001**	0.298	46	1	Lower during *test* period versus *baseline* period
Simpson's Diversity	**<0.001**	0.999	48	0	Lower during *test* period versus *baseline* period
Evenness	**<0.001**	0.728	50	0	Lower during *test* period versus *baseline* period
EPT	**0.045**	**0.005**	18	37	Lower during *test* period and increasing during *test* period
CA Axis 1	0.729	**0.001**	1	67	Decreasing during *test* period
CA Axis 2	**0.031**	**0.015**	19	24	Higher during *test* period versus *baseline* period and decreasing during *test* period

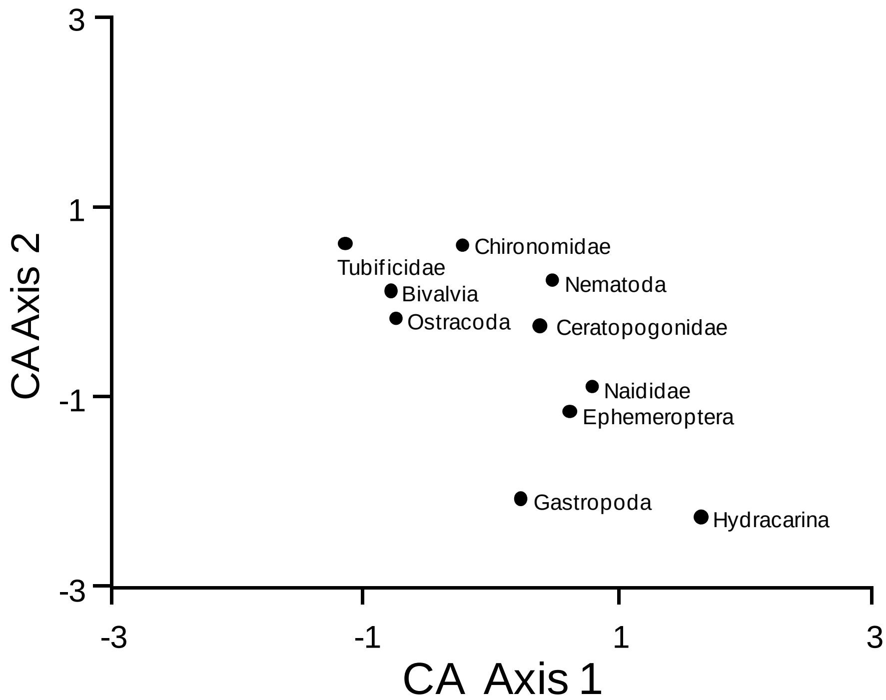
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

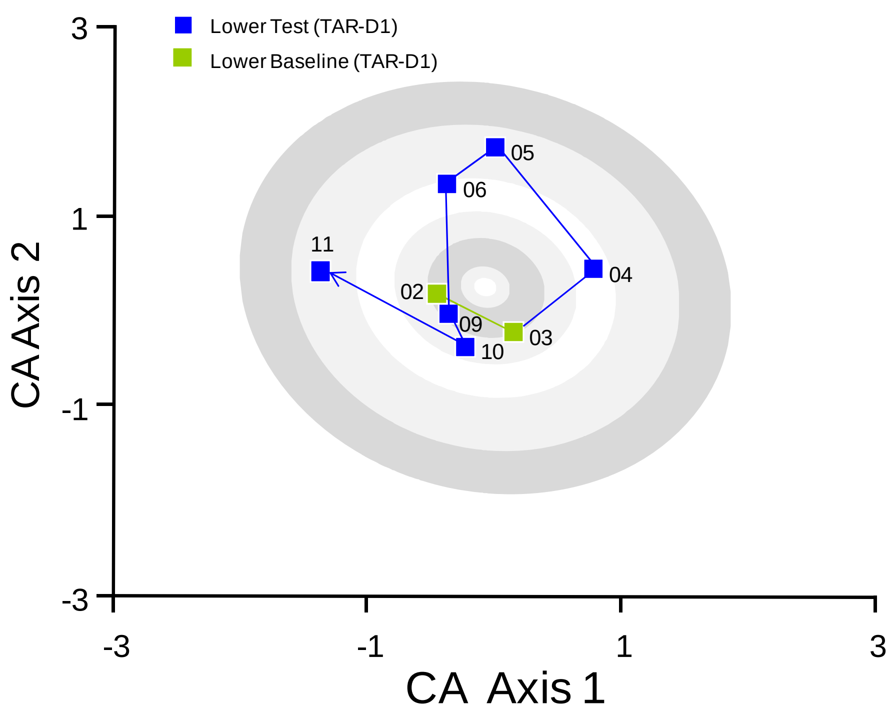
Figure 5.4-7 Variation in benthic invertebrate community measurement endpoints in the Tar River.



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.
Note: *Baseline* reaches TAR-E1 and TAR-E2 are erosional reaches but are shown here for comparison to *test* reach TAR-D1 over time but are not compared to the range of *baseline* depositional reaches.

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 5.4-11 Concentrations of selected sediment measurement endpoints, Tar River (*test* station TAR-D1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>29</u>	8	3	11	26
Silt	%	-	50	8	3	12	50
Sand	%	-	<u>21</u>	8	24	78	94
Total organic carbon	%	-	2.1	8	0.3	1.1	6.3
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]	<29	5	13	43	100
Fraction 3 (C16-C34)	mg/kg	300[1]	232	5	220	**667**	**860**
Fraction 4 (C34-C50)	mg/kg	2800[1]	<u>119</u>	5	170	360	460
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0142	8	0.0013	0.0041	0.0150
Retene	mg/kg	-	0.1930	7	0.0116	0.0430	2.1900
Total dibenzothiophenes	mg/kg	-	0.6713	8	0.1521	0.8336	6.2555
Total PAHs	mg/kg	-	3.9378	8	0.6243	2.4506	19.1394
Total Parent PAHs	mg/kg	-	0.2698	8	0.0473	0.0952	0.4486
Total Alkylated PAHs	mg/kg	-	3.6680	8	0.5220	2.3796	18.6908
Predicted PAH toxicity[3]	H.I.	1.0	**2.94**	8	0.21	**1.71**	**4.40**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>8.8</u>	5	5.0	6.6	8.6
Chironomus growth - 10d	mg/organism	-	1.63	5	0.90	2.00	4.00
Hyalella survival - 14d	# surviving	-	8.8	5	6.6	8.8	10.0
Hyalella growth - 14d	mg/organism	-	<u>0.56</u>	5	0.10	0.19	0.26

Values in **bold** indicate concentrations exceeding guidelines.

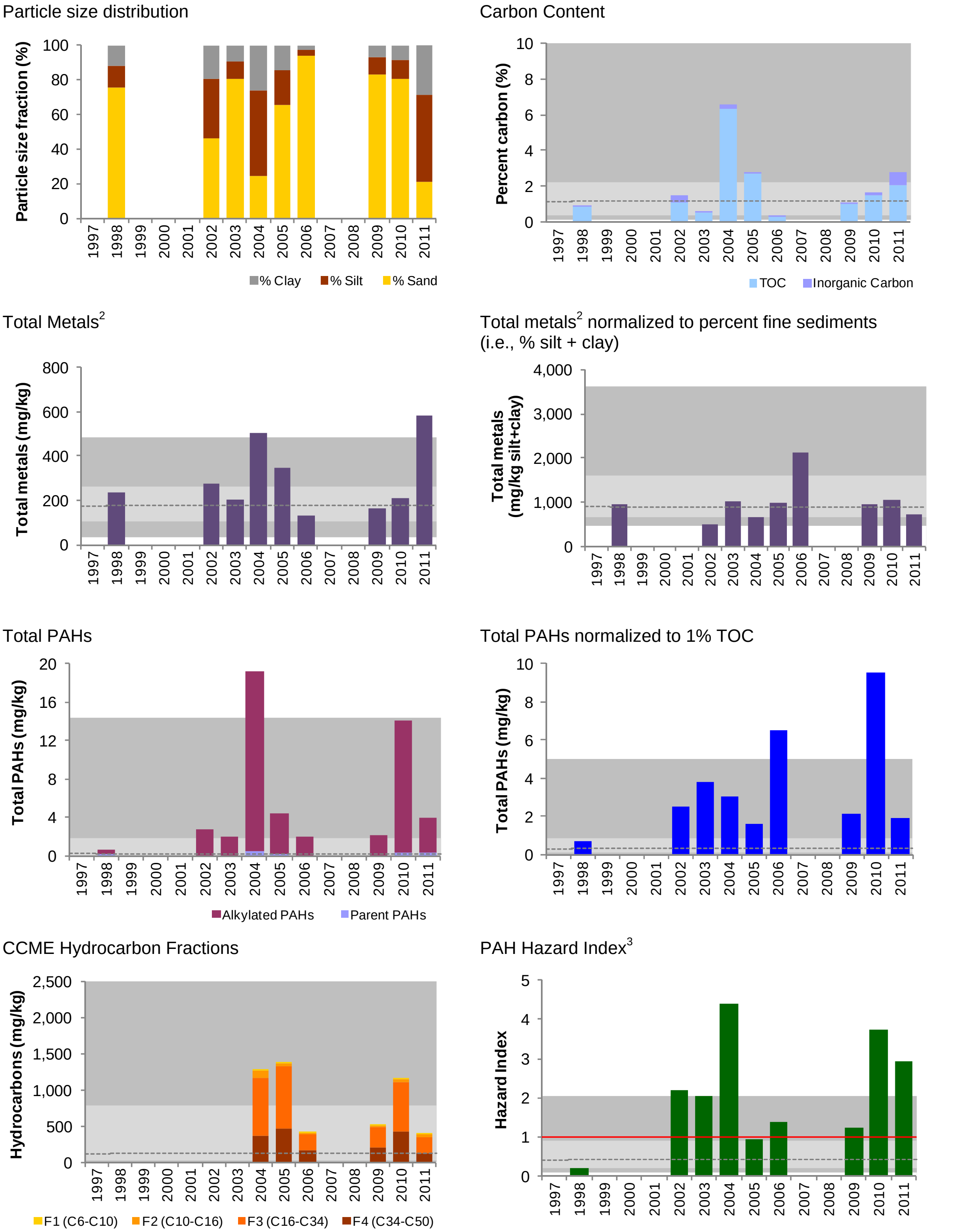
Values <u>underlined</u> indicate concentrations outside the range of historical observations.

[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 5.4-9 Variation in sediment quality measurement endpoints in the Tar River, *test* station TAR-D1.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.4-12 Average habitat characteristics of fish assemblage monitoring locations at *test* reach TAR-F1 and *baseline* reach TAR-F2 of the Tar River.

Variable	Units	TAR-F1 Lower *Test* Reach of Tar River	TAR-F2 Upper *Baseline* Reach of Tar River
Sample date	-	Sept. 7, 2011	Sept. 10, 2011
Habitat type	-	shallow run	riffle/pool
Maximum depth	m	0.94	0.68
Average bankfull channel width	m	10.4	13.4
Average wetted channel width	m	6.7	4.6
Substrate			
Dominant	-	sand	cobble
Subdominant	-	-	coarse gravel and silt/clay
Instream cover			
Dominant	-	small and large woody debris	small woody debris and overhanging vegetation
Subdominant	-	overhanging vegetation and undercut banks	large woody debris, undercut banks and boulders
Field water quality			
Dissolved oxygen	mg/L	7.8	8.8
Conductivity	µS/cm	353	357
pH	pH units	7.86	8.1
Water temperature	°C	15.6	12.7
Water velocity			
Left bank velocity	m/s	0.20	0.30
Left bank water depth	m	0.21	0.17
Centre of channel velocity	m/s	0.24	0.50
Centre of channel water depth	m	0.34	0.29
Right bank velocity	m/s	0.20	0.22
Right bank water depth	m	0.30	0.27
Riparian cover – understory (< 5 m)			
Dominant	-	woody shrubs and saplings	woody shrubs and saplings
Subdominant	-	overhanging vegetation	overhanging vegetation

Table 5.4-13 Percent composition and mean CPUE of fish species at *test* reach TAR-F1 and *baseline* reach TAR-F2 of the Tar River, 2009 to 2011.

Common Name	Code	Total Species			Percent of Total Catch		
		TAR-F1		TAR-F2	TAR-F1		TAR-F2
		2009	2011	2011	2009	2011	2011
Arctic Grayling	ARGR	-	-	1	0	0	0.9
brook stickleback	BRST	2	2	-	18.2	3.9	0
burbot	BURB	-	-	-	0	0	0
fathead minnow	FTMN	-	-	-	0	0	0
finescale dace	FNDC	-	5	-	0	9.8	0
lake chub	LKCH	4	26	5	36.4	51.0	4.7
lake whitefish	LKWH	-	-	-	0	0	0
longnose dace	LNDC	-	1	-	0	2.0	0
longnose sucker	LNSC	-	4	-	0	7.8	0
northern pike	NRPK	1	1	-	9.1	2.0	0
northern redbelly dace	NRDC	-	-	-	0	0	0
pearl dace	PRDC	-	-	-	0	0	0
slimy sculpin	SLSC	-	-	101	0	0	94.4
spoonhead sculpin	SPSC	-	-	-	0	0	0
spottail shiner	SPSH	-	-	-	0	0	0
trout-perch	TRPR	-	8	-	0	15.7	0
walleye	WALL	-	-	-	0	0	0
white sucker	WHSC	4	4	-	36.4	7.8	0
yellow perch	YLPR	-	-	-	0	0	0
Total Count		**11**	**51**	**107**	**100**	**100**	**100**
Total Abundance (#/m)		**0.06**	**0.65**	**0.71**	**-**	**-**	**-**
Total Species Richness		**4**	**8**	**3**	**4**	**8**	**3**
Electrofishing effort (secs)		**1,552**	**743**	**1,043**	**-**	**-**	**-**
CPUE (#/100secs)		**0.71**	**6.86**	**10.26**	**-**	**-**	**-**

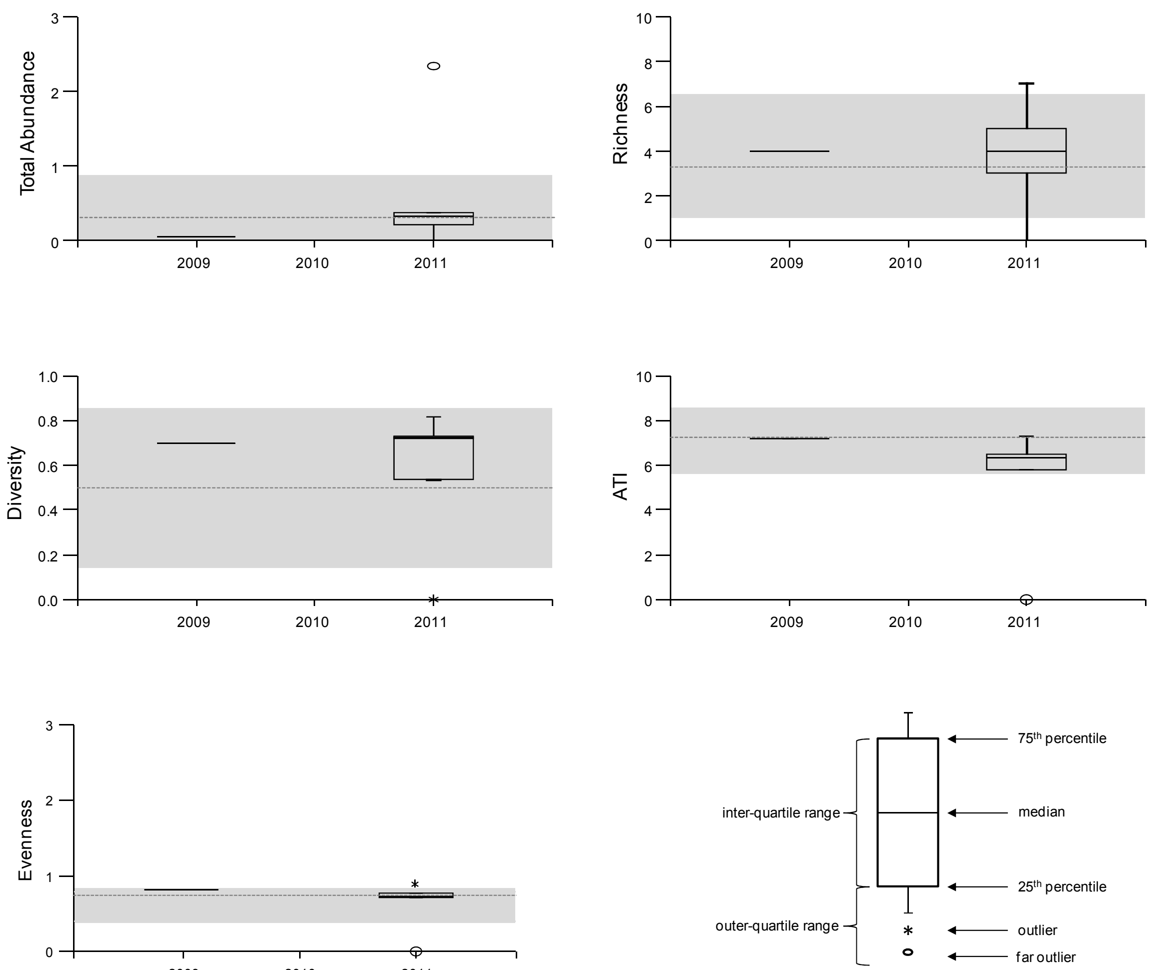
Table 5.4-14 Summary of fish assemblage measurement endpoints (±1SD) in reaches of the Tar River, 2009 to 2011.

Reach	Year	Abundance		Richness			Diversity		Evenness		ATI	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TAR-F1	2009	0.06	-	4	4	-	0.69	-	0.82	-	7.18	-
	2011	0.65	0.95	8	4	2.59	0.56	0.33	0.62	0.35	5.17	2.94
TAR-F2	2011	0.71	0.24	3	2	0.55	0.10	0.13	0.77	0.24	3.13	0.22

SD=standard deviation across sub-reaches within a reach.

Figure 5.4-10 Box-plots showing variation in fish assemblage measurement endpoints in reaches of the Tar River, 2009 to 2011.

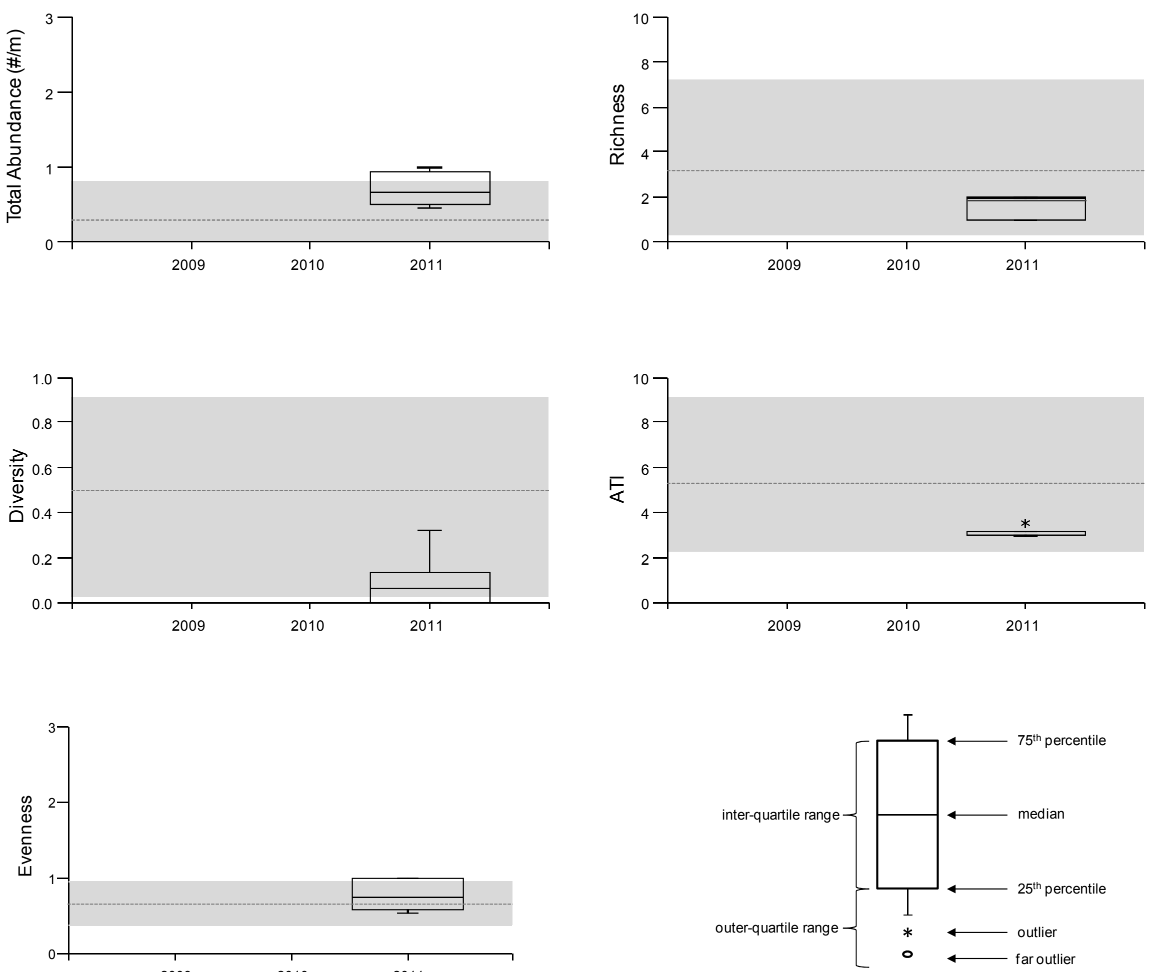
Depositional *Test* Reach TAR-F1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

Figure 5.4-10 (Cont'd.)

Erosional *Baseline* Reach TAR-F2



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

5.5 MACKAY RIVER WATERSHED

Table 5.5-1 Summary of results for the MacKay River watershed.

MacKay River Watershed	Summary of 2011 Conditions		
Climate and Hydrology			
Criteria	**S26** near Fort McKay	no stations sampled	
Mean open-water season discharge	Negligible-Low		
Mean winter discharge	Negligible-Low		
Annual maximum daily discharge	Negligible-Low		
Minimum open-water season discharge	Negligible-Low		
Water Quality			
Criteria	**MAR-1** at the mouth	**MAR-2A** upstream of Suncor MacKay	**MAR-2** upstream of Suncor Dover
Water Quality Index	Negligible-Low	Negligible-Low	Negligible-Low
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	Moderate	Negligible-Low	n/a
No Sediment Quality component activities conducted in 2011			
Fish Populations			
Criteria	**MAR-F1** at the mouth	**MAR-F2** upstream of Suncor MacKay	**MAR-F3** upstream of Suncor Dover
Fish Assemblages	Negligible-Low	Negligible-Low	n/a

Legend and Notes

- Negligible-Low
- Moderate
- High
- *baseline*
- *test*

n/a - not applicable, summary indicators for *test* reaches were designated based on comparisons with upper *baseline* reaches or regional *baseline* conditions.

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: Classification based on exceedances of measurement from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.5-1 MacKay River watershed.

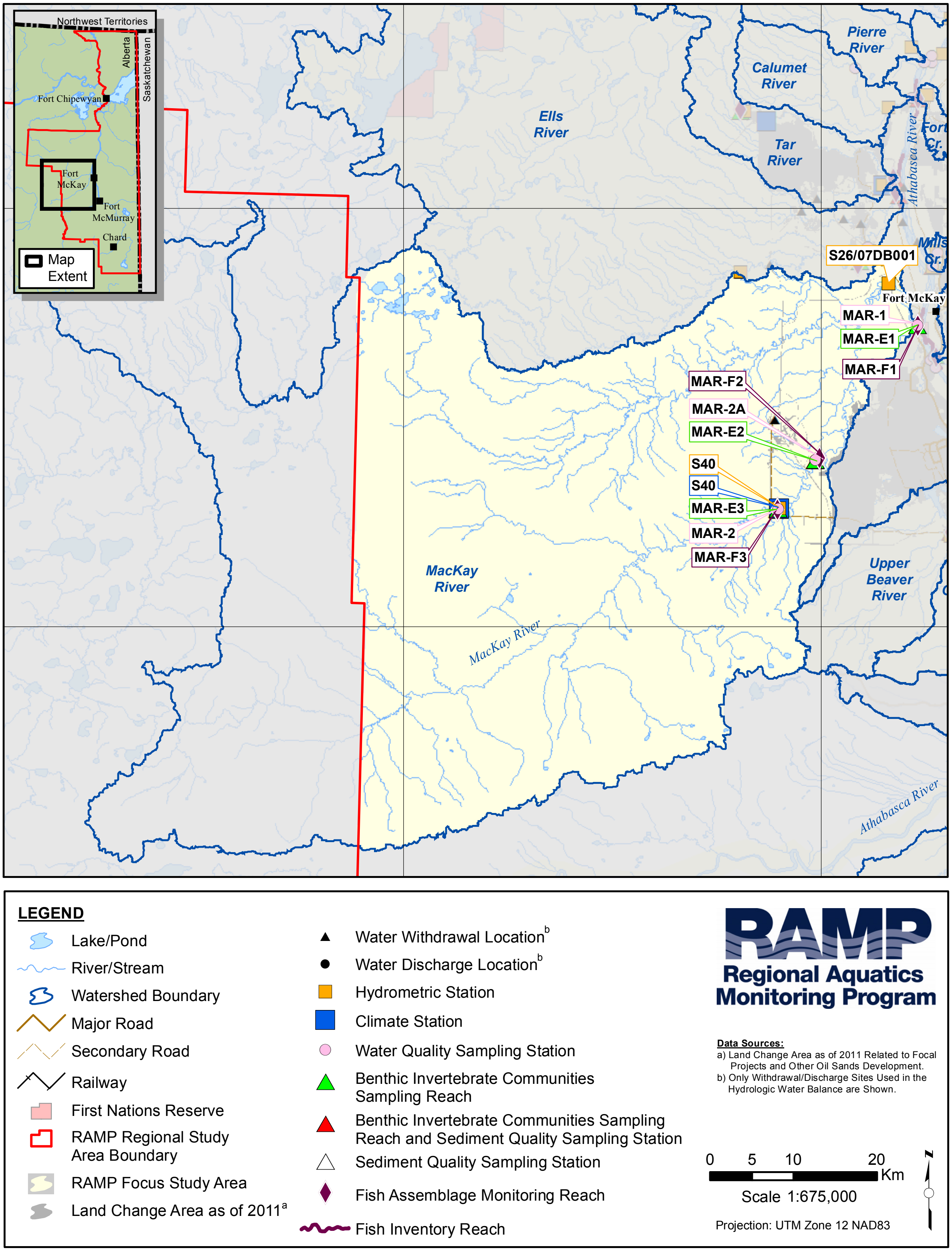


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Figure 5.5-2 Representative monitoring stations of the MacKay River watershed, fall 2011.

Benthic Invertebrate Reach MAR-E1: Left Downstream Bank

Water Quality Station MAR-2: facing downstream

Hydrology Station S40: at the Petro-Canada Bridge

Benthic Invertebrate Reach MAR-E3: Left Downstream Bank

5.5.1 Summary of 2011 Conditions

As of 2011, less than 1% (1,813 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 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities, and Fish Populations components of RAMP in the MacKay River watershed in 2011. Table 5.5-1 is a summary of the 2011 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 2011. Figure 5.5-2 contains fall 2011 photos of monitoring stations in the watershed.

Hydrology The 2011 WY mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph were 0.05% lower than from the estimated *baseline* hydrograph; these differences were classified as **Negligible-Low**.

Water Quality Concentrations of all water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of previously-measured concentrations with the exception of total arsenic, which exceeded previously-measured concentrations at *baseline* station MAR-2. Water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of regional *baseline* concentrations with the exception of total mercury, which was below the 5th percentile at *test* station MAR-2A and *baseline* station MAR-2. Water quality in fall 2011 at both *test* stations and the *baseline* station was very similar; differences relative to regional *baseline* water quality conditions were classified as **Negligible-Low**.

Benthic Invertebrate Communities Differences in measurement endpoints for benthic invertebrate communities at *test* reach MAR-E1 were classified as **Moderate** because percent EPT was significantly higher at *baseline* reach MAR-E3 compared to *test* reach MAR-E1 and abundance and richness were significantly higher during the *baseline* period, although the statistical signal in the difference explained slightly less than 20% of the variance in annual means. Despite having a lower proportion of EPT taxa compared to *baseline* reach MAR-E3, the benthic invertebrate community at *test* reach MAR-E1 still had a number of sensitive mayfly, stonefly and caddisfly taxa that are typical of an erosional watercourse. Differences in measurement endpoints of benthic invertebrate communities for *test* reach MAR-E2 were classified as **Negligible-Low** because the significant increases in richness, diversity, and percent EPT did not imply a negative change in the benthic invertebrate community. The benthic invertebrate community at *test* reach MAR-E2 was diverse, and contained a number of sensitive chironomid, mayfly, stonefly and caddisfly taxa typical of an erosional watercourse.

Fish Populations Differences in measurement endpoints for fish assemblages between *test* reaches MAR-F1 and MAR-F2 and regional *baseline* conditions were classified as **Negligible-Low** given there were no measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

5.5.2 Hydrologic Conditions: 2011 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 2011, 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 2011 water year (WY) was 313 million m^3. This value was 22% below the mean historical annual runoff volume based on the period of record. Flows steadily decreased from November 2010 to January 2011, but were generally in the upper quartile of historical flows recorded during these months (Figure 5.5-3). Flows from February until the peak of the freshet in early May were very close to historical median values. The freshet peak of 49.5 m^3/s recorded on May 10 was the maximum daily flow recorded in the 2011 WY, and was 52% lower than the historical mean open-water maximum daily flow. Flows decreased after May 10 until mid-June before increasing again due to rainfall events in late June. Flows generally decreased from mid-July until the end of the 2011 WY, with values within the historical inter-quartile range of flows. The minimum open-water daily flow of 3.57 m^3/s on September 16 was 2% lower than the historical mean open-water minimum daily flow of 3.65 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 2011 was estimated to be 5.4 km^2 (Table 2.5-1). The loss of flow to the MacKay River that would have otherwise occurred from this land area was estimated at 0.30 million m^3.

2. As of 2011, the area of land change in the MacKay watershed that was not closed-circuited was estimated to be 12.8 km^2 (Table 2.5-1). The increase in flow to the MacKay River that would not have otherwise occurred from this land area was estimated at 0.14 million m^3.

3. In the 2011 WY, Suncor withdrew approximately 3,000 m^3 of water for dust suppression.

The estimated cumulative effect of land change and water withdrawals was a loss of flow of 0.16 million m^3 in the 2011 WY at WSC Station 07DB001 (RAMP Station S26). The observed *test* and estimated *baseline* hydrographs are presented in Figure 5.5-3. The 2011 WY mean winter and open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge calculated from the observed *test* hydrograph were 0.05% lower than from the estimated *baseline* hydrograph (Table 5.5-3); these differences were classified as **Negligible-Low** (Table 5.5-1).

5.5.3 Water Quality

In fall 2011, 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 2011);

- the MacKay River upstream of the Suncor Dover development *(test* station MAR-2A, initiated as a new RAMP station in 2009) was sampled in winter, summer and fall 2011. Spring sampling of this station was scheduled for 2011 but could not be completed because all local helicopters (required to sample this station) were requisitioned for forest-fire duty for the same as week and for weeks before and after the scheduled spring sampling program; and

- the MacKay River upstream of the Suncor MacKay River Dover *in situ* developments (*baseline* station MAR-2, sampled from 2002 to 2011, excluded from the 2011 regional *baseline* calculations because of upstream, non-RAMP oil-sands activities).

Temporal Trends Significant (α=0.05) decreasing trends in concentrations of total boron and sulphate were observed in fall over time (1998 to 2011) at *test* station MAR-1. No significant trends were observed in water quality measurement endpoints at *baseline* station MAR-2. Trend analysis was not conducted for *test* station MAR-2A given that there are only two years of data.

2011 Results Relative to Historical Concentrations In fall 2011, concentrations of water quality measurement endpoints were within previously-measured concentrations (Table 5.5-4 to Table 5.5-6), with the exception of total arsenic, with a concentration that exceeded previously-measured maximum concentrations at *baseline* station MAR-2 (Table 5.5-6).

Ion Balance In fall 2011, the ionic composition of water at all 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 Water Quality Measurement Endpoints to Published Guidelines Concentrations of water quality variables at all three stations were within water quality guidelines (Table 5.5-4 to Table 5.5-6) with the exception of total nitrogen and total aluminum at *test* stations MAR-1 and MAR-2A and *baseline* station MAR-2.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in the MacKay River in 2011 (Table 5.5-7):

- **Winter** – dissolved iron, sulphide, total iron, total nitrogen and total phosphorous at *test* station MAR-2A;
- **Summer** – dissolved iron, sulphide, total aluminum, total chromium, total iron, total Kjeldahl nitrogen, total nitrogen, total phenols and total phosphorous at *test* station MAR-2A;
- **Fall** – dissolved iron, sulphide, total iron, total nitrogen and total phenols at *test* stations MAR-1 and MAR-2A and *baseline* station MAR-2; and
- **Fall** – total Kjeldahl nitrogen and total phosphorous at *test* station MAR-2A and *baseline* station MAR-2.

2011 Results Relative to Regional *Baseline* Concentrations In fall 2011, all water quality measurement endpoints were within the range of regional *baseline* concentrations with the exception of total mercury. Due to the decrease in the analytical detection limit for total mercury, concentrations in fall 2011 were below the 5th percentile of regional *baseline* concentrations at *test* station MAR-2A and *baseline* station MAR-2 (Figure 5.5-5).

Water Quality Index The WQI for *test* stations MAR-1 and MAR-2A and *baseline* station MAR-2 was 100, indicating **Negligible-Low** differences from regional *baseline* water quality conditions. The water quality index values were higher than previous years.

Classification of Results Concentrations of all water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of previously-measured concentrations with the exception of total arsenic, which exceeded previously-measured concentrations at *baseline* station MAR-2. Water quality measurement endpoints in the MacKay River watershed in fall 2011 were within the range of regional *baseline* concentrations with the exception of total mercury, which was below the 5th percentile at *test* station MAR-2A and *baseline* station MAR-2. Differences in water quality in fall 2011 at both *test* and *baseline* stations relative to regional *baseline* water quality conditions were classified 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 2011 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.

2011 Habitat Conditions Water at *test* reach MAR-E1 in fall 2011 was shallow (0.3 m), moderately flowing (0.5 m/s), alkaline (pH: 8.5), with moderate conductivity (277 µS/cm), and high dissolved oxygen (Table 5.5-8). The substrate was dominated by sand/silt/clay (47%) with some large gravel (23%) and small gravel (18%) (Table 5.5-8). Periphyton chlorophyll *a* biomass was 52 mg/m^2, which was within the range of variation in *baseline* erosional reaches, but higher than previously measured at this reach (Figure 5.5-6).

Water at *test* reach MAR-E2 was shallow (0.3 m), moderately flowing (0.56 m/s), alkaline (pH: 8.1), with moderate conductivity (205 µS/cm) and high dissolved oxygen (Table 5.5-8). The substrate was dominated by large cobble (46%) and small cobble (20%) (Table 5.5-8). Periphyton chlorophyll *a* biomass was 222 mg/m^2, which was within the range of variation for erosional *baseline* reaches, but higher than previously measured at this reach (Figure 5.5-6).

Water at *baseline* reach MAR-E3 was shallow (0.2 m), moderately flowing (0.32 m/s), alkaline (pH: 8.2), with moderate conductivity (233 µS/cm) and high dissolved oxygen (Table 5.5-8). The substrate was a nearly even mixture of small cobble (22%), large gravel and large cobble (20%), sand/silt/clay (19%), and small gravel (18%) (Table 5.5-8). Periphyton chlorophyll *a* biomass was 138 mg/m^2, which was within the range of variation for erosional *baseline* reaches, but approximately ten times higher than previously measured in fall 2010 for this reach (Figure 5.5-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach MAR-E1 in fall 2011 was dominated by chironomids (27%), Ephemeroptera (25%), and tubificid worms (23%), with subdominant taxa consisting of Hydracarina (5%), naidid worms (5%), and nematodes (3%) (Table 5.5-9). Chironomid taxa at *test* reach MAR-E1 were numerous and included the common genera *Polypedilum*, *Cladotanytarsus*, *Rheotanytaarsus* and *Tanytarsus* (Wiederholm 1983). Mayflies (Ephemeroptera) included *Acerpenna*, *Baetis*, and *Tricorythodes*. Stoneflies (Plecoptera) were present, reflecting that *test* reach MAR-E1 is a cool/cold water environment. Common stoneflies included *Isoperla* and *Taeniopteryx*.

The benthic invertebrate community at *test* reach MAR-E2 in fall 2011 was dominated by Naididae worms (32%), chironomids (23%), and Ephemeroptera (16%), with subdominant taxa consisting of Trichoptera and Hydracarina (6%), and Plecoptera and Nematoda (4%) (Table 5.5-10). Dominant chironomid taxa included *Lopescladius* and *Polypedilum.* Mayflies (Ephemeroptera) included *Baetis*, *Rhithrogena*, *Acerpenna, Tricorythodes, and Heptagenia*. Stoneflies (Plecoptera) were represented by the genera *Isoperla*, *Pteronarcys* and the family Chloroperlidae, while Trichoptera included *Hydropsyche*, *Protoptila*, *Glossosoma*, and *Cheumatopsych*e (Table 5.5-10).

The benthic invertebrate community at *baseline* reach MAR-E3 in fall 2011 was dominated by chironomids (35%), Naididae worms (18%), and Ephemeroptera (18%) (Table 5.5-10). Dominant chironomid taxa included *Polypedilum, Micropsectra / Tanytarsus,* and *Rheotanytarsus.* Mayflies were abundant and diverse, primarily represented by the genera *Baetis, Acerpenna, Tricorythodes*, and *Heptagenia*. Plecoptera (Chloroperlidae and *Isoperla*) and Trichoptera (*Protoptila, Hydropsyche, Cheumatopsyche*, and *Helicopsyche borealis*) were also present. Both Gastropoda (*Ferrissia rivularis)* and Bivalvia (*Pisidium / Sphaerium*) were present in low relative abundances.

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 conducted between *baseline* reach MAR-E3 and each of the *test* reaches (MAR-E1 and MAR-E2).

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 and richness were weakly significantly higher during the *baseline* period compared to the *test* period while the CA Axis 1 scores were higher in the *test* period; however, less than 20% of the total variation in the annual means of these measurement endpoints was explained by the difference between the *baseline* and *test* periods (Table 5.5-11 and Figure 5.5-7).

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). The Spearman rank correlation was used to test for a time trend over the last six years at *test* reach MAR-E1. There was a large increase in total abundance in fall 2011 (~ 28,000 individuals per m^2), which resulted in a significant Spearman rank correlation over the last six years (Table 5.5-11, Figure 5.5-7). There was a significant increase and decrease in the CA Axes 1 and 2 scores, respectively, over time at reach MAR-E1 during the *test* period, explaining approximately 20% of the variation in annual means (Table 5.5-11 and Figure 5.5-8). The change in CA Axes scores reflected a shift in dominant taxa from EPT taxa to tubificid worms (Figure 5.5-8).

Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* reach MAR-E2 (Hypothesis 1, Section 3.2.3.1). There were significant differences, explaining greater than 20% of the variation in annual means, in richness and CA axes 1 and 2 scores over time at *test* reach MAR-E2 (Table 5.5-12). All measurement endpoints were generally increasing over time (Figure 5.5-7). The CA Axis 1 and 2 scores were generally increasing and decreasing, respectively, over time (Figure 5.5-8). Based on a visual assessment of the measurement endpoints (Figure 5.5-7), some measurement endpoints appeared to differ in 2011 compared to previous years (e.g., total abundance). An additional time trend was tested to determine whether values in 2011 were higher or lower than all previous years. Total Abundance was much higher in 2011 (~ 75,000 individuals per m^2) than in previous years (~ 10,000 per m^2 on average from 2002 to 2010).

For spatial comparisons, differences in mean values of measurement endpoints for benthic invertebrate communities were tested between both *test* reaches (MAR-E1 and MAR-E2) and *baseline* reach MAR-E3 for the last two years (2010 to 2011) (Hypothesis 3, Section 3.2.3.1). Total abundance was significantly higher and percent EPT was significantly lower at *test* reach MAR-E1 compared to *baseline* reach MAR-E3 (Table 5.5-11); however, only the difference in percent EPT explained greater than 20% of the variation in annual means. The CA axis 2 scores were significantly lower at *test* reach MAR-E1, reflecting a higher relative abundance of tubificid worms (~ 15% on average in 2010 and 2011 at *test* reach MAR-E1 and ~1% at *baseline* reach MAR-E3) (Table 5.5-9 and Table 5.5-10).

There were no significant differences in measurement endpoints of benthic invertebrate communities, explaining greater than 20% of the variation in annual means between *test* reach MAR-E2 and *baseline* reach MAR-E3, indicating that the communities were highly similar. The CA Axis 2 scores was significantly lower at *test* reach MAR-E2; however, the difference explained a marginal amount of variation in annual means (i.e., < 20%) (Table 5.5-12). The difference is reflected in the highly similar composition of the communities, with low abundance of naidid and tubificid worms, moderate relative abundance of chironomids, and good relative abundances of mayflies, caddisflies and stoneflies in both reaches (Table 5.5-10, Figure 5.5-8).

Comparison to Published Literature The benthic invertebrate community at *test* reach MAR-E1 reflects healthy robust conditions, consisting of a relatively high proportion of EPT taxa, which increased in 2011 compared to 2010 (Figure 5.5-7). The percent taxa as Tubificid worms (23%) was slightly high and although Tubificids are typically always present, when they account for ~ 30% of the fauna or greater, it could indicate disturbances such as organic enrichment or low water levels (e.g., Griffiths 1998). In fall 2011, water levels were much lower than previous years (Figure 5.5-3). In contrast, Ephemeroptera and Chironomidae were also relatively abundant at *test* reach MAR-E1 and are indicative of good water and sediment quality conditions (Hynes 1960, Griffiths 1998).

The benthic invertebrate community at *test* reach MAR-E2 also reflected healthy conditions. Naididae worms had a high relative abundance (32%) and are a potential indicator that conditions are disturbed (Griffiths 1998, Mandaville 2001); however, the community also consisted of taxa that require good water quality and substrate including the chironomid *Lopescladius* mayflies (Ephemeroptera) such as *Baetis*, *Rhithrogena*, *Acerpenna, Tricorythodes, and Heptagenia*, stoneflies such as *Isoperla*, *Pteronarcys*, and caddisflies such as *Hydropsyche, Protoptila, Glossosoma,* and *Cheumatopsych*e (Mandaville 2001).

2011 Results Relative to Regional *Baseline* Conditions Values of all benthic invertebrate community measurement endpoints at *test* reach MAR-E1, *test* reach MAR-E2, and *baseline* reach MAR-E3 were within the range of variation of *baseline* erosional reaches, with the exception of abundance at *test* reach MAR-E2, which exceeded the 95th percentile of *baseline* variability (Figure 5.5-7).

Classification of Results Differences in measurement endpoints for benthic invertebrate communities at *test* reach MAR-E1 were classified as **Moderate** because percent EPT was significantly higher at *baseline* reach MAR-E3 compared to *test* reach MAR-E1 and abundance and richness were significantly higher during the *baseline* period, although the statistical signal in the difference explained slightly less than 20% of the variance in annual means. Despite having a lower proportion of EPT taxa compared to *baseline* reach MAR-E3, the benthic invertebrate community at *test* reach MAR-E1 still had a number of sensitive mayfly, stonefly and caddisfly taxa that are typical of an erosional watercourse.

Differences in measurement endpoints of benthic invertebrate communities for *test* reach MAR-E2 were classified as **Negligible-Low** because the significant increases in richness, diversity, and percent EPT over time did not imply a negative change in the benthic invertebrate community. The benthic invertebrate community at *test* reach MAR-E2 was diverse, and contained a number of sensitive chironomid, mayfly, stonefly and caddisfly taxa typical of an erosional watercourse.

5.5.4.2 Sediment Quality

No sediment quality sampling was conducted in the MacKay River in 2011 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

Fish assemblages were sampled in fall 2011 at:

- erosional *test* reach MAR-F1, sampled in 2009 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is at the same location as the benthic invertebrate community *test* reach MAR-E1);

- erosional *test* reach MAR-F2, sampled for the first time in 2011 (this reach is at the same location as the benthic invertebrate community *test* reach MAR-E2); and

- erosional *baseline* reach MAR-F3, sampled for the first time in 2011 (this reach is at the same location as the benthic invertebrate community *baseline* reach MAR-E3).

2011 Habitat Conditions *Test* reach MAR-F1 was comprised entirely of run habitat with a wetted width of 40.0 m and a bankfull width of 45.5 m (Table 5.5-13). The substrate was primarily silt and clay with a small amount of cobble. Water at *test* reach MAR-F1 in fall 2011 had an average depth of 0.5 m, was moderately flowing (average flow: 0.43 m/s), alkaline (pH: 7.92), with moderate conductivity (252 µS/cm), high dissolved oxygen (8.7 mg/L), and a temperature of 18.9°C. Instream cover consisted primarily of boulders with smaller amounts of small woody debris and macrophytes (Table 5.5-13).

Test reach MAR-F2 was comprised of riffle and run habitat with a wetted width of 22.3 m and a bankfull width of 28.7 m (Table 5.5-13). The substrate was primarily cobble with some bedrock. Water at *test* reach MAR-F2 in fall 2011 had an average depth of 0.8 m, was alkaline (pH: 8.39), with moderate conductivity (233 µS/cm), high dissolved oxygen (8.4 mg/L), and a temperature of 19.1°C. Flow was not measured at *test* reach MAR-F2 due to an equipment malfunction. Instream cover consisted primarily of boulders with some overhanging vegetation and filamentous algae (Table 5.5-13).

Baseline reach MAR-F3 was comprised entirely of run habitat with a wetted width of 27.5 m and a bankfull width of 29.0 m (Table 5.5-13). The substrate was primarily small boulder with some cobble. Water at *baseline* reach MAR-F3 in fall 2011 had an average depth of 0.8 m, was moderately flowing (average flow: 0.57 m/s), alkaline (pH: 8.32) with moderate conductivity (236 µS/cm), moderate dissolved oxygen (7.2 mg/L) and a temperature of 14.4°C. Instream cover consisted primarily of boulders with small amounts of filamentous algae and small woody debris (Table 5.5-13).

Temporal and Spatial Comparisons Sampling was initiated at *test* reach MAR-F1 in 2009 during the RAMP Fish Assemblage Pilot Study; therefore, temporal comparisons were conducted between 2009 and 2011. *Test* reach MAR-F2 and *baseline* reach MAR-F3 were first sampled in 2011; therefore, no temporal comparisons were conducted. Spatial comparisons between the three reaches were conducted for fall 2011.

There was an increase in abundance, richness, diversity, and CPUE of fish from 2009 to 2011 at *test* reach MAR-F1 (Table 5.5-14, Table 5.5-15, Figure 5.5-9). The ATI also slightly increased from 2009 to 2011, likely reflecting the increase in abundance of more tolerant fish species (e.g., trout-perch and white sucker) and a decrease in the abundance of some sensitive taxa including spoonhead sculpin (Table 5.5-14). *Test* reach MAR-F1 was dominated by trout-perch, while *test* reach MAR-F2 was dominated by lake chub, and *baseline* reach MAR-F3 was dominated by slimy sculpin (Table 5.5-14). All measurement endpoints for fish assemblages were relatively consistent among reaches of the MacKay River (Table 5.5-15) with the exception of higher richness, diversity and evenness at *test* reach MAR-F1 and higher abundance at *test* reach MAR-F2 compared to *baseline* reach MAR-F3. In addition, the ATI at *baseline* reach MAR-F3 was lower given the much higher abundance of slimy sculpin at this reach compared to either *test* reach (MAR-F1 and MAR-F2) (Table 5.5-15 and Figure 5.5-9).

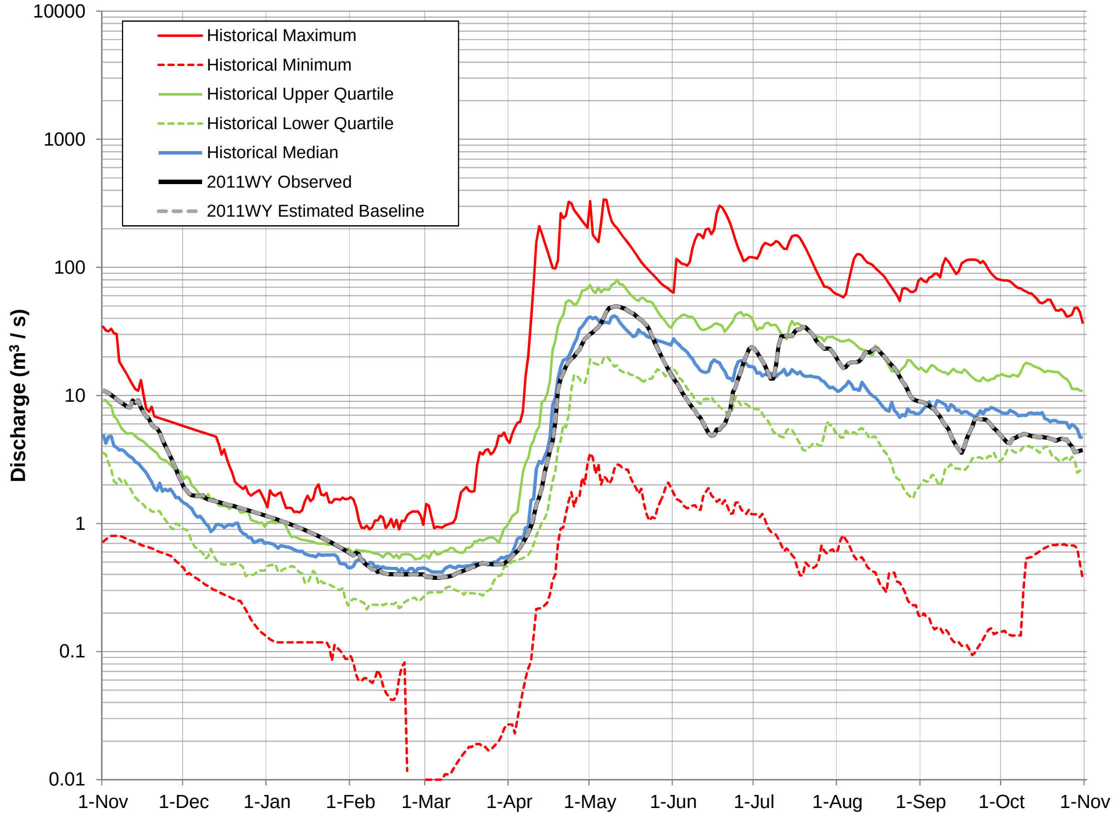
Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of 23 fish species were recorded in the MacKay River watershed; whereas RAMP found only 10 species from 2009 to 2011. As noted in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Golder (2004b) documented similar riffle habitat with substrate consisting of gravel, cobble, and boulders in the area of the river where both *test* reaches (MAR-F1 and MAR-F2), and the *baseline* reach (MAR-F3) are located (i.e., 1 km to 112 km from the mouth of the river), which is consistent with habitat conditions documented in fall 2011 (Table 5.5-13). This section of the river provides moderate to high fisheries potential (Golder 2004b).

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at both *test* reaches MAR-F1 and MAR-F2, and *baseline* reach MAR-F3 were within the range of regional *baseline* conditions (Figure 5.5-9).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reaches MAR-F1 and MAR-F2 and the regional *baseline* conditions were classified as **Negligible-Low** given there were no measurement endpoints that exceeded the regional range of variation of *baseline* reaches.

Figure 5.5-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the MacKay River in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph are based on provisional data for MacKay River near Fort McKay, WSC Station 07DB001, from March 1 to October 31, 2011, and RAMP Station S26 for other months in 2011. The upstream drainage area is 5,569.3 km^2. Historical values from March 1 to October 31 calculated for the period from 1972 to 2010, 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, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**313.31**	**Observed discharge, obtained from MacKay River near Fort McKay, WSC Station 07DB001 (RAMP Station S26)**
Closed-circuited area water loss from the observed *test* hydrograph	-0.30	Estimated 5.4 km^2 of the MacKay River watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.14	Estimated 12.8 km^2 of the MacKay River watershed with land change from focal projects as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the MacKay River watershed from focal projects	-0.003	Water withdrawn by Suncor for dust suppression (daily values provided)
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)	**313.48**	**Estimated *baseline* discharge at MacKay River near Fort McKay, WSC Station 07DB001 (RAMP Station S26)**
Incremental flow (change in total annual discharge)	-0.16	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**-0.05%**	**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, 2011 for WSC Station 07DB001 and on RAMP Station S26 for other months in the 2011 WY.

Table 5.5-3 Calculated change in hydrologic measurement endpoints for the MacKay River watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	16.58	16.57	-0.05%
Mean winter discharge	2.02	2.02	-0.05%
Annual maximum daily discharge	49.53	49.50	-0.05%
Open-water period minimum daily discharge	3.57	3.57	-0.05%

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, 2011 for WSC Station 07DB001 and on RAMP Station S26 for other months in the 2011 WY.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two decimal places.

Table 5.5-4 Concentrations of water quality measurement endpoints, mouth of MacKay River (*test* station MAR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	12	7.6	8.2	8.6
Total suspended solids	mg/L	-	7.0	12	<2	6.5	41.0
Conductivity	µS/cm	-	265	12	183	260	576
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.034	12	0.004	0.023	0.047
Total nitrogen	mg/L	1	**1.07**	12	0.40	**1.20**	**3.20**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	35.2	12	20.0	28.0	40.0
Ions							
Sodium	mg/L	-	16.6	12	15.0	20.0	60.0
Calcium	mg/L	-	24.8	12	20.8	27.9	44.7
Magnesium	mg/L	-	8.1	12	7.3	9.2	15.9
Chloride	mg/L	230, 860	3.7	12	1.2	5.0	41.2
Sulphate	mg/L	100	12.2	12	9.3	18.0	35.5
Total dissolved solids	mg/L	-	208	12	170	226	342
Total alkalinity	mg/L		118.0	12	80.2	120.0	202.0
Selected metals							
Total aluminum	mg/L	0.1	**0.28**	12	0.05	**0.22**	**1.74**
Dissolved aluminum	mg/L	0.1	0.019	12	0.007	0.022	0.046
Total arsenic	mg/L	0.005	0.0011	12	0.0007	0.0009	0.0013
Total boron	mg/L	1.2	0.076	12	0.051	0.082	0.140
Total molybdenum	mg/L	0.073	0.00029	12	0.00015	0.00038	0.00060
Total mercury (ultra-trace)	ng/L	5, 13	1.2	8	<1.2	<1.2	6.3
Total strontium	mg/L	-	0.16	12	0.11	0.15	0.29
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	49.9	0	-	-	-
Total PAHs	ng/L	-	271.9	0	-	-	-
Total Parent PAHs	ng/L	-	21.9	0	-	-	-
Total Alkylated PAHs	ng/L	-	250.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.69**	12	0.23	**0.45**	**0.79**
Sulphide	mg/L	0.002	**0.019**	12	<0.003	**0.012**	**0.032**
Total iron	mg/L	0.3	**1.28**	12	**0.31**	**0.92**	**23.30**
Total phenols	mg/L	0.004	**0.0085**	12	0.0010	0.0040	**0.0203**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.5-5 Concentrations of water quality measurement endpoints, upper MacKay River (*test* station MAR-2A), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	September 2009
			Value	Value
Physical variables				
pH	pH units	6.5-9.0	8.4	8.3
Total suspended solids	mg/L	-	5	3
Conductivity	µS/cm	-	223	268
Nutrients				
Total dissolved phosphorus	mg/L	0.05	0.038	0.034
Total nitrogen	mg/L	1	**1.11**	**1.75**
Nitrate+nitrite	mg/L	1.3	<0.071	<0.071
Dissolved organic carbon	mg/L	-	33.5	24.7
Ions				
Sodium	mg/L	-	12.9	15.1
Calcium	mg/L	-	24.7	31.3
Magnesium	mg/L	-	7.8	9.1
Chloride	mg/L	230, 860	0.53	0.58
Sulphate	mg/L	100	10.8	18.4
Total dissolved solids	mg/L	-	198	244
Total alkalinity	mg/L		102	122
Selected metals				
Total aluminum	mg/L	0.1	**0.14**	**0.12**
Dissolved aluminum	mg/L	0.1	0.022	0.017
Total arsenic	mg/L	0.005	0.0011	0.0011
Total boron	mg/L	1.2	0.056	0.072
Total molybdenum	mg/L	0.073	0.00031	0.00056
Total mercury (ultra-trace)	ng/L	5, 13	0.6	2.6
Total strontium	mg/L	-	0.13	0.17
Total hydrocarbons				
BTEX	mg/L	-	<0.1	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]				
Naphthalene	ng/L	-	<14.1	-
Retene	ng/L	-	4.2	-
Total dibenzothiophenes	ng/L	-	8.5	-
Total PAHs	ng/L	-	171.4	-
Total Parent PAHs	ng/L	-	19.8	-
Total Alkylated PAHs	ng/L	-	151.5	-
Other variables that exceeded CCME/AENV guidelines in fall 2011				
Dissolved iron	mg/L	0.3	**0.74**	**0.85**
Sulphide	mg/L	0.002	**0.018**	**0.013**
Total iron	mg/L	0.3	**1.05**	**1.26**
Total Kjeldahl Nitrogen	mg/L	1	**1.04**	**1.68**
Total phenols	mg/L	0.004	**0.010**	**0.009**
Total phosphorus	mg/L	0.05	**0.054**	0.043

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Table 5.5-6 Concentrations of water quality measurement endpoints, upper MacKay River (*baseline* station MAR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	9	7.8	8.2	8.3
Total suspended solids	mg/L	-	<3	9	<3	<3	23
Conductivity	µS/cm	-	228	9	164	220	264
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.037	9	0.008	0.031	0.043
Total nitrogen	mg/L	1	**1.13**	9	0.80	**1.30**	**3.10**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	0.1
Dissolved organic carbon	mg/L	-	33.5	9	22.0	32.0	41.0
Ions							
Sodium	mg/L	-	13.6	9	11.0	16.0	19.0
Calcium	mg/L	-	26.2	9	17.8	23.8	34.5
Magnesium	mg/L	-	8.8	9	6.6	8.4	11.0
Chloride	mg/L	230, 860	0.7	9	<0.5	2.0	3.0
Sulphate	mg/L	100	13.1	9	6.8	11.0	23.7
Total dissolved solids	mg/L	-	207	9	160	190	240
Total alkalinity	mg/L		104.0	9	74.6	104.0	128.0
Selected metals							
Total aluminum	mg/L	0.1	**0.13**	9	0.02	**0.16**	**1.08**
Dissolved aluminum	mg/L	0.1	0.022	9	<0.001	0.025	0.044
Total arsenic	mg/L	0.005	<u>0.0011</u>	9	0.0006	0.0009	0.0010
Total boron	mg/L	1.2	0.06	9	0.04	0.06	0.11
Total molybdenum	mg/L	0.073	0.00033	9	0.00013	0.00030	0.00055
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	1.45	5
Total strontium	mg/L	-	0.14	9	0.11	0.13	0.20
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	16.1	0	-	-	-
Total PAHs	ng/L	-	193.4	0	-	-	-
Total Parent PAHs	ng/L	-	20.0	0	-	-	-
Total Alkylated PAHs	ng/L	-	173.4	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	<u>**0.84**</u>	9	0.29	**0.54**	**0.76**
Sulphide	mg/L	0.002	**0.022**	9	**0.008**	**0.019**	**0.030**
Total iron	mg/L	0.3	**1.23**	9	**0.39**	**0.92**	**1.34**
Total Kjeldahl Nitrogen	mg/L	1	**1.06**	9	0.70	**1.20**	**3.00**
Total phenols	mg/L	0.004	**0.008**	9	<0.001	**0.011**	**0.020**
Total phosphorus	mg/L	0.05	**0.053**	9	0.014	0.047	**0.074**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.5-4 Piper diagram of fall ion concentrations in the MacKay River watershed.

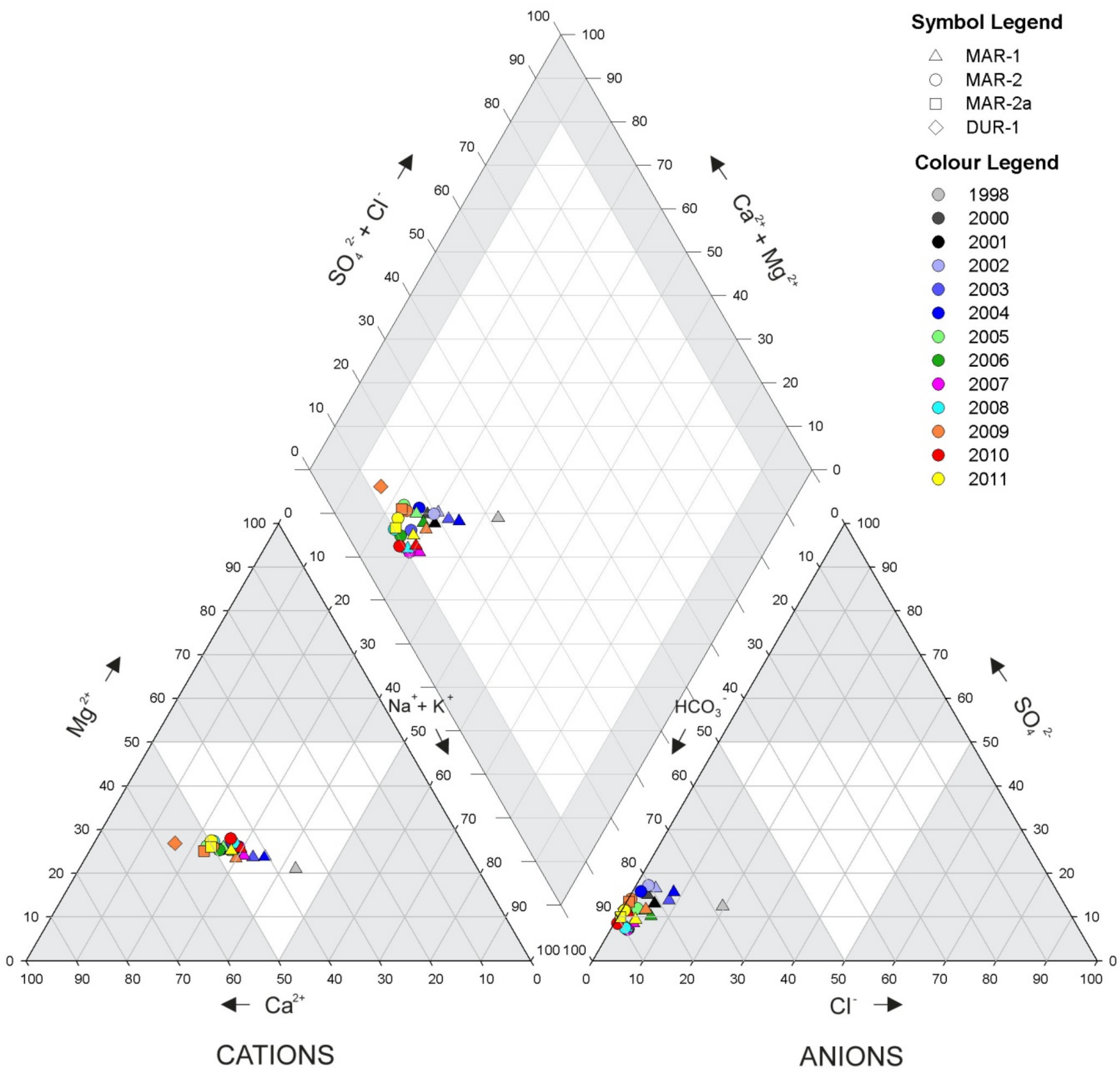


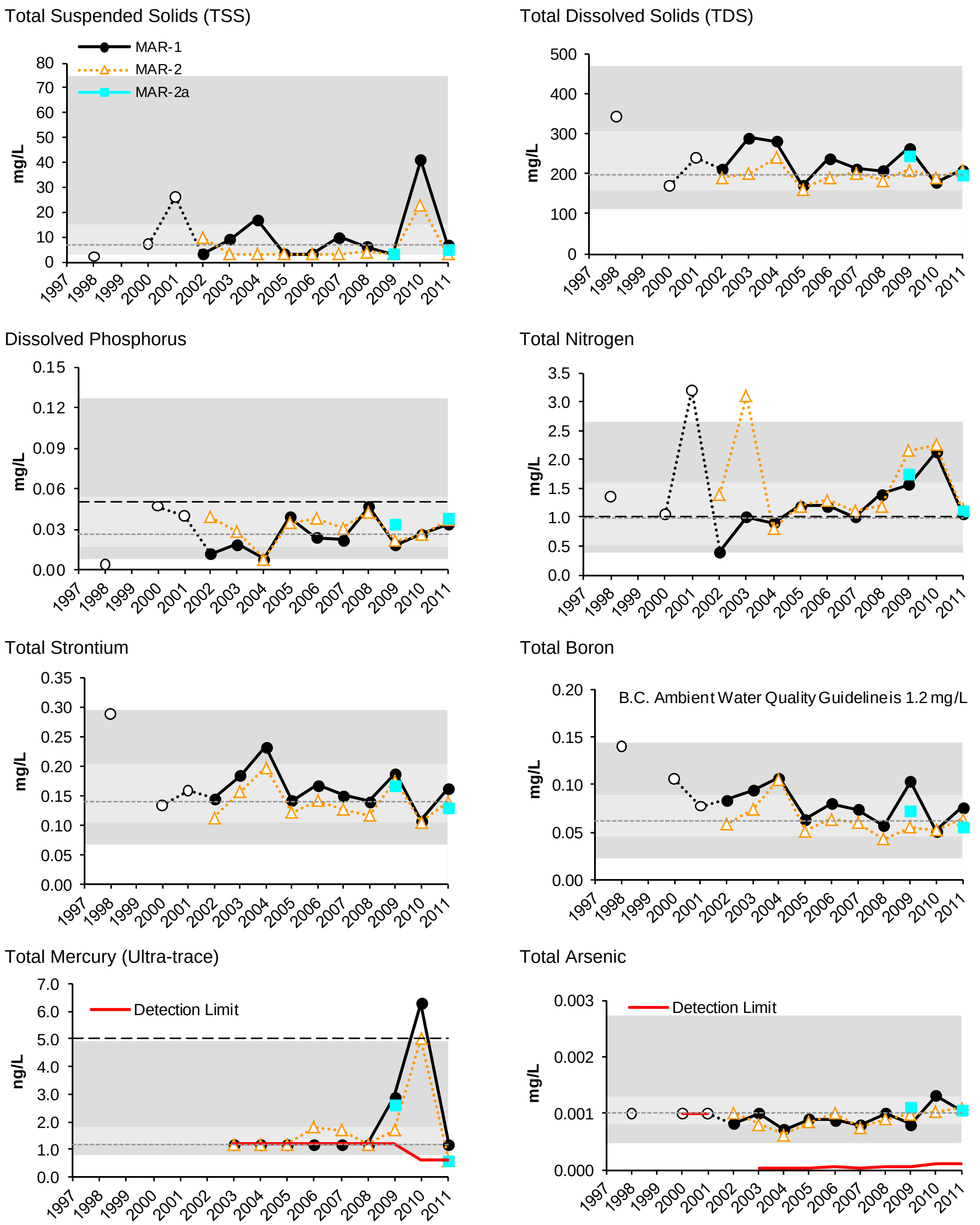
Table 5.5-7 Water quality guideline exceedances, MacKay River watershed, 2011.

Variable	Units	Guideline[a]	MAR-1	MAR-2	MAR-2A
Winter					
Dissolved iron	mg/L	0.3	ns	ns	0.7
Sulphide	mg/L	0.002	ns	ns	0.0064
Total iron	mg/L	0.3	ns	ns	1.91
Total nitrogen	mg/L	1	ns	ns	1.26
Total phosphorus	mg/L	0.5	ns	ns	0.096
Summer					
Dissolved iron	mg/L	0.3	ns	ns	0.47
Sulphide	mg/L	0.002	ns	ns	0.022
Total aluminum	mg/L	0.1	ns	ns	0.96
Total chromium	mg/L	0.001	ns	ns	0.0014
Total iron	mg/L	0.3	ns	ns	1.7
Total Kjeldahl Nitrogen	mg/L	1	ns	ns	1.23
Total nitrogen	mg/L	1	ns	ns	1.48
Total phenols	mg/L	0.004	ns	ns	0.015
Total phosphorus	mg/L	0.5	ns	ns	0.089
Fall					
Dissolved iron	mg/L	0.3	0.69	0.84	0.74
Sulphide	mg/L	0.002	0.019	0.022	0.018
Total aluminum	mg/L	0.1	0.28	0.13	0.14
Total iron	mg/L	0.3	1.28	1.23	1.05
Total Kjeldahl Nitrogen	mg/L	1	-	1.06	1.04
Total nitrogen	mg/L	1	1.07	1.13	1.11
Total phenols	mg/L	0.004	0.009	0.008	0.010
Total phosphorus	mg/L	0.5	-	0.053	0.054

[a] Sources for all guidelines are outlined in Table 3.2-5.

ns = not sampled

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.

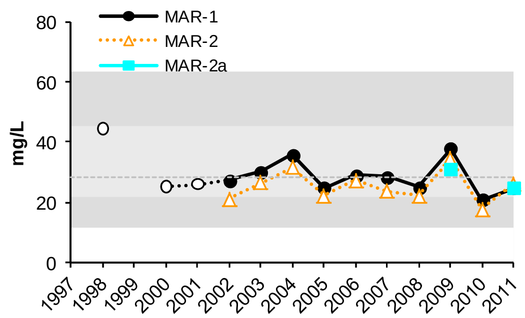
- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

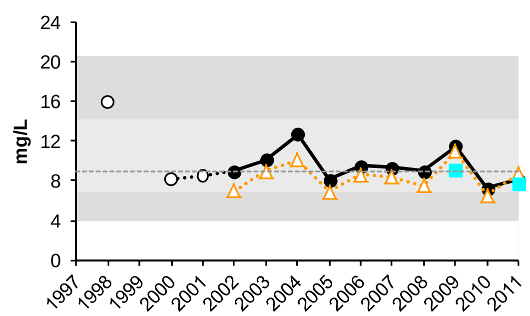
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.5-5 (Cont'd.)

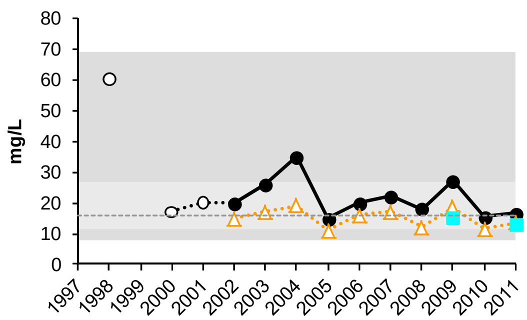
Calcium



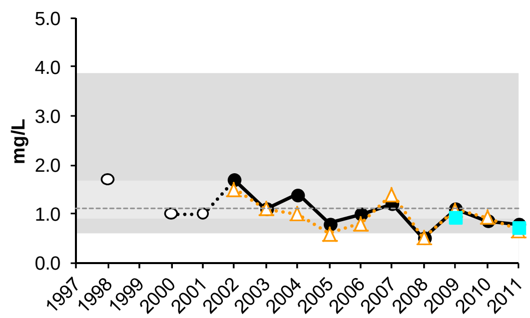
Magnesium



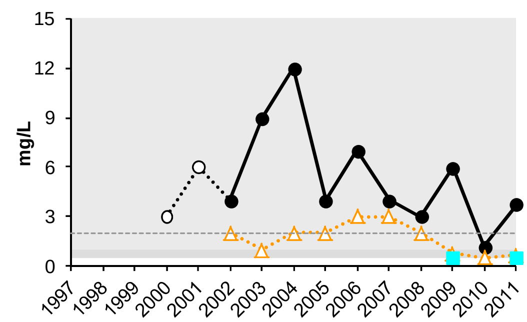
Sodium



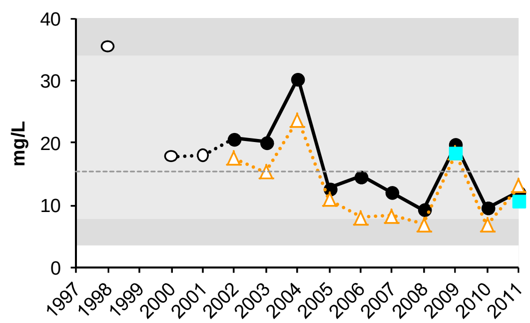
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.5-8 Average habitat characteristics of benthic invertebrate sampling locations in the MacKay River.

Variable	Units	MAR-E1 Lower *Test* Reach of MacKay River	MAR-E2 Middle *Test* Reach of MacKay River	MAR-E3 Upper *Baseline* Reach of MacKay River
Sample date	-	Sept. 14, 2011	Sept. 11, 2011	Sept. 15, 2011
Habitat	-	Erosional	Erosional	Erosional
Water depth	m	0.3	0.3	0.2
Current velocity	m/s	0.50	0.56	0.32
Field Water Quality				
Dissolved oxygen	mg/L	9.3	8.5	9.85
Conductivity	µS/cm	277	205	233
pH	pH units	8.5	8.1	8.2
Water temperature	°C	10.4	15.3	10.3
Sediment Composition				
Sand/Silt/Clay	%	47	10	19
Small Gravel	%	3	3	18
Large Gravel	%	23	15	20
Small Cobble	%	18	20	22
Large Cobble	%	7	46	20
Boulder	%	0	8	4
Bedrock	%	2	0	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.

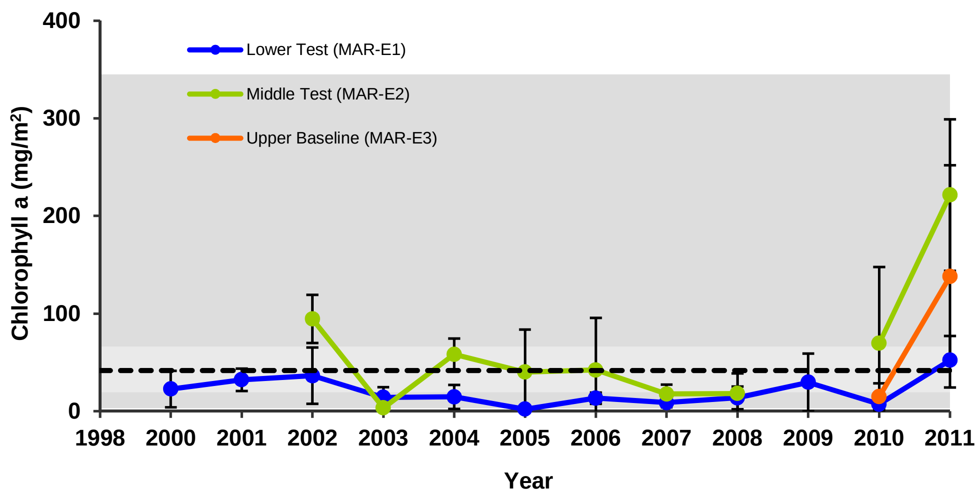


Table 5.5-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in the MacKay River (*test* reach MAR-E1).

Taxon	Percent Major Taxa Enumerated in Each Year												
	Reach MAR-E1												
	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Hydra	<1			1	<1					<1			
Nematoda	2	2	8	6	1	3	1	1	3	2	2	2	3
Erpobdellidae						<1							
Naididae	2	17	2	24	8	3	11	8	9	6	3	30	5
Tubificidae	2	<1	1	2	<1	1	6	2	1	3	2	5	23
Enchytraeidae	4	12	1	5	5	1	1	1	1	3	1	1	1
Lumbriculidae					<1								
Hydracarina	1	4	6	3	18	6	1	2	15	14	<1	8	5
Ostracoda	<1	1	1	6		<1		<1	1	1	<1	1	2
Macrothricidae		<1		1									
Copepoda	<1	<1	<1	<1				<1	1	<1	<1		<1
Gastropoda	<1	<1	1	2	<1	1		1	1	3		3	<1
Bivalvia		<1	<1	1	2	2	1		<1	1	<1	<1	1
Coleoptera	<1	<1			<1	<1		<1		<1		<1	<1
Ceratopogonidae	1	1	<1	1	<1	1	5	3	1	1	2	<1	2
Chironomidae	57	34	4	31	4	57	2	3	40	34	69	36	27
Empididae	1	1	4	3	2	2	12	6	1	1	1		1
Tipulidae	<1	<1			<1				1				
Tabanidae					<1		1		1			<1	
Simuliidae	1	<1	<1	<1	<1		2	<1	1	<1	<1	<1	<1
Ephemeroptera	26	21	18	12	19	13	25	29	13	21	16	11	25
Anisoptera	1	1	2	1	1	3	2	2	1	5	1	<1	1
Plecoptera	2	5	5	<1	1	3	3	8	2	3	1	1	1
Trichoptera	<1	<1	3	3	2	5	<1	5	1	<1	<1	1	<1
Heteroptera	<1		<1										
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	28,597
Richness	49	29	26	37	24	27	23	30	32	38	33	34	24
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	0.80
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	0.84
% EPT	26	25	24	16	23	20	28	42	15	26	23	13	27

Table 5.5-10 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**	**2011**	**2010**	**2011**
Hydra	<1											
Nematoda	3	1	3	1	3	3	3	3	1	4	1	1
Erpobdellidae		<1										
Naididae	48	15	4	15	2	9	11	5	8	32	41	18
Tubificidae	<1	<1	8	1	1	2	4	2	8	<1	<1	<1
Enchytraeidae	1	4	3	3	1	1	2	<1	3	3	2	3
Lumbriculidae		<1		<1		1				3		
Hydracarina	7	21	4	9	5	17	10	5	12	6	5	8
Ostracoda	<1	<1	<1			1	<1	1	2	<1	2	<1
Copepoda	<1		<1				<1		<1	<1	<1	<1
Gastropoda	<1	<1	<1	<1		1	1	<1	2	<1	1	<1
Bivalvia	<1	4	1	<1		<1	1		2	<1	1	<1
Coleoptera		<1	<1	<1		<1	<1		<1	<1	<1	1
Ceratopogonidae	<1	<1	1	1	1	1	2	1	3	<1	1	<1
Chironomidae	31	3	59	49	63	39	43	51	34	23	25	35
Empididae	1	2	1	5	<1	<1	<1	1	<1	<1	<1	<1
Tipulidae	<1	<1	<1		1	<1	<1	<1	<1	<1		<1
Tabanidae		<1							<1		<1	
Simuliidae		<1		<1	<1	1		<1	<1		<1	
Ephemeroptera	2	14	11	1	12	16	8	20	17	16	9	18
Anisoptera	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
Plecoptera	<1	3	3	1	2	3	2	1	3	4	3	4
Trichoptera	6	4	3	5	1	10	12	12	4	6	8	7
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	74,977	4,300	23,631
Richness	40	27	32	30	27	41	39	37	35	37	35	31
Simpson's Diversity	0.74	0.87	0.91	0.86	0.65	0.87	0.83	0.9	0.91	0.83	1	0.87
Evenness	0.76	0.91	0.94	0.89	0.65	0.89	0.87	0.93	0.94	0.85	1	0.91
% EPT	8	25	17	16	24	28	26	32	24	26	22	29

Table 5.5-11 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 Change(s)**	**Spearman Rank r_s**
	***Baseline* vs. *Test* Periods**	**Time Trend (*test* period)**	***Baseline* vs. *Test* Periods**	**Time Trend (*test* period)**		
Abundance	**0.014**	0.433	3	0	Higher during *baseline* period	**0.89**
Richness	**0.002**	0.201	10	1	Higher during *baseline* period	-0.03
Simpson's Diversity	0.325	0.142	5	12	No change	-0.83
Evenness	0.360	0.179	5	11	No change	-0.60
EPT	0.135	0.396	6	2	No change	-0.26
CA Axis 1	**0.006**	**<0.001**	11	18	Higher in *test* period and increasing over time in *test* period	0.83
CA Axis 2	0.069	**<0.001**	3	21	Decreasing over time in *test* period	-0.77

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Variable	**P-value**	**Variance Explained (%)**	**Nature of Change(s)**	**Spearman Rank r_s**
	***Baseline* Reach vs. *Test* Reach**	***Baseline* Reach vs. *Test* Reach**		
Abundance	**0.042**	17	Higher in *test* reach	0.68
Richness	0.314	13	No change	-0.17
Simpson's Diversity	0.842	0	No change	-0.42
Evenness	0.878	0	No change	-0.27
EPT	**0.030**	45	Higher in *baseline* reach	-0.24
CA Axis 1	0.253	42	No change	0.38
CA Axis 2	**<0.001**	63	Lower in *test* reach	-0.43

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Table 5.5-12 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 Change(s)	Spearman Rank r_s
	Time Trend	Compared to Fall 2010	Time Trend	Compared to Fall 2010		
Abundance	0.179	**<0.001**	1	39	Higher in 2011 than previous years	0.26
Richness	**<0.001**	0.388	57	1	Increasing over time	-0.11
Simpson's Diversity	**<0.001**	0.658	17	0	Increasing over time	0.54
Evenness	**<0.001**	0.669	15	0	Increasing over time	0.37
EPT	**0.007**	0.289	14	2	Increasing over time	-0.14
CA Axis 1	**<0.001**	0.923	40	0	Increasing over time	0.31
CA Axis 2	**<0.001**	0.673	52	0	Increasing over time	-0.37

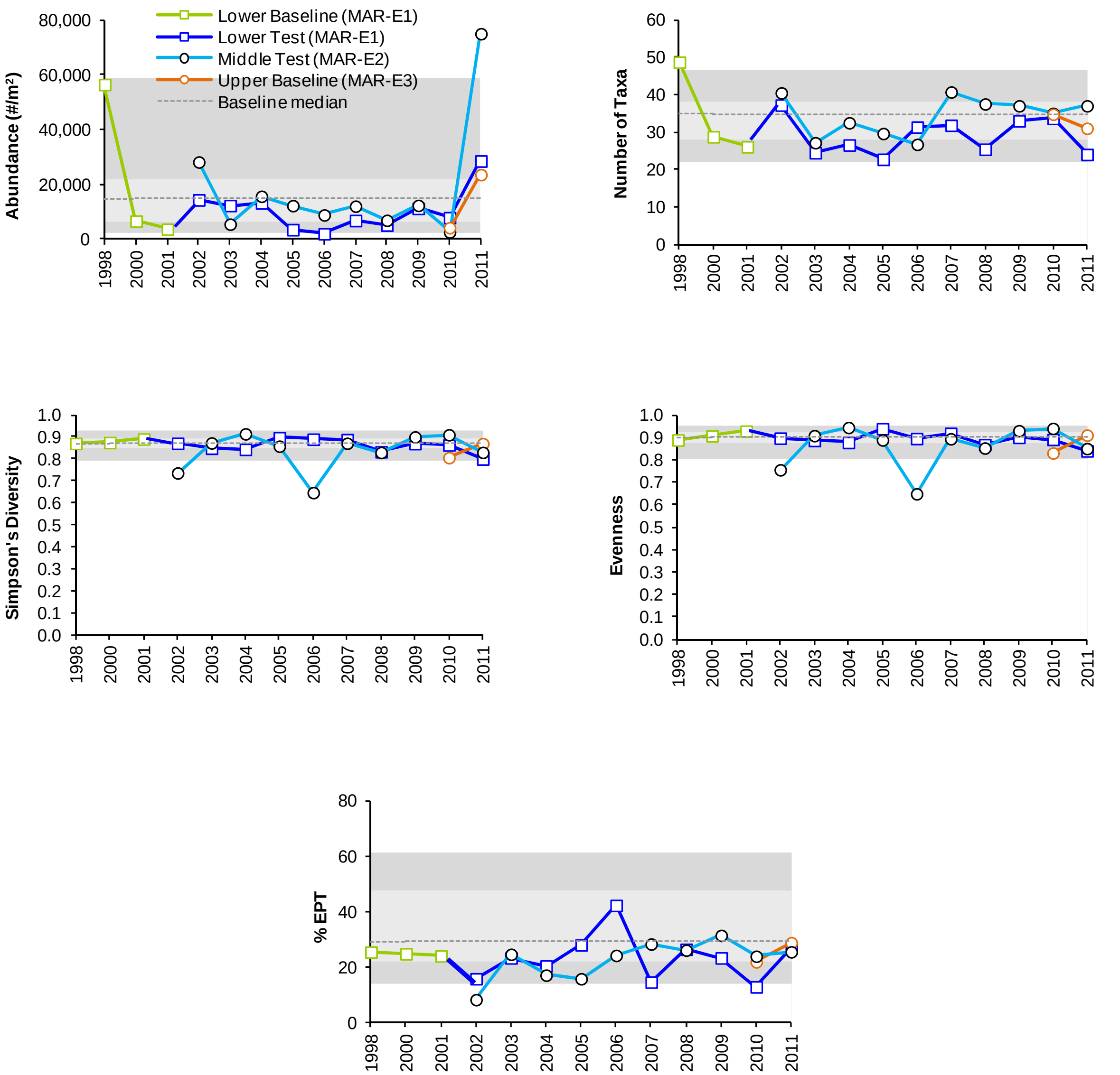
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Variable	P-value	Variance Explained (%)	Nature of Change(s)
	***Baseline* Reach vs. *Test* Reach**	***Baseline* Reach vs. *Test* Reach**	
Abundance	0.131	3	No change
Richness	0.231	44	No change
Simpson's Diversity	0.239	13	No change
Evenness	0.330	8	No change
EPT	0.562	14	No change
CA Axis 1	0.591	4	No change
CA Axis 2	**0.042**	16	Lower in *test* reach

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).

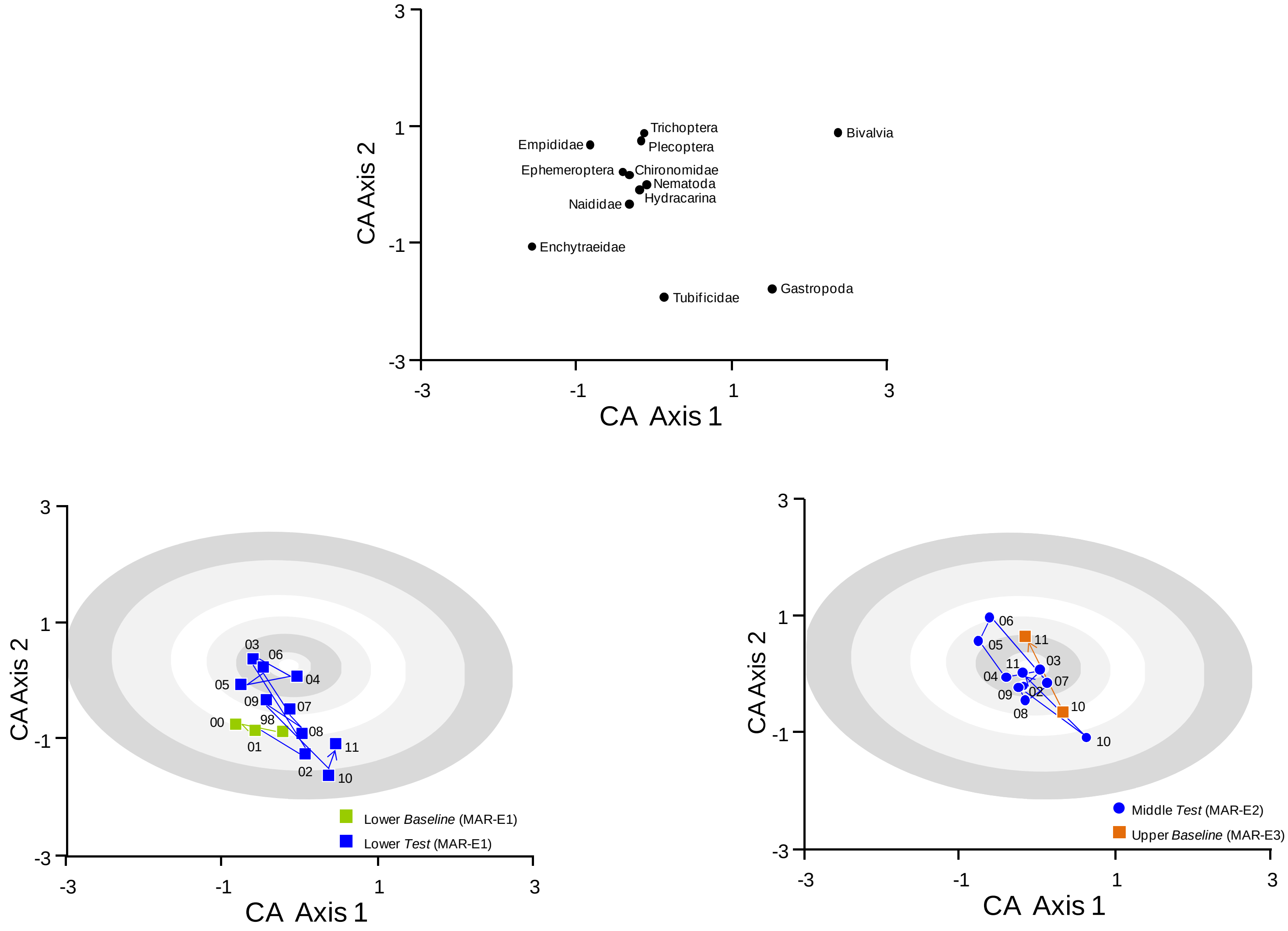
Figure 5.5-7 Variation in benthic invertebrate community measurement endpoints in the MacKay River.



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.

Table 5.5-13 Average habitat characteristics of fish assemblage monitoring locations in the MacKay River.

Variable	Units	MAR-F1 Lower *Test* Reach of MacKay River	MAR-F2 Middle *Test* Reach of MacKay River	MAR-F3 Upper *Baseline* reach of MacKay River
Sample date	-	Sept. 10, 2011	Sept. 10, 2011	Sept. 11, 2011
Habitat type	-	run	riffle/run	run
Maximum depth	m	0.62	1.30	-
Average bankfull channel width	m	45.5	28.7	29.0
Average wetted channel width	m	40.0	22.3	27.5
Substrate				
Dominant	-	silt/clay	cobble	small boulder
Subdominant	-	cobble	bedrock	cobble
Instream cover				
Dominant	-	boulders	boulders	boulders
Subdominant	-	small woody debris, macrophytes and filamentous algae	overhanging vegetation and filamentous algae	filamentous algae and small woody debris
Field water quality				
Dissolved oxygen	mg/L	8.7	8.4	7.2
Conductivity	µS/cm	252	233	236
pH	pH units	7.92	8.39	8.32
Water temperature	°C	18.9	19.1	14.4
Water velocity				
Left bank velocity	m/s	0.37	not measured	0.25
Left bank water depth	m	0.45	0.75	1.05
Centre of channel velocity	m/s	0.37	not measured	0.38
Centre of channel water depth	m	0.45	0.75	0.70
Right bank velocity	m/s	0.39	not measured	0.47
Right bank water depth	m	0.54	0.75	0.55
Riparian cover – understory (<5 m)				
Dominant	-	woody shrubs and saplings	woody shrubs and saplings	woody shrubs and saplings
Subdominant	-	overhanging vegetation	-	-

Table 5.5-14 Percent composition and mean CPUE of fish species at *test* reaches MAR-F1 and MAR-F2 and *baseline* reach MAR-F3 of the MacKay River, 2009 to 2011.

Common Name	Code	Total Species				Percent of Total Catch			
		MAR-F1		MAR-F2	MAR-F3	MAR-F1		MAR-F2	MAR-F3
		2009	2011	2011	2011	2009	2011	2011	2011
Arctic grayling	ARGR	-	-	-	-	0	0	0	0
brook stickleback	BRST	1	-	-	-	5.6	0	0	0
burbot	BURB	-	-	-	-	0	0	0	0
fathead minnow	FTMN	-	-	-	-	0	0	0	0
finescale dace	FNDC	-	1	-	-	0	3.4	0	0
lake chub	LKCH	1	3	22	6	5.6	10.3	40.7	15.8
lake whitefish	LKWH	-	-	-	-	0	0	0	0
longnose dace	LNDC	-	4	21	1	0	13.8	38.9	2.6
longnose sucker	LNSC	-	1	2	1	0	3.4	3.7	2.6
northern pike	NRPK	1	-	-	-	5.6	0	0	0
northern redbelly dace	NRDC	-	-	-	-	0	0	0	0
pearl dace	PRDC	-	-	-	-	0	0	0	0
slimy sculpin	SLSC	-	1	1	21	0	3.4	1.9	55.3
spoonhead sculpin	SPSC	9	7	-	-	50	24.1	0	0
spottail shiner	SPSH	-	-	-	-	0	0	0	0
trout-perch	TRPR	6	10	8	9	33.3	34.5	14.8	23.7
walleye	WALL	-	-	-	-	0	0	0	0
white sucker	WHSC	-	2	-	-	0	6.9	0	0
yellow perch	YLPR	-	-	-	-	0	0	0	0
Total Count		**18**	**29**	**54**	**38**	**100**	**100**	**100**	**100**
Total Abundance (#/m)		**0.04**	**0.12**	**0.22**	**0.15**				
Total Species Richness		**5**	**8**	**5**	**5**	**5**	**8**	**5**	**5**
Electrofishing effort (secs)		**2,980**	**1,372**	**1,480**	**1,375**	**-**	**-**	**-**	**-**
CPUE (#/100 secs)		**0.60**	**2.11**	**3.65**	**2.76**	**-**	**-**	**-**	**-**

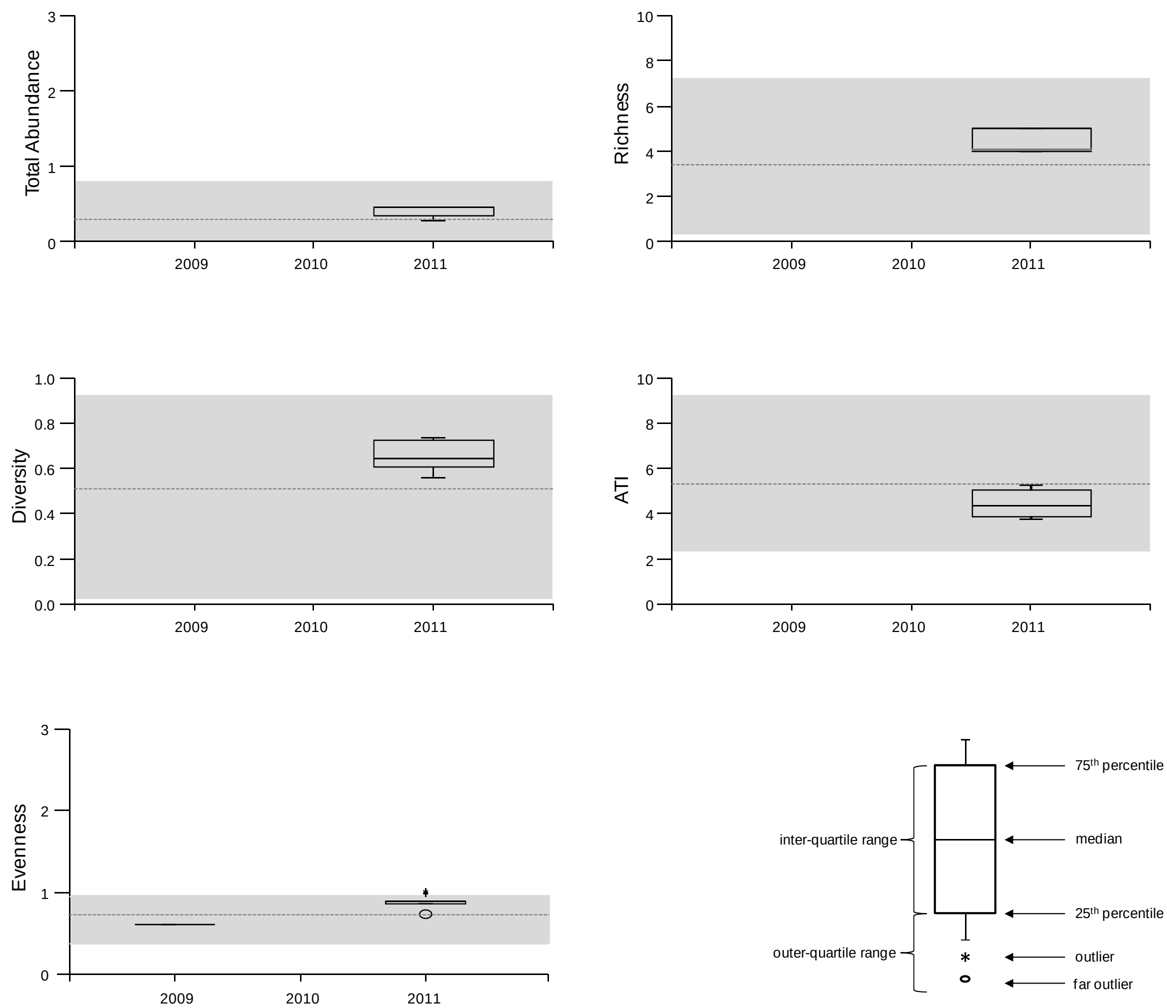
Table 5.5-15 Summary of fish assemblage measurement endpoints (± 1SD) in reaches of the MacKay River, 2009 to 2011.

Site	Year	Abundance		Richness			Diversity		Evenness		ATI	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MAR-F1	2009	0.04		4	4	-	0.58	-	0.60	-	5.57	-
	2011	0.12	0.05	7	4	0.84	0.69	0.06	0.87	0.10	5.93	0.95
MAR-F2	2011	0.22	0.05	5	3	1.10	0.52	0.21	0.75	0.18	6.17	0.32
MAR-F3	2011	0.15	0.05	5	3	1.30	0.44	0.28	0.79	0.05	4.66	1.51

SD=standard deviation across sub-reaches within a reach.

Figure 5.5-9 Box-plots showing variation in fish assemblage measurement endpoints in reaches of the MacKay River, 2009 to 2011.

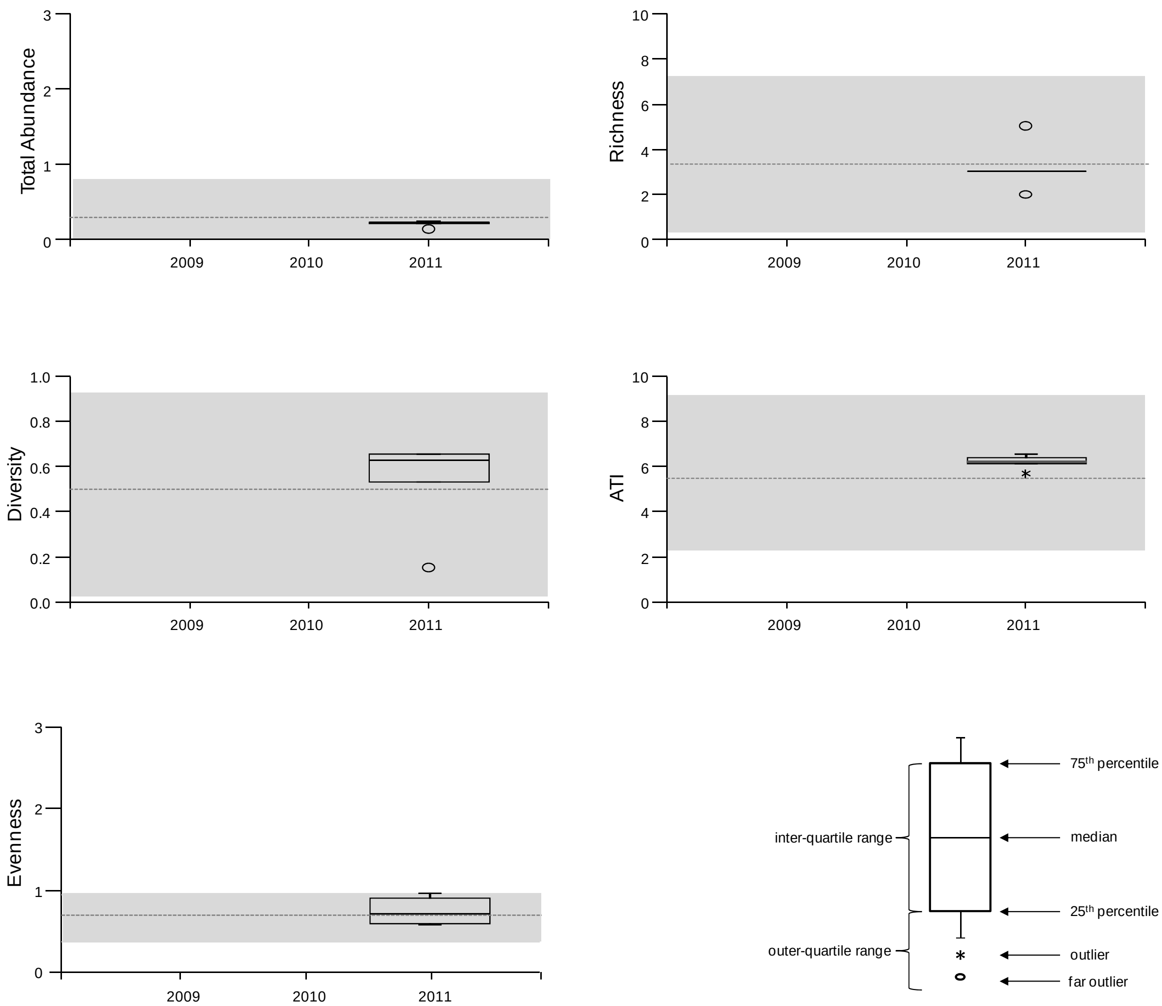
Erosional *Test* Reach MAR-F1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

Figure 5.5-9 (Cont'd.)

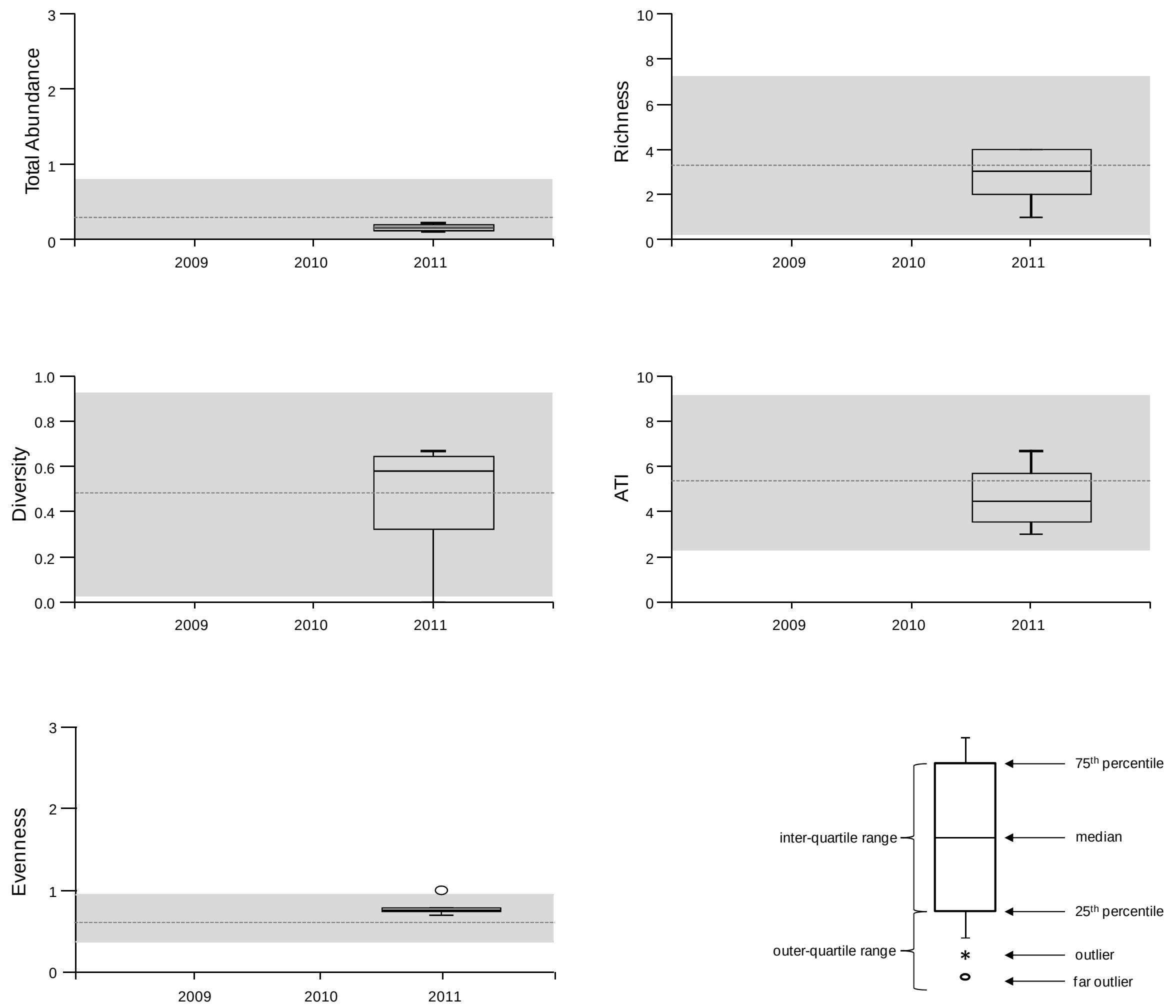
Erosional *Test* Reach MAR-F2



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

Figure 5.5-9 (Cont'd.)

Erosional *Baseline* Reach MAR-F3



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

5.6 CALUMET RIVER WATERSHED

Table 5.6-1 Summary of results for the Calumet River watershed.

Calumet River Watershed	Summary of 2011 Conditions	
Climate and Hydrology		
Criteria	**Station S16A** at the mouth	no station sampled
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 2011		
Fish Populations		
No Fish Populations component activities conducted in 2011		

Legend and Notes

- ○ (yellow) Negligible-Low
- ● (orange) Moderate
- ● (brown) High
- *baseline* (green shading)
- *test* (blue shading)

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 5.6-1 Calumet River watershed.

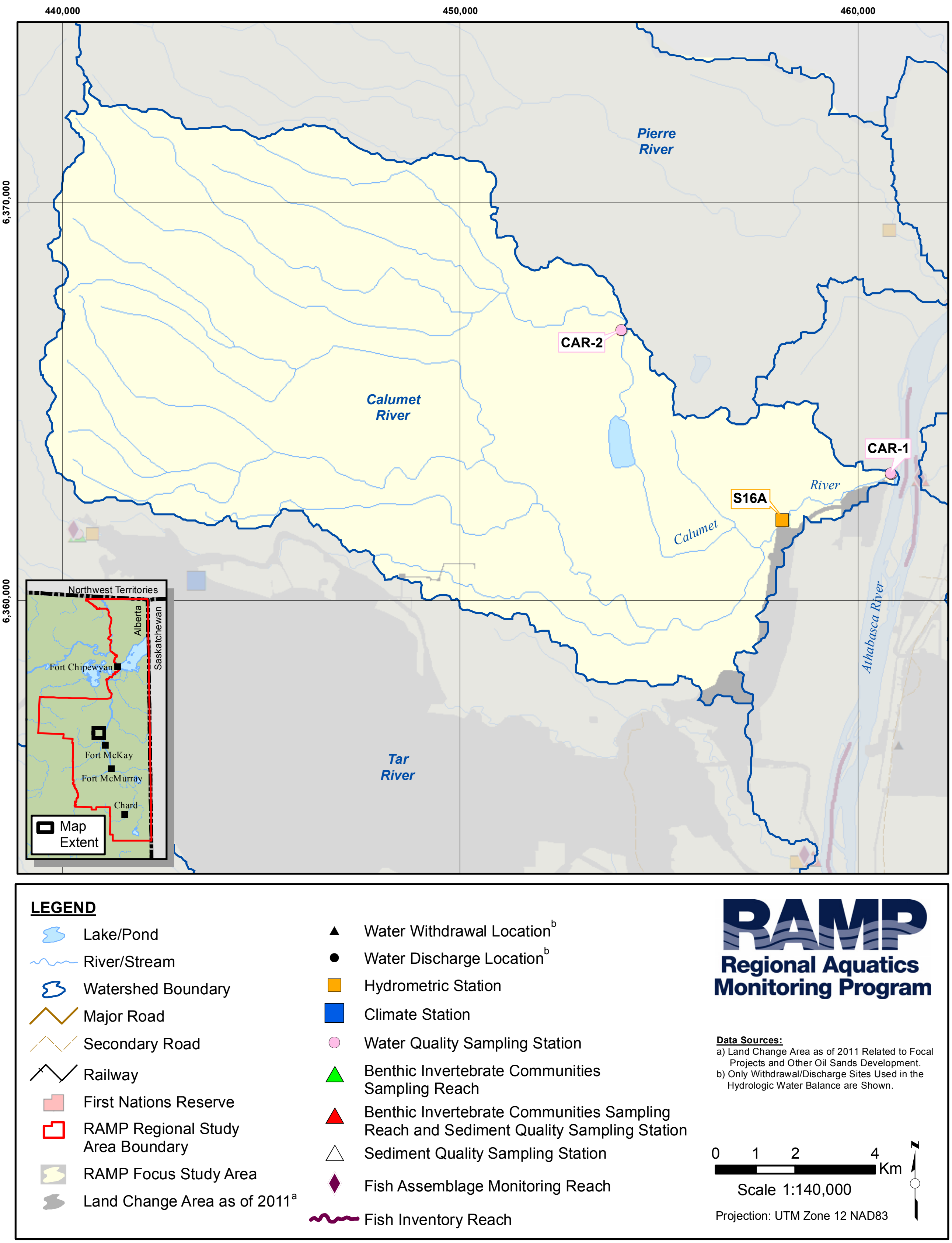


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Figure 5.6-2 Representative monitoring stations of the Calumet River, fall 2011.

Water Quality Station CAR-1: facing upstream

Water Quality Station CAR-1: Cross-channel, right downstream bank

Water Quality Station CAR-2: facing downstream

Water Quality Station CAR-2: Cross-channel, right downstream bank

5.6.1 Summary of 2011 Conditions

As of 2011, 1.14% (198 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).

Monitoring activities were conducted for the Climate and Hydrology and Water Quality components of RAMP in the Calumet River watershed in 2011. Table 5.6-1 is a summary of the 2011 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 2011. Figure 5.6-2 contains fall 2011 photos of the water quality monitoring stations in the watershed.

Hydrology For the 2011 WY, the mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for Station S16A were estimated to be 1.0% lower than from the estimated *baseline* hydrograph; these differences were classified as **Negligible-Low**.

Water Quality In fall 2011, water quality at both *test* station CAR-1 and *baseline* station CAR-2 showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of all water quality measurement endpoints at *test* station CAR-1 in fall 2011 were within the range of regional *baseline* concentrations with the exception of total dissolved solids, dissolved phosphorous, total strontium, total arsenic and sodium, which exceeded the 95th percentile of regional *baseline*. The ionic composition of water at *test* station CAR-1 was consistent with previous years, and the ionic composition of *baseline* station CAR-2 returned to that of historical measurements after a deviation in fall 2010.

5.6.2 Hydrologic Conditions: 2011 Water Year

Station S16A, Calumet River near the mouth Continuous hydrometric data have been collected during the open-water period at Station S16A since April 2010. In the 2011 WY, over two months of data (May 17 to July 26) were not recorded due to station damage by forest fires. Prior to 2010, 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 2011 WY data are not as robust.

In the 2011 WY, flows increased rapidly after monitoring began on April 24, and then decreased following a peak on May 5 to May 16 when monitoring ceased due to forest fires suggesting that a large proportion of the freshet runoff was captured within this short period (Figure 5.6-3). The peak flow of 2.2 m^3/s on May 5 was the highest value recorded in the 2011 WY and was slightly lower than the historical maximum daily flow recorded on May 5 in previous years (2.3 m^3/s). Flows were also slightly lower than historical maximum values during late July, when monitoring resumed following station repair. Flows decreased from a peak of 0.84 m^3/s on July 29 to a minimum open-water flow of 0.04 m^3/s on September 15. This minimum value was slightly lower than the minimum flow recorded on September 16 in previous years (0.05 m^3/s). Flows then remained relatively stable until the end of the 2011 WY period.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance for the 2011 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 2011 was estimated to be 1.89 km^2 (Table 2.5-1). The loss of flow to the Calumet River that would have otherwise occurred from this land area was estimated at approximately 43,000 m^3.
2. As of 2011, the area of land change in the Calumet watershed from focal projects that was not closed-circuited was estimated to be 0.44 km^2 (Table 2.5-1). The increase in flow to the Calumet River that would not have otherwise occurred from this land area was estimated at approximately 2,000 m^3.

The estimated cumulative effect of land change in the 2011 WY was a loss of flow 41,000 m^3 at Station S16A (Table 5.6-2). The observed *test* and estimated *baseline* hydrograph are presented in Figure 5.6-3. For the 2011 WY, the mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge for Station S16A were estimated to be 1.0% lower than from the estimated *baseline* hydrograph (Table 5.6-3); these differences were classified as Negligible-Low (Table 5.6-4).

5.6.3 Water Quality

In fall 2011, water quality samples were taken from:

- the Calumet River near its mouth (*test* station CAR-1, designated as *baseline* from 2002 to 2004 and *test* from 2005 to 2011); 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 or *baseline* station CAR-2.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints in fall 2011 were within the range of previously-measured concentrations (Table 5.6-4 and Table 5.6-5), with the exception of total suspended solids, dissolved organic carbon, total aluminum, and total mercury at *test* station CAR-1.

Ion Balance The ionic composition of water at *test* station CAR-1 in fall 2011 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 2011, the contribution of bicarbonate to the anion composition of water at *baseline* station CAR-2 returned to historic levels prior to the previous sampling year (i.e., 2010). Historically, water at *baseline* station CAR-2 has had a lower relative concentration of bicarbonate composition than water at *test* station CAR-1 (Figure 5.6-4).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints in fall 2011 were below water quality guidelines (Table 5.6-4 and Table 5.6-5) with the exception of:

- total dissolved phosphorous at *test* station CAR-1 and *baseline* station CAR-2;
- total aluminum at *test* station CAR-1 and *baseline* station CAR-2; and
- total nitrogen at *test* station CAR-1 and *baseline* station CAR-2.

Other Water Quality Guideline Exceedances *Test* station CAR-1 and *baseline* station CAR-2 had exceedances in fall 2011 of dissolved iron, sulphide, total chromium, total iron, total Kjeldahl nitrogen, total phenols and total phosphorous (Table 5.6-6).

2011 Results Relative to Regional *Baseline* Concentrations In fall 2011, concentrations of all water quality measurement endpoints were within the range of regional *baseline* concentrations at *test* station CAR-1 (Figure 5.6-5). At *baseline* station CAR-2, total dissolved solids, dissolved phosphorous, total strontium, total arsenic and sodium exceeded the 95th percentile of regional *baseline* concentrations. Similar to conditions observed in fall 2009 and 2010, 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 of 93.7 for *test* station CAR-1 in the Calumet River watershed in fall 2011 indicated a **Negligible-Low** difference from regional *baseline* conditions. This value is slightly lower than that measured in fall 2010, when the WQI value was 100. The WQI value of 80.9 at *baseline* station CAR-2 indicated a **Negligible-Low** difference from regional *baseline* conditions, but is also lower than the WQI value of 89.9 in fall 2010.

Classification of Results In fall 2011, water quality at both *test* station CAR-1 and *baseline* station CAR-2 showed **Negligible-Low** differences from regional *baseline* conditions. Concentrations of all water quality measurement endpoints at *test* station CAR-1 in fall 2011 were within the range of regional *baseline* concentrations with the exception of total dissolved solids, dissolved phosphorous, total strontium, total arsenic and sodium, which exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station CAR-2. The ionic composition of water at *test* station CAR-1 was consistent with previous years, and the ionic composition of *baseline* station CAR-2 returned to that of historical measurements after a deviation in fall 2010.

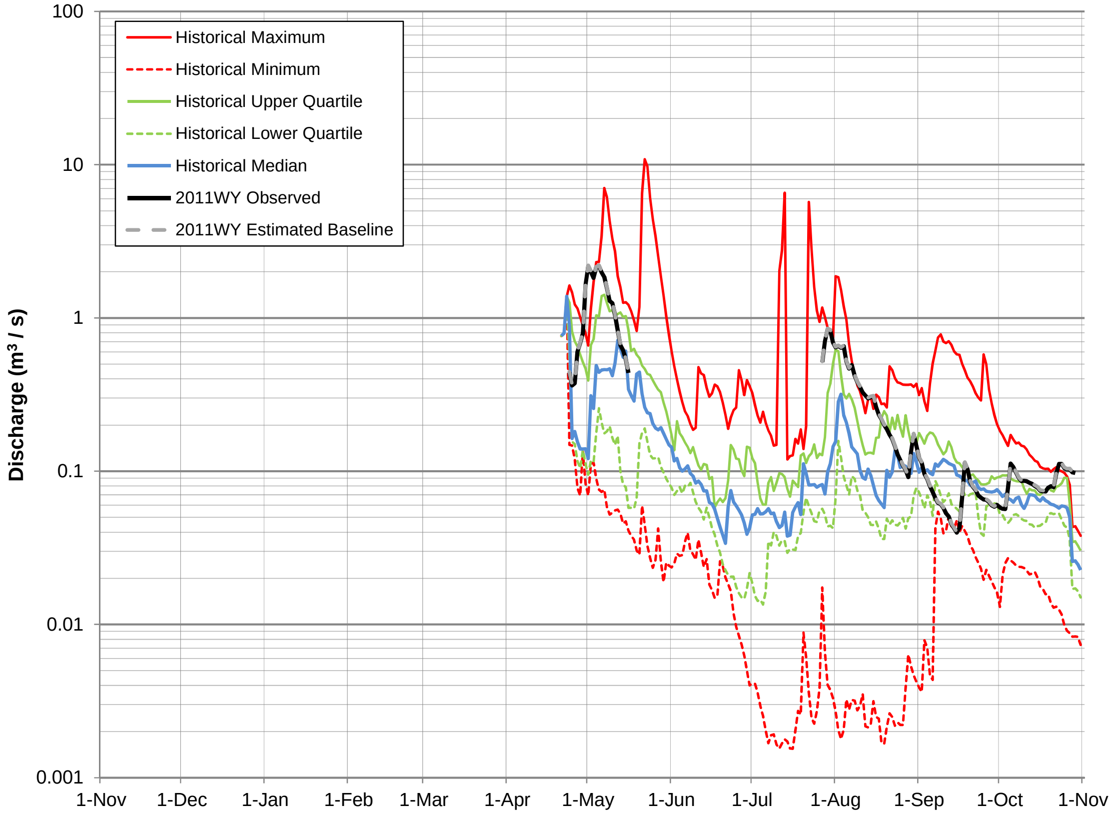
5.6.4 Benthic Invertebrate Communities and Sediment Quality

There were no Benthic Invertebrate Communities and Sediment Quality component activities conducted in the Calumet River watershed in 2011.

5.6.5 Fish Populations

There were no Fish Populations component activities conducted in the Calumet River watershed in 2011.

Figure 5.6-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Calumet River in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on Calumet River near the Mouth, RAMP Station S16A, provisional data for April 24 to May 16 and July 27 to October 29, 2011. The upstream drainage area is 173.5 km^2. Historical values from 2001 to 2010 calculated for the open-water period at Station S16 (2001 to 2004), Station CR-1 (2005 to 2009) and Station S16A (2010).

Table 5.6-2 Estimated water balance at Station S16A, Calumet River near the mouth, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**3.877**	**Observed discharge from Calumet River near the Mouth, RAMP Station S16A**
Closed-circuited area water loss from the observed *test* hydrograph	-0.043	Estimated 1.89 km^2 of the Calumet River watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.002	Estimated 0.44 km^2 of the Calumet River watershed with land change from focal projects as of 2011 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)	**3.918**	**Estimated *baseline* discharge from Calumet River near the Mouth, RAMP Station S16A.**
Incremental flow (change in total discharge)	-0.041	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 May 16 and July 27 to October 29, 2011 for Calumet River near the Mouth, RAMP Station S16A.

Table 5.6-3 Calculated change in hydrologic measurement endpoints in the Calumet River watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.364	0.360	-1.0%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	2.210	2.187	-1.0%
Open-water season minimum daily discharge	0.040	0.040	-1.0%

Note: Values are calculated from provisional data for April 24 to May 16 and July 27 to October 29, 2011 for Calumet River near the Mouth, RAMP Station S16A.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to three and one decimal places, respectively.

Table 5.6-4 Concentrations of water quality measurement endpoints, mouth of Calumet River (*test* station CAR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	9	8.1	8.2	8.4
Total suspended solids	mg/L	-	<u>66</u>	9	<3	10	41
Conductivity	µS/cm	-	651	9	188	554	702
Nutrients							
Total dissolved phosphorus	mg/L	0.05	**0.07**	9	0.03	0.06	0.08
Total nitrogen	mg/L	1.0	**1.5**	9	0.8	**1.3**	**1.5**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	<u>40.7</u>	9	22.0	32.0	38.0
Ions							
Sodium	mg/L	-	50.4	9	7.0	48.4	71.0
Calcium	mg/L	-	57.0	9	25.3	55.3	67.3
Magnesium	mg/L	-	19.3	9	7.8	17.9	22.5
Chloride	mg/L	230, 860	17.1	9	2.0	14.0	34.0
Sulphate	mg/L	100	6.9	9	3.6	12.3	20.5
Total dissolved solids	mg/L	-	468	9	151	394	480
Total alkalinity	mg/L		330	9	96	275	337
Selected metals							
Total aluminum	mg/L	0.1	<u>**1.28**</u>	9	0.04	**0.15**	**0.34**
Dissolved aluminum	mg/L	0.1	0.0033	9	0.0013	0.0036	0.0058
Total arsenic	mg/L	0.005	0.0016	9	0.0009	0.0010	0.0012
Total boron	mg/L	1.2	0.085	9	0.074	0.083	0.122
Total molybdenum	mg/L	0.073	0.00015	9	0.00011	0.00015	0.00030
Total mercury (ultra-trace)	ng/L	5, 13	<u>3.8</u>	8	<1.2	<1.2	2.6
Total strontium	mg/L	-	0.29	9	0.17	0.23	0.30
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	15.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	105.0	0	-	-	-
Total PAHs	ng/L	-	493.6	0	-	-	-
Total Parent PAHs	ng/L	-	29.1	0	-	-	-
Total Alkylated PAHs	ng/L	-	464.5	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.55**	9	0.27	**0.49**	**0.91**
Sulphide	mg/L	0.002	**0.020**	9	0.005	**0.014**	**0.028**
Total chromium	mg/L	0.001	<u>**0.0017**</u>	9	0.0002	0.0005	0.0010
Total iron	mg/L	0.3	**2.95**	9	**0.54**	**1.46**	**3.14**
Total Kjeldahl Nitrogen	mg/L	1	**1.4**	9	0.7	**1.2**	**1.5**
Total phenols	mg/L	0.004	**0.008**	8	<0.001	**0.009**	**0.013**
Total phosphorous	mg/L	0.05	**0.21**	9	**0.07**	**0.09**	**0.10**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.6-5 Concentrations of water quality measurement endpoints, upper Calumet River (*baseline* station CAR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.0	6	7.7	8.0	8.2
Total suspended solids	mg/L	-	22	6	<3	4	208
Conductivity	µS/cm	-	683	6	526	597	772
Nutrients							
Total dissolved phosphorus	mg/L	0.05	**0.16**	6	**0.09**	**0.12**	**0.31**
Total nitrogen	mg/L	1.0	**1.9**	6	**1.8**	**2.2**	**5.5**
Nitrate+nitrite	mg/L	1.3	<0.071	6	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	53.8	6	40.0	47.5	54.4
Ions							
Sodium	mg/L	-	70.5	6	53	67	76
Calcium	mg/L	-	47.3	6	44.0	50.7	68.2
Magnesium	mg/L	-	20.5	6	17.7	19.5	26.6
Chloride	mg/L	230, 860	14.4	6	12.3	15.7	17.0
Sulphate	mg/L	100	55.8	6	45.3	62.2	101.0
Total dissolved solids	mg/L	-	469	6	370	467	547
Total alkalinity	mg/L		284	6	188	236	315
Selected metals							
Total aluminum	mg/L	0.1	**0.60**	6	0.02	0.06	**4.10**
Dissolved aluminum	mg/L	0.1	0.007	6	0.004	0.015	0.024
Total arsenic	mg/L	0.005	0.0035	6	0.0021	0.0025	0.0050
Total boron	mg/L	1.2	0.111	6	0.081	0.091	0.128
Total molybdenum	mg/L	0.073	0.00057	6	0.00009	0.00042	0.00080
Total mercury (ultra-trace)	ng/L	5, 13	1.3	6	<1.2	1.3	4.4
Total strontium	mg/L	-	0.32	6	0.24	0.28	0.36
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	3.7	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.9	0	-	-	-
Total PAHs	ng/L	-	151.2	0	-	-	-
Total Parent PAHs	ng/L	-	19.3	0	-	-	-
Total Alkylated PAHs	ng/L	-	132.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.55**	6	0.24	**0.39**	**1.50**
Sulphide	mg/L	0.002	**0.08**	6	**0.02**	**0.03**	**0.59**
Total chromium	mg/L	0.001	**0.0012**	6	0.0005	0.0007	**0.0060**
Total iron	mg/L	0.3	**1.60**	6	**0.55**	**0.99**	**6.68**
Total Kjeldahl Nitrogen	mg/L	1	**1.8**	6	**1.7**	**2.1**	**5.5**
Total phenols	mg/L	0.004	**0.014**	6	**0.008**	**0.015**	**0.041**
Total phosphorous	mg/L	0.05	**0.30**	6	0.10	0.32	1.48

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.6-6 Water quality guideline exceedances, Calumet River watershed, fall 2011.

Variable	Units	Guideline[a]	CAR-1	CAR-2
Fall				
Dissolved iron	mg/L	0.3	0.55	0.55
Sulphide	mg/L	0.002	0.020	0.076
Total aluminum	mg/L	0.1	1.28	0.60
Total chromium	mg/L	0.001	0.0017	0.0012
Total dissolved phosphorus	mg/L	0.052	0.066	0.159
Total iron	mg/L	0.3	2.95	1.60
Total Kjeldahl Nitrogen	mg/L	1	1.4	1.8
Total nitrogen	mg/L	1	1.49	1.90
Total phenols	mg/L	0.004	0.008	0.014
Total phosphorous	mg/L	0.05	0.21	0.30

[a] Sources for all guidelines are outlined in Table 3.2-5.

Figure 5.6-4 Piper diagram of fall ion concentrations in Calumet River watershed.

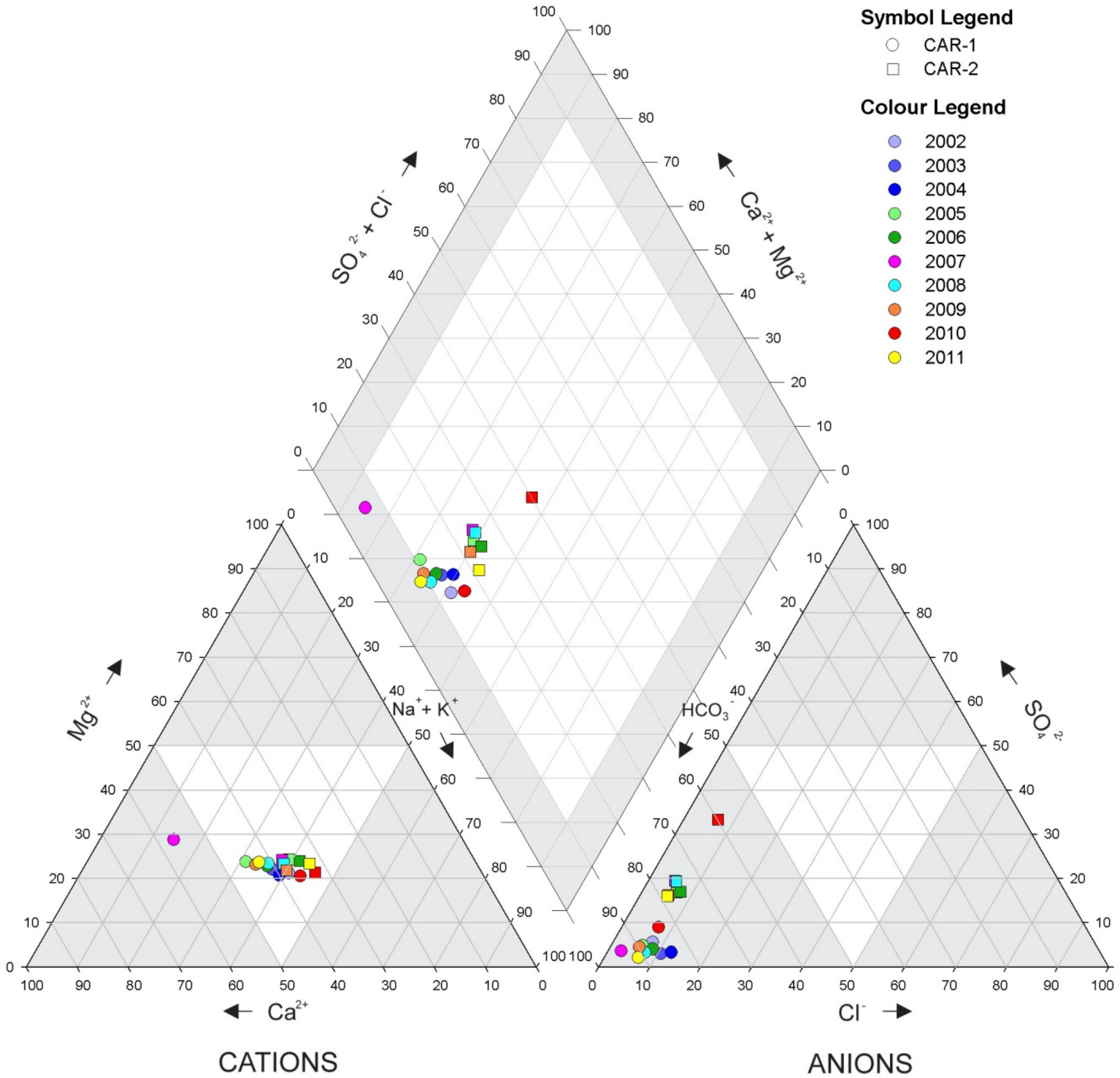
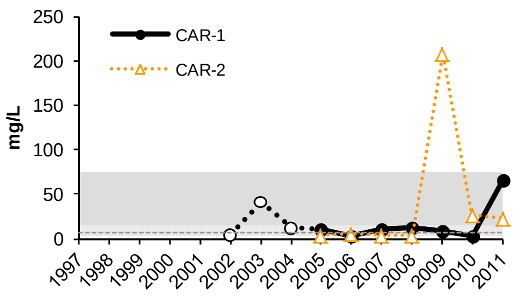
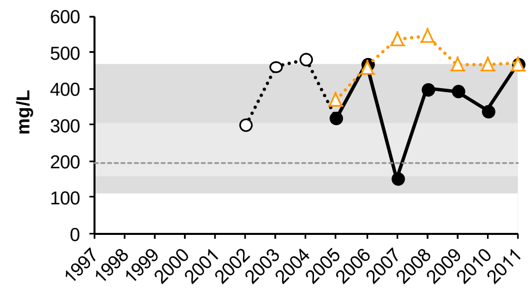


Figure 5.6-5 Concentrations of selected water quality measurement endpoints in the Calumet River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

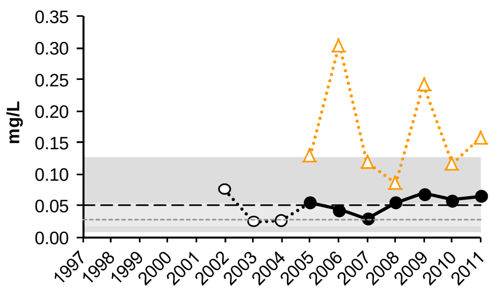
Total Suspended Solids (TSS)



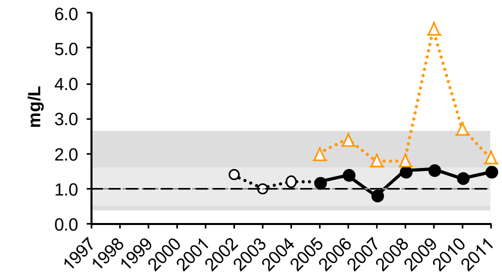
Total Dissolved Solids (TDS)



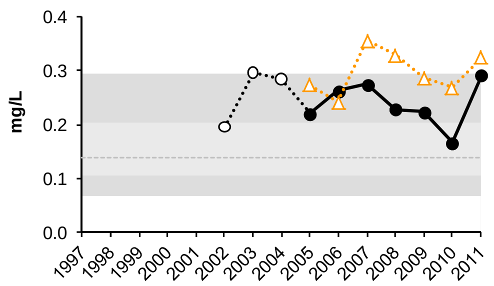
Dissolved Phosphorus



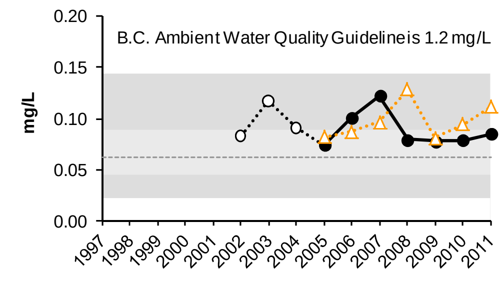
Total Nitrogen



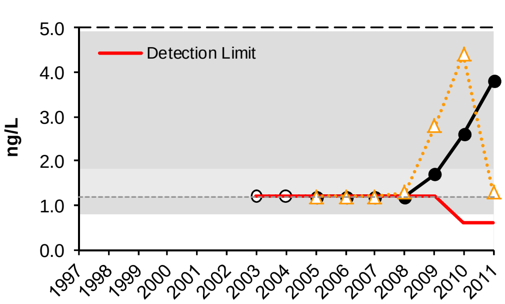
Total Strontium



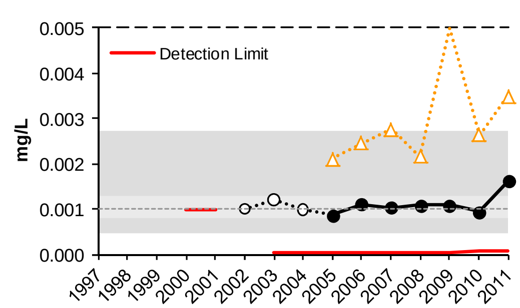
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



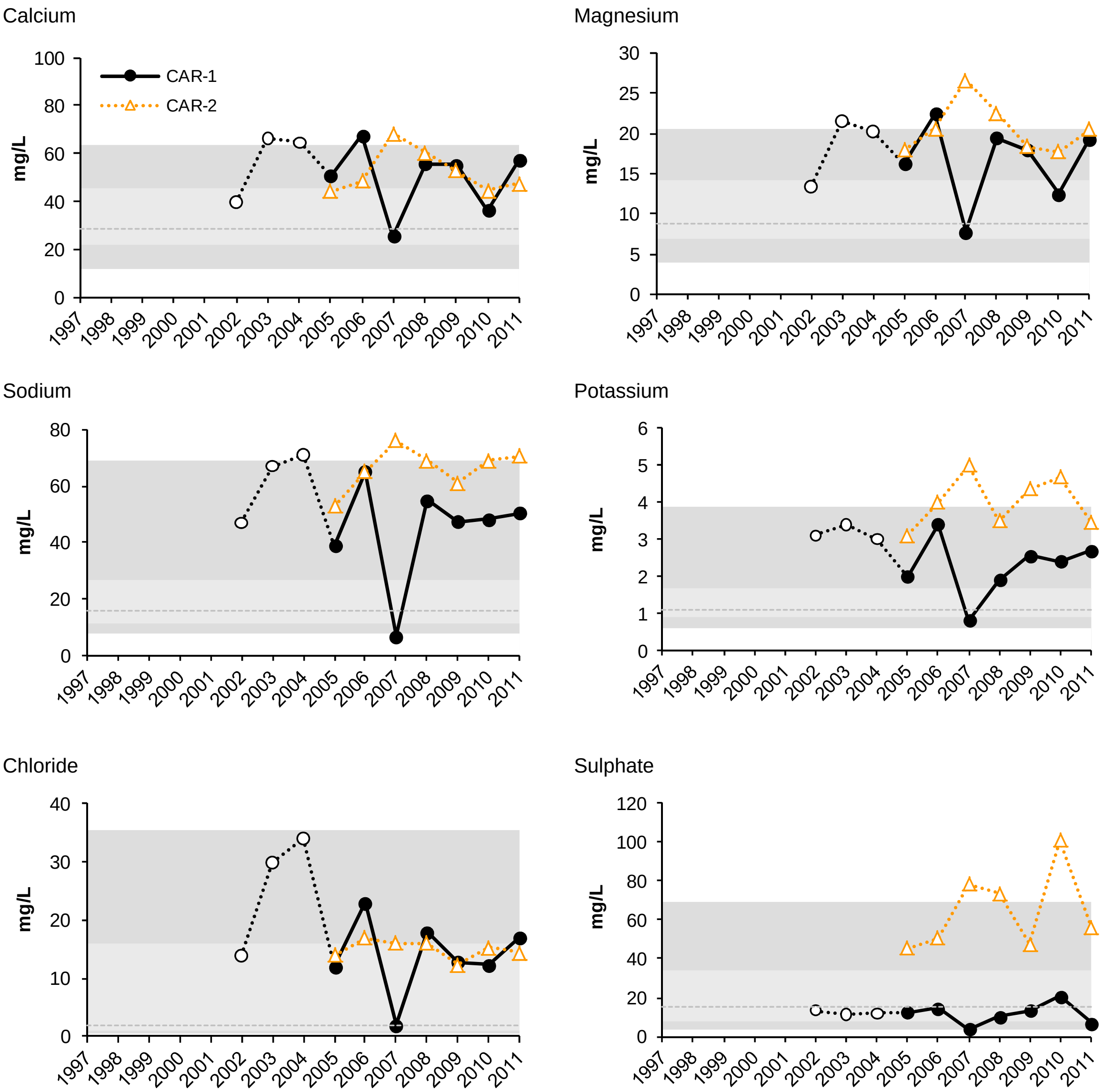
Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.6-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●———● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

5.7 FIREBAG RIVER WATERSHED

Table 5.7-1 Summary of results for the Firebag River watershed.

Firebag River Watershed	Summary of 2011 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	**JOL-1** Johnson Lake
Water Quality Index	○	○	n/a	n/a
Benthic Invertebrate Communities and Sediment Quality				
Criteria	**FIR-D1** at the mouth	**FIR-E2** upstream of Suncor Firebag	**MCL-1** McClelland Lake	**JOL-1** Johnson Lake
Sediment Quality Index	not sampled	not sampled	n/a	n/a
Benthic Invertebrate Communities	not sampled	not sampled	n/a	n/a
Fish Populations				
No Fish Populations component activities conducted in 2011				

Legend and Notes

- ○ (yellow) Negligible-Low
- ● (orange) Moderate
- ● (brown) High
- *baseline* (green shading)
- *test* (blue shading)

n/a - not applicable, summary indicators for *test* reaches/stations were designated based on comparisons with *baseline* reaches/station or regional *baseline* conditions. The WQI/SQI was not calculated given the limited existing *baseline* data for lakes.

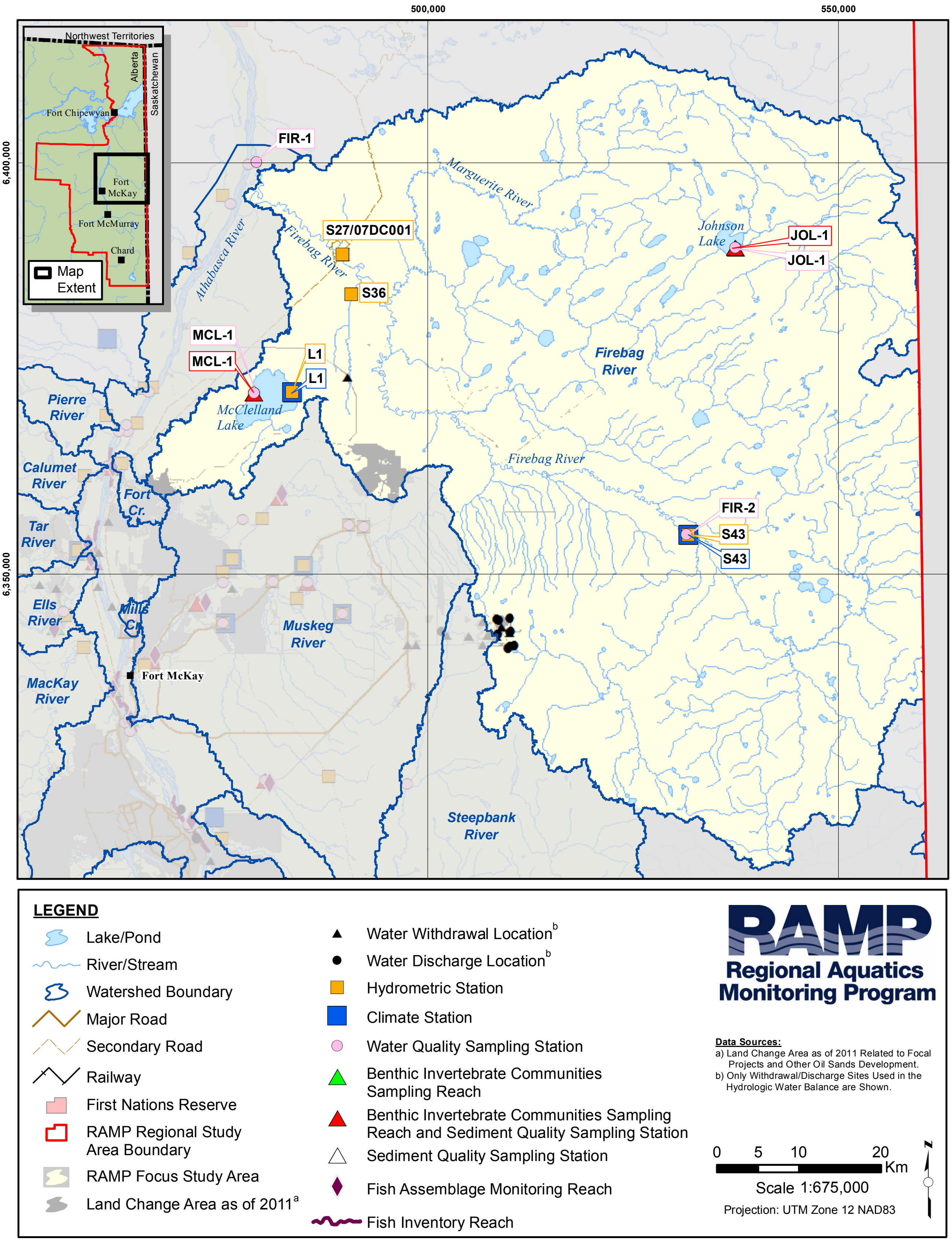
Hydrology: Measurement endpoints calculated on differences between observed *test* and estimated *baseline* hydrographs that would have been observed in the absence of focal projects and other oil sands developments in the watershed: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High.

Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions; 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\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_K07_Firebag_20120423.mxd

Figure 5.7-2 Representative monitoring stations of the Firebag River watershed, fall 2011.

Water Quality Station FIR-1:
Right Downstream Bank, facing upstream

Water Quality Station FIR-1:
Left Downstream Bank, cross-section

Water Quality Station FIR-2:
Right Downstream Bank, facing downstream

Water Quality Station JOL-1:
Johnston Lake, aerial view

Hydrology Station L1:
McClelland Lake

Water Quality Station MCL-1:
McClelland Lake

5.7.1 Summary of 2011 Conditions

Approximately 0.80% (4,500 ha) of the Firebag River watershed had undergone land change as of 2011 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, and Benthic Invertebrate Communities and Sediment Quality components of RAMP in the Firebag River watershed in 2011. Table 5.7-1 is a summary of the 2011 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 2011. Figure 5.7-2 contains fall 2011 photos of a number of monitoring stations in the watershed.

Hydrology The calculated mean open-water period discharge was 0.12% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph; the calculated mean winter discharge and open-water minimum daily discharge were 0.11% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated annual maximum daily discharge was 0.10% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality In fall 2011, 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 2011 at both Firebag River stations and McClelland Lake was consistent with previous sampling years. Concentrations of most water quality measurement endpoints at *test* station FIR-1 and *baseline* station FIR-2 were within the range of regional *baseline* concentrations in fall 2011. Concentrations of water quality measurement endpoints from *test* station MCL-1 and *baseline* station JOL-1 were not compared to regional *baseline* conditions given the ecological differences between lakes and rivers. Many water quality measurement endpoints, primarily ions and select metals, exceeded previously-measured maximum concentrations at all stations in the Firebag River watershed.

Benthic Invertebrate Communities and Sediment Quality The differences in measurement endpoints for benthic invertebrate communities of McClelland Lake were classified as **Negligible-Low** because, while there were significant increases in total abundance, taxa richness, and diversity at *test* station MCL-1 between the period it has been designated as *test* and the period it was designated as *baseline*, these increases generally implied improvements in water and/or sediment quality, particularly given that the dominant organisms in the lake did not change over time. The general composition of the community in terms of relative abundances, presence of fully aquatic forms and presence of generally sensitive taxa such as the mayfly *Caenis* and the caddisfly *Mystacides* all suggested that the benthic invertebrate community in McClelland Lake was in good condition and generally consistent with the community during the *baseline* period. The benthic invertebrate community at *baseline* station JOL-1 was indicative of good water and sediment quality conditions due to a large relative abundance of permanent aquatic forms such as Amphipoda and bivalve clams, the presence of relatively sensitive and large aquatic insect larvae (caddisflies *Molanna*, *Molannodes* and *Oecetis*), and a low relative abundance of tubificid worms. Johnson Lake will be used as a regional *baseline* station for comparisons to *test* lakes, once more data are collected over time.

Concentrations of sediment quality measurement endpoints at *test* station MCL-1 were generally within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although concentrations of silt and total organic carbon were higher than previously-measured maximum concentrations and concentrations of sand and naphthalene were lower than previously-measured minimum concentrations. Sediment toxicity to invertebrates showed historically high survival of both *Hyalella* and *Chironomus*, and historically high growth of *Hyalella* at *test* station MCL-1. Fall 2011 represented the first year of sampling at *baseline* station JOL-1; sediment quality collected at *baseline* station JOL-1 was generally similar to sediments collected from *test* station MCL-1, with the exception of concentrations of total hydrocarbons and total metals that were slightly higher, and measurement endpoints for sediment toxicity that were slightly lower than those measured at *test* station MCL-1.

5.7.2 Hydrologic Conditions: 2011 Water Year

WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth Continuous annual hydrometric data have been collected for the Firebag River near the Mouth, WSC Station 07DC001 (RAMP Station S27) from 1972 to 2011. The 2011 water year (WY) annual runoff volume was 615 million m^3, which was 23% lower than the historical annual runoff volume of 801 million m^3. The runoff volume in the 2011 open-water period (May to October) was 332 million m^3, which was 44% lower than the historical mean open-water runoff volume of 596 million m^3. Flows from November 2010 to February 2011 were generally higher than historical upper quartile values (Figure 5.7-3), and all values from December 24, 2010 to January 22, 2011 were higher than the historical maximum values recorded on these days in previous years. Flows increased during freshet in April and early May 2011 to a peak flow of 54.1 m^3/s on May 6. This was the highest flow recorded in the 2011 WY, and was 51% lower than the historical mean maximum daily flow for the open-water period. Flows decreased following the peak until mid-June, and generally remained in the lower quartile of historical values until the end of the 2011 WY. The minimum open-water daily flow of 13.8 m^3/s recorded on October 21 was 11% lower than the historical open-water mean minimum daily flow of 15.5 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 2011 in the Firebag River watershed was 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 was 0.26 million m^3.

2. As of 2011, the area of land change in the Firebag watershed from focal projects that was not closed-circuited was estimated to be 42.8 km^2 (Table 2.5-1). The increase in flow to the Firebag River that would not have otherwise occurred from this land area was estimated at 0.88 million m^3.

3. In the 2011 WY, Imperial withdrew water from Moose Creek and Suncor withdrew water from various sources in the Firebag watershed for dust suppression, totaling approximately 2,400 m^3.

4. Suncor discharged approximately 0.10 million m^3 of water to the Firebag watershed as part of water management activities.

The estimated cumulative effect was an increase in flow of 0.71 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 was 0.12% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph; the calculated mean winter discharge and open-water minimum daily discharge were 0.11% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph, while the calculated annual maximum daily discharge was 0.10% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.7-3). These differences were classified as **Negligible-Low** (Table 5.7-1).

McClelland Lake, RAMP Station L1 Water levels recorded at Station L1 increased gradually from November 2010 to April 2011, although only manual measurements of water level were available from January 23 to May 12 due to ice cover around the pressure transducer due to extreme weather conditions (Figure 5.7-4). Lake levels were consistently below the historical median during this six-month period, and were near historical minimum values recorded in December, February and March. When continuous monitoring resumed on May 12, lake levels decreased gradually until the end of the 2011 WY, with daily values consistently between historical median and minimum values. Lake levels receded to below historical minimum values from October 28 to 31, 2011.

5.7.3 Water Quality

In fall 2011, 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);
- McClelland Lake (*test* station MCL-1, designated as *baseline* from 2000 to 2009 and *test* in 2010 and 2011); and
- Johnson Lake, a new *baseline* station (JOL-1) that was added to the program in 2011.

Given *baseline* station JOL-1 is a new station, water quality samples were also taken in winter and summer 2011. Water quality samples were not taken in spring due to forest fires in the area of the lake.

Temporal Trends Significant (α=0.05) increasing and decreasing trends in total dissolved solids and sulphate, respectively, were observed in fall over time at *test* station MCL-1 (sampled 2000 to 2003 and 2006 to 2011). No significant trends in fall concentrations of water quality measurement endpoints were observed at *test* station FIR-1 or *baseline* station FIR-2 over time. Trend analysis could not be conducted on *baseline* station JOL-1, as this station was first sampled in 2011.

2011 Results Relative to Historical Concentrations Water quality measurement endpoints outside their historically measured ranges in fall 2011 were (Table 5.7-4 to Table 5.7-7):

- pH, conductivity, total alkalinity, sodium, chloride, total strontium and total boron, with concentrations that exceeded their previously-measured maximum concentrations at *test* station FIR-1;
- total dissolved phosphorus and dissolved aluminum, with concentrations that were below previously-measured minimum concentrations at *test* station FIR-1;

- total molybdenum and total boron, with concentrations that exceeded their previously-measured maximum concentrations and dissolved aluminum with a concentration that was below the previously-measured minimum concentration at *baseline* station FIR-2; and

- conductivity, total dissolved solids, total suspended solids, magnesium and total boron, with concentrations that exceeded their previously-measured maximum concentrations at *test* station MCL-1.

Historical comparisons of data at *baseline* station JOL-1 were not possible given this was the first year that this station was sampled.

Ion Balance The ionic composition of water sampled in fall 2011 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 relative concentrations of calcium were measured. The ionic composition of McClelland Lake, *test* station MCL-1, in fall 2011 was consistent with that of previous years and dominated by magnesium and bicarbonate (Figure 5.7-5). The new b*aseline* station, JOL-1, has an ionic composition similar to *test* station FIR-1 and *baseline* station FIR-2 (Figure 5.7-5), although absolute concentrations of several ions in Johnson Lake were generally higher than those at the other three stations in the watershed (e.g., calcium and chloride).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality endpoints in fall 2011 were below water quality guidelines with the exception of total nitrogen at *baseline* station JOL-1 (Table 5.7-7) and *test* station MCL-1 (Table 5.7-6).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in fall 2011 (Table 5.7-8):

- total iron at *test* station FIR-1;

- total phosphorous at *baseline* station FIR-2;

- dissolved silver, total phenols, and total silver at *test* station MCL-1; and

- sulphide, total iron, total Kjeldahl nitrogen, total phenols and total phosphorous at *baseline* station JOL-1.

The following water quality guideline exceedances were measured in other seasons at b*aseline* station JOL-1 (Table 5.7-8):

- total iron, total Kjeldahl nitrogen, total nitrogen, total phenols and total phosphorous in winter; and

- sulphide, total Kjeldahl nitrogen, total nitrogen, total phenols and total phosphorous in summer.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints in fall 2011 at *test* station FIR-1 were within regional *baseline* fall concentrations with the exception of total nitrogen, which was below the 5th percentile of regional *baseline* concentrations (Figure 5.7-6). Due to a decrease in the analytical detection limit for total mercury in 2010, fall concentrations in 2011 were below the 5th percentile of its regional *baseline* concentrations for *test* station FIR-1 and *baseline* station FIR-2. Concentrations of water quality measurement endpoints in McClelland

Lake (*test* station MCL-1) and Johnson Lake (*baseline* station JOL-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 (Figure 5.7-7).

Water Quality Index The WQI values for *test* station FIR-1 (98.7) and *baseline* station FIR-2 (98.7) in the Firebag River watershed in fall 2011 indicated **Negligible-Low** differences from regional *baseline* conditions, and were similar to WQI values in 2010. WQI values were not calculated for McClelland Lake and Johnson Lake because lakes were not compared to regional *baseline* conditions.

Classification of Results In fall 2011, 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 2011 at both Firebag River stations and McClelland Lake was consistent with previous sampling years. Concentrations of most water quality measurement endpoints at *test* station FIR-1 and *baseline* station FIR-2 were within the range of regional *baseline* concentrations in fall 2011. Concentrations of water quality measurement endpoints from *test* station MCL-1 and *baseline* station JOL-1 were not compared to regional *baseline* conditions given the ecological differences between lakes and rivers. Many water quality measurement endpoints, primarily ions and select metals, exceeded previously-measured maximum concentrations at all stations in the Firebag River watershed.

5.7.4 Benthic Invertebrate Communities and Sediment Quality

5.7.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 at:

- McClelland Lake (*test* station MCL-1), designated as *baseline* from 2002 to 2003 and 2006 to 2009 and as *test* in 2010 and 2011; and
- Johnson Lake (*baseline* station JOL-1, initiated as a new RAMP station in fall 2011).

McClelland Lake

2011 Habitat Conditions Samples were taken at a depth of 2 m at *test* station MCL-1. The substrate was dominated by silt and organic substrate (34% TOC). Water in McClelland Lake was alkaline (pH: 8.6), with low conductivity (239 µS/cm), which was consistent with previous years (Table 5.7-9).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* station MCL-1 in fall 2011 was dominated by chironomids (42%), with subdominant taxa consisting of Hydracarina (12%), naidid worms (10%), and Ostracoda (10%) (Table 5.7-10). Bivalve clams, gastropod snails, and caddisflies (Trichoptera) were present in low (1% or less) relative abundances. Mayflies were the most abundant of the EPT taxa (5%) and were represented by the common form *Caenis* and caddisflies were represented by *Oxyethira*. The dominant chironomids included *Dicrotendipes*, *Paratanytarsus*, *Einfeldia*, *Chironomus,* and *Ablabesmyia,* all of which are very common in northern temperate lakes (Wiederholm 1983).

Temporal Comparisons For temporal comparisons, changes in values of measurement endpoints for benthic invertebrate communities at *test* station MCL-1 were compared between years before (2002 through to 2009) and after (2010 and 2011) the station was designated as *test* (Hypothesis 2, Section 3.2.3.1). Total abundance and Simpson's diversity were significantly higher in the period that station MCL-1 has been designated as *test*, explaining approximately 30% of the variation in annual mean abundance and diversity. Richness was also significantly higher during the *test* period; however, the difference accounted for only a small amount of variation (<20%) in annual mean richness (Table 5.7-11, Figure 5.7-8). While evenness and percent EPT were not significantly different between *baseline* and *test* periods, both CA axis 1 and 2 scores were higher during the period that station MCL-1 has been designated as *test* (Table 5.7-11, Figure 5.7-9).

Comparison to Published Literature The benthic invertebrate community at *test* station MCL-1 is relatively typical of lake environments with a water depth of 2 m (Parsons *et al.* 2010, Pennak 1986) with both tolerant (e.g., *Chironomus*) and more sensitive chironomid taxa (e.g., *Einfeldia*) present in the lake (Resh and Unzicker 1975). *Test* station MCL-1 contained several taxa considered to be permanent aquatic forms including bivalves and gastropods in addition to flying insects (Ephemeroptera and Trichoptera) indicating good long-term water quality conditions (Niemi *et al.* 1990).

2011 Results Relative to Historical Conditions Values of all measurement endpoints for benthic invertebrate communities in fall 2011 at *test* station MCL-1 were within the range of previously-measured values (Figure 5.7-8) with the exception of richness (24 taxa) and diversity, which were higher than previously-measured values (Figure 5.7-8).

Classification of Results The differences in measurement endpoints for benthic invertebrate communities of McClelland Lake were classified as **Negligible-Low** because while there were significant increases in total abundance, taxa richness, and diversity at *test* station MCL-1 between the period it has been designated as *test* and the period it was designated as *baseline*, these increases generally implied improvements in water and/or sediment quality, particularly given that the dominant organisms in the lake did not change over time. The general composition of the community in terms of relative abundances, presence of fully aquatic forms and presence of generally sensitive taxa such as the mayfly *Caenis* and the caddisfly *Mystacides* all suggested that the benthic invertebrate community in McClelland Lake was in good condition and generally consistent with the community during the *baseline* period.

Johnson Lake

2011 Habitat Conditions Samples were taken at a depth of 1 m at *baseline* station JOL-1. The substrate at *baseline* station JOL-1 was dominated by silt (64%) with smaller amounts of sand (28%) and clay (8%) with high total organic carbon (19%) (Table 5.7-9). Water in Johnson Lake in fall 2011 was slightly alkaline (pH: 8.5), with moderate conductivity (338 µS/cm) (Table 5.7-9).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *baseline* station JOL-1 in fall 2011 was dominated by Amphipoda (37%) and chironomids (33%), with subdominant taxa consisting of bivalves (19%) ostracods (3%) and tubificids (3%) (Table 5.7-10). Common amphipods included *Hyalella azteca* and *Gammarus lacustris*, both of which are commonly distributed in Canada (Väinölä *et al*. 2008). Common bivalves were fingernail clams (Sphaeriidae; *Pisidium* and *Sphaerium*). Chironomids were diverse with 15 genera including the common forms *Microtendipes* and *Procladius* (Wiederholm 1983). Trichoptera were present in low relative abundance primarily from the well-distributed genera *Molanna*, *Molannodes* and *Oecetis* (Wiggins 1977).

Comparison to Published Literature The benthic invertebrate community at *baseline* station JOL-1 has fauna that reflected generally good water quality and lentic (lake-like) conditions with several permanent aquatic forms including Amphipoda and fingernail clams (Bivalvia: Sphaeriidae), which are consistent with good long-term water quality conditions (Niemi *et al*. 1990, Pennak 1989) and three genera of caddisflies. Tubificidae worms were present in low relative abundance. Comparisons to McClelland Lake indicate that Johnson Lake has lower values of all measurement endpoints; however, it should be noted that Johnson Lake is smaller and shallower than McClelland Lake and is more consistent in physical conditions to Kearl Lake within the Muskeg River watershed (Section 5.2; Figure 5.2-19).

2011 Results Relative to Historical Conditions Values of measurement endpoints for benthic invertebrate communities in fall 2011 were not compared to historical conditions given that 2011 was the first year that *baseline* station JOL-1 was sampled.

Classification of Results The benthic invertebrate community at *baseline* station JOL-1 was indicative of good water and sediment quality conditions due to a large relative abundance of permanent aquatic forms such as Amphipoda and bivalve clams, the presence of relatively sensitive and large aquatic insect larvae (caddisflies *Molanna*, *Molannodes* and *Oecetis*), and a low relative abundance of tubificid worms. Johnson Lake will be used as a regional *baseline* station for comparisons to *test* lakes, once more data are collected.

5.7.4.2 Sediment Quality

In fall 2011, sediment quality samples were taken from:

- McClelland Lake (*test* station MCL-1 as *baseline* in 2002, 2003, and 2006 to 2009, and as *test* in 2010 and 2011); and
- Johnson Lake (*baseline* station JOL-1, initiated as a new RAMP station in fall 2011).

Temporal Trends No significant trends ($\alpha=0.05$) in concentrations of sediment quality measurement endpoints were detected for *test* station MCL-1 in fall 2011. Trend analysis could not be completed for *baseline* station JOL-1, given only one year of data exists for this station.

2011 Results Relative to Historical Concentrations *Test* station MCL-1 in fall 2011 was dominated by silt, which comprised a higher percentage of total sediments than observed previously (Table 5.7-12, Figure 5.7-10), while sediment composition at *baseline* station JOL-1 was dominated by sand. Concentrations of total organic carbon exceeded previously-measured maximum concentrations at *test* station MCL-1. The absolute concentration of total metals was within the range of previously-measured concentrations at *test* station MCL-1; however, total metals normalized to %silt and clay were below previously-measured minimum concentrations due to the higher proportion of silt observed in fall 2011. Concentrations of total metals, both absolute and normalized to %sand and silt, were higher in sediments measured at *baseline* station JOL-1 than at *test* station MCL-1. In fall 2011, concentrations of all other sediment quality measurement endpoints were within the range of previously-measured concentrations at *test* station MCL-1 with the exception of naphthalene, which was lower than previously-measured minimum concentrations.

Concentrations of Fraction-1 and Fraction-2 hydrocarbons, and BTEX (benzene, toluene, ethylene, and xylene) were not detectable in fall 2011 at either station (Table 5.7-12 and Table 5.7-13). The concentration of total PAHs in sediment, both absolute and carbon normalized, was within previously-measured concentrations at *test* station MCL-1, and similar to concentrations at *baseline* station JOL-1 (Figure 5.7-10 and Figure 5.7-11). The predicted PAH toxicity in fall 2011 was low in both lakes and within the range of previously-measured values at *test* station MCL-1 (Table 5.7-12 and Table 5.7-13).

Direct tests of sediment toxicity to invertebrates at *test* station MCL-1 showed historically high survival of both the amphipod *Hyalella* and the midge *Chironomus* (98% and 96%, respectively). Ten-day growth of *Chironomus* was within the range of previously-measured observations, while 14-day growth of *Hyalella* exceeded previously-measured maximum values (Table 5.7-12). Measurement endpoints for all sediment toxicity growth and survival tests were higher at *test* station MCL-1 than *baseline* station JOL-1 (Table 5.7-12 and Table 5.7-13).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines No hydrocarbon, PAH, or metal concentrations measured at *test* station MCL-1 or *baseline* station JOL-1 exceeded relevant sediment or soil quality guidelines in fall 2011 with the exception of CCME fraction-1, -2, and -3 hydrocarbons at *test* station MCL-1 and CCME fraction-1 hydrocarbons at *baseline* station JOL-1. It should be noted that the concentration of CCME fraction-1 hydrocarbons at both stations and CCME fraction-2 hydrocarbon at *test* station MCL-1 were reported below the detection limits and the detection limits for these variables are above relevant sediment quality guidelines (Table 5.7-12 and Table 5.7-13).

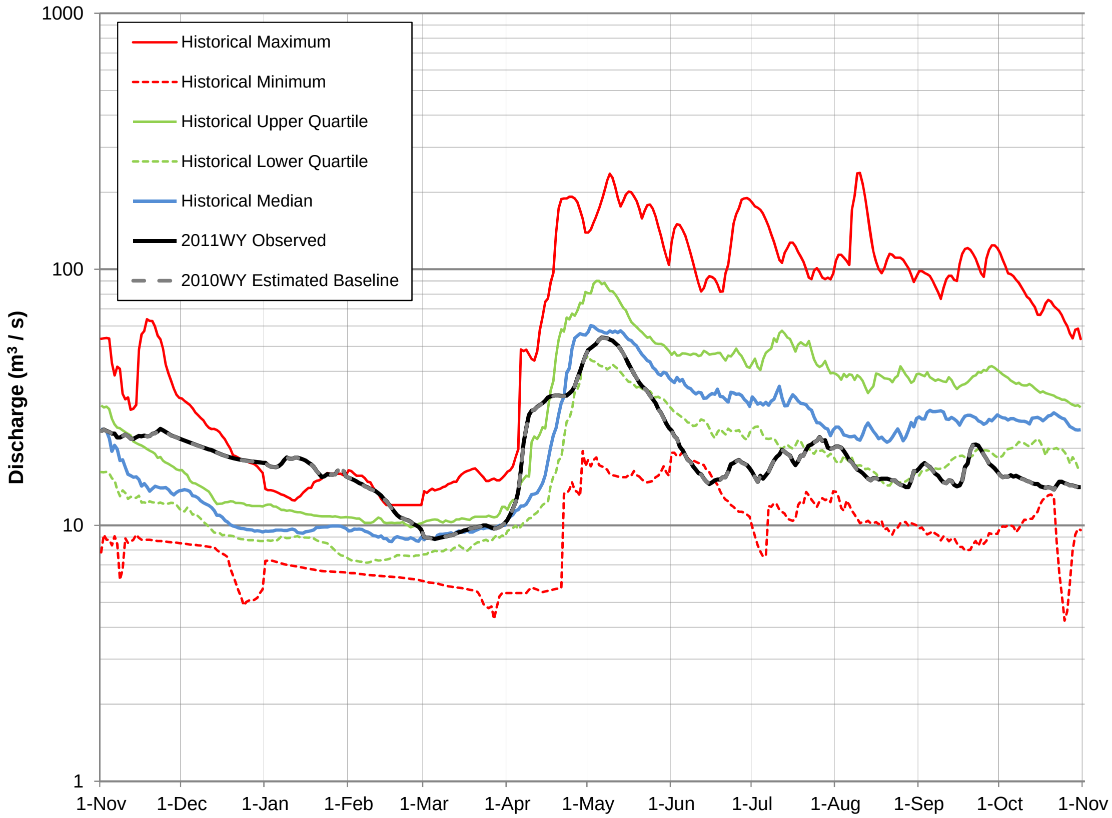
Sediment Quality Index A *baseline*-referenced SQI was not calculated for *test* station MCL-1 or *baseline* station JOL-1 because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers. Regional *baseline* ranges were not calculated for lakes given the small sample size of *baseline* lake-year combinations.

Classification of Results Concentrations of sediment quality measurement endpoints at *test* station MCL-1 were generally within previously-measured concentrations in fall 2011, including total PAHs and predicted PAH toxicity, although concentrations of silt and total organic carbon were higher than previously-measured maximum concentrations and concentrations of sand and naphthalene were lower than previously-measured minimum concentrations. Sediment toxicity to invertebrates showed historically high survival of both *Hyalella* and *Chironomus*, and historically high growth of *Hyalella* at *test* station MCL-1. Fall 2011 represented the first year of sampling at *baseline* station JOL-1; sediment quality collected at *baseline* station JOL-1 was generally similar to sediments collected from *test* station MCL-1, with the exception of concentrations of total hydrocarbons and total metals that were slightly higher, and measurement endpoints for sediment toxicity that were slightly lower than those measured at *test* station MCL-1.

5.7.5 Fish Populations

There were no Fish Populations component activities conducted in the Firebag River watershed in 2011.

Figure 5.7-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Firebag River in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on provisional data for Firebag River near the mouth, WSC Station 07DC001 (March 1 to October 31, 2011) and on data for RAMP Station S27 for other months in the 2011 WY. The upstream drainage area is 5,988 km^2. Historical values calculated for the period from 1972 to 2010.

Table 5.7-2 Estimated water balance at WSC Station 07DC001 (RAMP Station S27), Firebag River near the mouth, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**614.76**	**Observed discharge, obtained from Firebag River near the mouth, WSC Station 07DC001 (RAMP Station S27)**
Closed-circuited area water loss from the observed hydrograph	-0.26	Estimated 2.6 km^2 of the Firebag River watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.88	Estimated 42.8 km^2 of the Firebag River watershed with land change from focal projects as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Firebag River watershed from focal projects	-0.002	Imperial and Suncor reported withdrawals from various locations in the Firebag watershed (daily values provided)
Water releases into the Firebag River watershed from focal projects	+0.10	Suncor reported releases from various locations in the Firebag watershed (daily values provided)
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)	**614.05**	**Estimated *baseline* discharge at Firebag River near the Mouth, WSC Station 07DC001 (RAMP Station S27)**
Incremental flow (change in total discharge)	+0.71	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.12%**	**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, 2011 for Firebag River near the mouth, WSC Station 07DC001, and on RAMP Station S27 for other months in the 2011 WY.

Table 5.7-3 Calculated change in hydrologic measurement endpoints for the Firebag River near the mouth, 2011 WY.

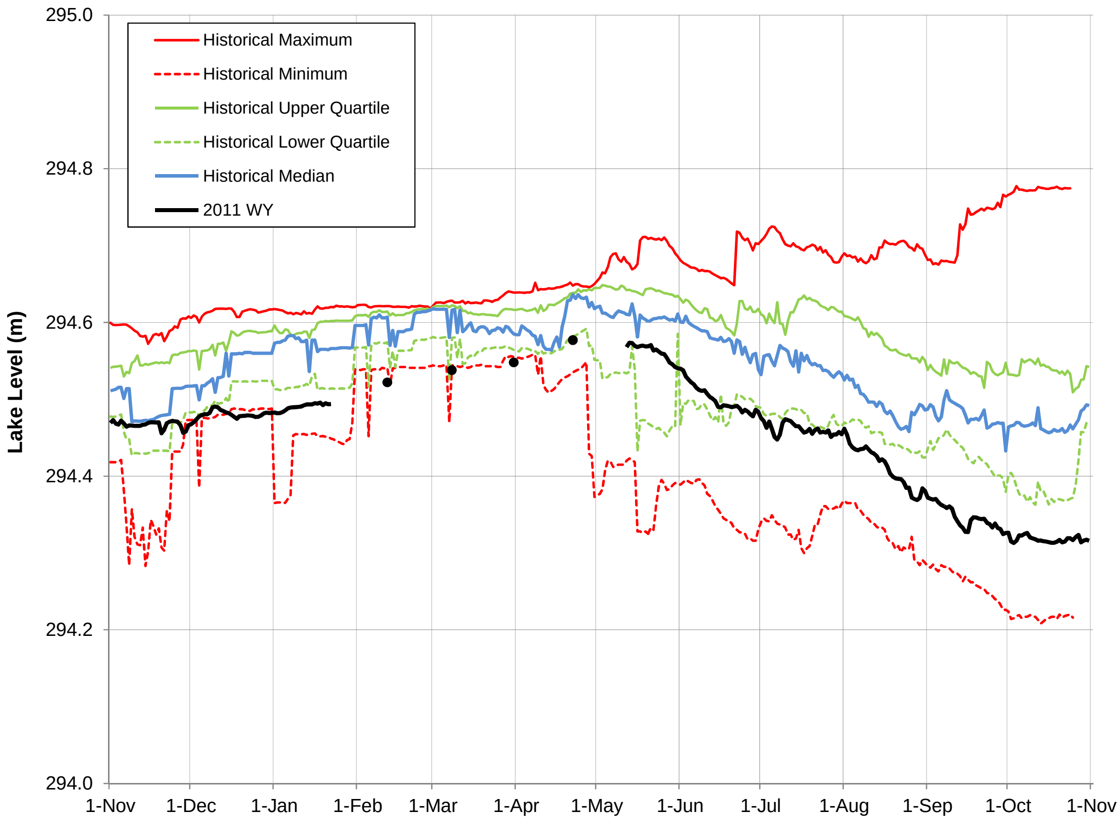
Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	20.87	20.89	+0.12%
Mean winter discharge	16.15	16.16	+0.11%
Annual maximum daily discharge	54.04	54.10	+0.10%
Open-water period minimum daily discharge	13.78	13.80	+0.11%

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, 2011 for Firebag River near the Mouth, WSC Station 07DC001, and on RAMP Station S27 for other months in the 2011 WY.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two decimal places.

Figure 5.7-4 McClelland Lake water level data for the 2011 WY, compared to historical values.



Note: Observed 2011 WY record based on McClelland Lake, RAMP Station L1 2011 provisional data. Continuous data not available from January 23 to May 11, with available manual measurements presented during this period. Historical values calculated for the period from 1997 to 2010 with numerous periods of missing data over the data record.

Note: Maximum and minimum data values are calculated based on the data record which includes numerous data gaps.

Table 5.7-4 Concentrations of water quality measurement endpoints, mouth of the Firebag River (*test* station FIR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.5</u>	9	7.9	8.2	8.2
Total suspended solids	mg/L	-	7	9	<3	5	21
Conductivity	µS/cm	-	<u>248</u>	9	171	199	227
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.01</u>	9	0.02	0.03	**0.06**
Total nitrogen	mg/L	1	0.4	9	0.4	0.6	**1.7**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	9.3	9	8.0	13.7	16.2
Ions							
Sodium	mg/L	-	<u>4.6</u>	9	2.0	4.0	4.0
Calcium	mg/L	-	31.0	9	22.6	30.2	33.2
Magnesium	mg/L	-	9.3	9	6.8	8.5	9.7
Chloride	mg/L	230, 860	<u>3.1</u>	9	1.0	2.0	3.0
Sulphate	mg/L	100	3.2	9	1.7	2.8	10.3
Total dissolved solids	mg/L	-	170	9	60	140	170
Total alkalinity	mg/L		<u>124.0</u>	9	85.4	108.0	114.0
Selected metals							
Total aluminum	mg/L	0.1	0.09	9	0.03	0.07	**0.43**
Dissolved aluminum	mg/L	0.1	<u>0.002</u>	9	0.003	0.005	0.009
Total arsenic	mg/L	0.005	0.00039	9	0.00028	0.00045	0.00056
Total boron	mg/L	1.2	<u>0.021</u>	9	0.014	0.016	0.020
Total molybdenum	mg/L	0.073	0.00017	8	0.00011	0.00013	0.00020
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	4.4
Total strontium	mg/L	-	<u>0.083</u>	8	<0.1	<0.1	0.077
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	9.1	0	-	-	-
Total PAHs	ng/L	-	176.8	0	-	-	-
Total Parent PAHs	ng/L	-	23.5	0	-	-	-
Total Alkylated PAHs	ng/L	-	153.3	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**<u>0.38</u>**	9	**0.39**	**0.79**	**1.06**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.7-5 Concentrations of water quality measurement endpoints, Firebag River above the Suncor Firebag project (*baseline* station FIR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.3	9	7.4	8.1	8.3
Total suspended solids	mg/L	-	5	9	<3	3	8
Conductivity	µS/cm	-	185	9	113	169	261
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.04	9	0.01	**0.06**	**0.10**
Total nitrogen	mg/L	1	0.73	8	0.5	0.7	**1.28**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	9.1	9	8	13.1	17.4
Ions							
Sodium	mg/L	-	3.1	9	2	4	16
Calcium	mg/L	-	22.2	9	16.4	25.0	28.4
Magnesium	mg/L	-	6.4	9	5.1	7.2	8.7
Chloride	mg/L	230, 860	0.6	9	<1	1	2
Sulphate	mg/L	100	1.1	9	0.8	1.9	22.6
Total dissolved solids	mg/L	-	149	9	110	134	158
Total alkalinity	mg/L		97.3	9	57.0	89.3	114.0
Selected metals							
Total aluminum	mg/L	0.1	0.018	9	0.015	0.036	0.082
Dissolved aluminum	mg/L	0.1	<u>0.001</u>	9	0.003	0.004	0.011
Total arsenic	mg/L	0.005	0.00057	9	0.00010	0.00056	0.00060
Total boron	mg/L	1.2	<u>0.024</u>	9	0.008	0.013	0.017
Total molybdenum	mg/L	0.073	<u>0.00027</u>	9	0.00004	0.00018	0.00022
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	1.7
Total strontium	mg/L	-	0.055	9	0.028	0.048	0.068
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.8	0	-	-	-
Total PAHs	ng/L	-	151.2	0	-	-	-
Total Parent PAHs	ng/L	-	19.2	0	-	-	-
Total Alkylated PAHs	ng/L	-	132.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total phosphorus	mg/L	0.05	**0.09**	9	0.05	**0.10**	**0.13**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.7-6 Concentrations of water quality measurement endpoints, McClelland Lake (*test* station MCL-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.7	9	8.1	8.5	8.7
Total suspended solids	mg/L	-	7	9	<3	<3	5
Conductivity	µS/cm	-	256	9	224	238	253
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.004	9	0.002	0.004	0.013
Total nitrogen	mg/L	1	**1.05**	9	0.55	1.00	**2.00**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.4	9	11.0	13.0	17.0
Ions							
Sodium	mg/L	-	5.7	9	4.0	4.5	6.0
Calcium	mg/L	-	22.2	9	19.3	21.3	25.8
Magnesium	mg/L	-	18.0	9	14.6	16.5	17.3
Chloride	mg/L	230, 860	<0.5	9	<1	<1	1
Sulphate	mg/L	100	<0.5	9	<0.5	1	4.3
Total dissolved solids	mg/L	-	194	9	80	155	171
Total alkalinity	mg/L		140	9	122	128	145
Selected metals							
Total aluminum	mg/L	0.1	0.0061	9	0.0028	0.0162	0.0260
Dissolved aluminum	mg/L	0.1	0.0012	9	<0.001	<0.001	0.010
Total arsenic	mg/L	0.005	0.00020	9	0.00019	0.00021	<0.00100
Total boron	mg/L	1.2	0.070	9	0.051	0.064	0.067
Total molybdenum	mg/L	0.073	<0.0001	9	<0.00001	<0.00002	<0.0001
Total mercury (ultra-trace)	ng/L	5, 13	0.6	6	<0.6	<1.2	2.4
Total strontium	mg/L	-	0.14	9	0.11	0.13	0.15
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	6.6	0	-	-	-
Total PAHs	ng/L	-	165.2	0	-	-	-
Total Parent PAHs	ng/L	-	20.5	0	-	-	-
Total Alkylated PAHs	ng/L	-	144.8	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved silver	mg/L	0.0001	**0.00011**	9	<0.000005	<0.000005	<0.0002
Total phenols	mg/L	0.004	**0.0049**	9	<0.001	0.0030	**0.0225**
Total silver	mg/L	0.0001	**0.00011**	9	<0.000005	<0.000005	<0.0004

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.7-7 Concentrations of water quality measurement endpoints, Johnson Lake (*baseline* station JOL-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.4
Total suspended solids	mg/L	-	61
Conductivity	µS/cm	-	341
Nutrients			
Total dissolved phosphorus	mg/L	0.05	0.013
Total nitrogen	mg/L	1	**2.20**
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	14.6
Ions			
Sodium	mg/L	-	6.6
Calcium	mg/L	-	41.6
Magnesium	mg/L	-	15.8
Chloride	mg/L	230, 860	6.07
Sulphate	mg/L	100	1.49
Total dissolved solids	mg/L	-	236
Total alkalinity	mg/L		172
Selected metals			
Total aluminum	mg/L	0.1	**0.13**
Dissolved aluminum	mg/L	0.1	0.016
Total arsenic	mg/L	0.005	0.00039
Total boron	mg/L	1.2	0.25
Total molybdenum	mg/L	0.073	0.00014
Total mercury (ultra-trace)	ng/L	5, 13	1.8
Total strontium	mg/L	-	0.14
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	17.3
Total dibenzothiophenes	ng/L	-	6.7
Total PAHs	ng/L	-	168.5
Total Parent PAHs	ng/L	-	19.7
Total Alkylated PAHs	ng/L	-	148.7
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Sulphide	mg/L	0.002	**0.0052**
Total iron	mg/L	0.3	**0.83**
Total Kjeldahl Nitrogen	mg/L	1	**2.13**
Total phenols	mg/L	0.004	**0.0063**
Total phosphorus	mg/L	0.05	**0.17**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Figure 5.7-5 Piper diagram of fall ion concentrations in the Firebag River watershed, fall 2011.

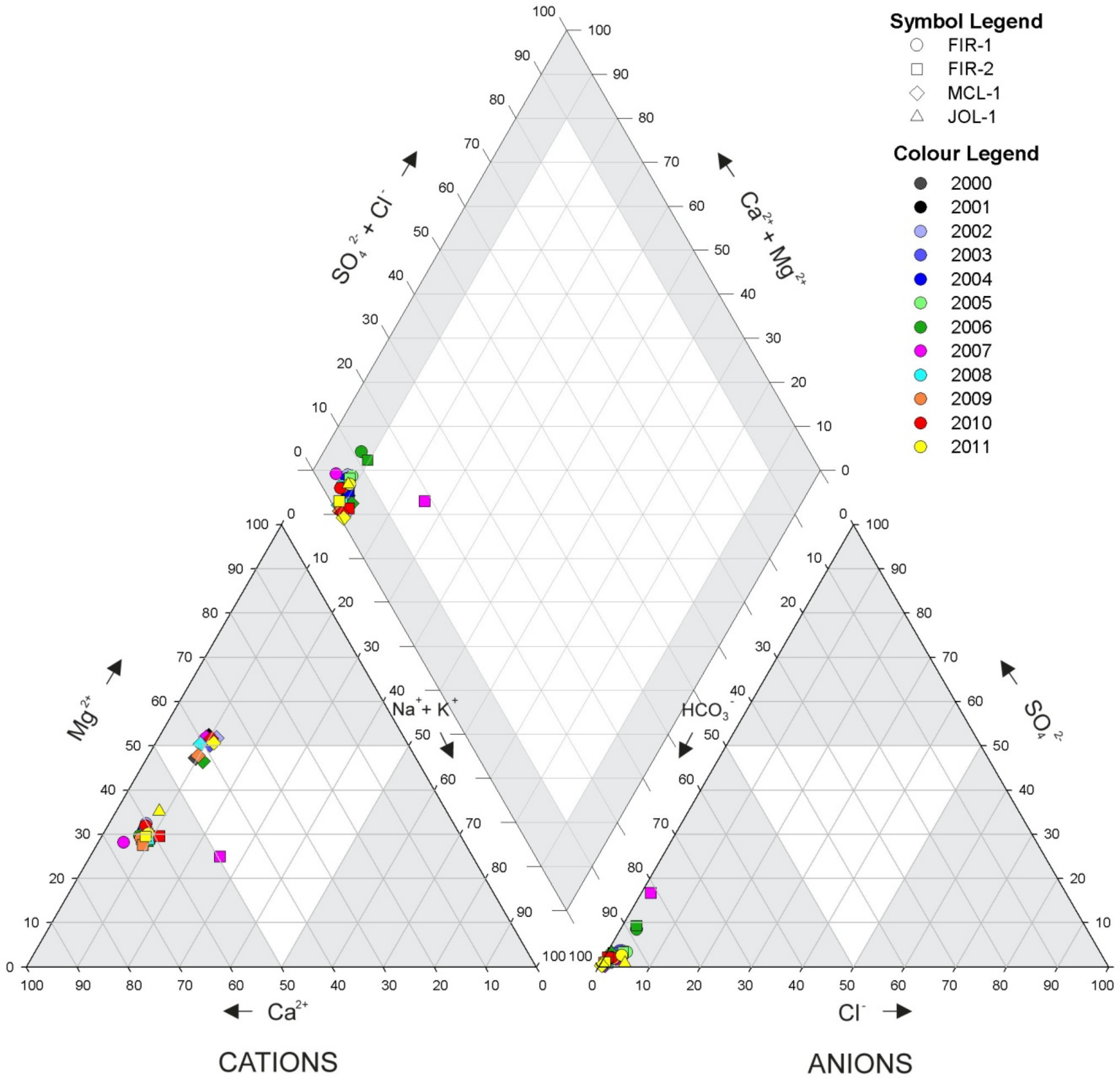


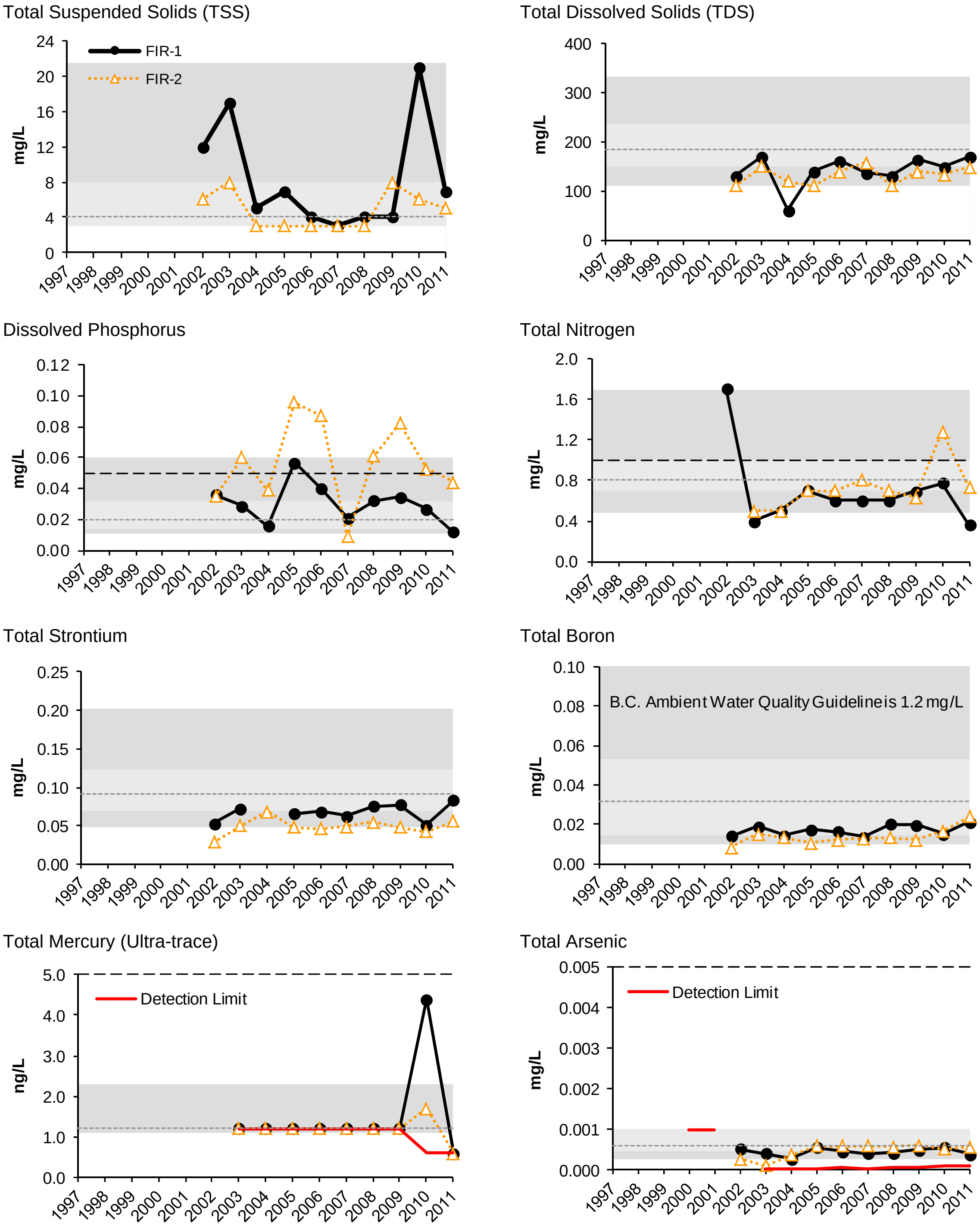
Table 5.7-8 Water quality guideline exceedances, Firebag River watershed, 2011.

Variable	Units	Guideline[a]	FIR-1	FIR-2	MCL-1	JOL-1
Winter						
Total iron	mg/L	0.3	ns	ns	ns	1.14
Total Kjeldahl Nitrogen	mg/L	1	ns	ns	ns	3.29
Total nitrogen	mg/L	1	ns	ns	ns	3.36
Total phenols	mg/L	0.004	ns	ns	ns	0.016
Total phosphorus	mg/L	0.05	ns	ns	ns	0.084
Summer						
Sulphide	mg/L	0.002	ns	ns	ns	0.0026
Total Kjeldahl Nitrogen	mg/L	1	ns	ns	ns	1.33
Total nitrogen	mg/L	1	ns	ns	ns	1.54
Total phenols	mg/L	0.004	ns	ns	ns	0.016
Total phosphorus	mg/L	0.05	ns	ns	ns	0.070
Fall						
Dissolved silver	mg/L	0.0001	-	-	0.00011	-
Sulphide	mg/L	0.002	-	-	-	0.0052
Total aluminum	mg/L	0.1	-	-	-	0.13
Total iron	mg/L	0.3	0.38	-	-	0.83
Total Kjeldahl Nitrogen	mg/L	1	-	-	-	2.13
Total nitrogen	mg/L	1	-	-	1.05	2.20
Total phenols	mg/L	0.004	-	-	0.0049	0.0063
Total phosphorus	mg/L	0.05	-	0.091	-	0.17
Total silver	mg/L	0.0001	-	-	0.00011	-

[a] Sources for all guidelines are outlined in Table 3.2-5.

ns = not sampled

Figure 5.7-6 Concentrations of selected water quality measurement endpoints in the Firebag River watershed (fall 2011) relative to historical concentrations and regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

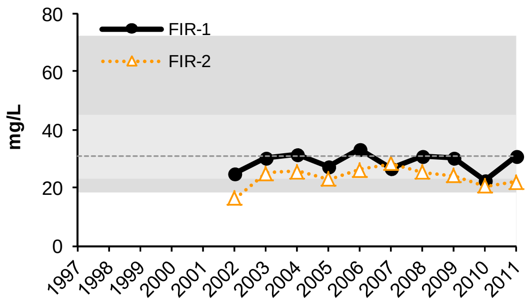
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

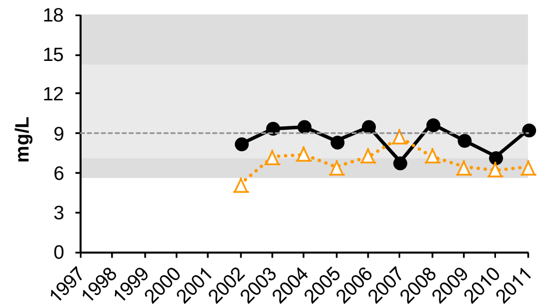
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-6 (Cont'd.)

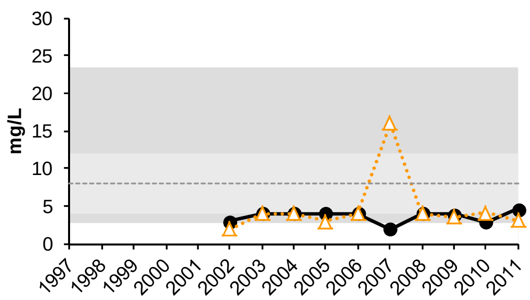
Calcium



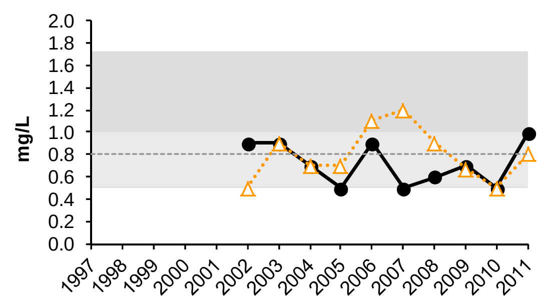
Magnesium



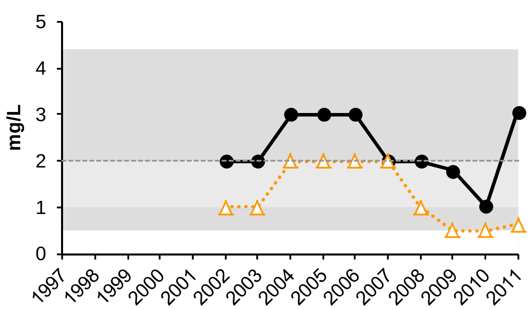
Sodium



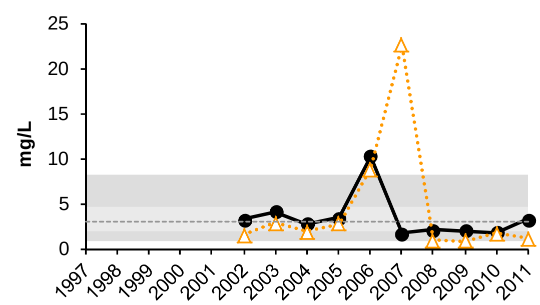
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

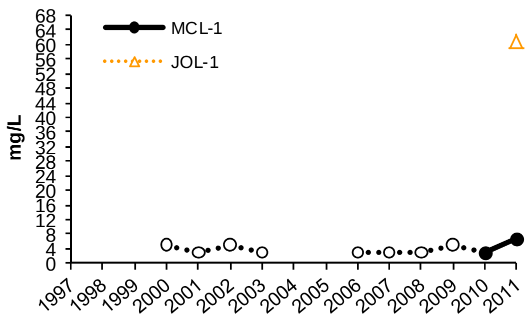
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

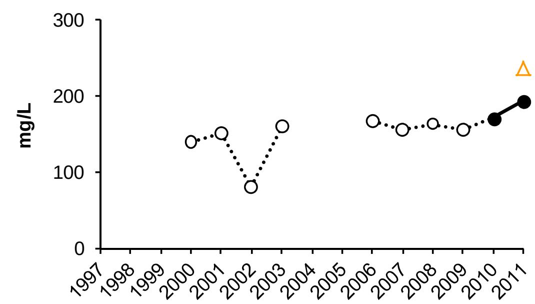
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.7-7 Concentrations of selected water quality measurement endpoints in McClelland Lake and Johnson Lake (fall 2011) relative to historical concentrations.

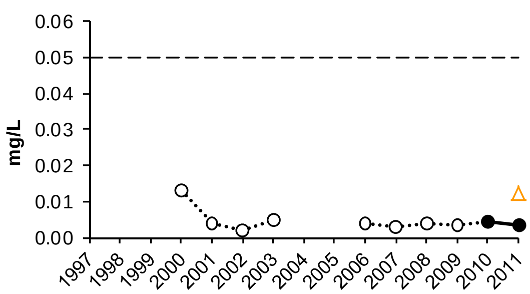
Total Suspended Solids (TSS)



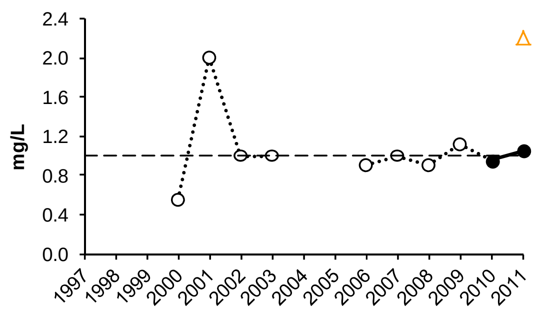
Total Dissolved Solids (TDS)



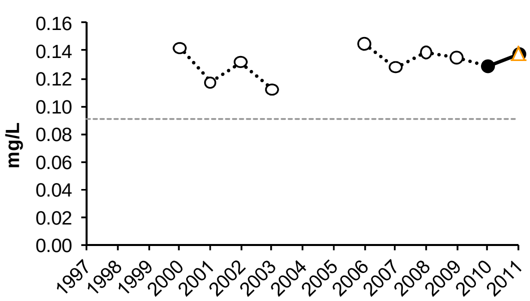
Dissolved Phosphorus



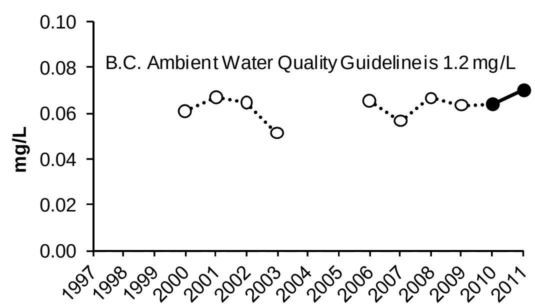
Total Nitrogen



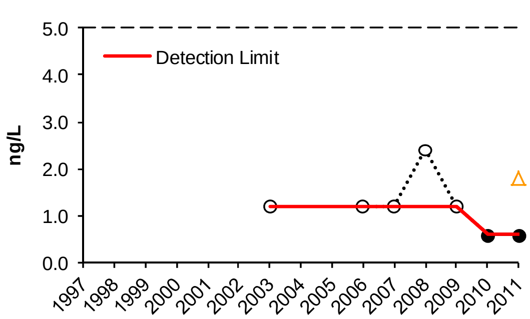
Total Strontium



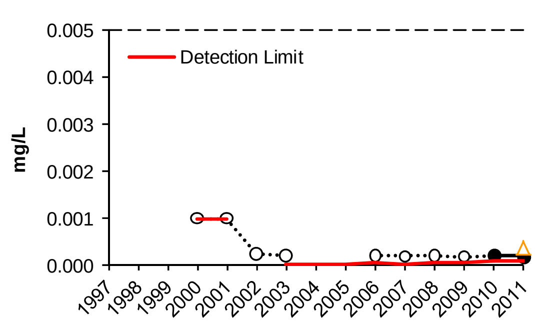
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic

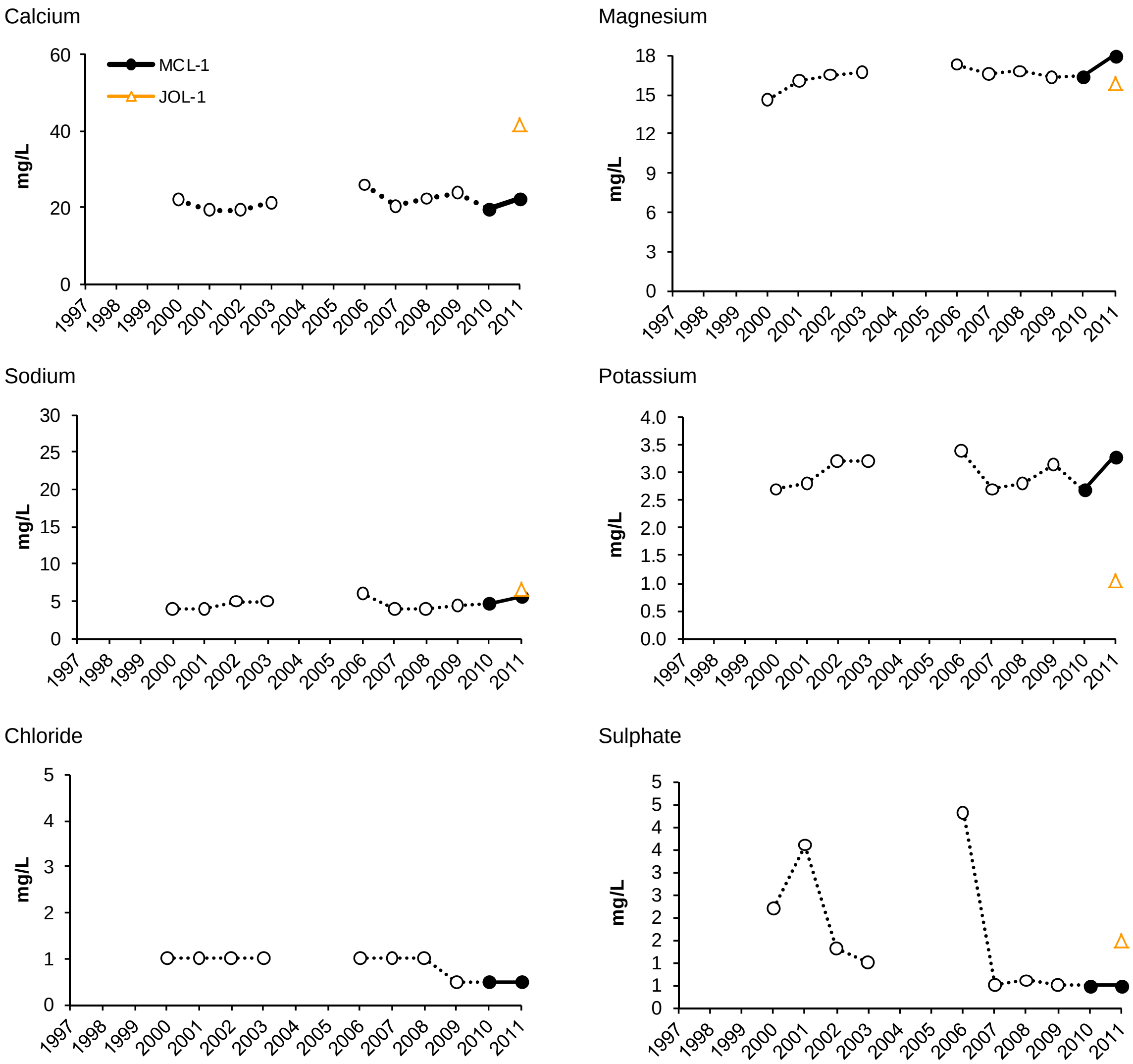


Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Figure 5.7-7 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

o·······o Sampled as a *baseline* station ●——● Sampled as a *test* station

Table 5.7-9 Average habitat characteristics of benthic invertebrate sampling locations in McClelland Lake and Johnson Lake, fall 2011.

Variable	Units	McClelland Lake	Johnson Lake
Sample date	-	Sept. 9, 2011	Sept. 10, 2011
Habitat	-	Depositional	Depositional
Water depth	m	1.8	1.0
Field Water Quality			
Dissolved oxygen	mg/L	8.8	6.4
Conductivity	µS/cm	239	338
pH	pH units	8.6	8.48
Water temperature	°C	19.0	18.1
Sediment Composition			
Sand	%	10	28
Silt	%	80	64
Clay	%	10	8
Total Organic Carbon	%	34	19

Table 5.7-10 Summary of major taxon abundances of benthic invertebrate community measurement endpoints in McClelland Lake and Johnson Lake.

Taxon	Percent Major Taxa Enumerated in Each Year										
	McClelland Lake										Johnson Lake
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2011
Nematoda	1	<1	4	<1	1		1	<1	<1	<1	1
Erpobdellidae	1	<1	<1				<1			<1	<1
Glossiphoniidae							<1			<1	<1
Naididae	14	13	7	12	2	12	17	3	9	10	<1
Tubificidae		6	<1		1		<1	1	<1	<1	3
Lumbriculidae		<1	<1	<1		8	<1	<1			
Hydracarina	1	<1		1			6	5	<1	12	<1
Amphipoda	11	22	21	7	<1	4	3	4		1	37
Ostracoda	10	8	15	29	1	3	3	5	4	10	3
Cladocera	<1		2	2	1	7	14	<1	2	6	
Copepoda			2	1	1	10	13	<1	1	9	1
Gastropoda	<1	1		2	<1		<1	1	2	<1	<1
Bivalvia	2	8	6	9	<1	1	1	3	<1	2	19
Ceratopogonidae				1	<1						1
Chaoboridae											<1
Chironomidae	58	39	24	27	91	41	33	75	80	42	33
Ephemeroptera	1	2	8	7	1	12	5	<1	<1	4	
Anisoptera			<1	1	<1		<1	<1	<1	<1	
Zygoptera		<1			1						
Trichoptera	1		3	1	<1	2	1	<1	<1	<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	56,354	10,613
Richness	11	11	6	11	23	12	22	23	17	24	11
Simpson's Diversity	0.71	0.71	0.66	0.72	0.76	0.72	0.85	0.74	0.78	0.87	0.69
Evenness	0.84	0.81	0.91	0.85	0.76	0.82	0.91	0.79	0.83	0.91	0.78
% EPT	2	2	10	7	2	6	5	2	1	5	<1

Table 5.7-11 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 Change(s)
	Before vs. After	Before vs. After	
Abundance	**<0.001**	31	Higher in *test* period
Richness	**<0.001**	18	Higher in *test* period
Simpson's Diversity	**0.013**	33	Higher in *test* period
Evenness	0.213	7	No difference between *baseline* and *test* period
EPT	0.786	1	No difference between *baseline* and *test* period
CA Axis 1	**0.001**	52	Higher in *test* period
CA Axis 2	**0.002**	32	Higher 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 5.7-8 Variation in benthic invertebrate community measurement endpoints in McClelland Lake and Johnson Lake.

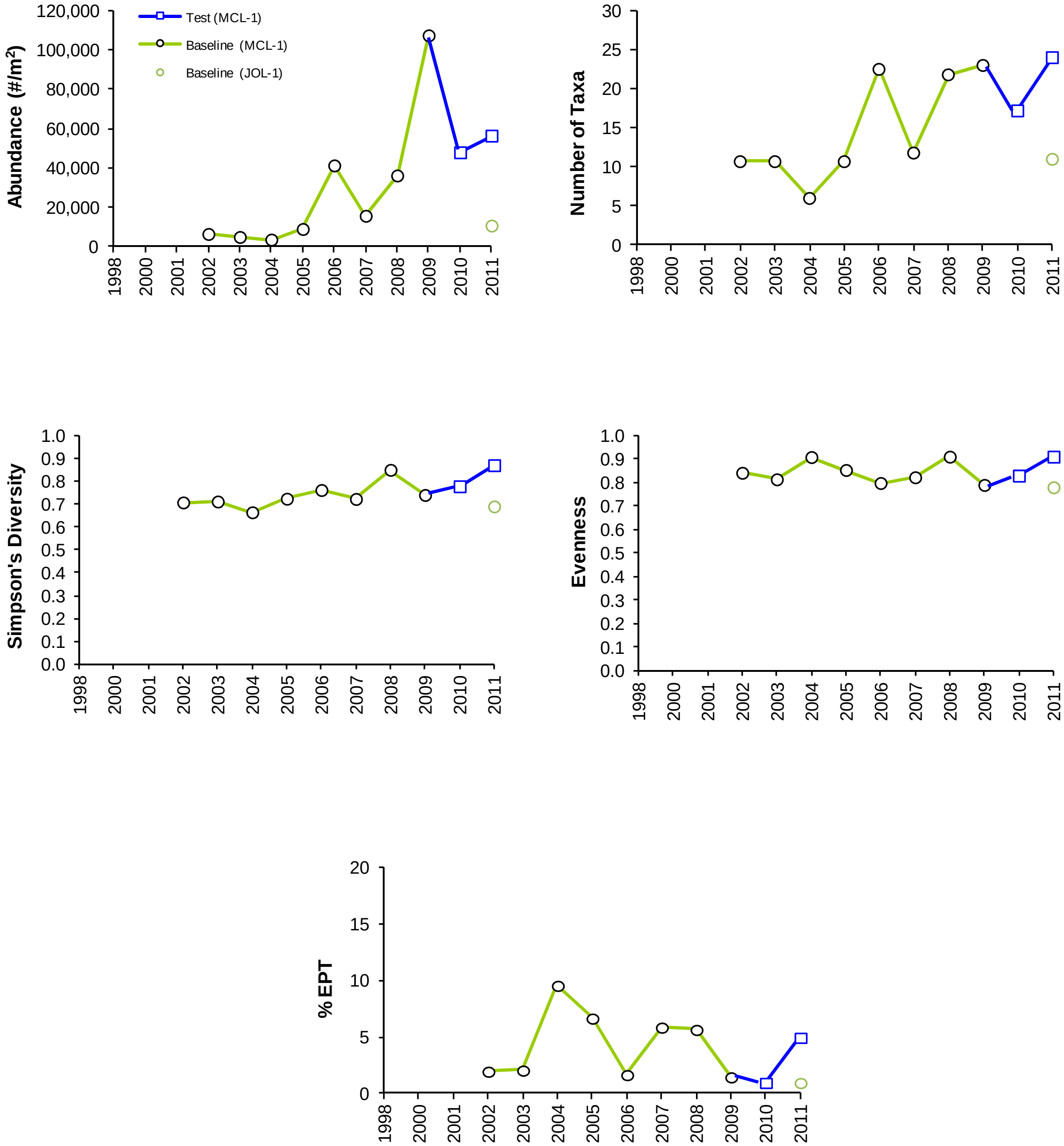
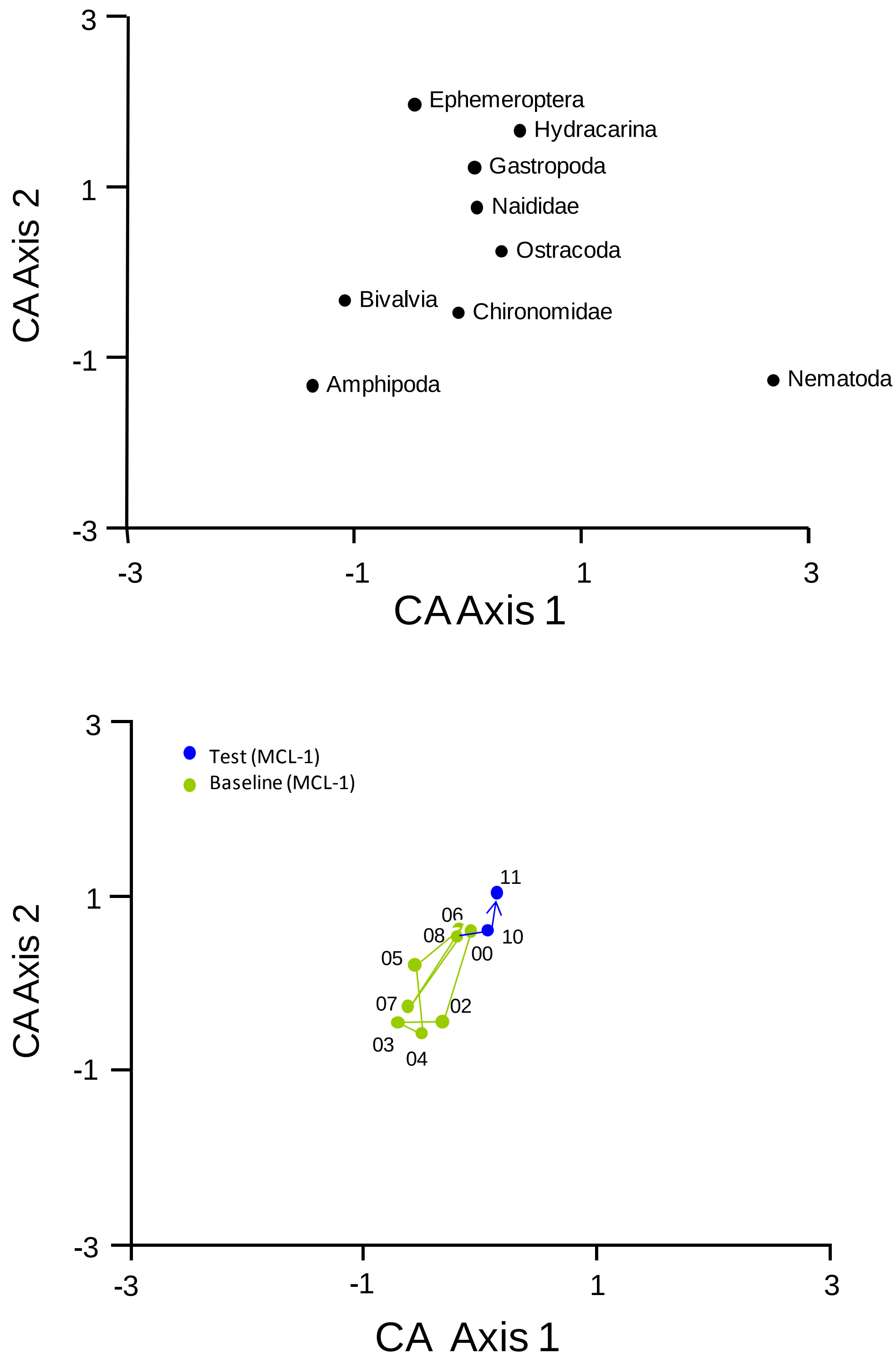


Figure 5.7-9 Ordination (Correspondence Analysis) of lake benthic invertebrate communities in McClelland Lake (MCL-1).



Note: lower panel is the scatterplot of sample scores while the upper panel is the scatterplot of taxa scores.

Table 5.7-12 Concentrations of sediment quality measurement endpoints, McClelland Lake (*test* station MCL-1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	10	7	2	12	49
Silt	%	-	<u>80</u>	7	14	23	59
Sand	%	-	<u>10</u>	7	14	38	83
Total organic carbon	%	-	<u>33.9</u>	7	16.7	27.6	30.5
Total hydrocarbons							
BTEX	mg/kg	-	<120	5	<5	<10	<150
Fraction 1 (C6-C10)	mg/kg	30[1]	**<120**	5	<5	<10	**<150**
Fraction 2 (C10-C16)	mg/kg	150[1]	**<154**	5	<5	65	**240**
Fraction 3 (C16-C34)	mg/kg	300[1]	**433**	5	**360**	**794**	**2900**
Fraction 4 (C34-C50)	mg/kg	2800[1]	241	5	38	580	2400
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0051</u>	4	0.0054	0.0111	0.0241
Retene	mg/kg	-	0.0842	7	0.0190	0.0861	0.1610
Total dibenzothiophenes	mg/kg	-	0.0365	7	0.0236	0.0293	0.0829
Total PAHs	mg/kg	-	0.5248	7	0.2613	0.5641	0.7534
Total Parent PAHs	mg/kg	-	0.0671	7	0.0227	0.0627	0.1071
Total Alkylated PAHs	mg/kg	-	0.4577	7	0.2386	0.4995	0.6906
Predicted PAH toxicity[3]	H.I.	1.0	0.18	7	0.04	0.11	0.37
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>9.6</u>	3	7.8	9.0	9.2
Chironomus growth - 10d	mg/organism	-	1.51	3	1.45	1.53	1.86
Hyalella survival - 14d	# surviving	-	<u>9.8</u>	3	7.4	8.0	9.6
Hyalella growth - 14d	mg/organism	-	<u>0.45</u>	3	0.22	0.29	0.31

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

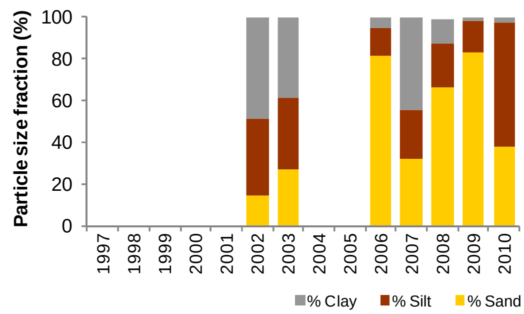
[1] Guideline is for residential/parkland coarse (median grain size > 75 µm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

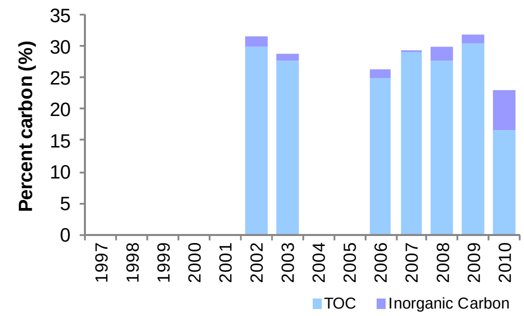
[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Figure 5.7-10 Variation in sediment quality measurement endpoints in McClelland Lake, *test* station MCL-1.

Particle size distribution

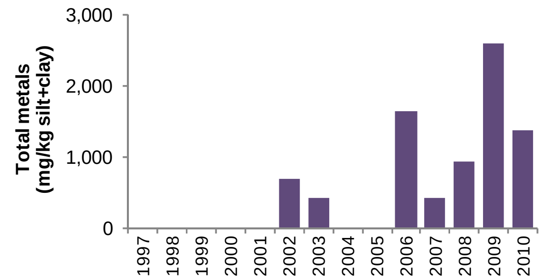


Carbon Content

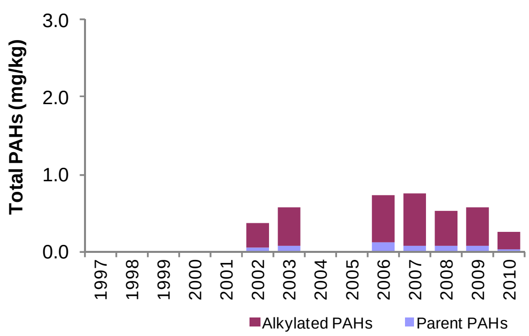


Total Metals[1]

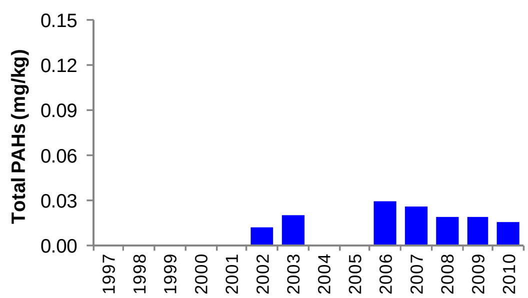
Total metals[1] normalized to percent fine sediments (i.e., % silt + clay)



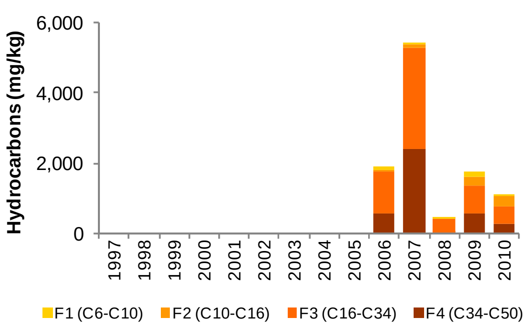
Total PAHs



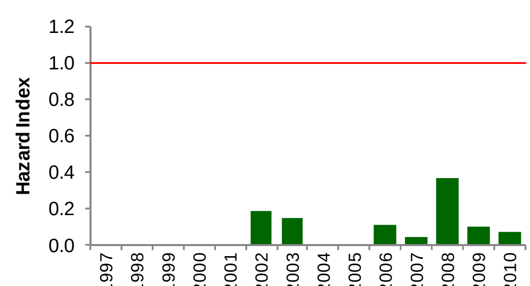
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index[2]



1 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

2 Red line indicates potential chronic effects level (HI = 1.0).

Table 5.7-13 Concentrations of sediment quality measurement endpoints, Johnson Lake (*baseline* station JOL-1), fall 2011.

Variables	Units	Guideline	September 2011
			Value
Physical variables			
Clay	%	-	8
Silt	%	-	64
Sand	%	-	28
Total organic carbon	%	-	19.0
Total hydrocarbons			
BTEX	mg/kg	-	<90
Fraction 1 (C6-C10)	mg/kg	30[1]	**<90**
Fraction 2 (C10-C16)	mg/kg	150[1]	<107
Fraction 3 (C16-C34)	mg/kg	300[1]	281
Fraction 4 (C34-C50)	mg/kg	2800[1]	174
Polycyclic Aromatic Hydrocarbons (PAHs)			
Naphthalene	mg/kg	0.0346[2]	0.0042
Retene	mg/kg	-	0.2190
Total dibenzothiophenes	mg/kg	-	0.0303
Total PAHs	mg/kg	-	0.5471
Total Parent PAHs	mg/kg	-	0.0299
Total Alkylated PAHs	mg/kg	-	0.5171
Predicted PAH toxicity[3]	H.I.	1.0	0.30
Metals that exceed CCME guidelines in 2011			
none	mg/kg	-	-
Chronic toxicity			
Chironomus survival - 10d	# surviving	-	9.4
Chironomus growth - 10d	mg/organism	-	1.17
Hyalella survival - 14d	# surviving	-	8.4
Hyalella growth - 14d	mg/organism	-	0.37

Values in **bold** indicate concentrations exceeding guidelines.

Values underlined indicate concentrations outside the range of historic observations.

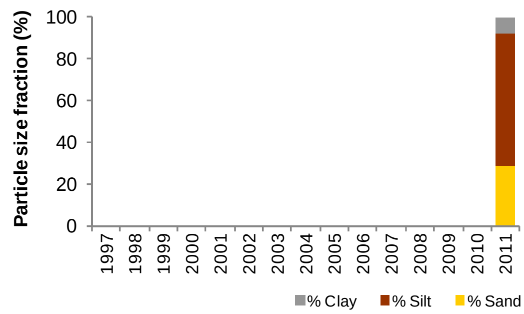
1 Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

2 Interim sediment quality guideline (ISQG) (CCME 2002).

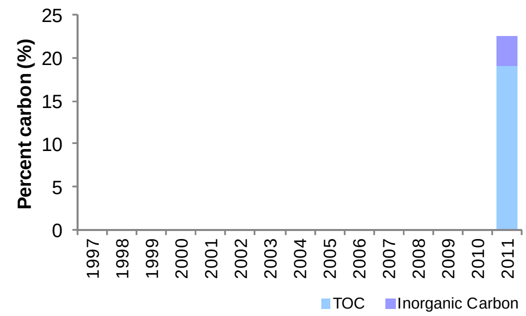
3 Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Figure 5.7-11 Variation in sediment quality measurement endpoints in Johnson Lake, *baseline* station JOL-1.

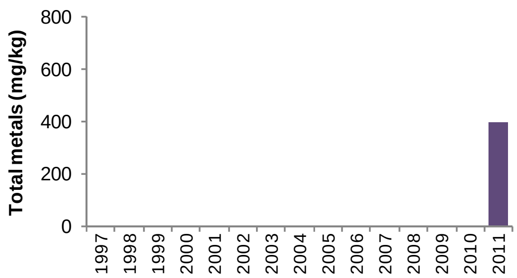
Particle size distribution



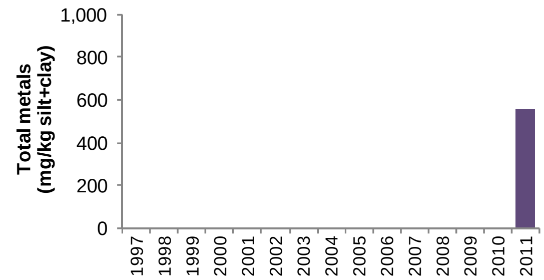
Carbon Content



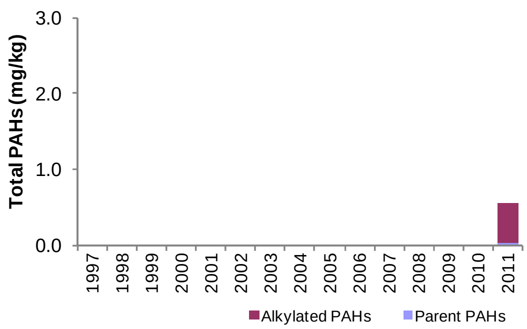
Total Metals[1]



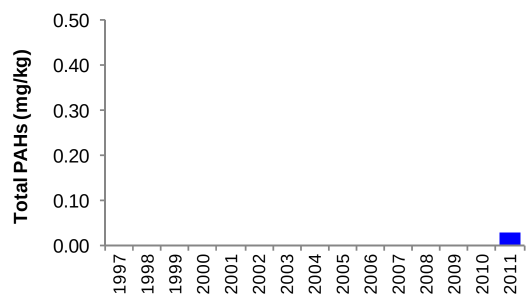
Total metals[1] normalized to percent fine sediments (i.e., % silt + clay)



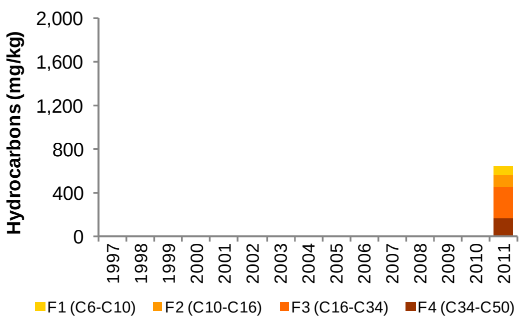
Total PAHs



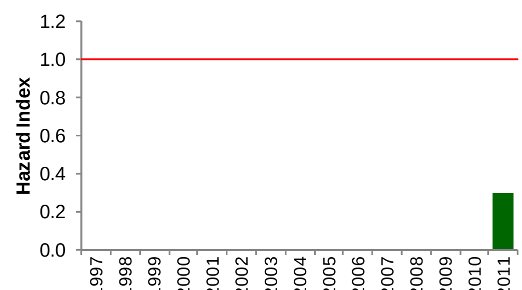
Total PAHs normalized to 1% TOC



CCME Hydrocarbon Fractions



PAH Hazard Index[2]



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red 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 2011 Conditions		
Climate and Hydrology			
Criteria		**S14A** at CNRL bridge	
Mean open-water season discharge		Negligible-Low	
Mean winter discharge		Negligible-Low	
Annual maximum daily discharge		Negligible-Low	
Minimum open-water season discharge		Negligible-Low	
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	Negligible-Low	Negligible-Low	Negligible-Low
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	Negligible-Low		n/a
Sediment Quality Index	Moderate		not sampled
Fish Populations			
Criteria	**ELR-F1** lower reach	no reach sampled	**ELR-F2A** upstream of Fort McKay water intake
Fish Assemblages	Negligible-Low		n/a

Legend and Notes

- ○ (yellow) Negligible-Low
- ● (orange) Moderate
- ● (brown) High
- *baseline* (green shading)
- *test* (blue shading)

n/a - not applicable, summary indicators for *test* reaches/stations were designated based on comparisons with *baseline* reaches/station or regional *baseline* conditions.

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.

Fish Populations: Classification based on exceedances of measurement from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.8-1 Ells River watershed.

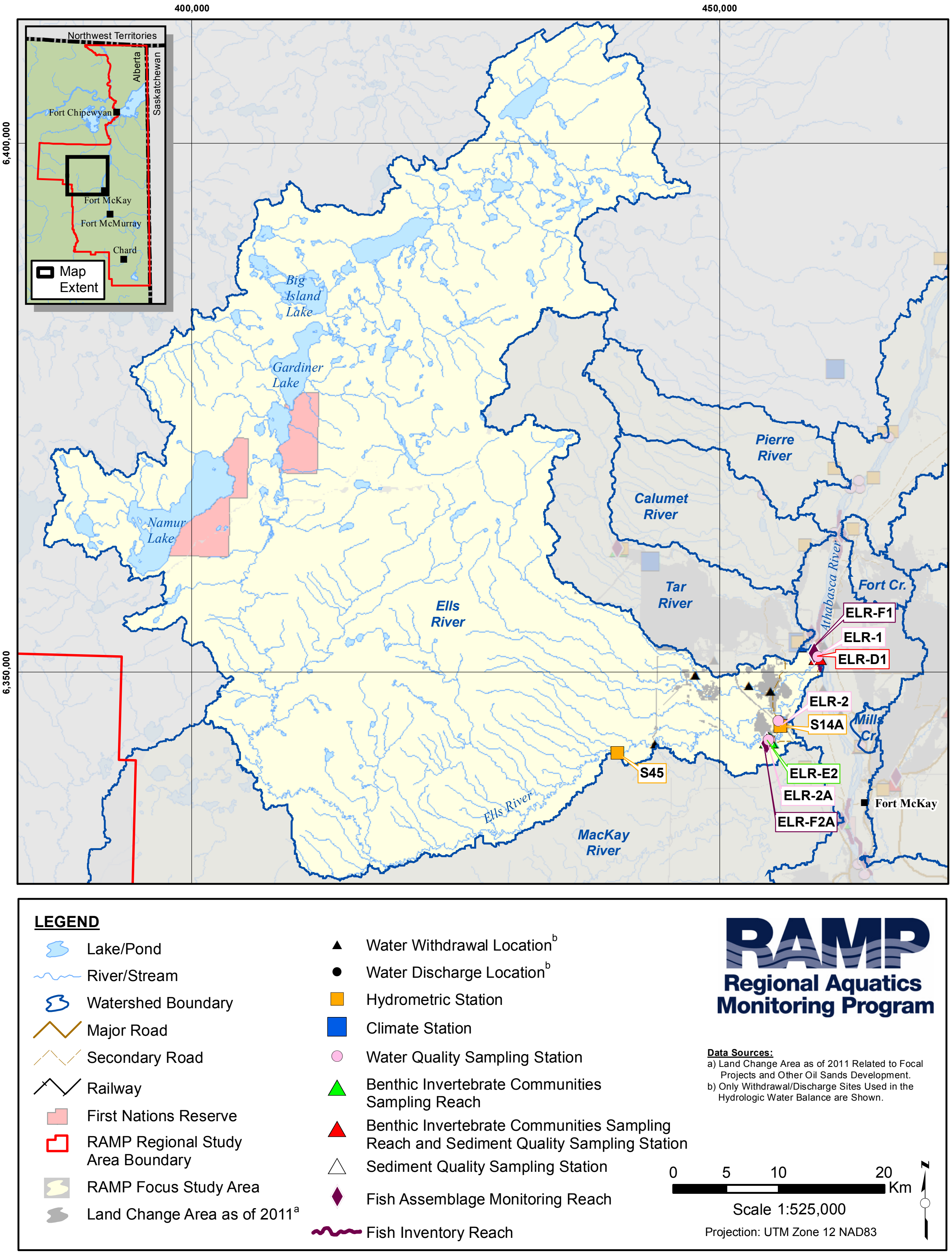


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Figure 5.8-2 Representative monitoring stations of the Ells River, fall 2011.

Water Quality Station ELR-1:
Left Downstream Bank

Water Quality Station ELR-2A:
Left Downstream Bank

Water Quality Station ELR-2:
Right Downstream Bank

Hydrology Station S14A:
at the Canadian Natural Bridge

5.8.1 Summary of 2011 Conditions

Approximately 0.7% (1,818 ha) of the Ells River watershed had undergone land change as of 2011 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 Total E&P Joslyn Project operations and 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components of RAMP in the Ells River watershed in 2011. Table 5.8-1 is a summary of the 2011 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 2011. Figure 5.8-2 contains fall 2011 photos of a number of monitoring stations in the watershed.

Hydrology The mean winter discharge (November to March) was 0.05% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**. The calculated mean open-water discharge (May to October), the annual maximum daily discharge, and the open-water minimum daily discharge were 0.07% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality Differences in water quality in fall 2011 between the Ells River and regional *baseline* fall conditions were classified as **Negligible-Low**. Water quality conditions were consistent with previous years for *test* stations ELR-1 and ELR-2 and generally within the range of previously-measured concentrations and regional *baseline* conditions. Water quality at *baseline* station ELR-2A in fall 2011 was similar to that at the other two stations and consistent with results from fall 2010 at this station.

Benthic Invertebrate Communities and Sediment Quality Differences in values of benthic invertebrate community measurement endpoints at *test* reach ELR-D1 were classified as **Negligible-Low** because the significant increase in taxa richness over time did not imply a negative change in the benthic invertebrate community. In addition, although evenness in fall 2011 was lower than regional *baseline* conditions, there were no other measurement endpoints that exceeded the range of *baseline* conditions and evenness was lower in 2005 than 2011. It should be noted; however, that habitat conditions at *test* reach ELR-D1 were of marginal quality for benthic invertebrate communities. The high relative abundance of tubificid worms (> 60% in 2011), the absence of caddisflies and stoneflies, and the low relative abundance of mayflies, with *Caenis* as the only representative, indicated an environment that was slightly limiting to depositional fauna. Differences in sediment quality observed in fall 2011 between *test* station ELR-D1 and regional *baseline* conditions were classified as **Moderate**, with concentrations of PAHs exceeding regional *baseline* conditions but within previously-measured concentrations at this station.

Fish Populations Differences in the fish assemblage observed in fall 2011 between *test* reach ELR-F1 and regional *baseline* conditions were classified as **Negligible-Low** with all median values of measurement endpoints within the range of regional *baseline* variability.

5.8.2 Hydrologic Conditions: 2011 Water Year

RAMP Station S14A, Ells River above Joslyn Creek Continuous annual hydrometric data have been collected for Station S14A from 2009 to 2011 with intermittent periods of flow data available from 2004 to 2008. Short data gaps occurred in April, July and August 2011 due to equipment malfunction. Comparison of the 2011 water year (WY) hydrologic conditions to historical values is less robust than for a number of the other hydrology stations in the RAMP FSA given the short record length for this station. Flows recorded during the 2011 WY decreased through the winter from 5.5 m^3/s on November 1, 2010, to a minimum of 1.2 m^3/s on March 9, 2011. All daily flows from December 14, 2010 to March 25, 2011 were higher than historical flows recorded during these months. Flows increased from March 9 through April to a peak value during freshet of 36 m^3/s on May 5. This peak was the highest flow recorded in the 2011 WY and was 6% higher than the historical mean maximum daily flow recorded during previous open-water periods. Flows then decreased to just below historical minimum flow values by July 7, before rising again during mid-July due to rainfall events. Flows from mid-August until the end of the 2011 WY were below historical median flows. The minimum open-water daily flow of 1.9 m^3/s recorded on October 27 was 26% lower than the historical open-water mean minimum daily flow.

Differences between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The 2011 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 on downstream sections of the Ells River associated with the confluence of the Ells River and the Athabasca 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 2011 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 2011 in the Ells watershed was 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 was estimated at 0.12 million m^3.

2. As of 2011, the area of land change in the Ells watershed from focal projects that was not closed-circuited was estimated to be 16.5 km^2 (Table 2.5-1). The increase in flow to the Ells River that would not have otherwise occurred from this land area was estimated at 0.25 million m^3.

3. In the 2011 WY, Total E&P withdrew approximately 6,000 m^3 of water from four locations within the Ells River watershed, from November 2010 to February 2011, to support construction activities.

The estimated cumulative effect of land change and water withdrawals was an increase of flow of approximately 0.12 million m^3 at RAMP Station S14A in the 2011 WY. The observed *test* and estimated *baseline* hydrographs are presented in Figure 5.8-1. The mean winter discharge (November to March) was 0.05% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.8-3). This difference was classified as **Negligible-Low** (Table 5.8-2). The calculated mean open-water discharge (May to October), the annual maximum daily discharge, and the open-water minimum daily discharge were 0.07% higher in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.8-3). These differences were classified as **Negligible-Low** (Table 5.8-2).

5.8.3 Water Quality

In fall 2011, 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 (*test* station ELR-2, established in 2000, sampled annually since 2004, changed to a *test* station in 2011); and
- the Ells River upstream of the Fort MacKay water intake (*baseline* station ELR-2A, initiated as a new station in fall 2010).

Baseline station ELR-2A was also sampled in winter and summer 2011. Water quality samples were not taken in spring due to forest fires in the area.

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 2011); and
- A decreasing concentration of chloride at *test* station ELR-2 (2004 to 2011).

No trend analysis could be conducted for water quality at *baseline* station ELR-2A as this station was first sampled in 2010.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within the range of previously-measured concentrations in fall 2011 with the exception of total mercury with a concentration that exceeded previously-measured concentrations at *test* station ELR-1; pH with a value that exceeded previously-measured values at *test* station ELR-2; and total nitrogen, which was lower than previously-measured minimum concentrations at *test* station ELR-2 (Table 5.8-4 and Table 5.8-5). B*aseline* station ELR-2A exhibited consistent water quality in 2011 to 2010, when it was first sampled (Table 5.8-6).

Ion Balance The ionic composition of water in fall 2011 at all three water quality stations was similar and dominated by calcium and bicarbonate (Figure 5.8-4). The ionic composition of sampled water at *test* stations ELR-1 and ELR-2 has remained consistent since water quality monitoring first began in 1998. The exception to this trend was at *test* station ELR-2 in 2007 when the anionic composition was more dominated by bicarbonate than in other years.

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints in the Ells River in fall 2011 were below water quality guidelines (Table 5.8-4 to Table 5.8-6) with the exception of total aluminum at *test* station ELR-1.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were observed in the Ells River (Table 5.8-7):

- total iron at *baseline* station ELR-2A in winter;
- sulphide, total aluminum, total iron, total nitrogen and total phenols at *baseline* station ELR-2A in summer; and
- sulphide and total phenols at *test* station ELR-2 and *baseline* station ELR-2A, and total iron and total aluminum at *test* station ELR-1 in fall.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of all water quality measurement endpoints in fall 2011 were within the range of regional *baseline* concentrations at all stations (Figure 5.8-5).

Water Quality Index The WQI value was 100 for *test* station ELR-1 and 98.7 for *baseline* station ELR-2A and *test* station ELR-2 indicating **Negligible-Low** differences in water quality from regional *baseline* conditions at all stations in fall 2011.

Classification of Results Differences in water quality in fall 2011 between the Ells River and regional *baseline* fall conditions were classified as **Negligible-Low**. Water quality conditions were consistent with previous years for *test* stations ELR-1 and ELR-2 and generally within the range of previously-measured concentrations and regional *baseline* conditions. Water quality at *baseline* station ELR-2A in fall 2011 was similar to that at the other two stations and consistent with results from fall 2010 at this station.

5.8.4 Benthic Invertebrate Communities and Sediment Quality

5.8.4.1 Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 at:

- depositional *test* reach ELR-D1, sampled since 2003; and
- erosional *baseline* 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 in the watershed.

2011 Habitat Conditions Water at *test* reach ELR-Dl in fall 2011 was moderately deep (1.1 m), alkaline (pH: 8.1), with high dissolved oxygen (10.6 mg/L), and moderate conductivity (196 µS/cm). The substrate was dominated by silt (45%) and sand (33%) with some clay (22%) and low amounts of total organic carbon (2.5%) (Table 5.8-8).

Water at *baseline* reach ELR-E2A in fall 2011 was shallow (0.3 m), moderately flowing (0.61 m/s), neutral (pH: 7.2), with high dissolved oxygen (9.9 mg/L), and moderate conductivity (212 µS/cm). The substrate was dominated by small and large cobble (30% and 33%, respectively) with some large gravel (13%) (Table 5.8-8). Periphyton biomass in *baseline* reach ELR-E2A averaged 188 mg/m^2, which was within the range of variation for regional *baseline* conditions and much higher than previously-measured in fall 2010 (Figure 5.8-6).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach ELR-Dl in fall 2011 was dominated by tubificid worms (61%) with sub-dominant taxa consisting of chironomids (25%) (Table 5.8-9). Ostracoda and Ceratopogonidae were present in low relative abundances (Table 5.8-9). Dominant chironomids included the common forms *Polypedilum*, *Procladius*, and *Micropsectra* (Wiederholm 1983). Only one genus of mayfly (Ephemeroptera; *Caenis*), which is relatively tolerant (Mandaville 2001), was observed in fall 2011.

The benthic invertebrate community at *baseline* reach ELR-E2A in fall 2011 was dominated by chironomids (42%) and Ephemeroptera (20%) with subdominant taxa consisting of Trichoptera (15%) and Hydracarina (water mites, 9%) (Table 5.8-10). Bivalves and gastropods were present in very low relative abundances (Table 5.8-10). Dominant chironomids included the rheophilic *Rheotanytarsus*, and the common forms *Cricotopus/Orthocladius*, *Polypedilum*, and *Micropsectra/Tanytarsus*. Ephemeroptera were primarily of the genera *Baetis*, *Acerpenna*, *Tricorythodes* and *Heptagenia*, while Trichoptera were represented by the genera *Glossosoma*, *Brachycentrus*, and the very common *Hydropsyche* (Wiggins 1977). Plecoptera (*Taeniopteryx*, *Isoperla*) were present in low relative abundance.

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested at *test* reach ELR-D1 (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 was observed across years with the relative change explaining 45% of the variation in annual mean values (Table 5.8-11); time trends in the other six measurement endpoints for benthic invertebrate communities were not statistically significant (Table 5.8-9 and Figure 5.8-7). Taxa richness increased over time from a low of nine in 2005 to a high of 20 in 2010 (17 in 2011) (Table 5.8-9 and Figure 5.8-7). Tubificid worms comprised greater than 50% of the fauna in four of the seven sampling years and comprised 61% of the fauna in 2011. Stoneflies and caddisflies have been sporadically observed at *test* reach ELR-D1 in previous sampling years but were not observed in 2011.

Changes in time trends of measurement endpoints for benthic invertebrate communities were not tested for *baseline* reach ELR-E2A given there are only two years of data for this reach.

Comparison to Published Literature *Test* reach ELR-Dl in fall 2011 had a moderately high total abundance (~33,000 per m^2) and a relatively high percent of the fauna as tubificid worms (> 60%), potentially indicating some level of degradation (Hynes 1960, Griffiths 1998). The increase in richness from a low of nine in 2005 to a high of 20 in 2010 and 17 in 2011 may also be an indication of modest nutrient enrichment (Hynes 1960, Lowell *et al.* 2003, 2005). The benthic invertebrate community at *test* reach ELR-Dl in fall 2001 contained only a single representative mayfly (i.e., *Caenis*), and no caddisflies or stoneflies, indicating that concentrations of dissolved oxygen may not have been consistently as high as measured on the sampling date.

Baseline reach ELR-E2A in fall 2011 had a higher abundance (> 50,000 individuals per m^2) than previously-measured at this reach or at *baseline* reach ELR-E2. *Baseline* reach ELR-E2A was dominated numerically by mayflies (20%) and caddisflies (15%), stoneflies (2%), clams (< 1%), snails (< 1%), and beetles (Coleoptera, <1%) indicative of high quality habitat conditions for benthic invertebrate communities (Hynes 1960, Griffiths 1998, Mandaville 2001).

2011 Results Relative to Regional *Baseline* Conditions Values of all benthic invertebrate community measurement endpoints in fall 2011 were within the range of regional *baseline* depositional reaches at *test* reach ELR-D1 with the exception of evenness, which was lower than the 5^{th} percentile of the *baseline* range (Figure 5.8-7). Diversity in fall 2011 at *test* reach ELR-D1 was the lowest it had been since 2005, but still within the range of regional *baseline* depositional reaches. In addition, the ordination of the benthic invertebrate community at *test* reach ELR-D1 in fall 2011 was similar to regional *baseline* depositional reaches (Figure 5.8-8).

The data from *baseline* reach ELR-E2A contributed to the range of variation for *baseline* erosional reaches.

Classification of Results Differences in values of benthic invertebrate community measurement endpoints were classified as **Negligible-Low** because the significant increase in taxa richness over time did not imply a negative change in the benthic invertebrate community. In addition, although evenness in fall 2011 was lower than regional *baseline* conditions, there were no other measurement endpoints that exceeded the range of *baseline* conditions and evenness was lower in 2005 (0.56) than 2011. It should be noted; however, that habitat conditions at *test* reach ELR-D1 were of marginal quality for benthic invertebrate communities. The high relative abundance of tubificid worms (> 60% in 2011), the absence of caddisflies and stoneflies, and the low relative abundance of mayflies, with *Caenis* as the only representative, indicated an environment that was slightly limiting to depositional fauna.

5.8.4.2 Sediment Quality

Sediment quality was sampled in fall 2011 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 2011.

Temporal Trends No statistically significant trends (α=0.05) in concentrations of sediment quality measurement endpoints were detected at *test* station ELR-D1 in fall 2011.

2011 Results Relative to Historical Concentrations 2011 sediment quality data from *test* station ELR-D1 were compared directly to data collected at this station in 2006 and 2007. Prior to the integration of the Sediment Quality component with the Benthic Invertebrate Communities component of RAMP in 2006, *test* station ELR-D1 corresponds to pre-2006 sediment quality station ELR-1.

Sediments at *test* station ELR-D1 in fall 2011 were dominated by silt with smaller proportions of sand and clay; this finer particle-size distribution was similar to that observed in 2005 (Table 5.8-12). Total organic carbon content and concentrations of total metals was near but within previously-measured maximum concentrations (Figure 5.8-9). Total metals, normalized to %silt and %clay were within the range of previously-measured concentrations (Figure 5.8-9). As in previous years, concentrations of hydrocarbons were dominated by Fraction 3 and Fraction 4, which indicated a presence of bitumen in sediments (Table 5.8-12). All hydrocarbon fractions and total PAHs (absolute and carbon-normalized concentrations) were within the range of previously-measured concentrations (Figure 5.8-9). The predicted PAH toxicity of 2.01 exceeded the potential chronic toxicity threshold of 1.0, but was within the range of previously-measured values observed at *test* station ELR-D1 (Table 5.8-12 and Figure 5.8-9).

Direct tests of sediment toxicity to invertebrates at *test* station ELR-D1 showed 94% survival in test organisms of the amphipod *Hyalella* and 68% survival in test organisms of the midge *Chironomus.* Both growth and survival of both test organisms were within the range of previous values for this station (Table 5.8-12).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines Fraction 2 and Fraction 3 hydrocarbons, total arsenic, benz[a]anthracene, and chrysene exceeded relevant CCME sediment quality guidelines at *test* station ELR-D1 in fall 2011 (Table 5.8-12). Concentrations of arsenic, benz[a]anthracene, and chrysene exceeded relevant CCME Interim Sediment Quality Guidelines (ISQGs), but were three to eight times below the CCME Probable Effect Levels (PEL).

Sediment Quality Index A SQI of 67.5 was calculated for *test* station ELR-D1 for fall 2011, indicating a **Moderate** difference from regional *baseline* conditions. Since 1998, this station has had a SQI that indicated **Negligible-Low** differences from regional *baseline* conditions with the exception of 2005 and 2006 when sediment conditions indicated a **Moderate** difference from regional *baseline* conditions. In all of these years (2005, 2006, and 2011), sediments were dominated by fine particle sizes, with high TOC, and concentrations of PAHs that exceeded regional *baseline* values (Figure 5.8-9).

Classification of Results Differences in sediment quality observed in fall 2011 between *test* station ELR-D1 and regional *baseline* conditions were classified as **Moderate**, with concentrations of PAHs exceeding regional *baseline* conditions but were within previously-measured concentrations at this station.

5.8.5 Fish Populations

Fish assemblages were sampled in fall 2011 at:

- depositional *test* reach ELR-F1, sampled in 2010 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is at the same location as the benthic invertebrate community *test* reach ELR-D1); and
- erosional *baseline* reach ELR-F2A, sampled in 2010 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is at the same location as the benthic invertebrate community *baseline* reach ELR-E2A).

2011 Habitat Conditions *Test* reach ELR-F1 was comprised entirely of run habitat with a wetted width of 27.0 m and a bankfull width of 31.9 m (Table 5.8-13). The substrate was dominated by silt and clay with a small amount of sand. Water at *test* reach ELR-F1 in fall 2011 was 0.87 m in depth, moderately flowing (0.45 m/s), alkaline (pH: 7.9) with low conductivity (222 µS/cm), high dissolved oxygen (8.2 mg/L), and a temperature of 18.4˚C. Instream cover was primarily dominated by small woody debris with small amounts of large woody debris (Table 5.8-13).

Baseline reach ELR-F2A was comprised of run and riffle habitat with a wetted width of 32 m and a bankfull width of 35.5 m (Table 5.8-13). The substrate was dominated by coarse gravel with smaller amounts of cobble. Water at *baseline* reach ELR-F2A in fall 2011 was 1.0 m in depth, moderately flowing (0.47 m/s), alkaline (pH: 7.7), with low conductivity (245 µ/cm), high dissolved oxygen of 8.8 mg/L, and a temperature of 13˚C. Instream cover was dominated by filamentous algae and boulders with small amounts of small and large woody debris (Table 5.8-13).

Temporal and Spatial Comparisons Sampling was initiated at *test* reach ELR-F1 and *baseline* reach ELR-F2A in 2010 during the second year of the RAMP Fish Assemblage pilot study; therefore, temporal comparisons were only conducted from 2010 to 2011. Spatial comparisons were not conducted with the upstream *baseline* reach given that *baseline* reach ELR-F2A is erosional and *test* reach ELR-D1 is depositional.

Decreases in abundance, diversity, and CPUE of fish were observed from 2010 to 2011 at *test* reach ELR-F1 and *baseline* reach ELR-F2A (Table 5.8-14). *Test* reach ELR-F1 was dominated by trout-perch while *baseline* reach ELR-F2A was dominated by pearl dace. The decrease observed in the assemblage tolerance index in 2011 at both reaches likely reflects the lower abundance of fish and not necessarily the presence of more sensitive fish species (Table 5.8-15). Species richness at *test* reach ELR-F1 and *baseline* reach ELR-F2A remained consistent from 2010 to 2011.

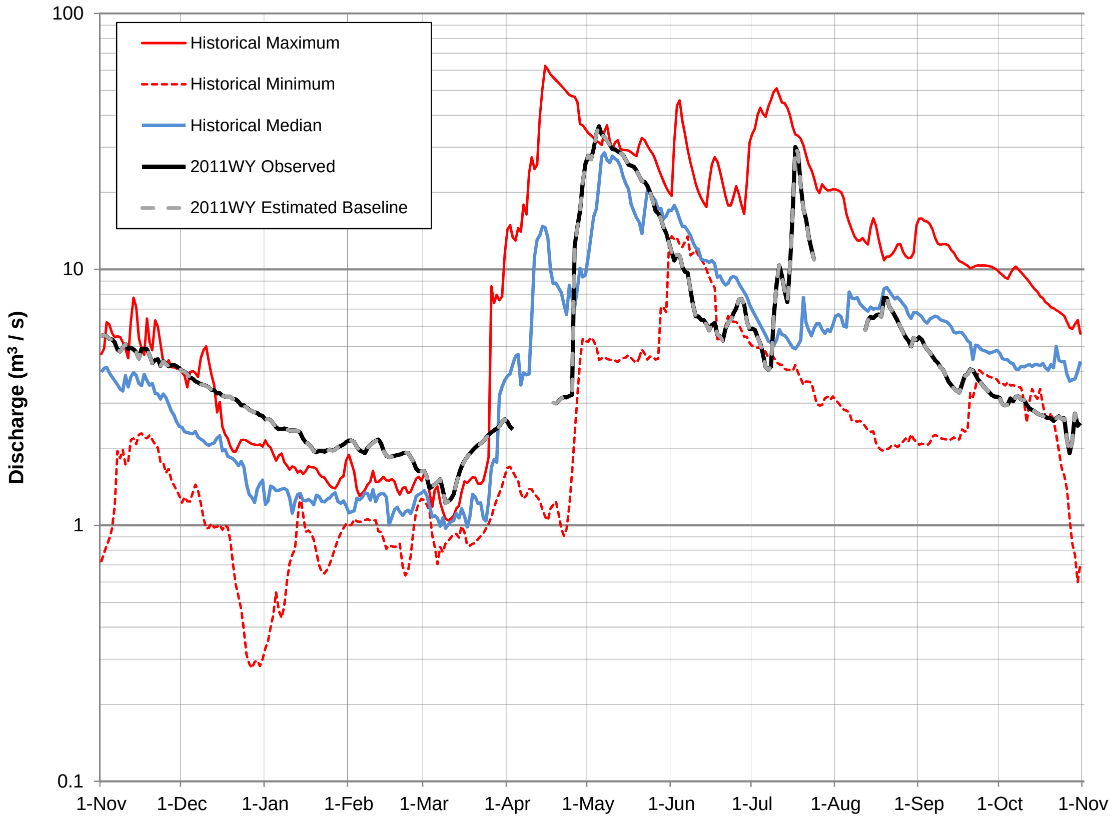
Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of 19 fish species were recorded in the Ells River watershed; whereas RAMP found only nine species from 2009 to 2011, as well as finescale dace, which has not been previously documented in the Ells River. As noted in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Golder (2004b) documented similar habitat conditions consisting of pools and riffles dominated by boulder, cobble, and gravel substrate in the area of the Ells River where *baseline* reach ELR-F2A is located, which is consistent with observations by RAMP. In the lower portion of the Ells River, where *test* reach ELR-F2A is located, Golder (2004b) documented habitat consisting primarily of fine sediment, which is also consistent with observations in 2011 (Table 5.8-13).

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at *test* reach ELR-F1 and *baseline* reach ELR-F2A were within the range of regional *baseline* conditions; however, the sub-reach variation for diversity, ATI, and richness at *test* reach ELR-F1 and total abundance at *baseline* reach ELR-F2 exceeded the range of *baseline* conditions (Figure 5.8-10).

Classification of Results Differences in the fish assemblage observed in fall 2011 between *test* reach ELR-F1 and regional *baseline* conditions were classified as **Negligible-Low** with all median values of measurement endpoints within the range of regional *baseline* variability for depositional reaches.

Figure 5.8-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Ells River in the 2011 WY, compared to historical values.



Note: The observed 2011 WY hydrograph is based on Ells River above Joslyn Creek, Station S14A, 2011 provisional data. The upstream drainage area is 2,450 km^2. Historical values are calculated for the period from 2001 to 2010 during the open-water period (May to October), and from 2004 to 2010 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), 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**184.70**	**Observed discharge at Ells River above Joslyn Creek, RAMP Station S14A**
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)	+0.25	Estimated 16.4 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	6,249 m^3 withdrawn from sources in the Ells River watershed for construction activities
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)	**184.58**	**Estimated *baseline* discharge at Ells River above Joslyn Creek, RAMP Station S14A**
Incremental flow (change in total discharge)	+0.12	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.06%**	**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 Ells River above Joslyn Creek, RAMP Station S14A, 2011 WY 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, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	9.581	9.587	0.07%
Mean winter discharge	2.797	2.798	0.05%
Annual maximum daily discharge	36.239	36.264	0.07%
Open-water period minimum daily discharge	1.912	1.913	0.07%

Note: Based on Ells River above Joslyn Creek, RAMP Station S14A, 2011 WY provisional data.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to three and two decimal places, respectively.

Table 5.8-4 Concentrations of water quality measurement endpoints, mouth of Ells River (*test* station ELR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	10	7.8	8.2	8.4
Total suspended solids	mg/L	-	10	10	<3	6.5	16
Conductivity	µS/cm	-	225	10	175	226	272
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.01	10	0.00	0.01	0.02
Total nitrogen	mg/L	1	0.6	10	0.3	0.7	**1.3**
Nitrate+nitrite	mg/L	1.3	<0.071	10	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	16.3	10	11	15	20
Ions							
Sodium	mg/L	-	10	10	8	11.0	18
Calcium	mg/L	-	23.1	10	21.6	24.5	30.4
Magnesium	mg/L	-	7.1	10	6.5	7.5	9.1
Chloride	mg/L	230, 860	1.3	10	<0.5	2.0	4.0
Sulphate	mg/L	100	15.5	10	10.5	16.6	27.9
Total dissolved solids	mg/L	-	164	10	110	165.5	220
Total alkalinity	mg/L		98	10	76	96.5	117
Selected metals							
Total aluminum	mg/L	0.1	**0.41**	10	0.06	**0.29**	**0.67**
Dissolved aluminum	mg/L	0.1	0.007	10	0.006	**0.016**	**0.078**
Total arsenic	mg/L	0.005	0.0009	10	<0.001	0.0010	0.0012
Total boron	mg/L	1.2	0.061	10	0.041	0.061	0.083
Total molybdenum	mg/L	0.073	0.0007	10	0.0006	0.0007	0.0008
Total mercury (ultra-trace)	ng/L	5, 13	<u>1.5</u>	8	<1.2	<1.2	1.4
Total strontium	mg/L	-	0.12	10	0.10	0.12	0.14
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	4.4	0	-	-	-
Total dibenzothiophenes	ng/L	-	120.2	0	-	-	-
Total PAHs	ng/L	-	448.1	0	-	-	-
Total Parent PAHs	ng/L	-	24.9	0	-	-	-
Total Alkylated PAHs	ng/L	-	423.1	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**0.69**	10	**0.45**	**0.71**	**1.14**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.8-5 Concentrations of water quality measurement endpoints, upper Ells River (*test* station ELR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.4</u>	7	7.7	8.1	8.3
Total suspended solids	mg/L	-	3	7	<3	4	8
Conductivity	µS/cm	-	208	7	164	195	219
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.01	7	0.004	0.01	**0.06**
Total nitrogen	mg/L	1	<u>0.55</u>	7	0.60	0.71	**2.01**
Nitrate+nitrite	mg/L	1.3	<0.071	7	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	15.6	7	10	14.5	20.7
Ions							
Sodium	mg/L	-	9.8	7	3	10.3	13
Calcium	mg/L	-	22.5	7	20.5	24.5	25.6
Magnesium	mg/L	-	7.5	7	6.2	7	7.8
Chloride	mg/L	230, 860	0.9	7	0.7	2	3
Sulphate	mg/L	100	13.8	7	2.2	13.6	18.9
Total dissolved solids	mg/L	-	143	7	110	155	190
Total alkalinity	mg/L		91.4	7	73	90.5	110
Selected metals							
Total aluminum	mg/L	0.1	0.05	7	0.05	**0.27**	**0.74**
Dissolved aluminum	mg/L	0.1	0.005	7	<0.001	0.014	0.026
Total arsenic	mg/L	0.005	0.0008	7	0.0006	0.0009	0.0011
Total boron	mg/L	1.2	0.06	7	0.04	0.05	0.08
Total molybdenum	mg/L	0.073	0.0007	7	0.0006	0.0007	0.0008
Total mercury (ultra-trace)	ng/L	5, 13	1.1	7	<1.2	<1.2	2
Total strontium	mg/L	-	0.12	7	0.09	0.11	0.14
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	44.4	0	-	-	-
Total PAHs	ng/L	-	240.5	0	-	-	-
Total Parent PAHs	ng/L	-	20.9	0	-	-	-
Total Alkylated PAHs	ng/L	-	219.6	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Sulphide	mg/L	0.002	**0.004**	7	**0.003**	**0.006**	**0.014**
Total phenols	mg/L	0.004	**0.005**	7	<0.001	0.004	**0.025**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.8-6 Concentrations of water quality measurement endpoints, upper Ells River (*baseline* station ELR-2A), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	September 2010
			Value	Value
Physical variables				
pH	pH units	6.5-9.0	8.4	8.2
Total suspended solids	mg/L	-	<3	5
Conductivity	µS/cm	-	209	206
Nutrients				
Total dissolved phosphorus	mg/L	0.05	0.01	0.01
Total nitrogen	mg/L	1	0.56	**2.31**
Nitrate+nitrite	mg/L	1.3	<0.071	<0.071
Dissolved organic carbon	mg/L	-	15.3	20.4
Ions				
Sodium	mg/L	-	9.4	10.2
Calcium	mg/L	-	21.7	22.6
Magnesium	mg/L	-	7.3	6.9
Chloride	mg/L	230, 860	0.79	0.65
Sulphate	mg/L	100	13.6	16.6
Total dissolved solids	mg/L	-	137	158
Total alkalinity	mg/L		92.3	87.8
Selected metals				
Total aluminum	mg/L	0.1	0.05	**0.51**
Dissolved aluminum	mg/L	0.1	0.01	0.01
Total arsenic	mg/L	0.005	0.001	0.001
Total boron	mg/L	1.2	0.06	0.05
Total molybdenum	mg/L	0.073	0.001	0.001
Total mercury (ultra-trace)	ng/L	5, 13	0.8	2
Total strontium	mg/L	-	0.12	0.12
Total hydrocarbons				
BTEX	mg/L	-	<0.1	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]				
Naphthalene	ng/L	-	<14.1	-
Retene	ng/L	-	<2.1	-
Total dibenzothiophenes	ng/L	-	24.9	-
Total PAHs	ng/L	-	179.8	-
Total Parent PAHs	ng/L	-	19.6	-
Total Alkylated PAHs	ng/L	-	160.2	-
Other variables that exceeded CCME/AENV guidelines in fall 2011				
Sulphide	mg/L	0.002	**0.004**	**0.006**
Total phenols	mg/L	0.004	**0.01**	**0.01**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.8-4 Piper diagram of fall ion concentrations in the Ells River watershed.

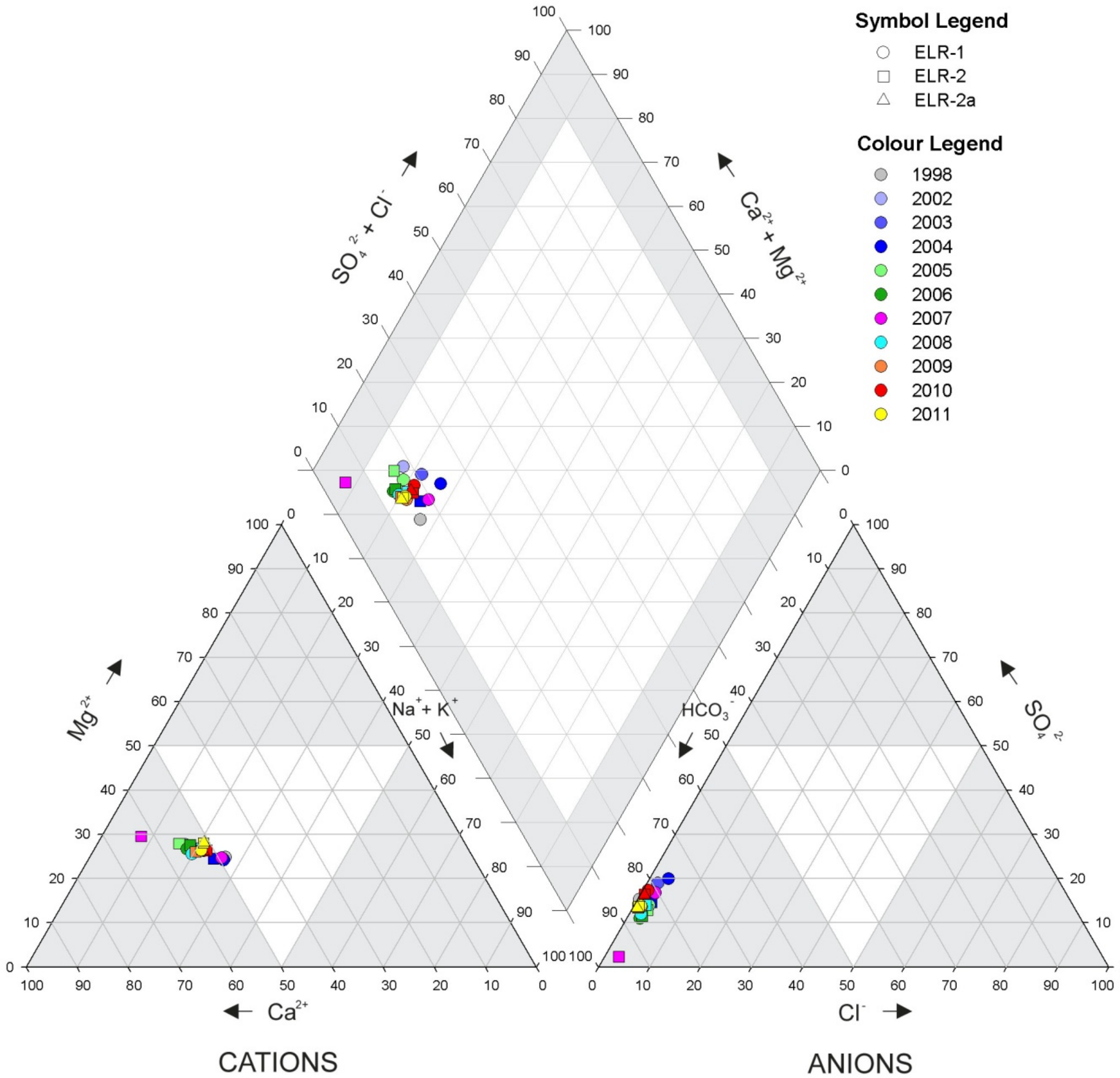


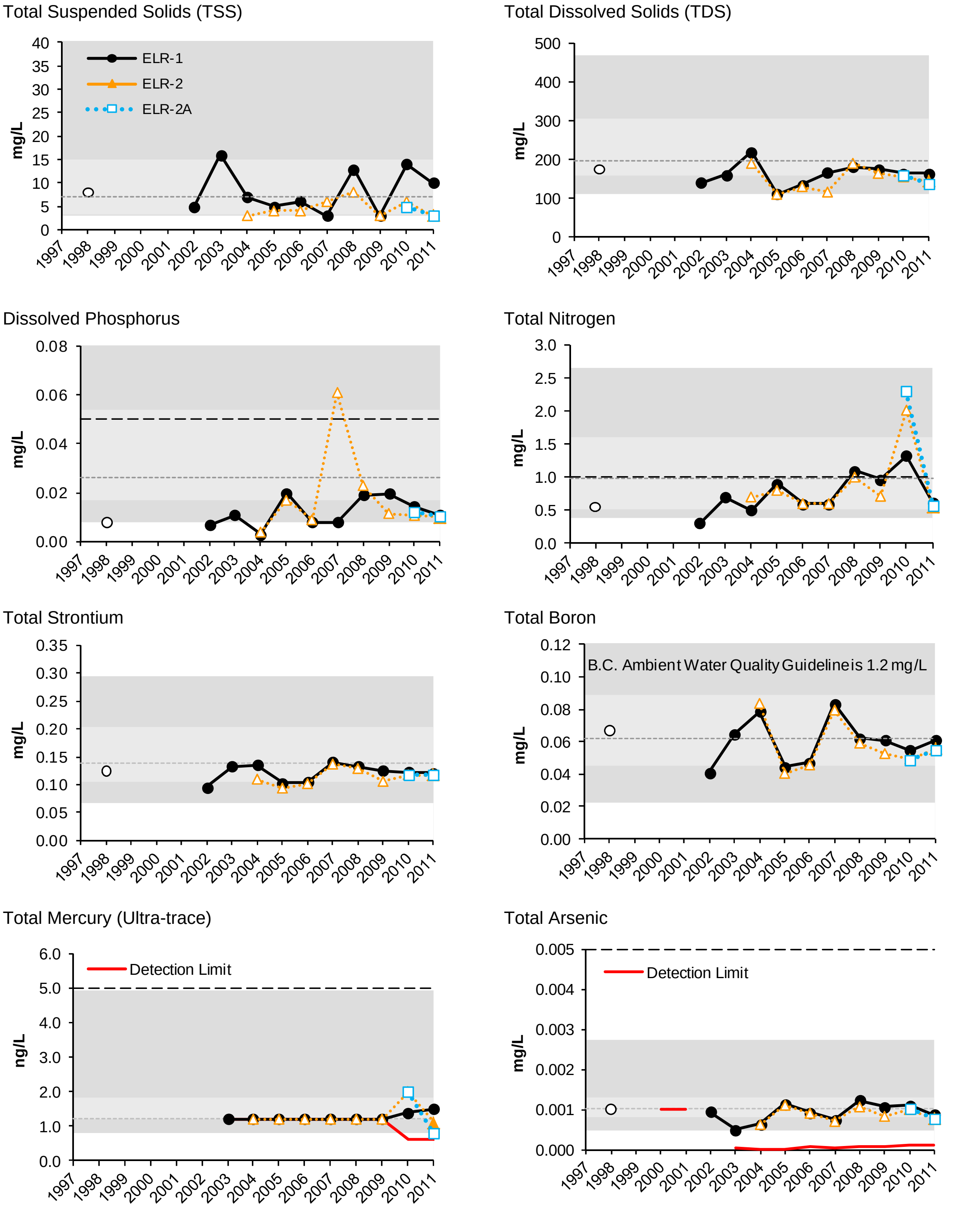
Table 5.8-7 Water quality guideline exceedances, Ells River, 2011.

Variable	Units	Guideline[a]	ELR-1	ELR-2	ELR-2A
Winter					
Total iron	mg/L	0.3	ns	ns	0.55
Summer					
Sulphide	mg/L	0.002	ns	ns	0.010
Total aluminum	mg/L	0.1	ns	ns	0.60
Total iron	mg/L	0.3	ns	ns	0.90
Total nitrogen	mg/L	1	ns	ns	1.08
Total phenols	mg/L	0.004	ns	ns	0.017
Fall					
Sulphide	mg/L	0.002	-	0.004	0.004
Total aluminum	mg/L	0.1	0.41	-	-
Total iron	mg/L	0.3	0.69	-	-
Total phenols	mg/L	0.004	-	0.005	0.006

[a] Sources for all guidelines are outlined in Table 3.2-5.

ns = not sampled

Figure 5.8-5 Selected water quality measurement endpoints in the Ells River (fall data) relative to historical concentrations and regional *baseline* fall concentrations.



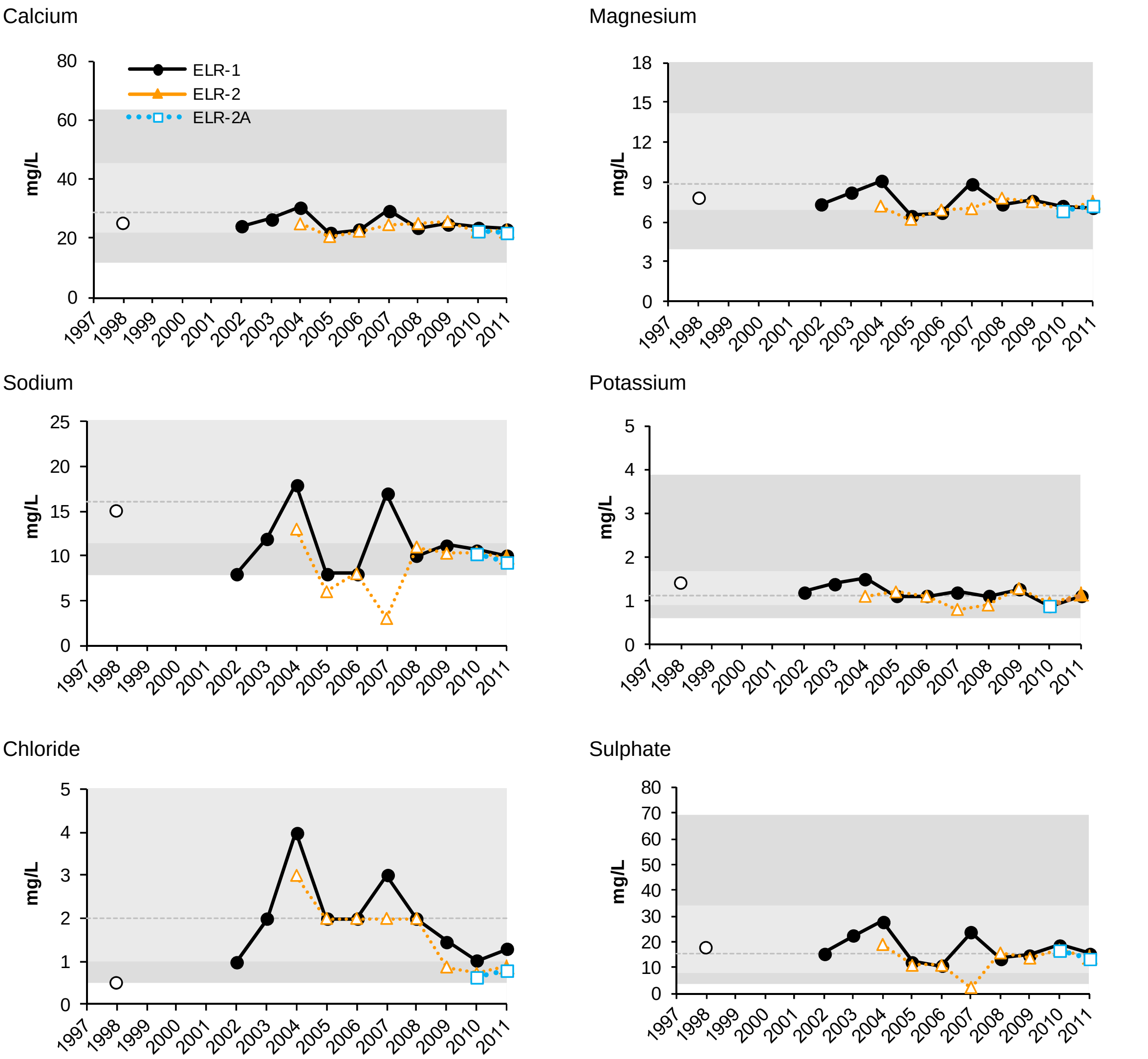
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.8-5 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.8-8 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, 2011	Sept. 12, 2011
Habitat	-	Depositional	Erosional
Water depth	m	1.1	0.3
Current velocity	m/s	-	0.6
Field Water Quality			
Dissolved oxygen	mg/L	10.6	9.9
Conductivity	µS/cm	196	212
pH	pH units	8.1	7.2
Water temperature	°C	7.9	13.9
Sediment Composition			
Sand	%	33	-
Silt	%	45	-
Clay	%	22	-
Total Organic Carbon	%	2.5	-
Sand/Silt/Clay	%	-	13
Small Gravel	%	-	5
Large Gravel	%	-	13
Small Cobble	%	-	30
Large Cobble	%	-	33
Boulder	%	-	4
Bedrock	%	-	4

Figure 5.8-6 Periphyton chlorophyll *a* biomass in *baseline* reaches ELR-E2 and ELR-E2A of the Ells River.

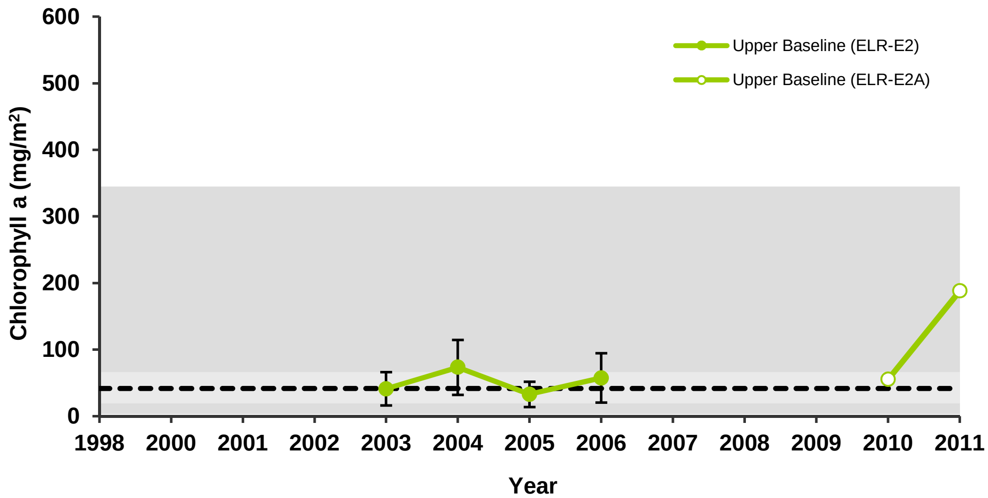


Table 5.8-9 Summary of major taxon abundances and benthic invertebrate community measurement endpoints at *test* reach ELR-D1.

Taxon	Percent Major Taxa Enumerated in Each Year						
	Reach ELR-D1						
	2003	2004	2005	2006	2007	2010	2011
Nematoda	<1	2	<1	3	1	1	2
Oligochaeta							1
Naididae	24	2	17	4	2	11	2
Tubificidae	52	55	57	28	18	29	61
Enchytraeidae		<1				<1	
Hydracarina	<1	<1		1	1	1	2
Ostracoda		<1	5		18	6	3
Cladocera							<1
Copepoda	<1				<1	1	
Gastropoda	<1	<1			1	<1	<1
Bivalvia	<1	<1			<1	<1	2
Coleoptera		<1			<1	<1	
Ceratopogonidae	3	5	1	5	7	3	1
Chironomidae	19	32	17	56	52	45	25
Chaoboridae							<1
Athericidae			<1				
Empididae	<1	<1	<1	2	1	1	<1
Tipulidae		<1					
Tabanidae	<1	1	<1	<1		<1	<1
Simuliidae			2		1	1	<1
Ephemeroptera	<1	<1	<1	1	1	<1	<1
Anisoptera	<1	<1	<1	<1	<1	<1	<1
Zygoptera		<1				<1	
Plecoptera				<1		<1	
Trichoptera	<1	<1			<1	<1	
Heteroptera	<1						
Benthic Invertebrate Community Measurement Endpoints							
Total Abundance (No./m^2)	30,917	11,129	12,939	8,731	10,405	34,606	32,745
Richness	12	10	9	10	15	20	17
Simpson's Diversity	0.69	0.65	0.47	0.70	0.77	0.79	0.56
Evenness	0.76	0.73	0.54	0.79	0.85	0.85	0.61
% EPT	1	1	0	1	<1	<1	<1

Table 5.8-10 Summary of major taxon abundances and benthic invertebrate community measurement endpoints at *baseline* reaches ELR-E2 and ELR-E2A.

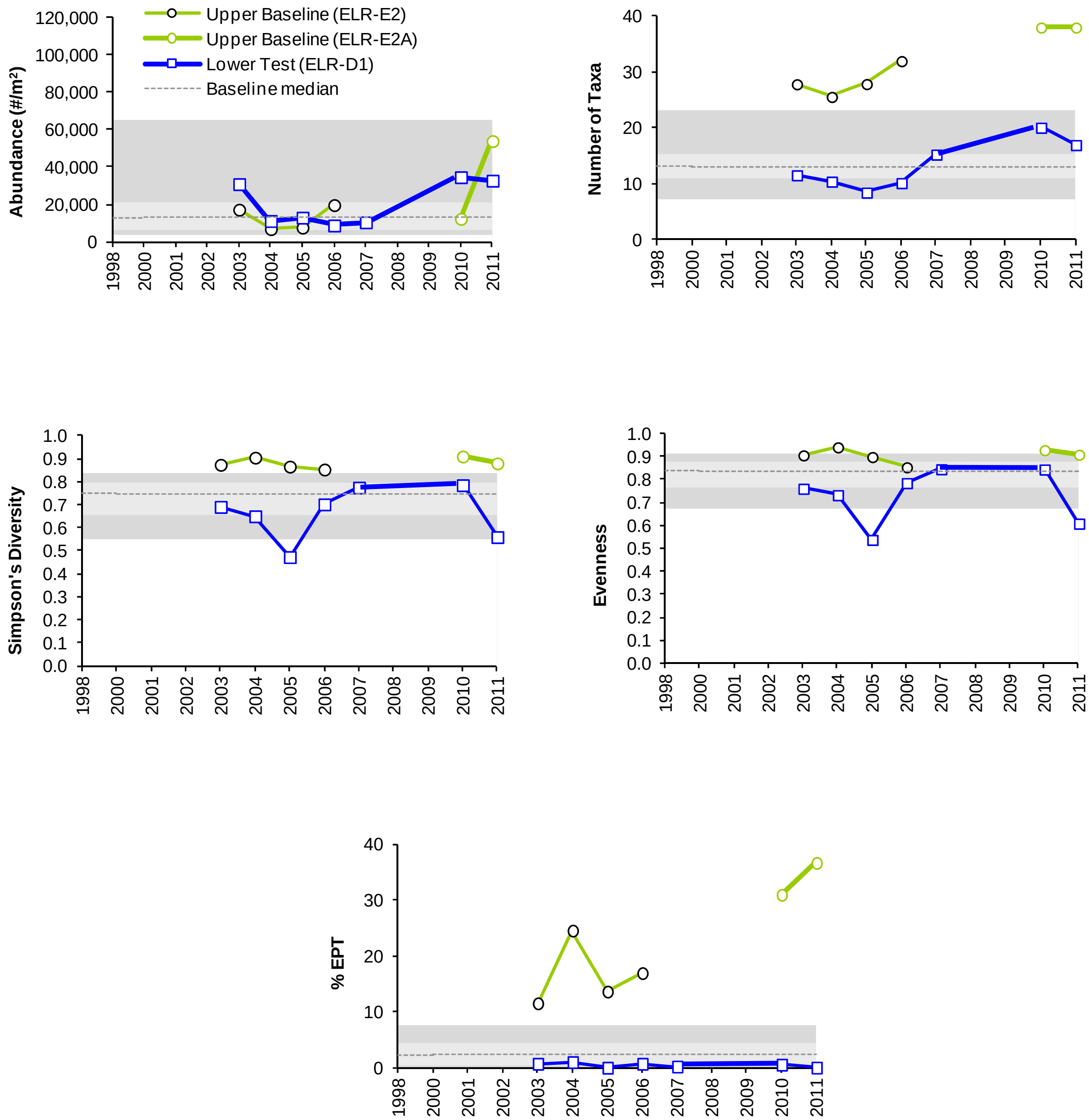
Taxon	Percent Major Taxa Enumerated in Each Year					
	Reach ELR-E2				Reach ELR-E2A	
	2003	2004	2005	2006	2010	2011
Nematoda	1	4	<1	2	2	2
Oligochaeta						<1
Naididae	13	5	28	21	10	4
Tubificidae	<1	<1	1	1	<1	1
Enchytraeidae	1	1	<1	<1	1	<1
Hydracarina	11	8	19	12	9	9
Ostracoda	<1	<1	<1	1	1	<1
Copepoda		<1		2	<1	<1
Gastropoda	1	<1	<1	<1	<1	<1
Bivalvia	<1	1	<1		<1	<1
Coleoptera		<1	<1	<1	<1	<1
Ceratopogonidae	1	2	<1	2	1	<1
Chironomidae	6	49	35	40	43	42
Athericidae	<1	<1		<1	<1	<1
Empididae	2	3	1	1	1	1
Tipulidae	<1		<1	<1	<1	<1
Tabanidae	<1		<1		<1	
Simuliidae	<1	<1	1	1	1	<1
Ephemeroptera	7	15	7	1	18	20
Anisoptera	<1	2	<1	<1	<1	<1
Zygoptera				<1		
Plecoptera	1	6	3	<1	2	2
Trichoptera	2	4	2	3	10	15
Benthic Invertebrate Community Measurement Endpoints						
Total Abundance (No./m^2)	17,207	6,779	7,592	19,659	12,286	53,976
Richness	28	26	28	32	38	38
Simpson's Diversity	0.87	0.91	0.87	0.85	0.91	0.88
Evenness	0.91	0.94	0.90	0.86	0.93	0.91
% EPT	12	25	14	17	30	37

Table 5.8-11 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints at *test* reach ELR-D1.

Variable	P-value	Variance Explained (%)	Nature of Change(s)
	Time Trend	Time Trend	
Abundance	0.228	23	No change
Richness	**0.013**	45	Increasing over time
Simpson's Diversity	0.602	2	No change
Evenness	0.793	0	No change
EPT	0.191	22	No change
CA Axis 1	0.924	0	No change
CA Axis 2	0.704	1	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).

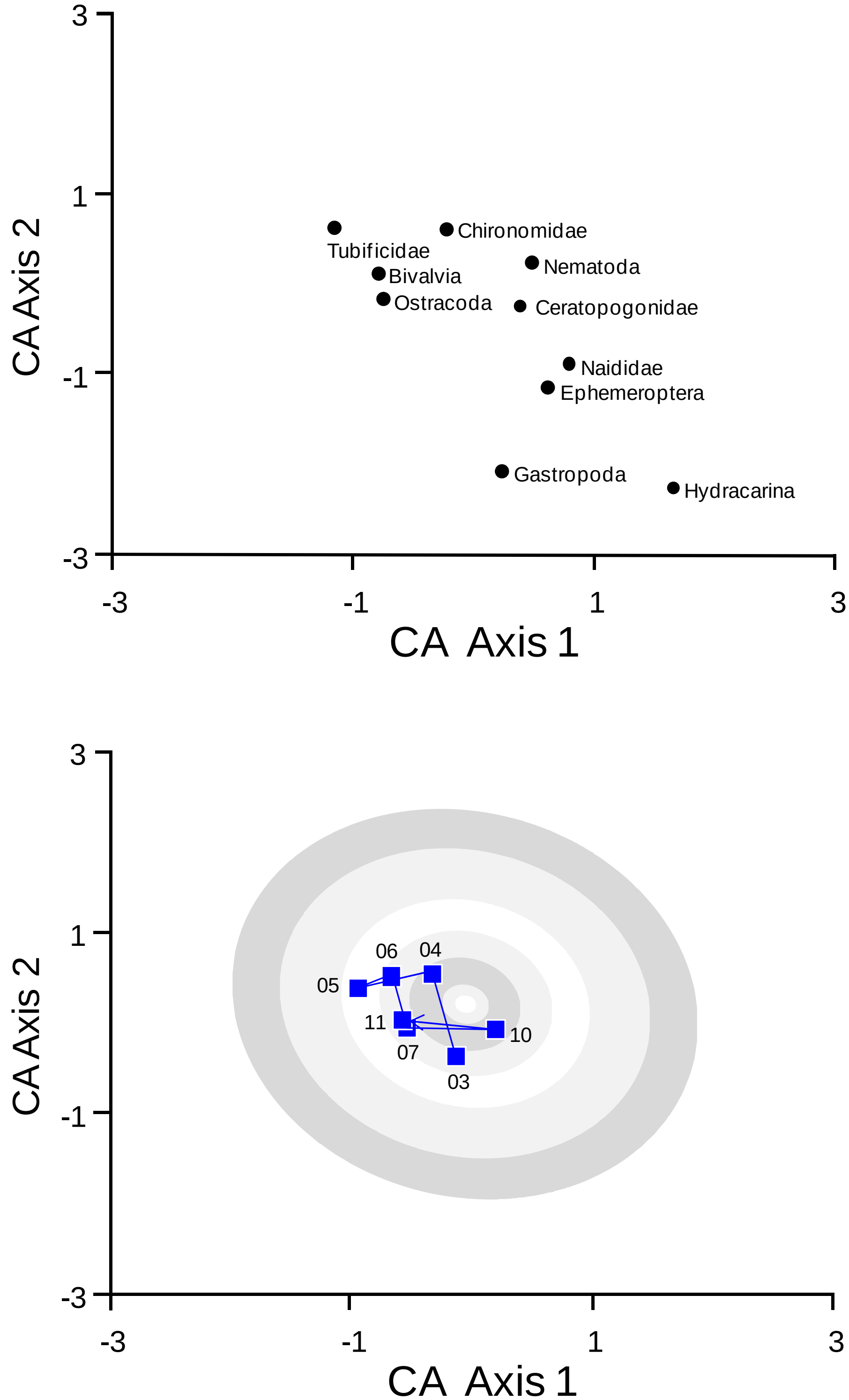
Figure 5.8-7 Variation in benthic invertebrate community measurement endpoints in the Ells River.



Note: 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: *Baseline* reaches ELR-E2 and ELR-E2A are erosional reaches but are shown here for comparison to *test* reach ELR-D1 over time but are not compared to the range of *baseline* depositional 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 5.8-12 Concentrations of selected sediment quality measurement endpoints, Ells River (*test* station ELR-D1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	22	8	3	7	26
Silt	%	-	45	8	3	13	51
Sand	%	-	33	8	23	81	94
Total organic carbon	%	-	2.6	8	0.4	1.3	2.8
Total hydrocarbons							
BTEX	mg/kg	-	<u>≤20</u>	5	<5	<5	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<u>≤20</u>	5	<5	<5	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	**198**	5	73	150	**320**
Fraction 3 (C16-C34)	mg/kg	300[1]	**1690**	5	**890**	**1500**	**3000**
Fraction 4 (C34-C50)	mg/kg	2800[1]	899	5	510	790	1600
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0042	8	0.0009	0.0040	0.0094
Retene	mg/kg	-	<u>0.7130</u>	7	0.0670	0.1950	0.2930
Total dibenzothiophenes	mg/kg	-	5.8042	8	1.2776	5.1694	9.8848
Total PAHs	mg/kg	-	18.9813	8	4.8094	13.7392	25.0964
Total Parent PAHs	mg/kg	-	0.4113	8	0.2183	0.3695	0.5713
Total Alkylated PAHs	mg/kg	-	18.5699	8	4.4612	13.4301	24.5252
Predicted PAH toxicity[3]	H.I.	1.0	**2.01**	8	**1.18**	**1.73**	**2.51**
Metals that exceed CCME guidelines in 2011							
Total Arsenic	mg/kg	5.9	**7.66**	8	1.70	3.75	**8.00**
Other analytes that exceeded CCME guidelines in 2011							
Benz[a]anthracene	mg/kg	0.0317	<u>**0.134**</u>	8	0.008	0.013	0.019
Chrysene	mg/kg	0.0571	**0.101**	8	**0.072**	**0.115**	**0.203**
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.8	5	5.0	7.0	7.6
Chironomus growth - 10d	mg/organism	-	1.97	5	0.72	2.10	2.80
Hyalella survival - 14d	# surviving	-	9.4	6	8.0	8.7	10.0
Hyalella growth - 14d	mg/organism	-	0.27	6	0.10	0.13	1.60

Values in **bold** indicate concentrations exceeding guidelines.

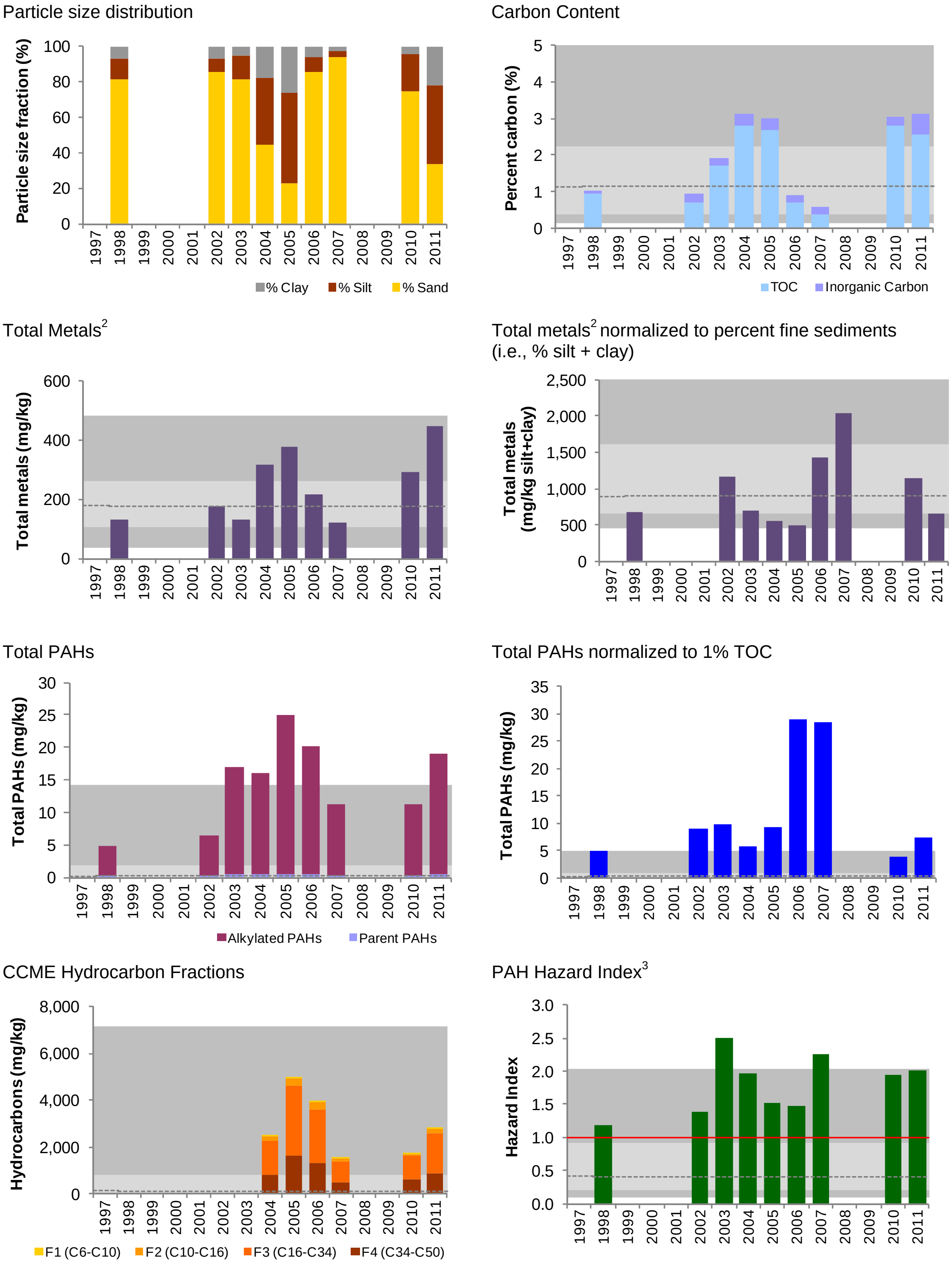
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.8-13 Average habitat characteristics of fish assemblage monitoring locations of the Ells River.

Variable	Units	ELR-F1 Lower *Test* Reach of Ells River	ELR-F2A Upper *Baseline* Reach of Ells River
Sample date	-	Sept. 7, 2011	Sept. 11, 2011
Habitat type	-	run	run/riffle
Maximum depth	m	0.87	1.00
Average bankfull channel width	m	31.9	35.5
Average wetted channel width	m	27.0	32.0
Substrate			
Dominant		silt/clay	coarse gravel
Subdominant	-	sand	cobble
Instream cover			
Dominant	-	small woody debris	filamentous algae and boulders
Subdominant	-	large woody debris	small and large woody debris
Field water quality			
Dissolved oxygen	mg/L	8.2	8.8
Conductivity	µS/cm	222	245
pH	pH units	7.9	7.7
Water temperature	°C	18.4	13
Water velocity			
Left bank velocity	m/s	0.41	0.67
Left bank water depth	m	0.69	0.37
Centre of channel velocity	m/s	0.56	0.58
Centre of channel water depth	m	0.53	0.42
Right bank velocity	m/s	0.18	0.47
Right bank water depth	m	0.32	0.32
Riparian cover – understory (<5 m)			
Dominant	-	woody shrubs and saplings	woody shrubs and saplings
Subdominant	-	overhanging vegetation	overhanging vegetation

Table 5.8-14 Percent composition and mean CPUE of fish species at *test* reach ELR-F1 and *baseline* reach ELR-F2A of Ells River, 2010 to 2011.

Common Name	Code	Total Species				Percent of Total Catch			
		ELR-F1		ELR-F2A		ELR-F1		ELR-F2A	
		2010	2011	2010	2011	2010	2011	2010	2011
Arctic grayling	ARGR	-	-	-	-	0	0	0	0
brook stickleback	BRST	-	-	-	-	0	0	0	0
burbot	BURB	-	-	-	-	0	0	0	0
fathead minnow	FTMN	-	-	-	-	0	0	0	0
finescale dace	FNDC	34	-	160	-	30.6	0	52.5	0
lake chub	LKCH	-	4	-	1	0	26.7	0	1.4
lake whitefish	LKWH	-	-	-	-	0	0	0	0
longnose dace	LNDC	2	2	-	19	1.8	13.3	0	26.4
longnose sucker	LNSC	-	-	13	-	0	0	4.3	0
northern pike	NRPK	-	-	-	-	0	0	0	0
northern redbelly dace	NRDC	-	-	-	-	0	0	0	0
pearl dace	PRDC	46	-	82	43	41.4	0	26.9	59.7
slimy sculpin	SLSC	-	-	-	1	0	0	0	1.4
spoonhead sculpin	SPSC	-	-	-	-	0	0	0	0
spottail shiner	SPSH	-	1	-	-	0	6.7	0	0
trout-perch	TRPR	1	6	4	6	0.9	40.0	1.3	8.3
walleye	WALL	-	-	-	-	0	0	0	0
white sucker	WHSC	12	-	46	2	10.8	0	15.1	2.8
yellow perch	YLPR	15	2	-	-	13.5	13.3	0	0
unknown sucker sp.*	-	1	-	-	-	0.9	0	0	0
Total Count		**111**	**15**	**305**	**72**	**100**	**100**	**100**	**100**
Total Abundance (#/m)		**0.37**	**0.06**	**0.61**	**0.29**	**-**	**-**	**-**	**-**
Total Species Richness		**6**	**5**	**5**	**6**	**6**	**5**	**5**	**6**
Electrofishing effort (secs)		**5,258**	**1,307**	**3,959**	**1,614**	**-**	**-**	**-**	**-**
CPUE (#/100secs)		**2.11**	**1.15**	**7.70**	**4.46**	**-**	**-**	**-**	**-**

* not included in total species richness count.

Table 5.8-15 Summary of fish assemblage measurement endpoints (±1SD) in reaches of the Ells River, 2010 to 2011.

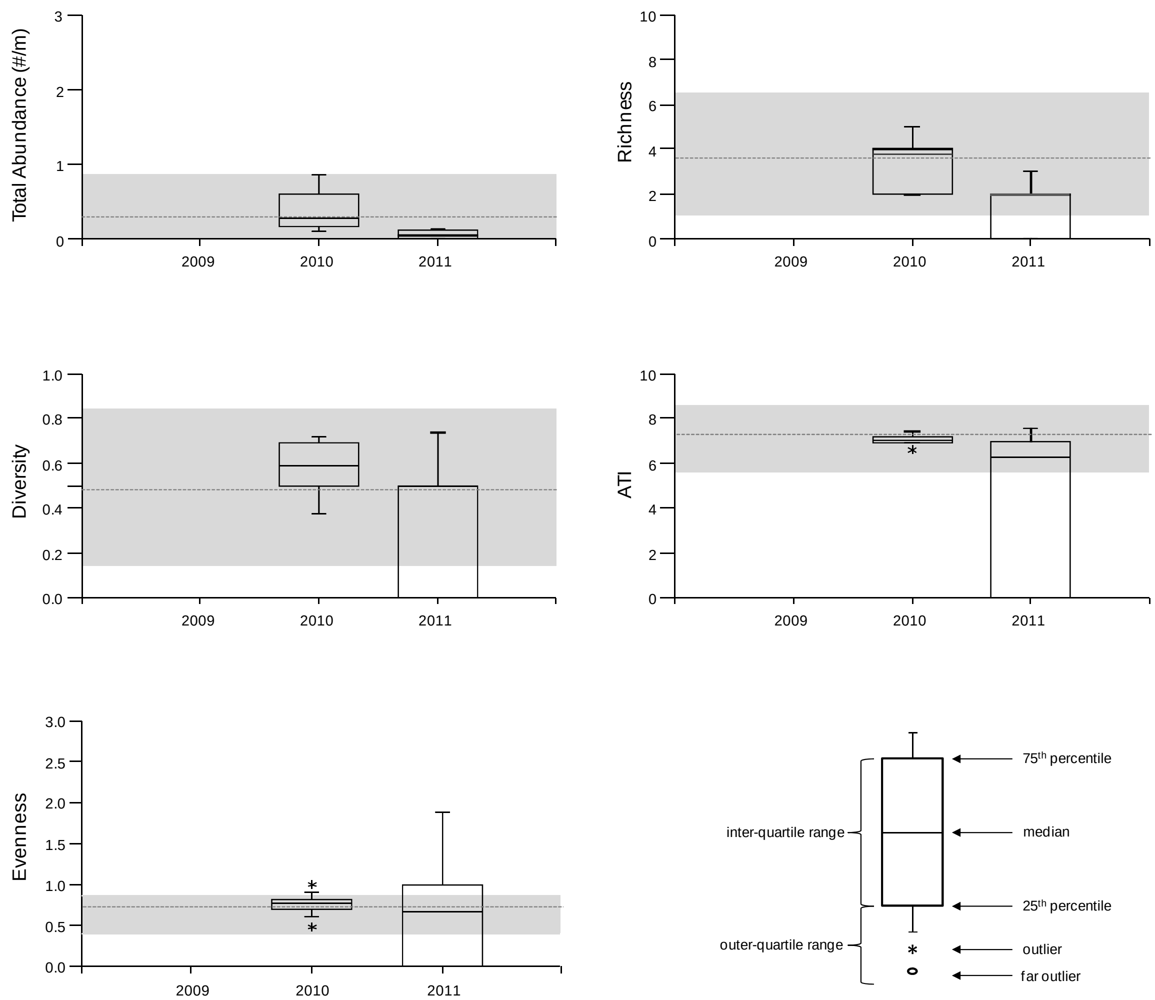
Reach	Year	Abundance		Richness*			Diversity*		Evenness*		ATI*	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ELR-F1	2010	0.37	0.25	7	3	1.07	0.58	0.12	0.77	0.13	7.02	0.21
	2011	0.06	0.07	6	1	1.34	0.30	0.27	0.53	0.50	4.15	3.82
ELR-F2A	2010	0.61	0.26	5	4	0.74	0.55	0.11	0.62	0.16	6.89	0.23
	2011	0.29	0.13	6	3	0.84	0.54	0.08	0.72	0.17	6.62	0.28

* Unknown species not included in the calculation.

SD=standard deviation across sub-reaches within a reach.

Figure 5.8-10 Box-plots showing variation in fish assemblage measurement endpoints in reaches of the Ells River, 2010 to 2011.

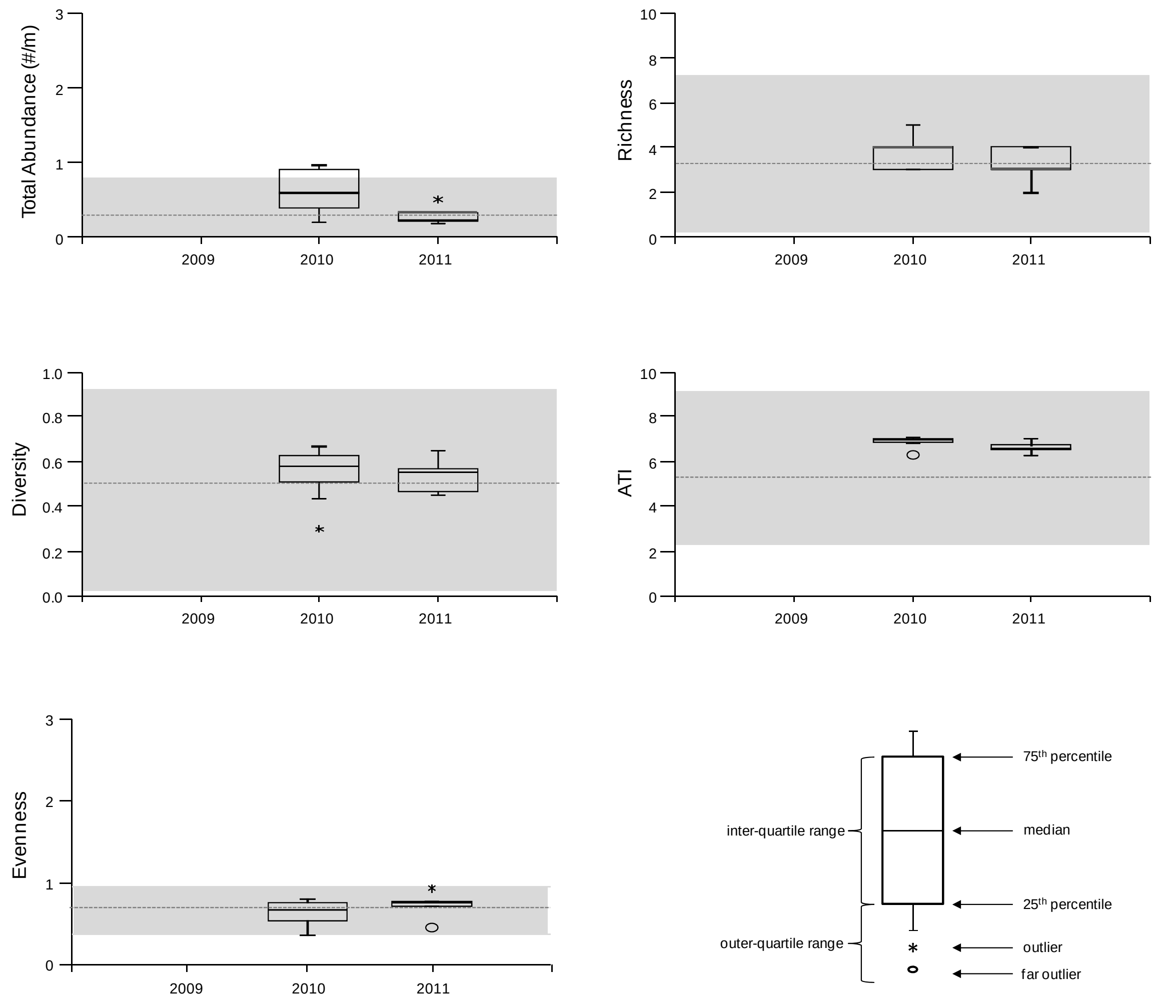
Depositional *Test* Reach ELR-F1



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all depositional *baseline* reaches.

Figure 5.8-10 (Cont'd.)

Erosional Baseline Reach ELR-F2A



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

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 2011 Conditions				
	Clearwater River		*Christina River*		*High Hills 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	**HHR-1** at the mouth
Water Quality	🟡	🟡	🟡	🟡	🟡
Benthic Invertebrate Communities and Sediment Quality					
Criteria	**CLR-D1** at the mouth	**CLR-D2** upstream of Christina River	no reach sampled	no reach sampled	**HHR-E1** at the mouth
Benthic Invertebrate Communities	🟠	n/a			n/a
Sediment Quality Index	🟡	🟡			not sampled
Fish Populations[1]					
Criteria	no reach sampled for the fish assemblage program	no reach sampled for the fish assemblage program	no reach sampled	no reach sampled	**HHR-F1** at the mouth
Fish Assemblages					n/a

Legend and Notes

🟡 Negligible-Low
🟠 Moderate
🟤 High
baseline
test

[1] no criteria established for the fish inventory on the Clearwater River

n/a - not applicable, summary indicators for *test* reaches/stations were designated based on comparisons with *baseline* reaches/station or regional *baseline* conditions.

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.

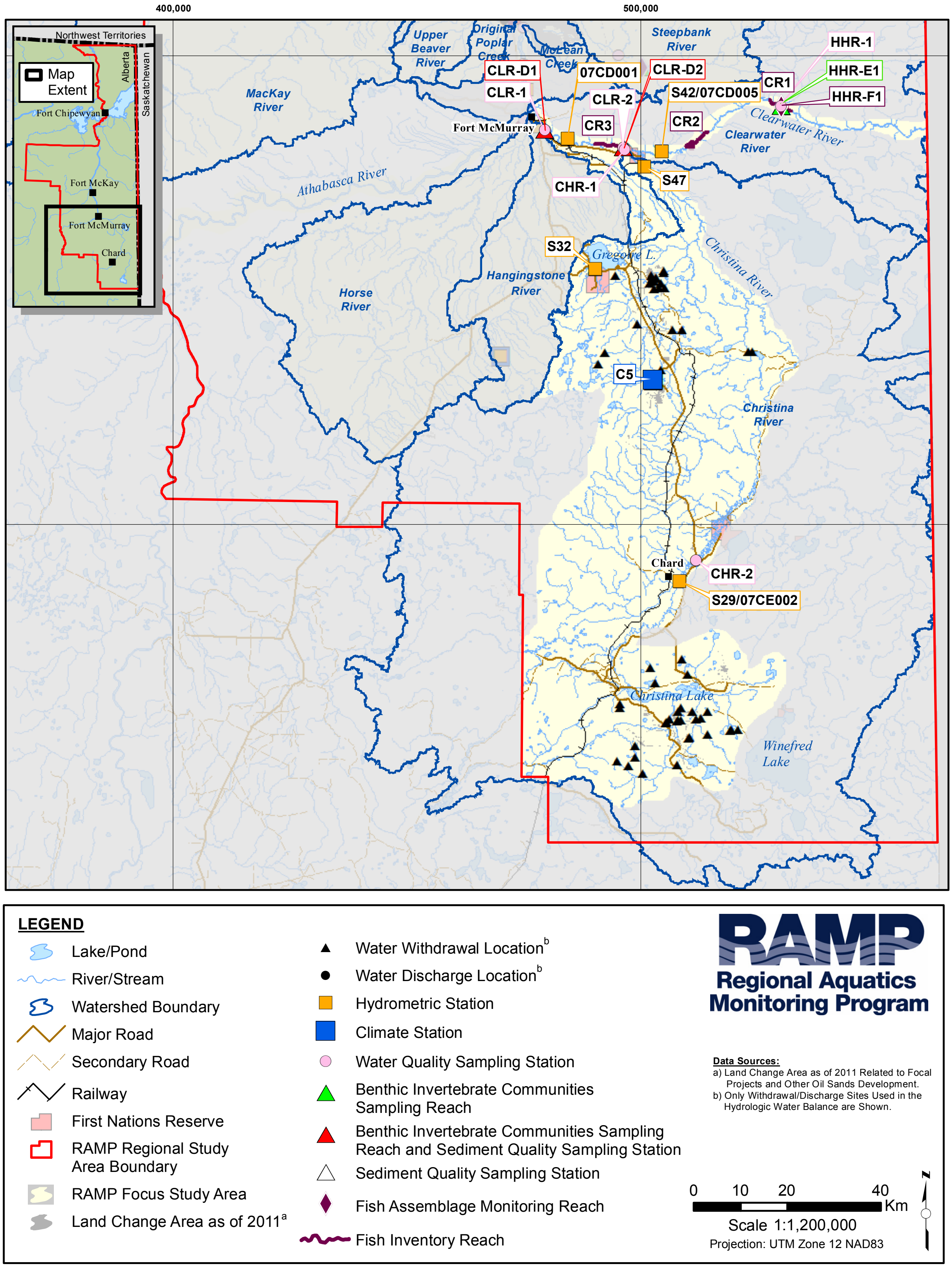
Water Quality: Classification based on adaptation of CCME water quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* 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.

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: Classification based on exceedances of measurement endpoints from the regional variation in *baseline* reaches; therefore, *baseline* reaches were excluded from the classification; see Section 3.2.4.3 for a detailed description of the classification methodology.

Figure 5.9-1 Clearwater-Christina River watersheds.



K:\Data\Project\RAMP1696\GIS_MXD\L_TechReport\RAMP1696_K09_ChrisClear_20120423.mxd

Figure 5.9-2 Representative monitoring stations of the Clearwater-Christina River watersheds, fall 2011.

Water Quality Station HHR-1 (High Hills River): Right Downstream Bank

Benthic and Sediment Quality Reach CLR-D2 (Clearwater River): Right Downstream Bank

Hydrology Station S47 (Christina River at the mouth): Aerial View

Water Quality Station CHR-1 (Christina River): Right Downstream Bank

5.9.1 Summary of 2011 Conditions

As of 2011, approximately 0.5% (6,038 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 Cenovus Energy, 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*.

Monitoring activities were conducted for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components of RAMP in the Clearwater-Christina River system in 2011. Table 5.9-1 is a summary of the 2011 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 2011. Figure 5.9-2 contains photos of monitoring stations in the watersheds.

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 were 0.02%, 0.03%, and 0.02%, respectively, greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

Water Quality In fall 2011, water quality at stations on the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2), the Christina River (*test* stations CHR-1 and CHR-2) and the High Hills River (*baseline* station HHR-1) exhibited **Negligible-Low** differences from regional *baseline* conditions. Concentrations of several water quality measurement endpoints were outside the range of previously-measured concentrations; however, this could be related to low water levels in September 2011, which would contribute to increases in conductivity, nutrients and dissolved species of metals. Concentrations of water quality measurement endpoints that were outside of regional *baseline* conditions were all lower than the 5th percentile of the range of *baseline* variation.

Benthic Invertebrate Communities and Sediment Quality Differences in values of measurement endpoints of benthic invertebrate communities at *test* reach CLR-D1 were classified as **Moderate** because of the significant differences in abundance, richness, and percent EPT between *test* reach CLR-D1 and *baseline* reach CLR-D2. It should be noted that although the values of these measurement endpoints were generally lower at *test* reach CLR-D1, values have increased in the two recent sampling years (2008 and 2001) to a level almost consistent with *baseline* reach CLR-D2. Values of measurement endpoints at *test* reach CLR-D1 were well within the range of regional *baseline* conditions. In addition, *test* reach CLR-D1 was diverse, and contained a number of taxa considered sensitive to degrading habitat conditions including chironomids (e.g., *Lopesocladius*), mayflies (*Ametropus neavei*), and stoneflies (e.g., *Isoperla* and *Taeniopteryx*). There was a high percentage of worms, indicating potential organic enrichment as well as a high percentage of chironomids and EPT taxa, which reflect good water quality. High Hills River will be used as a regional *baseline* reach for comparisons to *test* reaches, once more data are collected.

Concentrations of sediment quality measurement endpoints at *test* station CLR-D1 and *baseline* station CLR-D2 in fall 2011 were generally lower than previously measured. The substrate at both stations was comprised almost entirely of sand, with low concentrations of total organic carbon. Direct measurements of sediment toxicity indicated good survival (i.e., ≥90%) at both stations. Differences in sediment quality in fall 2011 were classified as **Negligible-Low** compared to regional *baseline* conditions.

Fish Populations (fish inventory) Species richness in 2011 was higher than all years in spring, with the exception of 2007 and 2008; significantly higher than summer 2010; and less than fall 2010 but within the historical range (2003 to 2011).

The relative abundance of fish species in the Clearwater River was variable without any clear trends observed over time. Similarly, there has been no marked shift in species dominance from year to year. There have been no significant differences in condition of large-bodied KIR fish species in the Clearwater River across years. Condition can not necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region. In 2011, a shift towards a younger age class was observed in northern pike and walleye. Although uncertain, this may reflect increasing fishing pressure on adult fish over the years within the Clearwater River causing a shift to a population dominated by younger individuals.

Fish Populations (fish assemblage) The fish assemblage at *baseline* reach HHR-F1 was generally consistent with other *baseline* erosional reaches in the region and all median values of measurement endpoints were within the range of regional *baseline* conditions. The fish assemblage had a high proportion of slimy sculpin, which are typical of riffle habitat with faster flowing water.

5.9.2 Hydrologic Conditions: 2011 Water Year

RAMP Station S47, Christina River near the mouth Hydrometric data have been estimated for the mouth of the Christina River from 2008 to 2011 by calculating the difference between the measured flow at Clearwater River above Christina River, WSC Station 07CD005 and Clearwater River above Draper, WSC Station 07CD001. These values are shown in the 2011 WY calculated *test* hydrograph (Figure 5.9-3). A gap in the data exists from April 16 to 23 when the estimated flow values using this method produced invalid results. Flow monitoring was initiated by RAMP in July 2011 at RAMP Station S47, Christina River near the mouth; flows from this station are also shown in Figure 5.9-3.

The 2011 water year (WY) open-water period (May to October) runoff volume was calculated to be 1,060 million m^3. This value is 11% higher than the historical mean open-water runoff volume calculated from 41 years of available record. Estimated flows increased from late March to early May, to a peak of 80 m^3/s on May 9, which was 48% higher than the historical median flow calculated for this day in previous years. Following the freshet, the estimated flow decreased until mid-June, and then increased in response to rainfall events in late June. The maximum daily flow of 199 m^3/s occurred on July 1, which was 15% higher than the historical mean maximum daily flow during the open-water period. Following the rainfall events, flows decreased steadily until the end of the 2011 WY. Flows from June 22 to September 11 were above the historical median level and flows from September 12 to October 31 were below historical median values.

The runoff volume during the initial period of monitoring at RAMP Station S47, Christina River near the mouth, was 341.5 million m^3 from July 28 to October 31. This volume corresponds with the runoff volume estimated by calculating the difference between the two WSC stations. The available observed hydrograph from Station S47 from July to October 2011 is presented in Figure 5.9-3 for comparison against the calculated hydrograph for the Christina River near the mouth.

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 2011 in the Christina River watershed was estimated to be 6.8 km^2 (Table 2.5-1). The loss of flow to the Christina River that would have otherwise occurred from this land area was estimated at 0.61 million m^3.
2. As of 2011, the area of land change in the Christina River watershed from focal projects that was not closed-circuited was estimated to be 48.5 km^2

(Table 2.5-1). The increase in flow to the Christina River that would not have otherwise occurred from this land area was estimated at 0.87 million m^3.

3. From March 1 to October 31, excluding April 16 to 23, Nexen and Cenovus withdrew 0.10 million m^3 of water from various surface water sources to support industrial activities.

The estimated cumulative effect of land change for this case was an increase of flow of 0.16 million m^3 to the Christina River. The resulting observed *test* and estimated *baseline* hydrographs for this case are presented in Figure 5.9-3. The 2011 WY mean open-water period (May to October) discharge, annual maximum daily discharge and open-water minimum discharge were 0.02%, 0.02%, and 0.01%, respectively, greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.9-3). These differences were 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 2011 in the Christina River watershed was estimated to be 6.8 km^2 (Table 2.5-1). The loss of flow to the Christina River that would have otherwise occurred from this land area was estimated at 0.61 million m^3.

2. As of 2011, the area of land change in the Christina River watershed from focal projects plus other oil sands developments that was not closed-circuited was estimated to be 53.6 km^2 (Table 2.5-1). The increase in flow to the Christina River that would not have otherwise occurred from this land area was estimated at 0.96 million m^3.

3. The water withdrawals by Nexen and Cenovus of 0.1 million m^3 described above are applied to this case as well.

The estimated cumulative effect of land change for this case was an increase in flow of 0.25 million m^3 to the Christina River. The 2011 WY 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 were 0.02%, 0.03%, and 0.02%, respectively, greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Figure 5.9-3). These differences were also classified as **Negligible-Low** and were within 0.01% of Case 1 (Table 5.9-1)**.**

5.9.3 Water Quality

In fall 2011, water quality samples were taken from:

- the Clearwater River upstream of Fort McMurray, but downstream of the confluence of the Christina River (*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);
- the Christina River upstream of Janvier (*test* station CHR-2, sampled since 2002, designated as *test* in 2010); and
- the High Hills River near its mouth, tributary to the Clearwater River (new *baseline* station HHR-1 in 2011).

Baseline station HHR-1 on the High Hills River was also sampled in winter and summer 2011 to obtain three years of seasonal *baseline* data. The station was not sampled in spring 2011 because all helicopters required to access the station were used for fighting forest fires in the region.

Temporal Trends The only significant (α=0.05) trend in fall concentrations of water quality measurement endpoints was a decreasing concentration of potassium at *test* station CHR-1 (2002 to 2011). Trend analysis was not conducted for *baseline* station HHR-1 because 2011 was the first year of sampling.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within the range of previously-measured concentrations (Table 5.9-4 to Table 5.9-8) with the exception of:

- conductivity, with values that exceeded previously-measured maximum values at *test* station CLR-1 and *baseline* station CLR-2;
- dissolved aluminum, with concentrations that were lower than previously-measured minimum concentrations at *baseline* station CLR-2 and *test* station CHR-2;
- total dissolved solids, with a concentration that exceeded the previously-measured maximum concentration at *baseline* station CLR-2;
- total suspended solids, with a concentration that was lower than the previously-measured minimum concentration at *baseline* station CLR-2; and
- total alkalinity, with values that exceeded previously-measured maximum values at *test* station CLR-1 and *baseline* station CLR-2;
- total strontium, with a concentration that exceeded the previously-measured maximum concentration at *baseline* station CLR-2.
- pH, with values that exceeded previously-measured maximum values at *baseline* station CLR-2 and *test* station CHR-2; and
- total dissolved phosphorous, with concentrations that were lower than previously-measured minimum concentrations at *baseline* station CLR-2 and *test* stations CHR-1 and CHR-2.

Ion Balance The ionic composition of water at all other stations in the Clearwater-Christina watersheds in fall 2011 was similar to those in previous years (Figure 5.9-4). *Baseline* station HHR-1 was similar in its ionic composition to *test* station CHR-2.

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of total aluminum at *baseline* stations HHR-1 and CLR-2 and *test* stations CLR-1 and CHR-1 exceeded water quality guidelines (Table 5.9-4 to Table 5.9-8).

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in the Clearwater-Christina River watersheds in fall 2011 (Table 5.9-9):

- sulphide at *test* station CLR-1;
- total phenols and dissolved iron at *test* station CHR-1;
- total iron at *baseline* stations HHR-1 and CLR-2 and *test* stations CLR-1, CHR-1 and CHR-2; and
- total phosphorous at *baseline* station HHR-1 and *test* station CLR-1.

In addition, the following water quality guideline exceedances occurred in winter and spring at *baseline* station HHR-1 (Table 5.9-9):

- total aluminum, total iron and total phosphorous in winter; and
- dissolved iron, dissolved phosphorous, sulphide, total aluminum, total chromium, total iron, total phenols and total phosphorous in summer.

2011 Results Relative to Regional *Baseline* Concentrations In fall 2011, most of the water quality measurement endpoints were within regional *baseline* concentrations with the exception of the following measurement endpoints, which were lower than the 5th percentile of regional *baseline* concentrations (Figure 5.9-5):

- dissolved phosphorous and total arsenic at *baseline* station CLR-2; and
- sulphate and nitrogen at *baseline* station HHR-1.

Due to the decrease in the analytical detection limit for total mercury, fall concentrations were below the 5th percentile of regional *baseline* concentrations for *baseline* station HHR-1 and *test* stations CHR-2 and CLR-1.

Concentrations of chloride exceeded the 95th percentile of regional *baseline* concentrations at *test* stations CHR-1 and CLR-1 and *baseline* station CLR-2.

Water Quality Index The WQI values for water quality stations on the Clearwater River (i.e., *test* station CLR-1: 98.7; *baseline* station CLR-2: 98.7), the Christina River (i.e., *test* station CHR-1: 97.5; *test* station CHR-2: 100), and High Hills River (*baseline* station HHR-1: 98.7) in fall 2011 indicated **Negligible-Low** differences from regional *baseline* water quality conditions. Concentrations of most water quality measurement endpoints were within the range of historical concentrations in fall 2011.

Classification of Results In fall 2011, water quality at stations on the Clearwater River (*test* station CLR-1 and *baseline* station CLR-2), the Christina River (*test* stations CHR-1 and CHR-2) and the High Hills River (*baseline* station HHR-1) indicated **Negligible-Low** differences from regional *baseline* conditions. Concentrations of several water quality measurement endpoints were outside the range of previously-measured concentrations; however, this could be related to low water levels in September 2011, which would contribute to increases in conductivity, nutrients and dissolved species of metals. Concentrations of water quality measurement endpoints that were outside of regional *baseline* conditions were all lower than the 5th percentile of the range of *baseline* variation.

5.9.4 Benthic Invertebrate Communities and Sediment Quality

5.9.4.1 Benthic Invertebrate Communities

Clearwater River

Benthic invertebrate communities were sampled in fall 2011 at lower *test* reach CLR-D1 (depositional) and upper *baseline* reach CLR-D2 (depositional). Both the lower and upper reaches were sampled from 2001 to 2005, 2008, and 2011.

2011 Habitat Conditions Water at *test* reach CLR-D1 in fall 2011 where samples were collected was an average of 0.6 m deep, slow flowing (0.3 m/s), alkaline, (pH: 8.2), with moderate conductivity (305 µS/cm) and high dissolved oxygen (8.9 mg/L) (Table 5.9-11).

Water at *baseline* reach CLR-D2 in fall 2011 where samples were collected was an average of 0.8 m deep, slow flowing (0.4 m/s), slightly basic (pH: 7.9), with moderate conductivity (255 µS/cm) and moderately high dissolved oxygen (9.1 mg/L) (Table 5.9-11).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach CLR-D1 was dominated by Chironomidae (59%), with subdominant taxa consisting of tubificids (7%), bivalve clams (7%), naididae worms (4%) and ceratopogonidae (4%) (Table 5.9-12). Dominant chironomids were primarily pollution-tolerant forms including *Paralauterborniella*, *Cryptochironomus*, *Polypedilum* and *Paracladopelma*. Mayflies (Ephemeroptera: *Ametropus neavei*) and stoneflies (Plecoptera: *Isoperla*) were present in low relative abundances. Clams included *Sphaerium* and *Pisidium*.

The benthic invertebrate community at *baseline* reach CLR-D2 was dominated by chironomids (87%), with subdominant taxa consisting of Nematoda (5%), and Ostracoda (4%) (Table 5.9-13). Dominant chironomids were generally forms associated with better water quality conditions including *Lopescladius* and *Robackia* (Mandaville 2001). Mayflies (Ephemeroptera: *Ametropus neavei*) were found in low relative abundance at one replicate location. *Baseline* reach CLR-D2 did not produce a variety of larger insect groups such as empidids, tipulids, tabanids, simuliids, Anisoptera, Zygoptera, Plecoptera, and Trichoptera that were typically found in low relative abundances in previous sampling years (Table 5.9-13).

Temporal and Spatial Comparisons Temporal comparisons were conducted by testing for changes in time trends of measurement endpoints for benthic invertebrate communities at *test* reach CLR-D1 (Hypothesis 1, Section 3.2.3.1). For spatial comparisons, changes in mean values of benthic invertebrate community measurement endpoints were tested between *test* reach CLR-D1 and *baseline* reach CLR-D2 (Hypothesis 3, Section 3.2.3.1).

There were differences over time for all benthic invertebrate community measurement endpoints with the exception of richness with most changes observed at *baseline* reach CLR-D2 (i.e., decrease in abundance and an increase in diversity and percent EPT) while remaining stable at *test* reach CLR-D1 (Table 5.9-14). Differences in diversity and evenness produced statistical signals that were greater than 20% of the variation in annual means (Table 5.9-14).

Total abundance, richness, percent EPT, and scores on CA Axes 1 and 2 were significantly higher at *baseline* reach CLR-D2 compared to *test* reach CLR-D1 and the differences explained greater than 20% of the variation in annual means (Table 5.9-14).

Comparison to Published Literature The benthic invertebrate community at *test* reach CLR-D1 was typical for a shifting-sand environment of the Clearwater River. The benthic invertebrate community was dominated by chironomids, including many forms that are widely distributed and tolerant of various conditions (e.g., *Polypedilum*, *Micropsectra/Tanytarsus*), as well as other forms that are common in sand or shifting sands (e.g., *Cryptochironomus*), and forms that are indicative of low levels of organic nutrients (e.g., *Lopesocladius*) (Beck 1977, Bode *et al.* 1996). Naidid and tubificid worms were present in low relative abundances (i.e., 11% combined), which indicates a low level of organic input in the river (Hynes 1960, Griffiths 1998, Mandaville 2001). The benthic invertebrate community also contained stoneflies (e.g., *Isoperla* and *Taeniopteryx*), which are representative of good water and sediment quality (Mandaville 2001).

The benthic invertebrate community at *baseline* reach CLR-D2 was generally similar to *test* reach CLR-D1. The benthic invertebrate community was dominated by chironomids, including *Robackia* and *Lopesocladius*. There were no caddisflies or stoneflies present and only three mayflies (*Ametropus neavei*) were found in ten replicate samples, which is a species known to occur in shifting sands in the Athabasca River watershed (Clifford and Barton 1979).

2011 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints of benthic invertebrate communities at *test* reach CLR-D1 were within the range of regional *baseline* conditions for depositional rivers (Figure 5.9-6, Figure 5.9-7). In previous years (2003 to 2005), abundance, richness, diversity and evenness at *test* reach CLR-D1 were lower than the median or 25th percentile of regional *baseline* conditions. Results from 2008 and 2011 produced measurement endpoints that are more consistent with regional *baseline* conditions.

Diversity and evenness of benthic invertebrate communities at *baseline* reach CLR-D2 were well below the 5th percentile of the range of *baseline* conditions (Figure 5.9-6), reflecting a dominance of chironomids, and an absence of a variety of insect larvae that have been present in previous years (e.g., empidids, tipulids, simuliids, Anisoptera, Zygoptera, Plecoptera, and Trichoptera).

Classification of Results Differences in values of measurement endpoints of benthic invertebrate communities at *test* reach CLR-D1 were classified as **Moderate** because of the significant differences in abundance, richness, and percent EPT between *test* reach CLR-D1 and *baseline* reach CLR-D2. It should be noted that although the values of these measurement endpoints were generally lower at *test* reach CLR-D1, values have increased in the two recent sampling years (2008 and 2001) to be generally consistent with *baseline* reach CLR-D2. Values of measurement endpoints at *test* reach CLR-D1 were well within the range of *baseline* conditions. In addition, *test* reach CLR-D1 was diverse, and contained a number of taxa considered sensitive to degrading habitat conditions including chironomids (e.g., *Lopesocladius*), mayflies (Ephemeroptera: *Ametropus neavei*), and stoneflies (e.g., *Isoperla* and *Taeniopteryx*).

High Hills River

Benthic invertebrate communities were sampled for the first time in fall 2011 at *baseline* reach HHR-E1 (erosional).

2011 Habitat Conditions Water at *baseline* reach HHR-E1 in fall 2011 was shallow (0.2 m), moderately flowing (~1 m/s), alkaline (pH: 8.7), with moderate dissolved oxygen (6.8 mg/L) and conductivity (229 µS/cm) (Table 5.9-11). The substrate consisted primarily of large gravel and small cobble (Table 5.9-11). Periphyton chlorophyll *a* biomass averaged just over 300 mg/m^2 and was near the 95th percentile of the range of variation for *baseline* erosional reaches (Figure 5.9-8).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *baseline* reach HHR-E1 was dominated by Naididae worms (42%), Ephemeroptera (19%; primarily *Caenis* and *Ephemerella*), and Chironomidae (13%), with subdominant taxa consisting of Enchytraeidae worms (7%), Trichoptera (6%; *Hydropsyche*, *Lepidostoma*, and *Psychomyia*), and water mites (Hydracarina; 5%) (Table 5.9-15). Dominant chironomids included *Rheotanytarsus*, *Sublettea*, and *Eukiefferiella*. Gastropoda (the limpet *Ferrissia rivularis*) and Plecoptera (stoneflies, nine genera including *Claassenia sabulosa* and *Haploperla*) were collected at *baseline* reach HHR-E1 in low relative abundances (Table 5.9-15).

Comparison to Published Literature The benthic invertebrate community at *baseline* reach HHR-E1 reflected moderate water and sediment quality, with a relatively high percent of the community as worms (42% *Naididae*, 7% *Enchytraeidae*). Naidid worms can be relatively abundant in streams with higher loads of organic constituents (Griffiths 1998). There were also high relative abundances of chironomids (13%) and EPT taxa (27%), with dominant forms of chironomidae found that are known to represent fair to good water quality (Mandaville 2001), including the chironomid *Rheotanytarsus,* which tends to occur in rocky streams with good flows (Merritt and Cummins 1996).

2011 Results Relative to Regional *Baseline* Conditions The total abundance (>50,000 individuals per m^2) at *baseline* reach HHR-E1 was near the 95^{th} percentile of regional *baseline* conditions for erosional reaches and diversity and evenness in fall 2011 were lower than the 5^{th} percentile of regional *baseline* conditions (Figure 5.9-9). Values of all other measurement endpoints for *baseline* reach HHR-E1 were within the range of regional *baseline* conditions (Figure 5.9-9). CA Axis scores were within the range of variation for *baseline* erosional reaches (Figure 5.9-10).

Classification of Results The benthic invertebrate community at *baseline* reach HHR-E1 was diverse with a combination of fauna that reflect both moderate and good water and sediment quality. There were a high percentage of worms, indicating potential organic enrichment as well as a high percentage of chironomids and EPT taxa, which reflected good water quality. High Hills River will be used as a regional *baseline* reach for comparisons to *test* reaches, once more data are collected.

5.9.4.2 Sediment Quality

Clearwater River

Sediment quality was sampled in depositional reaches of the Clearwater River watershed in the same locations as benthic invertebrate communities were sampled in fall 2011:

- *test* station CLR-D1 upstream of Fort McMurray, but downstream of the confluence of the Christina River (designated as *baseline* in 2001 and as *test* from 2002 to 2003, 2008, and 2011); and
- *baseline* station CLR-D2 upstream of the Christina River confluence (sampled from 2001 to 2003, 2008, and 2011).

Temporal Trends Insufficient data exists to conduct trend analysis for stations on the Clearwater River. At least seven years of data are required to complete trend analysis; only five years of sediment quality data exist for *test* station CLR-D1 and *baseline* station CLR-D2.

2011 Results Relative to Historical Concentrations Sediments sampled in 2011 from both stations on the Clearwater River were taken from the same locations as those reaches sampled in 2008. Prior to the integration of the Sediment Quality component with the Benthic Invertebrate Communities component in 2006, benthic invertebrate community reaches CLR-D1 and CLR-D2 corresponded to pre-2006 sediment quality stations CLR-1 and CLR-2, respectively.

Sediments at *test* station CLR-D1 and *baseline* station CLR-D2 were comprised almost entirely of sand in fall 2011, with smaller amounts of finer particles (i.e., clay and silt) (Table 5.9-16, Table 5.9-17, Figure 5.9-11, Figure 5.9-12). Total organic carbon was undetectable at *baseline* station CLR-D2 and equal to previously-measured minimum concentrations at *test* station CLR-D1. Concentrations of total metals were near previously-measured minimum concentrations at both stations in fall 2011; however, total metals normalized to percent fine sediments exceeded previously-measured maximum concentrations at both stations due to the low percent silt and clay observed in fall 2011. Concentrations of hydrocarbons were undetectable for all fractions at both stations (Table 5.9-16, Table 5.9-17). Concentrations of most PAH measurement endpoints were lower than previously-measured minimum concentrations at both stations of the Clearwater River, with the exception of total dibenzothiophenes and total alkylated PAHs at *baseline* station CLR-D2, with concentrations that exceeded previously-measured maximum concentrations (Table 5.9-17). Predicted PAH toxicity was low and within the range of previously-measured values at both stations (Table 5.9-16, Table 5.9-17).

Direct tests of sediment toxicity to invertebrates indicated good survival (i.e., ≥90%) of both the amphipod *Hyalella* and the midge *Chironomus* at *test* station CLR-D1 and *baseline* station CLR-D2 (Table 5.9-16 and Table 5.9-17). Ten-day growth of *Chironomus* and 14-day growth of *Hyalella* were within the historical range at *baseline* station CLR-D2. Growth and survival of both species exceeded previously-reported maximum values at *test* station CLR-D1 and *baseline* station CLR-D2; however, only a single year of chronic toxicity data exists for *test* station CLR-D1 and only two years of data exists for *baseline* station CLR-D2. All toxicity measurement endpoints with the exception of *Hyalella* growth were slightly higher at *baseline* station CLR-D2 compared to *test* station CLR-D1 (Table 5.9-16, Table 5.9-17).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines There were no sediment quality measurement endpoints in fall 2011 that exceeded the relevant CCME sediment quality guidelines at *test* station CLR-D1 and *baseline* station CLR-D2 (Table 5.9-16, Table 5.9-17).

Sediment Quality Index The SQI value of 98.9 for both stations of the Clearwater River in fall 2011 indicated **Negligible-Low** differences in sediment quality from regional *baseline* conditions.

Classifications of Results Concentrations of sediment quality measurement endpoints at *test* station CLR-D1 and *baseline* station CLR-D2 in fall 2011 were generally lower than previously-measured (Table 5.9-16, Table 5.9-17, Figure 5.9-11, Figure 5.9-12). The substrate at both stations was comprised almost entirely of sand, with low concentrations of total organic carbon. Direct measurements of sediment toxicity indicated good survival (i.e., ≥90%) at both stations. Differences in sediment quality in fall 2011 were classified as **Negligible-Low** compared to regional *baseline* conditions.

5.9.5 Fish Populations

In 2011, fish population monitoring in the Clearwater-Christina River watershed consisted of a spring, summer, and fall fish inventory. The *baseline* reaches (CR1 and CR2) have been continually sampled in spring and fall since 2003 with the exception of fall 2011, and in summer since 2009. *Test* reach (CR3) has been sampled in spring and fall since 2003. The *baseline* reaches were not sampled in fall 2011 due to low water levels, which prevented access by boat to the portion of the Clearwater River upstream of the confluence of the Christina River.

In addition to the Clearwater River fish inventory, fish assemblage monitoring was conducted in the lower High Hills River in fall 2011 at *baseline* reach HHR-F1, which flows into the Clearwater River.

5.9.5.1 Clearwater River

Temporal and Spatial Comparisons

To assess change over time by season, as well as among areas of the river, temporal and spatial comparisons were conducted for the following measurement endpoints: species composition, species richness, catch per unit effort (CPUE), age-frequency distributions, size-at-age, and condition factor.

Species Composition A total of 2,077 fish were captured during the 2011 spring and summer inventories in three sampling reaches and during the fall inventory in *test* reach CR3 of the Clearwater-Christina River (Table 5.9-18), of which:

- 567 fish representing 16 species were captured in the spring;
- 1,241 fish representing 16 species were captured in the summer; and
- 269 fish representing 14 species were captured in the fall.

A total of 20 species were captured across all three seasons during the 2011 Clearwater River fish inventory. The dominant large-bodied fish species captured across seasons were as follows: white sucker (49%) in spring; longnose sucker in summer (23%); and longnose sucker and white sucker in fall (14%) with sudominant large-bodied fish species consisting of northern pike (6%) in spring, longnose sucker (16%) in summer, and northern pike and walleye (6%) in fall. Trout-perch was the dominant small-bodied fish species in fall (22%), with spottail shiner as the dominant small-bodied species in summer (32%).

Species Richness Species richness was compared between *baseline* reaches CR1 and CR2 and *test* reach CR3 (Table 5.9-18 and Figure 5.9-13). In spring and summer 2011, the number of species caught in *test* reach CR3 was generally similar to the number of species caught in *baseline* reaches CR1 and CR2 (Figure 5.9-13). Sampling was not conducted in *baseline* reach in fall 2011 due to low water levels and difficulty in accessing that portion of the river.

Species richness was higher in spring 2011 than 2010 at both *test* and *baseline* reaches (Figure 5.9-13). Species richness in summer 2011 was generally consistent with the two previous sampling years in *test* and *baseline* reaches; species richness in fall 2011 was higher than 2010 at *test* reach CR3. Species richness across seasons and reaches has been generally consistent across sampling years (Figure 5.9-13).

Catch Per Unit Effort Seasonal catch per unit effort (CPUE) for each large-bodied KIR fish species in 2011 between *test* and *baseline* reaches is presented in Figure 5.9-14. In spring 2011, white sucker had the highest CPUE in both the *test* and *baseline* reaches, followed by walleye in *test* reach CR3 and northern pike in *baseline* reaches CR1 and CR2. In summer 2011, white sucker and longnose sucker had the highest CPUE at both the *test* and *baseline* reaches and white sucker had the highest CPUE in fall followed by longnose sucker (Figure 5.9-14).

Annual CPUE for each season is presented in Figure 5.9-15. Across all years, white sucker had the highest CPUE in spring, with the exception of 2006 when walleye was the dominant species captured. Across the three years that sampling has been conducted in summer (2009 to 2011), longnose and white sucker had the highest CPUE and white sucker had the highest CPUE across all years in fall (Figure 5.9-15).

Age-Frequency Distributions The relative age-frequency distributions of large-bodied KIR fish species for years when ageing data were collected are presented in Figure 5.9-16 to Figure 5.9-20. The species-specific results are as follows:

1. Ageing data for goldeye were only collected in 2011 from the Clearwater River. The dominant age class was ten years with subdominant age classes of four and five years (Figure 5.9-16). There was a moderate (R^2=0.65) correlation between length and age of goldeye (Figure 5.9-16).

2. Ageing data were collected for longnose sucker in 2006 and 2011 from the Clearwater River. There was a shift to a younger dominant age class for longnose sucker from 2006 to 2011 (Figure 5.9-17). In 2006 the co-dominant age classes were six and eight years and in 2011 the dominant age class was four years; however, given the small sample size in 2006 (n=4), the difference may not be indicative of a shift in the population structure for longnose sucker. Despite the small sample size in 2006, the size-at-age relationship of longnose sucker in 2006 and 2011 was consistent and moderate (R^2=0.62 and 0.67, respectively) (Figure 5.9-17).

3. Ageing data were collected for northern pike in 2004, 2005, 2006, 2009 and 2011 from the Clearwater River. There was no dominant age class in 2004 given that there was a consistent frequency of fish across age classes three, four, five, seven, eight, nine, eleven, and twelve years (Figure 5.9-18). The dominant age class in 2005, 2006, 2009, and 2011 were seven, four, three and five, and two years, respectively, indicating a slight shift to a younger dominant age class over time. The shift to a greater proportion of younger fish could be due to fishing pressure on older, larger fish. The majority of fish captured across all years were between two and seven years of age. The size-at-age relationship of northern pike was low in 2005 (R^2=0.45); moderate in 2006 and 2009 (R^2=0.71 and 0.67, respectively); and strong in 2004 and 2011 (R^2=0.90 and 0.82, respectively) (Figure 5.9-18).

4. Ageing data were collected for walleye in 2004, 2005, 2006, and 2011 from the Clearwater River. The dominant age classes for walleye in 2004, 2005, 2006, and 2011 were four, six, seven and four, respectively (Figure 5.9-19). In 2004 there was no discernible dominant age class due to a small sample size (n=4). There was no observed shift in age-frequency distribution across years with the exception of 2004 where the dominant age classes were older, but likely not representative of the population given the small sample size. In 2005, 2006 and 2011 the correlations between length and age were similar (R^2=0.58, 0.73, and 0.59, respectively) (Figure 5.9-19).

5. Ageing data were only collected for white sucker in 2011 from the Clearwater River. The co-dominant age classes were three and four years (Figure 5.9-20). The size-at-age relationship in white sucker was moderate (R^2=0.59) (Figure 5.9-20).

Condition Factor The mean condition factor for each large-bodied KIR fish species captured in summer and fall 2011 in *test* reach CR3 was compared to the mean condition of fish captured in summer 2001 in *baseline* reaches CR1 and CR2 (Figure 5.9-21). The mean condition factor for each large-bodied KIR fish species across all reaches in summer and fall from 2003 to 2011 is presented in Figure 5.9-22. An analysis of covariance (ANCOVA) was performed on condition of large-bodied KIR fish species captured in adequate sample sizes (n≥20) for summer and fall to determine if there are any differences in condition across years within the *baseline* and *test* reaches. Fish captured in spring were excluded from the analysis due to the influence of spawning on condition and not necessarily reflective of differences in energy storage (i.e., reproductive vs. somatic tissue). Comparisons over time were not completed for the *baseline* reaches in fall given these reaches were not sampled in fall 2011. The species-specific results are as follows:

1. Condition of summer-captured goldeye could not be statistically analyzed due to an inadequate sample size (n<20) in each reach-year combination.

2. Condition of fall-captured longnose sucker at *test* reach CR3 was not significantly different across years (p=0.36). Statistical analyses for *test* reach CR3 and *baseline* reaches CR1 and CR2 in summer, as well as *baseline* reaches CR1 and CR2 in fall could not be determined due to inadequate sample sizes (n<20) in each year.

3. Condition of summer-captured northern pike at *test* reach CR3 and *baseline* reaches CR1 and CR2 in summer was not significantly different across years (p=0.14 and p=0.66, respectively), as well as in fall in *test* reach CR3 and *baseline* reaches CR1 and CR2 (p=0.87 and p=0.28, respectively).

4. Condition of summer- and fall-captured walleye at *test* reach CR3 was not significantly different across years (p=0.46 and p=0.15, respectively). Statistical analyses of condition of walleye from *baseline* reaches in summer and fall could not be determined due to inadequate sample sizes (n<20) in each year.

5. Condition of summer- and fall-captured white sucker at *test* reach CR3 was not significantly different across years (p=0.21 and p=0.88, respectively), as well as for *baseline* reaches CR1 and CR2 in summer and fall (p=0.96 and p=0.79, respectively).

External Health Assessment

Abnormalities present among fish captured in 2011 were primarily associated with minor skin aberrations or wounds, scars and fin erosion. In 2011, 0.87%, 0.72%, and 0.05% of fish captured in spring, summer, and fall, respectively, were found to have some sort of external abnormality. In all seasons in 2011, the percent of external abnormalities was lower than previous years.

A summary from 2003 to 2011 of the percentage of fish of each species exhibiting some form of external pathology is presented in Table 5.9-19. Twelve of the 2,077 (0.58%) fish exhibited some form of external pathological abnormality such as parasites, growths, lesions or body deformities (Table 5.9-19 and Figure 5.9-23). Fish species that were documented with pathological abnormalities were longnose sucker, northern pike, white sucker, and yellow perch. External pathology in 2011 was primarily observed in white sucker (1.17%), but was lower compared to observed external pathology in this species in 2010 (5.1%).

Summary

The Clearwater 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 age-frequency distribution) for large-bodied KIR species rather than assessing detailed fish community structures. The gear used for the fish inventory is selective for large-bodied species, thus having an ability to provide a more detailed assessment of these species compared to small-bodied fish in the Clearwater River.

Species richness across reaches in spring 2011 was higher than all previous years, with the exception of 2007 and 2008; significantly higher than summer 2010; and less than fall 2010 but within the historical range (2003 to 2011). Species richness at *test* reach CR3 was generally consistent to species richness at *baseline* reaches CR1 and CR2 across seasons and years.

The relative abundance of fish species in the Clearwater River was variable without any clear trends observed over time. Similarly there has been no marked shift in species dominance from year to year. There have been no significant differences in condition of large-bodied KIR fish species in the Clearwater River across years. Condition cannot necessarily be attributed to the environmental conditions in the capture location, as these fish populations are highly migratory throughout the region.

In 2011 a shift towards a younger age class was observed in northern pike and walleye. Although uncertain, this may reflect increasing fishing pressure on adult fish over the years within the Clearwater River causing a shift to a population dominated by younger individuals (Almodóvar and Nicola 2004).

5.9.5.2 High Hills River

Fish assemblages were sampled for the first time in fall 2011 at erosional *baseline* reach HHR-F1, which was in the same location at the benthic invertebrate community *baseline* reach HHR-E1.

2011 Habitat Conditions *Baseline* reach HHR-F1 was comprised of riffle and run habitat with a wetted width of 14.9 m and a bankfull width of 19.8 m (Table 5.9-20). The substrate was dominated by coarse gravel with small amounts of silt and clay. Water at *baseline* HHR-F1 was an average of 0.59 m in depth, moderately flowing (average flow: 0.47 m/s), slightly alkaline (pH: 7.7), with moderate conductivity (245 µS/cm), high dissolved oxygen (8.8 mg/L), and a temperature of 13°C (Table 5.9-20). Instream cover was dominated by small and large woody debris with small amounts of overhanging vegetation (Table 5.9-20).

Temporal and Spatial Comparisons Sampling was initiated in High Hills River in fall 2011; therefore, no temporal comparisons could be conducted.

A summary of mean CPUE and fish assemblage measurement endpoints are presented in Table 5.9-21 and Table 5.9-22. Generally values of all measurement endpoints were consistent with the range of variation observed at other erosional *baseline* reaches in the region (i.e., *baseline* reach STR-F2 [Section 5.3], *baseline* reach ELR-F2A [Section 5.8], and *baseline* reach MAR-F3 [Section 5.5]). The dominant fish species captured at *baseline* reach HHR-F1 in 2011 was slimy sculpin followed by longnose sucker (Table 5.9-21). The low ATI value likely reflected the high proportion of slimy sculpin captured, which is a sensitive species with a low tolerance value (Whittier *et al.* 2007a).

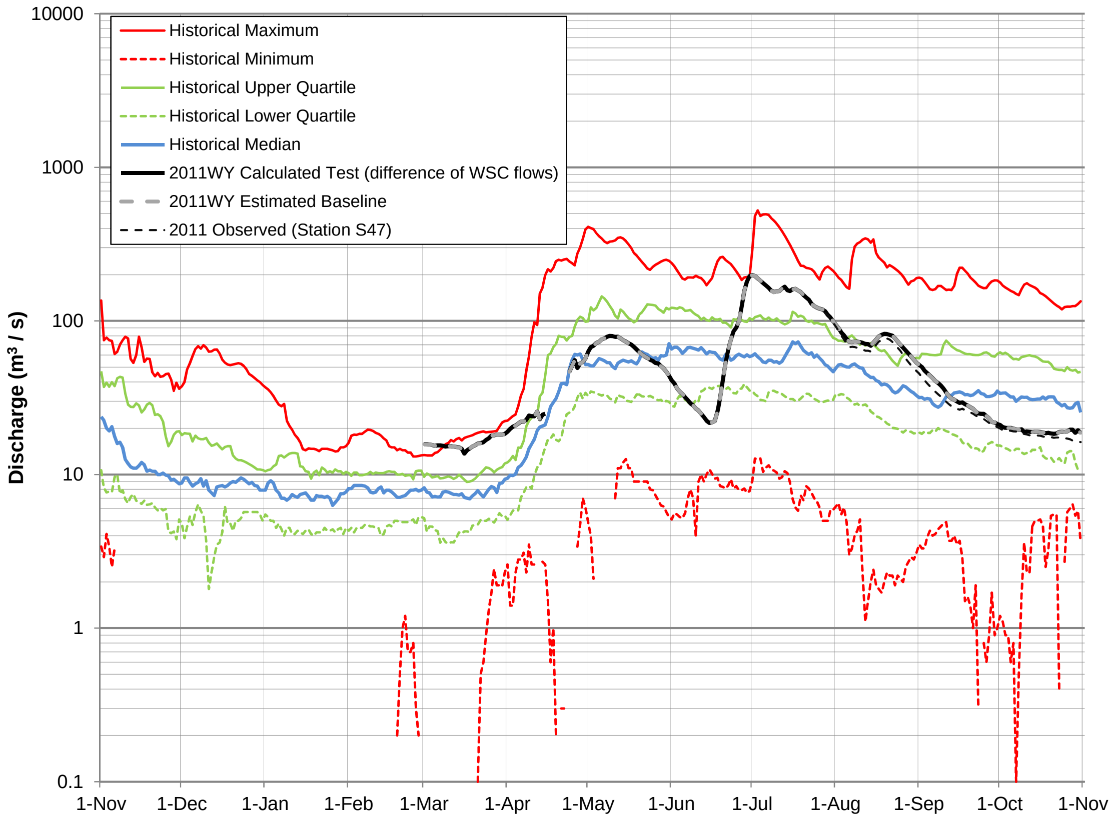
Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of nine fish species were recorded in the High Hills River; whereas RAMP found only three species in 2011 with two additional species (slimy sculpin and spoonhead sculpin), which have not been previously reported. As noted in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Golder (2004b) documented similar habitat conditions to what have been observed by RAMP in 2011, with the section of the river where *baseline* reach HHR-F1 is located, consisting of pools and riffles with substrate consisting of gravel in the riffles and sand, silt and gravel in the pools. These conditions provide excellent refugia and habitat for sport fish.

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at *baseline* reach HHR-F1 were within the range of regional *baseline* conditions for erosional reaches (Figure 5.9-24).

Classification of Results The fish assemblage at *baseline* reach HHR-F1 was generally consistent with other *baseline* erosional reaches in the region and all median values of measurement endpoints were within the range of regional *baseline* conditions. The fish assemblage had a high proportion of slimy sculpin, which are typical or riffle habitat with faster flowing water.

Figure 5.9-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the mouth of the Christina River in the 2011 WY, compared to historical values.



Note: The 2011 WY calculated *test* hydrograph is the difference between provisional 2011 data from Clearwater River above Christina River, WSC Station 07CD005, and Clearwater at Draper, WSC Station 07CD001. Historical data are calculated using the same method based on 43 years of record (1967 to 2010) from March to October, and 21 years of record for other months (1976 to 1996). Available observed flows at Christina River near the Mouth, Station S47 from July 28 to October 31, 2011 are shown for comparative purposes.

Note: 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, 2011 WY.

Component	Volume (million m^3)		Basis and Data Source
	Focal Projects	Focal Projects Plus Other Oil Sands Developments	
Calculated *test* hydrograph (total discharge)	**1,164.02**	**1,164.02**	**Calculated as the difference between provisional 2011 data from Clearwater River above Christina River, WSC Station 07CD005, and Clearwater at Draper, WSC Station 07CD001.**
Closed-circuited area water loss from the calculated *test* hydrograph	-0.61	-0.61	Estimated 6.8 km^2 and 6.8 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 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.87	+0.96	Estimated 48.5 km^2 and 53.6 km^2 of the Christina River watershed with land change from focal projects and from focal projects plus other oil sands developments as of 2011, respectively that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Christina River watershed from projects	-0.10	-0.10	Approximately 0.10 million m^3 of water withdrawn by Nexen and Cenovus from various water sources (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)	**1,163.86**	**1,163.77**	**Estimated *baseline* discharge for the mouth of the Christina River**
Incremental flow (change in total annual discharge)	+0.16	+0.25	Total discharge from calculated *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**+0.01%**	**+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 calculated for the mouth of the Christina River, calculated as the difference of 2011 provisional values collected on the Clearwater River, just upstream of where the Christina River joins the Clearwater River (Clearwater River above Christina River, WSC Station 07CD005), and immediately downstream of this confluence (Clearwater at Draper, WSC Station 07CD001).

Table 5.9-3 Calculated change in hydrologic measurement endpoints for the mouth of the Christina River, 2011 WY.

Measurement Endpoint	Value from ***Baseline*** Hydrograph (m^3/s)	Value from ***Test*** Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	66.69	66.70	+0.02%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	198.76	198.80	+0.02%
Open-water season minimum daily discharge	18.40	18.40	+0.01%

Note: Based on flows calculated for the mouth of the Christina River, calculated as the difference of 2011 provisional values collected on the Clearwater River, just upstream of where the Christina River joins the Clearwater River (Clearwater River above Christina River, WSC Station 07CD005), and immediately downstream of this confluence (Clearwater at Draper, WSC Station 07CD001).

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 (within 0.01%) and do not affect the measurement endpoint values or relative change (to the nearest unit).

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to two decimal places.

Table 5.9-4 Concentrations of water quality measurement endpoints, mouth of Clearwater River (*test* station CLR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	10	7.5	8.0	8.2
Total suspended solids	mg/L	-	5	10	<3	16	64
Conductivity	µS/cm	-	<u>300</u>	10	177	222	291
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.012	10	0.012	0.022	0.044
Total nitrogen	mg/L	1	0.57	10	0.30	0.60	**1.72**
Nitrate+nitrite	mg/L	1.3	<0.071	10	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	10.7	10	8.0	10.7	18.8
Ions							
Sodium	mg/L	-	28.6	10	13.1	20.0	31.0
Calcium	mg/L	-	19.1	10	14.7	17.3	20.1
Magnesium	mg/L	-	6.4	10	5.0	5.7	6.5
Chloride	mg/L	230, 860	40.9	10	13.2	25.0	43.0
Sulphate	mg/L	100	6.8	10	1.4	5.5	7.7
Total dissolved solids	mg/L	-	190	10	60	149	200
Total alkalinity	mg/L		<u>79.1</u>	10	55.5	65.1	74.0
Selected metals							
Total aluminum	mg/L	0.1	**0.26**	10	**0.14**	**0.59**	**1.46**
Dissolved aluminum	mg/L	0.1	0.006	10	0.006	0.009	0.016
Total arsenic	mg/L	0.005	0.0006	10	0.0005	0.0008	0.0014
Total boron	mg/L	1.2	0.053	10	0.021	0.032	0.055
Total molybdenum	mg/L	0.073	0.00023	10	0.00015	0.00020	0.00036
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	3.1
Total strontium	mg/L	-	<0.00001	10	<0.000005	<0.000005	0.000016
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	19.3	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	6.6	0	-	-	-
Total PAHs	ng/L	-	172.6	0	-	-	-
Total Parent PAHs	ng/L	-	25.2	0	-	-	-
Total Alkylated PAHs	ng/L	-	147.4	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Sulphide	mg/L	0.002	**0.003**	10	<0.003	**0.004**	**0.009**
Total iron	mg/L	0.3	**0.6**	10	**0.5**	**1.2**	**2.4**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.9-5 Concentrations of water quality measurement endpoints, upper Clearwater River (*baseline* station CLR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.1</u>	10	7.2	7.9	8.0
Total suspended solids	mg/L	-	<u>3</u>	10	7	18	36
Conductivity	µS/cm	-	<u>253</u>	10	138	190	249
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.008</u>	10	0.010	0.020	0.026
Total nitrogen	mg/L	1	0.4	10	0.3	0.5	1.2
Nitrate+nitrite	mg/L	1.3	<0.071	10	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	7	10	6	8	24
Ions							
Sodium	mg/L	-	26.2	10	11.0	16.5	29.0
Calcium	mg/L	-	12.4	10	10.0	11.9	21.6
Magnesium	mg/L	-	4.5	10	3.4	4.2	7.0
Chloride	mg/L	230, 860	39	10	16	26	43
Sulphate	mg/L	100	5.8	10	<0.5	5.3	7.7
Total dissolved solids	mg/L	-	<u>177</u>	10	40	127	160
Total alkalinity	mg/L		<u>52.9</u>	10	39	46	51
Selected metals							
Total aluminum	mg/L	0.1	**0.15**	10	0.10	**0.28**	**2.55**
Dissolved aluminum	mg/L	0.1	<u>0.003</u>	10	0.005	0.008	0.040
Total arsenic	mg/L	0.005	0.0004	10	0.0004	0.0005	0.0012
Total boron	mg/L	1.2	0.030	10	0.014	0.024	0.030
Total molybdenum	mg/L	0.073	0.00013	10	0.00009	0.00012	0.00020
Total mercury (ultra-trace)	ng/L	5, 13	0.8	8	<1.2	<1.2	2.1
Total strontium	mg/L	-	<u>0.103</u>	10	0.061	0.080	0.094
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.8	0	-	-	-
Total PAHs	ng/L	-	151.2	0	-	-	-
Total Parent PAHs	ng/L	-	19.2	0	-	-	-
Total Alkylated PAHs	ng/L	-	131.9	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	<u>**0.34**</u>	10	**0.55**	**0.81**	**2.42**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.9-6 Concentrations of water quality measurement endpoints, mouth of Christina River (*test* station CHR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	9	8.1	8.3	8.4
Total suspended solids	mg/L	-	14	9	<3	26	76
Conductivity	µS/cm	-	357	9	210	291	375
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.02</u>	9	0.02	0.02	0.05
Total nitrogen	mg/L	1	0.78	9	0.60	**1.10**	**1.80**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	19.1	9	14.0	20.0	25.3
Ions							
Sodium	mg/L	-	28.7	9	12.8	25.0	34.0
Calcium	mg/L	-	25.9	9	22	27.3	30.2
Magnesium	mg/L	-	8.0	9	7.0	8.4	9.4
Chloride	mg/L	230, 860	35.7	9	9.5	24.0	41.0
Sulphate	mg/L	100	6.6	9	2.2	6.8	8.5
Total dissolved solids	mg/L	-	236	9	140	189	250
Total alkalinity	mg/L		120	9	86.4	104	120
Selected metals							
Total aluminum	mg/L	0.1	**0.36**	9	**0.24**	**0.62**	**3.23**
Dissolved aluminum	mg/L	0.1	0.008	9	0.007	0.010	0.029
Total arsenic	mg/L	0.005	0.0010	9	0.0007	0.0011	0.0017
Total boron	mg/L	1.2	0.072	9	0.027	0.049	0.074
Total molybdenum	mg/L	0.073	0.00038	9	0.00016	0.00038	0.00040
Total mercury (ultra-trace)	ng/L	5, 13	1.3	8	<1.2	<1.2	5.1
Total strontium	mg/L	-	0.14	9	0.08	0.12	0.15
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	6.0	0	-	-	-
Total PAHs	ng/L	-	154.6	0	-	-	-
Total Parent PAHs	ng/L	-	19.5	0	-	-	-
Total Alkylated PAHs	ng/L	-	135.2	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.31**	9	0.26	**0.38**	**0.96**
Total iron	mg/L	0.3	**0.93**	9	**0.78**	**1.49**	**3.10**
Total phenols	mg/L	0.004	**0.005**	9	<0.001	0.004	**0.014**
Total phosphorus	mg/L	0.05	**0.05**	9	0.05	**0.06**	**0.13**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.9-7 Concentrations of water quality measurement endpoints, upper Christina River (*test* station CHR-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.4</u>	9	8.0	8.2	8.3
Total suspended solids	mg/L	-	<3	9	<3	8	30
Conductivity	µS/cm	-	263	9	152	205	268
Nutrients							
Total dissolved phosphorus	mg/L	0.05	<u>0.02</u>	9	0.03	0.04	0.05
Total nitrogen	mg/L	1	0.71	9	0.60	0.90	**1.40**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	13.7	9	13.0	18.0	26.0
Ions							
Sodium	mg/L	-	8.9	9	4.8	6.0	10.0
Calcium	mg/L	-	31.5	9	20.8	27.4	35.1
Magnesium	mg/L	-	9.5	9	6.2	8.0	10.6
Chloride	mg/L	230, 860	0.7	9	<0.5	2	2
Sulphate	mg/L	100	6.8	9	2.4	4.4	9.6
Total dissolved solids	mg/L	-	183	9	130	140	240
Total alkalinity	mg/L		132	9	75	102	138
Selected metals							
Total aluminum	mg/L	0.1	0.09	8	0.05	**0.21**	**0.47**
Dissolved aluminum	mg/L	0.1	<u>0.003</u>	8	0.004	0.010	0.019
Total arsenic	mg/L	0.005	0.0008	8	0.0007	0.0011	0.0016
Total boron	mg/L	1.2	0.05	8	0.02	0.03	0.05
Total molybdenum	mg/L	0.073	0.0006	8	0.0003	0.0004	0.0007
Total mercury (ultra-trace)	ng/L	5, 13	0.6	8	<1.2	<1.2	2.7
Total strontium	mg/L	-	0.13	8	0.08	0.10	0.16
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.8	0	-	-	-
Total PAHs	ng/L	-	153.7	0	-	-	-
Total Parent PAHs	ng/L	-	21.8	0	-	-	-
Total Alkylated PAHs	ng/L	-	131.9	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**<u>0.68</u>**	8	**1.00**	**1.42**	**2.62**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.9-8 Concentrations of water quality measurement endpoints, High Hills River (*baseline* station HHR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.4
Total suspended solids	mg/L	-	6
Conductivity	µS/cm	-	249
Nutrients			
Total dissolved phosphorus	mg/L	0.05	**0.07**
Total nitrogen	mg/L	1	0.38
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	12.8
Ions			
Sodium	mg/L	-	9.2
Calcium	mg/L	-	30.8
Magnesium	mg/L	-	9.74
Chloride	mg/L	230, 860	0.62
Sulphate	mg/L	100	2.64
Total dissolved solids	mg/L	-	155
Total alkalinity	mg/L		129
Selected metals			
Total aluminum	mg/L	0.1	**0.28**
Dissolved aluminum	mg/L	0.1	0.01
Total arsenic	mg/L	0.005	0.00052
Total boron	mg/L	1.2	0.057
Total molybdenum	mg/L	0.073	0.00025
Total mercury (ultra-trace)	ng/L	5, 13	0.7
Total strontium	mg/L	-	0.090
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	3.6
Total dibenzothiophenes	ng/L	-	6.0
Total PAHs	ng/L	-	164.2
Total Parent PAHs	ng/L	-	19.9
Total Alkylated PAHs	ng/L	-	144.3
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Total iron	mg/L	0.3	**0.62**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Figure 5.9-4 Piper diagram of fall ion concentrations in the Clearwater-Christina River watersheds.

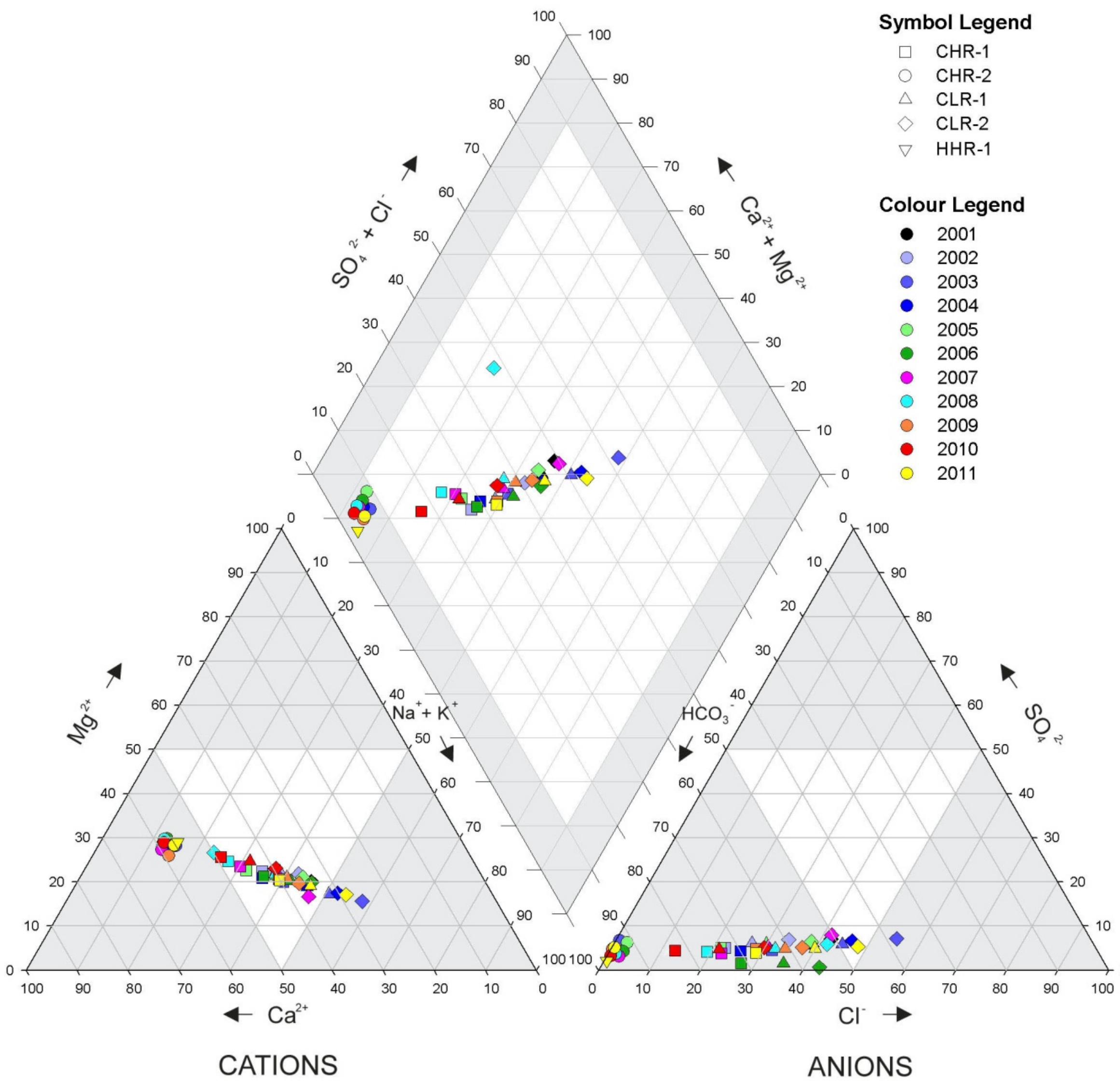


Table 5.9-9 Water quality guideline exceedances, Christina-Clearwater River watersheds, 2011.

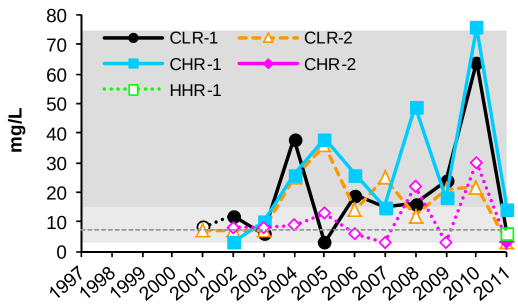
Variable	Units	Guideline[a]	CLR-1	CLR-2	CHR-1	CHR-2	HHR-1
Winter							
Total aluminum	mg/L	0.1	ns	ns	ns	ns	0.23
Total iron	mg/L	0.3	ns	ns	ns	ns	0.89
Total phosphorus	mg/L	0.05	ns	ns	ns	ns	0.09
Summer							
Dissolved iron	mg/L	0.3	ns	ns	ns	ns	0.36
Dissolved phosphorous	mg/L	0.05	ns	ns	ns	ns	0.078
Sulphide	mg/L	0.002	ns	ns	ns	ns	0.0071
Total aluminum	mg/L	0.1	ns	ns	ns	ns	1.73
Total chromium	mg/L	0.001	ns	ns	ns	ns	0.002
Total iron	mg/L	0.3	ns	ns	ns	ns	2.12
Total phenols	mg/L	0.004	ns	ns	ns	ns	0.0083
Total phosphorus	mg/L	0.05	ns	ns	ns	ns	0.18
Fall							
Dissolved iron	mg/L	0.3	-	-	0.31	-	-
Sulphide	mg/L	0.002	0.0034	-	-	-	-
Total aluminum	mg/L	0.1	0.26	0.15	0.36	-	0.28
Total iron	mg/L	0.3	0.56	0.34	0.93	0.68	0.62
Total phenols	mg/L	0.004	-	-	0.0054	-	-
Total phosphorus	mg/L	0.05	-	-	0.05	-	0.0689

[a] Sources for all guidelines are outlined in Table 3.2-5.

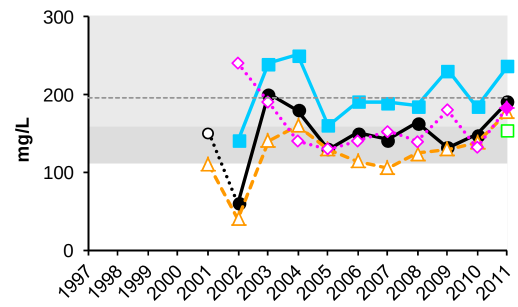
ns = not sampled

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.

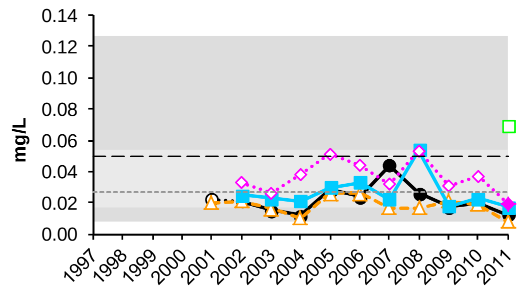
Total Suspended Solids (TSS)



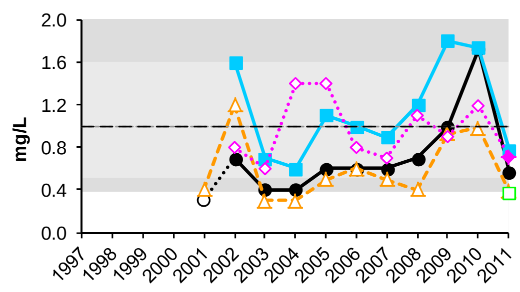
Total Dissolved Solids (TDS)



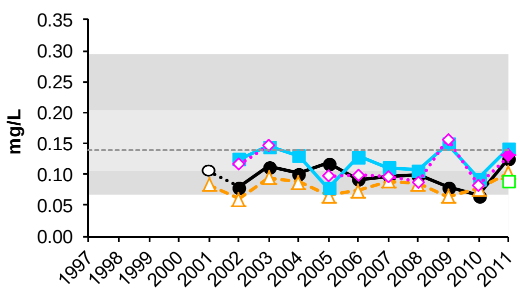
Dissolved Phosphorus



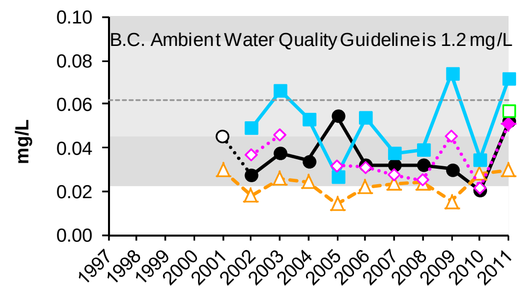
Total Nitrogen



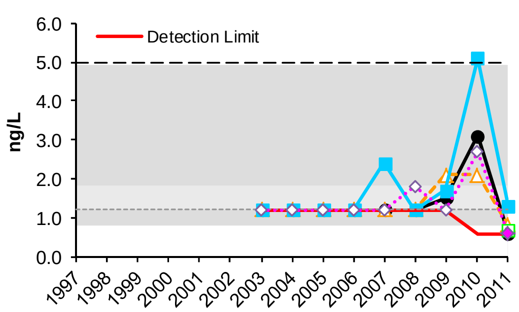
Total Strontium



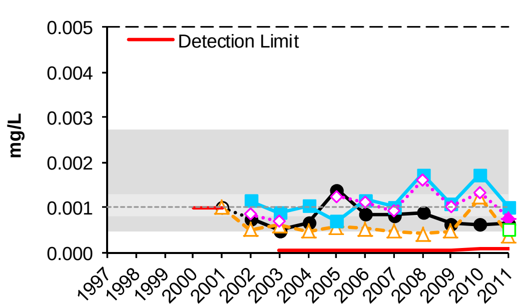
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



Non-detectable values are shown at the detection limit.

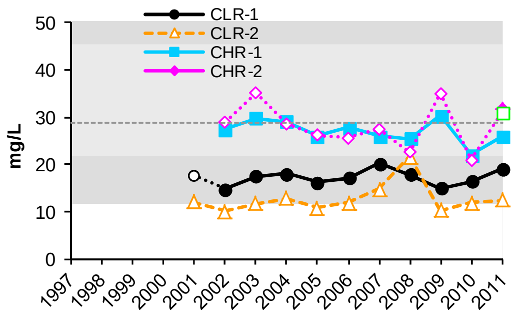
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

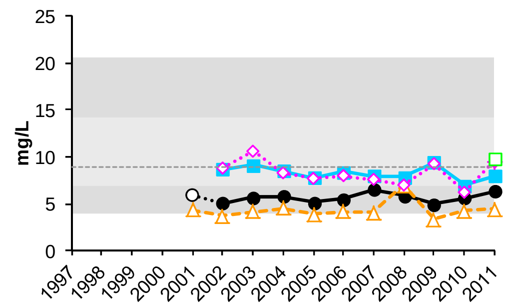
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.9-5 (Cont'd.)

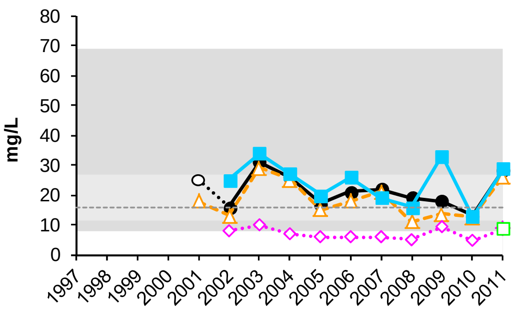
Calcium



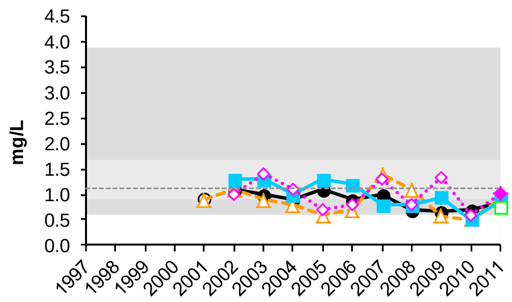
Magnesium



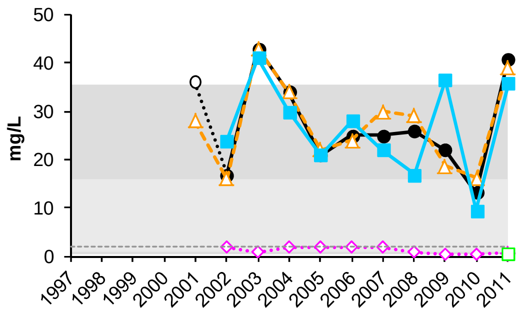
Sodium



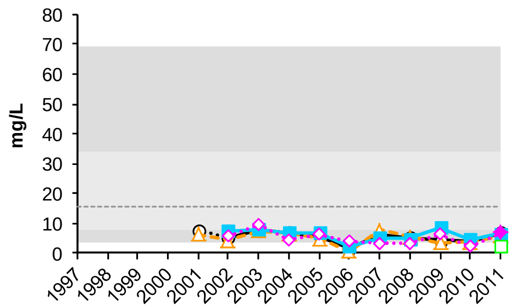
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.9-10 Water quality index (fall 2011) for stations in the Clearwater-Christina River watersheds.

Station Identifier	Location	2011 Designation	Water Quality Index	Classification
CLR-1	upstream of Fort McMurray	*test*	98.7	Negligible-Low
CLR-2	upstream of Christina River	*baseline*	98.7	Negligible-Low
CHR-1	near the mouth of the Christina River	*test*	97.5	Negligible-Low
CHR-2	upstream of Janvier	*test*	100	Negligible-Low
HHR-1	near the mouth of High Hills	*baseline*	98.7	Negligible-Low

Table 5.9-11 Average habitat characteristics of benthic invertebrate community sampling locations in the Clearwater and High Hills rivers.

Variable	Units	CLR-D2 Upper *Baseline* Reach of Clearwater River	CLR-D1 Lower *Test* Reach of Clearwater River	HHR-E1 Lower *Baseline* Reach of High Hills River
Sample date	-	Sept. 13, 2011	Sept. 15, 2011	Sept. 7, 2011
Habitat	-	Depositional	Depositional	Erosional
Water depth	m	0.8	0.6	0.2
Current velocity	m/s	0.42	0.31	1.00
Field Water Quality				
Dissolved oxygen	mg/L	9.1	8.9	6.9
Conductivity	µS/cm	255	305	229
pH	pH units	7.9	8.2	8.7
Water temperature	°C	12.9	11.0	13.6
Sediment Composition				
Sand	%	99	98	0.6
Silt	%	0.5	1	-
Clay	%	0.5	1	-
Small gravel		-	-	19
Large gravel		-	-	34
Small cobble		-	-	33
Large cobble		-	-	10
Boulder		-	-	4
Total Organic Carbon	%	0.1	0.1	-

Table 5.9-12 Summary of major taxon abundances of benthic invertebrate community measurement endpoints at *test* reach CLR-D1.

Taxon	Percent Major Taxa Enumerated in Each Year						
	Reach CLR-D1						
	2001	**2002**	**2003**	**2004**	**2005**	**2008**	**2011**
Nematoda	<1	<1	<1	<1	4	1	2
Glossiphoniidae	<1						
Naididae	3	3	2	1	<1	5	4
Tubificidae	27	10	14	6	31	17	7
Enchytraeidae		2		<1		<1	
Lumbriculidae			<1				
Hydracarina	<1			<1			
Ostracoda	6	2				14	1
Chydoridae	3			<1			
Gastropoda	<1	<1			<1	<1	
Bivalvia	20	6	1	1	<1	6	7
Coleoptera		<1		<1			
Ceratopogonidae	1	2	<1	1	6	2	4
Chironomidae	38	68	80	87	57	51	59
Empididae		1		<1	1	<1	<1
Tabanidae	<1	<1					
Simuliidae		<1	2			<1	
Ephemeroptera	<1	2	<1	1	<1	1	<1
Anisoptera	1	1	<1	<1	<1	1	<1
Zygoptera	<1	<1					
Plecoptera		1		<1		1	<1
Trichoptera		1				<1	
Heteroptera	<1						
Lepidoptera		<1					
Benthic Invertebrate Community Measurement Endpoints							
Total Abundance (No./m^2)	20,782	10,230	5,172	5,035	1,522	7,379	3,926
Richness	10	9	4	5	3	15	11
Simpson's Diversity	0.52	0.65	0.37	0.45	0.31	0.81	0.64
Evenness	0.71	0.84	0.62	0.64	0.40	0.88	0.74
% EPT	<1	2	<1	4.0	<1	6	2

Table 5.9-13 Summary of major taxon abundances of benthic invertebrate community measurement endpoints at *baseline* reach CLR-D2.

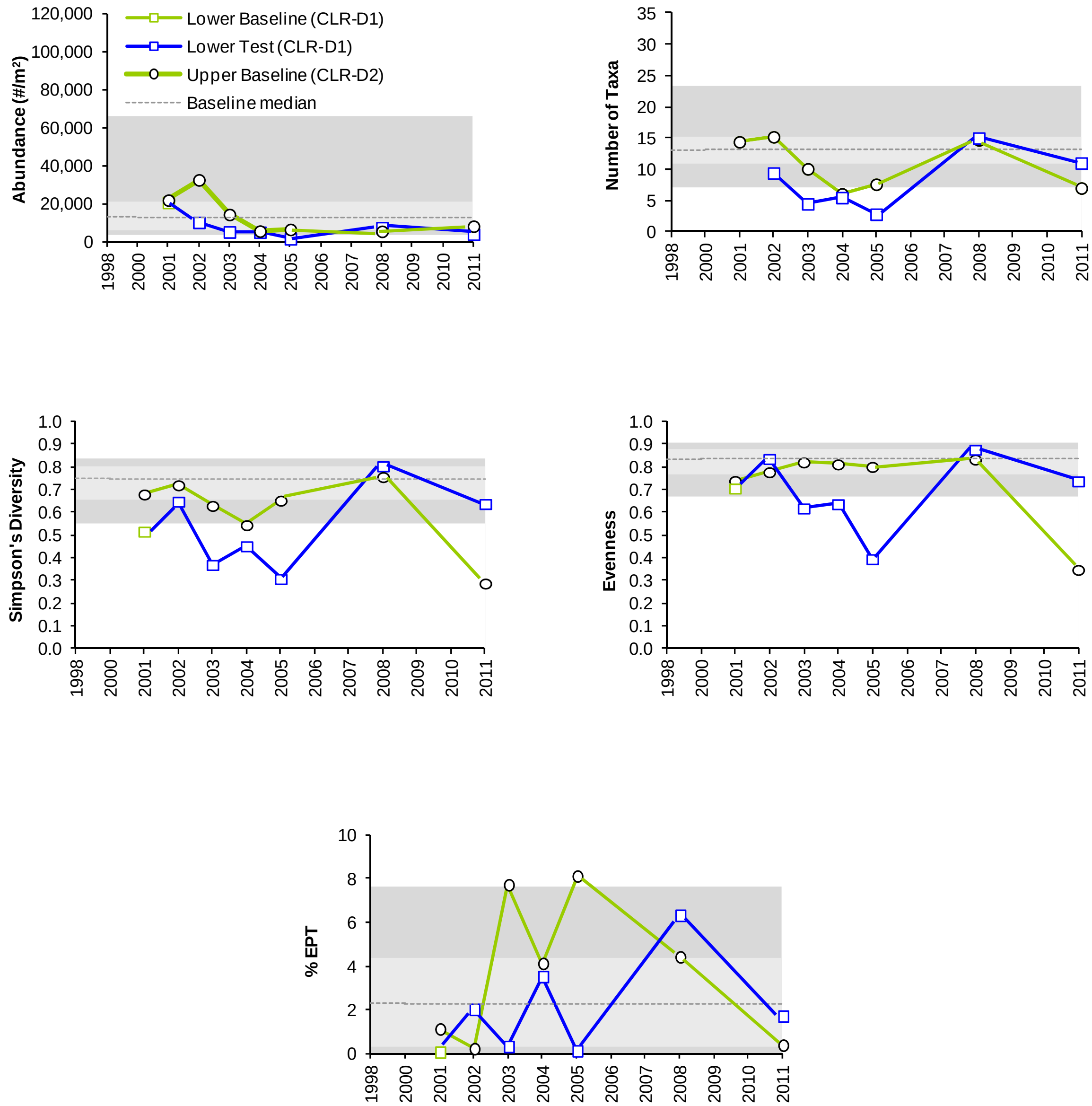
Taxon	Percent Major Taxa Enumerated in Each Year						
	Reach CLR-D2						
	2001	2002	2003	2004	2005	2008	2011
Nematoda	1	1	1	8	<1	5	5
Erpobdellidae			<1	<1			
Glossiphoniidae	<1		<1	<1			
Naididae	21	5	10	1	1	<1	<1
Tubificidae	26	17	8	40	45	3	<1
Enchytraeidae	<1		1		1	<1	
Lumbriculidae		<1	<1	<1			
Hydracarina	<1	<1	<1				
Amphipoda	<1	<1	<1				
Ostracoda	3	7	12	<1		4	4
Chydoridae	1	<1	<1				
Macrothricidae		5	<1	<1			
Copepoda	<1	<1		1		<1	<1
Gastropoda	1	<1	<1		<1	<1	
Bivalvia	11	10	33	14	1	21	<1
Coleoptera	<1	<1	<1				
Ceratopogonidae	1	1	4	<1	1	1	2
Chironomidae	34	51	27	32	44	58	87
Dolichopodidae			<1	<1			
Empididae	<1	<1		1	1	1	
Tipulidae		<1	<1	1		<1	
Tabanidae	<1	<1		<1	<1	<1	
Simuliidae	<1	<1				2	
Ephemeroptera	1	<1	<1	1	1	1	<1
Anisoptera	<1	<1	<1	1	2	<1	
Zygoptera	<1	<1		<1			
Plecoptera	<1		<1	<1	1	<1	
Trichoptera	<1	<1	<1		2	1	
Heteroptera		<1	<1				
Lepidoptera		<1					
Megaloptera	<1						
Benthic Invertebrate Community Measurement Endpoints							
Total Abundance (No./m^2)	22,035	32,778	14,437	5,621	6,443	5,452	8,157
Richness	14	15	10	6	8	15	7
Simpson's Diversity	0.68	0.72	0.63	0.55	0.65	0.76	0.29
Evenness	0.74	0.78	0.82	0.81	0.80	0.84	0.35
% EPT	1.1	0.2	7.7	4.1	8.1	4.4	0.4

Table 5.9-14 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints at *test* reach CLR-D1 and *baseline* reach CLR-D2.

Variable	P-value		Variance Explained (%)		Nature of Change(s)
	Time Trend	***Baseline* Reach vs. *Test* Reach**	Time Trend	***Baseline* Reach vs. *Test* Reach**	
Abundance	**0.003**	**<0.001**	1	42	Higher in *baseline* reach; decreasing in *baseline* reach and stable in *test* reach
Richness	0.071	**<0.001**	1	47	Higher in *baseline* reach
Simpson's Diversity	**<0.001**	0.999	33	0	Stable in *test* reach; increasing in *baseline* reach
Evenness	**<0.001**	0.292	31	1	Stable in *test* reach and increasing in *baseline* reach
EPT	**0.026**	**<0.001**	3	52	Higher in *baseline* reach; increasing in *baseline* reach
CA Axis 1	**0.008**	**<0.001**	2	30	Higher in *baseline* reach; stable in *baseline* reach and increasing in *test* reach
CA Axis 2	**0.001**	**<0.001**	2	64	Higher in *baseline* reach; stable in *baseline* reach and decreasing in *test* reach

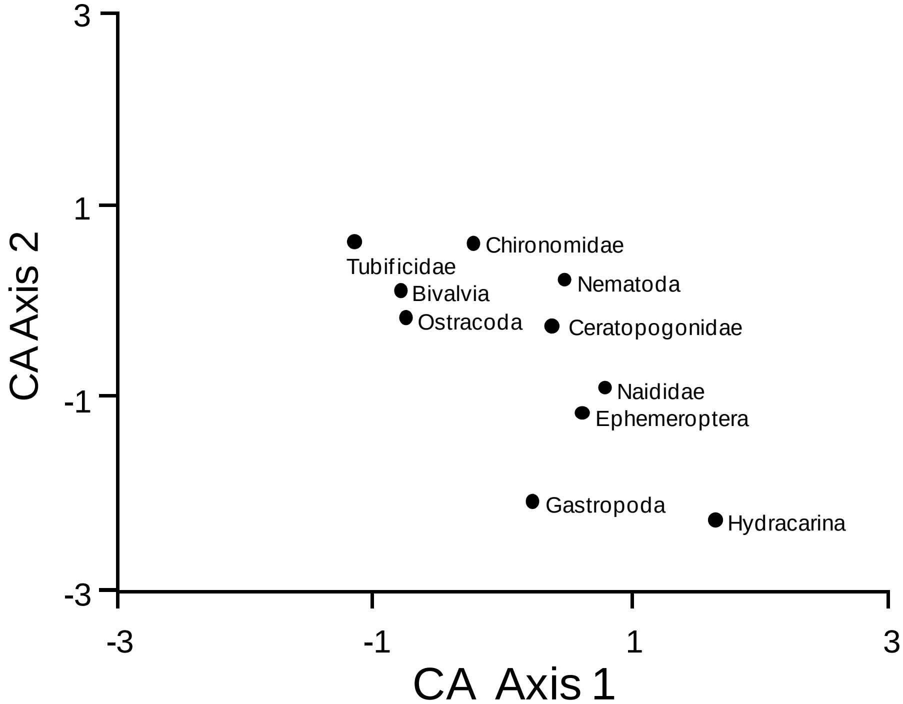
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low, Moderate, or High (Table 3.2-6).

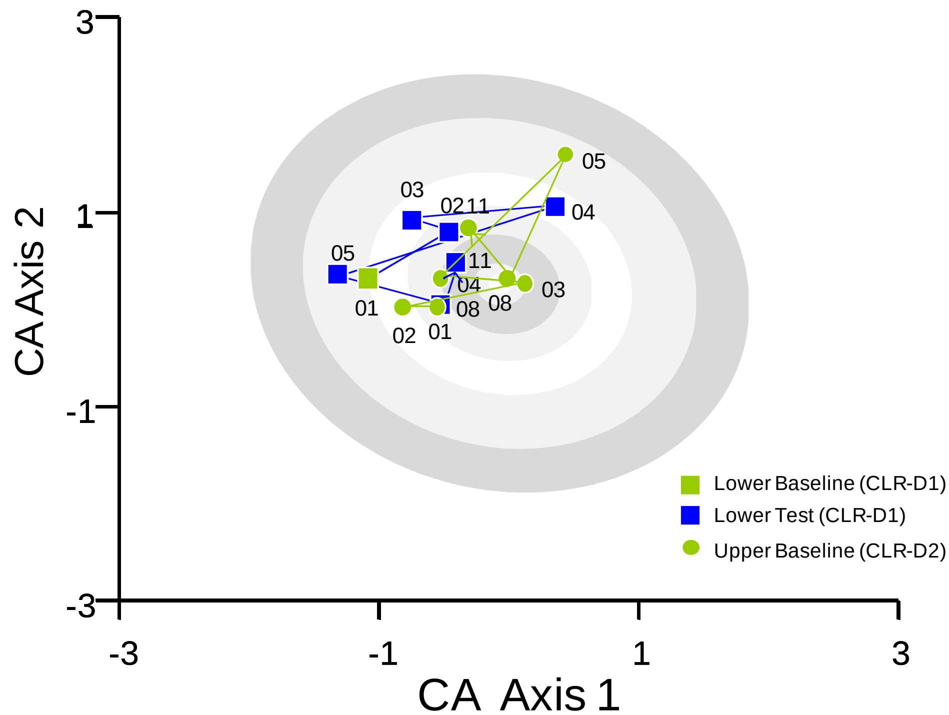
Figure 5.9-6 Variation in benthic invertebrate community measurement endpoints in the Clearwater River.



Note: Regional *baseline* values for all *baseline* depositional reaches sampled in the RAMP FSA. See Section 3.2.3.1 for a description of the approach.

Figure 5.9-7 Ordination (Correspondence Analysis) of benthic invertebrate communities at *test* reach CLR-D1 and *baseline* reach CLR-D2 of the Clearwater 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.

Figure 5.9-8 Periphyton chlorophyll *a* biomass in the High Hills River.

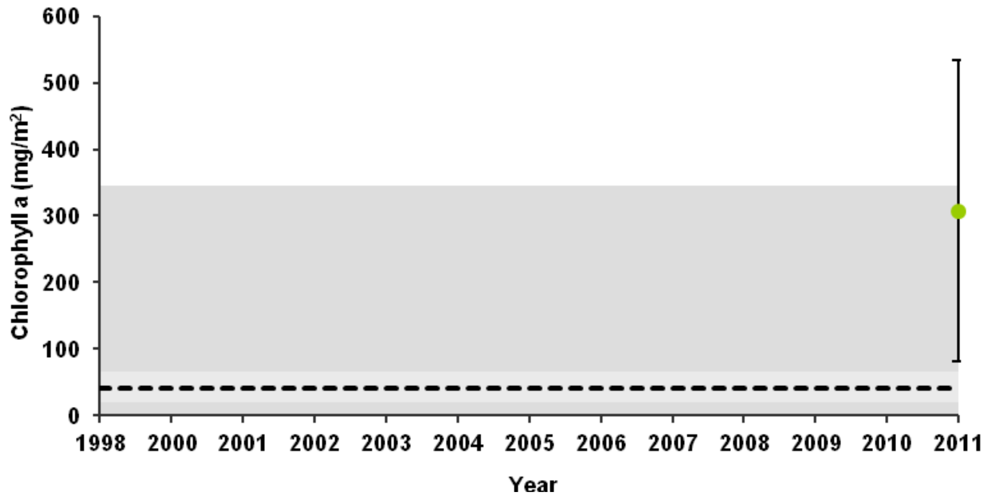
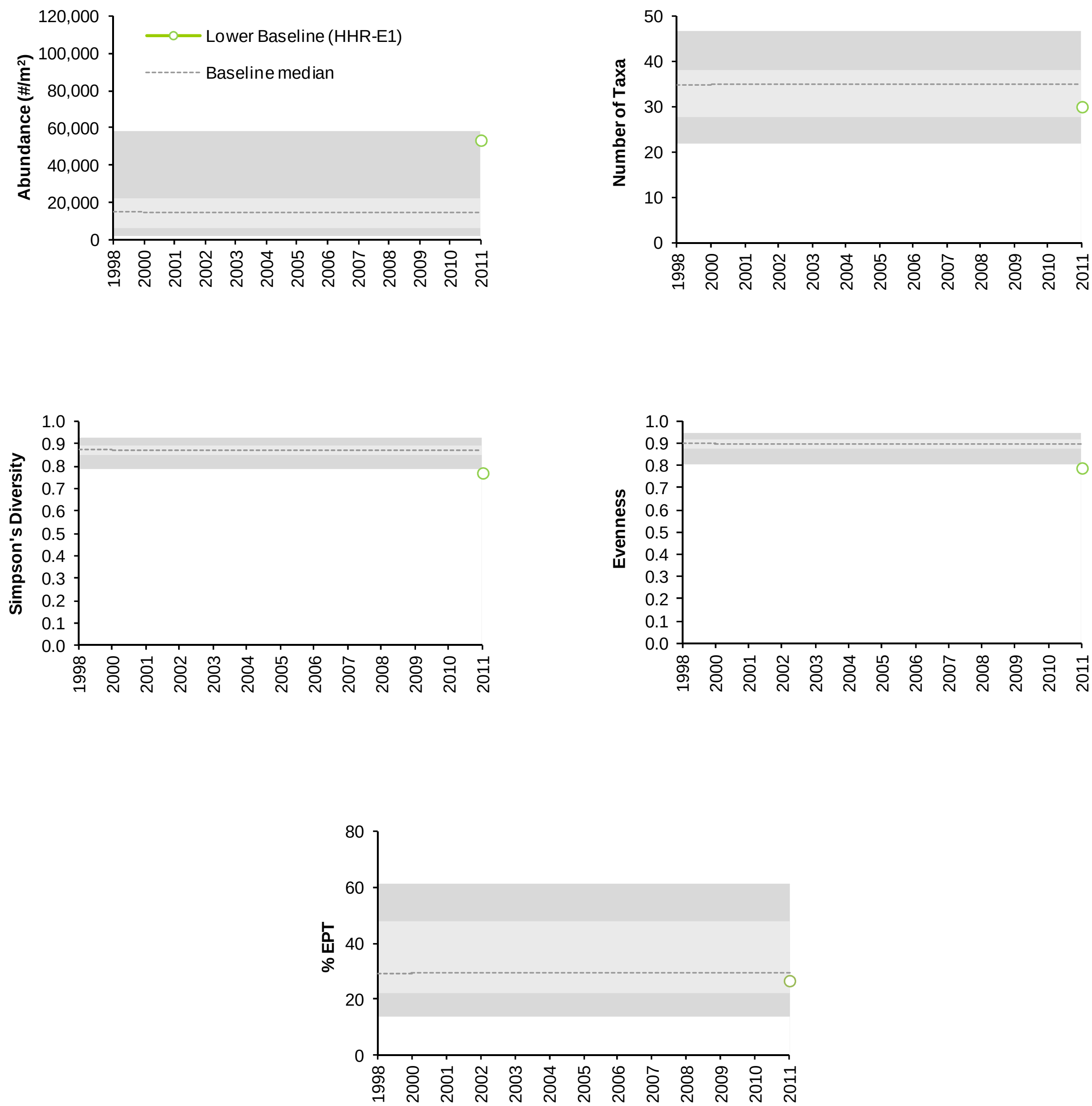


Table 5.9-15 Summary of major taxon abundances of benthic invertebrate community measurement endpoints at *baseline* reach HHR-E1.

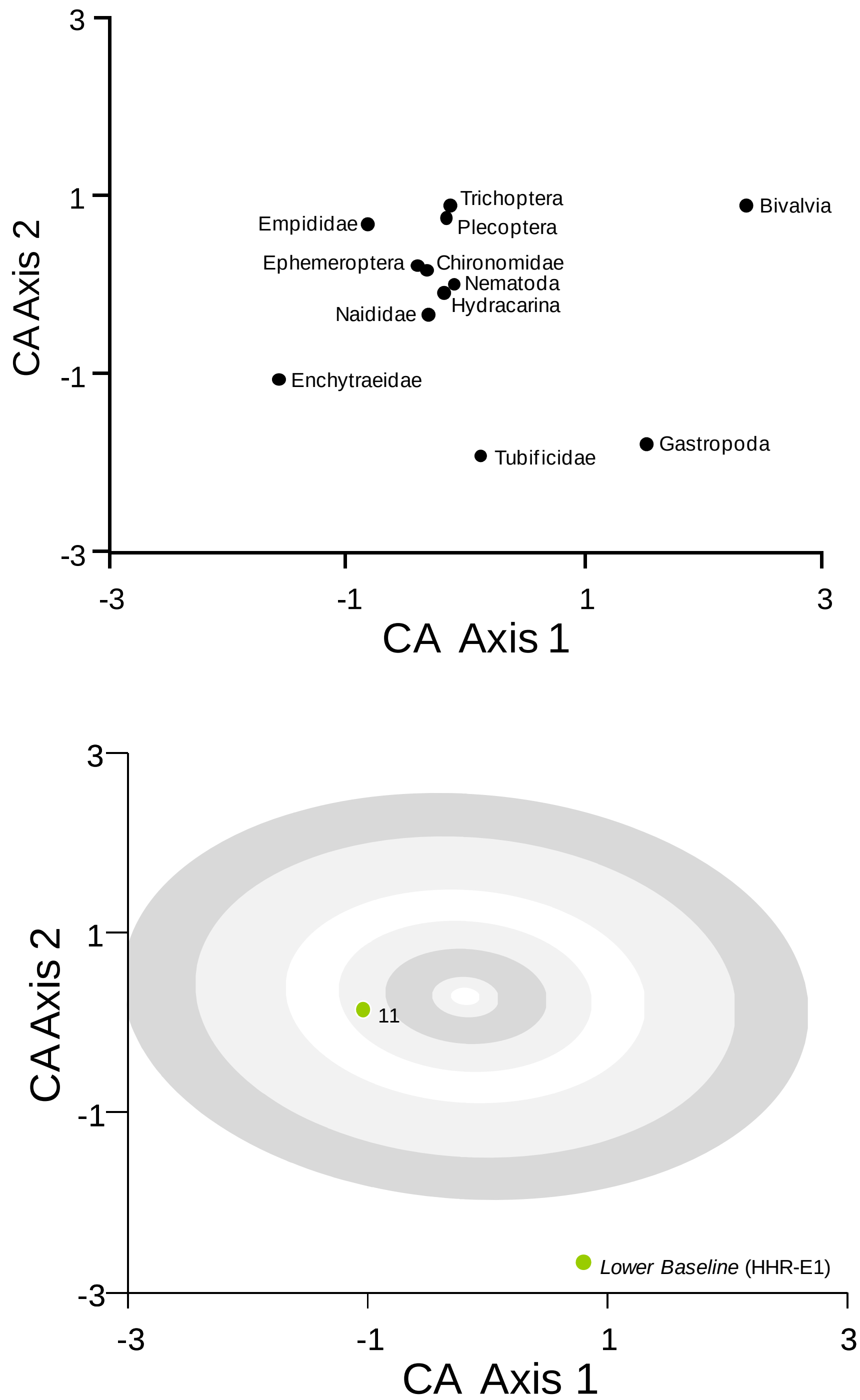
Taxon	Percent Major Taxa Enumerated in Each Year
	Reach HHR-E1
	2011
Nematoda	<1
Naididae	42
Enchytraeidae	7
Hydracarina	5
Copepoda	<1
Gastropoda	<1
Coleoptera	<1
Chironomidae	13
Athericidae	<1
Empididae	3
Psychodidae	<1
Tipulidae	<1
Simuliidae	<1
Ephemeroptera	19
Anisoptera	<1
Plecoptera	1
Trichoptera	6
Benthic Invertebrate Community Measurement Endpoints	
Total Abundance (No./m^2)	53,498
Richness	30
Simpson's Diversity	0.77
Evenness	0.79
% EPT	27

Figure 5.9-9 Variation in benthic invertebrate community measurement endpoints in the High Hills 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 5.9-10 Ordination (Correspondence Analysis) of benthic invertebrate communities at *baseline* reach HHR-E1 of the High Hills 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 5.9-16 Concentrations of selected sediment measurement endpoints, Clearwater River (*test* station CLR-D1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>0.7</u>	4	2.0	3.0	33.0
Silt	%	-	<u>0.7</u>	4	2.0	18.0	29.0
Sand	%	-	<u>98.6</u>	4	38.0	79.0	96.0
Total organic carbon	%	-	0.1	4	0.1	0.3	1.0
Total hydrocarbons							
BTEX	mg/kg	-	<10	1	-	-	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	1	-	-	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	1	-	-	5
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	1	-	-	<5
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	1	-	-	7
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0002</u>	4	0.0009	0.0014	0.0025
Retene	mg/kg	-	<u>0.0009</u>	4	0.0080	0.0100	0.0473
Total dibenzothiophenes	mg/kg	-	<u>0.0097</u>	4	0.0267	0.1068	0.5204
Total PAHs	mg/kg	-	<u>0.0705</u>	4	0.2971	0.5388	1.8128
Total Parent PAHs	mg/kg	-	<u>0.0039</u>	4	0.0282	0.0325	0.0871
Total Alkylated PAHs	mg/kg	-	<u>0.0666</u>	4	0.2689	0.5062	1.7257
Predicted PAH toxicity[3]	H.I.	1.0	0.34	4	0.17	**1.02**	**30.98**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	9.4	1	-	-	5.0
Chironomus growth - 10d	mg/organism	-	1.48	1	-	-	1.10
Hyalella survival - 14d	# surviving	-	9.0	1	-	-	7.0
Hyalella growth - 14d	mg/organism	-	0.34	1	-	-	0.10

Values in **bold** indicate concentrations exceeding guidelines.

Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[1] Guideline is for residential/parkland coarse (median grain size > 75 μm) surface soils (CCME 2008).

[2] Interim sediment quality guideline (ISQG) (CCME 2002).

[3] Toxicity of PAH assemblage estimated using the equilibrium partitioning approach. A hazard index (H.I.) is calculated from individual PAH concentrations in sediment, values of K_{ow} (octanol-water partition coefficient), and chronic toxicity of the individual PAH species.

Table 5.9-17 Concentrations of selected sediment measurement endpoints, Clearwater River (*baseline* station CLR-D2), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>0.4</u>	4	2.0	6.5	12.0
Silt	%	-	<u>0.2</u>	4	1.0	9.0	35.0
Sand	%	-	<u>99.5</u>	4	52.0	84.5	98.0
Total organic carbon	%	-	<0.1	4	<0.1	0.4	1.6
Total hydrocarbons							
BTEX	mg/kg	-	<10	1	-	-	<5
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	1	-	-	<5
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	1	-	-	65
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	1	-	-	**740**
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	1	-	-	450
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u><0.0001</u>	4	0.0009	0.0012	0.0020
Retene	mg/kg	-	<u>0.0002</u>	4	0.0018	0.0029	0.0040
Total dibenzothiophenes	mg/kg	-	0.0018	4	0.0013	0.0015	0.0046
Total PAHs	mg/kg	-	<u>0.0119</u>	4	0.0127	0.0340	0.2007
Total Parent PAHs	mg/kg	-	<u>0.0011</u>	4	0.0041	0.0070	0.0244
Total Alkylated PAHs	mg/kg	-	0.0109	4	0.0086	0.0270	0.1763
Predicted PAH toxicity[3]	H.I.	1.0	0.05	4	0.003	0.22	0.39
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>9.6</u>	2	8.0	-	9.2
Chironomus growth - 10d	mg/organism	-	1.53	2	1.10	-	2.60
Hyalella survival - 14d	# surviving	-	<u>9.8</u>	2	8.0	-	8.8
Hyalella growth - 14d	mg/organism	-	0.25	2	0.10	-	0.33

Values in **bold** indicate concentrations exceeding guidelines.

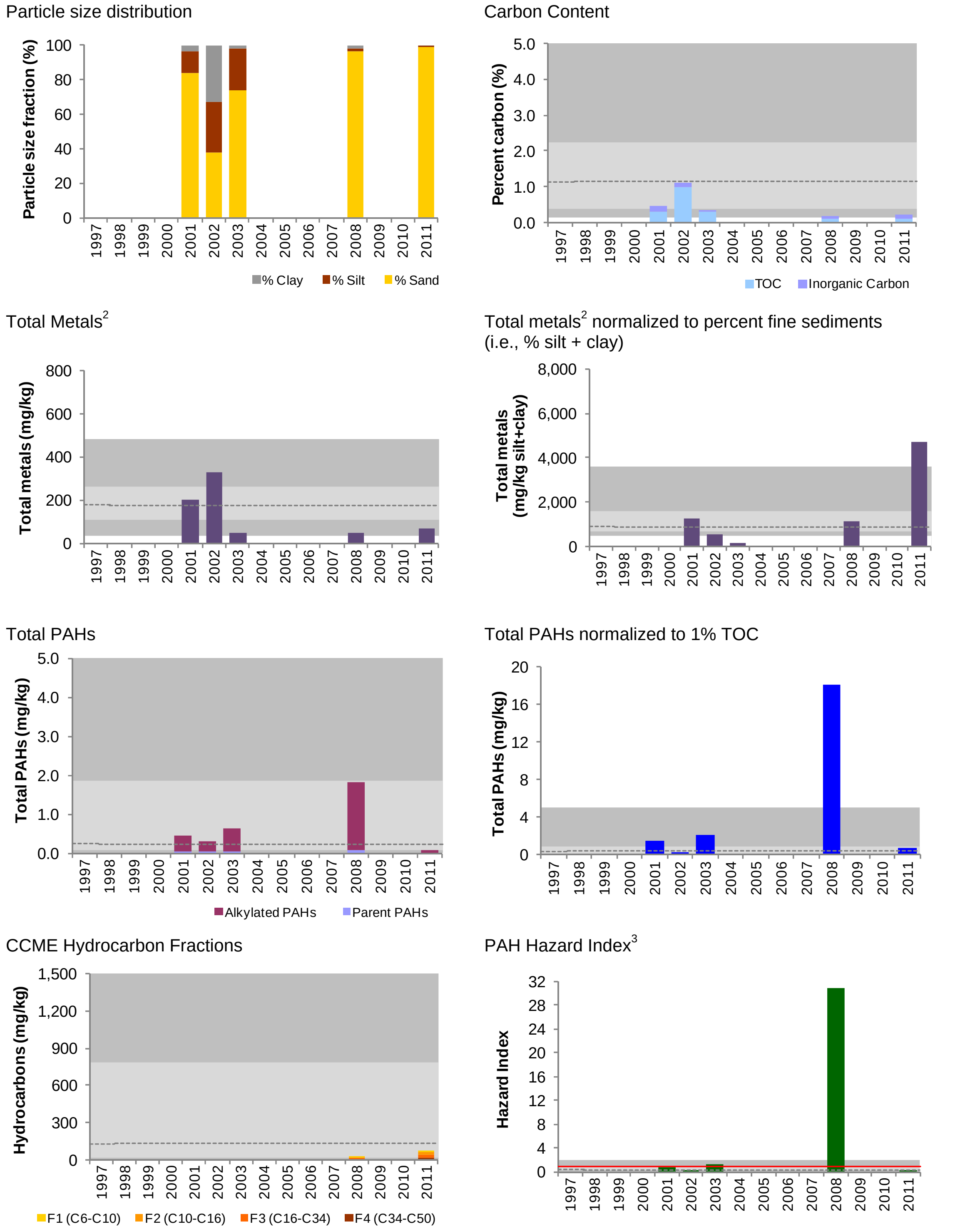
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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 5.9-11 Variation in sediment quality measurement endpoints in the Clearwater River, *test* station CLR-D1.



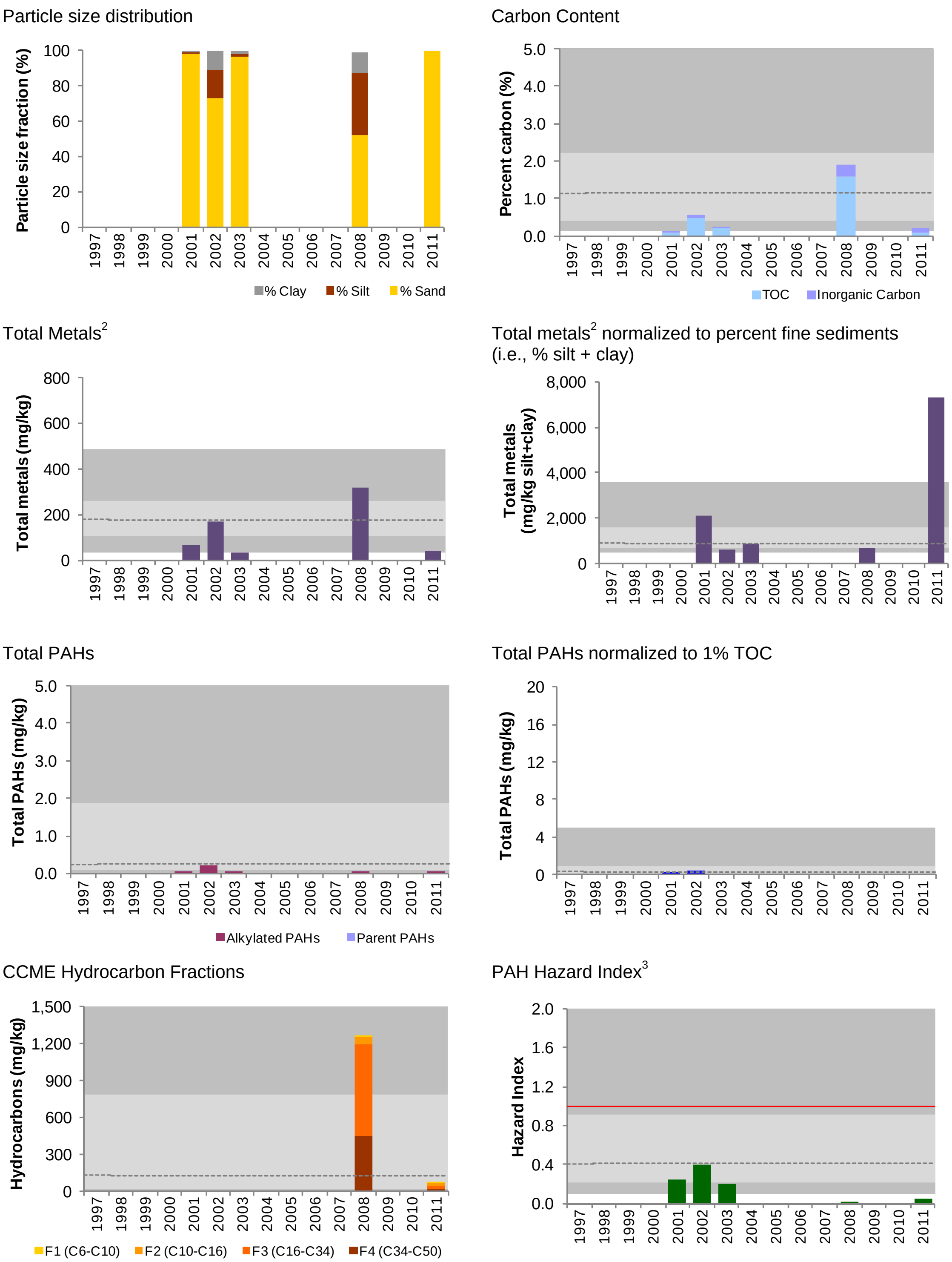
Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

1 Regional *baseline* values represent "total" values for multi-variable data.

2 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

3 Red line indicates potential chronic effects level (HI = 1.0).

Figure 5.9-12 Variation in sediment quality measurement endpoints in the Clearwater River, *baseline* station CLR-D2.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.9-18 Seasonal species composition in *baseline* (CR1, CR2) and *test* (CR3) reaches of the Clearwater River, 2011.

Species	Spring				Summer				Fall			
	Baseline	%	Test	%	Baseline	%	Test	%	Baseline	%	Test	%
Arctic grayling	-	-	1	0.5	-	-	-	-	-	-	1	0.4
burbot	-	-	-	-	-	-	-	-	-	-	1	0.4
flathead chub	-	-	3	1.4	-	-	4	1.5	-	-	-	-
finescale dace	-	-	-	-	1	0.1	-	-	-	-	-	-
fathead minnow	-	-	-	-	-	-	-	-	-	-	1	0.4
goldeye	5	1.4	20	9.2	1	0.1	3	1.1	-	-	5	1.9
lake chub	16	4.6	4	1.8	169	17.5	22	8.0	-	-	4	1.5
lake whitefish	4	1.1	-	-	4	0.4	3	1.1	-	-	-	-
longnose dace	-	-	-	-	2	0.2	-	-	-	-	-	-
longnose sucker	1	0.3	31	14.3	92	9.5	109	39.6	-	-	39	14.5
mountain whitefish	-	-	1	0.5	1	0.1	-	-	-	-	5	1.9
northern pike	23	6.6	10	4.6	19	2.0	12	4.4	-	-	15	5.6
pearl dace	1	0.3	-	-	1	0.1	1	0.4	-	-	-	-
slimy sculpin	7	2.0	23	10.6	2	0.2	6	2.2	-	-	44	16.4
spoonhead sculpin	-	-	3	1.4	-	-	-	-	-	-	-	-
spottail shiner	36	10.3	4	1.8	377	39.0	25	9.1	-	-	40	14.9
trout-perch	50	14.3	20	9.2	34	3.5	21	7.6	-	-	59	21.9
walleye	9	2.6	16	7.4	20	2.1	26	9.5	-	-	16	5.9
white sucker	197	56.3	81	37.3	243	25.2	40	14.5	-	-	38	14.1
yellow perch	1	0.3	-	-	-	-	3	1.1	-	-	1	0.4
Total # Species	**12**	**-**	**13**	**-**	**14**	**-**	**13**	**-**	**-**	**-**	**14**	**-**
Total # Fish	**350**	**100**	**217**	**100**	**966**	**100**	**275**	**100**	**-**	**-**	**269**	**100**

Note: *Baseline* reaches CR1 and CR2 were not sampled in fall 2011 due to low water levels, which prevented access by boat to the portion of the Clearwater River where these reaches are located.

Figure 5.9-13 Number of species captured in *test* and *baseline* sampling areas during the Clearwater River spring, summer, and fall fish inventories, 2003 to 2011.

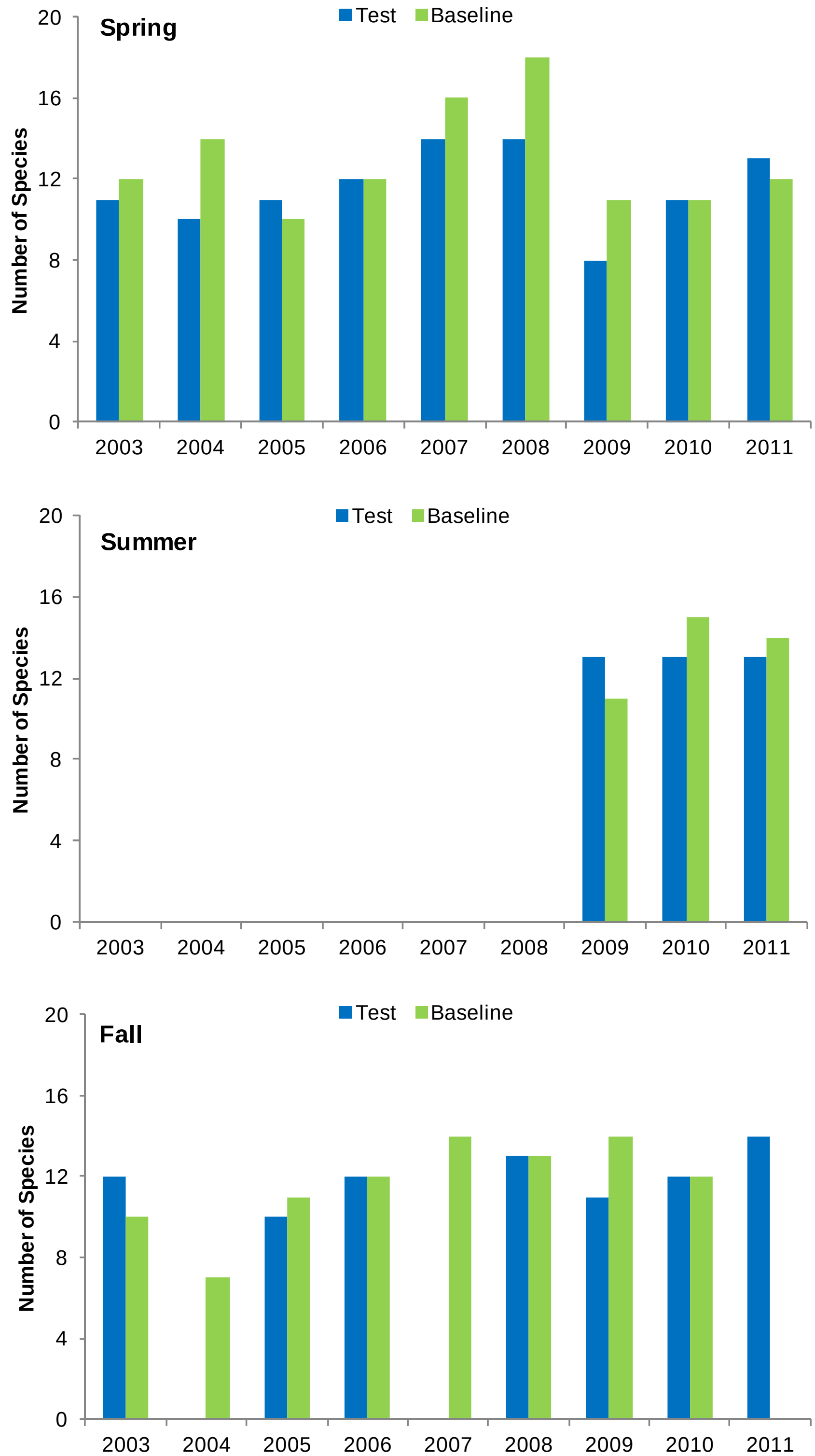


Figure 5.9-14 Comparison of the seasonal catch per unit effort (CPUE ± 1SD) of large-bodied KIR fish species between the *test* and *baseline* reaches of the Clearwater River, 2011.

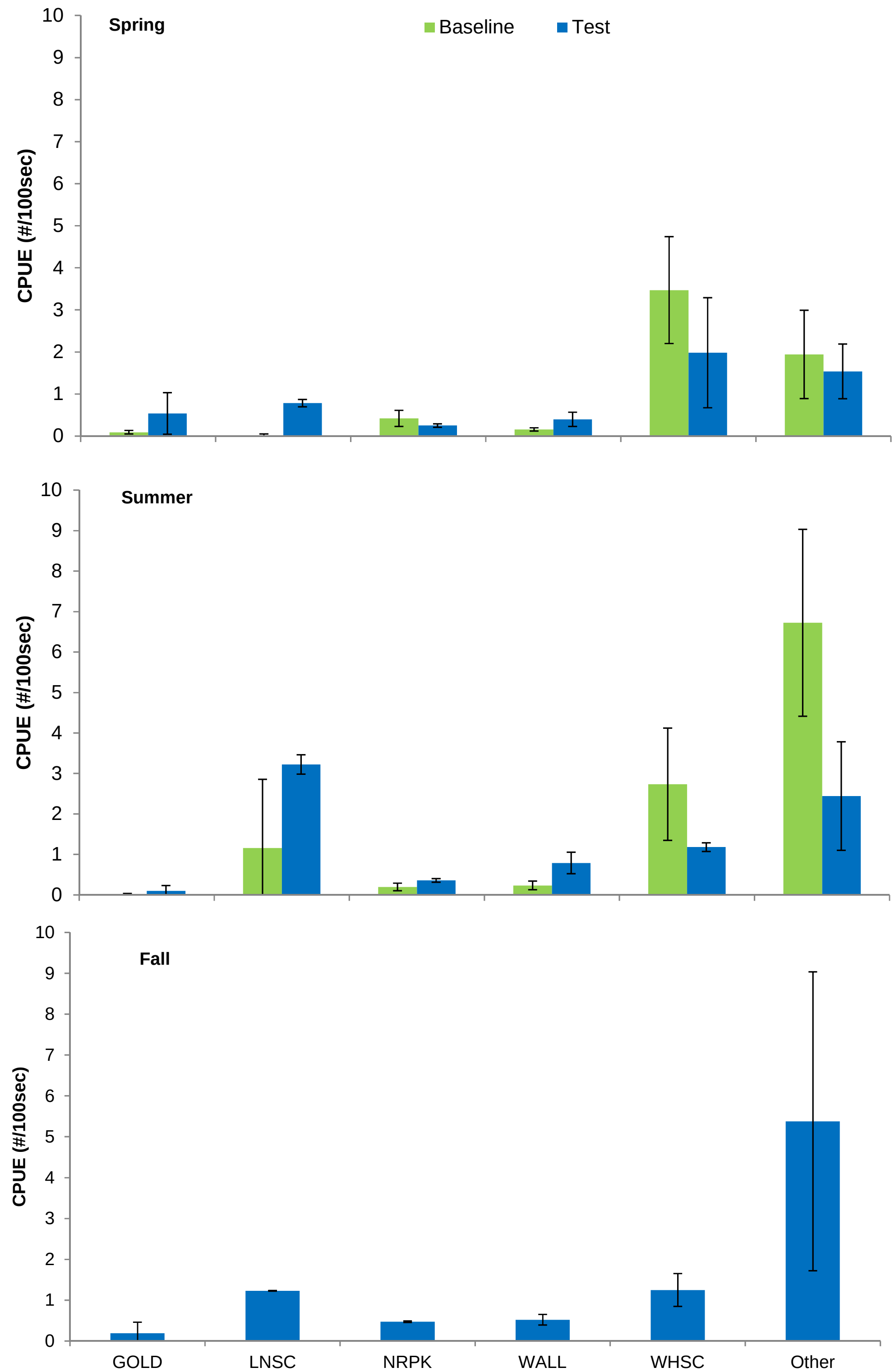
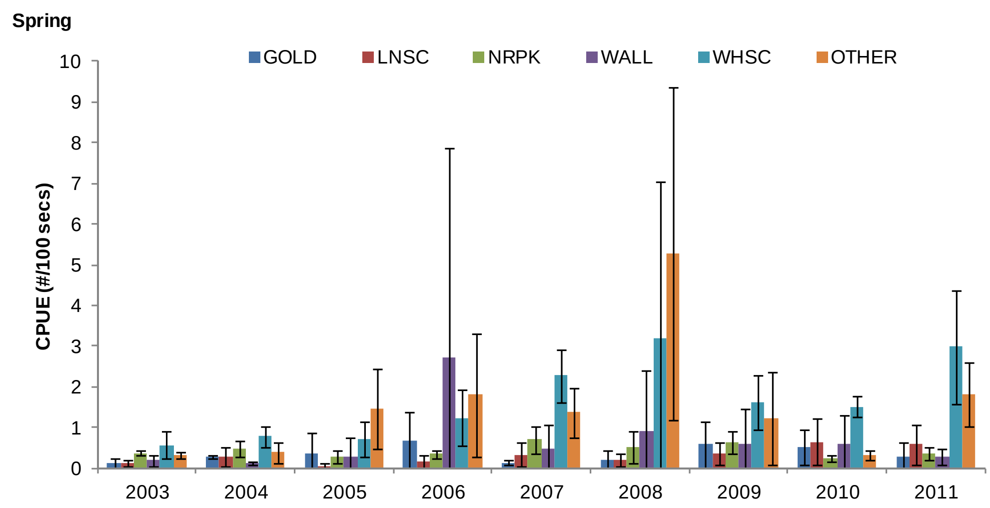
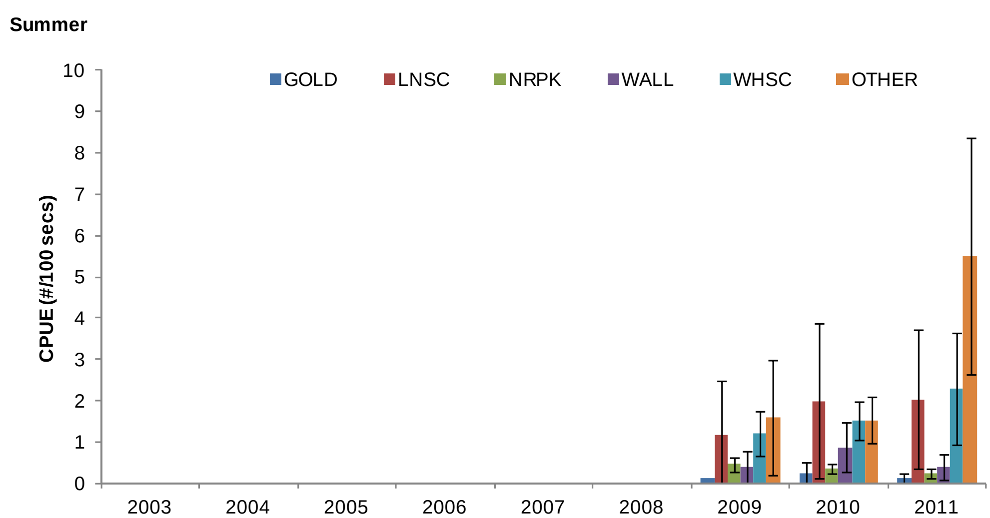


Figure 5.9-15 Seasonal catch per unit effort (CPUE ± 1SD) of large-bodied KIR fish species and other species in the Clearwater River, 2003 to 2011.





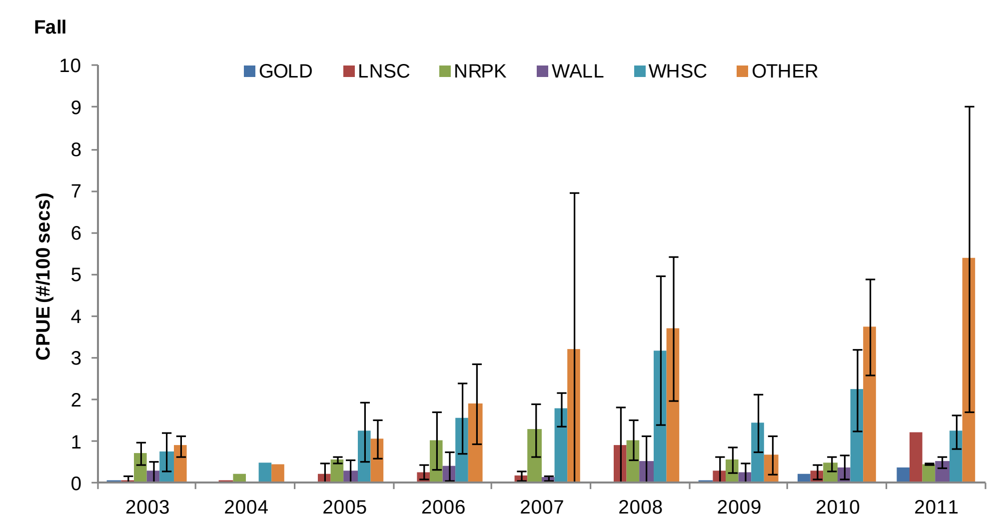
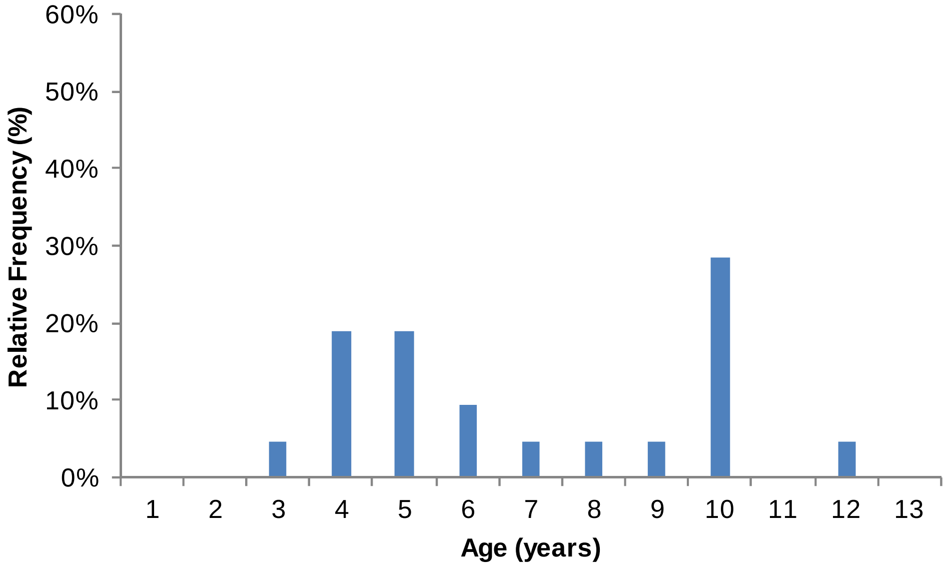


Figure 5.9-16 Relative age-frequency distributions and size-at-age relationships for goldeye in spring, summer, and fall, 2011.



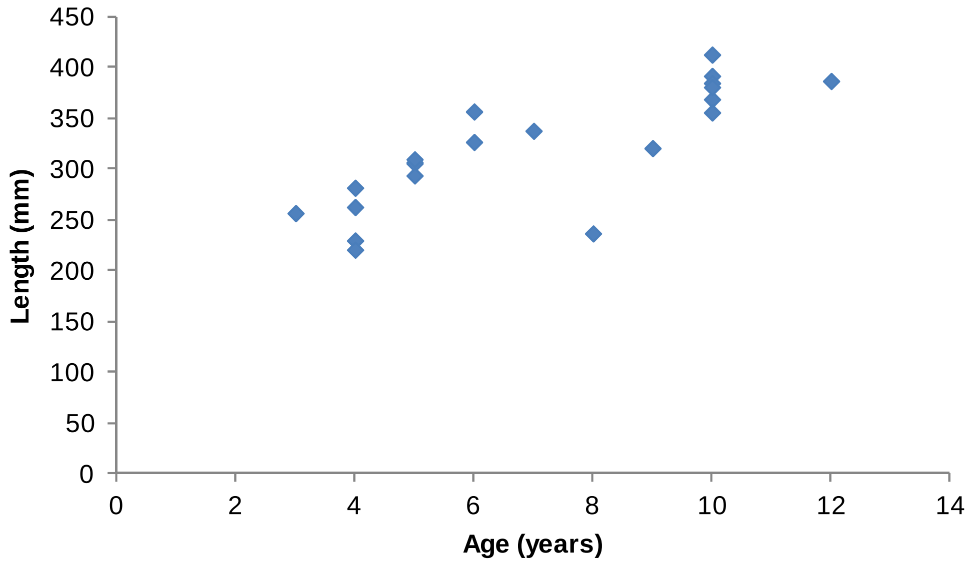
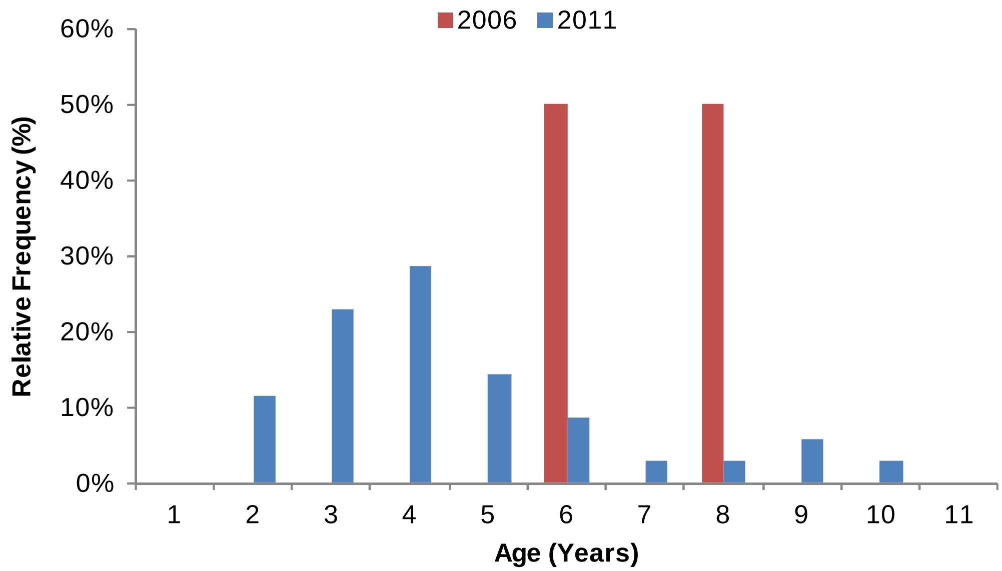


Figure 5.9-17 Relative age-frequency distributions and size-at-age relationships for longnose sucker in spring, summer, and fall, 2006 and 2011.



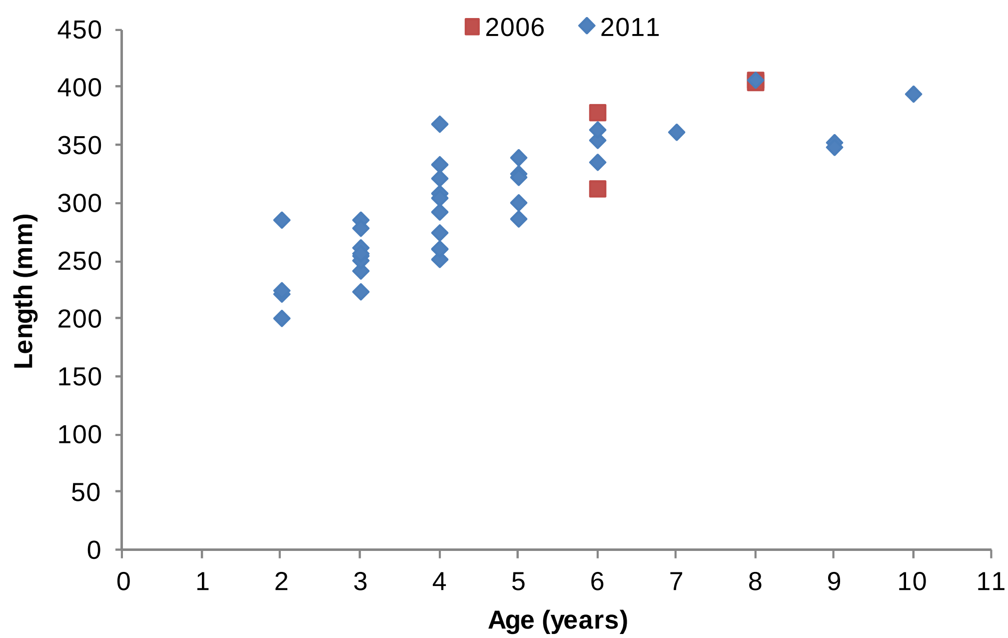


Figure 5.9-18 Relative age-frequency distributions and size-at-age relationships for northern pike in spring, summer, and fall, 2004 to 2011.

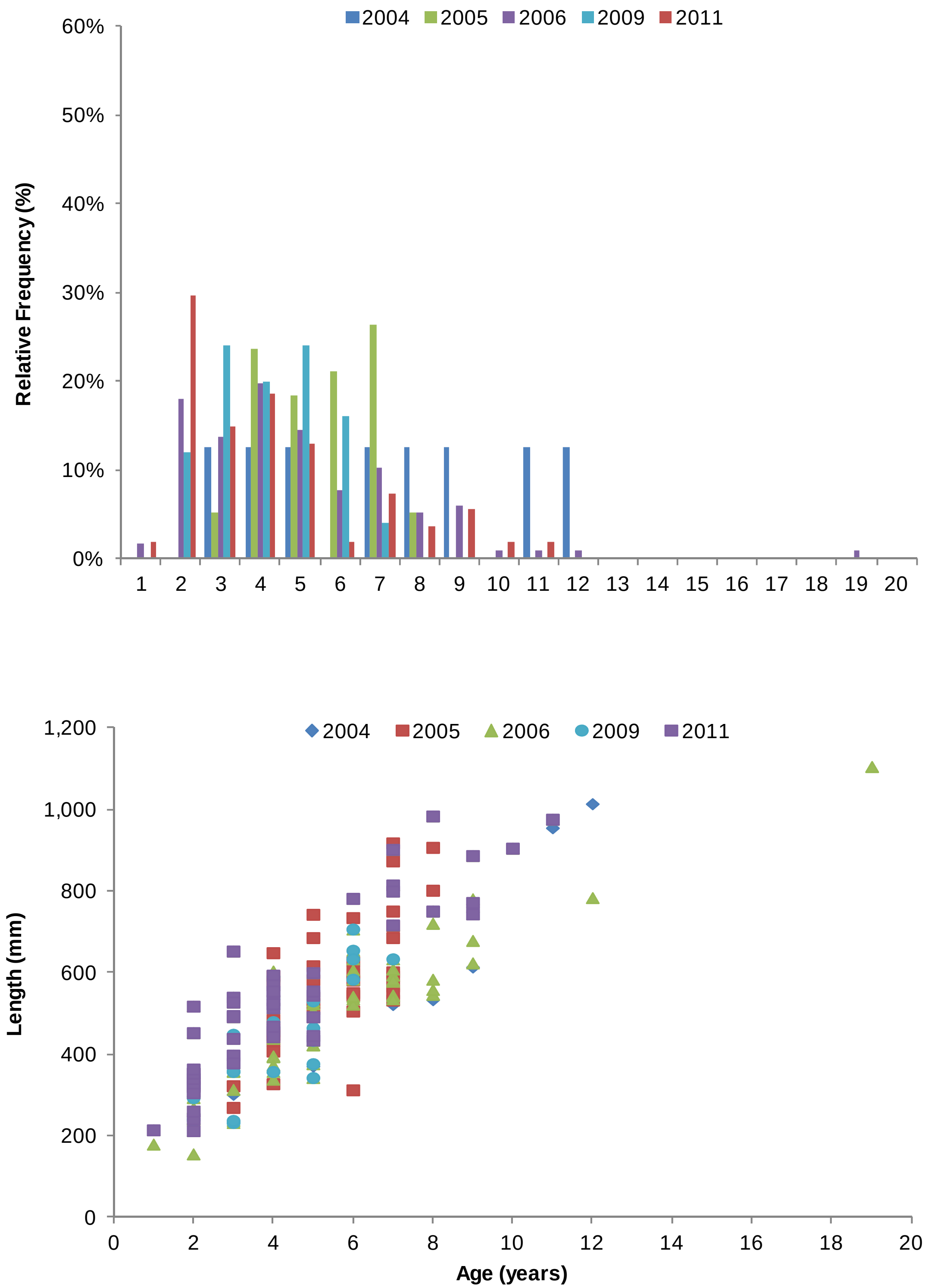
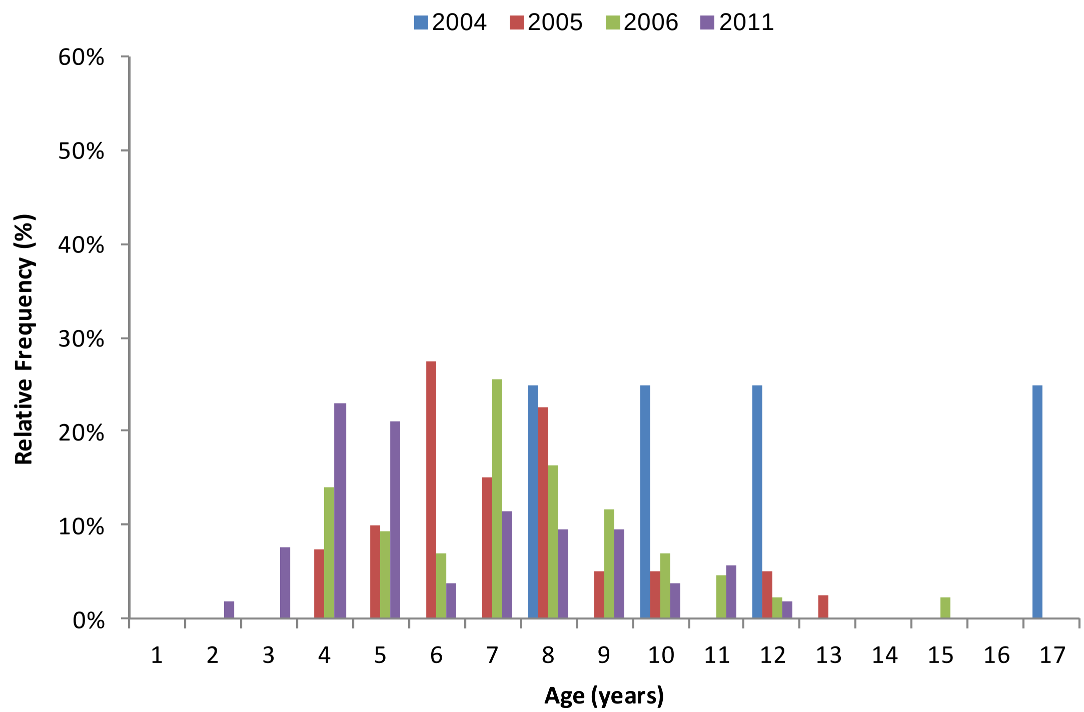


Figure 5.9-19 Relative age-frequency distributions and size-at-age relationships for walleye in spring, summer, and fall, 2004 to 2011.



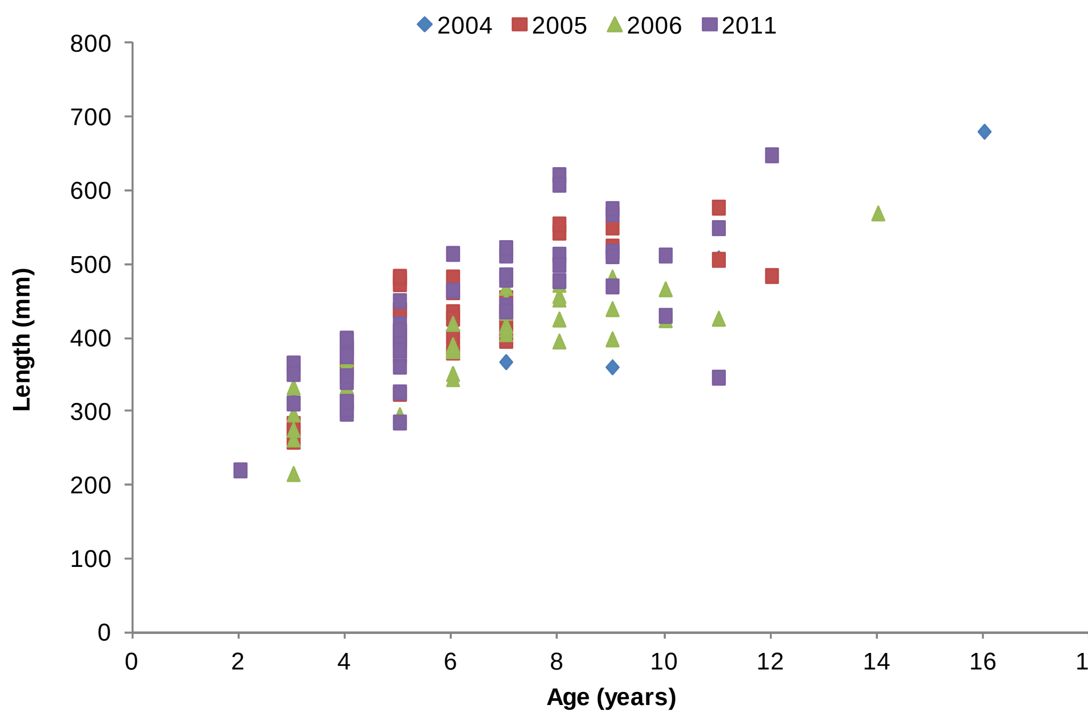


Figure 5.9-20 Relative age-frequency distributions and size-at-age relationships for white sucker in spring, summer, and fall, 2011.

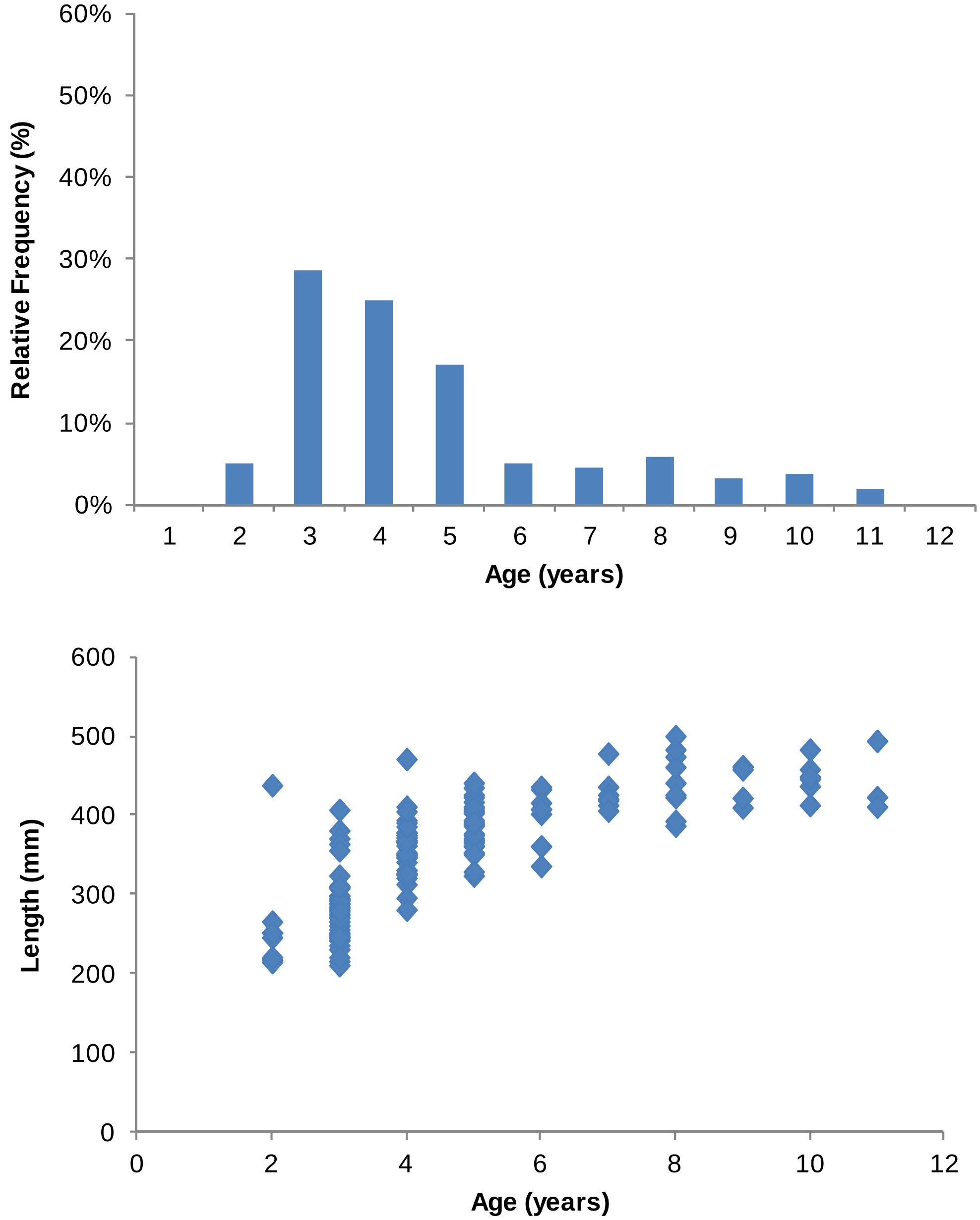
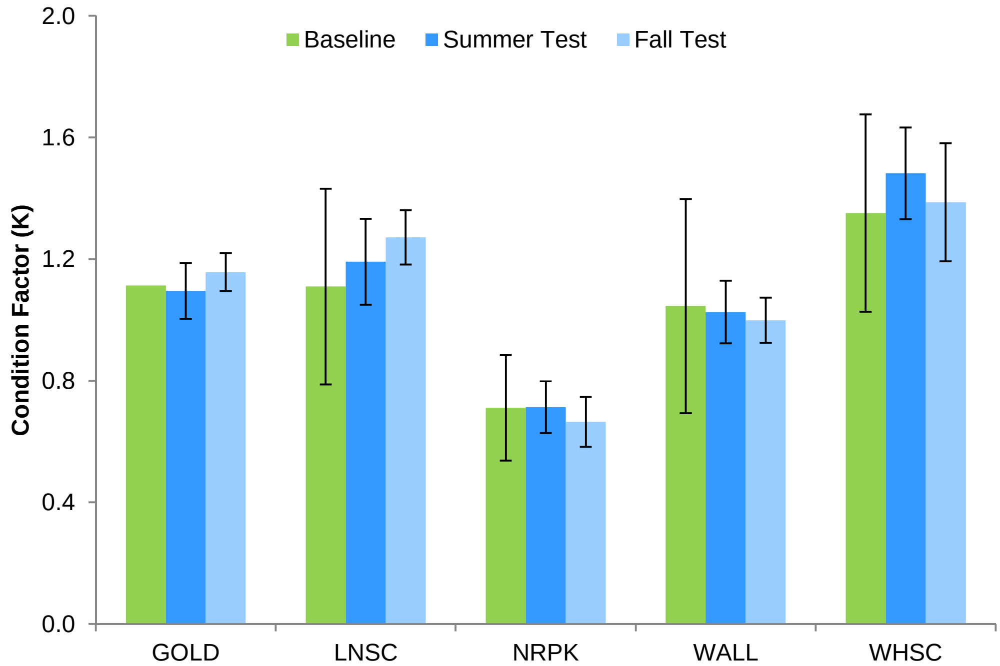


Figure 5.9-21 Condition factor (±2SD) for large-bodied KIR fish species captured in *test* and *baseline* areas of the Clearwater River during the summer and fall fish inventories, 2011.



Note: only one goldeye was captured in summer 2011.

Note: *baseline* reaches were not sampled in fall 2011; therefore, comparisons were made to the mean condition of fish captured in summer 2011 in *baseline* reaches CR1 and CR2

Figure 5.9-22 Condition factor (±2SD) for large-bodied KIR fish species captured in the Clearwater River, summer and fall 2003 to 2011.

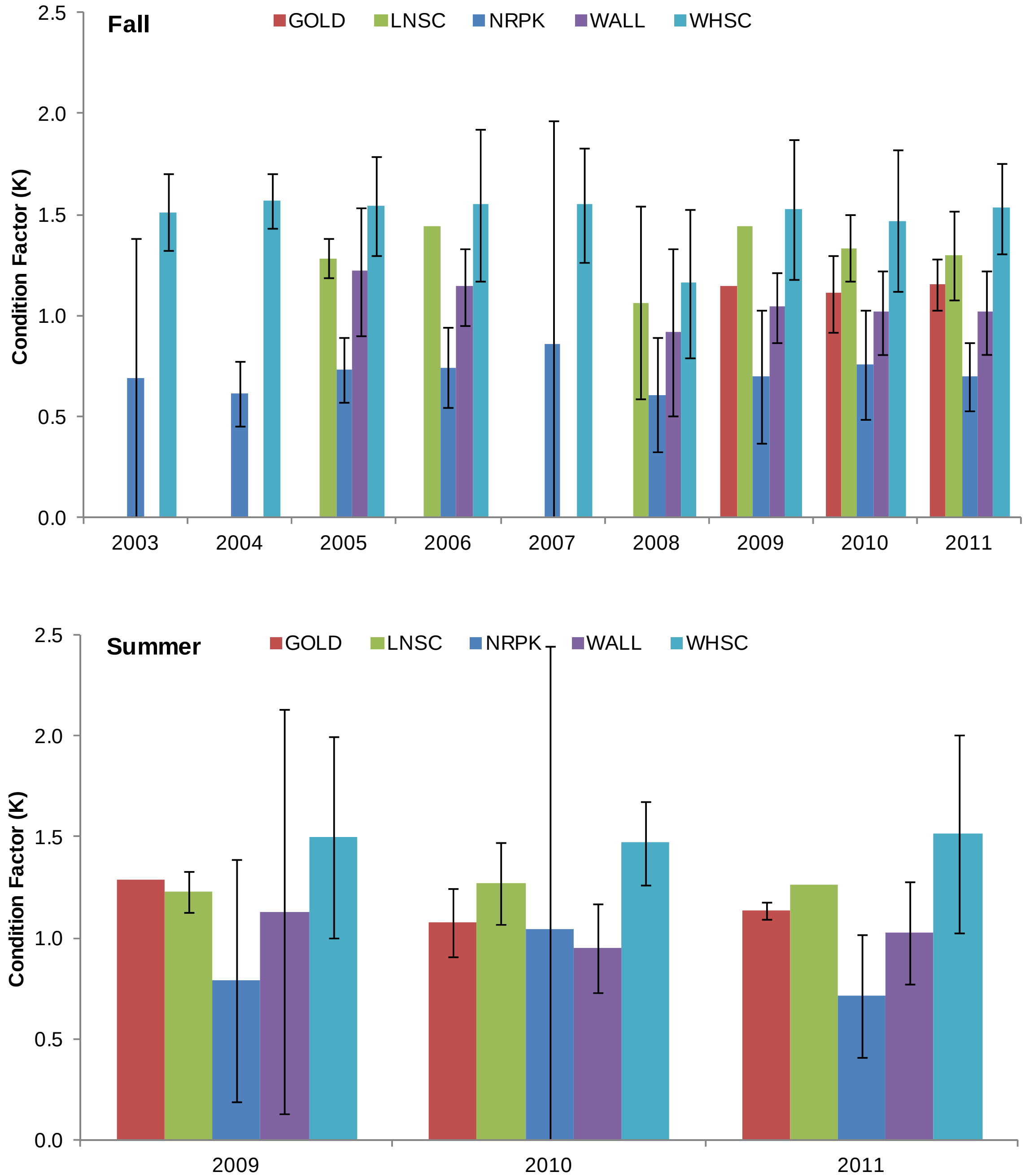


Table 5.9-19 Percent of total fish captured by species with external pathology (i.e., growth/lesion, deformity, and parasite), 2003 to 2011.

Year	% Growth/Lesion	% Deformity (body/fins)	% Parasites	Total # fish
1999	2.78	1.39	1.39	72
2003	0.17	0.51	0.17	584
2004	0.00	0.00	0.88	453
2005	0.19	0.00	0.00	1,081
2006	0.26	0.13	0.65	1,546
2007	0.38	0.19	0.48	1,043
2008	0.49	0.05	0.60	1,845
2009	0.27	0.13	1.67	1,493
2010	0.53	0.21	0.64	1,871
2011	0.19	0.14	0.24	2,077

Figure 5.9-23 Percent of total fish captured in the Clearwater River with external pathology, 2003 to 2011.

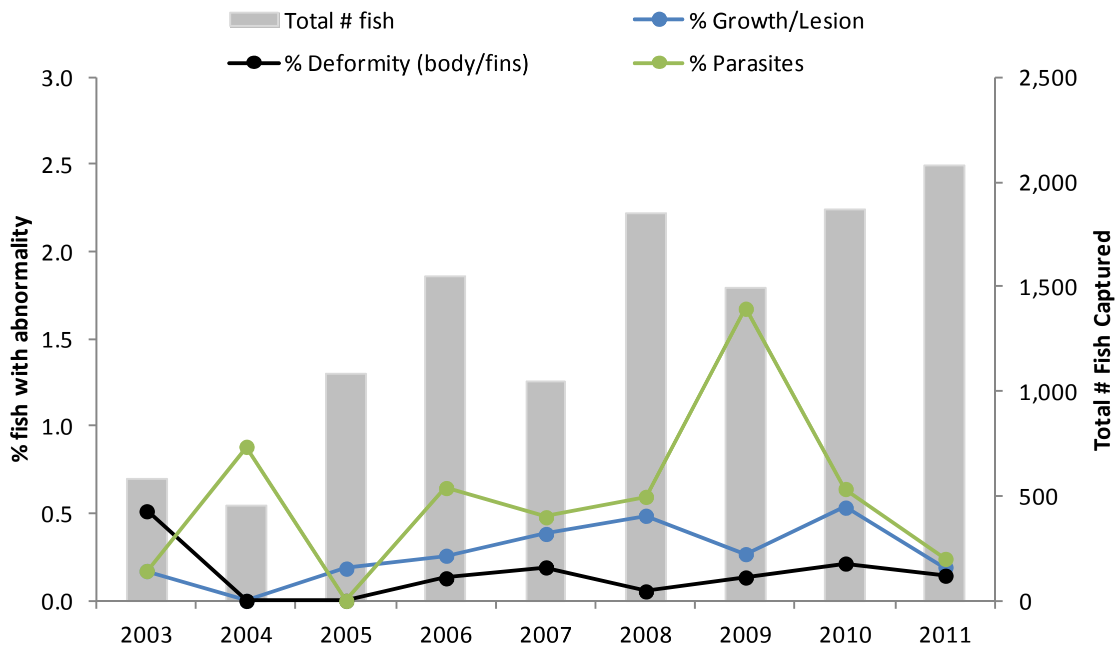


Table 5.9-20 Average habitat characteristics of fish assemblage monitoring locations of High Hills River.

Variable	Units	HHR-F1 Lower *Baseline* Reach of High Hills River
Sample date	-	Sept. 8, 2011
Habitat type	-	riffle/run
Maximum depth	m	0.59
Average bankfull channel width	m	19.8
Average wetted channel width	m	14.9
Substrate		
Dominant	-	coarse gravel
Subdominant	-	silt/clay
Instream cover		
Dominant	-	small and large woody debris
Subdominant	-	overhanging vegetation
Field water quality		
Dissolved oxygen	mg/L	8.8
Conductivity	µS/cm	245
pH	pH units	7.7
Water temperature	°C	13
Water velocity		
Left bank velocity	m/s	0.67
Left bank water depth	m	0.37
Centre of channel velocity	m/s	0.58
Centre of channel water depth	m	0.42
Right bank velocity	m/s	0.47
Right bank water depth	m	0.32
Riparian cover- understory (<5 m)		
Dominant	-	woody shrubs and saplings
Subdominant	-	overhanging vegetation

Table 5.9-21 Percent composition and mean CPUE of all fish species at *baseline* reach HHR-F1 in the High Hills River in 2011.

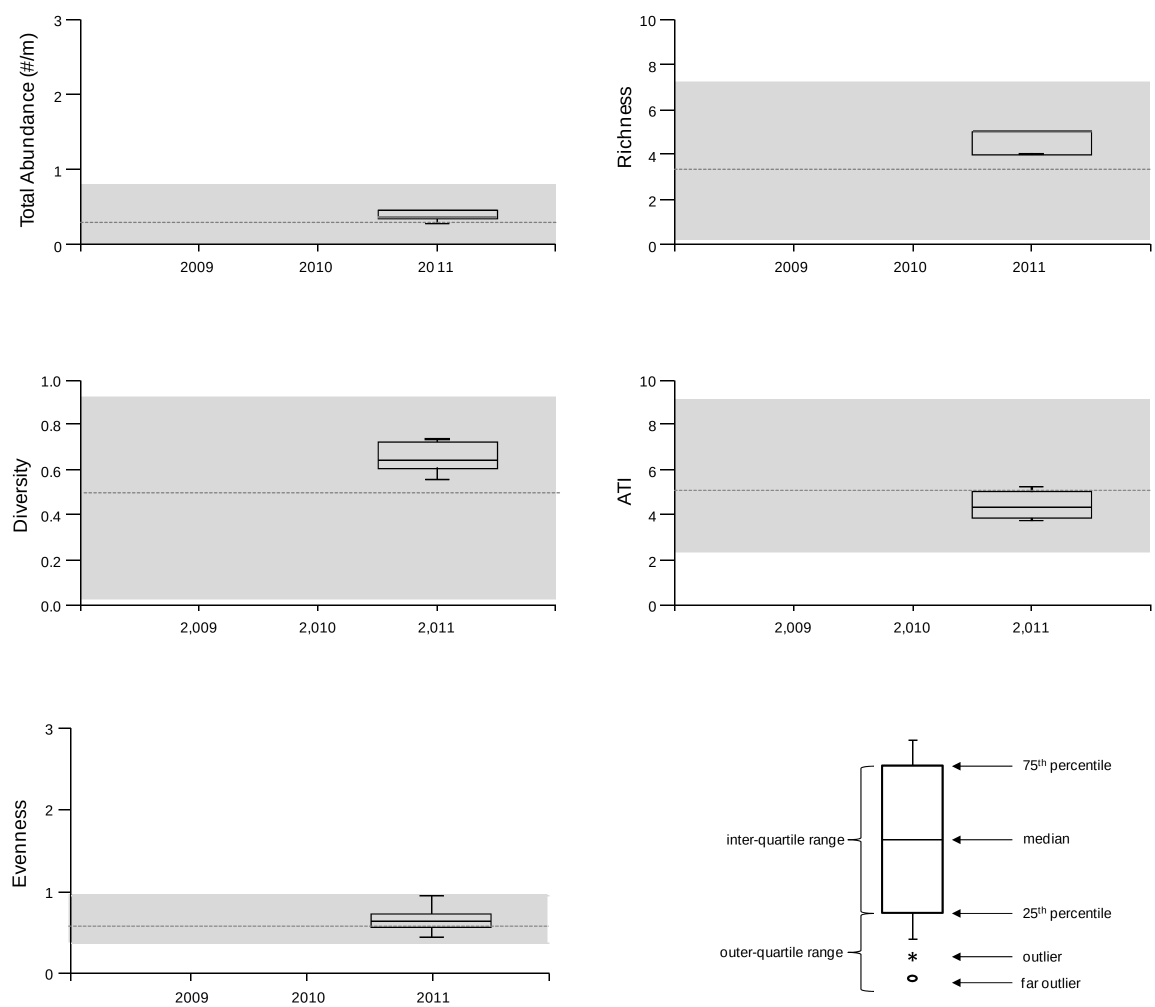
Common Name	Code	Total Species	Percent of Total Catch
Arctic grayling	ARGR	-	0
brook stickleback	BRST	-	0
burbot	BURB	-	0
fathead minnow	FTMN	-	0
finescale dace	FNDC	-	0
lake chub	LKCH	-	0
lake whitefish	LKWH	-	0
longnose dace	LNDC	8	8
longnose sucker	LNSC	22	22
northern pike	NRPK	-	0
northern redbelly dace	NRDC	-	0
pearl dace	PRDC	-	0
slimy sculpin	SLSC	47	47
spoonhead sculpin	SPSC	6	6
spottail shiner	SPSH	-	0
trout-perch	TRPR	-	0
walleye	WALL	-	0
white sucker	WHSC	17	17
yellow perch	YLPR	-	0
Total Count		100	100
Total Abundance (#/m)		0.40	-
Total Species Richness		5	5
Electrofishing effort (secs)		1,355	-
CPUE (#/100secs)		7.38	-

Table 5.9-22 Summary of fish assemblage measurement endpoints for *baseline* reach HHR-F1 in the High Hills River, 2011.

Reach	Year	Abundance		Richness			Diversity		Evenness		ATI	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HHR-F1	2011	0.40	0.08	5	5	0.55	0.65	0.08	0.66	0.19	4.44	0.67

SD = standard deviation across sub-reaches within a reach.

Figure 5.9-24 Box-plots showing variation in fish assemblage measurement endpoints in High Hills River in 2011.



Note: Regional *baseline* values reflect pooled results for all *baseline* reaches for abundance, richness, and diversity; *baseline* values for ATI are for all erosional *baseline* reaches.

5.10 HANGINGSTONE RIVER WATERSHED

Table 5.10-1 Summary of results for the Hangingstone River watershed.

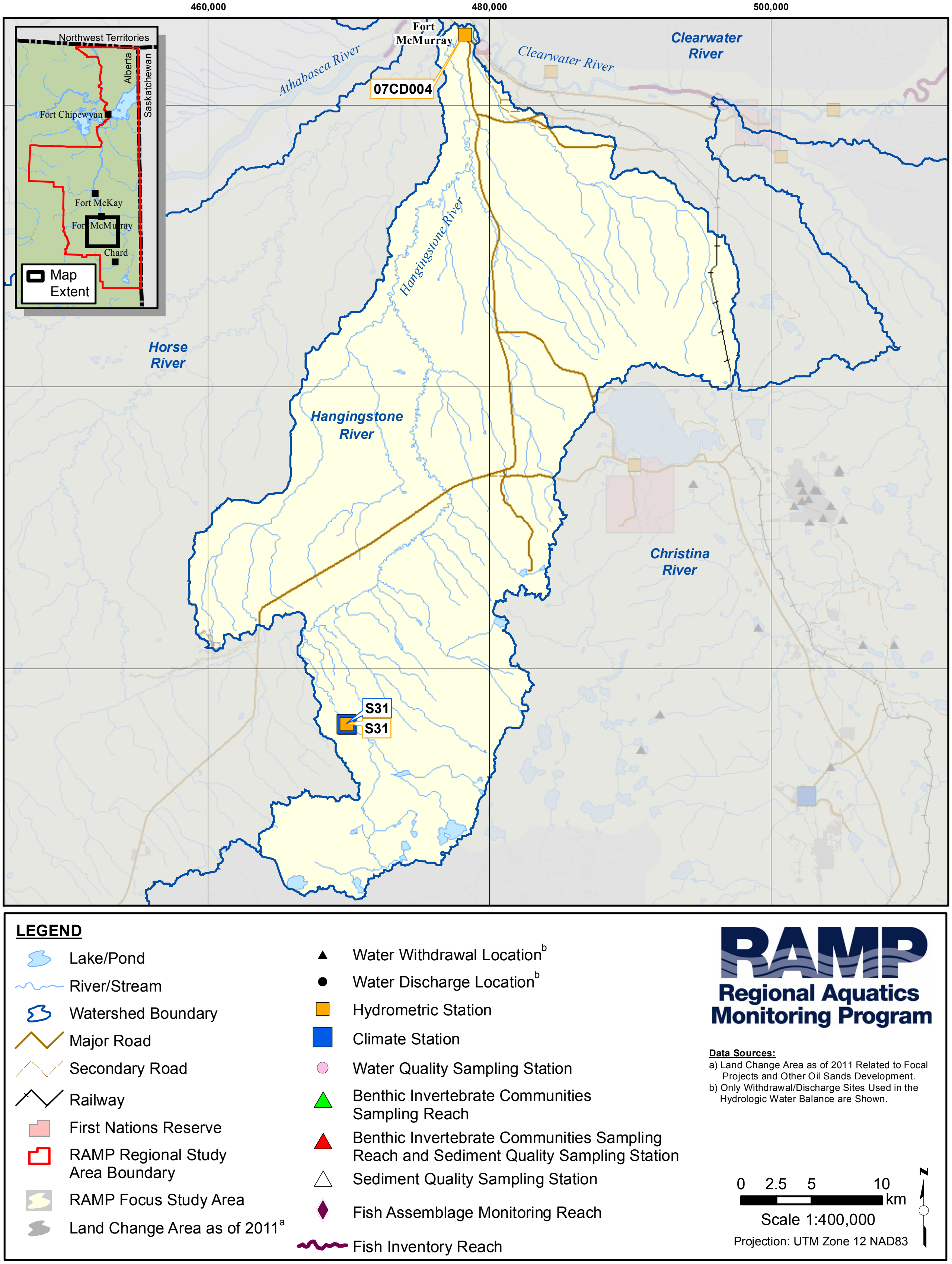
Hangingstone River	**Summary of 2011 Conditions**
Climate and Hydrology	
Criteria	**WSC 07CD004,** Hangingstone River at at Fort McMurray
Mean open-water season discharge	○
Mean winter discharge	not measured
Annual maximum daily discharge	○
Minimum open-water season discharge	○
Water Quality	
No Water Quality component activities conducted in 2011	
Benthic Invertebrate Communities and Sediment Quality	
No Benthic Invertebrate Communities and Sediment Quality component activities conducted in 2011	
Fish Populations	
No Fish Populations component activities conducted in 2011	

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 2011 Conditions

Approximately 0.05% (56 ha) of the Hangingstone River watershed had undergone land change as of 2011 from focal projects, with no change from 2010 (Table 2.5-2). Land change has occurred in a small area in the upper portion of the watershed related to the JACOS Hangingstone project.

Monitoring activities were conducted for the Climate and Hydrology component of RAMP in the Hangingstone River watershed in 2011. Table 5.10-1 is a summary of the 2011 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 2011 in the Hangingstone River watershed.

Hydrology The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge were 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **Negligible-Low**.

5.10.2 Hydrologic Conditions: 2011 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 68 million m^3. This value was 28% lower than the historical mean open-water runoff volume. Flows increased during freshet in April 2011, to a peak of 11.2 m^3/s on May 5. Daily flows recorded until this date were similar to the historical median flows. Flows then decreased to 0.85 m^3/s on June 15, which is slightly above the historical minimum flow recorded on this date. Flows increased following rainfall in late June and early July, to a peak of 40 m^3/s on July 11. This was the highest daily flow recorded in the seasonal (March to October) period, and slightly lower than both the historical maximum flow recorded on this date (52 m^3/s), and the historical mean maximum seasonal daily flow (42 m^3/s). Flows generally decreased until the end of the 2011 WY with flows in the historical lower quartile range. The seasonal minimum daily flow of 0.17 m^3/s recorded on March 5 was within 1% of the historical mean minimum seasonal daily flow (Figure 5.10-2).

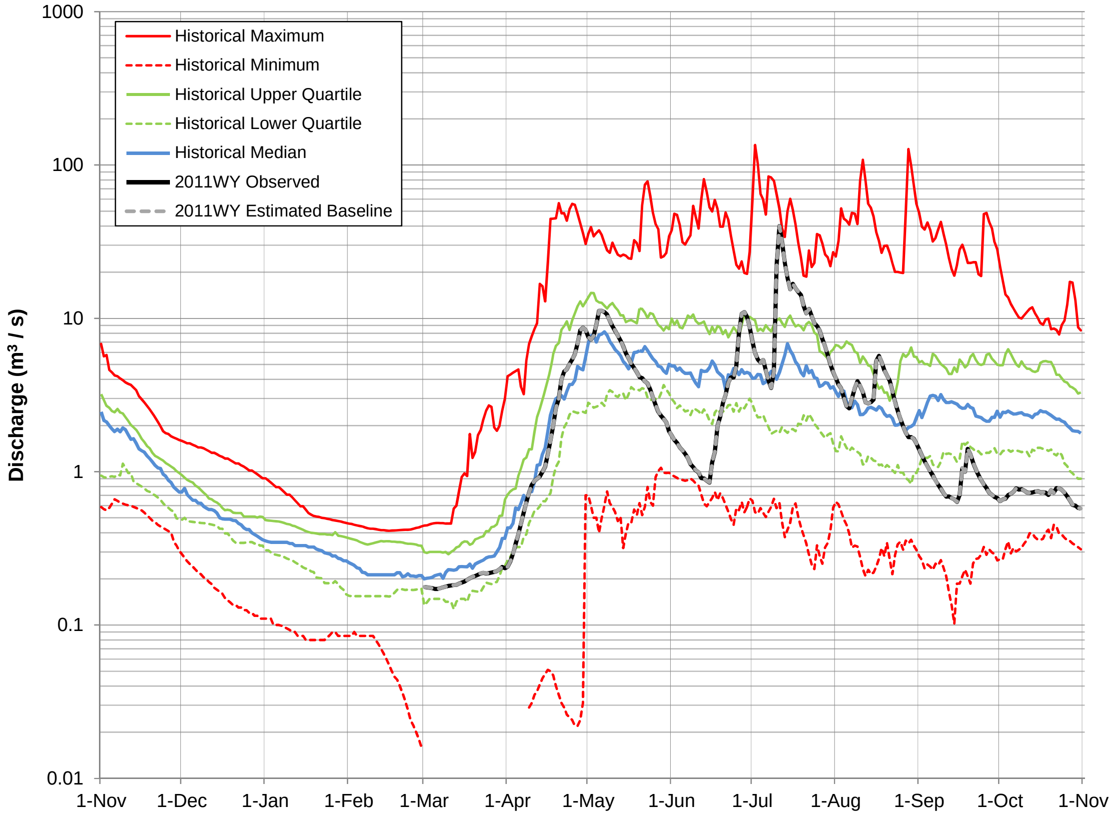
Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at WSC Station 07CD004, for March 1 to October 31, 2011 is provided in Table 5.10-2 and described as follows:

1. The closed-circuited land area from focal projects as of 2011 in the Hangingstone River watershed was 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 was estimated at 0.037 million m^3.

2. As of 2011, the area of land change in the Hangingstone watershed from focal projects that was not closed-circuited was 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 was estimated at 0.001 million m^3.

The estimated cumulative effect was a decrease in flow of 0.036 million m^3 to the Hangingstone River. The resulting observed *test* and estimated *baseline* hydrographs are presented in Figure 5.10-2. The calculated mean open-water period discharge, annual maximum daily discharge, and open-water minimum daily discharge were 0.05% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.10-3). These differences were classified as **Negligible-Low** (Table 5.10-1).

Figure 5.10-2 The observed (*test*) hydrograph and estimated *baseline* hydrograph for the Hangingstone River in the 2012 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on Hangingstone River at Fort McMurray, WSC Station 07CD004, provisional data for March 1 to October 31, 2011. The upstream drainage area of WSC Station 07CD004 is 962 km^2, which is 10% smaller than the size of the entire Hangingstone River watershed (1,066 km^2). Historical values from March 1 to October 31 calculated for the period from 1965 to 2010, 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, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**75.61**	**Observed discharge, obtained from Hangingstone River at Fort McMurray, WSC Station 07CD004**
Closed-circuited area water loss from the observed hydrograph	-0.037	Estimated 0.47 km^2 of Hangingstone River watershed closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.001	Estimated 0.09 km^2 of Hangingstone River watershed with land change from focal projects as of 2011 that is not closed-circuited (Table 2.5-1)
Water withdrawals from the Hangingstone River watershed from focal projects	0	Assumed
Water releases into the Hangingstone River watershed from focal projects	0	Assumed
Diversions into or out of the watershed	0	Assumed
The difference between observed and estimated hydrographs on tributary streams	0	No focal projects on tributaries of Hangingstone River not accounted for by figures contained in this table
Estimated *baseline* hydrograph (total discharge)	**75.65**	**Estimated discharge at Hangingstone River at Fort McMurray, WSC Station 07CD004**
Incremental flow (change in total discharge)	-0.036	Total discharge from observed *test* hydrograph less total discharge of estimated *baseline* hydrograph
Incremental flow (% of total discharge)	**-0.05%**	**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, 2011 for Hangingstone River at Fort McMurray, WSC Station 07CD004.

Table 5.10-3 Estimated change in hydrologic measurement endpoints for the Hangingstone River watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water period discharge	4.28	4.28	-0.05%
Mean winter discharge	not measured	not measured	not measured
Annual maximum daily discharge	40.02	40.00	-0.05%
Open-water period minimum daily discharge	0.58	0.58	-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 Hangingstone River at Fort McMurray, WSC Station 07CD004.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are 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 2011 Conditions													
	Lakes				*Rivers/Creeks*									
Climate and Hydrology														
Criteria	**S25** Susan Lake Outlet	**L3** Isadore's Lake			**S6** Mills Creek at Highway 63	**S11** Poplar Creek at Highway 63	**S12** Fort Creek at Highway 63							
Mean open-water season discharge	not measured	not measured			🟤	🟡	🟠							
Mean winter discharge	not measured	not measured			🟤	not measured	not measured							
Annual maximum daily discharge	not measured	not measured			🟤	🟡	🟠							
Minimum open-water season discharge	not measured	not measured			🟤	🟡	🟠							
Water Quality														
Criteria	no station sampled	**ISL-1** Isadore's Lake	**SHL-1** Shipyard Lake	**MIC-1** Mills Creek	**MIC-1** Mills Creek	**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	**BIC-1** Big Creek at the mouth River	**PIR-1** Pierre River at the mouth River	**RCC-1** Red Clay Creek at the mouth River	**EYC-1** Eymundson Creek at the mouth River
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	no reach sampled	no reach sampled	**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	no reach sampled	no reach sampled	no reach sampled
Benthic Invertebrate Communities		🟡	🟡			🟠	🟤		n/a					
Sediment Quality Index		n/a	n/a			🟡	🟡		🟡					
Fish Populations														
Criteria	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled	**POC-F1** Poplar Creek lower reach	**FOC-F1** Fort Creek at the mouth	no reach sampled	**BER-F2** Beaver River upper reach	no reach sampled	no reach sampled	no reach sampled	no reach sampled	no reach sampled
Fish Assemblages						🟡	🟡		n/a					

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 or regional *baseline* conditions. The WQI/SQI were 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.

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 3.3.1.10 for a detailed description of the classification methodology.

Sediment Quality: Classification based on adaptation of CCME sediment quality index; scores classified as follows: 80 to 100: Negligible-Low difference from regional *baseline* conditions; 60 to 80: Moderate difference from regional *baseline* conditions; Less than 60: High difference from regional *baseline* conditions.

Fish Populations: Classification based on differences in measurement endpoints from the range of variation in regional *baseline* conditions; see Section 3.2.4.3 for a description of the classification methodology.

Figure 5.11-1 Miscellaneous aquatic systems.

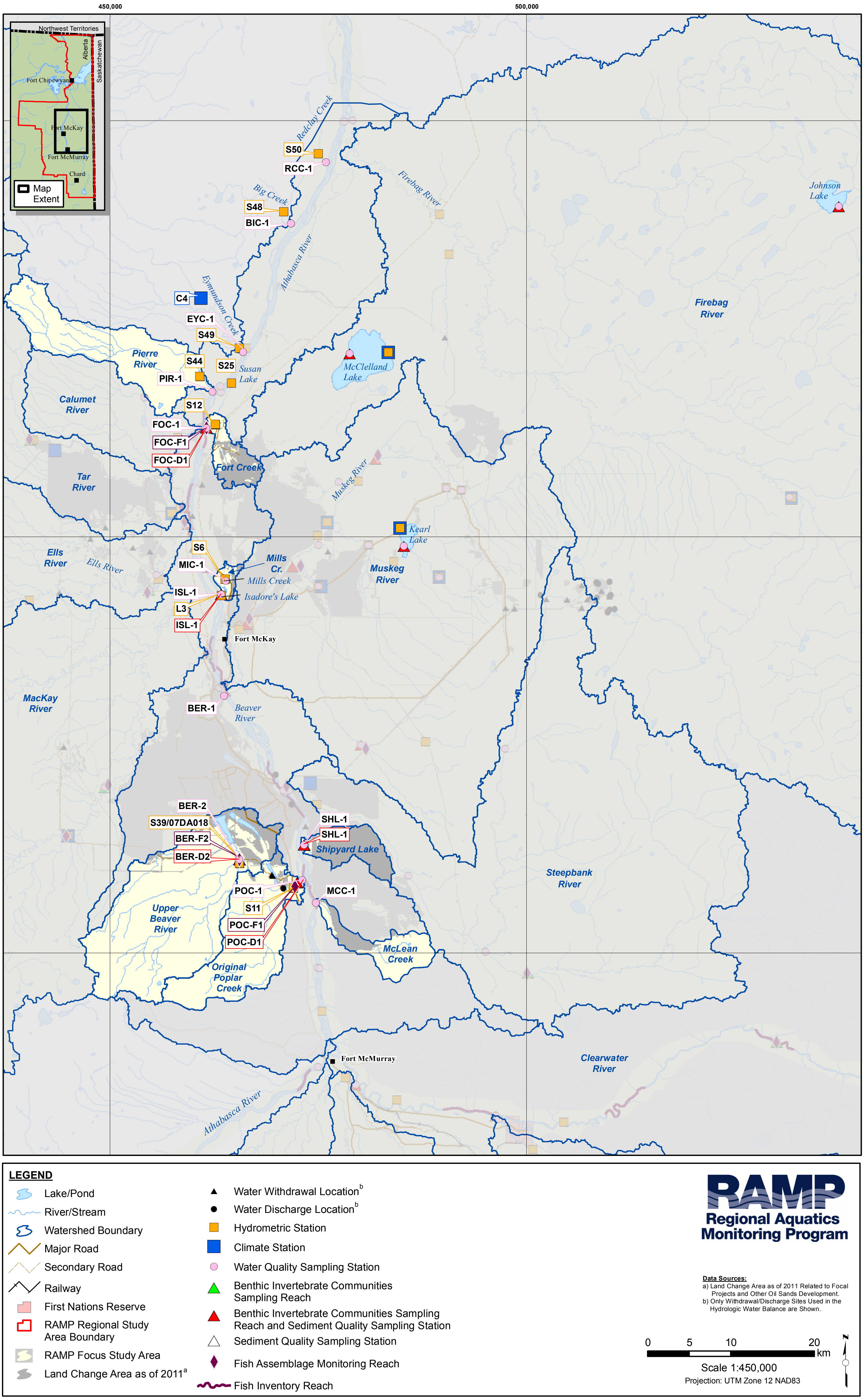


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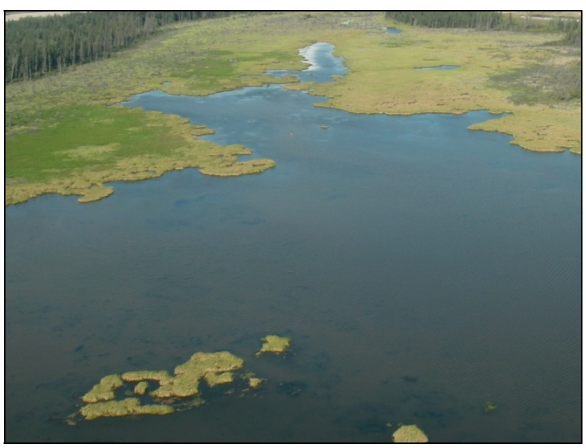
Figure 5.11-2 Representative monitoring stations of miscellaneous aquatic systems, fall 2011.

Hydrology Station L3: Isadore's Lake

Hydrology Station S50: Red Clay Creek

Water Quality Station EYC-1 (Eymundson Creek): Left Downstream Bank

Hydrology Station S6: Mills Creek



Water Quality Station SHL-1 (Shipyard Lake): aerial view

Water Quality Station PIR-1 (Pierre River): Left Downstream Bank

5.11.1 Summary of 2011 Conditions

This section includes 2011 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 2011 comprises approximately 3.6% (492 ha) of the original Poplar Creek watershed, 62.6% (1,999 ha) of the Fort Creek watershed, 25.2% (1,187 ha) of the McLean Creek watershed, approximately 32.9% (293 ha) of the Mills Creek watershed, 93% (3,754 ha) of the original watershed draining into Shipyard Lake[1], and approximately 9.7% (2,789 ha) of the Upper Beaver watershed (Table 2.5-2); and
- Pierre River, Red Clay Creek, Big Creek, Eymundson Creek, and the Susan Lake outlet are designated as *baseline* for 2011.

Table 5.11-1 is a summary of the 2011 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 2011. Figure 5.11-2 contains 2011 photos of various 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 for Mills Creek were 37% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. These differences were classified as **High**.

The water level in Isadore's Lake increased in late June and early July in response to rainfall events and backwater effects from the Athabasca River to the maximum recorded lake level over the 12-year record period at Isadore's Lake. Following the increase in lake levels in July, water levels receded to near lower quartile levels by the end of the 2011 WY.

Differences in water quality in fall 2011 between Mills Creek and regional *baseline* fall conditions were classified as **Moderate**, likely due to relatively high concentrations of many ions and other dissolved species that exceeded the 95th percentile of regional *baseline* concentrations. The ionic compositions of *test* stations ISL-1 and MIC-1 were similar, with an increase in bicarbonate relative to previous years.

Differences in the benthic invertebrate community at *test* station ISL-1 were classified as **Negligible-Low** because there were no significant time trends in any of the benthic invertebrate community measurement endpoints. In addition, diversity was the only measurement endpoint that was outside (below) the range of previously-measured values. Historically, Isadore's Lake has had a unique benthic invertebrate community compared to other lakes in the region (e.g., McClelland, Kearl and Shipyard lakes), with low diversity and a high abundance of nematodes. While there has been very little negative change over time, the benthic invertebrate community in Isadore's Lake has been representative of a degraded system since sampling was initiated in 2006.

Shipyard Lake Concentrations of most water quality measurement endpoints in fall 2011 at *test* station SHL-1 were within previously-measured concentrations with only a few exceptions (i.e., sulphate and total strontium). The ionic composition of water at *test* station SHL-1 continued to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, perhaps due to reduced surface-water inflow and

[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.

increased groundwater influence in the lake associated with focal projects in the upper portion of the Shipyard Lake watershed (the upper 93% of the Shipyard Lake watershed has been disturbed). The WQI was not calculated for lakes in 2011 due to potential ecological differences in regional water quality characteristics between lakes and rivers and the limited *baseline* lake data.

Differences in the benthic invertebrate community at *test* station SHL-1 in fall 2011 were 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 lake contained a number of fully aquatic forms including amphipods, clams and snails, indicating generally good water and sediment quality.

Poplar Creek and Beaver River The calculated mean open-water discharge (May to October) was 4.9% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph of Poplar Creek. This difference was classified as **Negligible-Low**. The annual maximum daily discharge was 1.2% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**. The open-water minimum daily discharge was 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low**.

Concentrations of several water quality measurement endpoints, primarily ions and other dissolved species, were historically high and/or exceeded regional *baseline* concentrations at *test* station BER-1 (Beaver River), resulting in a **Moderate** difference from regional *baseline* conditions. Although concentrations of several measurement endpoints were historically high at *test* station POC-1 and *baseline* station BER-2, water quality was generally similar to regional *baseline* conditions, with differences classified as **Negligible-Low**.

Differences in measurement endpoints of benthic invertebrate communities at *test* reach POC-Dl (Poplar Creek) were classified as **Moderate** because of the significant difference in percent EPT and CA Axis scores compared to *baseline* reach BER-D2, implying a negative change in the benthic invertebrate community. The benthic invertebrate community at *test* reach POC-D1 was generally in good condition, reflected by low relative abundance of tubificid worms and higher relative abundance of fingernail clams; however, the low relative abundance of mayflies and caddisflies, and absence of stoneflies potentially indicated some level of disturbance.

Differences in sediment quality observed in fall 2011 at *test* station POC-D1 and *baseline* station BER-D2 compared to regional *baseline* conditions were classified as **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within the range or lower than previously-measured concentrations at both stations.

Differences in measurement endpoints for fish assemblages between *test* reach POC-F1 and regional *baseline* conditions were classified as **Negligible-Low** because the lower assemblage tolerance index (ATI) value in fall 2011 compared to 2009 did not imply a negative change in the fish assemblage.

McLean Creek Concentrations of water quality measurement endpoints at *test* station MCC-1 were often higher than previously-measured maximum concentrations and higher than regional *baseline* concentrations in fall 2011. Many ions and dissolved species of water quality measurement endpoints caused a shift in ionic balance, as well as a **Moderate** difference from regional *baseline* concentrations.

Fort Creek The calculated mean open-water period (May to October) discharge volume was 11.3% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Moderate**. In addition to changes in flow volume, variability in daily flow had also increased due to focal project activity in the watershed.

Relatively high concentrations of several water quality measurement endpoints were observed in fall 2011 at FOC-1, but these were within the range of previously-measured concentrations and within regional *baseline* water quality conditions. Differences in water quality in fall 2011 between *test* station FOC-1 and regional *baseline* conditions were classified as **Negligible-Low**. Only total iron exceeded relevant water quality guidelines. A large increase in the concentration of sulphate have been observed at *test* station FOC-1 since 2008 (although a slight decrease was observed in 2011), which appeared to have occurred in the absence of other apparent changes in ionic composition.

Differences in measurement endpoints of benthic invertebrate communities at *test* reach FOC-Dl were classified as **High** because decreases in abundance, richness, diversity and evenness were significant and abundance, 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 in the *test* period suggesting degradation of habitat quality at *test* reach FOC-D1.

Differences in measurement endpoints for fish assemblages between *test* reach FOC-F1 and regional *baseline* conditions were classified as **Negligible-Low** given that median values of all measurement endpoints were within the regional range of variation of *baseline* reaches.

Big Creek, Pierre River, Red Clay Creek, and Eymundson Creek Differences in water quality in fall 2011 between *baseline* stations BIC-1 (Big Creek), PIR-1 (Pierre River), and RCC-1 (Red Clay Creek) and regional *baseline* fall conditions were classified as **Negligible-Low**. Differences in water quality were classified as **Moderate** at *baseline* station EYC-1 (Eymundson Creek), where concentrations of several water quality measurement endpoints exceeded water quality guidelines or regional *baseline* concentrations. *Baseline* station EYC-1 also differed from the other *baseline* stations (BIC-1, PIR-1 and RCC-1) in its ion balance, with a higher concentration of sulphate and less bicarbonate, which may suggest greater groundwater influence at this station.

5.11.2 Mills Creek and Isadore's Lake

Monitoring was conducted in 2011 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: 2011 Water Year

RAMP Station S6, Mills Creek at Highway 63 Continuous hydrometric data during the open-water season (May to October) have been collected at the RAMP Station S6 from 1997 to 2011, with annual data collected from 2006 to 2011. In the 2011 water year (WY), the annual and open-water runoff volumes were 0.45 million m^3 and 0.22 million m^3, respectively. The 2011 WY annual runoff volume was 49% lower than the historical mean annual runoff, and the 2011 WY open-water runoff volume was 71% lower than the historical mean open-water runoff. Flows decreased steadily from November 2010 to March 2011, and were generally similar to historical median flows recorded during this period (Figure 5.11-3). Flows increased in mid-April, during the freshet to a peak open-water flow of 0.064 m^3/s recorded on May 6. This flow was 64% lower than the historical mean maximum daily flow in the open-water period. Following the peak flow, daily flows decreased sharply to late June, and all daily flows from June 5 to July 20 were below historical minimum flows. Rainfall in late June and early July increased flows to historical median values, but flows decreased again, and all recorded flows from August 25 to October 27 were below historical minimum values. The minimum open-water flow of 0.01 m^3/s recorded on September 30 was 66% lower than the historical mean 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 2011 in the Mills Creek watershed is estimated to be 2.4 km^2 (Table 2.5-1). The loss of flow to Mills Creek that would have otherwise occurred from this land area was estimated at 0.28 million m^3.

2. As of 2011, the area of land change in the Mills Creek watershed from focal projects that was not closed-circuited was estimated to be 0.6 km^2 (Table 2.5-1). The increase in flow to Mills Creek that would not have otherwise occurred was estimated at 0.01 million m^3.

The estimated cumulative effect of land change was a loss of flow of 0.27 million m^3 to Mills Creek. The resulting observed *test* 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 were 37% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.11-3). These differences were 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 2011 WY, lake levels at Isadore's Lake were consistently above historical median levels from November 2010 to mid-February 2011, and occasionally exceeded historical maximum values in January and February (Figure 5.11-4). Lake levels slightly increased in April, during the spring freshet, and then decreased until mid-June. Lake levels increased in late June and early July in response to rainfall events. A large, rapid increase of 64 cm in lake level was recorded from July 12 to 14, due to backwater effects from the Athabasca River, which is located close to the outlet of Isadore's Lake. As measured at WSC Station 07DA001, water levels in the Athabasca River increased by approximately 2.5 m during these dates, in response to a significant runoff event within the upper Athabasca watershed upstream of the RAMP FSA (Section 4.2.1). The peak lake level of 233.5 m on July 14 was the maximum recorded lake level over the 12-year record period at Isadore's Lake. Following July 14, lake levels receded to near lower quartile levels by the end of the 2011WY.

5.11.2.2 Water Quality

In fall 2011, 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 were 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 chloride, sodium, total boron and total strontium at *test* station ISL-1 (2000, 2001, 2004 to 2011); and
- An increasing concentration of total dissolved solids and a decreasing concentration of sulphate at *test* station MIC-1.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within the range of historical concentrations in fall 2011 at *test* station ISL-1 with the exception of (Table 5.11-4):

- magnesium, with a concentration that was lower than the previously-measured minimum concentration; and
- total boron and total strontium, with concentrations that exceeded previously-measured maximum concentrations.

Given only one previous year of data exists for *test* station MIC-1, all observations in fall 2011 represent historical maxima or minima concentrations. Water quality measurement endpoints at *test* station MIC-1 were similar between fall 2010 and 2011 (Table 5.11-5).

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 of water in fall 2010 and 2011 at *test* station MIC-1 was consistent with that of *test* station ISL-1, with a slightly lower relative concentration of magnesium (Figure 5.11-5). However, both stations were more dominant in bicarbonate in fall 2011. The consistent ionic composition between Mills Creek and Isadore's Lake supports the hypothesis that flows from Mills Creek have been responsible for determining the ion composition of Isadore's Lake in recent years.

Comparison of 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 2011 (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 2011 (Table 5.11-6):

- sulphide total Kjeldahl nitrogen, total phenols and total phosphorous at *test* station ISL-1; and
- sulphate and total iron at *test* station MIC-1.

2011 Results Relative to Regional *Baseline* Concentrations In fall 2011, 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:

- calcium, chloride, magnesium, potassium, sulphate, total dissolved solids, total strontium, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations; and
- dissolved phosphorus, total mercury, total nitrogen, 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; however, water quality in the lake was generally similar to *test* station MIC-1, and most exceedances of regional *baseline* concentrations would similarly apply to Isadore's Lake (Figure 5.11-7).

Water Quality Index The WQI value for Mills Creek in fall 2011 was 69.7, indicating a **Moderate** difference in water quality compared to regional *baseline* conditions (Table 5.11-7). This WQI value was lower than the fall 2010 WQI value of 84.1, which indicated a **Negligible-Low** difference in water quality. The decrease in the WQI may be related to the number of ions and dissolved measurement endpoints, which exceeded the 95th percentile of regional *baseline* concentrations at *test* station MIC-1. The WQI was not calculated for ISL-1 in 2011 given lakes are not compared to regional *baseline* concentrations; however, water quality in Isadore's Lake was similar to that in Mills Creek and similar exceedances of regional *baseline* concentrations would likely be observed.

Classification of Results Differences in water quality in fall 2011 between Mills Creek and regional *baseline* fall conditions were classified as **Moderate**, likely due to relatively high concentrations of many ions and other dissolved species that exceeded the 95th percentile of regional *baseline* concentrations. The ionic compositions of *test* stations ISL-1 and MIC-1 were similar, with an increase in bicarbonate relative to previous years.

5.11.2.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 at depositional *test* station ISL-1 in Isadore's Lake (sampled from 2006 to 2011).

2011 Habitat Conditions Water in Isadore's Lake in fall 2011 was alkaline (pH = 8.0), with high conductivity (544 µS/cm). The substrate was dominated by silt (86%), with moderate total organic carbon content (6%) (Table 5.11-8).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community of Isadore's Lake in fall 2011 was dominated by nematodes (69%) and chironomids (17%), with subdominant taxa consisting of naidid worms (8%) and Ostracoda (4%) (Table 5.11-9). Dominant chironomids included genera such as *Einfeldia*, *Chironomus*, *Dicrotendipes*, and *Endochironomus* all of which are commonly distributed in north-temperate lakes (Wiederholm 1983). One gastropod (*Valvata tricarinata*) and one damselfly (*Cordulia shurtleffi*) were present in Isadore's Lake.

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* station ISL-1 (Hypothesis 1, Section 3.2.3.1). There were no statistically significant time trends in any of the measurement endpoints for benthic invertebrate communities (Table 5.11-10).

Comparison to Published Literature The benthic invertebrate community of Isadore's Lake in fall 2011 showed an indication of poor water quality (Pennak 1986). The benthic taxa consisted primarily of nematodes, which are generally tolerant of degraded water quality (Pennak 1986); however, the low relative abundance of tubificid worms indicated that the water is oxic (Hynes 1960, Griffiths 1998).

2011 Results Relative to Historical Conditions Total abundance, richness, evenness and percent EPT were within the range of values previously measured at *test* station ISL-1 in fall 2011 (Figure 5.11-8). Diversity was lower in 2011 than previous years. CA Axis 1 and 2 scores in 2011 reflected a higher relative abundance of nematodes (Figure 5.11-9). No Ephemeroptera or Trichoptera taxa were found in Isadore's Lake in 2011, which was consistent with previous years.

Classification of Results Differences in the benthic invertebrate community at *test* station ISL-1 were classified as **Negligible-Low** because there were no significant time trends in any of the benthic invertebrate community measurement endpoints. In addition, diversity was the only measurement endpoint that was outside (below) the range of previously-measured values. Historically, Isadore's Lake has had a unique benthic invertebrate community compared to other lakes in the region (e.g., McClelland, Kearl and Shipyard lakes), with low diversity and a high abundance of nematodes. While there has been very little negative change over time, the benthic invertebrate community in Isadore's Lake has been representative of a degraded system since sampling was initiated in 2006.

Sediment Quality

Sediment quality in fall 2011 was sampled in Isadore's Lake (*test* station ISL-1, sampled in 2001 and continuously from 2006 to 2011) in the same location as the sampling for benthic invertebrate communities was conducted.

Temporal Trends Trend analysis could not be conducted for *test* station ISL-1 due to the insufficient data record for this station (n=5).

2011 Results Relative to Historical Concentrations In fall 2011, sediments at *test* station ISL-1 were dominated by high proportions of silt, with lower proportions of clay than previously measured (Table 5.11-11 and Figure 5.11-10). Total organic carbon was within the range of previously-measured values, but total carbon (inorganic and organic) exceeded previously-measured maximum concentrations (Figure 5.11-10). Concentrations of low-molecular-weight hydrocarbons (CCME Fraction-1 including BTEX, and Fraction-2) were below detection limits, while concentrations of heavier hydrocarbon fractions (CCME Fraction-3 and Fraction-4) were within the range of previously-measured concentrations. Concentrations of total PAHs (including total dibenzothiophenes and total carbon-normalized PAHs) were below previously-measured minimum concentrations (Table 5.11-11).

Survival of both the amphipod *Hyalella* and the midge *Chironomus* were lower than previously-measured values. Fourteen-day growth of *Hyalella* exceeded previously-measured maximum values and ten-day growth of *Chironomus* was lower than the previously-measured value (Table 5.11-11).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines There were no sediment quality measurement endpoints with concentrations that exceeded sediment or soil quality guidelines in fall 2011, with the exception of Fraction-3 (C16-C34) and Fraction-1 (C6-C10) hydrocarbons; however, Fraction-1 (C6-C10) hydrocarbons was reported as undetectable with a detection limit above the guideline (Table 5.11-11).

Sediment Quality Index A *baseline* referenced SQI was not calculated for *test* station ISL-1 because lakes were not included in the regional *baseline* conditions given potential ecological differences between lakes and rivers.

5.11.3 Shipyard Lake

Monitoring was conducted in Shipyard Lake in fall 2011 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 2011 at *test* station SHL-1 (sampled annually from 1998 to 2011).

Temporal Trends 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; and
- Increasing concentrations of chloride, magnesium, potassium, sodium, total boron and total dissolved solids.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints at *test* station SHL-1 in fall 2011 were within previously-measured concentrations (Table 5.11-12) with the exception of:

- sulphate, with a concentration that was below the previously-measured minimum concentration; and
- total strontrium, with a concentration that exceeded the previously-measured maximum concentration.

Ion Balance The ionic composition of water at *test* station SHL-1 in fall 2011 continued the recent trend towards increasing relative concentrations of sodium and chloride (Figure 5.11-5). As discussed in RAMP (2010, 2011) the shift in the ionic composition of water in Shipyard Lake from calcium-bicarbonate to sodium-chloride may be a result of reduced surface-water inflow and increases in groundwater influence in the lake's catchment area.

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of all water quality measurement endpoints at *test* station SHL-1 in fall 2011 were below water quality guidelines (Table 5.11-12).

Other Water Quality Guideline Exceedances Concentrations of dissolved iron, sulphide, total iron and total phenols exceeded water quality guidelines in fall 2011 at *test* station SHL-1 (Table 5.11-6).

Classification of Results Concentrations of most water quality measurement endpoints in fall 2011 at *test* station SHL-1 were within previously-measured concentrations with only a few exceptions (i.e., sulphate and total strontium). The ionic composition of water at *test* station SHL-1 continued to exhibit an increase in sodium and chloride concentrations relative to historical concentrations, perhaps due to 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 upper 93% of the Shipyard Lake watershed has been disturbed; see Table 2.5-2). The WQI was not calculated for lakes in 2011 due to potential ecological differences in regional water quality characteristics between lakes and rivers.

5.11.3.2 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 in Shipyard Lake (depositional *test* station SHL-1, sampled from 2000 to 2011).

2011 Habitat Conditions Water in Shipyard Lake was slightly alkaline (pH = 7.8), with moderate conductivity (~ 450 µS/cm) (Table 5.11-13). The substrate in Shipyard Lake in fall 2011 was characterized by nearly equal amounts of sand (34%), silt (38%), and clay (28%) and moderate total organic carbon content (9%) (Table 5.11-13).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* station SHL-1 in fall 2011 was dominated by chironomids (44%) and naidid worms (33%), with subdominant taxa consisting of Cladocerans (10%) (Table 5.11-14). Mayflies (Ephemeroptera) from the genus *Caenis* and Damselflies (Anisoptera) from the genus *Leucorrhinia* were present in low relative abundances (<1%). Dominant chironomids included *Einfeldia*, *Chironomus, Psectrocladius,* and *Dicrotendipes* all of which are commonly distributed in north temperate regions (Wiederholm 1983). Gastropoda (snails) included *Armiger crista, Valvata sincera,* and *Gyraulus*, which are all are common in northern parts of Canada (Clarke 1981). Bivalves were represented by fingernail clams (Sphaeriidae, including the genus *Pisidium*), which are commonly distributed in Canada (Mackie 2007).

Temporal and Spatial Comparisons Changes in time trends of measurement endpoints for benthic invertebrate communities were tested for *test* station SHL-1 (Hypothesis 1, Section 3.2.3.1). Spearman rank correlations were also used to test for trends over the last six years. There were significant increases in total abundance and taxa richness over time, explaining greater than 20% of the variance in annual means (Table 5.11-15). There were also strong variations over time in CA Axis 1 and 2 scores reflecting a decrease in relative abundance of amphipods and increase in relative abundance of water mites (Hydracarina) over time (Table 5.11-15, Figure 5.11-11, Figure 5.11-12).

Comparison to Published Literature The benthic invertebrate community in Shipyard Lake in 2011 was what would be expected for a lake benthic community in the Fort McMurray region (Parsons *et al.* 2010). The benthic invertebrate community contained several permanent aquatic forms including fingernail clams (Bivalvia: Sphaeriidae) and snails (Gastropoda). Several flying insects (Ephemeroptera and Trichoptera) were also present in the lake, which is consistent with previous years. The presence of both permanent and flying insects is indicative of good long-term water quality (Niemi *et al.* 1990, Pennak 1986).

2011 Results Relative to Historical Conditions Total abundance was greater in 2011 (67,700 individuals per m^2) than previous years (Figure 5.11-11). All other measurement endpoints of benthic invertebrate communities were within the range of previously-measured values (Figure 5.11-11). The percent EPT taxa decreased from 5% in 2010 to nearly 0% in 2011, but was still within the range of previously-measured values.

Classification of Results Differences in the benthic invertebrate community at *test* station SHL-1 in fall 2011 were 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 lake contained a number of fully aquatic forms including amphipods, clams and snails, indicating generally good water and sediment quality.

Sediment Quality

Sediment quality in fall 2011 was sampled in Shipyard Lake (*test* station SHL-1, sampled from 2001 to 2004 and 2006 to 2011) in the same location as the sampling for benthic invertebrate communities was conducted.

Temporal Trends The following significant (α=0.05) trends in concentrations of sediment quality measurement endpoints were detected at *test* station SHL-1 in fall 2011:

- An increasing concentration of total PAHs (however, carbon-normalized total PAHs did not show a significant increase);
- A decreasing concentration of total arsenic (however, when data from 1998 to 2001 were removed because detection limits for arsenic were significantly higher than presently measured, were removed, no significant trend in arsenic concentrations was detected); and
- Increasing concentrations of total alkylated PAHs and C4-hydrocarbons.

2011 Results Relative to Historical Concentrations Sediments at *test* station SHL-1 in fall 2011 contained similar proportions of sand, silt, and clay (34%, 38%, and 28%, respectively) (Table 5.11-16 and Figure 5.11-13). Total organic carbon content was moderate (8%) and within previously-measured concentrations (Table 5.11-16). Low-molecular-weight hydrocarbons (CCME Fraction 1 including BTEX, and CCME Fraction-2) were below detection limits at *test* station SHL-1; however these detection limits are above previously-measured maximum concentrations observed at this station, and above relevant sediment quality guidelines. Concentrations of CCME Fraction-3 hydrocarbons were within previously-measured concentrations, while Fraction-4 hydrocarbons exceeded the previously-measured maximum concentration (Table 5.11-16). Concentrations of all other sediment quality measurement endpoints at *test* station SHL-1 in fall 2011 were within previously-measured concentrations (Table 5.11-16, Figure 5.11-13).

Survival of both the amphipod *Hyalella* and the midge *Chironomus* were within the range of previously-measured values in fall 2011 (Table 5.11-16). Ten-day growth of *Chironomus* was below previously-measured minimum values while 14-day growth of *Hyalella* exceeded previously-measured maximum values in fall 2011.

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines Fraction-3 (C16-C34) hydrocarbons exceeded its comparable soil quality, guidelinebenz[a]anthracene, benz[a]pyrene, and chrysene exceeded the relevant CCME Interim Sediment Quality Guideline (ISQG) by approximately two times, but were between six and 12 times lower than the CCME Probable Effect Level (PEL). Fraction-1 (C6-C10) and Fraction-2 (C10-C16) hydrocarbons were not detectable in sediments, but their detection limits fell above relevant guidelines for this sample (Table 5.11-16).

Sediment Quality Index A SQI was not calculated for *test* station SHL-1 because lakes were not included in the regional *baseline* conditions given the ecological differences between lakes and rivers.

5.11.4 Poplar Creek and Beaver River

Monitoring was conducted in the Poplar Creek and Beaver River watersheds in 2011 for the Climate and Hydrology (Poplar Creek only), Water Quality, and Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components.

5.11.4.1 Hydrologic Conditions: 2011 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 2011, with annual data collected from 1973 to 1986. The open-water runoff volume during the 2011 WY was 12.1 million m^3, which was 44% lower than the historical mean open-water runoff volume of 21.6 million m^3. Flows were within the historical inter-quartile range for most of the 2011 WY. The maximum open-water daily flow of 3.5 m^3/s on May 8 was 54% less than the historical mean maximum daily flow for the open-water period. Flows exceeded the historical median values from June 28 to July 28 in response to precipitation in late June and early July, but then decreased to a minimum open-water daily flow of 0.06 m^3/s on September 13. This value was similar to the historical mean minimum daily flow for the open-water period. Following September 13, flows increased to 1.13 m^3/s on October 14, which corresponds to water releases to Poplar Creek via the Poplar Creek spillway beginning on October 13.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The 2011 WY estimated water balance at WSC Station 07DA007 (RAMP Station S11) is presented in Table 5.11-17 and described below:

1. The closed-circuited land area from focal projects as of 2011 in the Poplar Creek watershed was 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 was estimated at 0.25 million m^3.
2. As of 2011, the area of land change from focal projects in the Poplar Creek watershed that was not closed-circuited was estimated to be 1.8 km^2 (Table 2.5-1). The increase in flow to Poplar Creek that would not have otherwise occurred from this land area was estimated at 0.03 million m^3.
3. From April 26 to October 31, Syncrude reported a total discharge of 1.14 million m^3 of water to Poplar Creek via the Poplar Creek spillway.

The estimated cumulative effects of land change and water discharges was an increase in flow of 0.92 million m^3 to Poplar Creek in the 2011 WY. The resulting observed *test* and estimated *baseline* hydrographs for WSC Station 07DA007 (RAMP Station S11), Poplar Creek at Highway 63 are presented in Figure 5.11-14. The calculated mean open-water discharge (May to October) was 4.9% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph (Table 5.11-17). This difference was classified as **Negligible-Low** (Table 5.11-18). The annual maximum daily discharge was 1.2% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low** (Table 5.11-18). The open-water minimum daily discharge was 1.8% lower in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was classified as **Negligible-Low** (Table 5.11-18).

5.11.4.2 Water Quality

In fall 2011, water quality samples were taken from:

- the Beaver River near its mouth (*test* station BER-1, sampled from 2003 to 2011);
- Poplar Creek near its mouth (*test* station POC-1, sampled from 2000 to 2011); and
- the upper Beaver River upstream of all focal project developments (*baseline* station BER-2, sampled from 2008 to 2011).

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 located downstream 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* stations BER-1 and 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.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints were within their historical ranges at *test* station POC-1 (Table 5.11-19). Concentrations of several water quality measurement endpoints in fall 2011 at *test* station BER-1 and *baseline* station BER-2 were higher than previously-measured maximum concentrations, including:

- pH, conductivity, total dissolved solids, total alkalinity, total suspended solids, calcium, chloride, sodium, total boron, total molybdenum, and total strontium at *test* station BER-1 (Table 5.11-20); and
- pH, conductivity, total alkalinity, total dissolved solids, dissolved organic carbon, magnesium, sodium, sulphate, total boron, total mercury, total molybdenum, total nitrogen and total strontium at *baseline* station BER-2 (Table 5.11-21).

Ion Balance The ionic composition of water at *test* station POC-1 has been highly variable across sampling years; however, data from fall 2011 fell within the range of historical concentrations (Figure 5.11-15). The ion balance at *test* station BER-1 was strongly skewed toward high concentrations of sodium and chloride, to a greater degree than observed in previous years (Figure 5.11-15). There was a greater influence of sodium at *baseline* station BER-2 in fall 2011 compared to previous years.

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of the following water quality measurement endpoints exceeded water quality guidelines in fall 2011 (Table 5.11-19 to Table 5.11-21):

- Total aluminum, total nitrogen, and chloride at *test* station BER-1;
- Total aluminum and total nitrogen at *test* station POC-1; and
- Total aluminum and total dissolved phosphorus at *baseline* station BER-2.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured in 2011 (Table 5.11-6):

- Total and dissolved iron, sulphide, total Kjeldahl nitrogen, total phenols and total phosphorous at *test* station POC-1;
- Total iron, total and dissolved chromium, sulphide, total Kjeldahl nitrogen, total phenols and total phosphorous at *test* station BER-1; and
- Total and dissolved iron, sulphide, total phenols and total phosphorous at *baseline* station BER-2.

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of several water quality measurement endpoints in fall 2011 at *test* stations BER-1 and POC-1 exceeded regional *baseline* concentrations, while only one measurement endpoint at *baseline* station BER-2 exceeded regional *baseline* concentrations (Figure 5.11-16):

- calcium, chloride, magnesium, sodium, total boron, total dissolved solids, total strontium, total suspended solids, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station BER-1;
- sodium, chloride, total boron and total strontium, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *test* station POC-1; and
- total boron, with a concentration that exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station BER-2.

Water Quality Index The WQI values for fall 2011 for *test* station POC-1 and *baseline* station BER-2 indicated **Negligible-Low** differences from regional *baseline* concentrations (Table 5.11-7). The WQI value for *test* station BER-1 was 63.0 indicating a **Moderate** difference from regional *baseline* concentrations, likely due to the high concentrations of several ions and other variables (i.e., nutrients and metals) relative to regional *baseline* concentrations.

Classification of Results Concentrations of several water quality measurement endpoints, primarily ions and other dissolved species, were historically high and/or exceeded regional *baseline* concentrations at *test* station BER-1, resulting in a **Moderate** difference from regional *baseline* conditions. Although concentrations of several measurement endpoints were high at *test* station POC-1 and *baseline* station BER-2, differences in water quality in fall 2011 between *test* station 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 2011 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.

2011 Habitat Conditions Water at *test* reach POC-D1 in fall 2011 was deep (0.6 m), slow flowing (0.11 m/s), slightly alkaline (pH: 7.6), with high conductivity (685 µS/cm). The substrate was dominated by silt (44%) and sand (36%) with a moderate amount of clay (20%), and low total organic carbon (2%) (Table 5.11-22).

Water at *baseline* reach BER-D2 in fall 2011 was deep (0.8 m), slow flowing (0.08 m/s), moderately alkaline (pH: 8.1), with high conductivity (504 µS/cm). The substrate was dominated by sand (95%), and had low total organic carbon content (0.1%) (Table 5.11-13).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach POC-D1 was dominated by Chironomidae (41%) and Tubificidae worms (17%) with subdominant taxa consisting of Ostracoda (14%) and Bivalvia (13%) (Table 5.11-23). Dominant chironomid genera consisted primarily of *Micropsectra* with subdominant taxa consisting of *Thienemannimyia*, *Paralauterborniella* and *Polypedilum*, all of which are common in north-temperate waters (Wiederholm 1983).

The benthic invertebrate community at *baseline* reach BER-D2 was dominated by Chironomidae (46%) and Tubificidae worms (20%) with subdominant taxa consisting of Naididae (8%), Copepoda (7%), and Ephemeroptera (4%) (Table 5.11-23). Dominant chironomid genera consisted primarily of *Tanytarsus*, *Polypedilum* and *Stempellina*, all of which are common (Wiederholm 1983). Ephemeroptera (*Caenis*) 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 and *baseline* reach BER-D2 (Hypothesis 4, Section 3.2.3.1). There were significant increases in richness, diversity and evenness at *test* reach POC-Dl compared to *baseline* reach BER-D2 over time, but only differences in time trends for diversity and evenness explained more than 20% of the variation in annual means (Table 5.11-24, Figure 5.11-17).

For spatial comparisons, changes in mean values of measurement endpoints for benthic invertebrate communities were tested between *baseline* reach BER-D2 and *test* reach POC-D1 (i.e., Hypothesis 3, Section 3.2.3.1). Abundance was significantly higher and percent EPT was significantly lower at *test* reach POC-D1 compared to *baseline* reach BER-D2, explaining greater than 20% of the variation in the annual means (Table 5.11-24).

The benthic invertebrate community at *test* reach POC-D1 had lower CA Axis 1 scores and higher CA Axis 2 scores than *baseline* reach BER-D2 (Table 5.11-24, Figure 5.11-18) reflecting a higher relative abundance of bivalves (*Pisdium*/*Sphaerium*) and a lower relative abundance of mayflies (Ephemeroptera) at *test* reach PC-D1. The relative abundance of tubificid worms generally increased and the relative abundance of chironomids generally decreased at *test* reach POC-Dl from 2008 to 2011, while the relative abundance of tubificid worms generally decreased at *baseline* reach BER-D2 (Table 5.11-24, Figure 5.11-17, Figure 5.11-18).

Comparison to Published Literature The benthic invertebrate community at *test* reach POC-D1 in fall 2011 was what would be expected for a sand-based watercourse. The percentage of the fauna as tubificid worms (17%) and chironomids (41%) (Table 5.11-24) were typical of a sand environment (Hynes 1960, Griffiths 1998). The benthic invertebrate community at *test* reach POC-D1 also included a relatively high percent of fingernail clams (*Pisidium*/*Sphaerium*) (13%). Mayflies and caddisflies were present in low relative abundances relative to what might be expected in a *baseline* condition (e.g., Hynes 1960, Griffiths 1998).

2011 Results Relative to Regional *Baseline* Conditions Values of all measurement endpoints with the exception of taxa richness at *test* reach POC-Dl were within the range of regional *baseline* depositional conditions (Figure 5.11-17). Taxa richness per sample (~25) and abundance at *test* reach POC-D1 exceeded previously-measured values for this reach and *baseline* reach BER-D2 and richness exceeded the 95th percentile of regional *baseline* conditions.

Classification of Results Differences in measurement endpoints of benthic invertebrate communities at *test* reach POC-Dl were classified as **Moderate** because of the significant difference in percent EPT and CA Axis scores compared to *baseline* reach BER-D2, implying a negative change in the benthic invertebrate community. The benthic invertebrate community at *test* reach POC-D1 was generally in good condition, reflected by low relative abundance of tubificid worms and higher relative abundance of fingernail clams; however, the low relative abundance of mayflies and caddisflies, and absence of stoneflies potentially indicated some level of disturbance.

Sediment Quality

Sediment quality was sampled in fall 2011 at:

- *test* station POC-D1 (sampled in 1997, 2002, 2004, and 2008 to 2011); and
- *baseline* station BER-D2 (sampled from 2008 to 2011).

Temporal Trends No significant trends (α=0.05) in concentrations of sediment quality measurement endpoints were detected for *test* station POC-D1 in fall 2011. Trend analysis could not be conducted for *baseline* station BER-D2 due to the insufficient data record for this station (n=3).

2011 Results Relative to Historical Concentrations Sediments at *test* station POC-D1 in fall 2011 contained similar proportions of sand, silt, and clay (36%, 44%, and 20%, respectively), while sediments at *baseline* station BER-D2 contained historically high proportions of sand with lower concentrations of clay than seen previously (Table 5.11-25, Table 5.11-26, Figure 5.11-19, Figure 5.11-20). Total organic carbon was low at *test* station POC-D1 and undetectable at *baseline* station BER-D2. Concentrations of all measured total hydrocarbon fractions at *baseline* station BER-D2, and Fraction-1 (including BTEX) and Fraction-2 at *test* station POC-D1 were undetectable in sediments collected in fall 2011 (Table 5.11-25 and Table 5.11-26). Higher-molecular-weight hydrocarbon fractions (F3 and F4) at *test* station POC-D1 were within the range of previously-measured concentrations. Concentrations of most PAHs were within the range of previously-measured concentrations at *test* station POC-D1 and *baseline* station BER-D2, with the exception of retene at *test* station POC-D1, with a concentration that exceeded previously-measured maximum concentrations, and total parent PAHs at *test* station POC-D1 and naphthalene at *baseline* station BER-D2, with concentrations that were below previously-measured minimum concentrations. Predicted PAH toxicity was below previously-measured minimum concentrations at *baseline* station BER-D2 and within the range of previously-measured concentrations at *test* station POC-D1.

Direct tests of sediment toxicity to invertebrates at *test* station POC-D1 showed that growth and survival of the amphipod *Hyalella* were above the range of previously-measured values, while survival of the midge *Chironomus* was below previously-measured minimum values (Table 5.11-25 and Table 5.11-26). Ten-day growth of *Chironomus* and survival of *Hyalella* were below previously-measured minimum values at *baseline* station BER-D2 (Table 5.11-26).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines There were no sediment quality measurement endpoints with concentrations that exceeded sediment or soil quality guidelines in fall 2011. Predicted PAH toxicity of sediments at *test* station POC-D1 exceeded the threshold value of 1.0 (Table 5.11-25).

Sediment Quality Index The SQI values for *test* station POC-D1 and b*aseline* station BER-D2 were 84.7 and 100.0, respectively (Table 5.11-27) indicating **Negligible-Low** differences in sediment quality compared to regional *baseline* conditions.

Classification of Results Differences in sediment quality observed in fall 2011 at *test* station POC-D1 and *baseline* station BER-D2 compared to regional *baseline* conditions were classified as **Negligible-Low**. Concentrations of most sediment quality measurement endpoints were within the range or lower than previously-measured concentrations at both stations.

5.11.4.4 Fish Populations

Fish assemblages were sampled in fall 2011 at:

- depositional *test* reach POC-F1, sampled in 2009 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is in the same location as the benthic invertebrate community *test* reach POC-D1); and
- depositional *baseline* reach BER-F2, sampled in 2009 as part of the Fish Assemblage Pilot Study and in 2011 (this reach is in the same location as the benthic invertebrate community *baseline* reach BER-D2).

2011 Habitat Conditions *Test* reach POC-F1 was comprised of run and shallow riffle habitat with a wetted width of 7.4 m and a bankfull width of 10.7 m (Table 5.11-28). The substrate consisted entirely of slit/clay/sand. Water at *test* reach POC-F1 in fall 2011 was 0.22 m in depth, slow flowing (average flow: 0.30 m/s), neutral (pH: 7.51), with high conductivity (660 µS/cm), low dissolved oxygen (5.8 mg/L), and a temperature of 16.7°C (Table 5.11-28). Instream cover was dominated by macrophytes and small woody debris with small amounts of large woody debris, undercut banks, and boulders (Table 5.11-28).

Baseline reach BER-F2 was comprised of run habitat with a wetted width of 6.7 m and a bankfull width of 10.05 m (Table 5.11-28). The substrate consisted entirely of silt/clay/sand. Water at *baseline* reach BER-F2 in fall 2011 was 1.01 m in depth, slow flowing (average flow: 0.39 m/s), neutral (pH: 7.72), with high conductivity (535 µS/cm), low dissolved oxygen (5.4 mg/L), and a temperature of 16.2°C. Instream cover was dominated by macrophytes and small amounts of small woody debris and overhanging vegetation (Table 5.11-28).

Temporal and Spatial Comparisons Sampling was initiated at *test* reach POC-F1 and *baseline* reach BER-F2 in 2009 during the RAMP Fish Assemblage Pilot Study; therefore, temporal and spatial comparisons were conducted between 2009 and 2011.

There was an increase in abundance and CPUE of fish at *baseline* reach BER-F2 and *test* reach POC-F1 from 2009 to 2011 (Table 5.11-29). There was a decrease in richness and diversity in both reaches from 2009 to 2011; however, the assemblage tolerance index has also decreased over time indicating a higher proportion of sensitive species in both reaches (Table 5.11-30). The decrease in species richness from 2009 to 2011 could be related to lower water levels in fall 2011 resulting in less suitable habitat within the wetted portion of the channels. *Baseline* reach BER-F2 was dominated by pearl dace, and the *test* reach POC-F1 was dominated by longnose sucker.

Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of seventeen and fourteen fish species were recorded in Poplar Creek and the Beaver River, respectively; whereas RAMP found only ten and seven species in 2009 and 2011 in Poplar Creek and the Beaver River, respectively. RAMP also documented pearl dace, spoonhead sculpin and walleye at *test* reach POC-F1 and pearl dace at *baseline* reach BER-F2, which have not been previously documented. As indicated in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Similar habitat conditions were historically documented to what was observed by RAMP at *baseline* reach BER-F2, which consisted of run habitat with silt/sand substrate (Golder 2004b). Habitat of the upper Beaver River where *baseline* reach BER-F2 is located was characterized as having low habitat diversity and poor fish habitat (Golder 2004b).

Golder (2004b) documented similar habitat conditions to what was observed by RAMP at *test* reach POC-F1, consisting of riffle to run habitat with substrate dominated by boulders, sand, and silt. The habitat in Poplar Creek, where *test* reach POC-F1 is located, was documented as limited for feeding and overwintering activities (Golder 2004b).

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 for *test* reach POC-F1 were within the range of regional *baseline* conditions with the exception of the ATI value, which was lower than the 5th percentile of regional *baseline* conditions (Figure 5.11-21). A lower ATI value indicates that there is a greater proportion of sensitive fish species in the fish assemblage compared to *baseline* reaches in the region. Median values of all measurement endpoints in fall 2011 for *baseline* reach BER-F2 were within the range of regional *baseline* conditions with the exception of diversity (Figure 5.11-22).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reach POC-F1 and regional *baseline* conditions were classified as **Negligible-Low** because the lower assemblage tolerance index (ATI) value in fall 2011 for this reach compared to regional *baseline* values did not imply a negative change in the fish assemblage.

5.11.5 McLean Creek

Monitoring was conducted in the McLean Creek watershed in 2011 for the Water Quality component.

5.11.5.1 Water Quality

In fall 2011, water quality samples were collected near the mouth of McLean Creek at *test* station MCC-1, sampled from 1999 to 2011.

Temporal Trends A significant (α=0.05) decreasing concentration of total arsenic was observed at *test* station MCC-1 in fall 2011. This trend is likely related to improvements in the analytical detection limit for arsenic over the sampling period.

2011 Results Relative to Historical Concentrations Concentrations of all water quality measurement endpoints at *test* station MCC-1 in fall 2011 were within previously-measured concentrations with the exception of chloride, conductivity, sodium, total boron, total dissolved solids and total strontium, with concentrations that exceeded previously-measured maximum concentrations (Table 5.11-31).

Ion Balance The ionic composition of water at *test* station MCC-1 shifted considerably in fall 2011 relative to previous years (Figure 5.11-15), with a greater proportion of sodium, chloride and potassium. The smaller influence of calcium and bicarbonate may be related to the very low flows in the creek at the time of sampling, which would reduce the influence of bicarbonate-dominated surface runoff to the stream.

Comparison of Water Quality Measurement Endpoints to Published Guidelines All measurement endpoints were within water quality guidelines at *test* station MCC-1 in fall 2011, with the exception of total aluminum (Table 5.11-31).

Other Water Quality Guideline Exceedances Concentrations of total and dissolved iron, sulphide, and total phenols exceeded relevant water quality guidelines at *test* station MCC-1 in fall 2011 (Table 5.11-6).

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints that exceeded the 95th percentile of regional *baseline* concentrations included chloride, potassium, sodium, sulphate, total boron, total dissolved solids, total strontium, total suspended solids at *test* station MCC-1 in fall 2011. The concentration of dissolved phosphorous was below the 5th percentile of the regional *baseline* concentration (Figure 5.11-6).

Water Quality Index The WQI value of 61.7 for *test* station MCC-1 in fall 2011 indicated a **Moderate** difference from regional *baseline* conditions (Table 5.11-7), which is likely due to many ions and dissolved analytes that exceeded the 95th percentile of regional *baseline* concentrations.

Classification of Results Concentrations of water quality measurement endpoints at *test* station MCC-1 were often higher than previously-measured maximum concentrations and higher than regional *baseline* concentrations in fall 2011. Many ions and dissolved species of water quality measurement endpoints caused a shift in ionic balance, as well as a **Moderate** difference from regional *baseline* concentrations.

5.11.6 Fort Creek

Monitoring was conducted in the Fort Creek watershed in 2011 for the Climate and Hydrology, Water Quality, Benthic Invertebrate Communities and Sediment Quality, and Fish Populations components.

5.11.6.1 Hydrologic Conditions: 2011 Water Year

RAMP Station S12, Fort Creek at Highway 63 Hydrometric data have been collected during the open-water period (May to October) at RAMP Station S12 from 2000 to 2001 and 2006 to 2011. The 2011 WY open-water runoff volume at Station S12 was 1.1 million m^3; this was 28% lower than the historical mean open-water runoff volume of 1.5 million m^3. Daily flows were between historical extreme values for most days in the 2011 WY open-water period, but were highly variable (Figure 5.11-23). The maximum open-water daily flow of 0.18 m^3/s recorded on October 23 was 64% below the historical mean maximum daily flow. The minimum open-water daily flow of 0.025 m^3/s recorded on June 15 was 13% higher than the historical mean open-water minimum daily flow. This variability in daily flows is likely due to the fact that, as of 2011, 62% of the watershed has been affected by land change resulting from oil sands development.

Differences Between Observed *Test* Hydrograph and Estimated *Baseline* Hydrograph The estimated water balance at RAMP Station S12 is presented in Table 5.11-32 and described below:

1. The closed-circuited land area from focal projects as of 2011 in the Fort Creek watershed was 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 was estimated at 0.012 million m^3.

2. As of 2011, the area of land change from focal projects in the Fort Creek watershed that was not closed-circuited was 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 was estimated at 0.14 million m^3.

The estimated cumulative effect of this land change was an increase in flow of 0.13 million m^3 to Fort Creek. The resulting observed *test* and estimated *baseline* hydrographs are presented in Figure 5.11-23. The calculated mean open-water period (May to October) discharge volume was 11.3% greater in the observed *test* hydrograph than in the estimated *baseline* hydrograph. This difference was 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 2011 WY showed no discernible precipitation-driven annual maximum daily discharge within 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 2011 WY.

5.11.6.2 Water Quality

In fall 2011, water quality samples were taken from the mouth of Fort Creek at *test* station FOC-1 (sampled intermittently from 2000 to 2011).

Temporal Trends The following significant (α=0.05) temporal trends in concentrations of water quality measurement endpoints were detected at *test* station FOC-1:

- A decreasing concentration of total dissolved phosphorous; and
- Increasing concentrations of calcium and total strontium.

2011 Results Relative to Historical Concentrations In fall 2011, concentrations of water quality measurement endpoints were within previously-measured concentrations with the exception of (Table 5.11-33):

- conductivity, total dissolved solids total alkalinity, magnesium, and total strontium, with concentrations that exceeded previously-measured maximum concentrations; and
- total arsenic, with a concentration that was below the previously-measured minimum concentration.

Ion Balance The ionic composition of water at *test* station FOC-1 in fall 2011 was generally similar to that observed in 2009 and 2010 showing a slightly greater influence of sulphate, which was not associated with any changes in cation composition (Figure 5.11-24).

Comparison of 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 in fall 2011 (Table 5.11-33).

Other Water Quality Guideline Exceedances The concentration of total iron exceeded the water quality guideline at *test* station FOC-1 in fall 2011 (Table 5.11-6).

2011 Results Relative to Regional *Baseline* Concentrations Concentrations of water quality measurement endpoints at *test* station FOC-1 in fall 2011, were within regional *baseline* concentrations with the exception of (Figure 5.11-6):

- calcium, magnesium, sulphate, total dissolved solids and total strontium, with concentrations that exceeded the 95th percentile of their regional *baseline* concentrations; and
- total arsenic, with a concentration that was below the 5th percentile of regional *baseline* concentrations.

Due to the decrease in the analytical detection limit for total mercury, the fall concentration was below the 5th percentile of its regional *baseline* concentration at *test* station FOC-1.

Water Quality Index The WQI value for *test* station FOC-1 (81.2) indicated a **Negligible-Low** difference from regional *baseline* water quality conditions (Table 5.11-7).

Classification of Results Differences in water quality in fall 2011 between *test* station FOC-1 and regional *baseline* conditions were classified as **Negligible-Low**. However, relatively high concentrations of several water quality measurement endpoints were observed, but were within the range of previously-measured concentrations and within regional *baseline* water quality conditions. A large increase in the concentration of sulphate have been observed at *test* station FOC-1 since 2008 (although a slight decrease was observed in 2011), which appears to have occurred in the absence of other apparent changes in ionic composition.

5.11.6.3 Benthic Invertebrate Communities and Sediment Quality

Benthic Invertebrate Communities

Benthic invertebrate communities were sampled in fall 2011 at depositional *test* reach FOC-D1 (designated as *baseline* from 2001 to 2003 and as *test* from 2004 to 2011).

2011 Habitat Conditions Water at *test* reach FOC-D1 fall 2011 was very shallow (0.1 m), slow flowing (0.2 m/s), and alkaline (pH: 8.1), with high conductivity (567 µS/cm). The substrate was dominated by sand (98%) with low total organic carbon (1.5%) (Table 5.11-34).

Relative Abundance of Benthic Invertebrate Community Taxa The benthic invertebrate community at *test* reach FOC-Dl was dominated by chironomids (50%) and tubificid worms (32%) with subdominant taxa consisting of bivalves (6%), nematodes (5%), and ostracods (5%) (Table 5.11-35). The dominant chironomid was the common form *Polypedilum*. There were no Ephemeroptera, Plecoptera or Trichoptera present in fall 2011.

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 were tested between the years before and after the reach was designated as *test* (Hypothesis 2, Section 3.2.3.1). Abundance and taxa richness were significantly lower during the *test* period compared to the *baseline* period, accounting for greater than 20% of the variation in annual means (Table 5.11-36, Figure 5.11-25).

Second, changes in time trends of measurement endpoints for benthic invertebrate communities were tested for the period that reach FOC-D11 has been designated as *test* (Hypothesis 1, Section 3.2.3.1). There were no significant increases or decreases in any measurement endpoints during the *test* period (Table 5.11-36, Figure 5.11-25).

Comparison to Published Literature The benthic invertebrate community at *test* reach FOC-D1 had a fauna that was somewhat indicative of degradation given the absence of mayflies, caddisflies and stoneflies, which are sensitive fauna.

2011 Results Relative to Regional *Baseline* Conditions Abundance, richness, diversity, evenness and percent EPT were below the 5th percentile of regional *baseline* conditions (Figure 5.11-25). The CA axis 1 and 2 scores were within regional *baseline* conditions, but outside of the range of scores during the *baseline* period for *test* reach FOC-Dl (Figure 5.11-26). The differences in CA axis scores reflected a shift towards an increasing dominance of tubificid worms and a smaller proportion of chironomids.

Classification of Results Differences in measurement endpoints of benthic invertebrate communities at *test* reach FOC-Dl were classified as **High** because decreases in abundance, richness, diversity and evenness were significant and abundance, 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 in the *test* period suggesting degradation of habitat quality at *test* reach FOC-D1.

Sediment Quality

Sediment quality was sampled in fall 2011 at *test* station FOC-D1 in the same location as the benthic invertebrate communities were collected. *Test* reach FOC-D1 was designated as *baseline* in 2000 and 2002 and as *test* from 2006 to 2008 and 2010 to 2011.

Temporal Trends No significant trends (α=0.05) in concentrations of sediment quality measurement endpoints were detected for *test* station FOC-D1 in fall 2011.

2011 Results Relative to Historical Concentrations Sediments at *test* station FOC-D1 were dominated by historically high proportions of sand (97.8%) and contained historically low levels of clay, silt, and total organic carbon (Table 5.11-37, Figure 5.11-27). Low-molecular-weight hydrocarbons (CCME Fraction 1 including BTEX) were below detection limits at *test* station FOC-D1 in fall 2011. Concentrations of heavier hydrocarbon fractions and all PAHs were within previously-measured concentrations with the exception of carbon normalized PAHs, which exceeded historical maximum concentrations and naphthalene, which was undetectable and; therefore, below historical minimum concentrations in fall 2011. Predicted PAH toxicity was historically high, and exceeded the threshold value of 1.0. Total PAHs at *test* station FOC-D1 were comprised almost exclusively of alkylated species, indicating a petrogenic origin of these compounds.

Direct tests of sediment toxicity to invertebrates at *test* station FOC-D1 showed growth and survival of the amphipod *Hyalella* and growth of the midge *Chironomus* that were within previously-measured historical values. Only *Chironomus* survival (100%) exceeded the previously-observed maximum value at *test* station FOC-D1 (Table 5.11-37).

Comparison of Sediment Quality Measurement Endpoints to Published Guidelines In fall 2011, concentrations of all sediment quality measurement endpoints at *test* station FOC-D1 were within sediment quality guidelines with the exception of CCME F3 hydrocarbons and chrysene (Table 5.11-37).

Sediment Quality Index A SQI value of 97.6 was calculated for *test* station FOC-D1 for fall 2011 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=6).

Classification of Results Differences in sediment quality observed in fall 2011 between *test* station FOC-D1 and regional *baseline* conditions were classified as **Negligible-Low** with nearly all sediment quality measurement endpoints falling within the range of previously measured concentrations.

5.11.6.4 Fish Populations

Fish Assemblages were sampled for the first time in fall 2011 at depositional *test* reach FOC-F1.

2011 Habitat Conditions *Test* reach FOC-F1 was comprised of shallow run habitat with a wetted width of 1.9 m and a bankfull width of 7.6 m (Table 5.11-38). The substrate was dominated entirely by slit/clay/sand. Water at *test* reach FOC-F1 in fall 2011 was 0.31 m in depth, slow flowing (average flow: 0.19 m/s), slightly alkaline (pH: 7.92), with high conductivity (669 µ/cm), high dissolved oxygen (8.6 mg/L), and a temperature of 11.6˚C. Instream cover consisted of small woody debris with small portions of large woody debris (Table 5.11-38).

Temporal and Spatial Comparisons Sampling was initiated at *test* reach FOC-F1 in 2011; therefore, no temporal comparisons were conducted. There were no spatial comparisons given that there is no upstream *baseline* reach on Fort Creek.

A summary of species composition, mean CPUE of fish, and fish assemblage measurement endpoints are provided in Table 5.11-39 and Table 5.11-40. The dominant species captured in *test* reach FOC-F1 in 2011 was lake chub with finescale dace as the subdominant species (Table 5.11-39).

Comparison to Published Literature Golder (2004b) summarized results of historical fish inventory studies conducted within watersheds of the oil sands region. Most studies were conducted prior to large-scale oil sands development and provide important *baseline* data on fish presence and distribution for comparison to fish assemblage data reported by RAMP. Based on past studies, a total of eight fish species were recorded in Fort Creek; whereas RAMP found only four species in 2011 in addition to finescale dace and white sucker, which have not been previously documented. As indicated in Section 5.2, possible reasons for discrepancies in species richness may be due to differences in sampling gear, as well as the total amount of the watercourse sampled (i.e., RAMP samples a smaller, defined reach length relative to multiple locations/reaches documented in Golder [2004b]).

Golder (2004b) documented similar habitat conditions to what has been observed by RAMP, with Fort Creek consisting of shallow runs and pools with some riffle sections dominated by silt substrate. Woody debris was also documented as the primary instream cover.

2011 Results Relative to Regional *Baseline* Conditions Median values of all measurement endpoints in fall 2011 at *test* reach FOC-F1 were within the range of regional *baseline* conditions (Figure 5.11-28).

Classification of Results Differences in measurement endpoints for fish assemblages between *test* reach FOC-F1 and regional *baseline* conditions were classified as **Negligible-Low** given that median values of all measurement endpoints were within the regional range of variation of *baseline* reaches.

5.11.7 Susan Lake Outlet

Monitoring was conducted at the Susan Lake outlet in 2011 for the Climate and Hydrology component.

5.11.7.1 Hydrologic Conditions: 2011 Water Year

RAMP Station S25, Susan Lake Outlet Continuous hydrometric data during the open-water season (May to October) have been collected for RAMP Station S25 in 2002 and 2006 to 2011, but the data record is intermittent in all six years. In the 2011 WY, data were collected from June 18 to October 25. Comparison of the 2011 WY hydrologic conditions to historical values is less robust due to this limited historic record. Flows during late June and July were generally between historical median and upper quartile values recorded during this period (Figure 5.11-29). The highest flow in the 2011 WY occurred on July 10 (0.081 m^3/s) in response to a rainfall event. Flows then generally decreased to new historical low values recorded from August 21 to 28, and remained near historical minimum values during September and October.

5.11.8 Big Creek, Eymundson Creek, Pierre River and Red Clay Creek

Monitoring was conducted in four new watersheds in 2011 for the Water Quality component. Development activities for the Shell Pierre River Mine project and the Silverbirch Frontier project are approved for these watersheds; therefore, *baseline* monitoring was initiated in 2011 in advance of these future developments.

5.11.8.1 Water Quality

In fall 2011, water quality sampling was initiated at several stations near the Shell Pierre River project lease, in advance of project development, including:

- Big Creek (*baseline* station BIC-1, sampled in spring, summer and fall);
- Eymundson Creek (*baseline* station EYC-1, sampled in spring, summer and fall);
- Pierre River (*baseline* station PIR-1, sampled in spring, summer and fall); and
- Red Clay Creek (*baseline* station RCC-1, sampled in spring, summer and fall);

Temporal Trends Trends could not be detected at these stations because there is only one year of data (Table 5.11-41 to Table 5.11-44).

2011 Results Relative to Historical Concentrations Historical comparisons were not possible at these stations because sampling was initiated in 2011.

Ion Balance The ionic composition of water at *baseline* stations BIC-1, PIR-1 and RCC-1 in fall 2011 was generally similar, and dominated by calcium and bicarbonate. Water at *baseline* station EYC-1 was less dominated by bicarbonate and showed a larger influence of sulphate (Figure 5.11-30).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of most water quality measurement endpoints measured at *baseline* stations BIC-1, PIR-1, RCC-1, and EYC-1 were below water quality guidelines in fall 2011 with the exception of (Table 5.11-41 to Table 5.11-44):

- total aluminum at *baseline* station BIC-1;
- total aluminum, total nitrogen and total dissolved phosphorous at *baseline* station PIR-1;

- total aluminum at *baseline* station RCC-1; and
- total aluminum, total nitrogen, sulphate and total mercury at *baseline* station EYC-1.

Other Water Quality Guideline Exceedances The following other water quality guideline exceedances were measured at these four *baseline* stations (Table 5.11-45):

- total aluminum, total and dissolved iron, sulphide, total phenols and total phosphorous at *baseline* station BIC-1 in spring;
- total aluminum, total iron, total and total dissolved phosphorous, total Kjeldahl nitrogen, sulphide, and total phenols at *baseline* station BIC-1 in summer;
- total iron, total phenols, and total phosphorous at *baseline* station BIC-1 in fall;
- total aluminum, total iron, total lead, sulphide, total arsenic, total cadmium, total chromium, total copper, total Kjeldahl nitrogen, total phenols, total phosphorous, total selenium, and total zinc at *baseline* station EYC-1 in spring;
- total aluminum, total iron, total cadmium, total chromium, total lead, total zinc, total mercury, total nitrogen, total Kjeldahl nitrogen, sulphide, total phenols, total phosphorous at *baseline* station EYC-1 in summer; and
- total and dissolved iron, nitrite, total cadmium, total chromium, total Kjeldahl nitrogen, total phenols, and total phosphorous at *baseline* station EYC-1 in fall;
- total aluminum, total iron, total chromium, total Kjeldahl nitrogen, total nitrogen, sulphate, sulphide, total phenols and total phosphorous at *baseline* station PIR-1 in spring;
- total aluminum, total and dissolved iron, sulphate, total phenols, and total phosphorous at *baseline* station PIR-1 in summer;
- total and dissolved iron, total chromium, total Kjeldahl nitrogen, sulphide, total phenols, and total phosphorous at *baseline* station PIR-1 in fall;
- total aluminum, and total iron at *baseline* station RCC-1 in spring;
- total aluminum, total iron, total chromium, and total phosphorous at *baseline* station RCC-1 in summer; and
- total iron at *baseline* station RCC-1 in fall.

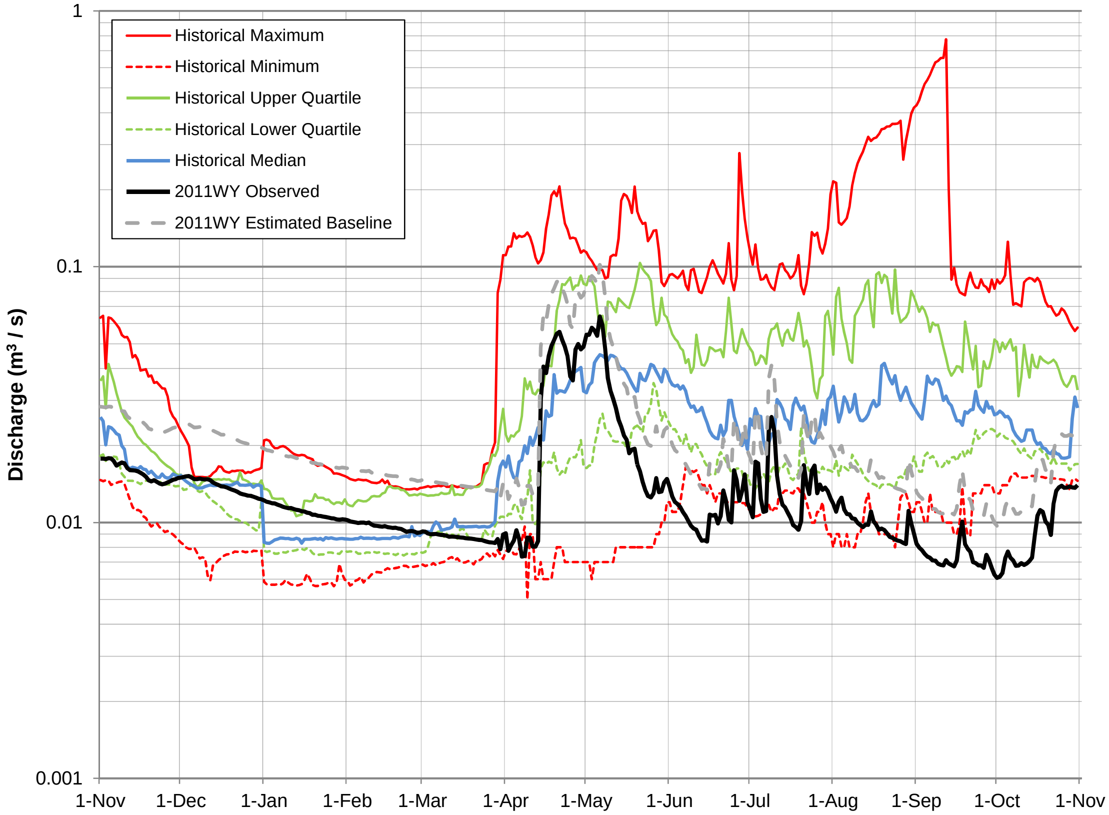
2011 Results Relative to Regional *Baseline* Concentrations In fall 2011, concentrations of water quality measurement endpoints at *baseline* stations BIC-1, EYC-1, PIR-1 and RCC-1 were within regional *baseline* concentrations with the exception of (Figure 5.11-31):

- total mercury (ultra-trace), with a concentration that was lower than the 5th percentile of regional *baseline* concentrations at *baseline* station BIC-1;
- total suspended solids, total arsenic, total mercury and sulphate, with concentrations that exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station EYC-1;
- calcium, with a concentration that exceeded the 95th percentile of regional *baseline* concentrations at *baseline* station RCC-1; and
- total arsenic, with a concentration that was lower than the 5th percentile of regional *baseline* concentrations at *baseline* station RCC-1.

Water Quality Index The WQI values for *baseline* stations BIC-1 (97.5), PIR-1 (93.7), and RCC-1 (96.2) indicated **Negligible-Low** differences from regional *baseline* water quality conditions (Table 5.11-7). The WQI value for *baseline* station EYC-1 (64.1) indicated a **Moderate** difference from regional *baseline* water quality conditions, likely due to the high number of measurement endpoints that exceeded water quality guidelines and several variables that exceeded regional *baseline* concentrations.

Classification of Results Differences in water quality in fall 2011 between *baseline* stations BIC-1, PIR-1, and RCC-1 and regional *baseline* fall conditions were classified as **Negligible-Low**. Differences in water quality were classified as **Moderate** at *baseline* station EYC-1, where concentrations of several water quality measurement endpoints exceeded water quality guidelines or regional *baseline* concentrations. *Baseline* station EYC-1 also differed from the other *baseline* stations (BIC-1, PIR-1 and RCC-1) in its ion balance, with a higher concentration of sulphate and less bicarbonate, which may suggest greater groundwater influence at this station.

Figure 5.11-3 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Mills Creek in the 2011 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 2010 and from 2006 to 2010 for other months.

Table 5.11-2 Estimated water balance at Station S6, Mills Creek at Highway 63, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed test hydrograph (total discharge)	**0.45**	**Observed discharge, obtained from Mills Creek at Highway 63, RAMP Station S6**
Closed-circuited area water loss from the observed test hydrograph	-0.28	Estimated 2.4 km^2 of the Mills Creek watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.01	Estimated 0.6 km^2 of the Mills Creek watershed with land change from focal projects as of 2011, 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)	**0.71**	**Estimated baseline discharge at RAMP Station S6, Mills Creek at Highway 63**
Incremental flow (change in total discharge)	-0.26	Total discharge from observed test hydrograph less total discharge from estimated baseline hydrograph.
Incremental flow (% of total discharge)	**-37%**	**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 2011 WY provisional data for Mills Creek at Highway 63, RAMP Station S6.

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.

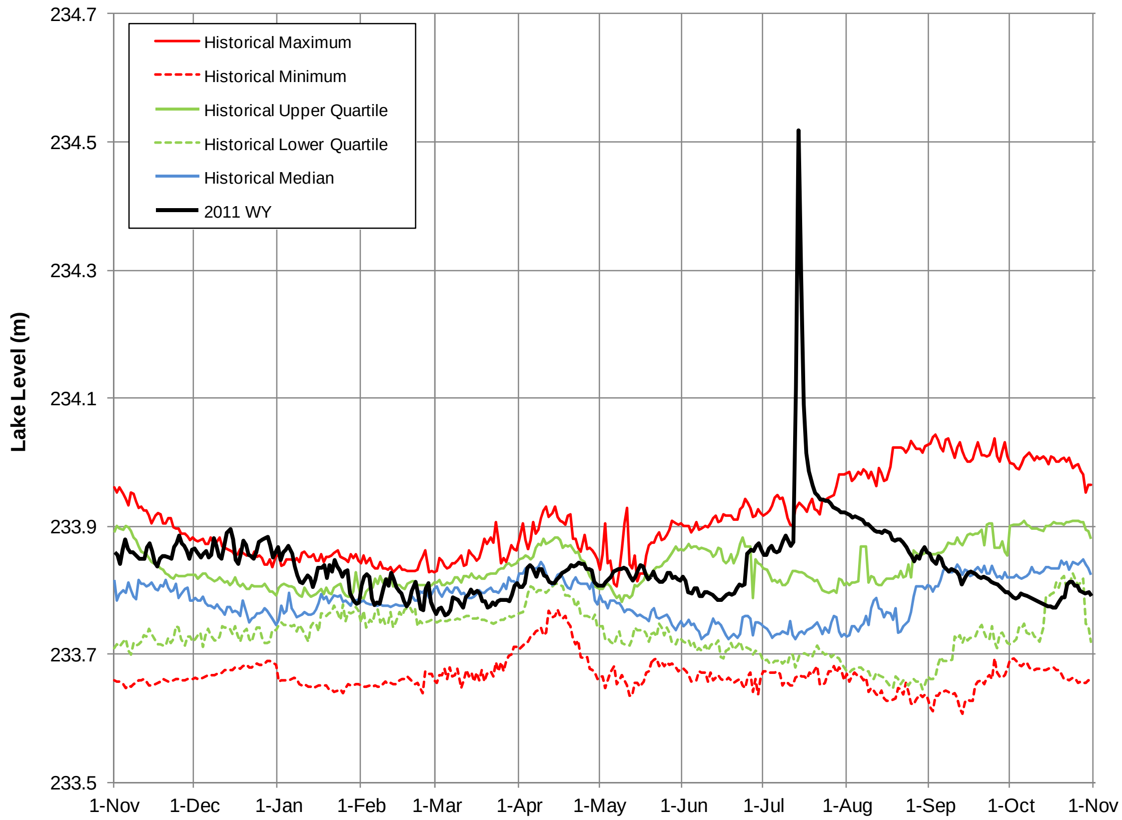
Table 5.11-3 Calculated change in hydrologic measurement endpoints for the Mills Creek watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.022	0.014	-37%
Mean winter discharge	0.019	0.012	-37%
Annual maximum daily discharge	0.102	0.064	-37%
Open-water season minimum daily discharge	0.010	0.006	-37%

Note: Values are calculated from 2011 WY provisional data for Mills Creek at Highway 63, RAMP Station S6.

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows are presented to three decimal places.

Figure 5.11-4 Isadore's Lake: 2010 hydrograph and historical context.



Note: Based on provisional 2011 WY data recorded at Isadore's Lake, RAMP Station L3. Historical values were calculated for the period 2000 to 2010.

Table 5.11-4 Concentrations of water quality measurement endpoints, Isadore's Lake (*test* station ISL-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	9	7.7	8.2	8.3
Total suspended solids	mg/L	-	7	9	<3	6	10
Conductivity	µS/cm	-	553	9	353	551	672
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.006	9	0.004	0.009	**0.067**
Total nitrogen	mg/L	1	**1.2**	9	0.3	**1.1**	**1.3**
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.05	<0.1	0.3
Dissolved organic carbon	mg/L	-	14.2	9	8.0	11.0	12.1
Ions							
Sodium	mg/L	-	12.8	9	6.0	11.0	13.0
Calcium	mg/L	-	57.2	9	37.0	66.8	85.4
Magnesium	mg/L	-	<u>25.0</u>	9	25.6	30.6	36.0
Chloride	mg/L	230, 860	17.5	9	4.0	16.0	22.6
Sulphate	mg/L	100	86.8	9	63.9	109	148
Total dissolved solids	mg/L	-	377	9	250	340	456
Total alkalinity	mg/L		174	9	122	158	227
Selected metals							
Total aluminum	mg/L	0.1	0.014	9	0.006	0.020	**0.182**
Dissolved aluminum	mg/L	0.1	<0.001	9	<0.001	<0.001	0.02
Total arsenic	mg/L	0.005	0.00088	9	0.00046	0.00078	0.00116
Total boron	mg/L	1.2	<u>0.054</u>	9	0.035	0.042	0.049
Total molybdenum	mg/L	0.073	<0.0001	9	<0.000008	0.0000189	0.000125
Total mercury (ultra-trace)	ng/L	5, 13	1.1	7	1.0	<1.2	1.4
Total strontium	mg/L	-	<u>0.28</u>	9	0.16	0.23	0.25
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	6.0	0	-	-	-
Total PAHs	ng/L	-	176.7	0	-	-	-
Total Parent PAHs	ng/L	-	21.8	0	-	-	-
Total Alkylated PAHs	ng/L	-	155.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Sulphide	mg/L	0.002	**<u>0.088</u>**	9	**0.003**	**0.008**	**0.015**
Total Kjeldahl Nitrogen	mg/L	1	**1.15**	9	<0.2	0.90	**1.20**
Total phenols	mg/L	0.004	**0.0043**	9	<0.001	**0.0050**	**0.0070**
Total phosphorus	mg/L	0.05	**0.072**	9	<0.021	0.039	**0.098**

[a] Sources for all guidelines are outlined in Table 3.2-5

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.11-5 Concentrations of water quality measurement endpoints, Mills Creek (*test* station MIC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	September 2010
			Value	Value
Physical variables				
pH	pH units	6.5-9.0	8.19	8.1
Total suspended solids	mg/L	-	5	<3
Conductivity	µS/cm	-	910	859
Nutrients				
Total dissolved phosphorus	mg/L	0.05	0.0011	<0.001
Total nitrogen	mg/L	1	0.301	0.45
Nitrate+nitrite	mg/L	1.3	<0.071	<0.071
Dissolved organic carbon	mg/L	-	6.4	8.4
Ions				
Sodium	mg/L	-	9.4	10.5
Calcium	mg/L	-	138	139
Magnesium	mg/L	-	35.9	36.1
Chloride	mg/L	230, 860	19.4	21.1
Sulphate	mg/L	100	**169**	**192**
Total dissolved solids	mg/L	-	598	607
Total alkalinity	mg/L		313	254
Selected metals				
Total aluminum	mg/L	0.1	0.0107	<0.003
Dissolved aluminum	mg/L	0.1	<0.001	0.0024
Total arsenic	mg/L	0.005	0.000368	0.00029
Total boron	mg/L	1.2	0.0419	0.036
Total molybdenum	mg/L	0.073	<0.0001	<0.0001
Total mercury (ultra-trace)	ng/L	5, 13	0.6	<0.6
Total strontium	mg/L	-	0.392	0.32
Total hydrocarbons				
BTEX	mg/L	-	<0.1	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]				
Naphthalene	ng/L	-	<14.1	-
Retene	ng/L	-	<2.1	-
Total dibenzothiophenes	ng/L	-	6.8	-
Total PAHs	ng/L	-	177.8	-
Total Parent PAHs	ng/L	-	24.2	-
Total Alkylated PAHs	ng/L	-	153.6	-
Other variables that exceeded CCME/AENV guidelines in fall 2011				
Total iron	mg/L	0.3	**1.16**	**0.52**

[a] Sources for all guidelines are outlined in Table 3.2-5

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Figure 5.11-5 Piper diagram of fall ion balance in Isadore's Lake, Mills Creek and Shipyard Lake.

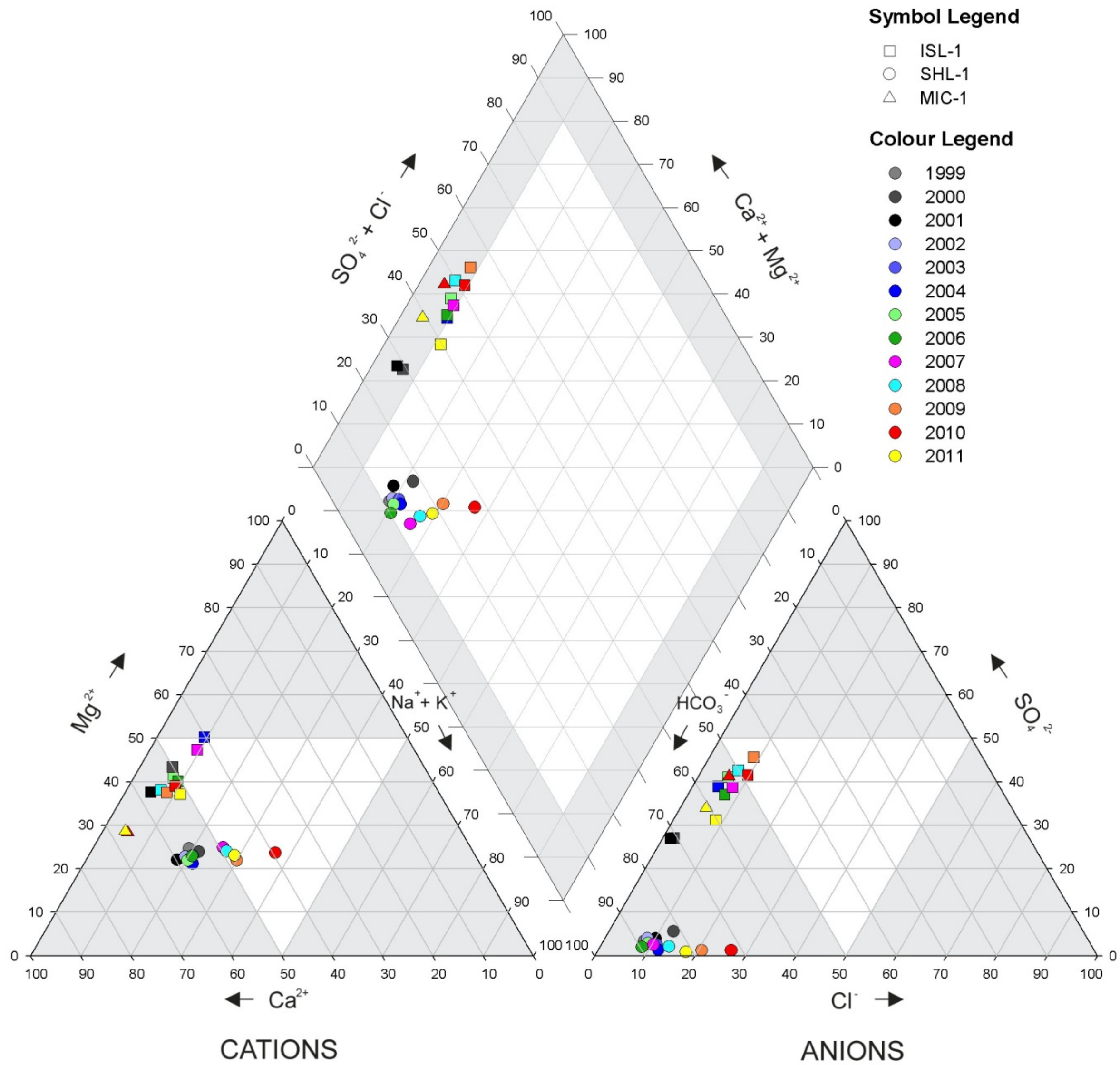
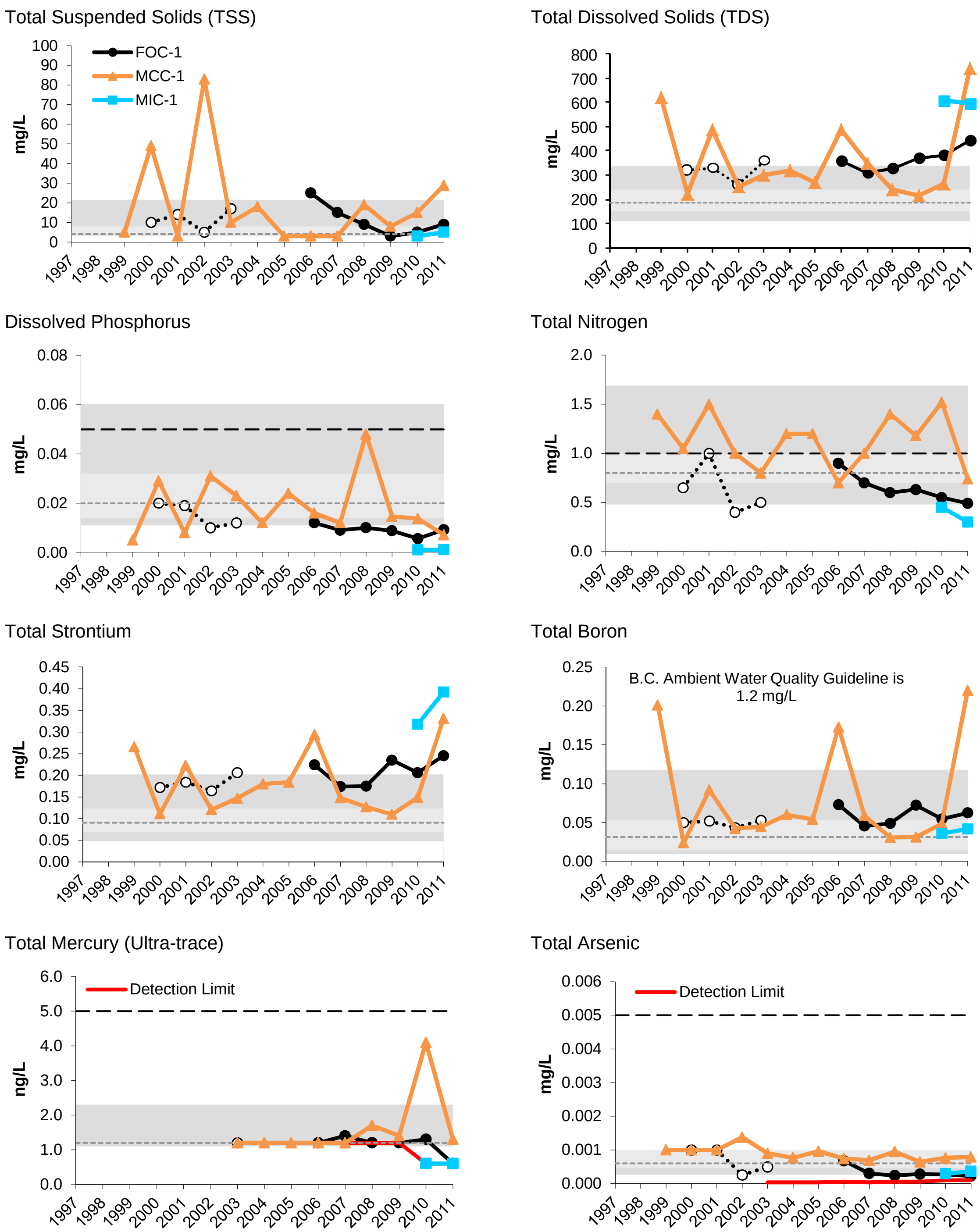


Table 5.11-6 Water quality guideline exceedances in *baseline* station BER-1, *test* station POC-1, *test* station MCC-1, *test* station ISL-1, *test* station SHL-1, and *test* station FOC-1, 2011.

Variable	Units	Guideline[a]	POC-1	BER-1	BER-2	MCC-1	ISL-1	SHL-1	MIC-1	FOC-1
Fall										
Chloride	mg/L	230, 860	-	364	-	-	-	-	-	-
Dissolved chromium	mg/L	0.001	-	0.0016	-	-	-	-	-	-
Dissolved iron	mg/L	0.3	0.84	-	0.01	0.33	-	0.68	-	-
Sulphate	mg/L	100	-	-	-	-	-	-	169	-
Sulphide	mg/L	0.002	0.006	0.013	0.820	0.011	0.088	0.009	-	-
Total aluminum	mg/L	0.1	0.76	2.34	0.50	0.45	-	-	-	-
Total chromium	mg/L	0.001	-	0.0028	-	-	-	-	-	-
Total dissolved phosphorus	mg/L	0.05	-	-	0.056	-	-	-	-	-
Total iron	mg/L	0.3	2.13	6.97	0.01	0.83	-	1.54	1.16	0.69
Total Kjeldahl Nitrogen	mg/L	1	1.05	1.03	-	-	1.15	-	-	-
Total nitrogen	mg/L	1	1.13	1.10	-	-	1.22	-	-	-
Total phenols	mg/L	0.004	0.0051	0.0082	0.1330	0.0065	0.0043	0.0058	-	-
Total phosphorus	mg/L	0.05	0.0506	0.0930	0.8910	-	0.0718	-	-	-

[a] Sources for all guidelines are outlined in Table 3.2-5.

Figure 5.11-6 Concentrations of selected fall water quality measurement endpoints, Mills Creek (MIC-1), McLean Creek (MCC-1), and Fort Creek (FOC-1) (fall data), relative to historical concentrations and regional *baseline* fall concentrations.



Non-detectable values are shown at the detection limit.

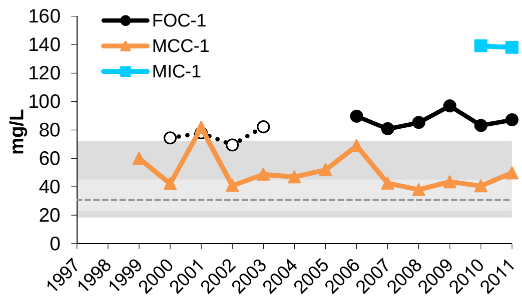
- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

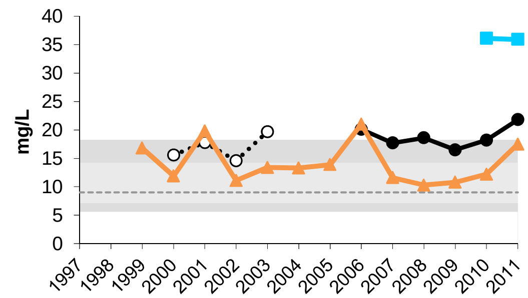
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-6 (Cont'd.)

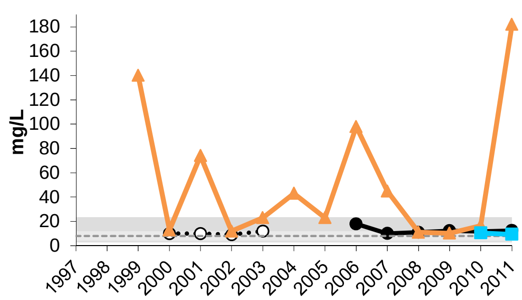
Calcium



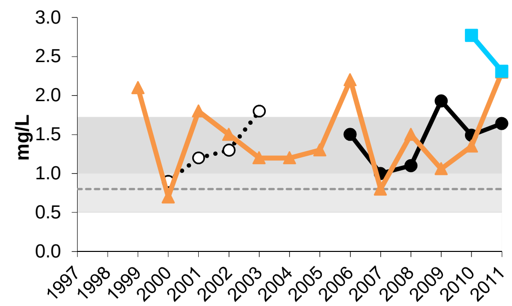
Magnesium



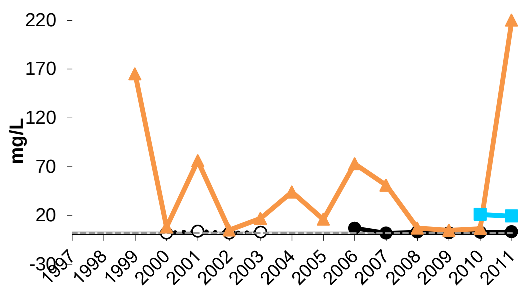
Sodium



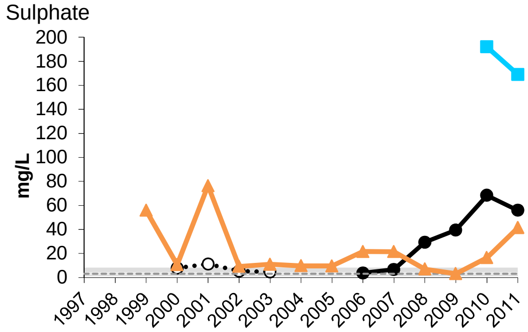
Potassium



Chloride



Sulphate



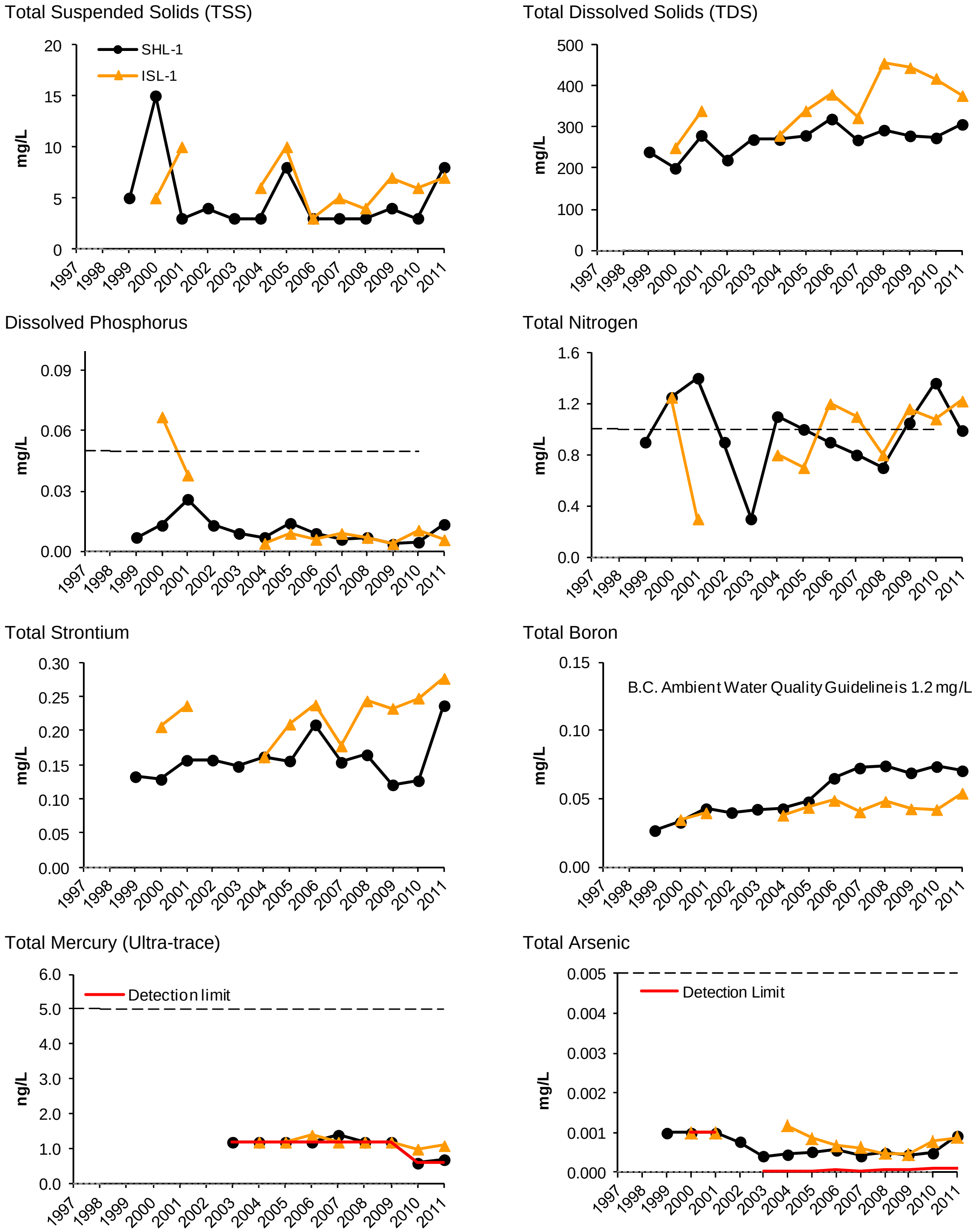
Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-7 Concentrations of selected fall water quality measurement endpoints, Isadore's Lake (ISL-1) and Shipyard Lake (SHL-1) (fall data), relative to historical concentrations.

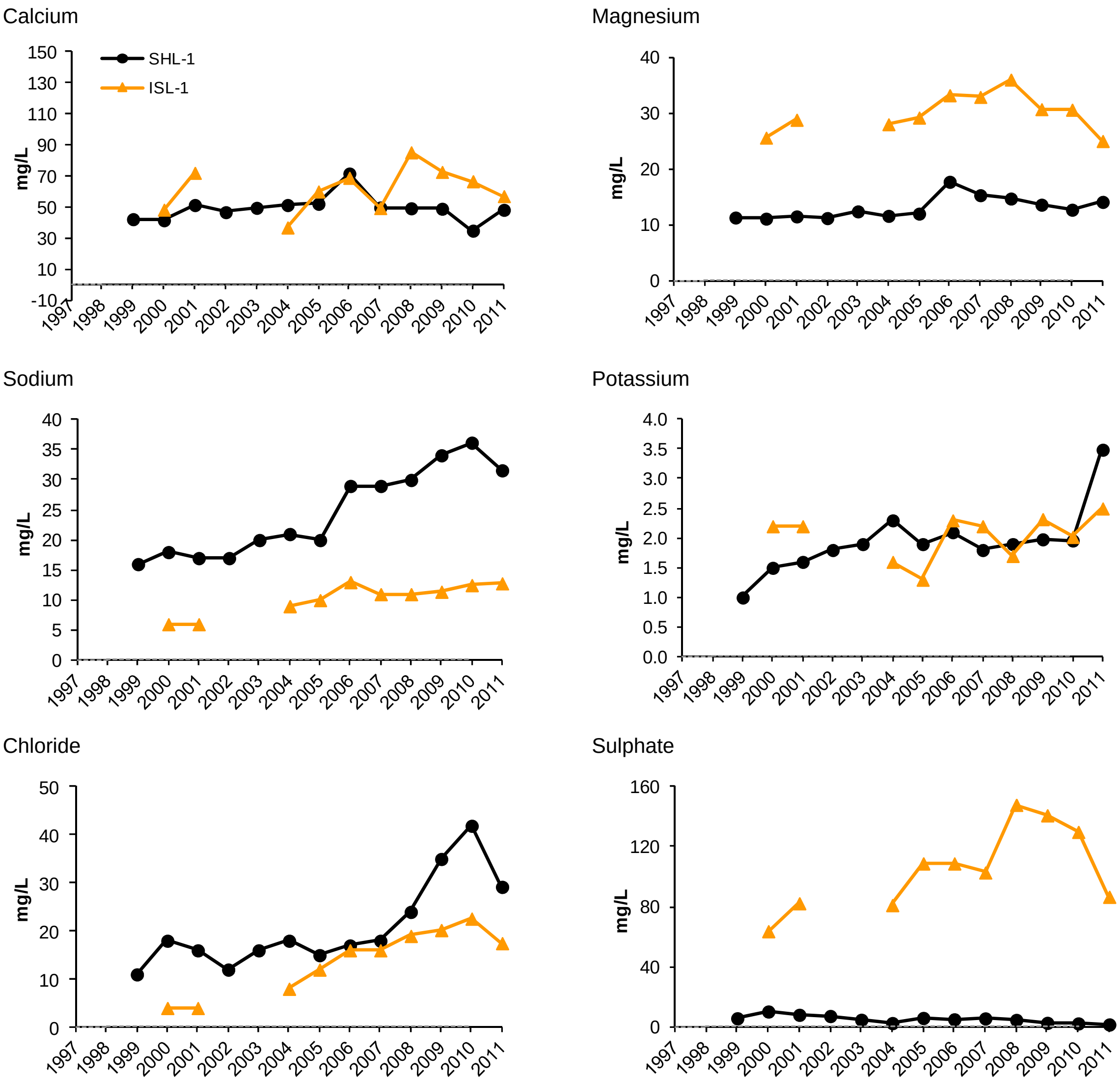


Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Figure 5.11-7 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O⋯⋯O Sampled as a *baseline* station ●——● Sampled as a *test* station

Table 5.11-7 Water quality index (fall 2011) for miscellaneous watershed stations.

Station Identifier	Location	2011 Designation	Water Quality Index	Classification
POC-1	near the mouth of Poplar Creek	*test*	89.8	Negligible-Low
FOC-1	near the mouth of Fort Creek	*test*	81.2	Negligible-Low
BER-1	near the mouth of Beaver River	*test*	63.0	Moderate
BER-2	upper Beaver River	*baseline*	93.0	Negligible-Low
MCC-1	near the mouth of McLean Creek	*test*	61.7	Moderate
MIC-1	Mills Creek	*test*	69.7	Moderate
PIR-1	near the mouth of Pierre River	*baseline*	93.7	Negligible-Low
EYC-1	near the mouth of Eymundson Creek	*baseline*	64.1	Moderate
BIC-1	near the mouth of Big Creek	*baseline*	97.5	Negligible-Low
REC-1	near the mouth of Red Clay Creek	*baseline*	96.2	Negligible-Low

Table 5.11-8 Average habitat characteristics of benthic invertebrate sampling locations in Isadore's Lake.

Variable	Units	Isadore's Lake (ISL-1)
Sample date	-	Sept. 11, 2011
Habitat	-	Depositional
Water depth	m	2.0
Field Water Quality		
Dissolved oxygen	mg/L	6.9
Conductivity	µS/cm	544
pH	pH units	8.0
Water temperature	°C	19
Sediment Composition		
Sand	%	3
Silt	%	86
Clay	%	11
Total Organic Carbon	%	6

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					
	Isadore's Lake					
	2006	2007	2008	2009	2010	2011
Nematoda	72	32	49	25	12	69
Glossiphoniidae						<1
Naididae	4	1	6		2	8
Tubificidae				<1		<1
Hydracarina			8		<1	
Amphipoda	<1				<1	
Ostracoda	1	2	7	<1	14	4
Cladocera		4				
Copepoda	3	4	11	67	22	<1
Gastropoda				<1	<1	<1
Bivalvia					<1	
Ceratopogonidae	<1					<1
Chaoboridae	<1			<1	<1	<1
Chironomidae	2	57	19	7	50	17
Ephemeroptera		1			<1	
Anisoptera			<1		<1	<1
Benthic Invertebrate Community Measurement Endpoints						
Total Abundance (No./m^2)	33,987	20,110	13,870	10,948	23,623	15,614
Richness	10	9	6	5	8	7
Simpson's Diversity	0.41	0.63	0.66	0.46	0.61	0.38
Evenness	0.42	0.75	0.69	0.62	0.71	0.45
% EPT	0	1	0	0	<1	0

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	Variance Explained (%)	Nature of Change(s)	Spearman Rank
	Time Trend	Time Trend		r_s
Abundance	0.923	0	No change	-0.37
Richness	0.117	20	No change	-0.54
Simpson's Diversity	0.428	4	No change	-0.31
Evenness	0.993	0	No change	0.03
EPT	0.469	20	No change	-0.54
CA Axis 1	0.293	5	No change	0.14
CA Axis 2	0.190	7	No change	-0.20

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Figure 5.11-8 Annual changes in values of benthic invertebrate community measurement endpoints in Isadore's Lake (*test* station ISL-1).

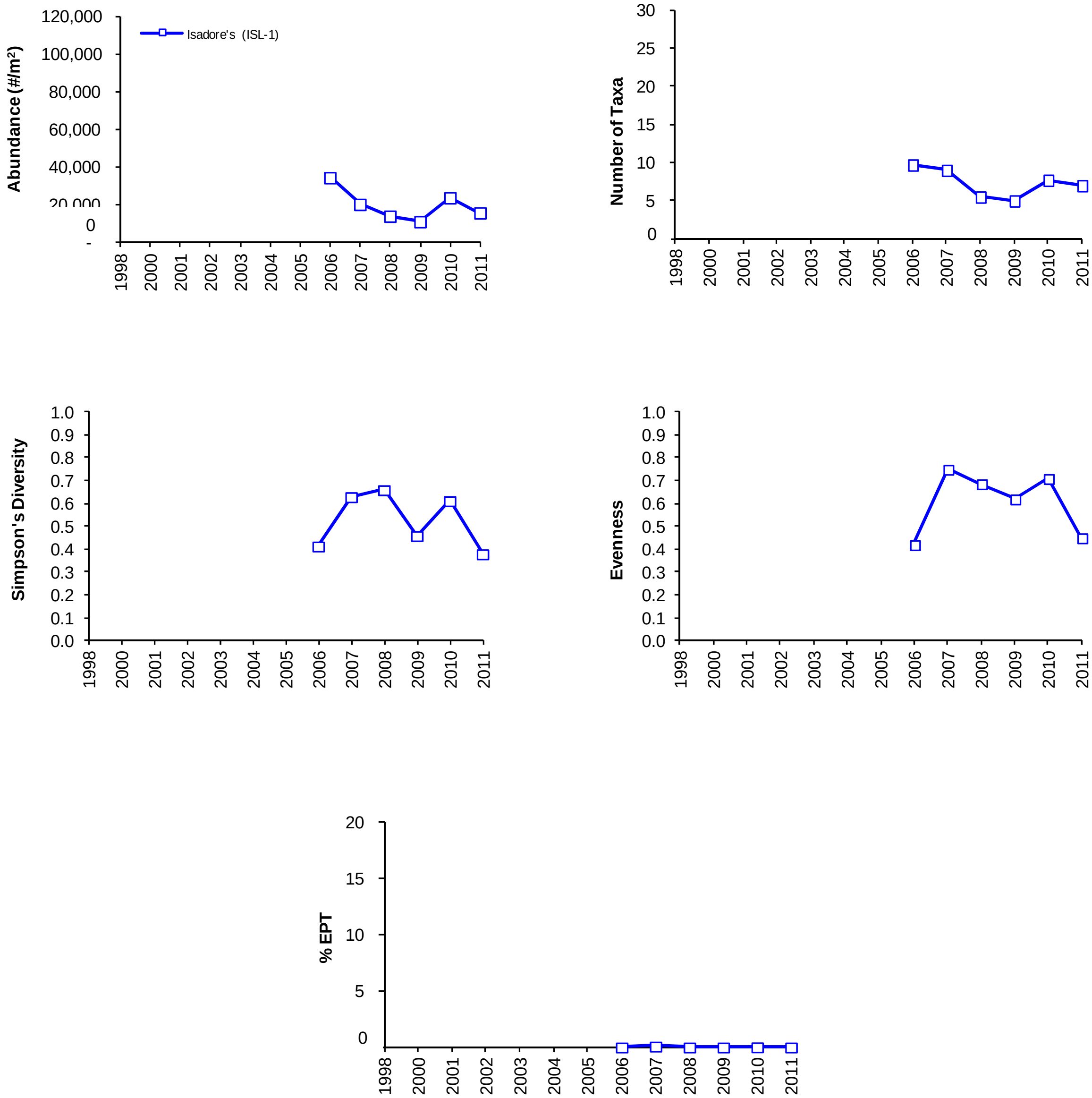
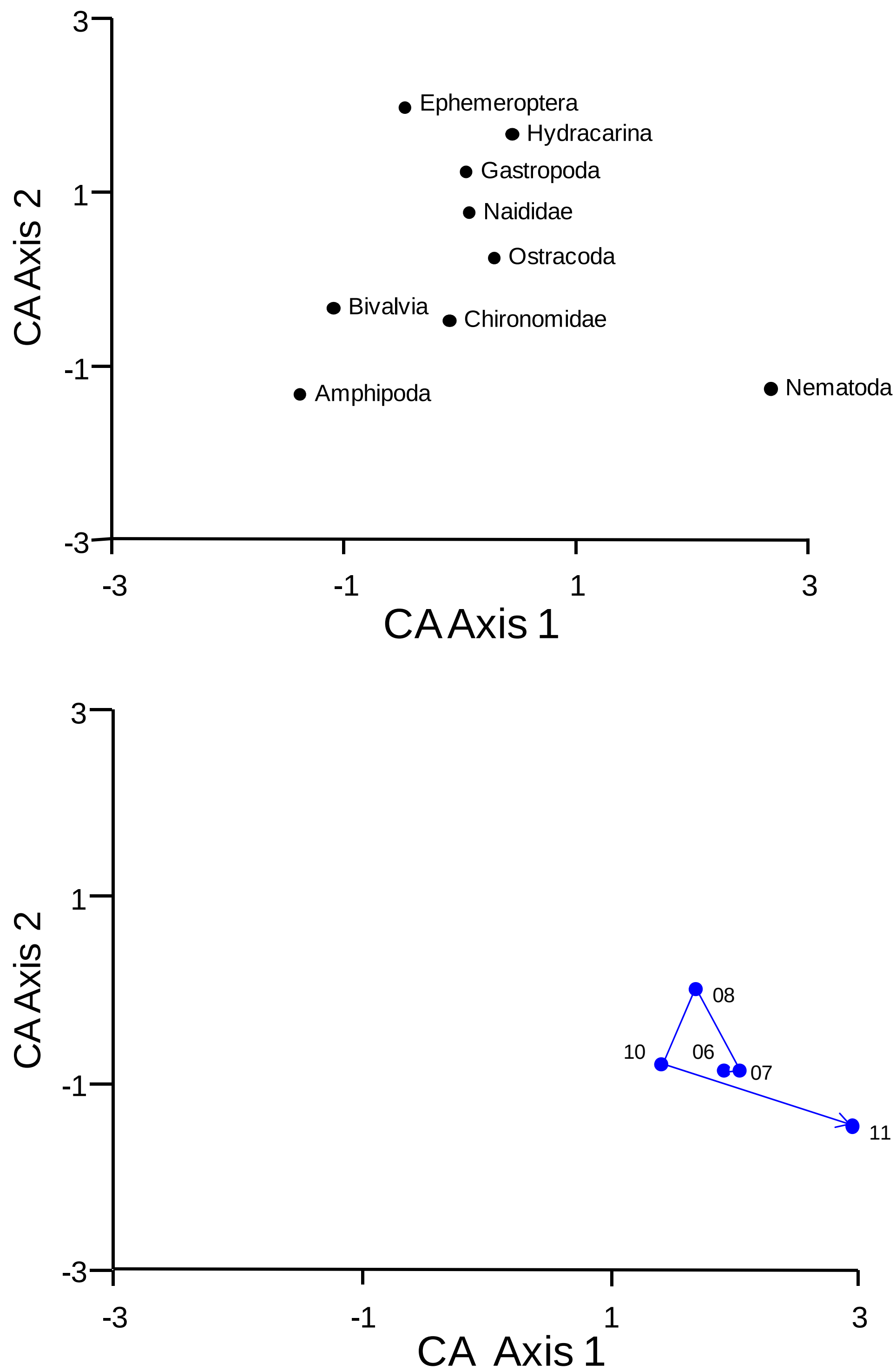


Figure 5.11-9 Ordination (Correspondence Analysis) of benthic invertebrate communities in Isadore's Lake.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores.

Table 5.11-11 Concentrations of sediment quality measurement endpoints, Isadore's Lake (*test* station ISL-1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	11	6	19	26	57
Silt	%	-	86	6	39	57	64
Sand	%	-	3	6	3	12	35
Total organic carbon	%	-	5.7	6	1.3	4.6	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<100	5	<5	<10	<50
Fraction 1 (C6-C10)	mg/kg	30[1]	**<100**	5	<5	<10	**<50**
Fraction 2 (C10-C16)	mg/kg	150[1]	<90	5	<5	23	91
Fraction 3 (C16-C34)	mg/kg	300[1]	**539**	5	150	**323**	**4600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	319	5	89	252	3500
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0067	6	0.0060	0.0074	0.0110
Retene	mg/kg	-	0.0437	6	0.0367	0.0608	0.0710
Total dibenzothiophenes	mg/kg	-	0.1146	6	0.1449	0.1722	0.2607
Total PAHs	mg/kg	-	0.7792	6	1.2792	1.4648	2.0559
Total Parent PAHs	mg/kg	-	0.0683	6	0.0997	0.1450	0.1751
Total Alkylated PAHs	mg/kg	-	0.7109	6	1.1150	1.3438	1.8808
Predicted PAH toxicity[3]	H.I.	1.0	0.23	6	0.07	0.58	**1.29**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	6.4	3	7.0	7.0	9.0
Chironomus growth - 10d	mg/organism	-	1.06	3	1.89	2.43	2.63
Hyalella survival - 14d	# surviving	-	7.6	3	8.0	9.6	9.8
Hyalella growth - 14d	mg/organism	-	0.44	3	0.20	0.26	0.36

Values in **bold** indicate concentrations exceeding guidelines.

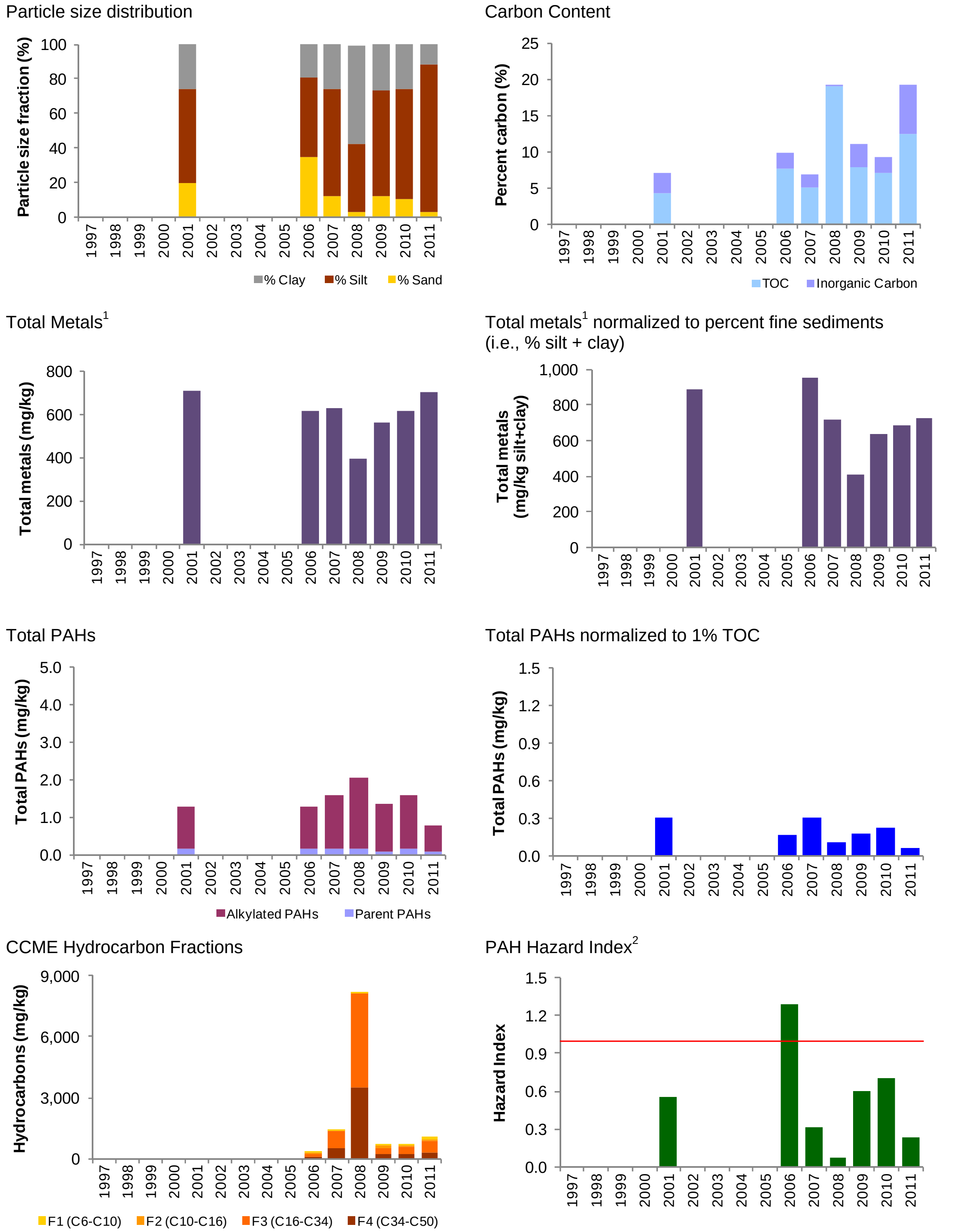
Values underlined indicate concentrations outside the range of historic observations.

[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 5.11-10 Variation in sediment quality measurement endpoints in Isadore's Lake, *test* station ISL-1.



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red 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 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.1	12	7.7	8.1	8.2
Total suspended solids	mg/L	-	8	12	<3	3	15
Conductivity	µS/cm	-	454	12	358	408	509
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.014	12	0.004	0.008	0.026
Total nitrogen	mg/L	1	0.99	12	0.30	0.95	**1.40**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	21.2	12	16.7	19.6	24.0
Ions							
Sodium	mg/L	-	31.6	12	16.0	20.5	36.2
Calcium	mg/L	-	48.4	12	35.0	49.6	71.8
Magnesium	mg/L	-	14.1	12	11.1	12.2	17.7
Chloride	mg/L	230, 860	29.2	12	11.0	17.5	41.9
Sulphate	mg/L	100	<u>1.9</u>	12	2.6	5.6	10.5
Total dissolved solids	mg/L	-	307	12	200	272	320
Total alkalinity	mg/L		187	12	159	184	251
Selected metals							
Total aluminum	mg/L	0.1	0.050	12	<0.002	0.009	**0.140**
Dissolved aluminum	mg/L	0.1	0.0019	12	<0.001	0.0012	<0.01
Total arsenic	mg/L	0.005	0.00093	12	0.0004	0.00050	0.00100
Total boron	mg/L	1.2	0.071	12	0.027	0.046	0.074
Total molybdenum	mg/L	0.073	0.00013	12	0.00002	0.00008	0.00020
Total mercury (ultra-trace)	ng/L	5, 13	0.7	8	<0.6	<1.2	1.4
Total strontium	mg/L	-	<u>0.24</u>	12	0.12	0.16	0.21
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	8.4	0	-	-	-
Total PAHs	ng/L	-	163.3	0	-	-	-
Total Parent PAHs	ng/L	-	21.3	0	-	-	-
Total Alkylated PAHs	ng/L	-	142.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.68**	12	<0.01	0.16	**0.86**
Sulphide	mg/L	0.002	**0.009**	12	<0.003	**0.009**	**0.014**
Total iron	mg/L	0.3	**<u>1.54</u>**	12	0.27	**0.4185**	**1.48**
Total phenols	mg/L	0.004	**0.0058**	12	<0.001	**0.006**	**0.012**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Table 5.11-13 Average habitat characteristics of benthic invertebrate sampling locations in Shipyard Lake.

Variable	Units	Shipyard Lake (SHL-1)
Sample date	-	Sept. 11, 2011
Habitat	-	Depositional
Water depth	m	1.8
Field Water Quality		
Dissolved oxygen	mg/L	3.8
Conductivity	µS/cm	451
pH	pH units	7.8
Water temperature	°C	18
Sediment Composition		
Sand	%	34
Silt	%	38
Clay	%	28
Total Organic Carbon	%	9

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											
	Shipyard Lake											
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Hydra												<1
Nematoda			3	2	2	1	1	1	1	5	4	3
Erpobdellidae							1				<1	
Glossiphoniidae		<1	<1	<1							<1	<1
Naididae	8	<1	3		4	9	16	6	5	3	12	33
Tubificidae	1		1	3	1	7			<1	<1	<1	<1
Enchytraeidae										7		<1
Lumbriculidae						<1						<1
Hydracarina		1	<1		<1	1		3	2	2	4	1
Amphipoda	7		2	3		2	2	2	1	<1	<1	<1
Ostracoda	6	2	25	8	87	5	22	40	22	32	9	<1
Cladocera	3				<1	2		1	3	<1	6	10
Copepoda	1	<1		9	1	3	1	11	16	16	27	1
Gastropoda	18	1	7	5	1	2	<1	3	2	7	5	1
Bivalvia	7	<1	8	6	1	<1	2	1	1	2	3	2
Ceratopogonidae		1	<1	1			6			<1	<1	<1
Chaoboridae	3	53	1	32	1	<1	6			2	<1	<1
Chironomidae	25	40	48	32	3	30	37	27	40	20	26	44
Ephemeroptera	16	1	2			<1	<1	3	6	<1	4	<1
Anisoptera	<1	1	<1			<1			<1		<1	<1
Zygoptera	3		1		<1				1		<1	
Trichoptera	2	1	<1		<1	1	1	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	67,703
Richness	13	6	13	4	9	15	12	15	21	11	27	19
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	0.77
Evenness	0.92	0.55	0.84	0.83	0.24	0.69	0.72	0.81	0.89	0.71	0.87	0.82
% EPT	19	1	2	<1	<1	1	<1	2	4	<1	5	<1

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	Variance Explained (%)	Nature of Change(s)	Spearman Rank
	Time Trend	Time Trend		r_s
Abundance	**<0.001**	43	Increasing over time	0.66
Richness	**<0.001**	38	Increasing over time	0.43
Simpson's Diversity	**<0.001**	11	Increasing over time	0.31
Evenness	**0.017**	4	Increasing over time	0.31
EPT	0.130	2	No change	-0.20
CA Axis 1	**0.001**	28	Increasing over time	0.66
CA Axis 2	**0.001**	28	Increasing over time	0.37

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).

Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Figure 5.11-11 Annual changes in values of benthic invertebrate community measurement endpoints in Shipyard Lake (*test* station SHL-1).

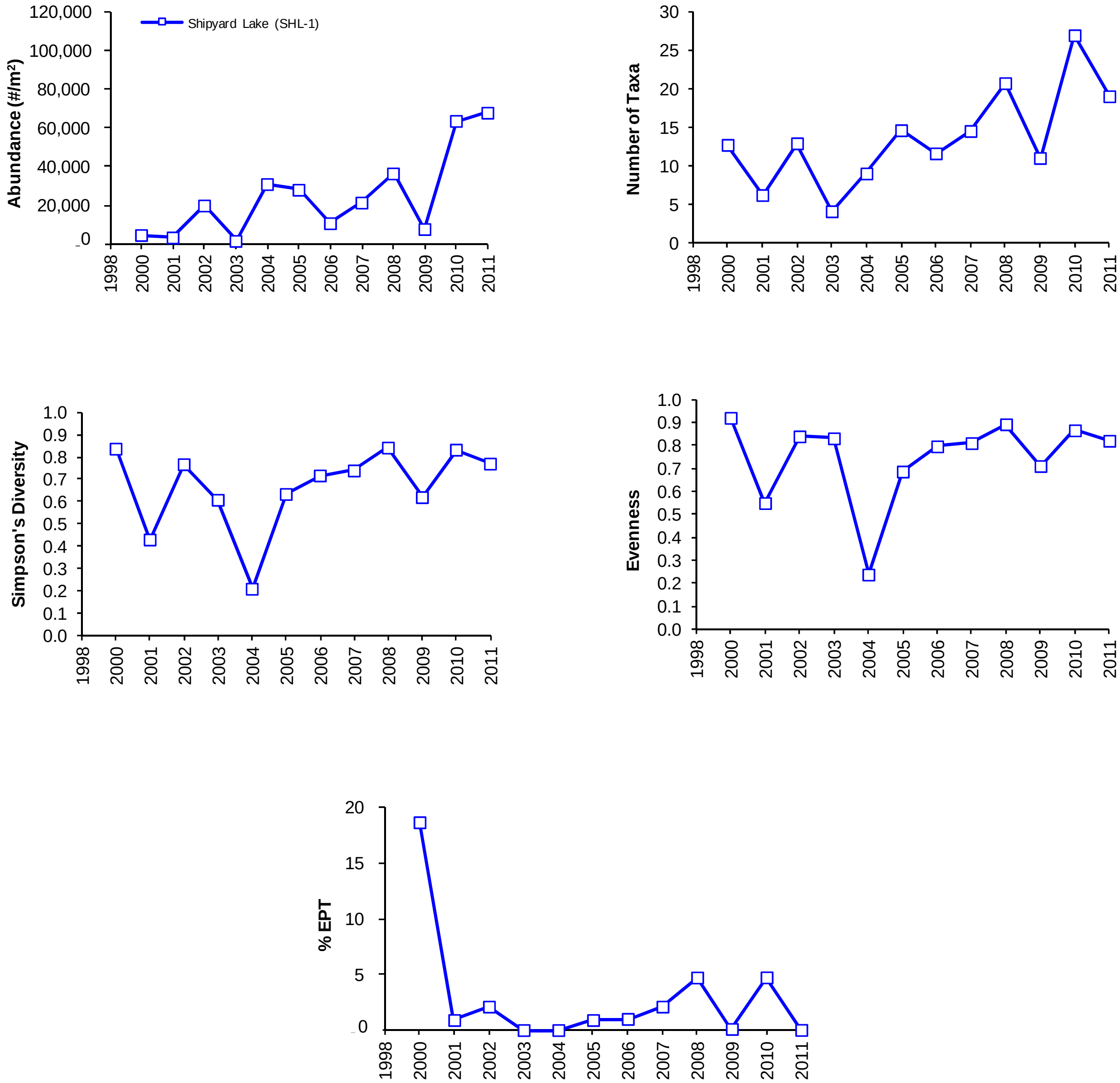
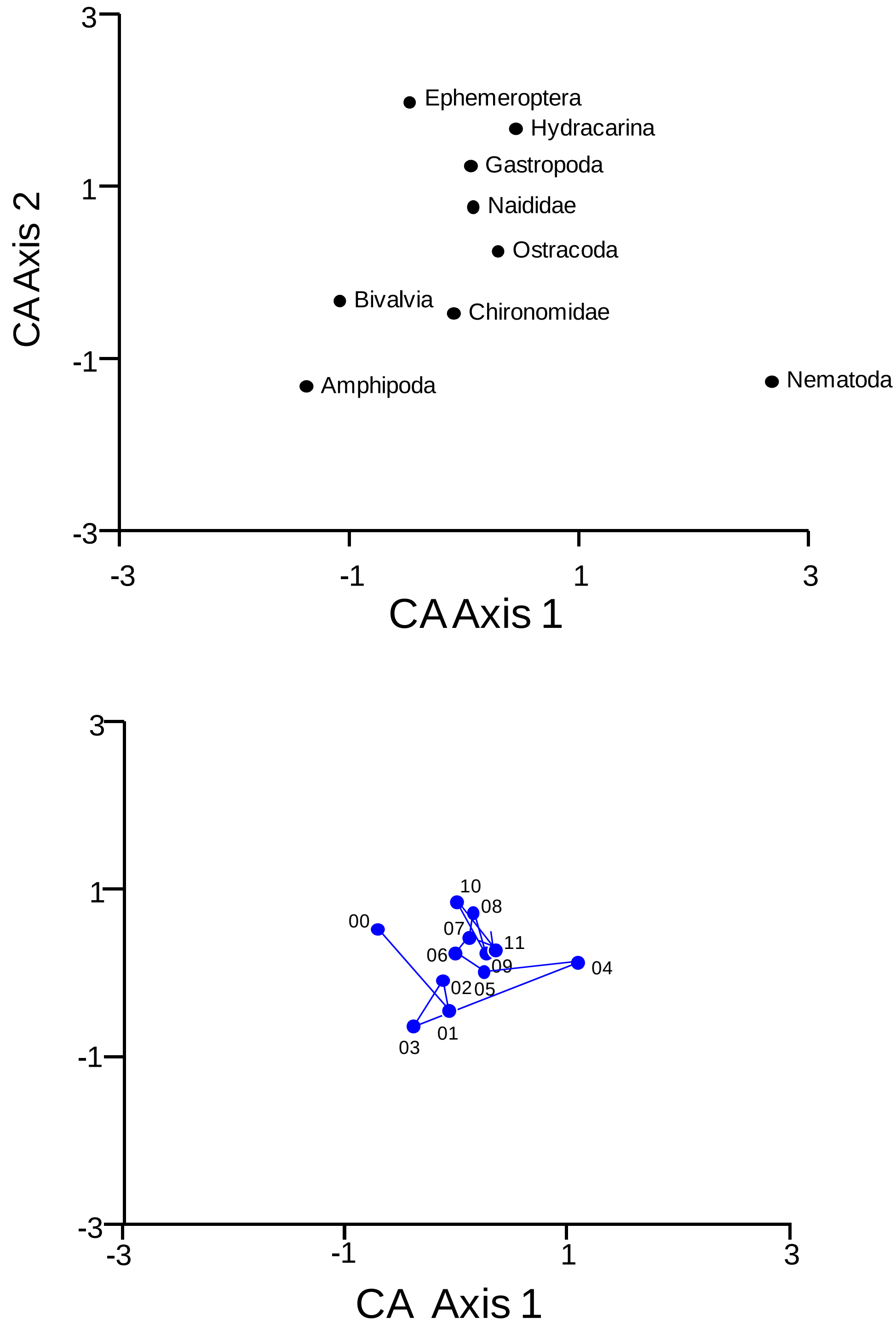


Figure 5.11-12 Ordination (Correspondence Analysis) of benthic invertebrate communities in Shipyard Lake.



Note: The upper panel is the scatterplot of taxa scores while the lower panel is the scatterplot of sample scores.

Table 5.11-16 Concentrations of sediment quality measurement endpoints, Shipyard Lake (*test* station SHL-1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	28	8	18	45	60
Silt	%	-	38	8	36	41	69
Sand	%	-	34	8	2	5	41
Total organic carbon	%	-	8.8	9	5.5	13.4	18.8
Total hydrocarbons							
BTEX	mg/kg	-	<240	6	<5	<8	<150
Fraction 1 (C6-C10)	mg/kg	30[1]	**<240**	6	<5	<8	**<150**
Fraction 2 (C10-C16)	mg/kg	150[1]	**<313**	6	<5	37	**243**
Fraction 3 (C16-C34)	mg/kg	300[1]	**1990**	6	290	**860**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	<u>1180</u>	6	<5	255	919
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0140	7	0.0108	0.0186	0.0306
Retene	mg/kg	-	0.1210	9	0.0460	0.0821	0.1990
Total dibenzothiophenes	mg/kg	-	1.3669	9	0.2645	0.6284	2.6221
Total PAHs	mg/kg	-	6.9108	9	2.2756	4.3648	10.7175
Total Parent PAHs	mg/kg	-	0.5720	9	0.2305	0.2556	0.6725
Total Alkylated PAHs	mg/kg	-	6.3388	9	2.0200	4.0365	10.1060
Predicted PAH toxicity[3]	H.I.	1.0	0.55	9	0.10	0.89	**3.79**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Other analytes that exceeded CCME guidelines in 2011							
Benz[a]anthracene	mg/kg	0.0317	**0.0605**	7	0.0100	0.0159	**0.0639**
Benzo[a]pyrene	mg/kg	0.0319	**0.0617**	7	0.0130	0.0190	**0.0702**
Chrysene	mg/kg	0.0571	**0.1270**	7	0.0334	0.0450	**0.1630**
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.6	5	5.6	7.6	8.2
Chironomus growth - 10d	mg/organism	-	<u>1.25</u>	5	1.50	2.00	2.56
Hyalella survival - 14d	# surviving	-	8.2	5	6.0	7.7	8.4
Hyalella growth - 14d	mg/organism	-	<u>0.45</u>	5	0.10	0.21	0.37

Values in **bold** indicate concentrations exceeding guidelines.

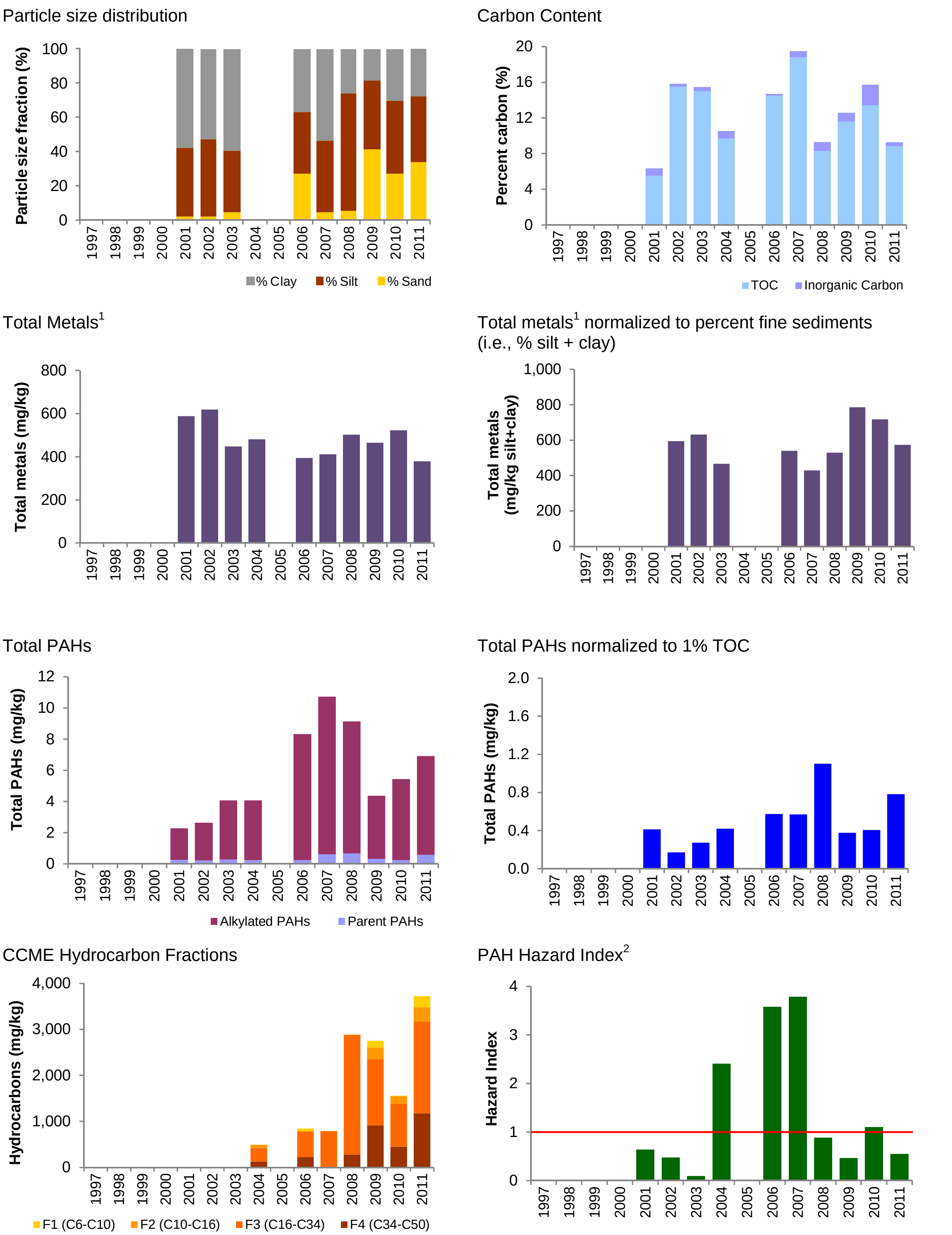
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

[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.

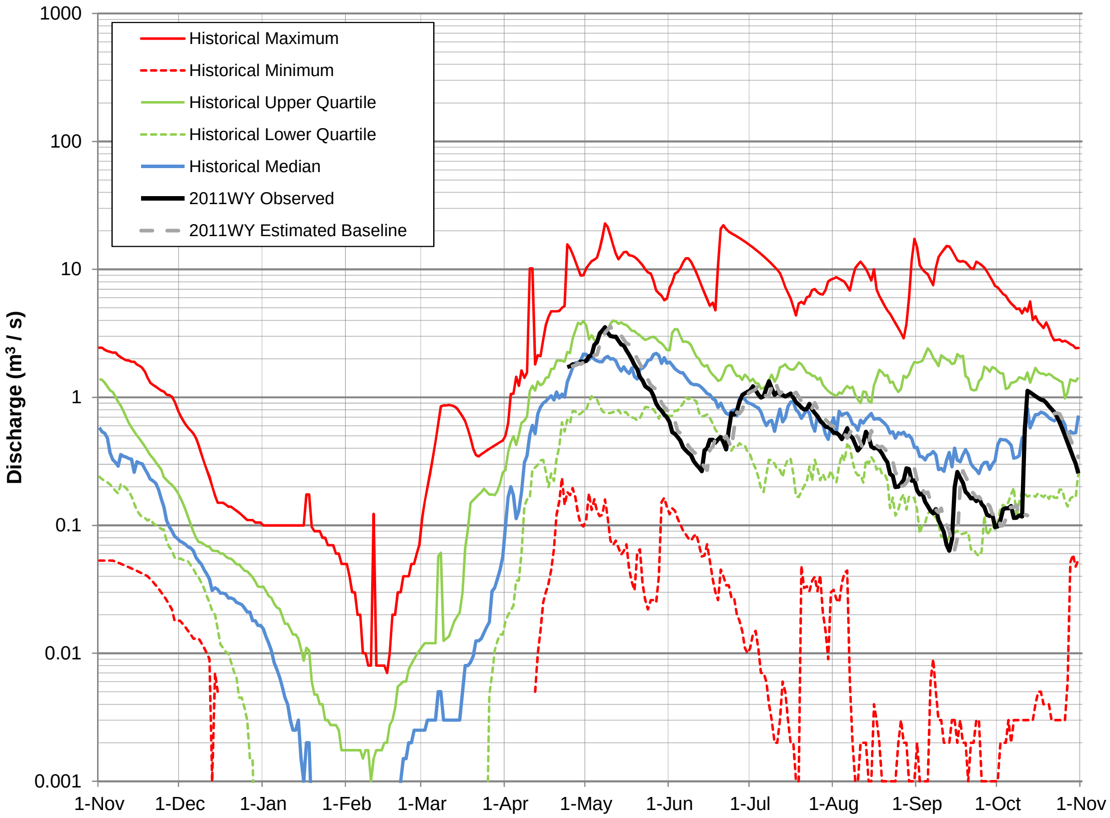
Figure 5.11-13 Variation in sediment quality measurement endpoints in Shipyard Lake, *test* station SHL-1.



[1] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[2] Red line indicates potential chronic effects level (HI = 1.0).

Figure 5.11-14 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Poplar Creek in 2011, compared to historical values.



Note: Observed values are calculated from provisional data for April 24 to October 31, 2011 WY for Poplar Creek at Highway 63, WSC Station 07DA007 (RAMP Station S11). 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 to 2010, 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, 2011. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a, RAMP 2010), 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, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* hydrograph (total discharge)	**13.20**	**Observed daily discharges, obtained from Poplar Creek at Highway 63, WSC Station 07DA007 (RAMP Station S11).**
Closed-circuited area water loss from the observed *test* hydrograph	-0.25	Estimated 3.1 km^2 of the Poplar Creek watershed is closed-circuited by focal projects as of 2011 (Table 2.5-1)
Incremental runoff from land clearing (not closed-circuited area)	+0.03	Estimated 1.8 km^2 of the Poplar Creek watershed with land change from focal projects as of 2011 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	+1.14	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)	**12.63**	**Estimated *baseline* discharge at Poplar Creek at Highway 63, WSC Station 07DA007 (RAMP Station S11).**
Incremental flow (change in total discharge)	+0.92	Total discharge from observed *test* hydrograph less total discharge from estimated *baseline* hydrograph.
Incremental flow (% of total discharge)	**+4.5%**	**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 26 to October 31, 2011 for Poplar Creek at Highway 63, WSC Station 07DA007 (RAMP Station S11). 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, 2011. *Baseline* values on these days were set to zero, in accordance with previous reports (e.g., RAMP 2008, RAMP 2009a, RAMP 2010, RAMP 2011).

Table 5.11-18 Calculated change in hydrologic measurement endpoints for the Poplar Creek watershed, 2011 WY.

Measurement Endpoint	Value from *Baseline* Hydrograph (m^3/s)	Value from *Test* Hydrograph (m^3/s)	Relative Change
Mean open-water season discharge	0.75	0.78	+4.9%
Mean winter discharge	not measured	not measured	-
Annual maximum daily discharge	3.59	3.54	-1.2%
Open-water season minimum daily discharge	0.065	0.063	-1.8%

Note: Definitions and assumptions are discussed in Section 3.2.1.4.

Note: Values are calculated from provisional data for April 26 to October 31, 2011 for Poplar Creek at Highway 63, WSC Station 07DA007 (RAMP Station S11). 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, RAMP 2010, RAMP 2011).

Note: The relative change for each measurement endpoint is calculated using observed and *baseline* flow values, which are estimated to several decimal places. However, for clarity in this table, all flows and percentage change values are presented to three and one decimal places, respectively.

Table 5.11-19 Concentrations of water quality measurement endpoints, Poplar Creek (*test* station POC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.2	11	8.2	8.3	8.4
Total suspended solids	mg/L	-	15	11	4	10	61
Conductivity	µS/cm	-	694	11	308	459	1590
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.015	11	0.007	0.013	0.027
Total nitrogen	mg/L	1	**1.13**	11	0.30	1.00	**2.11**
Nitrate+nitrite	mg/L	1.3	0.08	11	<0.05	0.10	0.10
Dissolved organic carbon	mg/L	-	25	11	10	24	32
Ions							
Sodium	mg/L	-	75.4	11	10.0	44.0	238.0
Calcium	mg/L	-	41.3	11	28.2	39	74.4
Magnesium	mg/L	-	16.1	11	9.7	13.5	29.3
Chloride	mg/L	230, 860	64.6	11	2.0	20.0	321.0
Sulphate	mg/L	100	30.2	11	7.8	14.7	44.2
Total dissolved solids	mg/L	-	417	11	200	270	890
Total alkalinity	mg/L		225	11	135	191	304
Selected metals							
Total aluminum	mg/L	0.1	**0.76**	11	**0.05**	**0.32**	**1.44**
Dissolved aluminum	mg/L	0.1	0.005	11	0.002	0.007	0.090
Total arsenic	mg/L	0.005	0.0022	11	0.0008	0.0010	0.0023
Total boron	mg/L	1.2	0.18	11	0.04	0.12	0.18
Total molybdenum	mg/L	0.073	0.00043	11	0.00010	0.00025	0.00072
Total mercury (ultra-trace)	ng/L	5, 13	1.2	8	0.8	<1.2	2
Total strontium	mg/L	-	0.34	11	0.15	0.20	0.51
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	2.17	0	-	-	-
Total dibenzothiophenes	ng/L	-	17.0	0	-	-	-
Total PAHs	ng/L	-	184.6	0	-	-	-
Total Parent PAHs	ng/L	-	20.4	0	-	-	-
Total Alkylated PAHs	ng/L	-	164.2	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.84**	11	0.05	0.18	**2.32**
Sulphide	mg/L	0.002	**0.0062**	11	<0.003	**0.0070**	**0.0102**
Total iron	mg/L	0.3	**2.13**	11	**0.70**	**1.08**	**3.63**
Total Kjeldahl Nitrogen	mg/L	1	**1.05**	11	<0.2	0.9	**2.04**
Total phenols	mg/L	0.004	**0.0051**	11	<0.001	**0.0070**	**0.0190**
Total phosphorus	mg/L	0.05	**0.051**	11	0.029	0.036	**0.064**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.11-20 Concentrations of water quality measurement endpoints, lower Beaver River (*test* station BER-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	8	8.0	8.2	8.3
Total suspended solids	mg/L	-	77	8	<3	9	35
Conductivity	µS/cm	-	1930	8	566	801	1430
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.008	8	0.004	0.010	0.022
Total nitrogen	mg/L	1	**1.10**	8	0.70	**1.05**	**1.68**
Nitrate+nitrite	mg/L	1.3	<0.071	8	<0.071	<0.1	<0.1
Dissolved organic carbon	mg/L	-	33.9	8	15.0	32.5	52.0
Ions							
Sodium	mg/L	-	267	8	53	74	181
Calcium	mg/L	-	91.5	8	49.1	66.9	91.4
Magnesium	mg/L	-	28.1	8	15.5	19.1	27.9
Chloride	mg/L	230, 860	**364**	8	55	75	221
Sulphate	mg/L	100	65.5	8	50.7	70.8	117.0
Total dissolved solids	mg/L	-	1110	8	450	573	830
Total alkalinity	mg/L		349	8	158	230	294
Selected metals							
Total aluminum	mg/L	0.1	**2.34**	8	0.03	0.25	5.13
Dissolved aluminum	mg/L	0.1	0.004	8	0.002	0.008	0.045
Total arsenic	mg/L	0.005	0.0018	8	0.0007	0.0009	0.0021
Total boron	mg/L	1.2	0.24	8	0.09	0.12	0.17
Total molybdenum	mg/L	0.073	0.00043	8	0.00019	0.00031	0.00040
Total mercury (ultra-trace)	ng/L	5, 13	2.5	8	<1.2	1.3	8.1
Total strontium	mg/L	-	0.63	8	0.23	0.27	0.43
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	15.7	0	-	-	-
Retene	ng/L	-	8.3	0	-	-	-
Total dibenzothiophenes	ng/L	-	39.9	0	-	-	-
Total PAHs	ng/L	-	372.3	0	-	-	-
Total Parent PAHs	ng/L	-	30.3	0	-	-	-
Total Alkylated PAHs	ng/L	-	342.0	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved chromium	mg/L	0.001	**0.0016**	8	0.0004	0.0008	**0.0018**
Sulphide	mg/L	0.002	**0.013**	8	**0.003**	**0.021**	**0.038**
Total chromium	mg/L	0.001	**0.0028**	8	0.0004	0.0010	**0.0075**
Total iron	mg/L	0.3	**7.0**	8	**1.8**	**2.3**	**5.9**
Total Kjeldahl Nitrogen	mg/L	1	**1.03**	8	0.60	0.95	**1.61**
Total phenols	mg/L	0.004	**0.008**	7	0.002	**0.009**	**0.015**
Total phosphorus	mg/L	0.05	**0.09**	8	0.02	0.03	**0.13**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; underlined values are outside of historical range.

Table 5.11-21 Concentrations of water quality measurement endpoints, upper Beaver River (*baseline* station BER-2), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	<u>8.4</u>	3	7.8	8.2	8.3
Total suspended solids	mg/L	-	9	3	6	10	93
Conductivity	µS/cm	-	<u>511</u>	3	255	315	445
Nutrients							
Total dissolved phosphorus	mg/L	0.05	**0.056**	3	0.037	**0.067**	**0.074**
Total nitrogen	mg/L	1	<u>0.89</u>	3	**1.30**	**2.16**	**2.44**
Nitrate+nitrite	mg/L	1.3	<0.071	3	<0.071	<0.071	<0.1
Dissolved organic carbon	mg/L	-	<u>22.5</u>	3	24.6	32	34
Ions							
Sodium	mg/L	-	<u>67.7</u>	3	20.9	31.0	53.5
Calcium	mg/L	-	34.1	3	22.5	29.7	35.8
Magnesium	mg/L	-	<u>12.2</u>	3	7.5	10.3	11.3
Chloride	mg/L	230, 860	1.35	3	0.68	1.67	2.00
Sulphate	mg/L	100	<u>12.5</u>	3	13.2	14.8	15.3
Total dissolved solids	mg/L	-	<u>348</u>	3	210	238	332
Total alkalinity	mg/L		<u>266</u>	3	118	151	225
Selected metals							
Total aluminum	mg/L	0.1	**0.50**	3	**0.27**	**0.43**	**2.17**
Dissolved aluminum	mg/L	0.1	0.018	3	0.012	0.027	0.034
Total arsenic	mg/L	0.005	0.0016	3	0.0014	0.0017	0.0018
Total boron	mg/L	1.2	<u>0.42</u>	3	0.09	0.16	0.22
Total molybdenum	mg/L	0.073	<u>0.00063</u>	3	0.00020	0.00030	0.00055
Total mercury (ultra-trace)	ng/L	5, 13	<u>0.9</u>	3	1.5	1.9	**10.6**
Total strontium	mg/L	-	<u>0.27</u>	3	0.15	0.18	0.24
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	2.9	0	-	-	-
Total dibenzothiophenes	ng/L	-	5.8	0	-	-	-
Total PAHs	ng/L	-	151.1	0	-	-	-
Total Parent PAHs	ng/L	-	19.2	0	-	-	-
Total Alkylated PAHs	ng/L	-	131.9	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	<u>**0.74**</u>	3	**0.81**	**0.99**	**1.16**
Sulphide	mg/L	0.002	<u>**0.006**</u>	3	**0.011**	**0.014**	**0.017**
Total iron	mg/L	0.3	**1.86**	3	**1.79**	**2.14**	**3.23**
Total phenols	mg/L	0.004	**0.0061**	3	**0.0047**	**0.0080**	**0.0092**
Total phosphorus	mg/L	0.05	**0.13**	3	**0.10**	**0.11**	**0.14**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.11-15 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 to 2011.

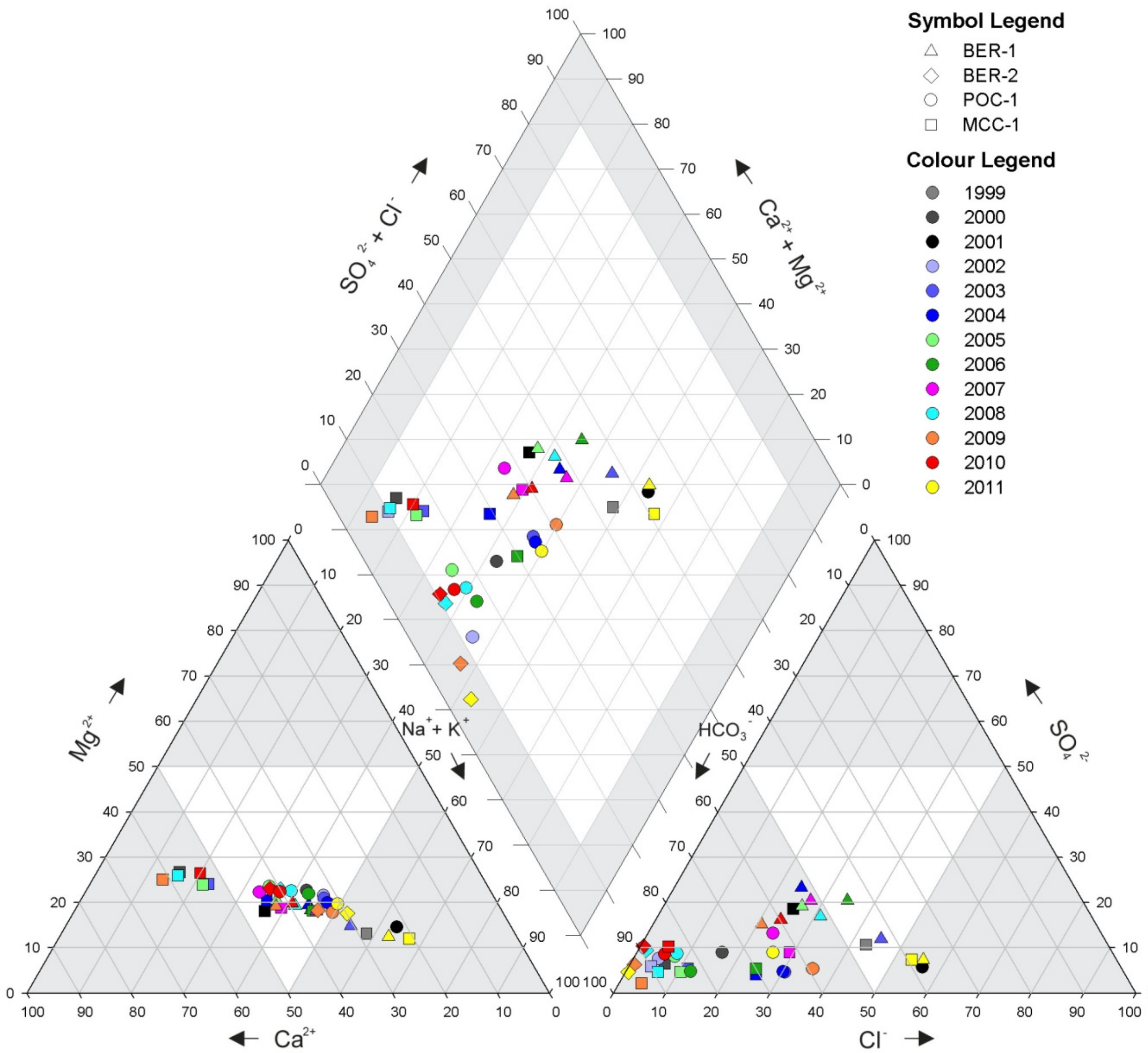
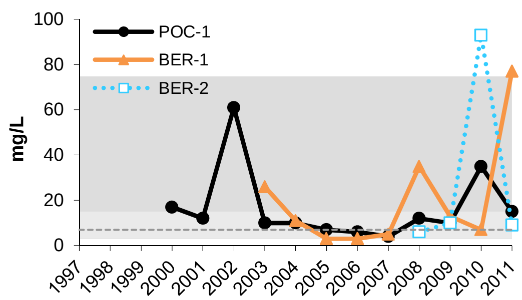
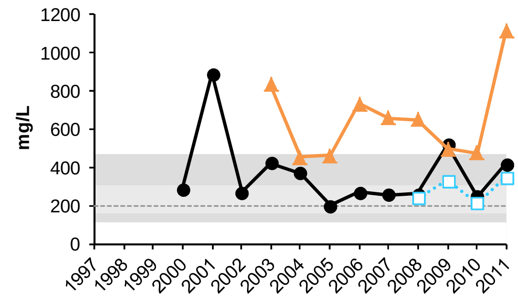


Figure 5.11-16 Concentrations of selected water quality measurement endpoints in *test* station BER-1, *test* station POC-1, and *baseline* station BER-2 (fall data) relative to historical concentrations and regional *baseline* fall concentrations.

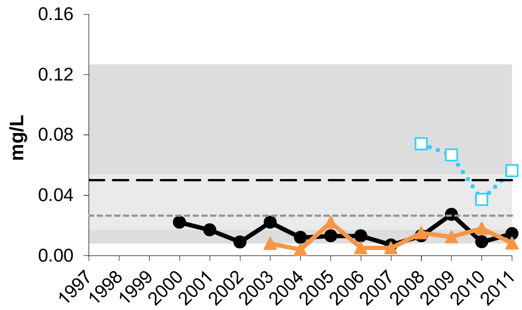
Total Suspended Solids (TSS)



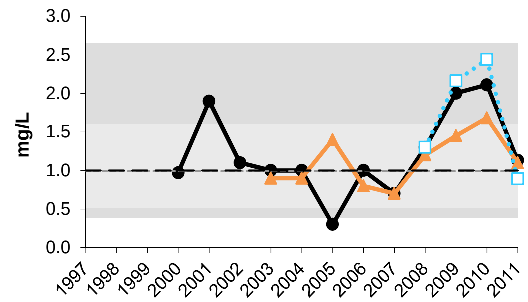
Total Dissolved Solids (TDS)



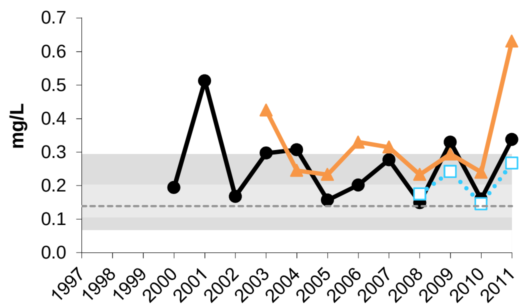
Dissolved Phosphorus



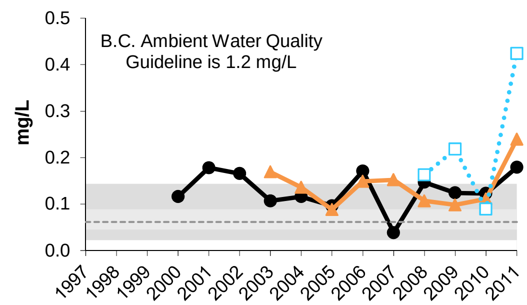
Total Nitrogen



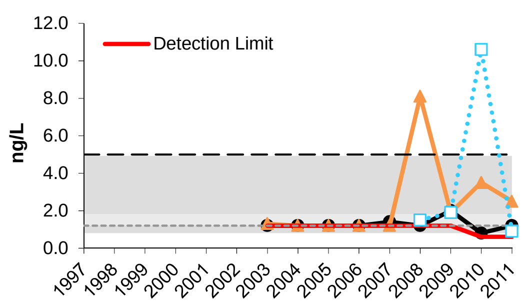
Total Strontium



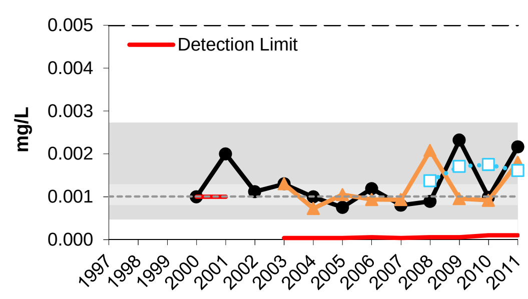
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



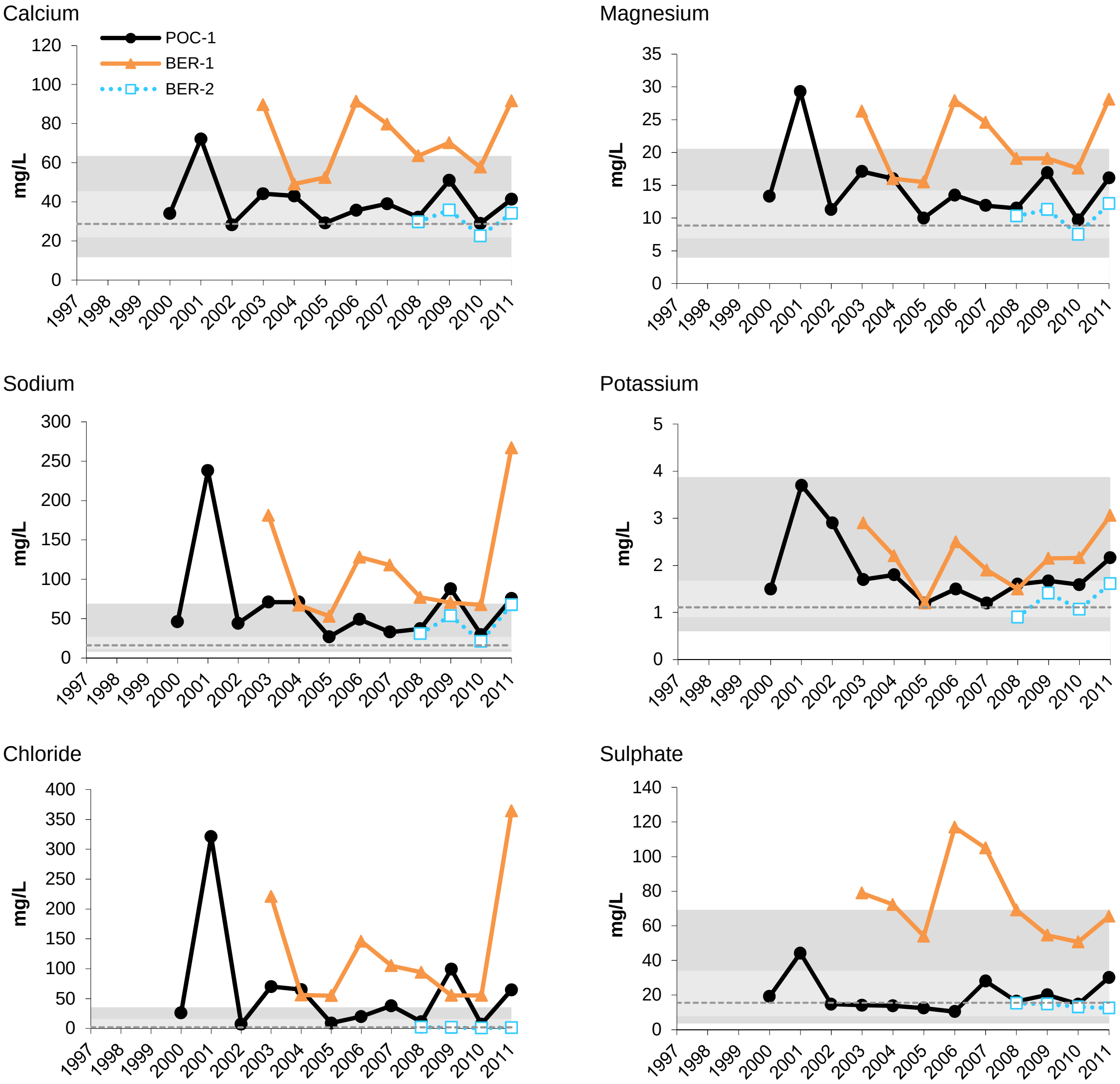
Non-detectable values are shown at the detection limit.

\- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-16 (Cont'd.)



Non-detectable values are shown at the detection limit.

– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O·······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Table 5.11-22 Average habitat characteristics of benthic invertebrate sampling locations in the Beaver River and Poplar Creek.

Variable	Units	BER-D2 Upper *Baseline* Reach of Beaver River	POC-D1 Lower *Test* Reach of Poplar Creek
Sample date	-	Sept. 6, 2011	Sept. 12, 2011
Habitat	-	Depositional	Depositional
Water depth	m	0.8	0.6
Current velocity	m/s	0.08	0.11
Field Water Quality			
Dissolved oxygen	mg/L	7.9	6.1
Conductivity	µS/cm	504	685
pH	pH units	8.1	7.6
Water temperature	°C	17.0	13.9
Sediment Composition			
Sand	%	95	36
Silt	%	2	44
Clay	%	3	20
Total Organic Carbon	%	0.1	2

Table 5.11-23 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in Upper Beaver River and Lower Poplar Creek.

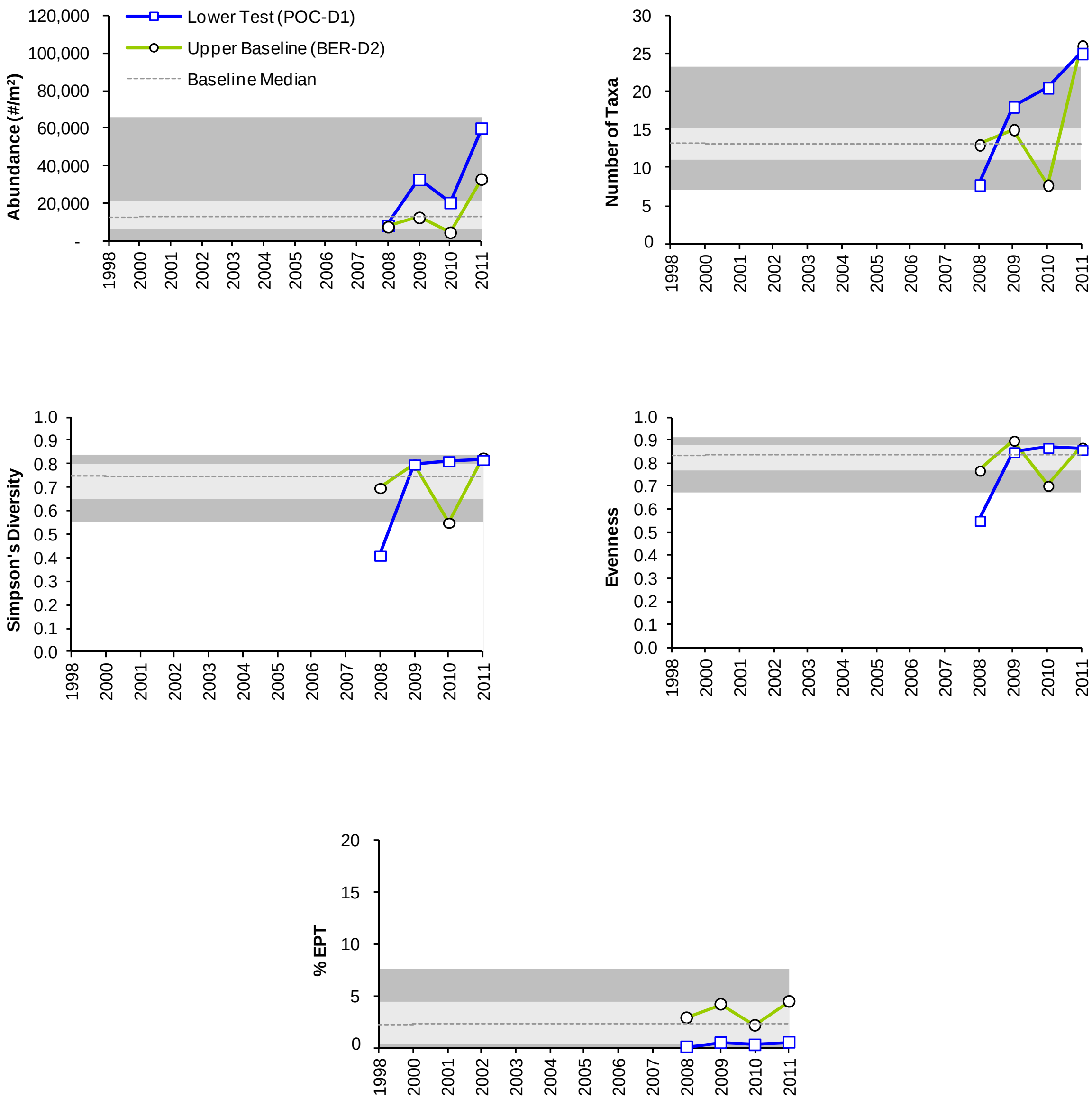
Taxon	Percent Major Taxa Enumerated in Each Year							
	Reach BER-D2				Reach POC-D1			
	2008	2009	2010	2011	2008	2009	2010	2011
Hydra				<1				<1
Nematoda	1	<1	<1	<1	2	1	5	2
Oligochaeta				<1				<1
Glossiphoniidae	<1			<1				<1
Naididae	<1	4	5	8	<1	<1	1	1
Tubificidae	1	2	19	20	72	22	22	17
Enchytraeidae	<1	<1				<1	17	
Hydracarina	1	>1	8	2			<1	<1
Amphipoda								<1
Ostracoda	1		6	2	1	4	14	14
Cladocera				2				3
Copepoda	<1	<1	1	7			2	3
Gastropoda	<1	1	3	<1		<1	<1	<1
Bivalvia	1	<1	<1	<1	1	4	10	13
Coleoptera		10	8	2	<1	1	<1	2
Ceratopogonidae	6	4	11	3	2		5	3
Chironomidae	84	71	32	46	21	64	20	41
Empididae	1	<1		<1		<1	<1	
Tipulidae				<1				
Tabanidae		<1	1	<1	<1	<1		<1
Simuliidae								<1
Ephemeroptera	4	6	6	4	<1	<1	<1	<1
Anisoptera								<1
Plecoptera				<1				
Trichoptera	<1		<1	<1	<1	<1	<1	<1
Lepidoptera				<1				
Benthic Invertebrate Community Measurement Endpoints								
Total Abundance (No./m^2)	7687	12,618	4,696	33,032	8,345	32,810	20,518	60,133
Richness	13	15	8	26	8	18	21	25
Simpson's Diversity	0.7	0.80	0.55	0.83	0.41	0.80	0.81	0.82
Evenness	0.77	0.90	0.70	0.88	0.55	0.85	0.87	0.86
% EPT	3	4	<1	4	<1	<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 Change(s)
	Baseline* vs. *Test	**Time Trend**	***Baseline* vs. *Test***	**Time Trend**	
Abundance	**<0.001**	0.262	24	2	Higher in *test* reach
Richness	0.098	**0.031**	5	8	Increasing over time at a greater rate in *test* reach
Simpson's Diversity	0.852	**0.001**	0	20	Increasing over time at a greater rate in *test* reach
Evenness	0.458	**0.017**	2	21	Increasing over time at a greater rate in *test* reach
EPT	**<0.001**	0.676	67	1	Higher in *baseline* reach
CA Axis 1	**0.008**	**0.029**	25	17	Higher in *baseline* reach and changing over time at different rates in *test* and *baseline* reaches
CA Axis 2	**<0.001**	0.867	46	0	Higher in *test* reach

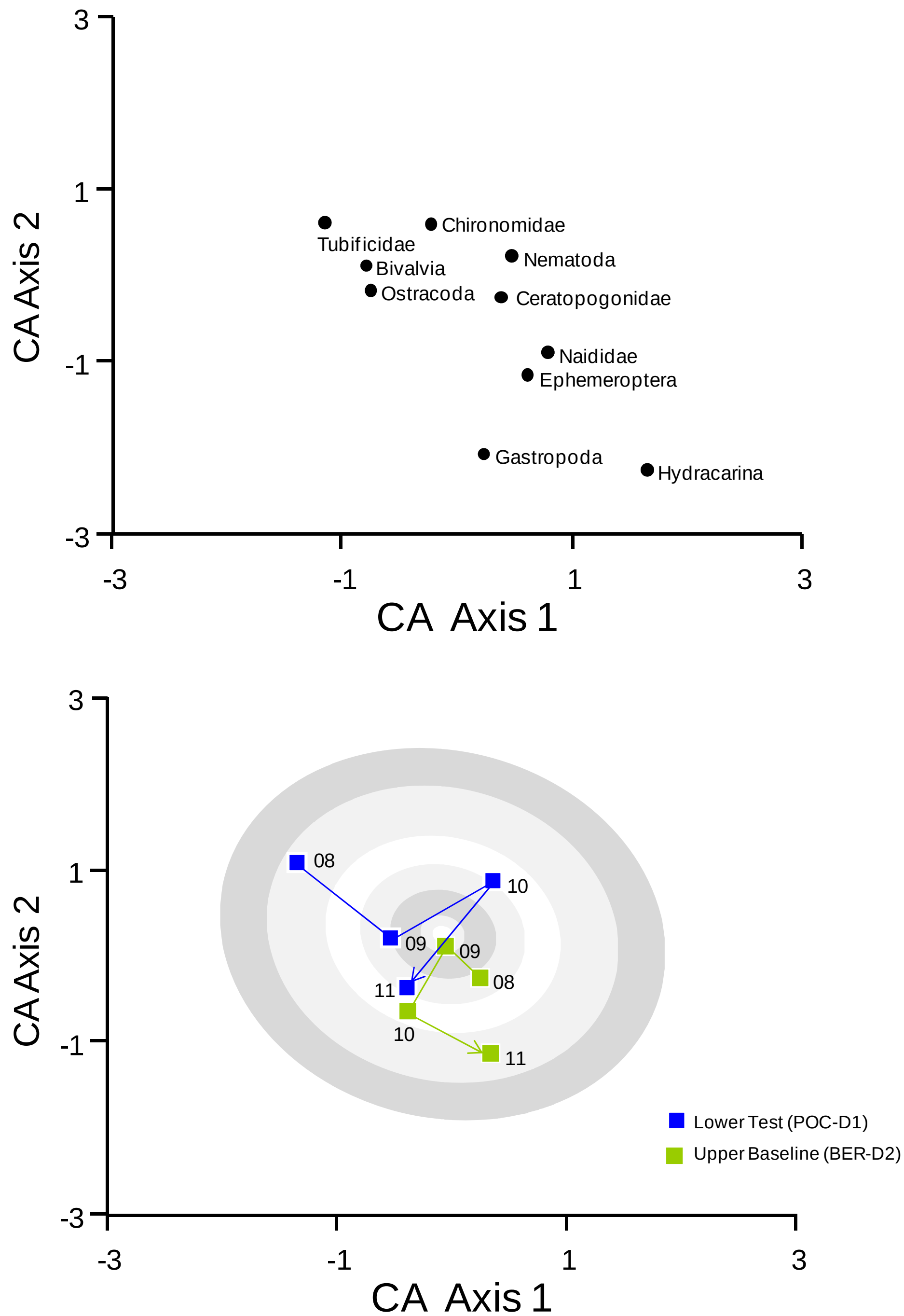
Note: >20% variance is considered a strong signal in the comparison of time trends to classify results as Negligible-Low; Moderate or High (Table 3.2-6).

Figure 5.11-17 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 5.11-18 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 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	20	6	10	16	35
Silt	%	-	44	6	13	26	63
Sand	%	-	36	6	12	63	73
Total organic carbon	%	-	1.9	6	1.1	2.2	2.5
Total hydrocarbons							
BTEX	mg/kg	-	<10	4	<5	<8	<20
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	4	<5	<8	<20
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	4	<5	80	143
Fraction 3 (C16-C34)	mg/kg	300[1]	227	4	170	**1162**	**2830**
Fraction 4 (C34-C50)	mg/kg	2800[1]	105	4	54	1185	**2820**
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	0.0076	6	0.0019	0.0110	0.0205
Retene	mg/kg	-	<u>0.1350</u>	5	0.0482	0.1050	0.1140
Total dibenzothiophenes	mg/kg	-	0.4549	6	0.3070	1.1323	3.8983
Total PAHs	mg/kg	-	2.5462	6	1.7530	4.1144	13.2610
Total Parent PAHs	mg/kg	-	<u>0.1216</u>	6	0.1480	0.2051	0.4398
Total Alkylated PAHs	mg/kg	-	2.4246	6	1.6050	3.9155	12.8211
Predicted PAH toxicity[3]	H.I.	1.0	**2.11**	6	0.16	0.63	**4.15**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>6.8</u>	4	7.4	7.9	9.0
Chironomus growth - 10d	mg/organism	-	1.62	4	1.61	2.06	2.45
Hyalella survival - 14d	# surviving	-	<u>9.6</u>	5	8.0	8.6	9.0
Hyalella growth - 14d	mg/organism	-	<u>0.66</u>	5	0.10	0.20	0.26

Values in **bold** indicate concentrations exceeding guidelines.

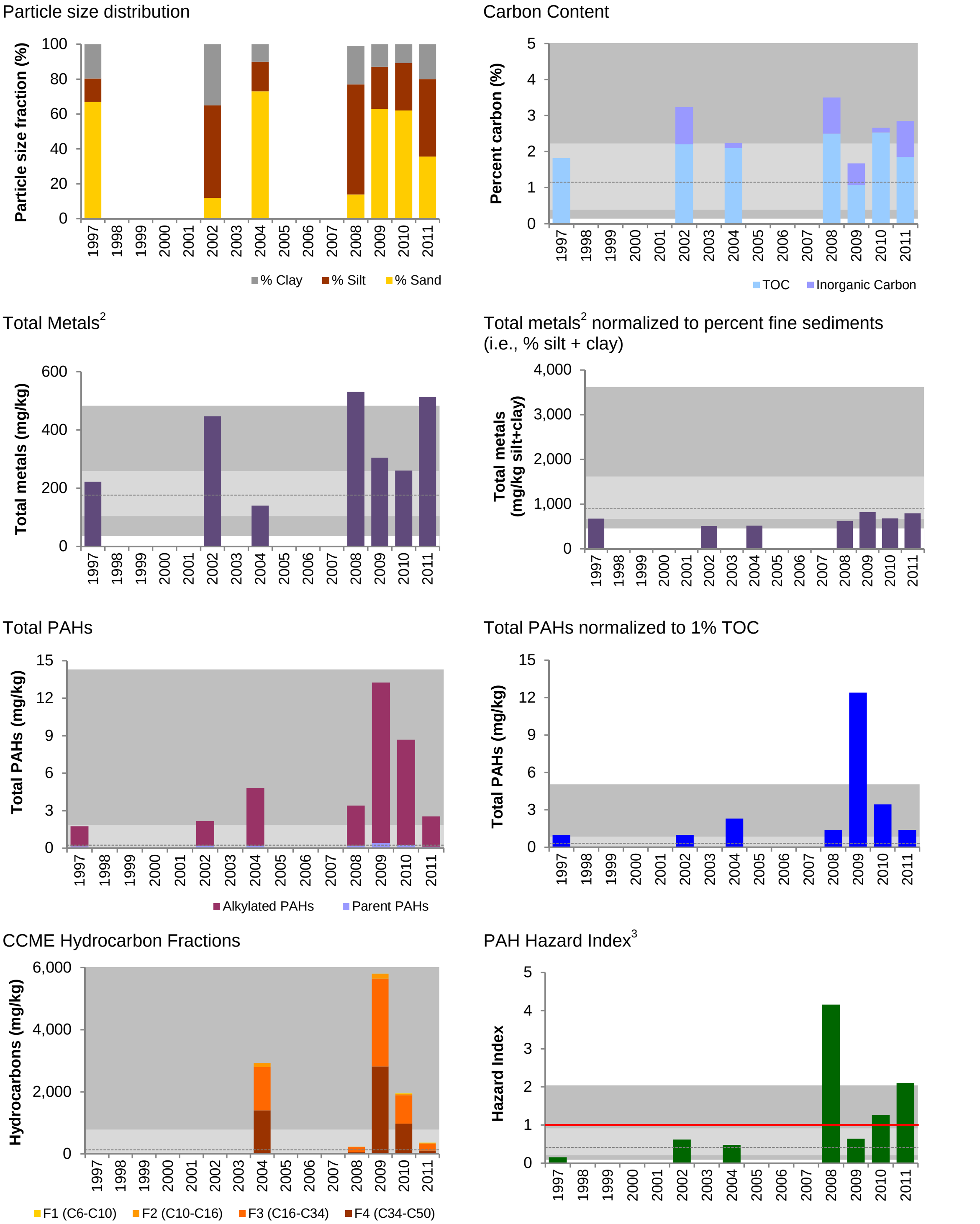
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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 5.11-19 Variation in sediment quality measurement endpoints at *test* station POC-D1.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

1 Regional *baseline* values represent "total" values for multi-variable data.

2 Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

3 Red 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.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>2.4</u>	3	5	6	9
Silt	%	-	2.3	3	1	7	21
Sand	%	-	<u>95.3</u>	3	70	87	94
Total organic carbon	%	-	<u><0.1</u>	3	0.2	0.4	2.0
Total hydrocarbons							
BTEX	mg/kg	-	<10	2	<10	<15	<20
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	2	<10	<15	<20
Fraction 2 (C10-C16)	mg/kg	150[1]	<20	2	<20	30	40
Fraction 3 (C16-C34)	mg/kg	300[1]	<20	2	<20	70	119
Fraction 4 (C34-C50)	mg/kg	2800[1]	<20	2	<20	57	94
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u>0.0003</u>	3	0.0010	0.0010	0.0030
Retene	mg/kg	-	0.0111	3	0.0052	0.0055	0.5200
Total dibenzothiophenes	mg/kg	-	0.0027	3	0.0015	0.0036	0.0145
Total PAHs	mg/kg	-	0.0325	3	0.0178	0.1136	0.7036
Total Parent PAHs	mg/kg	-	0.0045	3	0.0037	0.0085	0.0173
Total Alkylated PAHs	mg/kg	-	0.0280	3	0.0141	0.1051	0.6864
Predicted PAH toxicity[3]	H.I.	1.0	<u>0.16</u>	2	0.49	0.69	0.88
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	7.6	3	7.4	8.0	8.8
Chironomus growth - 10d	mg/organism	-	<u>1.71</u>	3	2.09	2.14	2.63
Hyalella survival - 14d	# surviving	-	<u>6.6</u>	3	8.6	9.0	9.6
Hyalella growth - 14d	mg/organism	-	0.40	3	0.17	0.24	0.44

Values in **bold** indicate concentrations exceeding guidelines.

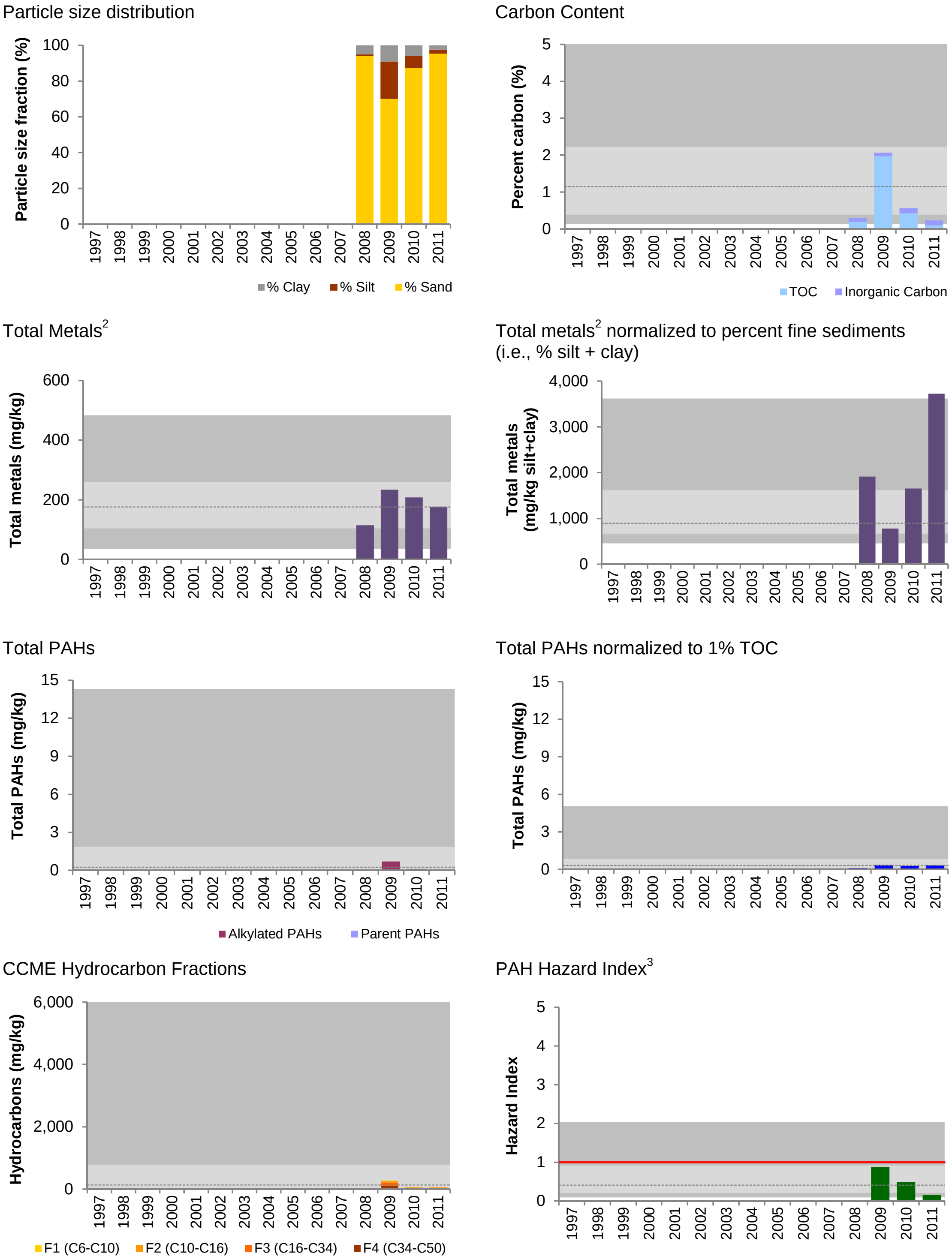
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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 5.11-20 Variation in sediment quality measurement endpoints at *test* station BER-D2.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.11-27 Sediment quality index (fall 2011) for miscellaneous watershed stations.

Station Identifier	Location	2011 Designation	Sediment Quality Index	Classification
POC-D1	mouth of Poplar Creek	*test*	85.0	Negligible-Low
FOC-D1	mouth of Fort Creek	*test*	93.0	Negligible-Low
BER-D2	upper Beaver River	*baseline*	100	Negligible-Low

Table 5.11-28 Average habitat characteristics of fish assemblage monitoring locations of Poplar Creek and Beaver River.

Variable	Units	POC-F1 Lower *Test* Reach of Poplar Creek	BER-F2 Upper *Baseline* Reach of Beaver River
Sample date	-	Sept. 9, 2011	Sept. 9, 2011
Habitat type	-	run/shallow riffle	run
Maximum depth	m	0.22	1.01
Average bankfull channel width	m	10.7	10.1
Average wetted channel width	m	7.4	6.7
Substrate			
Dominant	-	silt/clay/fines	silt/clay
Subdominant	-	-	-
Instream cover			
Dominant	-	macrophytes and small woody debris	macrophytes
Subdominant	-	large woody debris, undercut banks and boulders	small woody debris and over hanging vegetation
Field water quality			
Dissolved oxygen	mg/L	5.8	5.4
Conductivity	µS/cm	660	535
pH	pH units	7.51	7.72
Water temperature	°C	16.7	16.2
Water velocity			
Left bank velocity	m/s	0.35	0.20
Left bank water depth	m	0.38	0.41
Centre of channel velocity	m/s	0.15	0.33
Centre of channel water depth	m	0.46	0.55
Right bank velocity	m/s	0.13	0.35
Right bank water depth	m	0.36	0.53
Riparian cover- understory (<5 m)			
Dominant	-	woody shrubs and saplings	overhanging vegetation
Subdominant	-	overhanging vegetation	woody shrubs and saplings

Table 5.11-29 Percent composition and mean CPUE of fish species at *test* reach POC-F1 of Poplar Creek and *baseline* reach BER-F2 of the Beaver River, 2009 to 2011.

Common Name	Code	Total Species				Percent of Total Catch			
		BER-F2		POC-F1		BER-F2		POC-F1	
		2009	2011	2009	2011	2009	2011	2009	2011
Arctic grayling	ARGR	-	-	-	-	0	0	0	0
brook stickleback	BRST	1	2	4	-	3.3	6.3	20.0	0
burbot	BURB	-	-	-	-	0	0	0	0
fathead minnow	FTMN	2	2	-	-	7	6.3	0	0
finescale dace	FNDC	-	-	-	2	0	0	0	7.7
lake chub	LKCH	10	-	1	-	33.3	0	5.0	0
lake whitefish	LKWH	-	-	-	-	0	0	0	0
longnose dace	LNDC	-	-	-	-	0	0	0	0
longnose sucker	LNSC	-	-	-	15	0	0	0	57.7
northern pike	NRPK	-	-	1	-	0	0	5.0	0
northern redbelly dace	NRDC	-	-	-	-	0	0	0	0
pearl dace	PRDC	-	28	-	4	0	87.5	0	15.4
slimy sculpin	SLSC	-	-	-	-	0	0	0	0
spoonhead sculpin	SPSC	-	-	1	-	0	0	5.0	0
spottail shiner	SPSH	-	-	-	-	0	0	0	0
trout-perch	TRPR	2	-	5	-	6.7	0	25.0	0
walleye	WALL	-	-	4	-	0	0	20.0	0
white sucker	WHSC	15	-	4	5	50.0	0	20.0	19.2
yellow perch	YLPR	-	-	-	-	0	0	0	0
sucker sp. *		-	1	-	-	0	3.1	0	0
Total Count		**30**	**33**	**20**	**26**	**100**	**100**	**100**	**100**
Total Abundance (#/m)		**0.10**	**0.22**	**0.07**	**0.17**	**-**	**-**	**-**	**-**
Total Species Richness		**5**	**3**	**7**	**4**	**5**	**3**	**7**	**4**
Electrofishing Effort (secs)		**1,678**	**1,412**	**1,534**	**1,003**	**-**	**-**	**-**	**-**
CPUE (#/100secs)		**1.19**	**1.84**	**1.96**	**3.29**	**-**	**-**	**-**	**-**

* not included in total species richness count.

Table 5.11-30 Summary of fish assemblage measurement endpoints in reaches of the Beaver River and Poplar Creek, 2009 and 2011.

Site	Year	Abundance		Richness*			Diversity*		Evenness*		ATI*	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BER-F2	2009	0.10	-	5	5	-	0.62	-	0.62	-	7.04	-
	2011	0.22	0.38	4	1	0.84	0.13	0.47	0.72	0.83	6.19	3.63
POC-F1	2009	0.07	-	7	7	-	0.81	-	0.75	-	8.29	-
	2011	0.17	0.22	4	1	1.34	0.30	0.28	0.53	0.49	3.60	3.33

* Unknown species not included in the calculation.
SD=standard deviation across sub-reaches within a reach.

Figure 5.11-21 Box-plots showing variation in fish assemblage measurement endpoints in Poplar Creek, 2009 and 2011.

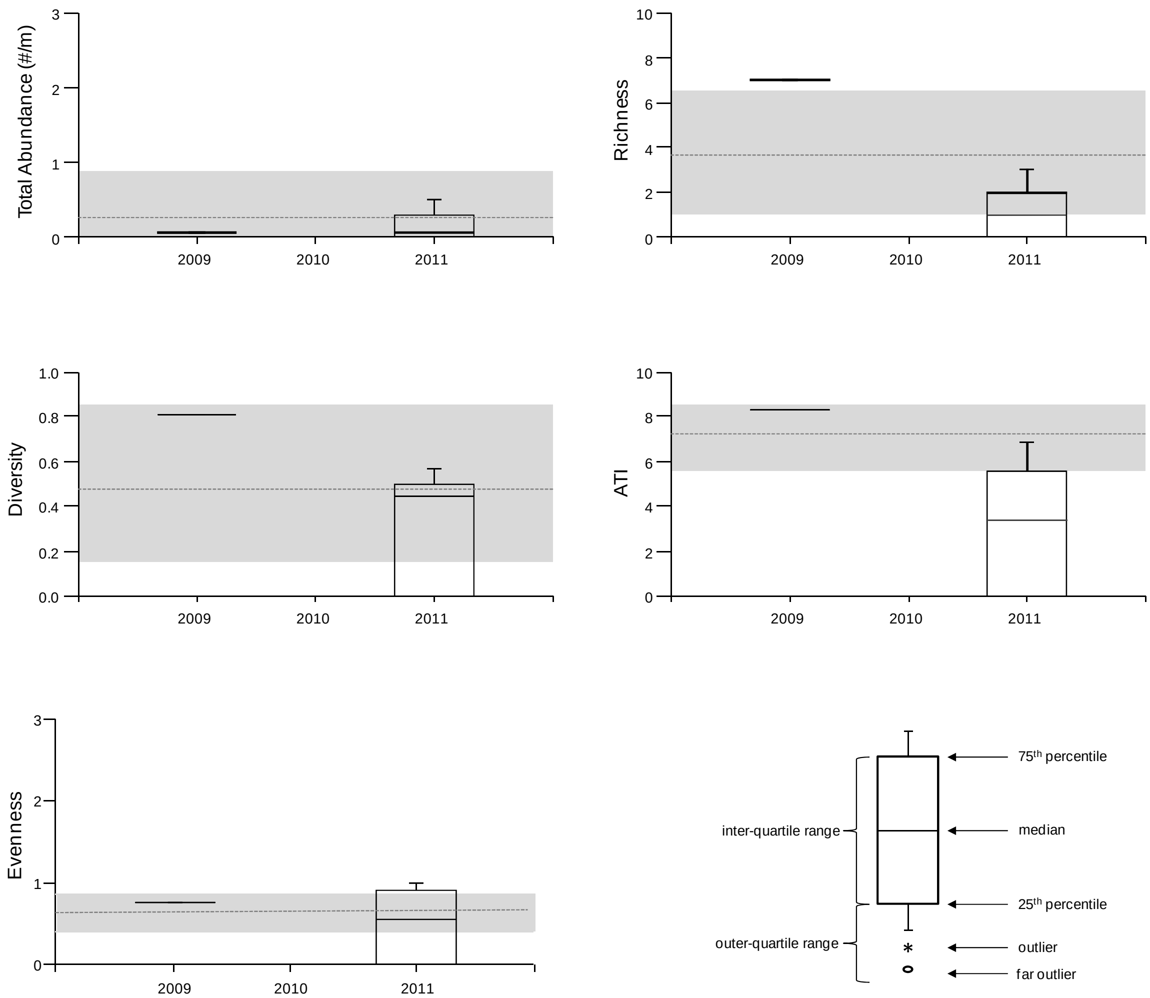


Figure 5.11-22 Box-plots showing variation in fish assemblage measurement endpoints in Beaver River, 2009 and 2011.

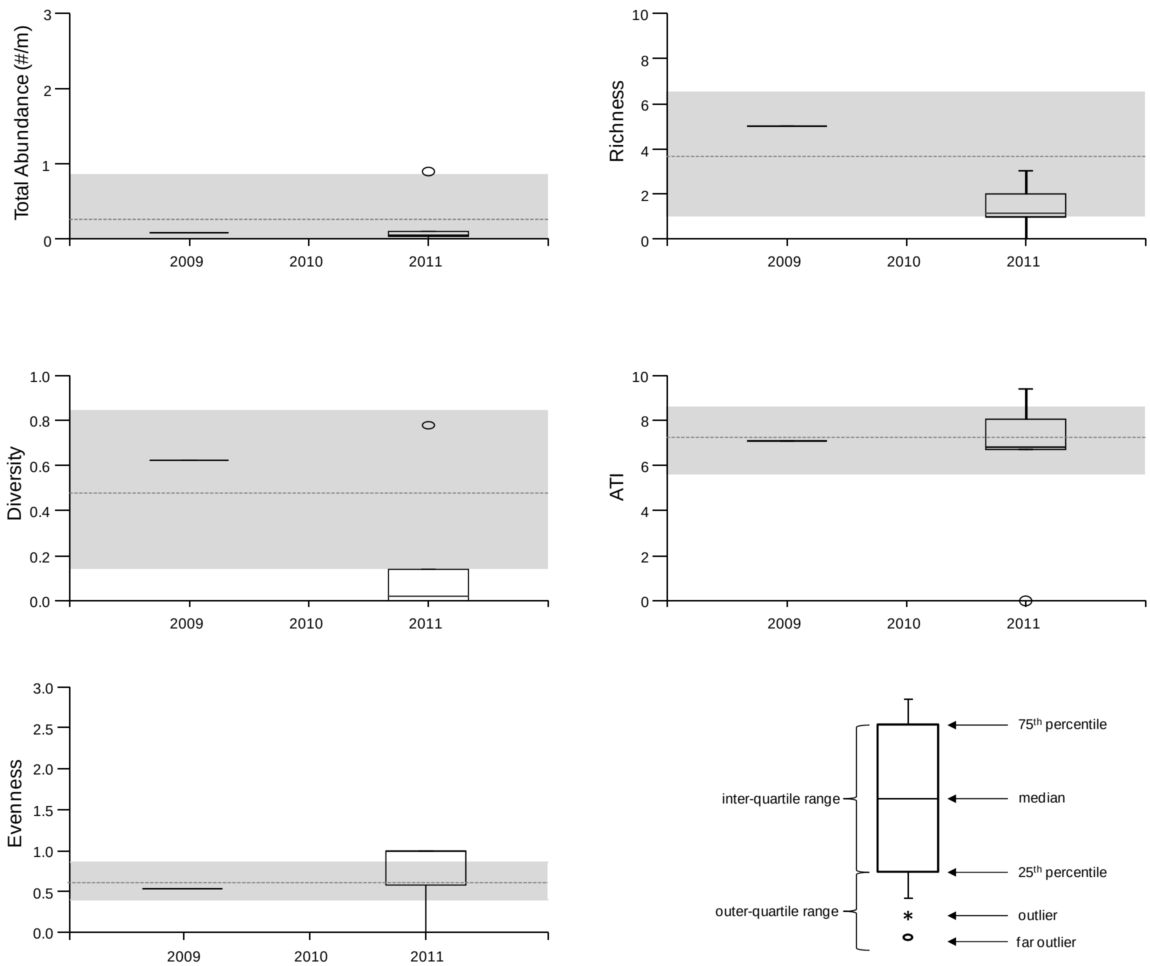


Table 5.11-31 Concentrations of water quality measurement endpoints, McLean Creek (*test* station MCC-1), fall 2011.

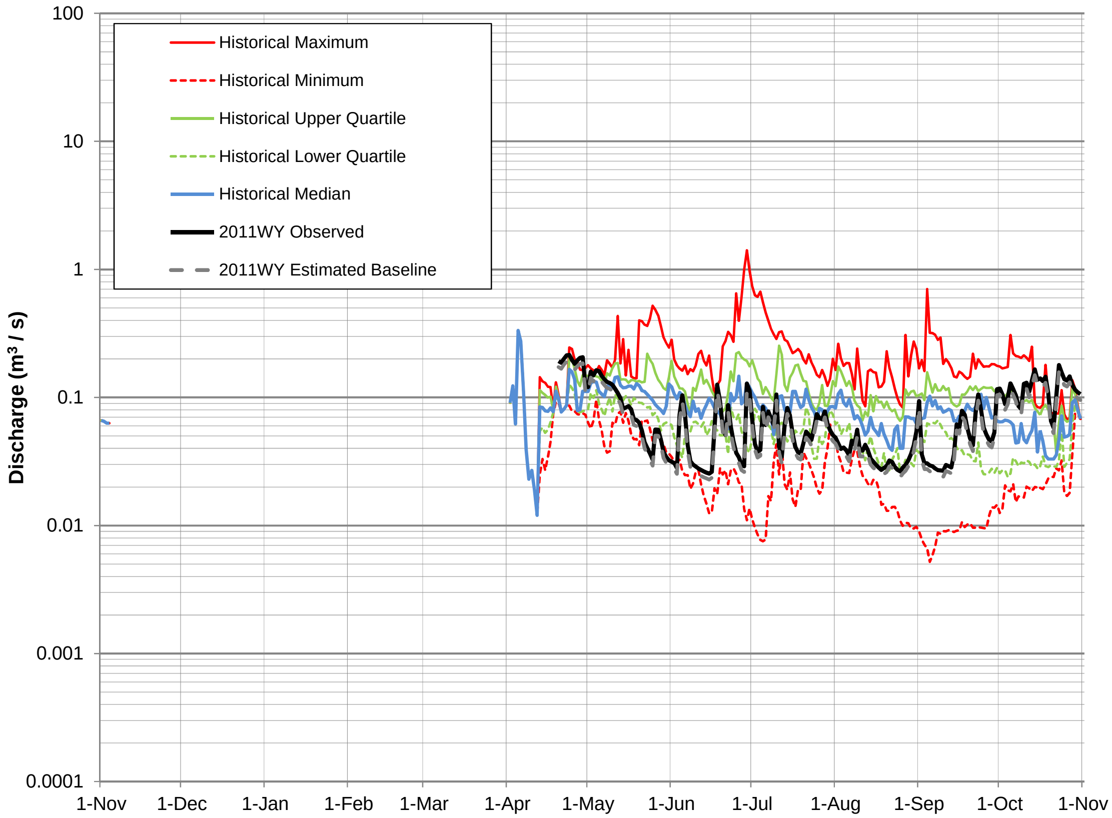
Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	12	8.0	8.3	8.6
Total suspended solids	mg/L	-	29	12	<3	9	83
Conductivity	µS/cm	-	1220	12	289	386	1000
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.007	12	0.005	0.015	0.048
Total nitrogen	mg/L	1	0.74	12	0.70	**1.19**	**1.52**
Nitrate+nitrite	mg/L	1.3	<0.071	12	<0.05	<0.1	<1
Dissolved organic carbon	mg/L	-	24.0	12	14.0	25.3	35.0
Ions							
Sodium	mg/L	-	182	12	10	23	140
Calcium	mg/L	-	49.8	12	37.9	45.2	81.7
Magnesium	mg/L	-	17.5	12	10.3	12.8	21.0
Chloride	mg/L	230, 860	220.0	12	4.8	16.5	165.0
Sulphate	mg/L	100	41.4	12	3.2	10.8	76.4
Total dissolved solids	mg/L	-	743	12	218	285	620
Total alkalinity	mg/L		237	12	141	164	319
Selected metals							
Total aluminum	mg/L	0.1	**0.45**	12	0.07	**0.34**	**2.58**
Dissolved aluminum	mg/L	0.1	0.006	12	0.003	0.008	0.016
Total arsenic	mg/L	0.005	0.0008	12	0.0006	0.0009	0.0014
Total boron	mg/L	1.2	0.22	12	0.02	0.05	0.20
Total molybdenum	mg/L	0.073	0.00026	12	0.00012	0.00018	0.00050
Total mercury (ultra-trace)	ng/L	5, 13	1.3	8	<1.2	<1.2	4.1
Total strontium	mg/L	-	0.33	12	0.11	0.15	0.29
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	32.3	0	-	-	-
Total PAHs	ng/L	-	302.3	0	-	-	-
Total Parent PAHs	ng/L	-	25.6	0	-	-	-
Total Alkylated PAHs	ng/L	-	276.7	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Dissolved iron	mg/L	0.3	**0.33**	12	0.04	0.20	**0.45**
Sulphide	mg/L	0.002	**0.011**	12	<0.003	**0.009**	**0.025**
Total iron	mg/L	0.3	**0.83**	12	**0.36**	**0.64**	**3.46**
Total phenols	mg/L	0.004	**0.007**	12	<0.001	**0.005**	**0.012**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Figure 5.11-23 The observed (*test*) hydrograph and estimated *baseline* hydrograph for Fort Creek in the 2011 WY, compared to historical values.



Note: Observed 2011 WY hydrograph based on Fort Creek at Highway 63, RAMP Station S12, 2011 WY provisional data from April 20 to October 31. The upstream drainage area is 31.9 km2. Historical values from April 20 to October 30, 2010 were calculated using data collected from 2000 to 2002 and from 2006 to 2010.

Table 5.11-32 Estimated water balance at Station S12, Fort Creek at Highway 63, 2011 WY.

Component	Volume (million m^3)	Basis and Data Source
Observed *test* discharge	1.26	**Observed *test* discharge, obtained from Fort Creek at Highway 63, RAMP Station S12.**
Closed-circuited area water loss from the observed *test* discharge	-0.012	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)	+0.14	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	1.14	**Estimated *baseline* discharge at Fort Creek at Highway 63, RAMP Station S12.**
Incremental flow (change in total discharge)	+0.13	Total discharge from observed *test* volume less total discharge of estimated *baseline* volume
Incremental flow (% of total discharge)	**+11.3%**	**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 20 to October 31, 2011 for Fort Creek at Highway 63 RAMP Station S12.

Table 5.11-33 Concentrations of water quality measurement endpoints, Fort Creek (*test* station FOC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011	1997-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
pH	pH units	6.5-9.0	8.4	9	8.1	8.3	8.4
Total suspended solids	mg/L	-	9.0	9	<3	14.0	35.5
Conductivity	µS/cm	-	<u>649</u>	9	432	546	573
Nutrients							
Total dissolved phosphorus	mg/L	0.05	0.009	9	0.006	0.010	0.019
Total nitrogen	mg/L	1	0.5	9	0.4	0.6	1.0
Nitrate+nitrite	mg/L	1.3	<0.071	9	<0.05	<0.1	<0.1
Dissolved organic carbon	mg/L	-	12.4	9	11.0	13.0	14.0
Ions							
Sodium	mg/L	-	12.5	9	9.0	11.0	18.0
Calcium	mg/L	-	87.0	9	69.4	82.2	96.8
Magnesium	mg/L	-	<u>21.8</u>	9	14.6	17.8	20.1
Chloride	mg/L	230, 860	3.3	9	2.0	2.8	7.0
Sulphate	mg/L	100	55.9	9	3.7	7.8	68.3
Total dissolved solids	mg/L	-	<u>443</u>	9	260	330	383
Total alkalinity	mg/L		<u>309</u>	9	231	277	304
Selected metals							
Total aluminum	mg/L	0.1	0.084	9	0.031	0.074	**0.850**
Dissolved aluminum	mg/L	0.1	0.0021	9	<0.001	0.0013	0.0500
Total arsenic	mg/L	0.005	<u>0.00023</u>	9	0.00024	0.00030	<0.001
Total boron	mg/L	1.2	0.063	9	0.038	0.052	0.073
Total molybdenum	mg/L	0.073	<0.0001	8	0.00003	0.00009255	0.0001
Total mercury (ultra-trace)	ng/L	5, 13	0.6	6	<1.2	<1.2	1.4
Total strontium	mg/L	-	<u>0.25</u>	9	0.16	0.18	0.24
Total hydrocarbons							
BTEX	mg/L	-	<0.1	0	-	-	-
Fraction 1 (C6-C10)	mg/L	-	<0.1	0	-	-	-
Fraction 2 (C10-C16)	mg/L	-	<0.25	0	-	-	-
Fraction 3 (C16-C34)	mg/L	-	<0.25	0	-	-	-
Fraction 4 (C34-C50)	mg/L	-	<0.25	0	-	-	-
Polycyclic Aromatic Hydrocarbons (PAHs)[b]							
Naphthalene	ng/L	-	<14.1	0	-	-	-
Retene	ng/L	-	<2.1	0	-	-	-
Total dibenzothiophenes	ng/L	-	42.5	0	-	-	-
Total PAHs	ng/L	-	298.1	0	-	-	-
Total Parent PAHs	ng/L	-	22.6	0	-	-	-
Total Alkylated PAHs	ng/L	-	275.6	0	-	-	-
Other variables that exceeded CCME/AENV guidelines in fall 2011							
Total iron	mg/L	0.3	**0.69**	9	0.07	**0.64**	**1.94**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of historical range.

Figure 5.11-24 Piper diagram of ion balance in Fort Creek.

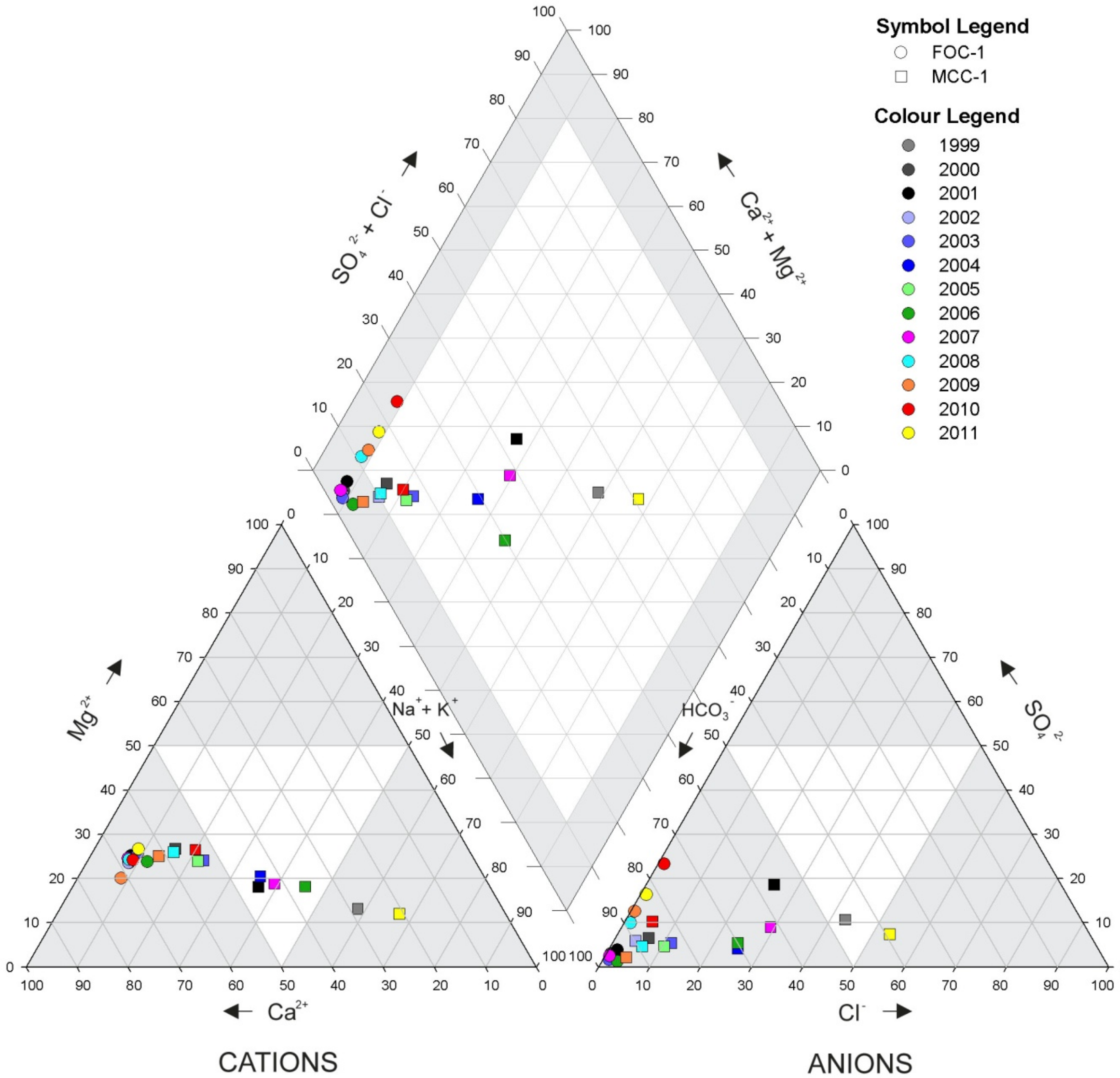


Table 5.11-34 Average habitat characteristics of benthic invertebrate sampling locations in Fort Creek.

Variable	Units	FOC-D1 Lower *Test* Reach of Fort Creek
Sample date	-	Sept. 13, 2011
Habitat	-	Depositional
Water depth	m	0.1
Current velocity	m/s	0.22
Field Water Quality		
Dissolved oxygen	mg/L	10.6
Conductivity	µS/cm	567
pH	pH units	8.1
Water temperature	°C	7.9
Sediment Composition		
Sand	%	98
Silt	%	1
Clay	%	1
Total Organic Carbon	%	1.5

Table 5.11-35 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in 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**	**2011**
Nematoda	2	1	1	24	4	1	3	6	5
Erpobdellidae		<1							
Glossiphoniidae		<1							
Oligochatea									2
Naididae	1	1	<1		1	2			
Tubificidae		1	<1	6	29	66	22	62	32
Enchytraeidae	1	<1	1		<1	1	1		
Hydracarina	<1		<1					2	
Ostracoda	1		<1	6	1	1		1	5
Macrothricidae		<1	<1						
Copepoda	<1	1	1					4	
Gastropoda	<1		<1			1	3		
Bivalvia	5	1	<1	8		2			6
Ceratopogonidae	<1	<1	1		2	8	1	<1	<1
Chironomidae	80	95	95	56	55	18	68	23	50
Empididae	1		<1					1	
Tipulidae	8	<1	<1		3			1	
Tabanidae		<1			1			1	
Simuliidae			<1						
Ephemeroptera	<1					<1	1		
Plecoptera						1			
Trichoptera			<1			<1		<1	
Heteroptera			<1						
Benthic Invertebrate Community Measurement Endpoints									
Total Abundance (No./m^2)	4,069	41,905	69,802	913	2,948	11,270	591	8,479	1,085
Richness	15	13	13	4	10	11	4	6	4
Simpson's Diversity	0.84	0.69	0.57	0.65	0.76	0.56	0.53	0.44	0.52
Evenness	0.91	0.79	0.68	0.9	0.77	0.62	0.70	0.00	0.67
% EPT	<1	0	2	0	0	9	<1	<1	0

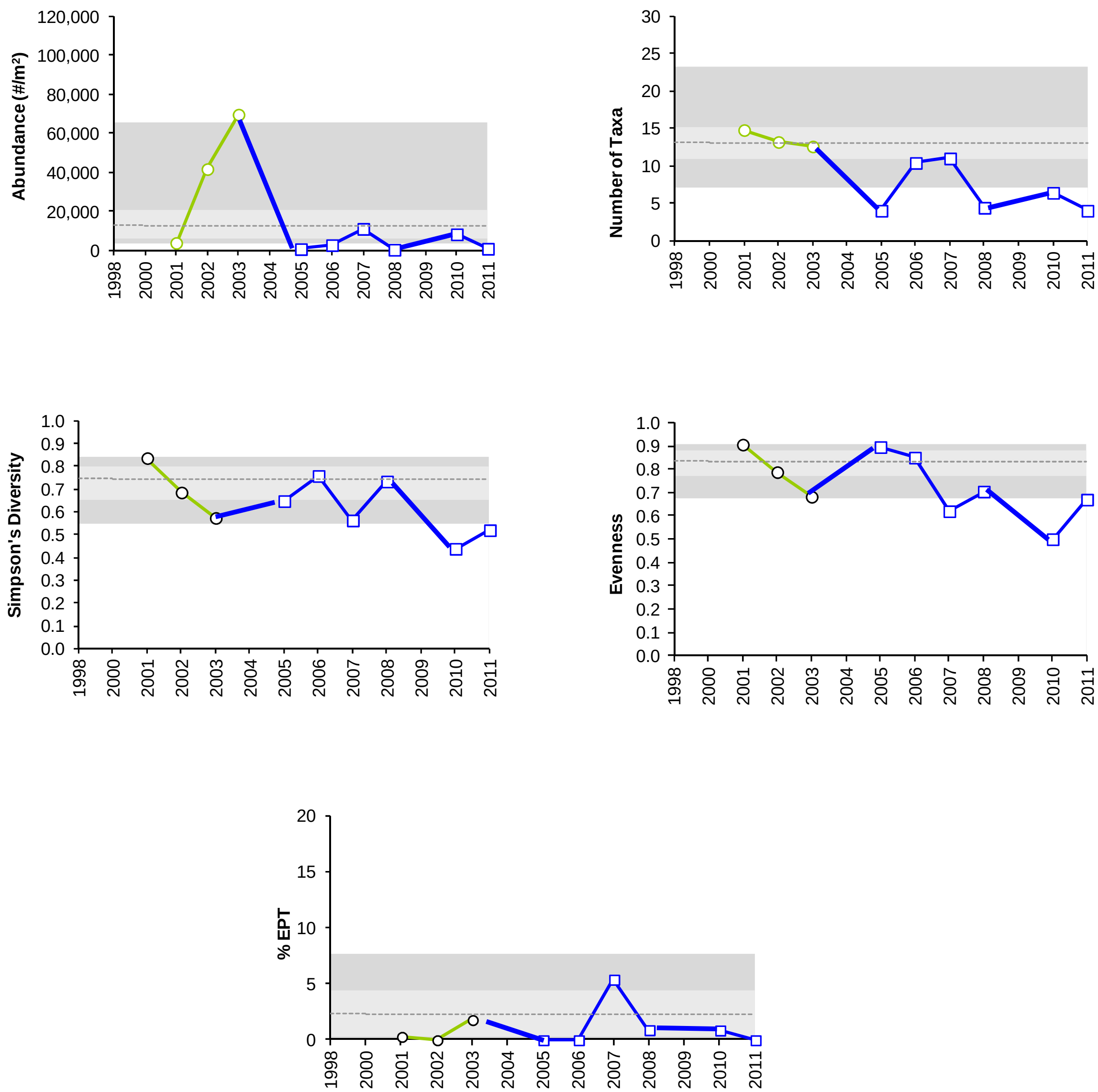
Table 5.11-36 Results of analysis of variance (ANOVA) testing for differences in benthic invertebrate community measurement endpoints in lower Fort Creek (*test* reach FOC-D1).

Variable	P-value		Variance Explained (%)		Nature of Change(s)	Spearman Rank r_s
	***Baseline* vs. *Test* Periods**	**Time Trend (*test* period)**	***Baseline* vs. *Test* Periods**	**Time Trend (*test* period)**		
Abundance	**0.008**	0.499	34	2	Lower in *test* period	0.09
Richness	**0.003**	0.297	45	5	Lower in *test* period	-0.29
Simpson's Diversity	0.117	0.103	23	25	No change	-0.66
Evenness	0.324	0.065	10	37	No change	-0.71
EPT	0.714	0.936	1	0	No change	-0.06
CA Axis 1	0.082	0.425	23	5	No change	-0.49
CA Axis 2	0.916	0.987	1	0	No change	0.09

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).

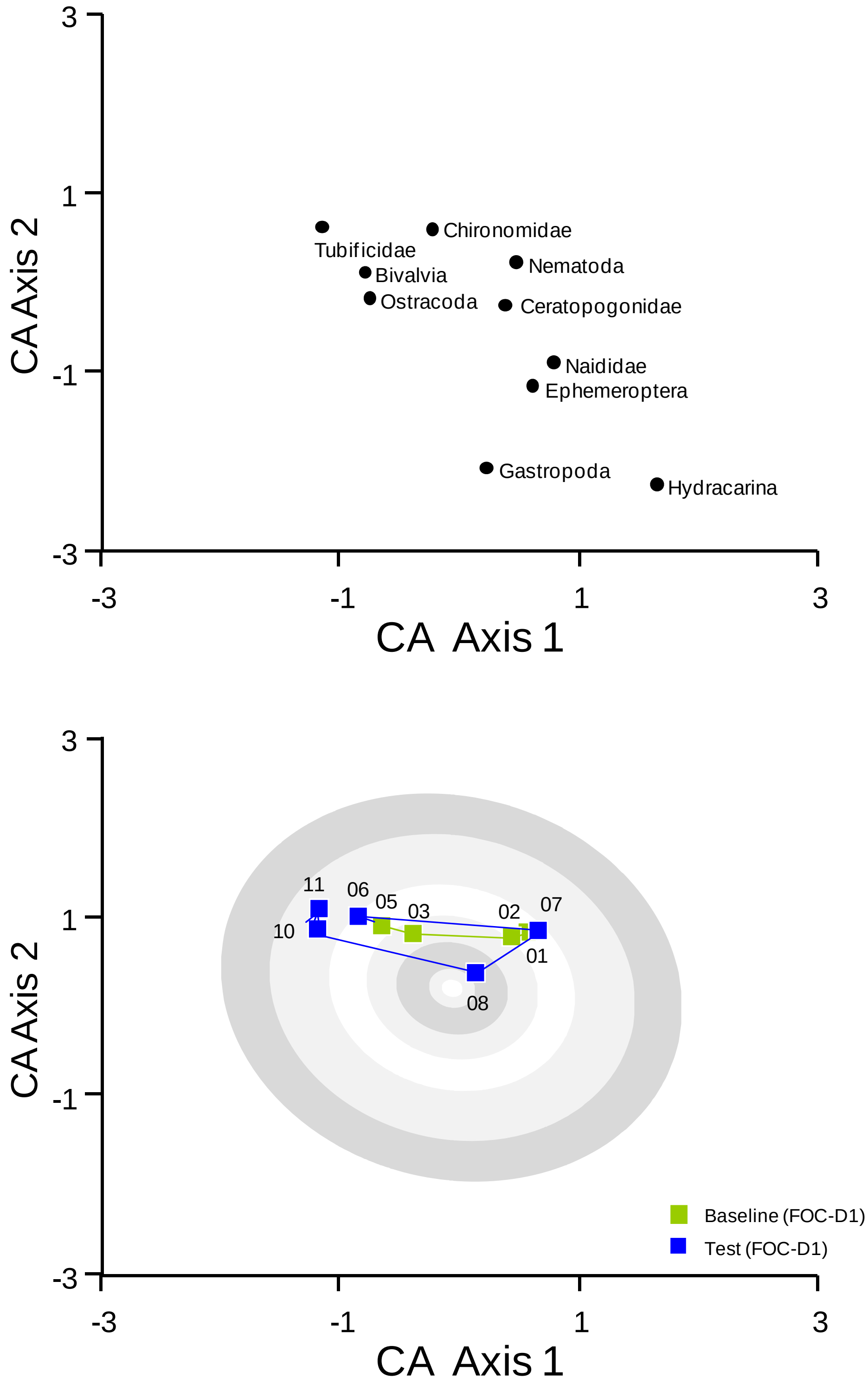
Note: Spearman Rank Correlations (r_s) are considered significant at |0.87| at n=6.

Figure 5.11-25 Variation in benthic invertebrate community measurement endpoints in Fort 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 5.11-26 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 5.11-37 Concentrations of sediment quality measurement endpoints, Fort Creek (*test* station FOC-D1), fall 2011.

Variables	Units	Guideline	September 2011	2001-2010 (fall data only)			
			Value	n	Min	Median	Max
Physical variables							
Clay	%	-	<u>1.0</u>	4	4	4	15
Silt	%	-	<u>1.3</u>	4	5	10	29
Sand	%	-	<u>97.8</u>	4	56	86	91
Total organic carbon	%	-	<u>1.5</u>	6	2	3.3	7.1
Total hydrocarbons							
BTEX	mg/kg	-	<10	3	<5	<10	<10
Fraction 1 (C6-C10)	mg/kg	30[1]	<10	3	<5	<10	<10
Fraction 2 (C10-C16)	mg/kg	150[1]	40	3	16	93	**170**
Fraction 3 (C16-C34)	mg/kg	300[1]	**787**	3	**440**	**2020**	**2600**
Fraction 4 (C34-C50)	mg/kg	2800[1]	774	3	450	1500	1980
Polycyclic Aromatic Hydrocarbons (PAHs)							
Naphthalene	mg/kg	0.0346[2]	<u><0.0006</u>	6	0.0026	0.0081	0.0170
Retene	mg/kg	-	0.0479	6	0.0325	0.2306	0.6790
Total dibenzothiophenes	mg/kg	-	2.1858	6	0.1613	2.0628	3.2203
Total PAHs	mg/kg	-	8.2523	6	1.8536	7.9884	14.2560
Total Parent PAHs	mg/kg	-	0.2018	6	0.1592	0.2616	0.8740
Total Alkylated PAHs	mg/kg	-	8.0504	6	1.6890	7.7479	13.3820
Predicted PAH toxicity[3]	H.I.	1.0	**<u>1.50</u>**	5	0.42	0.73	**1.02**
Metals that exceed CCME guidelines in 2011							
none	mg/kg	-	-	-	-	-	-
Other analytes that exceeded CCME guidelines in 2011							
Chrysene	mg/kg	0.0571	**0.076**	6	0.018	**0.075**	**0.230**
Chronic toxicity							
Chironomus survival - 10d	# surviving	-	<u>10</u>	5	6.8	9.0	9.2
Chironomus growth - 10d	mg/organism	-	1.39	5	1.24	1.89	2.98
Hyalella survival - 14d	# surviving	-	9.6	5	6.0	9.0	9.6
Hyalella growth - 14d	mg/organism	-	0.20	5	0.10	0.21	0.28

Values in **bold** indicate concentrations exceeding guidelines.

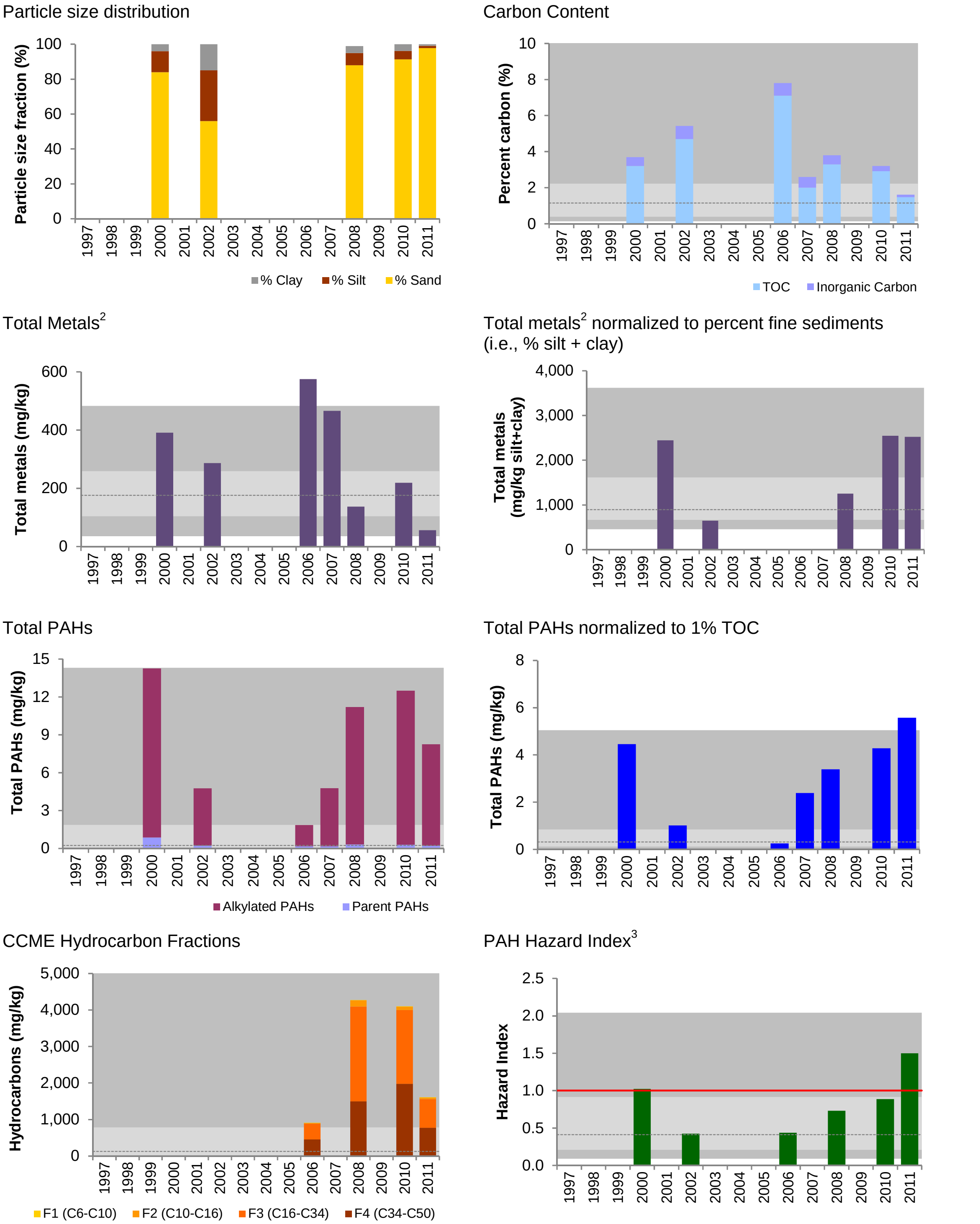
Values <u>underlined</u> indicate concentrations outside the range of historic observations.

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 5.11-27 Variation in sediment quality measurement endpoints in Fort Creek, *test* station FOC-D1.



Regional *baseline* values reflect pooled results for all *baseline* stations excluding the Athabasca Delta, from all years of sampling (1997-2011).

[1] Regional *baseline* values represent "total" values for multi-variable data.

[2] Total metals include: As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Tl, Ti, Sn, Ag, U, V, Zn (measured in all years).

[3] Red line indicates potential chronic effects level (HI = 1.0).

Table 5.11-38 Average habitat characteristics of fish assemblage monitoring locations in Fort Creek.

Variable	Units	FOC-F1 Lower *Test* Reach of Fort Creek
Sample date	-	Sept. 26, 2011
Habitat type	-	run
Maximum depth	m	0.31
Average bankfull channel width	m	7.55
Average wetted channel width	m	1.85
Substrate		
Dominant	-	silt/clay
Subdominant	-	-
Instream cover		
Dominant	-	small woody debris
Subdominant	-	large woody debris
Field water quality		
Dissolved oxygen	mg/L	8.6
Conductivity	µS/cm	669
pH	pH units	7.92
Water temperature	°C	11.6
Water velocity		
Left bank velocity	m/s	0.16
Left bank water depth	m	0.28
Centre of channel velocity	m/s	0.17
Centre of channel water depth	m	0.21
Right bank velocity	m/s	0.14
Right bank water depth	m	0.18
Riparian cover- understory (<5 m)		
Dominant	-	woody shrubs and saplings

Table 5.11-39 Percent composition and mean CPUE of species at *test* reach FOC-F1 of Fort Creek, 2011.

Common Name	Code	Total Species	Percent of Total Catch
Arctic grayling	ARGR	-	0
brook stickleback	BRST	8	9.8
burbot	BURB	-	0
fathead minnow	FTMN	-	0
finescale dace	FNDC	23	28.0
lake chub	LKCH	33	40.2
lake whitefish	LKWH	-	0
longnose dace	LNDC	-	0
longnose sucker	LNSC	16	19.5
northern pike	NRPK	-	0
northern redbelly dace	NRDC	-	0
pearl dace	PRDC	-	0
slimy sculpin	SLSC	1	1.2
spoonhead sculpin	SPSC	-	0
spottail shiner	SPSH	-	0
trout-perch	TRPR	-	0
walleye	WALL	-	0
white sucker	WHSC	1	1.2
yellow perch	YLPR	-	0
Total Count		**82**	**100**
Total Abundance (#/m)		**0.67**	
Total Species Richness		**6**	**6**
Electrofishing effort (secs)		**1,097**	**-**
CPUE (#/100secs)		**7.47**	**-**

Table 5.11-40 Summary of fish assemblage measurement endpoints in reaches of Fort Creek, 2011.

Reach	Year	Abundance		Richness			Diversity		Evenness		ATI	
		Mean	SD	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FOC-F1	2011	0.67	0.36	6	3	1.14	0.52	0.16	0.70	0.22	6.44	1.06

SD=standard deviation across sub-reaches within a reach.

Figure 5.11-28 Box-plots showing variation in fish assemblage measurement endpoints in Fort Creek, 2011.

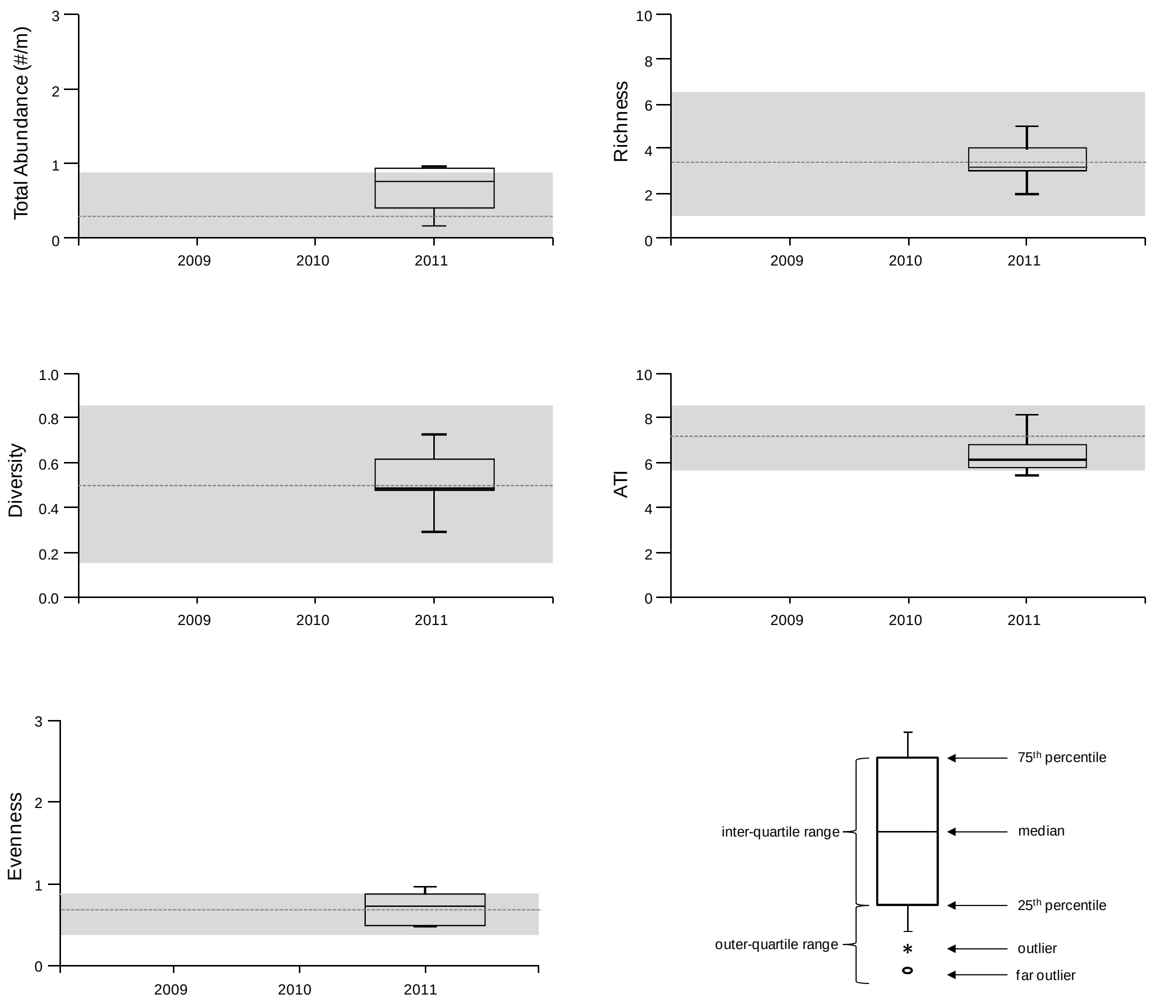
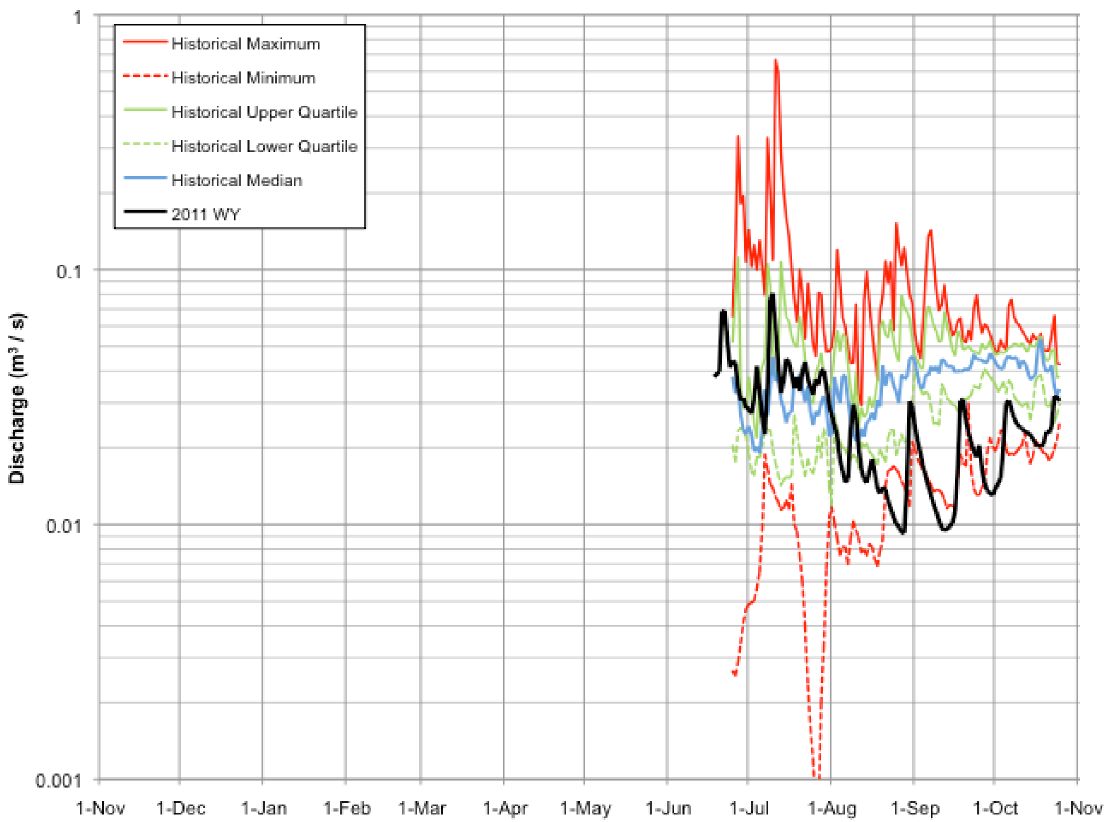


Figure 5.11-29 Susan Lake Outlet: 2011 WY hydrograph.



Note: Observed 2011 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 2010.

Table 5.11-41 Concentrations of water quality measurement endpoints, Big Creek (*baseline* station BIC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.4
Total suspended solids	mg/L	-	15
Conductivity	µS/cm	-	446
Nutrients			
Total dissolved phosphorus	mg/L	0.05	0.023
Total nitrogen	mg/L	1	0.89
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	21
Ions			
Sodium	mg/L	-	11.1
Calcium	mg/L	-	55.2
Magnesium	mg/L	-	15.1
Chloride	mg/L	230, 860	0.63
Sulphate	mg/L	100	21.5
Total dissolved solids	mg/L	-	307
Total alkalinity	mg/L		223
Selected metals			
Total aluminum	mg/L	0.1	**0.42**
Dissolved aluminum	mg/L	0.1	0.0031
Total arsenic	mg/L	0.005	0.0010
Total boron	mg/L	1.2	0.069
Total molybdenum	mg/L	0.073	0.00042
Total mercury (ultra-trace)	ng/L	5, 13	0.6
Total strontium	mg/L	-	0.20
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	3.5
Total dibenzothiophenes	ng/L	-	9.0
Total PAHs	ng/L	-	168.6
Total Parent PAHs	ng/L	-	20.1
Total Alkylated PAHs	ng/L	-	148.5
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Total iron	mg/L	0.3	**1.25**
Total phenols	mg/L	0.004	**0.0043**
Total phosphorous	mg/L	0.05	**0.071**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Table 5.11-42 Concentrations of water quality measurement endpoints, Pierre River (*baseline* station PIR-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.3
Total suspended solids	mg/L	-	74
Conductivity	µS/cm	-	478
Nutrients			
Total dissolved phosphorus	mg/L	0.05	**0.060**
Total nitrogen	mg/L	1	**1.08**
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	31.7
Ions			
Sodium	mg/L	-	24.7
Calcium	mg/L	-	51
Magnesium	mg/L	-	15.2
Chloride	mg/L	230, 860	7.48
Sulphate	mg/L	100	34.9
Total dissolved solids	mg/L	-	380
Total alkalinity	mg/L		206
Selected metals			
Total aluminum	mg/L	0.1	**1.38**
Dissolved aluminum	mg/L	0.1	0.0078
Total arsenic	mg/L	0.005	0.0026
Total boron	mg/L	1.2	0.11
Total molybdenum	mg/L	0.073	0.0012
Total mercury (ultra-trace)	ng/L	5, 13	4.9
Total strontium	mg/L	-	0.22
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	4.5
Total dibenzothiophenes	ng/L	-	51.3
Total PAHs	ng/L	-	309.5
Total Parent PAHs	ng/L	-	24.1
Total Alkylated PAHs	ng/L	-	285.4
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Dissolved iron	mg/L	0.3	**0.79**
Sulphide	mg/L	0.002	**0.018**
Total chromium	mg/L	0.001	**0.0019**
Total iron	mg/L	0.3	**2.78**
Total Kjeldahl Nitrogen	mg/L	1	**1.01**
Total phenols	mg/L	0.004	**0.0068**
Total phosphorous	mg/L	0.05	**0.15**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Table 5.11-43 Concentrations of water quality measurement endpoints, Red Clay Creek (*baseline* station RCC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.3
Total suspended solids	mg/L	-	7
Conductivity	µS/cm	-	519
Nutrients			
Total dissolved phosphorus	mg/L	0.05	0.015
Total nitrogen	mg/L	1	0.501
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	12.9
Ions			
Sodium	mg/L	-	13.5
Calcium	mg/L	-	68.6
Magnesium	mg/L	-	19.3
Chloride	mg/L	230, 860	1.62
Sulphate	mg/L	100	45.2
Total dissolved solids	mg/L	-	337
Total alkalinity	mg/L		235
Selected metals			
Total aluminum	mg/L	0.1	**0.30**
Dissolved aluminum	mg/L	0.1	0.0012
Total arsenic	mg/L	0.005	0.00026
Total boron	mg/L	1.2	0.083
Total molybdenum	mg/L	0.073	0.00012
Total mercury (ultra-trace)	ng/L	5, 13	1
Total strontium	mg/L	-	0.25
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	<2.1
Total dibenzothiophenes	ng/L	-	6.2
Total PAHs	ng/L	-	151.5
Total Parent PAHs	ng/L	-	19.2
Total Alkylated PAHs	ng/L	-	132.3
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Total iron	mg/L	0.3	**0.58**

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.

Values in **bold** are above the guideline.

Table 5.11-44 Concentrations of water quality measurement endpoints, Eymundson Creek (*baseline* station EYC-1), fall 2011.

Measurement Endpoint	Units	Guideline[a]	September 2011
			Value
Physical variables			
pH	pH units	6.5-9.0	8.3
Total suspended solids	mg/L	-	144
Conductivity	µS/cm	-	531
Nutrients			
Total dissolved phosphorus	mg/L	0.05	0.025
Total nitrogen	mg/L	1	**1.10**
Nitrate+nitrite	mg/L	1.3	<0.071
Dissolved organic carbon	mg/L	-	26.1
Ions			
Sodium	mg/L	-	22.5
Calcium	mg/L	-	57.2
Magnesium	mg/L	-	17.3
Chloride	mg/L	230, 860	3.61
Sulphate	mg/L	100	**119**
Total dissolved solids	mg/L	-	400
Total alkalinity	mg/L		151
Selected metals			
Total aluminum	mg/L	0.1	**4.24**
Dissolved aluminum	mg/L	0.1	0.022
Total arsenic	mg/L	0.005	0.0038
Total boron	mg/L	1.2	0.11
Total molybdenum	mg/L	0.073	0.0025
Total mercury (ultra-trace)	ng/L	5, 13	**13**
Total strontium	mg/L	-	0.23
Total hydrocarbons			
BTEX	mg/L	-	<0.1
Fraction 1 (C6-C10)	mg/L	-	<0.1
Fraction 2 (C10-C16)	mg/L	-	<0.25
Fraction 3 (C16-C34)	mg/L	-	<0.25
Fraction 4 (C34-C50)	mg/L	-	<0.25
Polycyclic Aromatic Hydrocarbons (PAHs)[b]			
Naphthalene	ng/L	-	<14.1
Retene	ng/L	-	13.6
Total dibenzothiophenes	ng/L	-	37.1
Total PAHs	ng/L	-	278.4
Total Parent PAHs	ng/L	-	24.5
Total Alkylated PAHs	ng/L	-	253.8
Other variables that exceeded CCME/AENV guidelines in fall 2011			
Dissolved iron	mg/L	0.3	**0.87**
Nitrite	mg/L	0.06	**0.26**
Total cadmium	mg/L	0.000064[c]	**0.00019**
Total chromium	mg/L	0.001	**0.0062**
Total iron	mg/L	0.3	**7.46**
Total Kjeldahl Nitrogen	mg/L	1	**1.03**
Total phenols	mg/L	0.004	**0.007**
Total phosphorous	mg/L	0.05	**1.10**

[a] Sources for all guidelines are outlined in Table 3.2-5.
[b] For Total calculations, non-detectable values treated as 1x calculated Method Detection Limit.
[c] Guideline is hardness-dependent. See Table 3.2-5 for equation.
Values in **bold** are above the guideline.

Figure 5.11-30 Piper diagram of ion balance in Big Creek, Pierre River, Red Clay Creek, and Eymundson Creek.

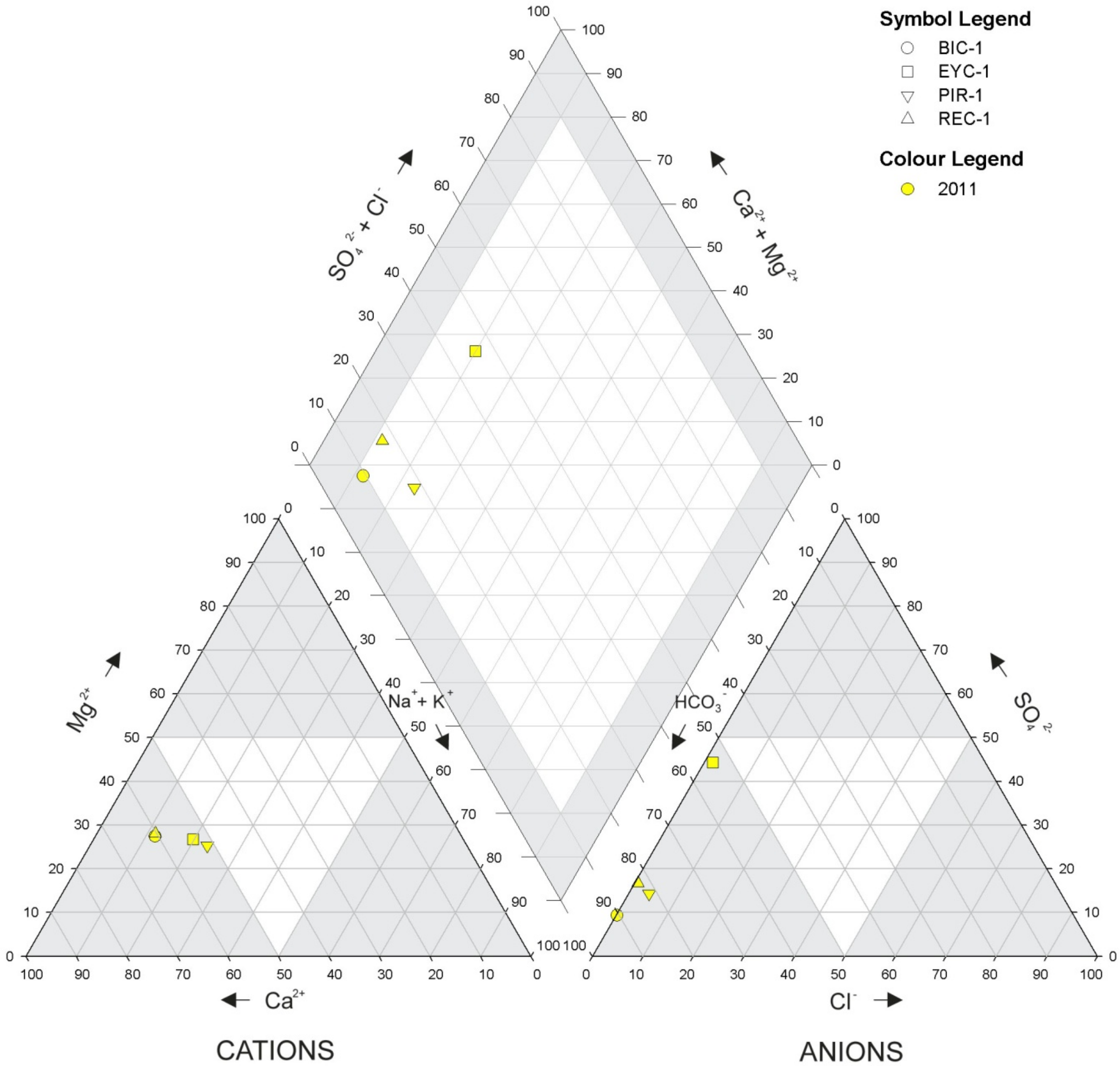


Table 5.11-45 Water quality guideline exceedances at *baseline* stations BIC-1, PIR-1, RCC-1, and EYC-1, 2011.

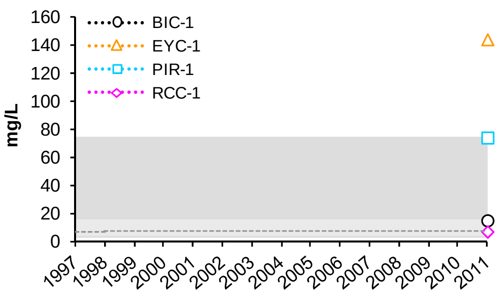
Variable	Units	Guideline[a]	BIC-1	EYC-1	PIR-1	RCC-1
Spring						
Dissolved iron	mg/L	0.3	0.58	-	-	-
Sulphate	mg/L	100	-	-	109	-
Sulphide	mg/L	0.002	0.006	0.032	0.010	-
Total aluminum	mg/L	0.1	0.45	10.50	0.84	0.30
Total arsenic	mg/L	0.005	-	0.0058	-	-
Total cadmium	mg/L	0.000037[b]	-	0.00065	-	-
Total chromium	mg/L	0.001	-	0.021	0.0017	-
Total copper	mg/L	0.013[b]	-	0.015	-	-
Total iron	mg/L	0.3	1.21	14.40	2.04	0.58
Total Kjeldahl nitrogen	mg/L	1	-	3.4	1.1	-
Total lead	mg/L	0.0038[b]	-	0.015		-
Total nitrogen	mg/L	1.0	-	-	1.17	-
Total phenols	mg/L	0.004	0.0042	0.0061	0.0049	-
Total phosphorus	mg/L	0.05	0.064	0.608	0.121	-
Total selenium	mg/L	0.001	-	0.0013	-	-
Total zinc	mg/L	0.03	-	0.061	-	-
Summer						
Dissolved iron	mg/L	0.3	-	-	0.43	-
Dissolved phosphorus	mg/L	0.05	0.096	-	-	-
Sulphate	mg/L	100	-	-	107	-
Sulphide	mg/L	0.002 [1]	0.014	0.014	-	-
Total aluminum	mg/L	0.1	0.23	8.63	0.26	2.76
Total cadmium	mg/L	0.000032[b]	-	0.00029	-	-
Total chromium	mg/L	0.001	-	0.014	-	0.0034
Total iron	mg/L	0.3	1.59	10.90	0.96	2.22
Total Kjeldahl nitrogen	mg/L	1	1.27	1.45	-	-
Total lead	mg/L	0.003[b]	-	0.0085	-	-
Total mercury (ultra-trace)	ng/L	5, 13	-	6.9	-	-
Total nitrogen	mg/L	1.0	1.61	2.02	-	-
Total phenols	mg/L	0.004	0.0096	0.0083	0.0101	-
Total phosphorus	mg/L	0.05	0.123	0.421	0.076	0.086
Total zinc	mg/L	0.03	-	0.047	-	-
Fall						
Dissolved iron	mg/L	0.3	-	0.87	0.79	-
Nitrite	mg/L	0.06	-	0.26	-	-
Sulphate	mg/L	100	-	119	-	-
Sulphide	mg/L	0.002	-	-	0.018	-
Total aluminum	mg/L	0.1	0.42	4.24	1.38	0.30
Total cadmium	mg/L	0.000064[b]	-	0.00019	-	-
Total chromium	mg/L	0.001	-	0.0062	0.0019	-
Total dissolved phosphorus	mg/L	0.05	-	-	0.060	-
Total iron	mg/L	0.3	1.25	7.46	2.78	0.58
Total Kjeldahl nitrogen	mg/L	1	-	1.03	1.01	-
Total mercury (ultra-trace)	ng/L	5, 13	-	13	-	-
Total nitrogen	mg/L	1	-	1.10	1.08	-
Total phenols	mg/L	0.004	0.0043	0.007	0.0068	-
Total phosphorus	mg/L	0.05	0.071	1.10	0.15	-

[a] Sources for all guidelines are outlined in Table 3.2-5.

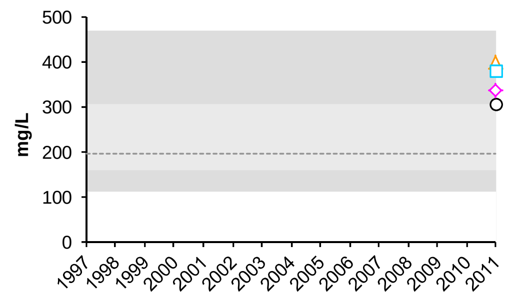
[b] Guideline is hardness-dependent. See Table 3.2-5 for equation.

Figure 5.11-31 Concentrations of selected water quality measurement endpoints in *baseline* stations BIC-1, PIR-1, RCC-1, and EYC-1 (fall data) relative to regional *baseline* fall concentrations.

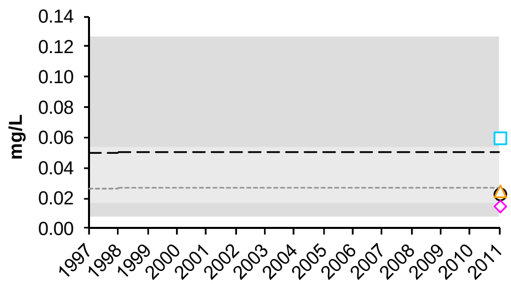
Total Suspended Solids (TSS)



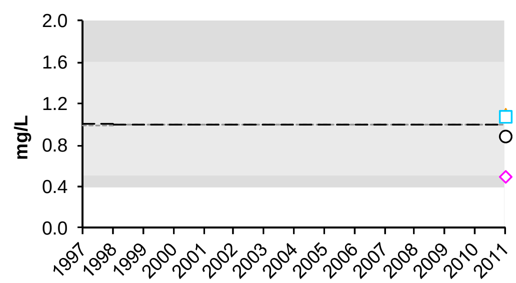
Total Dissolved Solids (TDS)



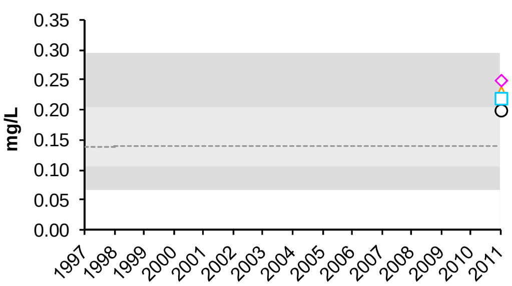
Dissolved Phosphorus



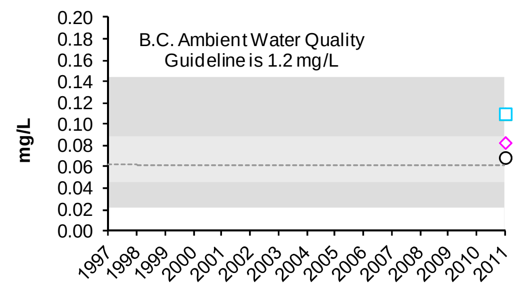
Total Nitrogen



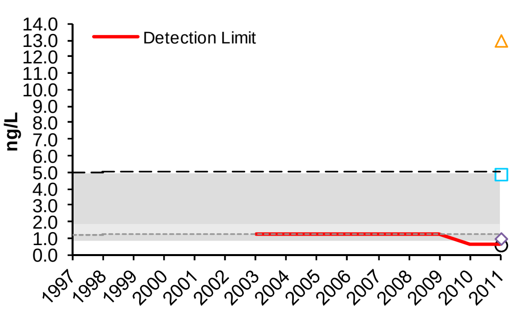
Total Strontium



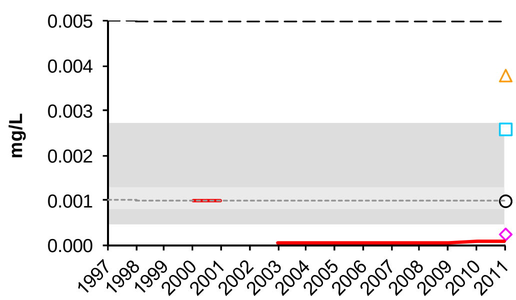
Total Boron



Total Mercury (Ultra-trace)



Total Arsenic



Non-detectable values are shown at the detection limit.

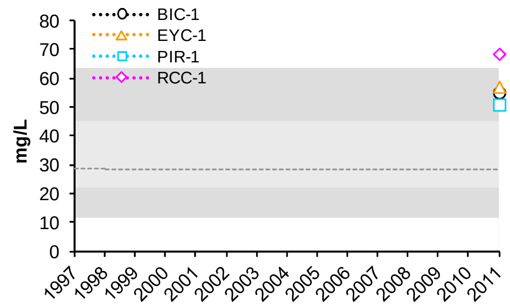
– – – – – Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

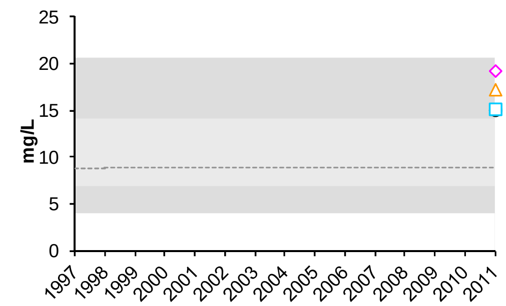
Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

Figure 5.11-31 (Cont'd.)

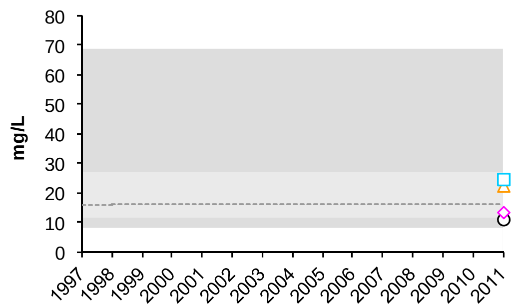
Calcium



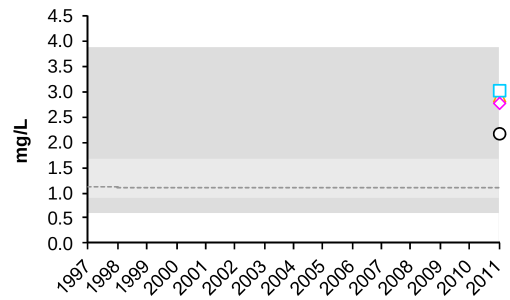
Magnesium



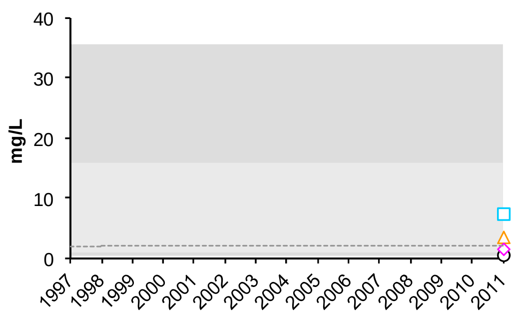
Sodium



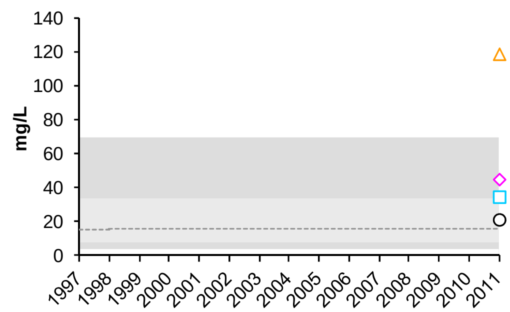
Potassium



Chloride



Sulphate



Non-detectable values are shown at the detection limit.

- - - - - Water quality guideline. See Table 3.2-5 for all WQ guidelines.

O······O Sampled as a *baseline* station ●——● Sampled as a *test* station

Regional *baseline* values reflect pooled results for all *baseline* stations in a similar region, from all years of RAMP sampling. See Sections 3.2.7.3 and 3.2.7.4, as well as Appendix D for a discussion of this approach.

5.12 ACID-SENSITIVE LAKES

This section presents the results of the Acid-Sensitive Lakes (ASL) component of RAMP for 2011.

5.12.1 General Characteristics of the RAMP ASL Component Lakes in 2011

The RAMP ASL component lakes (RAMP lakes) are typically small and shallow with a median area of 1.32 km^2 and maximum depth of only 1.83 m (Table 5.12-1). Given the shallow depth of these lakes, a large proportion of the water volume in many of the lakes freezes to depth each winter. The freezing to depth in most lakes results in large changes in lake chemistry (e.g., anoxia, decrease in pH, increase in alkalinity) that reverse when melting occurs in spring (See Appendix H in RAMP [2008]). The chemical variables measured in the 50 RAMP lakes from 1999 to 2011 are summarized in Table 5.12-2. The RAMP 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 6.80. The median pH in 2011 was 6.93. Gran alkalinity has ranged from negative values to 1,910 µeq/L with a median value of 198 µeq/L. The median Gran alkalinity in 2011 was 241 µeq/L. Concentrations of sulphate are relatively low and range from 0.02 mg/L to 19.0 mg/L with a median concentration of only 1.20 mg/L. The median concentration in 2011 was 1.18 mg/L. By conventional standards, most of the RAMP lakes are considered humic with a median concentration of dissolved organic carbon (DOC) of 21.6 mg/L (Korteleinen *et al*. 1989, Forsius 1992, Driscoll *et al*. 1991). In general, concentrations of nitrates are quite low (median 3.0 µg/L), although individual lakes may have concentrations of nitrate 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 historical median of 39.0 µg/L. The lower concentrations of dissolved phosphorus (historical median: 11 µg/L) indicate that a large fraction of the phosphorus is bound to suspended particulates.

Lakes having "unusual" chemistry were identified in the 2011 monitoring data as those below or above the 5^{th} and 95^{th} percentile for the three measurement endpoints of pH, Gran alkalinity, and DOC (Table 5.12-3). Generally, these were the same lakes identified in previous years as having "unusual" water chemistry (RAMP 2011). Three lakes (168/SM10, 169/SM9 and Clayton Lake/BM7) had very low levels of pH and Gran alkalinity and are the most poorly buffered of the RAMP lakes (Table 5.12-3). All three lakes are found in organic soils in upland regions, with two in the Stony Mountains subregion and one in the Birch Mountains subregion. The highest values of Gran alkalinity and buffering capacities were found in lakes 182/NE6, 270/NE9, and Kearl Lake/NE11, all located in mineral soils northeast of Fort McMurray. Lakes 182/NE6, 271/NE10, located in mineral soils northeast of Fort McMurray subregion, and 91/CM5/O-1 in the Caribou Mountains subregion had the highest pH of the RAMP lakes. The lowest concentrations of DOC were found in two lakes in the Birch Mountains subregion (Namur/BM2 and Legend /BM1) and in Weekes Lake/S1 in the Canadian Shield subregion. The highest concentrations of DOC were found in Lake 268/NE5 located in the Northeast of Fort McMurray subregion, Lake 166/SM7 located in the Stony Mountains subregion, and Lake 223/WF4 in the West of Fort McMurray subregion.

In general, lakes with lowest levels of Gran alkalinity and pH are found in organic soils in the upland regions. Unique to the RAMP lakes are lakes such as Kearl Lake that are simultaneously high in pH and high in DOC. Most coloured (high DOC) lakes are typically low in pH (Korteleinen *et al*. 1989).

The chemistry of the RAMP 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. In 2011, there were no measurement endpoints that showed a significant change over the ten years of monitoring. In previous years (e.g., 2010) nitrates were observed to have decreased significantly over time; however, this trend was not observed in 2011. Concentrations on nitrates are variable in the RAMP lakes, which makes it difficult to detect a change in nitrates in the RAMP lakes attributable to acidification.

5.12.2.2 Among-Year Comparisons of Measurement Endpoints using the General Linear Model

The GLM was applied to three separate cases:

- Case 1 – all 50 RAMP lakes;
- Case 2 – the ten *baseline* lakes from the Caribou Mountains and the Canadian Shield located outside of the area receiving acidifying deposition from oil sands development; and
- Case 3 – the 40 lakes potentially exposed to acidifying emissions (i.e., *test*).

Table 5.12-4 provides the variables showing statistically significant changes across years, the direction of the change (slope as positive or negative) as well as the statistical significance of the interaction term (lake x year). When the interactive term was significant, the percentage of the variability attributable to the interaction between lake and year was indicated in brackets. The interaction term accounted for more than 5% of the variability for sodium, calcium and sulphate in Case 2 (*baseline* lakes). For these three variables in Case 2, the significant/non-significant designation is; therefore, less reliable.

There was a significant increase in pH in all 50 lakes (Case 1) from 2002 to 2011. There was also a significant increase in pH in the ten *baseline* lakes (Case 2), but not a significant increase in pH in the 40 *test* lakes exposed to acidifying emissions (Case 3). An increase in pH is the opposite effect expected under an acidification scenario.

There was a significant increase in Gran alkalinity in the *baseline* lakes (Case 2), but not for all 50 lakes (Case 1) or for the exposed *test* lakes (Case 3). As with pH, an increase in Gran alkalinity is inconsistent with an acidification scenario.

The only measurement endpoint showing a significant change in a direction indicative of acidification was DOC. A significant decrease in DOC was observed in all 50 lakes (Case 1) and the *test* lakes exposed to acidifying emissions (Case 3). A decrease in DOC has also been observed in previous years (e.g., 2009 and 2010).

As discussed in previous years, it is unlikely that the decrease in DOC in the RAMP lakes is caused by acidification given that a response to acidification would have been expected first in Gran alkalinity or in pH rather than DOC and significant changes in these measurement endpoints (at least in a direction indicative of acidification) were not detected. In addition, the mean value of DOC in all three cases show that the trend depends largely on unusually high concentrations of this measurement endpoint observed in 2004 (Figure 5.12-1). When 2004 is excluded from the GLM, the trend in DOC was not statistically significant. As DOC is largely exported from surrounding fens in the lakes, it is likely that the trends observed in Figure 5.12-1 were likely related to annual variability in hydrologic conditions (e.g., runoff) rather than acidification. Changes in DOC will be monitored over time in order to determine whether a decrease in DOC continues in the RAMP lakes and whether the decrease is attributable to acidification.

Other significant changes in lake chemistry include an increase in sodium observed in all three cases and a decrease in chloride observed in all 50 lakes (Case 1) and in the exposed *test* lakes (Case 3). The significant trends in these relatively conservative variables also suggest the role of hydrologic conditions in controlling lake chemistry. Further analysis of these trends and their significance are discussed in Appendix G.

5.12.3 Critical Loads of Acidity and Critical Load Exceedances

The critical loads of acidity (CL) were calculated for each RAMP lake for the years 2002 to 2011 using the Henriksen steady state water chemistry model modified to include the contribution of organic anions as both strong acids and weak organic buffers (WRS 2006, RAMP 2005).

Table 5.12-5 provides the estimates of the critical loads of acidity for each individual RAMP lake between 2002 and 2011; summary statistics are provided in Table 5.12-6. Critical loads in 2011 ranged from -0.420 keq H^+/ha/yr to 4.54 keq H^+/ha/yr with a median CL of 0.566 keq H^+/ha/y.

The runoff to each lake, an influential term in the Henriksen model, was calculated using the isotopic mass balance (IMB) technique of Gibson *et al*. (2002, 2005, 2010) and the values for each lake are presented in Appendix G. Figure 5.12-2 provides the distributions of runoff (water yields) and the critical loads in all 50 lakes from 2002 to 2011. As noted by Gibson *et al*. (2010), water yields vary considerably between years. For example, in Kearl Lake, the water yields changed 3- to 4- fold over the ten years of data (Appendix G). The highest values of water yield occur in years with high precipitation. This is especially evident in 2005, where the median water yield (263 mm/y) was 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 hence the acid sensitivity of each lake will vary between years, depending upon the hydrologic regime.

Mean critical loads in 2011 in the six subregions are presented in Table 5.12-7. Consistent with the findings of previous years, the lowest 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. Negative values of the critical load occur when the export of alkalinity to the lakes is less than the biological threshold assumed in the model to maintain the ecological integrity of the lake (see Section 3.5.5.2). The Stony Mountain lakes, having the lowest critical loads, are the most acid-sensitive of the RAMP lakes.

5.12.4 Comparison of Critical Loads of Acidity to Modeled Net Potential Acid Input

The critical loads of acidity for each individual lake were compared to modeled rates of acid deposition for each lake published in Teck (2011) and CEMA (2010c). In both cases, a maximum emissions scenario was assumed representing existing emissions sources as well as emissions from industrial sources that have been approved by regulators. Acid input was expressed as the Net Potential Acid Input (PAI) which corrects for the nitrogen uptake by plants in the lake catchments (AENV 2007b, CEMA 2004b).

Lakes having a modeled Net PAI greater than the critical load are identified individually in Table 5.12-8 and 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 (Figure 5.12-6). Differences between years reflect differences between water yields and the base cation concentrations in each lake.

The percentage of RAMP lakes in which the modeled Net PAI is greater than the critical load (18.4 to 32.6%) was 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 RAMP 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 Teck (2011) and 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 5.12-5 represent future risk (not current risk) to the RAMP 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. Their study did not include modifications to the model for organic anions or the 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 (7 of 11) are found in the Stony Mountain subregion (Table 5.12-5).

5.12.5 Comparisons to Modeled 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 RAMP lakes. Table 5.12-9 presents 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) 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 variable 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 with care. In order to help 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 were fewer significant trends detected in values of ASL measurement endpoints in 2011 than in previous years. These include the following:

1. A significant decrease in pH over time in Lake 223 in the West of Fort McMurray subregion, which was also observed in 2010. The control chart for this lake indicates that the decline in pH in this lake is very small (Figure 5.12-3). Over ten years, the pH varied by less than 0.3. 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

significant increases in concentrations of sulphate or nitrates that would account for this decrease. In addition, there was no decrease in Gran alkalinity associated with the change in pH. 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 RAMP lakes. Gran alkalinity actually increased significantly in eight lakes in the Stony Mountains, Birch Mountains and Caribou Mountains subregions (Table 5.12-9). Lakes from the Stony Mountains, in particular, are considered the most highly sensitive to acidification and would likely show the earliest indications of acidification (see Section 5.12.4).

3. A significant increase in the concentration of sulphate over time in Lake 436 in the Birch Mountains, which was also observed in 2010. As with 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 to 2010 and then decreased in 2011. The increase in sulphate was accompanied by increases in Gran alkalinity and pH in this lake, which is the opposite of what would be expected under an acidifying scenario. The control charts suggest that there is no significant trend in sulphate occurring in Lake 436.

4. A significant increase in the concentration of nitrate over time in Lake 199 from the Birch Mountains subregion. The control chart for Lake 199 indicates that nitrate concentrations in this lake are extremely low and variable with a mean concentration of 3 µg/L (Figure 5.12-3). The concentration of nitrate in 2008 approached the two standard deviation limit of 8 µg/L. The concentration in 2011 decreased below the long-term mean. The high variability of nitrates and the limitations of its use as a measurement endpoint were noted in previous reports (RAMP 2011). Following the established criteria of interpretation, the control charts suggest that there is no significant trend in nitrate occurring in this lake (Figure 5.12-3).

5. Significant decreases in concentrations of DOC over time in lakes 287 and 290 in the Stony Mountains subregion and Lake 271 in the Northeast of Fort McMurray subregions, which were also observed in 2010. Significant decreases in DOC were also indicated by the ANOVAs for all 50 lakes and for the subset of 40 *test* lakes exposed to acidifying emissions. The control charts for these three individual lakes are consistent with trends shown in Figure 5.12-1. These changes likely do not indicate lake acidification but rather changes in hydrologic conditions. There are no significant decreases in pH or Gran alkalinity associated with the decreases in DOC in any of the three lakes. The control charts indicate 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 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 subregion, a remote area that does not receive acidifying emissions. Three of the lakes (146, 152 and 166) also show significant increases in Gran alkalinity, which suggests 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).

In summary, the results of the Mann-Kendall trend analysis did not indicate that acidification is occurring in the RAMP 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 5.12-10. The greater this ratio in a lake, the greater is the risk for acidification. The ten lakes with the highest ratios are indicated with shading in Table 5.12-10. These ten lakes are scattered throughout the oil sands region and are found in the Stony Mountains (6), Birch Mountains (2), Northeast of Fort McMurray (1) and West of Fort McMurray (1) subregions. If acidification is occurring, it should be evident first in these lakes.

Control charts for pH, SBC, sulphate, DOC, nitrates and Gran alkalinity are presented in Figure 5.12-4 to Figure 5.12-9. The interpretation of these control charts follows the rules outlined in Section 3.2.5.7. For Lake 170, values in 1999 for pH and SBC were considered true outliers or anomalies and excluded from calculations of the control limits. Similarly, the nitrate concentrations in Lakes 168 in 1999 and 172 in 2010 were considered as outliers. Exclusion of these outliers makes the control limits more stringent and conservative. These outliers were still retained in the plots.

As in previous years, the control plots for all the measurement endpoints show isolated excursions beyond ±2SDs during the 10 to 13 years of monitoring. Some of these excursions were in a direction consistent with acidification, while other excursions were not. The following is a list of endpoints/lakes where excursions occurred in a direction consistent with acidification at some point during the RAMP data record, as well as those excursions observed specifically in 2011 (in parentheses):

- pH in lakes 166, 167 and 290:
- SBC in lakes 170 and 290;
- Sulphate in lakes 167, 168, 185, 447, 452 (lakes 185 and 452 in 2011);
- DOC in lakes 170, 172, 185 and 447;
- Gran alkalinity in lakes 290 and 447; and
- Nitrates in all ten lakes (lakes 290 and 452 in 2011).

In all cases (except for those occurring in 2011), concentrations of these measurement endpoints returned to normal values (i.e., within ±2SDs) the following year.

Nitrate concentrations were extremely variable and a logarithmic scale was used to present this measurement endpoint that could vary by three orders of magnitude within a lake (e.g., Lake 167, Figure 5.12-8). It is notable that concentrations of nitrate exceeded the three standard deviation limit in Lake 290 in 2011 and in Lake 172 in 2010 although the control charts for both lakes suggests that these excursions were actually anomalies rather than the result of a trend (Figure 5.12-8). For Lake 290, there is no significant increase in nitrate over the twelve years preceding 2011. In fact, concentrations of nitrate have been decreasing in this lake. Concentrations of nitrate in Lake 172 were variable but relatively stable over the preceding years, increased significantly in 2010 and returned to values in 2011 consistent with years prior to 2010 (Figure 5.12-8). Concentrations of nitrate in both lakes will be observed 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 lakes that are most at risk.

5.12.7 Classification of Results

Results of the analysis of the 2011 RAMP lakes compared to historical data suggest that there was no significant change in the overall chemistry of the 50 RAMP lakes across years that were attributable to acidification. A long-term decline was noted for DOC, although this appeared to be the result of factors other than acidifying emissions (e.g., hydrology). 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 was no evidence to suggest acidification in these lakes.

A summary of the state of the RAMP lakes in 2011 with respect to the potential for acidification was prepared for each physiographic subregion by examining deviations from the mean chemical concentrations of measurement endpoints (in a direction indicative of acidification) for each lake within a subregion. A two standard deviation criterion was used in each case. In general, data in 2011 were more variable than previous years resulting in a greater number of exceedances of the two standard deviation criterion than in previous years. In most cases, these exceedances were caused by one lake in a subregion having unusual water chemistry in 2011 (e.g., Lake 225/WF5 in the West of Fort McMurray subregion, Lake 448/BM7 in the Birch Mountains and Lake 146/CM1 in the Caribou Mountains). There was no indication that acidification has occurred in any lakes and that these exceedances were caused by other factors influencing water chemistry such as changes in hydrology or groundwater inputs. Taking into account these other factors, the subregions were classified as having a **Negligible-Low** indication of incipient acidification.

Table 5.12-1 Morphometry statistics for the RAMP acid-sensitive 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 RAMP acid-sensitive lakes.

Variable	Mean		Median		Minimum		Maximum		5th Percentile 2011	95th Percentile 2011
	1999-2011	2011	1999-2011	2011	1999-2011	2011	1999-2011	2011		
Lab pH	6.61	6.82	6.80	6.93	3.97	4.40	9.46	9.42	4.904	8.27
Total Alkalinity (µeq/L)	324	394	222	258	0	0	1894	1894	25.960	1267
Gran Alkalinity (µeq/L)	310	377	198	241	-57	-34	1910	1910	-3.080	1254
Specific Cond. (µS/cm)	45	49	33	36	10	11	183	183	13.104	122
Total Dissolved Solids (mg/L)	67	73	60	59	0.02	17.00	219	186	34.350	136
Total Suspended Solids (mg/L)	7.9	11.2	2.8	4.0	0.00	0.025	175.0	86.0	0.025	46.4
Sodium (mg/L)	2.07	2.20	1.40	1.54	0.18	0.44	12.34	12.34	0.519	6.35
Potassium (mg/L)	0.514	0.570	0.430	0.475	0.000	0.110	2.40	2.130	0.175	1.162
Calcium (mg/L)	5.70	6.47	4.63	6.47	0.002	0.005	32.2	21.8	1.212	18.9
Magnesium (mg/L)	1.84	2.14	1.44	1.61	0.005	0.005	13.6	8.03	0.325	6.21
Bicarbonate (mg/L)	19.6	23.6	13.6	15.8	0.000	0.000	116	116	1.588	73.4
Chloride (mg/L)	0.339	0.312	0.175	0.140	0.015	0.015	2.636	2.500	0.070	1.246
Sulphate (mg/L)	2.40	2.34	1.20	1.18	0.020	0.020	19.0	15.1	0.080	10.2
Total Dissolved Nitrogen (µg/L)	833	807	693	693	105	220	2891	2700	327	1659
Ammonia (µg/L)	38.0	44.4	17.0	26.5	0.4	2.5	1509	487	5.01	131
Nitrate + Nitrite (µg/L)	20.6	22.1	3.00	8.14	0.02	1.00	732.9	223.0	2.000	88.7
Total Phosphate (µg/L)	54.8	60.9	39.0	41.0	3.0	9.0	341	208	12.5	181
Dissolved Phosphorous (µg/L)	20.5	21.1	11.0	9.5	1.0	2.00	167	127	4.000	86.5
Dissolved Inorganic Carbon (mg/L)	3.34	4.24	2.05	2.55	0.027	0.300	21.6	21.6	0.400	14.6
Dissolved Organic Carbon (mg/L)	22.8	23.3	21.6	22.7	6.8	7.5	81.2	49.2	10.535	43.7
Chlorophyll *a* (µg/L)	20.6	27.5	9.2	10.6	0.3	2.8	371.0	236.0	3.678	106.0
Iron (mg/L)	0.393	0.356	0.185	0.110	0.00001	0.005	3.88	2.17	0.005	1.42
Total Nitrogen (µg/L)	1214	1299	968	960	274	366	6558	5960	411	3231
Total Kjeldahl Nitrogen (µg/L)	1192	1254	939	909	273	354	6552	5945	401.432	3206
Sum base cations (meq/L)	539	609.2	427	447	38.2	61.4	2305	2305	139	1543
Dissolved Aluminum (mg/L)	71.4	75.2	25.5	19.8	0.100	1.36	71	75	1.87	317

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 RAMP acid-sensitive lakes with chemical characteristics either below the 5th or above the 95th percentile in 2011.

Lake	Subregion	pH	Gran Alkalinity (µeq/L)	DOC (mg/L)
5th percentile 2011		**4.90**	**-3.1**	**10.535**
95th percentile 2011		**8.27**	**1,254**	**43.700**
168 (SM10/A21)	Stony Mountains	4.85	-3.80	22.90
169 (SM9/A24)	Stony Mountains	4.49	-22.80	23.10
166 (SM7/A86)	Stony Mountains	6.69	137.00	45.80
223 (WF4/P94)	West of Fort McMurray	7.19	693.20	49.20
268 (NE5/E15)	Northeast of Fort McMurray	7.07	408.00	44.60
182 (NE6/P23)	Northeast of Fort McMurray	9.42	1268.20	17.90
270 (NE9/4)	Northeast of Fort McMurray	7.98	1398.00	21.40
271 (NE10/6)	Northeast of Fort McMurray	8.80	1220.00	23.40
418 (NE11/Kearl L.)	Northeast of Fort McMurray	8.08	1910.00	24.60
436 (BM2/L18/Namur L.)	Birch Mountains	7.48	446.40	8.00
444 (BM1/L25/Legend L.)	Birch Mountains	7.08	194.20	7.50
448 (BM7/L29/Clayton L.)	Birch Mountains	4.40	-34.00	27.00
118 (S1/L107/Weekes L.)	Canadian Shield	7.39	474.00	9.50
91 (CM5/O-1/E55)	Caribou Mountains	8.33	333.20	21.30

Yellow shading denotes values below the 5th percentile in 2011.

Green shading denotes values above the 95th percentile in 2011.

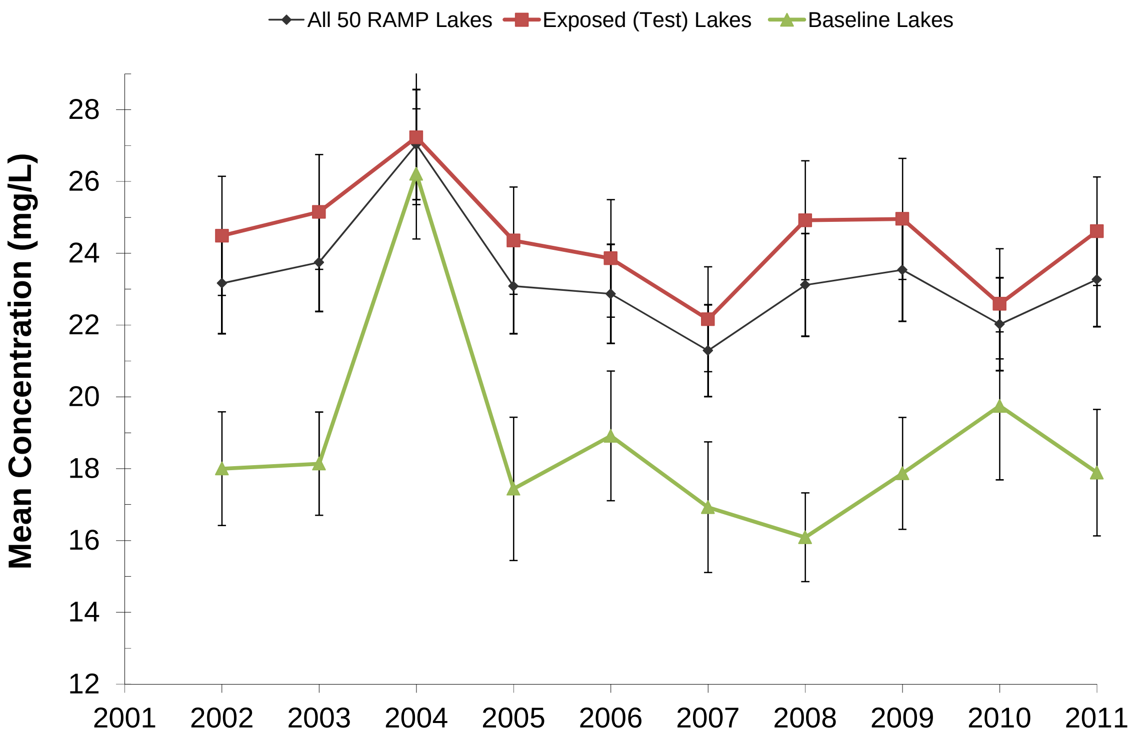
Table 5.12-4 Results of the ANOVA using the GLM for all 50 RAMP acid-sensitive lakes, *baseline* lakes, and *test* lakes.

Variable	ANOVA	Case 1 - All Lakes			Case 2 - *Baseline* Lakes			Case 3 - *Test* Lakes		
	Significance	Significance	Direction (slope)	Interactive Term	Significance	Direction (slope)	Interactive Term	Significance	Direction (slope)	Interactive Term
pH	NS	S	Positive	NS	S	Positive	NS	NS	Positive	NS
Gran alkalinity	NS	NS	Positive	S (1.3%)	S	Positive	S (3.4%)	NS	Positive	S (1.2%)
Conductivity	NS	NS	Negative	S (1.3%)	NS	Positive	S (3.8%)	NS	Negative	S (1.2%)
Colour	NS	NS	Positive	NS	NS	Positive	NS	NS	Positive	NS
Sodium	NS	S	Positive	NS	S	Positive	S (9.9%)	S	Positive	NS
Calcium	NS	NS	Negative	NS	NS	Positive	S (5.5%)	NS	Negative	NS
Magnesium	NS	NS	Negative	NS	NS	Negative	NS	NS	Negative	S (1.2%)
Chloride	NS	S	Negative	NS	NS	Negative	NS	S	Negative	NS
Sulphates	NS	NS	Positive	NS	NS	Positive	S (6.2%)	NS	Positive	NS
Nitrates	NS	NS	Negative	NS	NS	Positive	NS	NS	Negative	NS
DOC	NS	S	Negative	NS	NS	Negative	NS	S	Negative	NS
Sum Base Cations	NS	NS	Positive	NS	NS	Positive	NS	NS	Negative	NS
Aluminum	NS	NS	Negative	NS	NS	Positive	S (4.9%)	NS	Negative	NS

Note: S= statistically significant ($p<0.05$), NS = not statistically significant. Percentage of the variation in the variable attributable to the interaction between lake number and year is indicated in brackets when the term was significant.

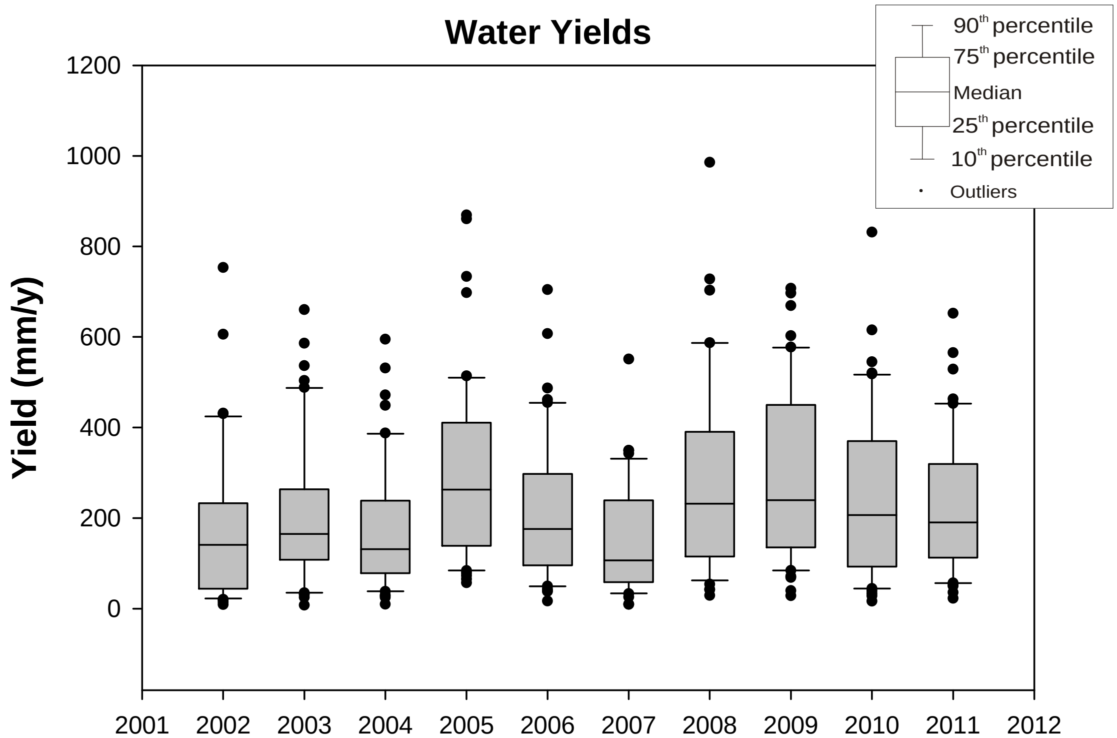
Shading denotes measurement endpoints for the ASL program.

Figure 5.12-1 Concentrations of dissolved organic carbon (± 1SE) in all the 50 RAMP ASL component lakes combined, in *baseline* lakes and in *test* 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 RAMP lakes, 2002 to 2011.



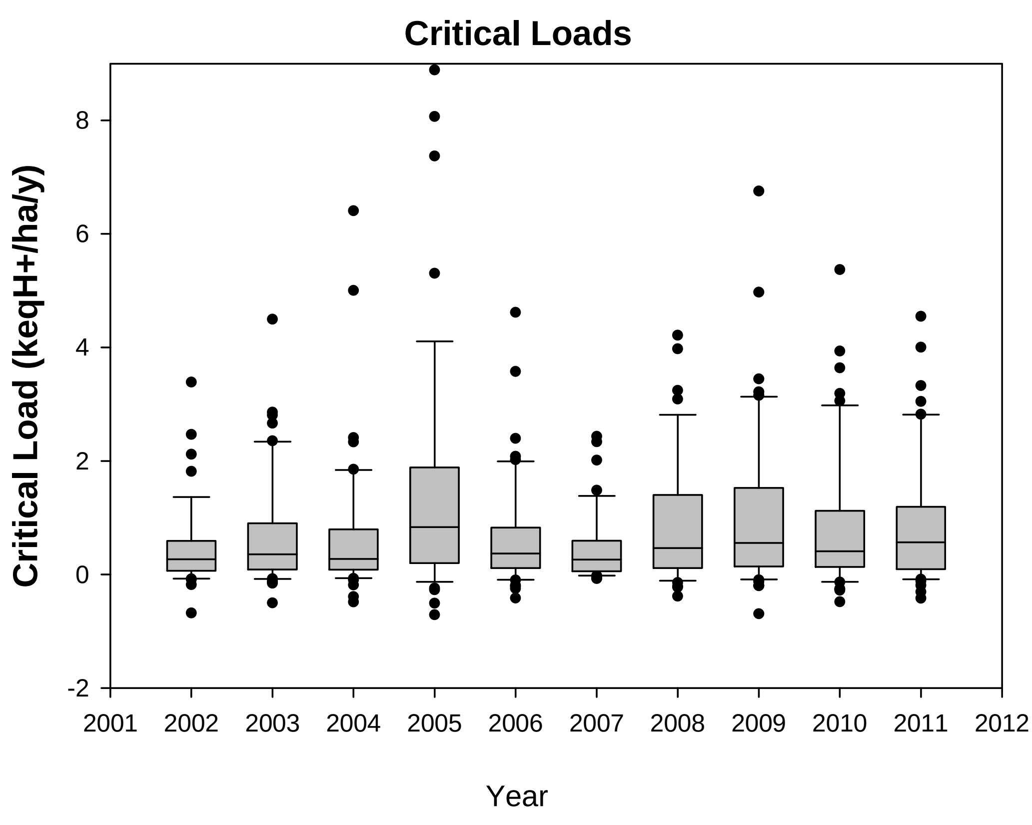


Table 5.12-5 Critical loads[1] of acidity in the RAMP acid-sensitive lakes, 2002 to 2011.

NO_x-SO_x GIS No.	Original RAMP Designation	Current AEW Name	Gross Catchment Area (km^2)	Critical Loads (keqH+/Ha/y)										
				2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	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	-0.119	0.134
169	A24	SM9	8.3	-0.182	-0.137	-0.391	-0.509	-0.252	-0.069	-0.226	-0.199	-0.254	-0.420	0.121
170	A26	SM6	13.1	-0.015	-0.019	-0.028	-0.052	-0.041	-0.008	0.004	-0.025	-0.049	-0.034	0.125
167	A29	SM5	3.7	-0.072	-0.052	-0.006	0.016	0.099	-0.005	-0.210	0.062	-0.278	-0.089	0.105
166	A86	SM7	6.9	0.065	0.146	0.192	0.262	0.213	0.150	0.515	0.560	0.340	0.055	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	-0.193	0.120
289	27	SM3	7.4	0.036	0.078	0.087	0.159	0.093	0.095	0.112	0.144	0.008	0.066	0.118
290	28	SM4	11.7	0.001	0.020	-0.004	-0.004	0.007	-0.007	0.002	0.001	-0.032	-0.007	0.115
342	82	SM2	15.4	0.065	0.059	0.119	0.158	0.119	0.012	0.117	0.140	0.140	0.095	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	0.729	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	1.359	0.044
171	A47	WF2	4.3	0.107	0.173	0.132	0.496	0.153		0.829	0.403	0.180	0.246	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	0.013	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	0.151
225	P96	WF5	5.0	0.123	0.265	0.230	1.509	0.386	0.203	0.418	0.455	0.556	0.882	0.172
226	P97	WF6	4.2	0.088	0.342	0.206	2.710	0.194	0.168	0.290	0.402	0.470	0.375	0.240
227	P98	WF7	1.6	0.290	1.147	0.583	0.862	0.956	0.465	1.076	1.489	1.675	1.246	0.209
267	1	WF8	23.1	0.197	0.401	0.350	0.937	0.415	0.147		0.760	0.348	0.518	0.161
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	0.215	0.188
470	L7	NE2	15.1	0.176	0.143	0.075	0.316	0.771	0.159	0.235	0.205	0.210	0.290	0.166
471	L8	NE3	24.0	0.344	0.609	0.438	1.137	0.626	0.229	0.593	0.496	0.428	0.584	0.145
400	L39	NE4	3.2	1.154	0.959	0.788	0.769	1.570	0.793	1.456	1.461	0.851	1.352	0.059
268	E15	NE5	7.3	1.363	2.226	1.488	2.383	0.273	0.419	2.052	2.923	2.310	2.043	0.163
182	P23	NE6	8.3	0.361	1.256	1.445	4.107	0.350	2.012	0.066	2.376	3.188	2.818	0.251
185	P27	NE7	5.9	0.044	0.016	-0.071	0.281	-0.028	0.034	0.052	0.018	0.051	0.094	0.189

Shaded values denote modeled Potential Acid Input that exceed critical loads. PAI obtained from the Frontier Project EIA (Teck 2011) or 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 nitrogen 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. comms.).

Table 5.12-5 (Cont'd.)

NO_x-SO_x GIS No.	Original RAMP Designation	Current AEW Name	Gross Catchment Area (km^2)	Critical Loads (keqH+/Ha/y)										
				2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Net PAI
Northeast of Fort McMurray Subregion – cont.														
209	P7	NE8	0.8	0.899	0.808	0.355	0.651	0.428	0.422	2.594	0.877	1.323	0.976	0.178
270	4	NE9	11.2	3.385	4.496	5.000	8.066	4.615	1.341	3.973	6.751	5.369	4.544	0.137
271	6	NE10	17.1	2.464	2.663	6.406	7.369	3.572	2.334	3.087	4.968	3.638	4.001	0.064
418	Kearl L.	NE11	77.2		2.858	2.407	5.302	1.775	0.814	2.663	2.823	2.082	3.046	0.618
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	2.795	0.066
442	L23	BM9	33.3	0.268	0.366	0.277	0.378	0.330	0.305	0.445	0.458	0.245	0.125	0.056
444	L25	BM1	58.7	0.632	1.072	0.988	0.977	1.107	0.635	1.401	1.627	1.088	1.173	0.067
447	L28	BM6	13.7	-0.083	-0.155	0.006	-0.246	-0.214	0.006	0.044	-0.130	0.162	-0.038	0.050
448	L29	BM7	4.7	-0.683	-0.502	-0.487	-0.713	-0.419	-0.076	-0.385	-0.694	-0.483	-0.308	0.046
454	L46	BM8	32.5	0.511	0.677	0.394	1.160	0.492	0.355	0.594	0.762	0.391	0.621	0.053
455	L47	BM4	37.3	0.725	0.857	1.753	2.266	1.146	0.493	1.401	2.061	1.227	1.499	0.054
457	L49	BM5	30.6	0.628	0.938	0.495	1.580	0.721	0.278	0.962	1.155	0.569	0.734	0.052
464	L60	BM3	29.8	0.366	0.692	0.509	0.833	0.417	0.245	0.620	0.693	0.498	0.636	0.055
175	P13	BM10	5.2	0.403	0.348	0.666	1.500	0.627	0.300	0.826	3.154	0.526	0.942	0.084
199	P49	BM11	0.6	0.112	0.152	0.174	0.200	0.215	0.080	0.141	0.148	0.105	0.155	0.086
Canadian Shield Subregion														
473	A301	S4	114.6	0.105	0.131	0.102	0.332	0.166		0.214	0.197	0.148	0.197	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	2.375	0.007
84	L109	S2	112.6	0.181	0.208	0.148	0.334	0.156		0.245	0.320	0.166	0.279	0.014
88	O-10	S5	4.5	0.275	0.316	0.204		0.289		0.408	0.551	0.213	0.331	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	0.549	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	3.325	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	0.964	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	0.709	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	0.745	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	1.097	0.027

Shaded values denote modeled Potential Acid Input that exceed critical loads. PAI obtained from the Frontier Project EIA (Teck 2011) or 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 nitrogen 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. comms.).

Table 5.12-6 Summary of Critical Loads in the RAMP acid-sensitive lakes, 2002 to 2011.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011 (provisional)
No. of lakes	49	50	50	49	50	46	49	50	50	50
Minimum CL	-0.683	-0.502	-0.487	-0.713	-0.419	-0.076	-0.385	-0.694	-0.483	-0.420
Maximum CL	3.385	4.496	6.406	8.886	4.615	2.429	4.211	6.751	5.369	4.54
Average CL	0.462	0.681	0.678	1.432	0.650	0.457	0.893	1.076	0.863	0.877
Median CL	0.268	0.357	0.274	0.833	0.368	0.261	0.466	0.555	0.410	0.566
No. of lakes in which the PAI is greater than the CL	15	14	15	9	13	18	12	11	11	11
Percent of lakes in which the PAI is greater than the CL	30.6	28.0	30.0	18.4	26.0	39.1	24.5	22.0	22.0	22.0

Table 5.12-7 Mean critical loads for each subregion, 2011.

Subregion	Critical Load keq H^+/ha/y
Stony Mountains	0.008
West of Fort McMurray	0.614
Northeast of Fort McMurray	1.815
Birch Mountains	0.758
Canadian Shield	0.746
Caribou Mountains	1.368

Table 5.12-8 Chemical characteristics of the RAMP acid-sensitive lakes having the modeled PAI greater than the critical load in 2011.

NO_x-SO_x GIS No.	Original RAMP Designation	Subregion	pH	Gran Alkalinity (μeq/L)	Conductivity (μS/cm)	DOC (mg/L)	Lake Area (km^2)
168	A21	Stony Mts.	4.85	-3.8	14.85	22.90	1.38
169	A24	Stony Mts.	4.49	-22.8	15.85	23.10	1.45
170	A26	Stony Mts.	5.27	11.2	12.6	17.70	0.71
167	A29	Stony Mts.	5.97	44	10.77	15.40	1.05
287	25	Stony Mts.	4.97	-2.2	11.65	16.20	2.176
289	27	Stony Mts.	6.62	76.8	14.17	13.30	1.829
290	28	Stony Mts.	5.61	42.4	14.46	20.00	0.544
172	A59	West Ft. Mc.	5.16	35	27.5	36.00	2.06
185	P27	N.E. Ft. Mc.	5.78	81	22.2	26.90	0.094
447	L28	Birch Mts.	5.51	44.6	18.68	29.30	1.30
448	L29	Birch Mts.	4.40	-34	13.72	27.00	0.65

Table 5.12-9 Results of Mann-Kendall trend analyses on measurement endpoints for the RAMP acid-sensitive lakes, 2011.

ID Number	Original Name	Current AEW Name	pH		Gran Alkalinity (mg/L)		Sulphate (mg/L)		Nitrates and Nitrites (mg/L)		Dissolved Organic Carbon (mg/L)		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*		0.134
169	A24	SM9		1.44		-1.15		0.00		-1.11		-0.21		-0.21	*-7*		0.121
170	A26	SM6		0.89		2.02		-1.03		-0.48		-0.55		-0.75	*-1*		0.125
167	A29	SM5		1.65		2.65		-0.62		-0.35		0.00		1.30	*13*		0.105
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*		0.120
289	27	SM3	*4*		*18*		*8*		*13*		*-2*		*6*		*-5*		0.118
290	28	SM4	*8*		*14*		*-1*		*-22*		*-20*		*-14*		*-6*		0.115
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*		0.151
225	P96	WF5	*3*		*-4*		*-2*		*-3*		*-4*		*-16*		*-2*		0.172
226	P97	WF6	*-4*		*4*		*4*		*-1*		*10*		*6*		*-2*		0.240
227	P98	WF7	*12*		*8*		*-4*		*4*		*-4*		*10*		*2*		0.209
267	1	WF8	*6*		*-4*		*-12*		*1*		*-6*		*-12*		*-9*		0.161
452	L4	NE1		0.69		0.93		-0.21		-0.48		0.00		0.00	*7*		0.188
470	L7	NE2		0.41		0.93		0.07		0.82		-0.21		0.62	*1*		0.166
471	L8	NE3		0.75		-1.56		0.07		-0.55		-0.07		-1.85	*-1*		0.145
400	L39	NE4		1.10		0.93		0.07		0.48		1.24		-0.48	*7*		0.059
268	E15 (L15b)	NE5		0.16		-0.93		1.40		-0.78		0.31		-0.78	*-3*		0.163
182	P23	NE6	*4*		*12*		*-2*		*11*		*10*		*8*		*1*		0.251
185	P27	NE7	*-7*		*12*		*10*		*-1*		*12*		*8*		*4*		0.189

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 AEW Name	pH		Gran Alkalinity (mg/L)		Sulphate (mg/L)		Nitrates and Nitrites (mg/L)		Dissolved Organic Carbon (mg/L)		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*		0.178
270	4	NE9	*-14*		*-10*		*6*		*1*		*-16*		*-16*		*-3*		0.137
271	6	NE10	*0*		*-12*		*8*		*-5*		*-22*		*-18*		*-13*		0.064
418	Kearl L.	NE11	*11*		*12*		*-8*		*-5*		*12*		*10*		*4*		0.618
436	L18	BM2		1.92		3.43		2.13		-1.10		-0.89		1.71	*-3*		0.066
442	L23	BM9		1.44		1.17		-1.30		1.10		-1.17		-1.44	*-5*		0.056
444	L25	BM1		1.51		1.71		-0.34		0.00		-0.75		1.03	*-7*		0.067
447	L28	BM6		0.62		1.40		-1.30		-0.55		-0.07		0.48	*3*		0.050
448	L29	BM7		0.78		-1.32		-1.25		-0.55		0.78		0.00	*-4*		0.046
454	L46	BM8		-1.17		0.31		-1.58		0.07		0.62		-1.85	*-5*		0.053
455	L47	BM4		0.62		0.62		-0.41		0.62		1.44		-0.07	*-13*		0.054
457	L49	BM5		-0.41		-0.62		-1.51		-0.34		1.30		-2.81	*7*		0.052
464	L60	BM3		-0.75		0.93		-1.03		0.64		1.24		-0.62	*9*		0.055
175	P13	BM10	*-10*		*-8*		*-16*		*1*		*-8*		*-8*		*-3*		0.084
199	P49	BM11	*-6*		*-10*		*0*		*21*		*-4*		*-14*		*9*		0.086
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		1.51		2.02		0.07		-2.26		-1.03		-2.95	*-1*		0.027
91	O-1/E55	CM5		0.14		0.70		-0.34		-0.75		1.17		2.95	*5*		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 for acid-sensitive lakes showing significant trends in measurement endpoints using Mann-Kendall trend analysis.

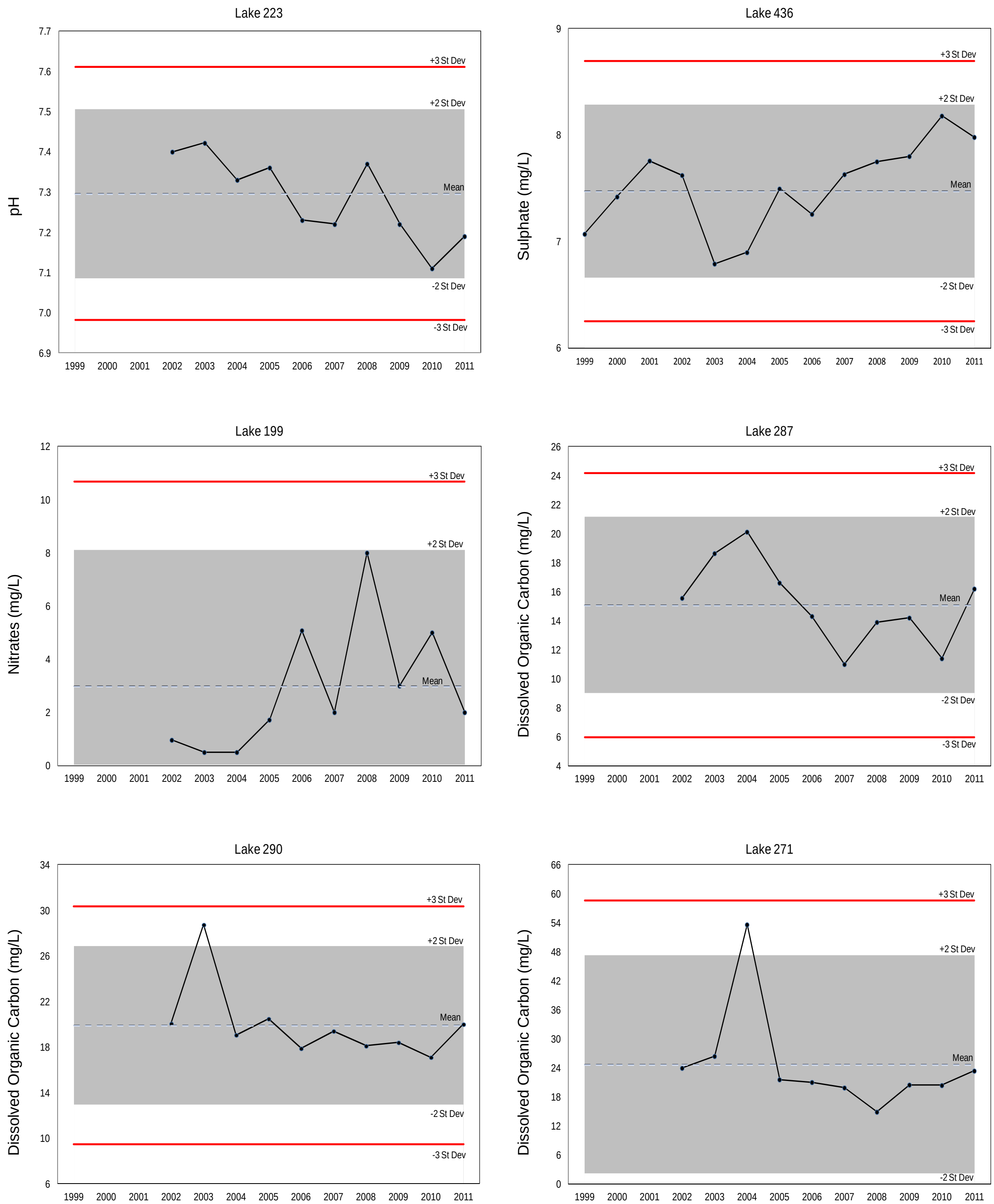
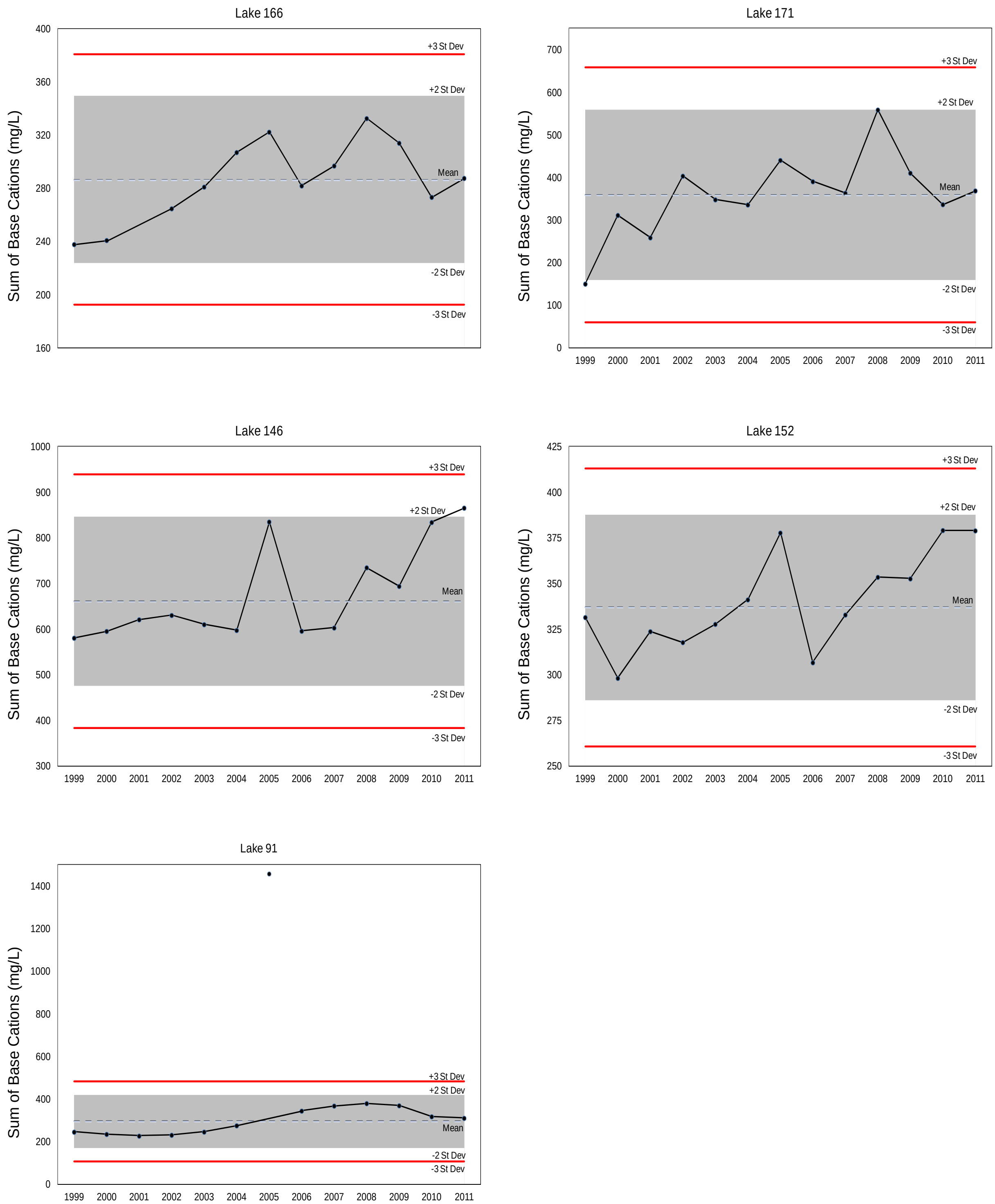


Figure 5.12-3 (Cont’d.)



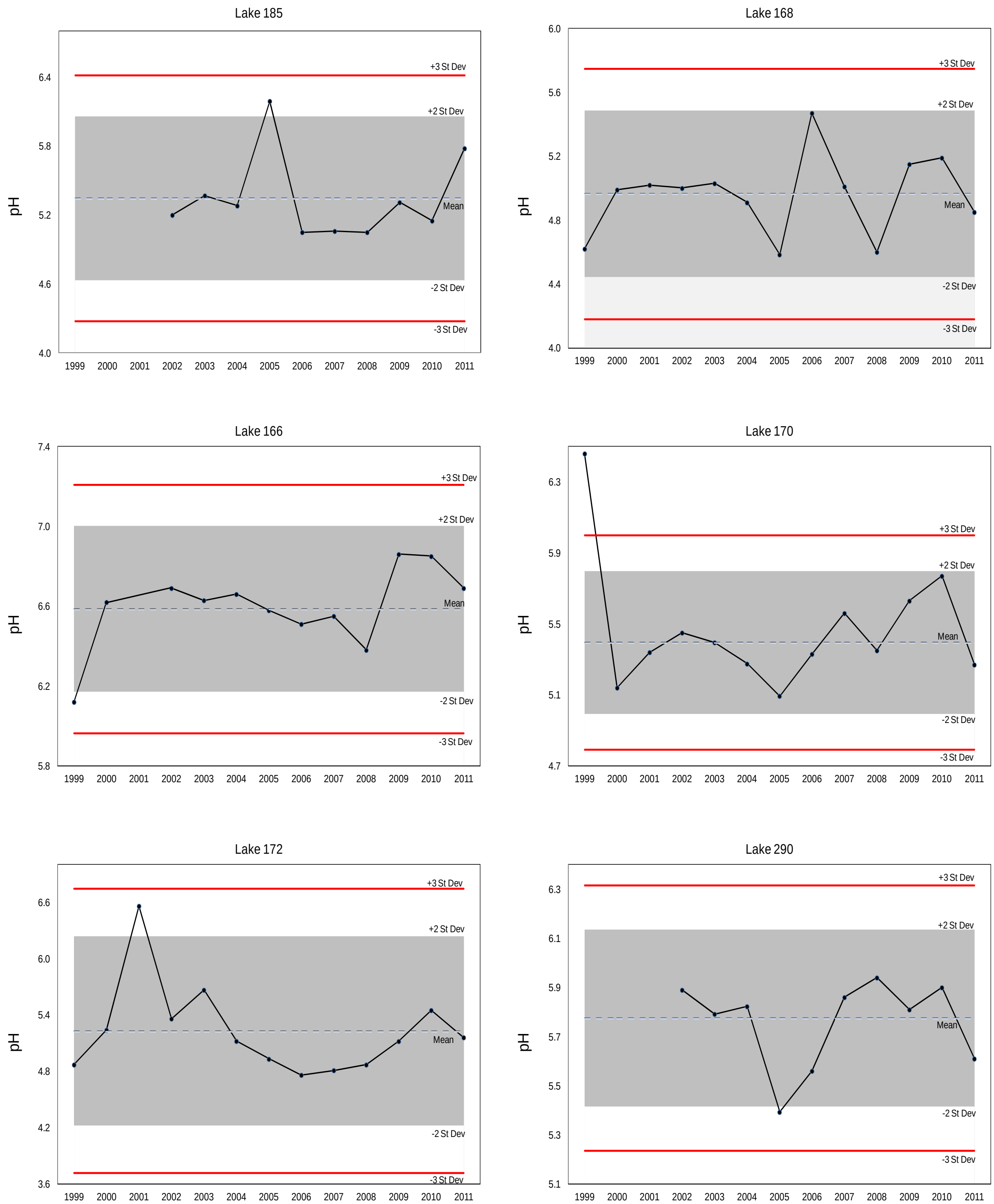
Outlier in Lake 91 was excluded from the control limit calculations.

Table 5.12-10 Acidification risk factor for individual RAMP lakes.

RAMP Lake No.	Original Designation	AEW Designation	Subregion	Critical Load (keq/Ha/y) IMB	PAI	Acidification Risk Factor PAI/CL
168	A21	SM 10	Stony Mountains	-0.119	0.134	134.316
169	A24	SM 9	Stony Mountains	-0.420	0.121	120.614
170	A26	SM 6	Stony Mountains	-0.034	0.125	124.547
167	A29	SM 5	Stony Mountains	-0.089	0.105	105.358
166	A86	SM 7	Stony Mountains	0.055	0.043	0.788
287	25	SM 8	Stony Mountains	-0.193	0.120	119.502
289	27	SM 3	Stony Mountains	0.066	0.118	1.784
290	28	SM 4	Stony Mountains	-0.007	0.115	115.279
342	82	SM 2	Stony Mountains	0.095	0.027	0.285
354	94	SM 1	Stony Mountains	0.729	0.043	0.059
165	A42	WF1	West of Fort McMurray	1.359	0.044	0.032
171	A47	WF-2	West of Fort McMurray	0.246	0.082	0.334
172	A59	WF-3	West of Fort McMurray	0.013	0.049	3.881
223	P94	WF-4	West of Fort McMurray	0.271	0.151	0.556
225	P96	WF-5	West of Fort McMurray	0.882	0.172	0.195
226	P97	WF-6	West of Fort McMurray	0.375	0.240	0.639
227	P98	WF-7	West of Fort McMurray	1.246	0.209	0.168
267	1	WF-8	West of Fort McMurray	0.518	0.161	0.310
452	L4	NE 1	Northeast of Fort McMurray	0.215	0.188	0.876
470	L7	NE2	Northeast of Fort McMurray	0.290	0.166	0.571
471	L8	NE 3	Northeast of Fort McMurray	0.584	0.145	0.248
400	L39	NE 4	Northeast of Fort McMurray	1.352	0.059	0.044
268	E15	NE-5	Northeast of Fort McMurray	2.043	0.163	0.080
182	P23	NE6	Northeast of Fort McMurray	2.818	0.251	0.089
185	P27	NE-7	Northeast of Fort McMurray	0.094	0.189	2.021
209	P7	NE-8	Northeast of Fort McMurray	0.976	0.178	0.182
270	4	NE 9	Northeast of Fort McMurray	4.544	0.137	0.030
271	6	NE 10	Northeast of Fort McMurray	4.001	0.064	0.016
418	Kearl L.	NE 11	Northeast of Fort McMurray	3.046	0.618	0.203
436	L18	BM 2	Birch Mountains	2.795	0.066	0.024
442	L23	BM 9	Birch Mountains	0.125	0.056	0.451
444	L25	BM 1	Birch Mountains	1.173	0.067	0.057
447	L28	BM 6	Birch Mountains	-0.038	0.050	50.154
448	L29	BM 7	Birch Mountains	-0.308	0.046	46.148
454	L46	BM 8	Birch Mountains	0.621	0.053	0.086
455	L47	BM 4	Birch Mountains	1.499	0.054	0.036
457	L49	BM 5	Birch Mountains	0.734	0.052	0.071
464	L60	BM 3	Birch Mountains	0.636	0.055	0.087
175	P13	BM-10	Birch Mountains	0.942	0.084	0.089
199	P49	BM-11	Birch Mountains	0.155	0.086	0.552
473	A301	S-4	Canadian Shield	0.197	0.014	0.071
118	L107	S-1	Canadian Shield	2.375	0.007	0.003
84	L109	S-2	Canadian Shield	0.279	0.014	0.050
88	O-10	S-5	Canadian Shield	0.331	0.014	0.042
90	R1	S-3	Canadian Shield	0.549	0.014	0.026
146	E52	CM-1	Caribou Mountains	3.325	0.027	0.008
152	E59	CM-2	Caribou Mountains	0.964	0.027	0.028
89	E68	CM-3	Caribou Mountains	0.709	0.027	0.038
97	O-2 E67	CM-4	Caribou Mountains	0.745	0.027	0.036
91	O-1/E55	CM-5	Caribou Mountains	1.097	0.027	0.025

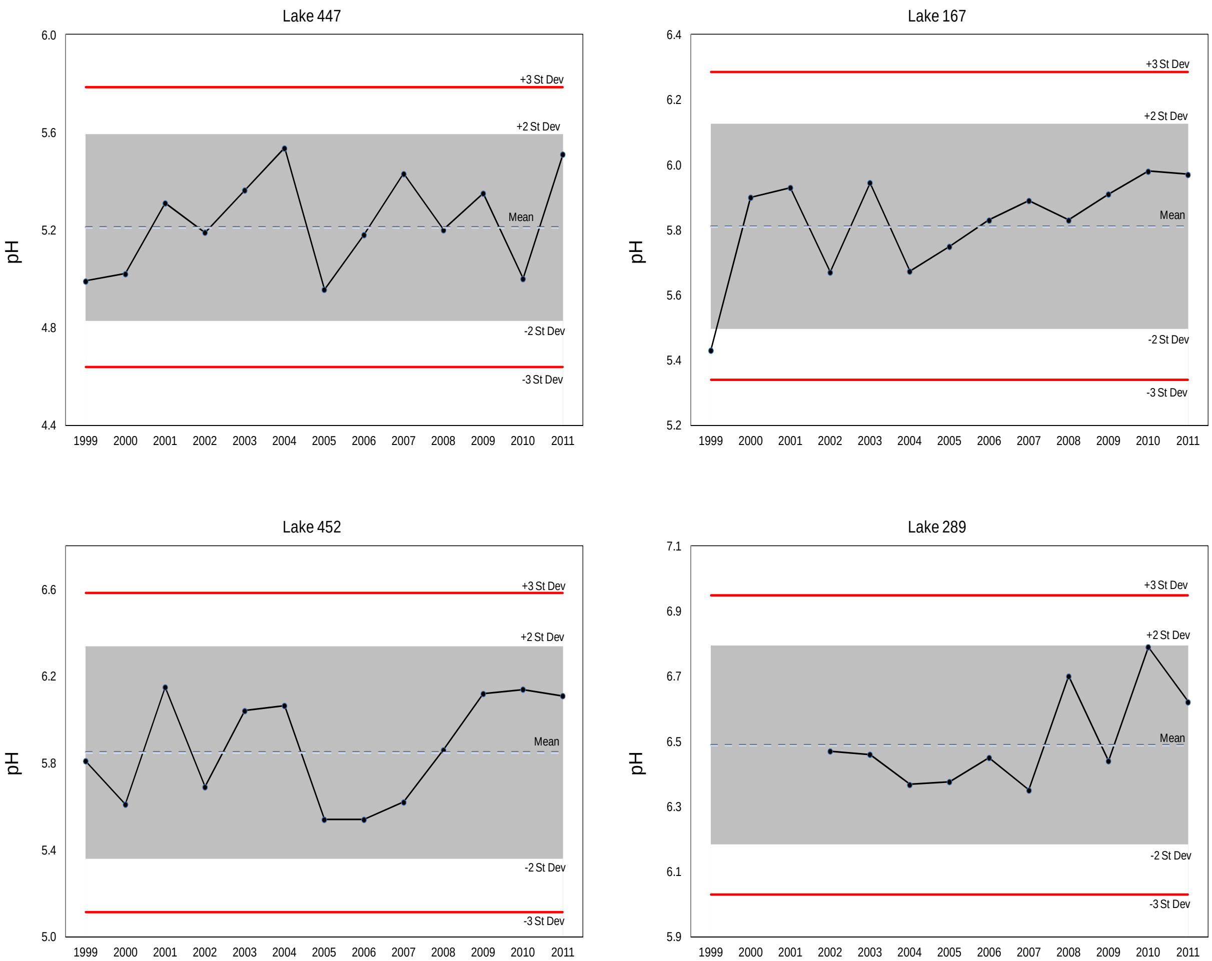
Shading denotes those lakes most at risk to acidification.

Figure 5.12-4 Control charts of pH in ten RAMP acid-sensitive lakes most at risk to acidification.



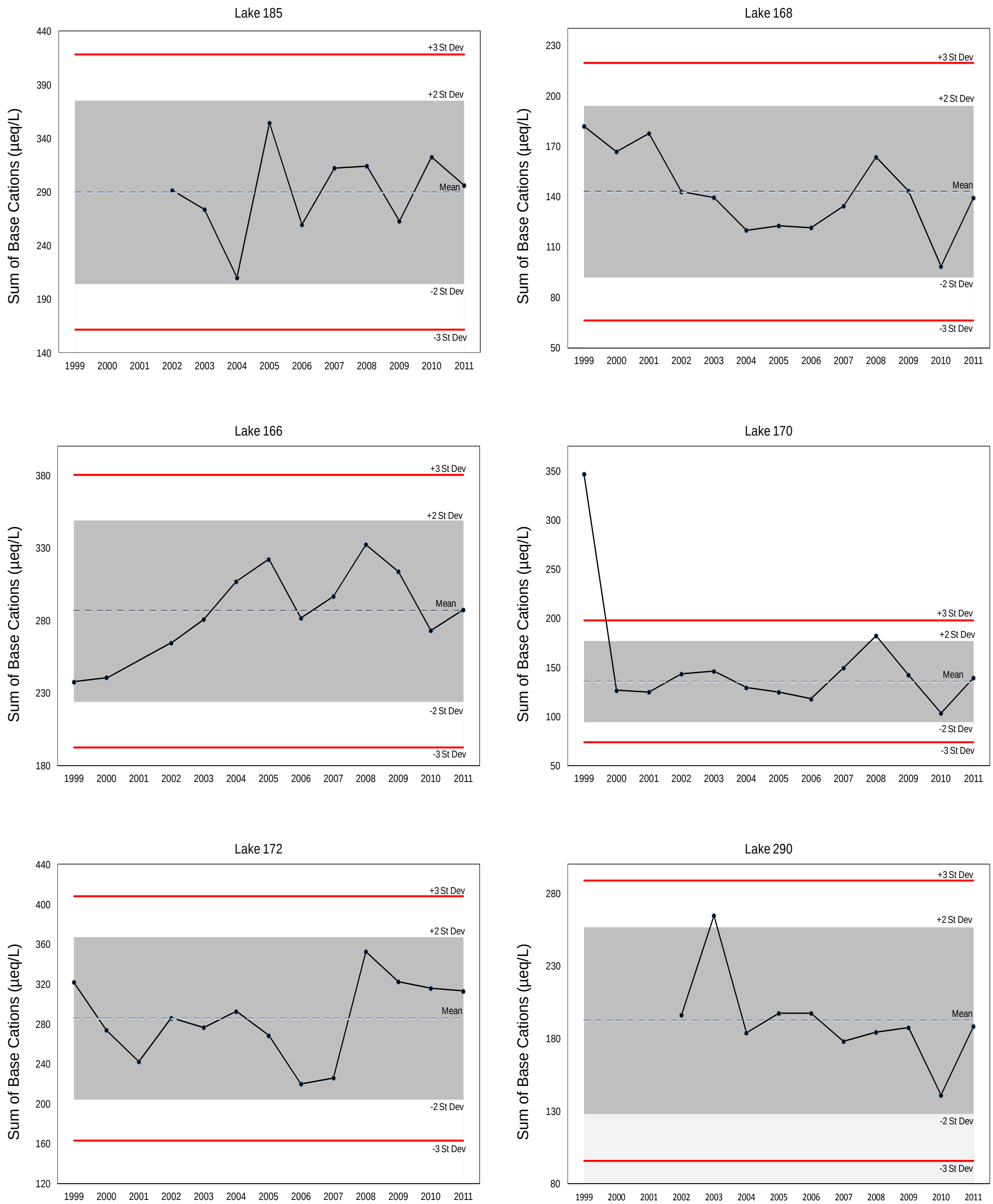
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-4 (Cont'd.)



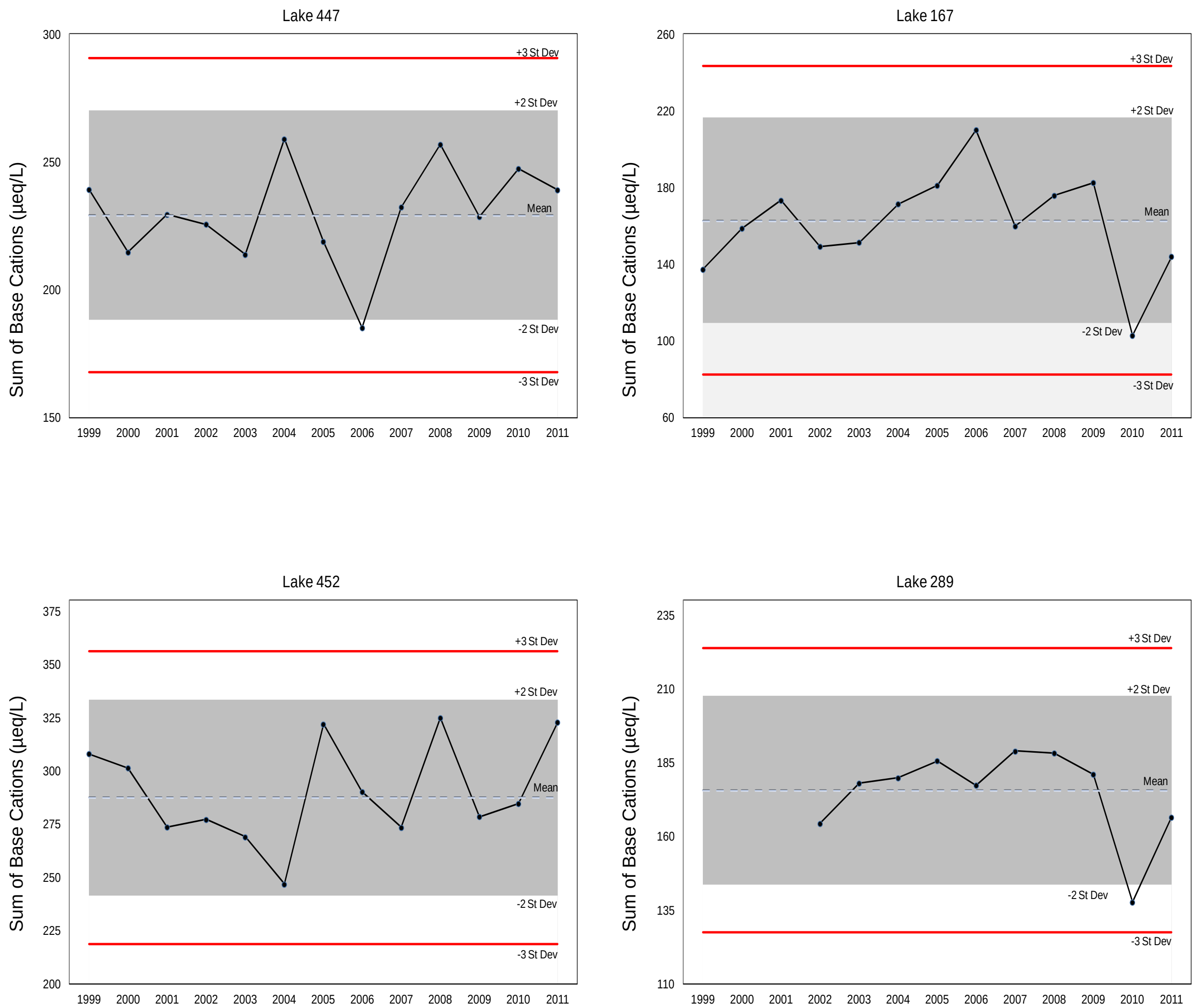
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-5 Control charts of the sum of base cations in ten RAMP acid-sensitive lakes most at risk to acidification.



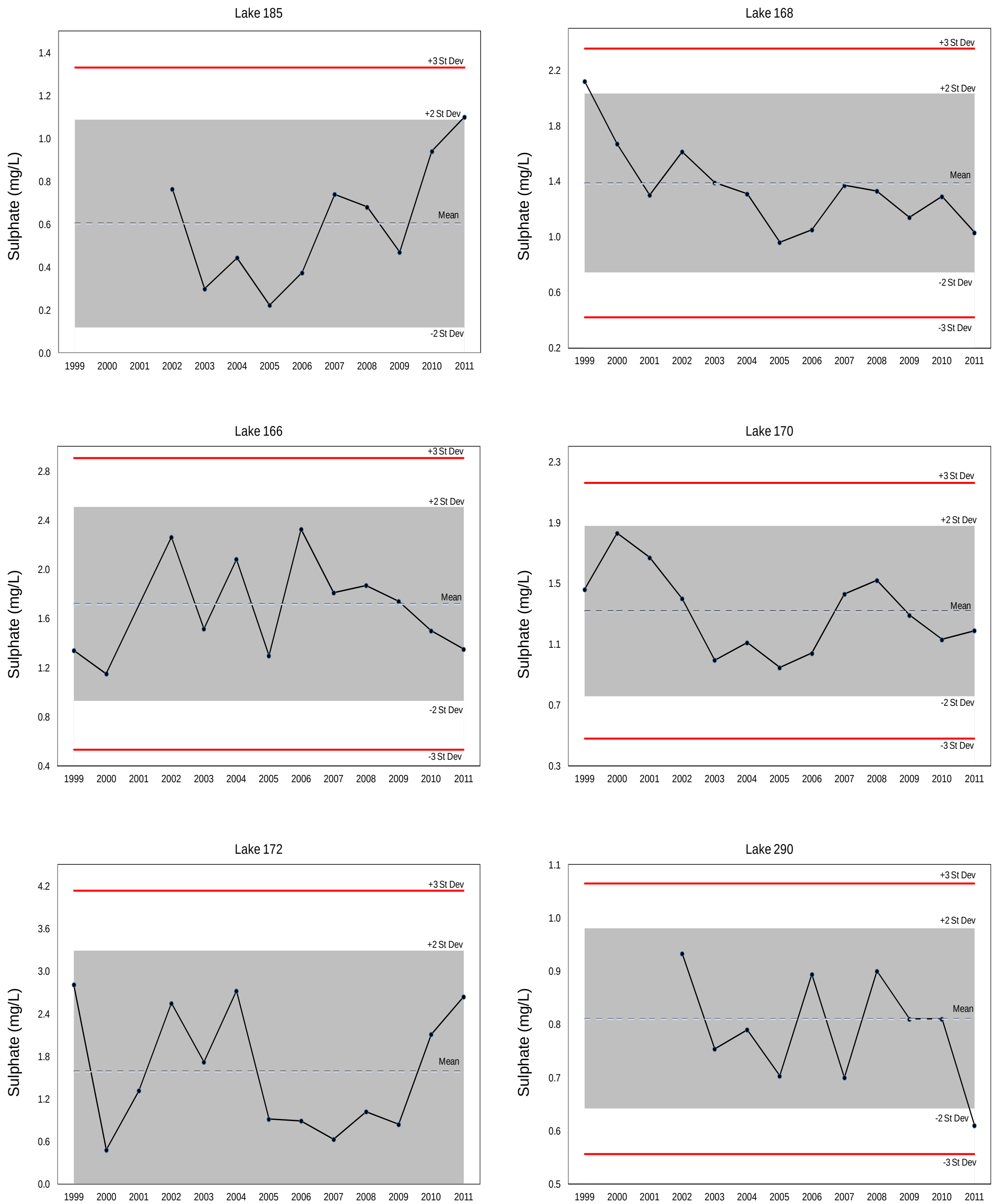
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-5 (Cont'd.)



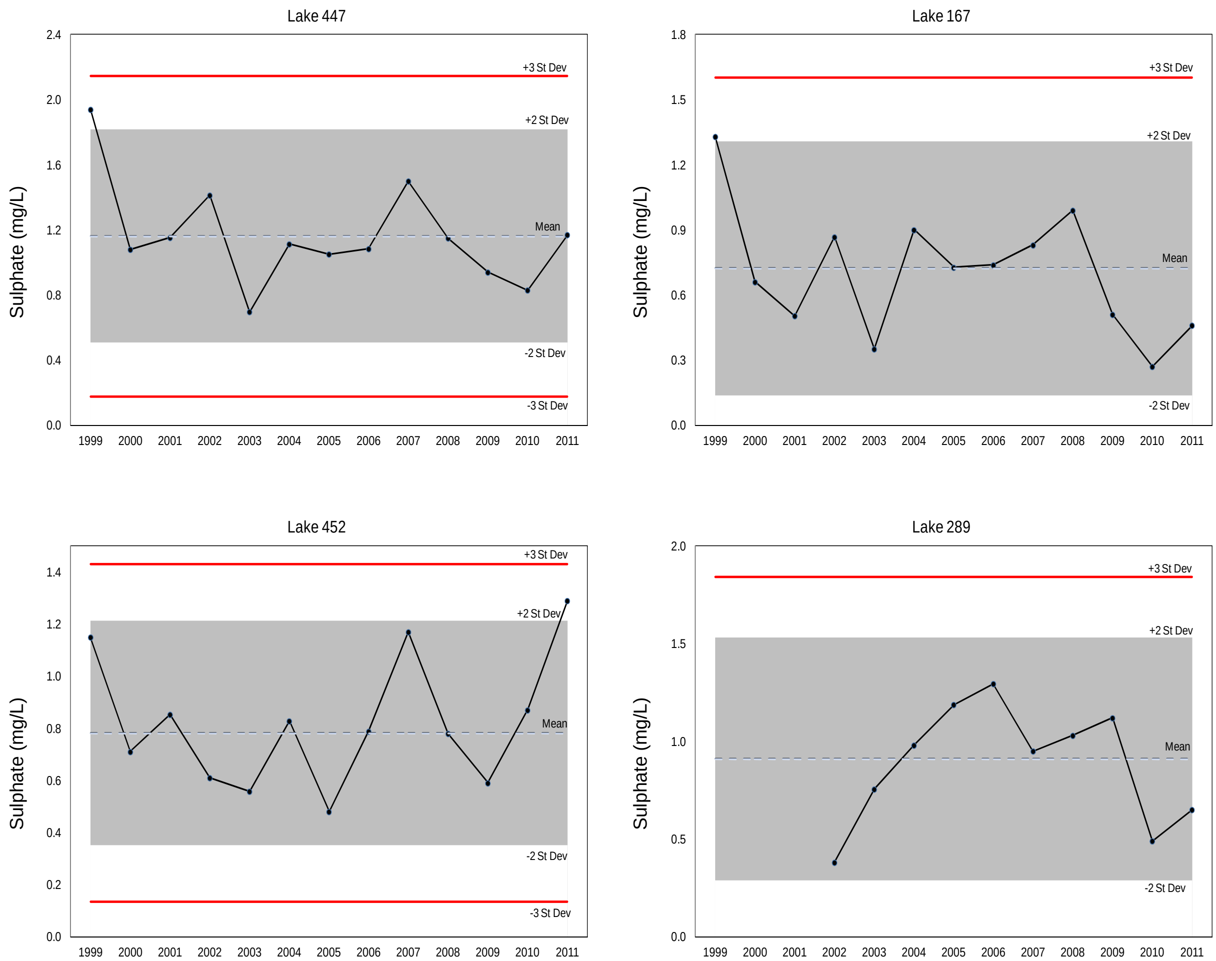
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-6 Control charts of sulphate in ten RAMP acid-sensitive lakes most at risk to acidification.



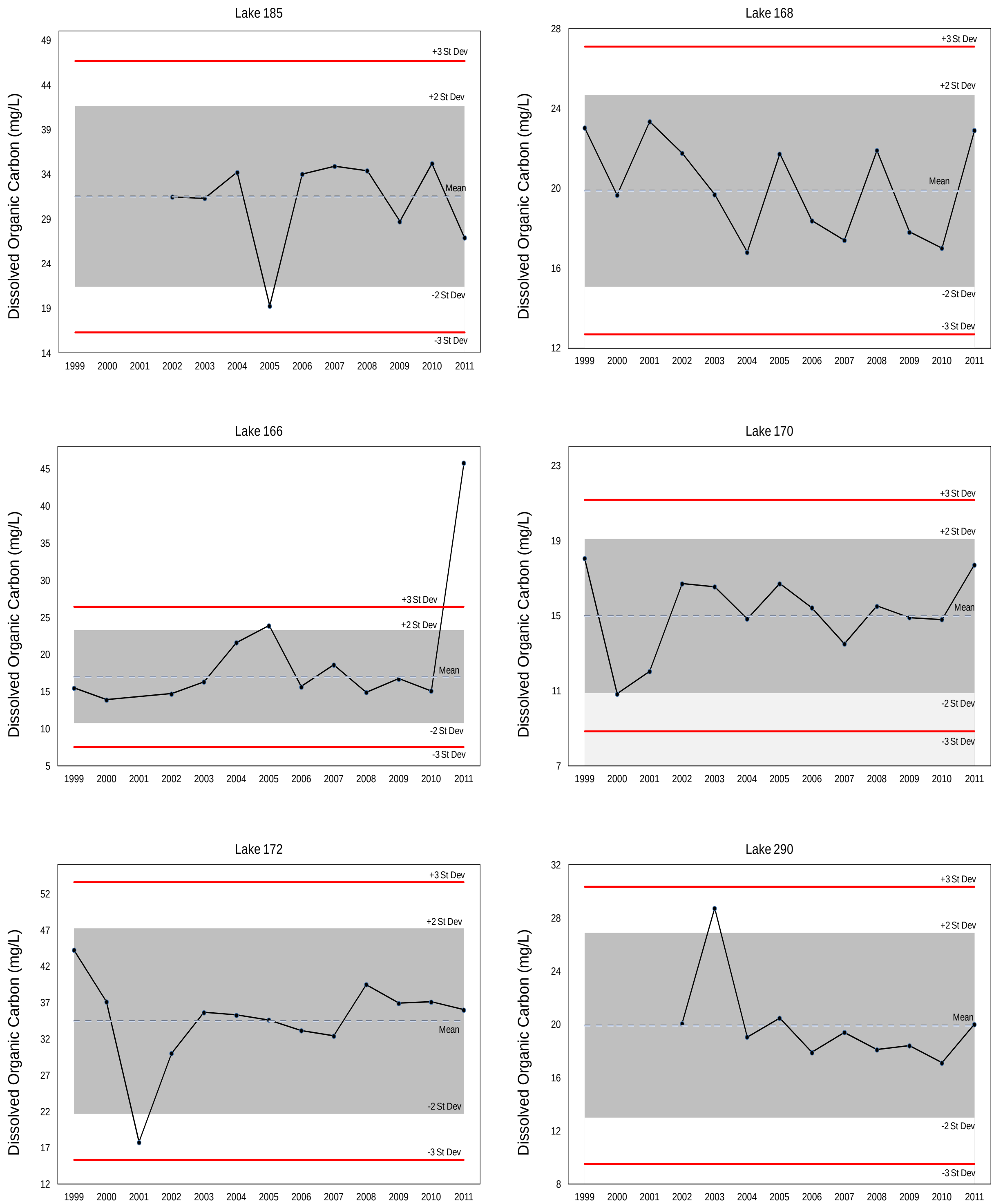
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-6 (Cont'd.)



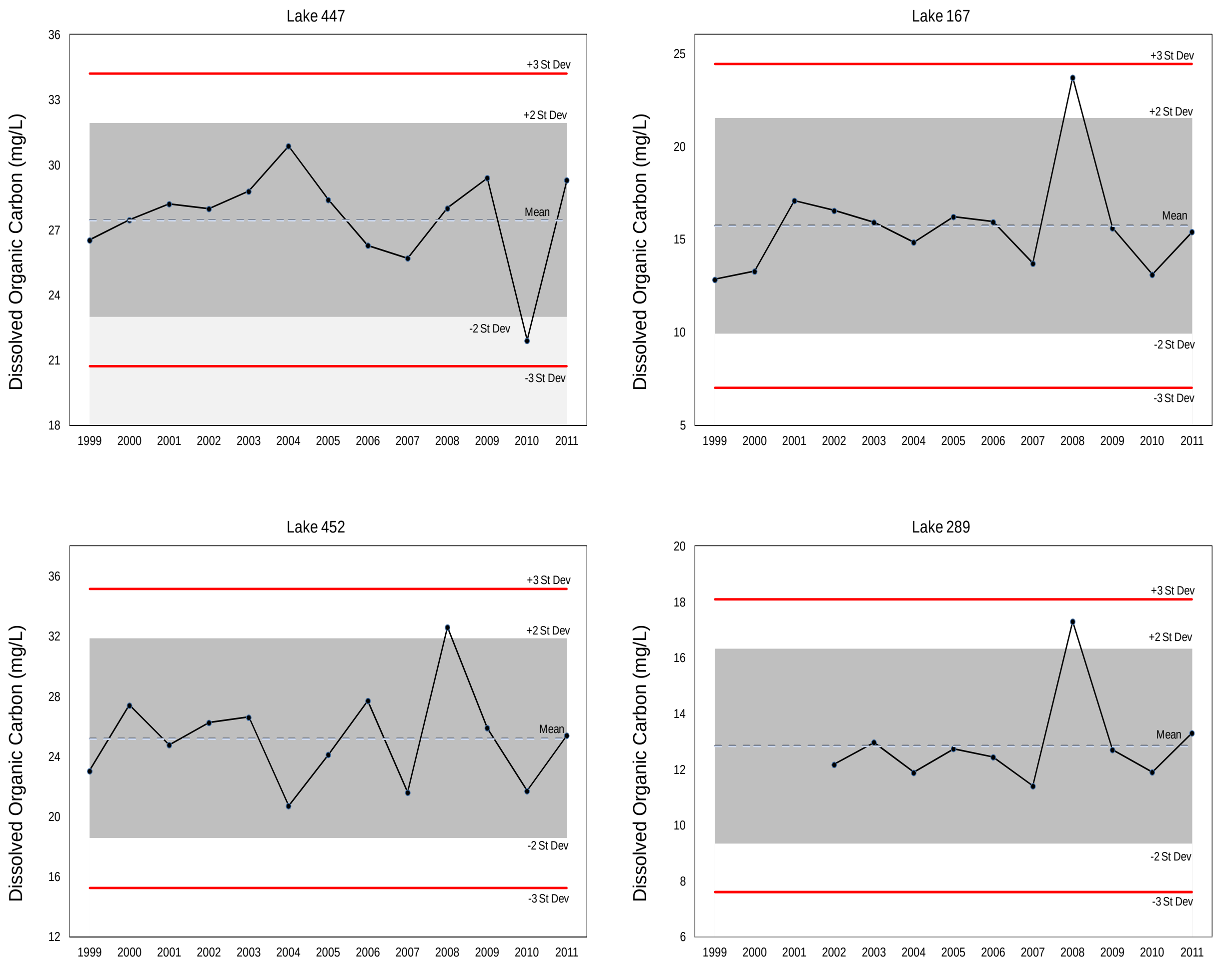
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-7 Control charts of dissolved organic carbon in ten RAMP acid-sensitive lakes most at risk to acidification.



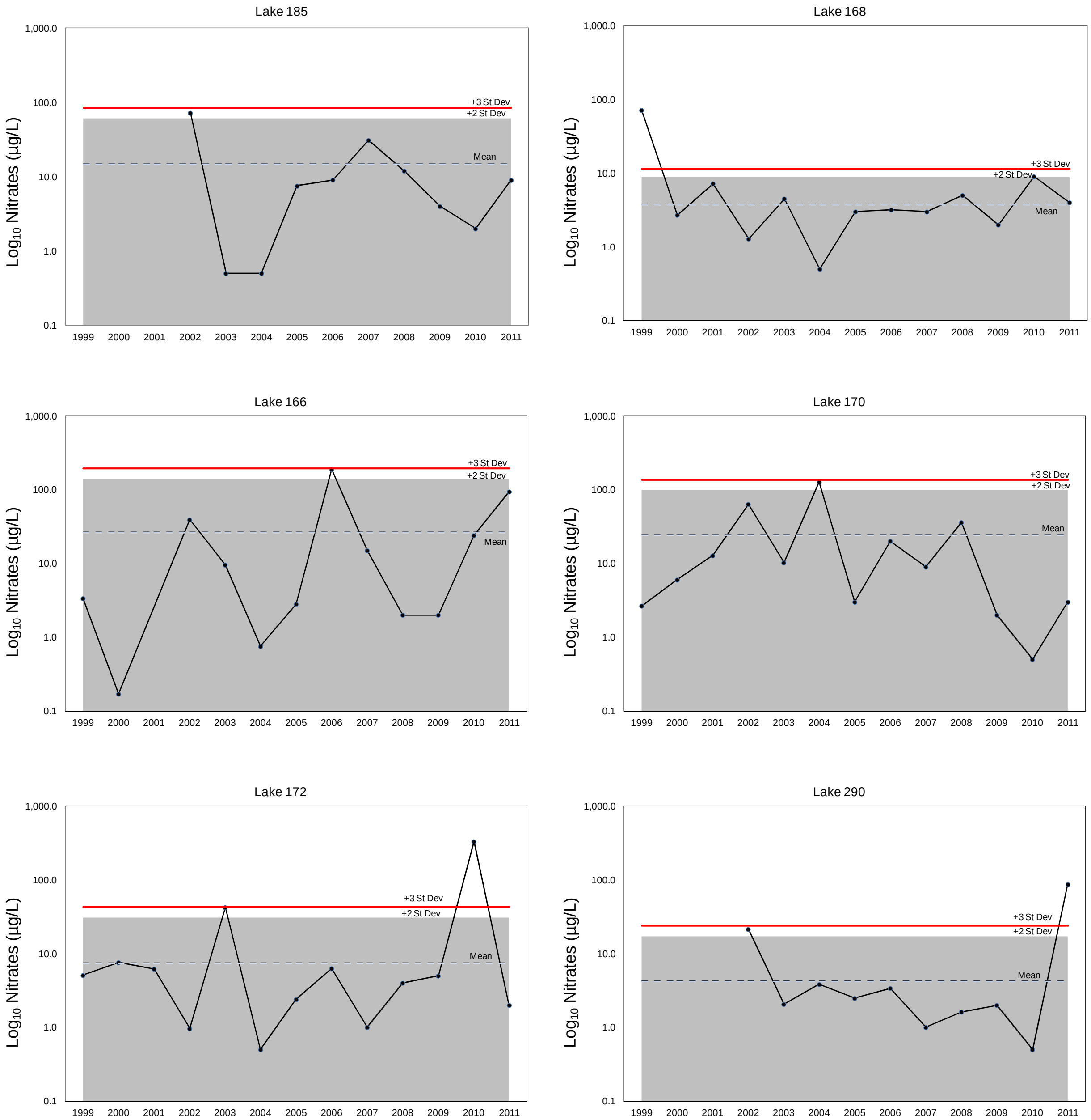
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-7 (Cont'd.)



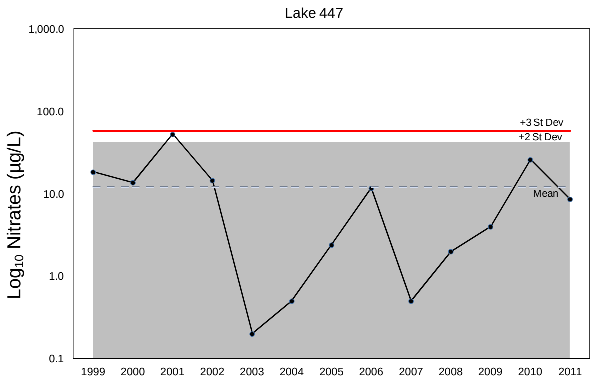
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

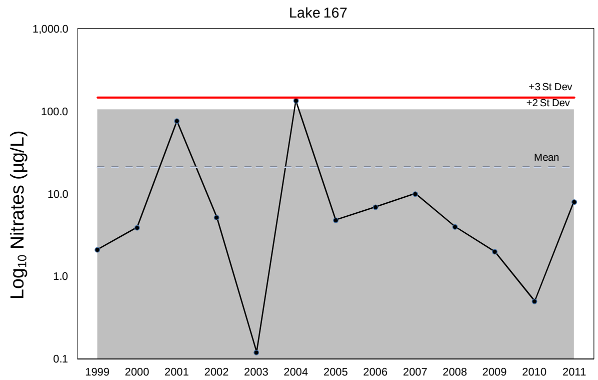
Figure 5.12-8 Control charts of nitrates in ten RAMP acid-sensitive lakes most at risk to acidification.

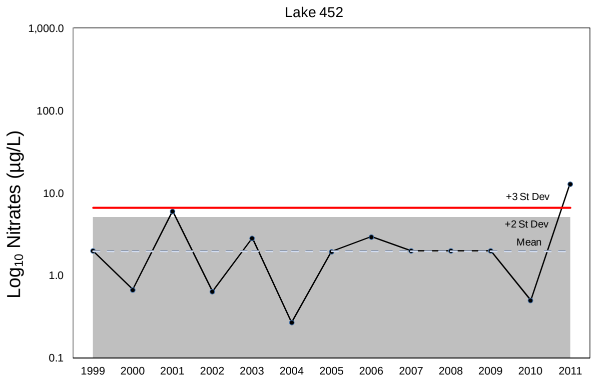


Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-8 (Cont'd.)



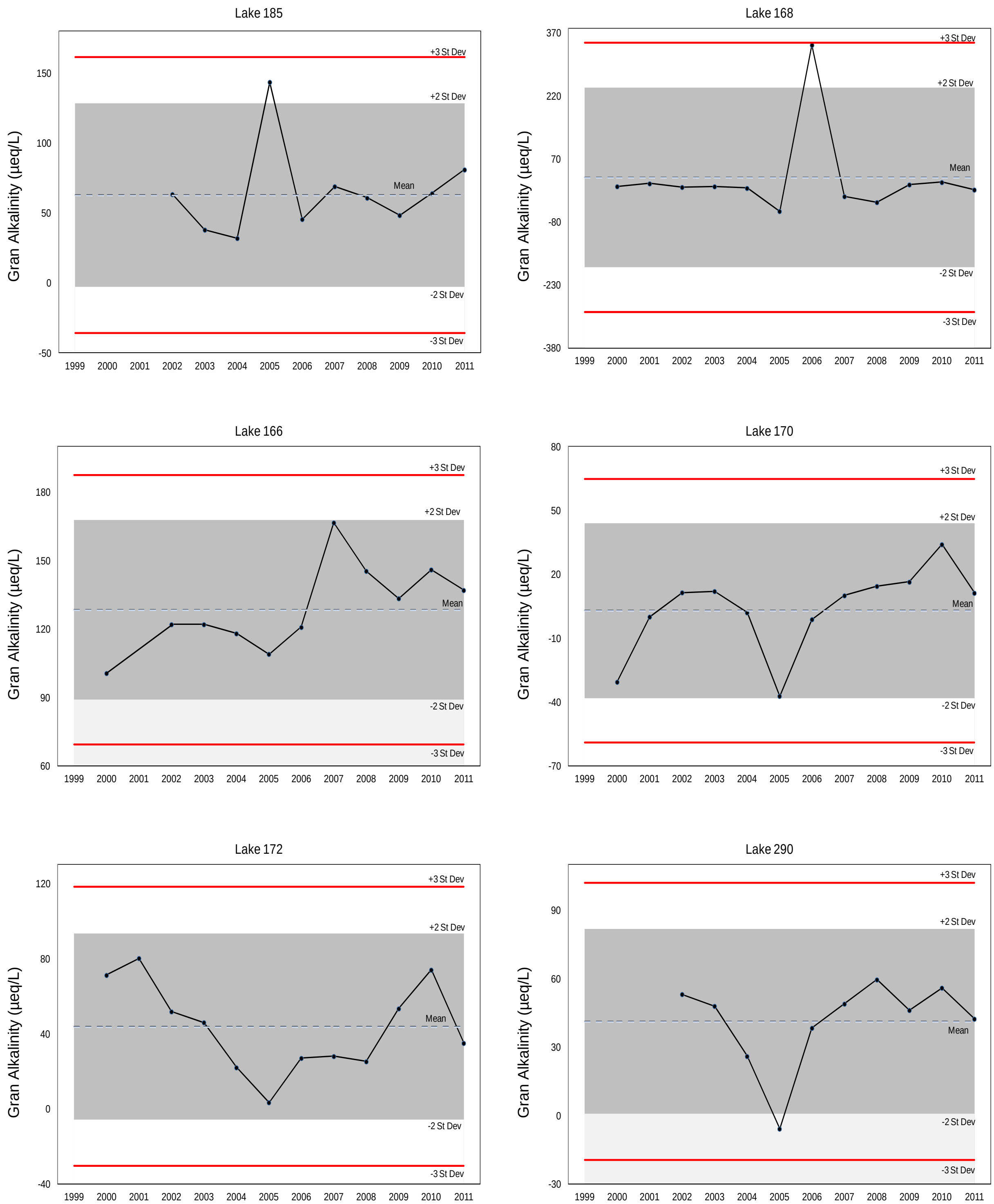




Log_{10} Nitrates (µg/L)

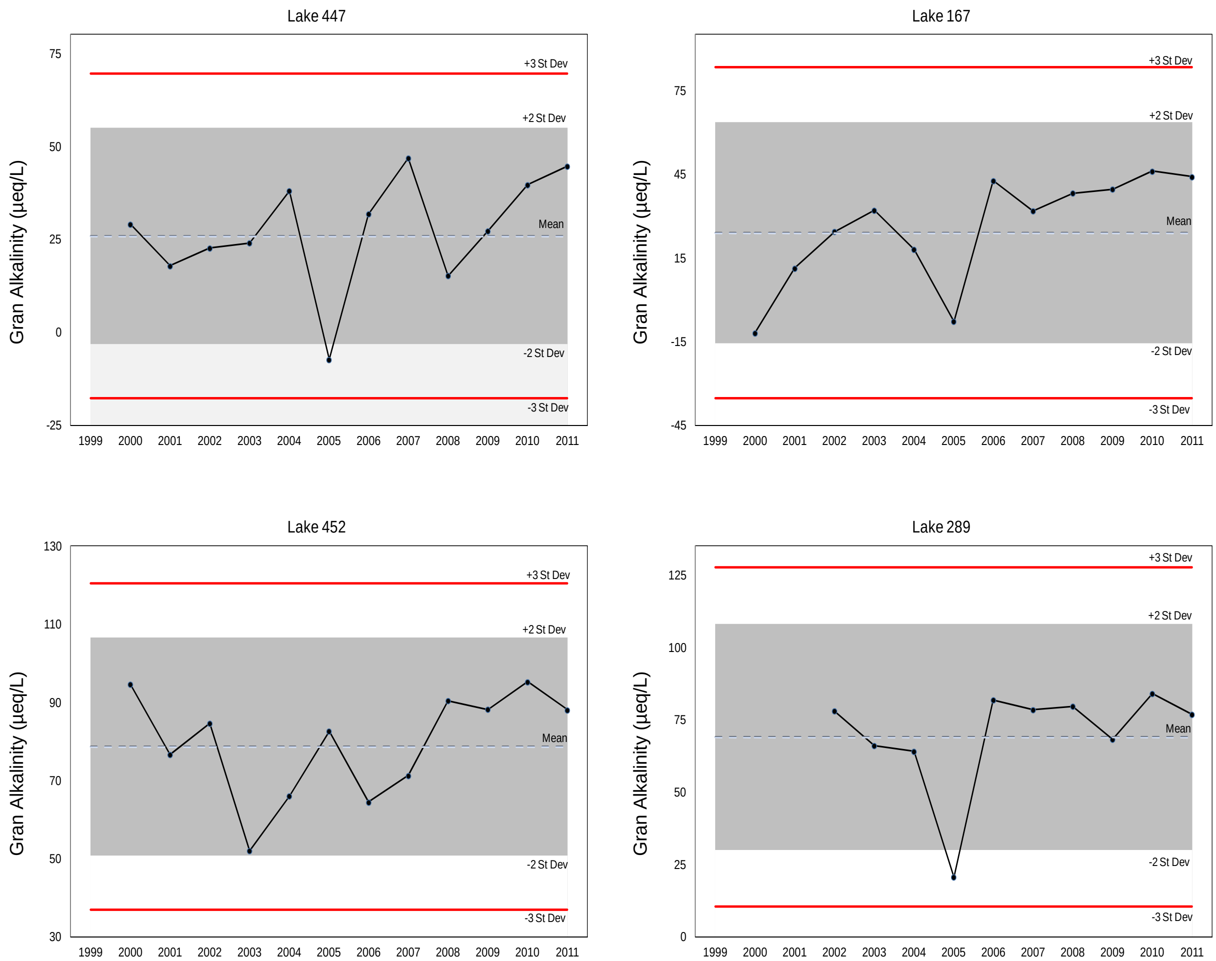
Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-9 Control charts of Gran alkalinity in ten RAMP acid-sensitive lakes most at risk to acidification.



Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

Figure 5.12-9 (Cont'd.)



Grey shading: ±2 standard deviations; Red lines: ± 3 standard deviations; dotted line – mean.

6.0 SPECIAL STUDIES

This part of the RAMP 2011 Technical Report presents results from special studies that were conducted in 2011, 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, document non-core monitoring activities or to refine current methods used by RAMP.

In 2011, there were seven 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 PAHs and total hydrocarbons in water, the reporting of water quality results for a subset of lakes in the Nexen Lakes Wetlands Monitoring Program (Hatfield 2012), an assessment of various sampling gear to conduct benthic invertebrate communities monitoring in the Athabasca River, an analysis of the variation in benthic invertebrate communities and sediment quality in Fletcher Channel, and the results of a *baseline* reach reconnaissance survey 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 AEW (formerly 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 concentrations of naphthenic acids 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 in addition to "naphthenic acids". Given significant differences in laboratory methods used by different contributors of data to this section, laboratories are identified as part of the analyte name when data are presented, where appropriate.

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 AEW and RAMP in 2009, 2010 and 2011 for analysis of ambient water quality samples;
- Dr. Jon Martin's laboratory at the University of Alberta (Edmonton, AB), which uses an liquid/liquid extraction using dichloromethane followed by analysis of reconstituted extracts by reversed-phase liquid chromatography, time-of-flight mass spectrometry (LC-TOF-MS) and applied this method to analysis of a duplicate set of RAMP water samples collected in fall 2011;

- 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 (naphthenic acids) and 267.0836 (^{13}C-tetradecanoic acid), and applied this method to the analysis of a duplicate set of RAMP water samples collected in fall 2010; 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 AEW's ongoing Contaminant Load Study in the Athabasca River).

In 2009, AEW began contracting AITF for analysis of naphthenic acids in surface waters collected for routine monitoring at AEW'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 AEW. 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 2011 RAMP Water Samples for Naphthenic Acids

Recognizing current uncertainties and ongoing method development in the identification and quantification of acid-extractable organic acids, RAMP collected triplicate samples in spring, summer and fall 2010 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. Comparative results from AITF and ALS were reported in the RAMP 2010 Technical Report (RAMP 2011).

RAMP continued this approach to support method development in 2011, by collecting a duplicate set of water quality samples in fall 2011 and providing one set to AITF and the other set to Dr. Martin's laboratory at the University of Alberta for naphthenic acids analysis. Further details of AITF's analytical method and methods and results from Dr. Martin's laboratory appear in Appendix D.

6.1.3 Results and Discussion

Comparison with 2009 and 2010 Data

Figure 6.1-1 presents results of naphthenic acids analyses performed by AITF on water samples collected from RAMP water quality stations in fall from 2009 to 2011. Although spatial patterns among stations were generally similar from 2009 to 2011, concentrations in many tributary watersheds were considerably higher in 2011 than 2009 or 2010. Particularly, samples from the Muskeg watershed, Poplar Creek, McLean Creek and lower Beaver River showed increases from 2009/2010, with concentrations in McLean Creek (MCC-1) and lower Beaver River (BER-1) approximately an order of magnitude higher than concentrations measured in any other waterbody (Figure 6.1-1). All of these watersheds exhibited flows near or below historical minima in fall 2011, with associated changes in water quality including high total dissolved solids (TDS) and major ions that suggested a greater influence of groundwater relative to surface runoff (see sections 5.2

and 5.11). Given naphthenic acids in the RAMP FSA are known to occur naturally in near-surface groundwater at concentrations up to several mg/L (WorleyParsons 2008), the increased concentrations of naphthenic acids at these stations in 2011 versus 2009 and 2010 could be consistent with an increased influence of groundwater in surface waters in the RAMP FSA in fall 2011. For McLean Creek and the lower Beaver River specifically, these watersheds also are very small and highly modified by upstream oil sands activity (i.e., the Mildred Lake Settling Basin in the case of Beaver River, and the Suncor Millennium mine in the case of McLean Creek); the degree to which these upstream activities influenced concentrations of naphthenic acids in water in fall 2011 is unknown.

In contrast to the tributaries, concentrations of naphthenic acids in the Athabasca River mainstem were generally consistent from 2009 to 2011, and did not show any clear longitudinal trends. This is perhaps indicative of the substantial influence of waters upstream of Fort McMurray on water quality in the Athabasca River mainstem through the core (surface-mineable area) portion of the RAMP FSA, relative to local tributaries.

Comparison of Methods

Table 6.1-1 compares naphthenic acids data reported by AITF and University of Alberta from duplicate samples collected by RAMP in fall 2011. Concentrations reported by AITF were approximately two orders of magnitude higher than those reported by the University of Alberta, suggesting that a wider range of organic acids are being captured by the AITF method compared to the University of Alberta method, which measured a more specific set of compounds. Perhaps more interesting than the difference in reported magnitude of concentrations is the lack of consistent patterns among stations between the two methods: stations with relatively high concentrations reported by one method did not consistently exhibit relatively high concentrations measured by the other method (Figure 6.1-2).

For example, *test* station BER-1 exhibited an AITF concentration (7.26 mg/L) that was an order of magnitude higher than almost any other station measured by AITF, but the University of Alberta concentration for *test* station BER-1 (0.0109 mg/L) was similar to that of several other stations measured by the University of Alberta. Both methods found the highest concentration in McLean Creek (*test* station MCC-1). The differences in results suggest that the different sets of target compounds measured by each method were not consistently distributed among sampling stations.

Figure 6.1-1 Acid-extractable organic acids (naphthenic acids) measured by AITF in the RAMP FSA, fall 2011, relative to fall 2009 and 2010.

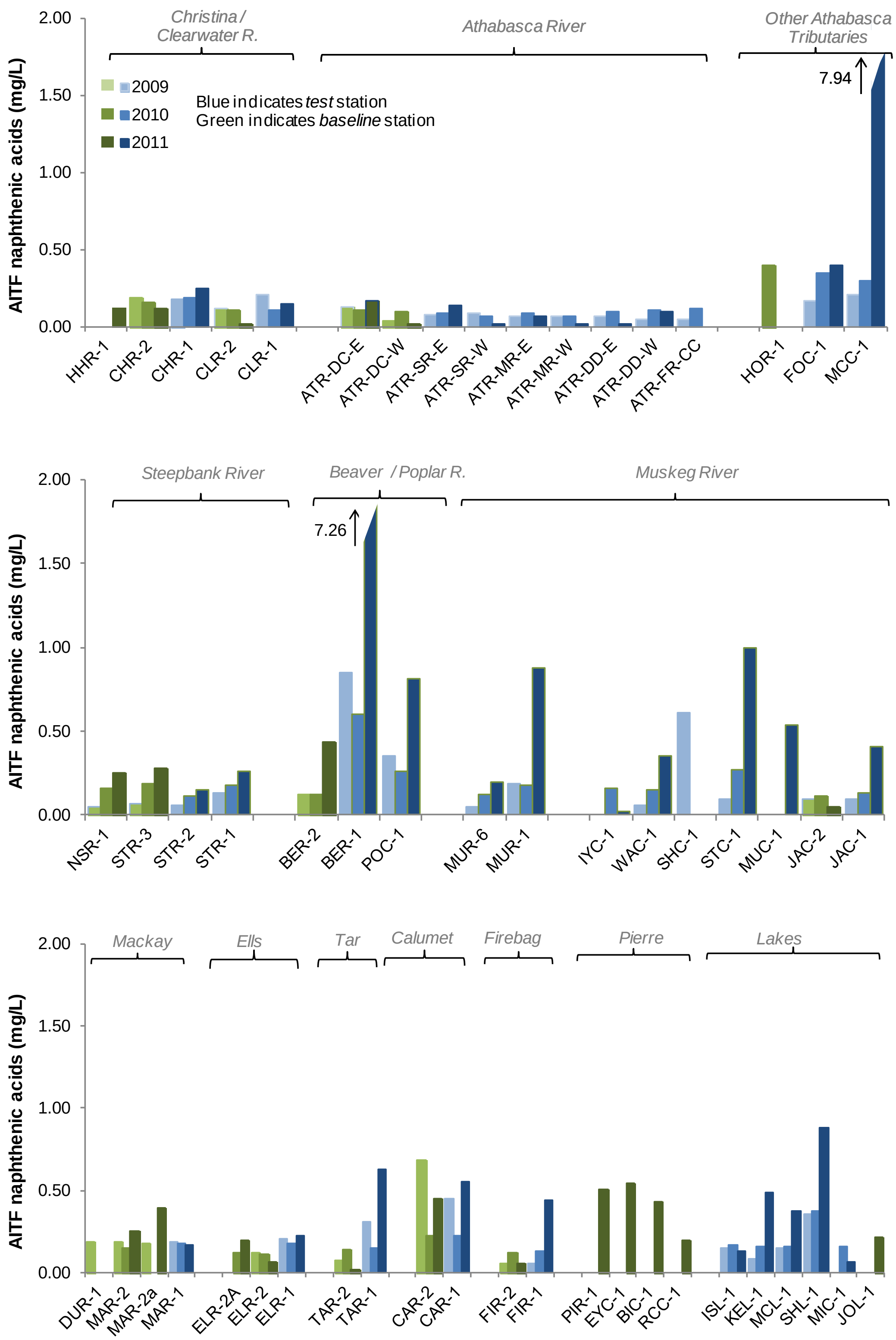
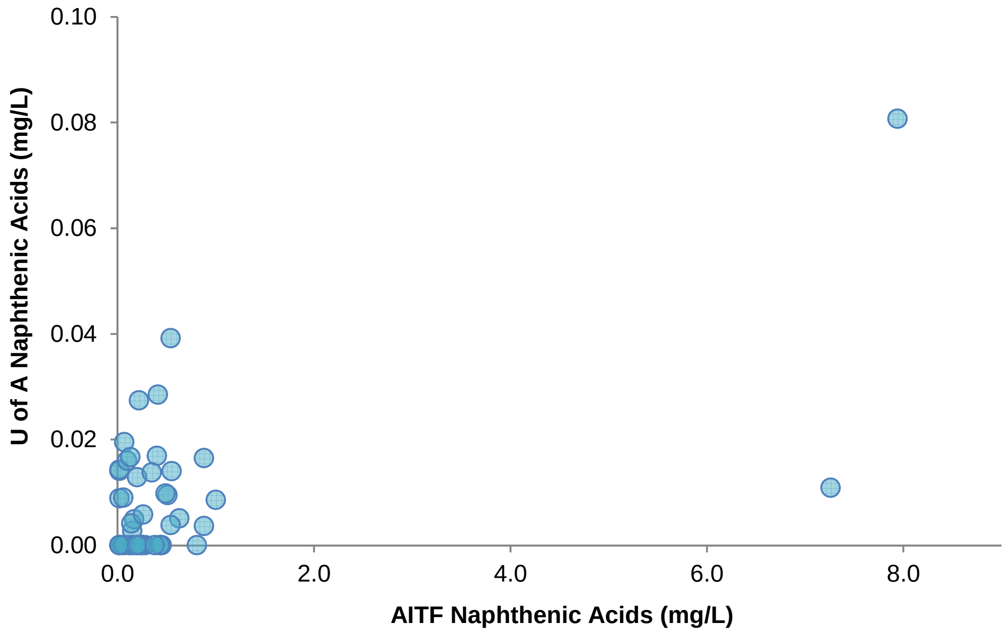


Table 6.1-1 Reported naphthenic acids (mg/L) in duplicate samples of ambient water collected by RAMP in September 2011, as analyzed by AITF and University of Alberta using different methods.

Station	AITF value (mg/L)	Univ. of Alberta value (mg/L)	Station	AITF value (mg/L)	Univ. of Alberta value (mg/L)
Athabasca River			**Other eastern tributaries**		
ATR-DC-E	0.17	0.00491	FOC-1	0.40	0.0169
ATR-DC-W	0.02	0.0141	MCC-1	7.94	0.0807
ATR-SR-E	0.14	0.00413	FIR-1	0.44	<0.002
ATR-SR-W	0.02	<0.002	FIR-2	0.06	0.009
ATR-MR-E	0.07	0.0195	**Western tributaries**		
ATR-MR-W	0.02	0.00889	POC-1	0.81	<0.002
ATR-DD-E	0.02	0.0143	BER-1	7.26	0.0109
ATR-DD-W	0.10	0.016	BER-2	0.44	<0.002
Southern Tributaries			MAR-1	0.17	<0.002
CLR-1	0.15	0.00274	MAR-2	0.25	<0.002
CLR-2	0.02	<0.002	ELR-1	0.23	<0.002
CHR-1	0.25	<0.002	ELR-2	0.07	<0.002
CHR-2	0.12	<0.002	ELR-2A	0.20	<0.002
HHR-1	0.12	<0.002	TAR-1	0.63	0.00511
Steepbank River			TAR-2	0.02	<0.002
STR-1	0.26	0.00582	CAR-1	0.55	0.014
STR-2	0.15	<0.002	CAR-2	0.45	<0.002
STR-3	0.28	<0.002	PIR-1	0.51	0.00947
NSR-1	0.25	<0.002	EYC-1	0.54	0.00384
Muskeg River watershed			BIC-1	0.43	<0.002
MUR-1	0.88	0.00364	RCC-1	0.20	<0.002
MUR-6	0.20	0.0129	**Lakes**		
JAC-1	0.41	0.0285	ISL-1	0.13	0.0167
JAC-2	0.05	<0.002	KEL-1	0.49	0.0098
MUC-1	0.54	0.0392	MCL-1	0.38	<0.002
STC-1	1.00	0.00856	SHL-1	0.88	0.0165
IYC-1	0.02	<0.002	JOL-1	0.22	0.0274
WAC-1	0.35	0.0138			

Figure 6.1-2 Correspondence between naphthenic acids concentrations reported by AITF and University of Alberta from duplicate samples collected by RAMP in September 2011.



6.1.4 Need for Clarity and Agreement Moving Forward

The environmental chemistry of naphthenic acids and other acid-extractable organics in the oil sands region continues to be 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.

In response to concerns expressed by various parties involved in aquatic assessment in the oil-sands region, including RAMP, in November 2011 Environment Canada and Alberta Environment and Water began a multi-stakeholder assessment of existing methods and approaches being taken by different laboratories, with the goal of establishing consistent approaches to the measurement and meaningful interpretation of naphthenic acids in waters of the Athabasca oil-sands region.

Differences in results from AITF and University of Alberta reported for duplicate water samples collected by RAMP in fall 2011 indicate that the spatial heterogeneity of compounds captured by different methods may be as or more important than differences in magnitude of reported results.

6.2 TOTAL HYDROCARBONS IN WATER

Background

Since 1997, RAMP has measured total hydrocarbons in water using the analyte Total Recoverable Hydrocarbons (TRH). This analyte provides a gross estimate of total hydrocarbons (from petroleum or non-petroleum sources), based on a partition-infrared (IR) method (APHA method 5520C) that measures IR absorbance by C-H bonds (AENV

1993, APHA *et al.* 2000, Farmaki *et al.* 2007). TRH has nearly always returned non-detectable (<1 mg/L) concentrations of hydrocarbons in waters sampled by RAMP.

Beginning in spring 2011, analyses included both TRH and a potential future replacement, CCME Total Petroleum Hydrocarbons (TPH), which provides a more comprehensive and higher-resolution set of data describing hydrocarbons in water. This test was developed through CCME to provide a nationally standardized method for the assessment of hydrocarbons in petroleum-contaminated soils and groundwater, with consistent analytical and QA approaches and associated ecotoxicological standards (CCME 2008). Specifically, the CCME uses GC-based methods to measure a set of eleven variables, including four molecular-size fractions of total hydrocarbons including F1 (6 to 10 carbon atoms); F2 (C10-C16); F3 (C16-34); and F4 (C34-50) as well as a fraction specifically measuring volatile hydrocarbons, benzene, toluene, ethylbenzene, and xylenes, collectively known as BTEX. Concentrations of these specific BTEX compounds also are generated in the analysis.

Relative to TRH, CCME TPH includes lower detection limits: 0.0005 mg/L for individual BTEX compounds; 0.10 mg/L for Fraction 1, and 0.25 mg/L for heavier fractions 2 to 4. Adoption of the CCME TPH test for waters sampled by RAMP also aligns with RAMP's use of the CCME TPH test for soils, which has been used for analysis of TPH in sediments since 2004 (see Section 3). Although environmental standards associated with these tests are intended for application to soils, the intent of applying this test to waters as well was to provide more detailed information about hydrocarbons in waters of the RAMP FSA that was directly comparable with data for sediments also collected by RAMP.

Following a decision by the RAMP Technical Committee in April 2011, both TRH and TPH were adopted as target variables for RAMP water quality in the spring, summer and fall 2011 sampling programs (the winter 2011 program had already been completed in advance of this decision).

The purpose of this potential change in method analysis was to provide more detailed information regarding hydrocarbon concentrations in water in the RAMP FSA, as well as to align with AEW sampling programs, which also are beginning to shift from TRH to CCME TPH.

Results

A brief summary of results of hydrocarbons measured in water by RAMP in spring, summer and fall 2011 appears in Table 6.2-1. Key findings include the following:

- TRH was non-detectable (i.e., <1.0 mg/L) at all stations in all seasons sampled;
- All aggregate TPH Fractions were non-detectable in waters sampled in spring and summer (DLs ranging from 0.10 to 0.25 mg/L);
- In fall, all TPH Fractions were non-detectable with the exception of F1 and F1-BTEX at *baseline* station ATR-DC-E (Athabasca River upstream of Donald Creek, 0.11 mg/L), and F3 at *test* station MCC-1 (McLean Creek, 0.32 mg/L);
- In spring and summer, some individual BTEX compounds were measured at specific stations, all of which are *baseline* stations located near Shell's Pierre River lease, specifically:

- toluene (0.00116 mg/L) and m+p-xylene (0.00059 mg/L), in spring at *baseline* station RCC-1 (Red Clay Creek);
- toluene (0.0006 mg/L) in summer at *baseline* station BIC-1 (Big Creek); and
- toluene (0.00264 mg/L), m+p-xylene (0.00164 mg/L), o-xylene (0.00067 mg/L) and total xylenes (0.00231 mg/L) in summer at *baseline* station EYC-1 (Eymundson Creek).

The source of measurable concentrations of BTEX compounds in waters of the currently undeveloped Pierre River lease in spring and summer 2011 is unknown. However, this area was significantly affected by forest fires in May/June 2011 (see Section 2), which are known to potentially affect concentrations of toluene and xylene compounds in water (CCME 2004). In place hydrocarbons also may have influenced these concentrations.

Of the two other stations where TPH was measured above the detection limit in fall 2011 (i.e., F1-BTEX at *baseline* station ATR-DC-E and F3 at *test* station MCC-1), *test* station ATR-DC-E is located in an area of bituminous outcropping along the Athabasca River, which may have been a source of measured hydrocarbons. McLean Creek (*test* station MCC-1) is a small, highly modified watershed, which contained very little flow in fall 2011 (see Section 2 and Section 5.11). The concentration of naphthenic acids at *test* station MCC-1 in fall 2011 was very high relative to almost all other stations; total PAHs at *test* station MCC-1 was intermediate among all *baseline* and *test* stations measured in 2011 (see Sections 6.2.2 and 6.2.3). In both cases (ATR-DC-E and MCC-1), the measured concentration was near (i.e., within 1.3 times) the method detection limit.

In summary, the CCME TPH suite of analyses provided much more detailed and higher-resolution information regarding petroleum hydrocarbons than the existing TRH test; therefore, analysis of CCME TPH analytes should be continued in future RAMP sampling programs, and should replace Total Recoverable Hydrocarbons in the RAMP analytical suite.

Table 6.2-1 Concentrations of total recoverable hydrocarbons and CCME hydrocarbon fractions at RAMP water quality stations, 2011.

Variable	Method DL	Winter (March)		Spring (May)		Summer (July)		Fall (September)	
	(mg/L)	n	Value	n	Value	n	Value	n	Value
Total recoverable hydrocarbons	1.0	7	All nd	8	All nd	12	All nd	52	All nd
CCME Fraction 1: BTEX (total)	0.10	0	ns	8	All nd	12	All nd	52	All nd except ATR-DC-E (0.11)
Benzene	0.0005	0	ns	8	All nd	12	All nd	52	All nd
Ethylbenzene	0.0005	0	ns	8	All nd	12	All nd	52	All nd
Toluene	0.0005	0	ns	8	All nd except RRC-1 (0.00116)	12	All nd except EYC-1 (0.00264), BIC-1 (0.0006)	52	All nd
Xylenes (total)	0.00071	0	ns	8	All nd	12	All nd except EYC-1 (0.00231)	52	All nd
o-Xylene	0.0005	0	ns	8	All nd	12	All nd except EYC-1 (0.00067)	52	All nd
m+p-Xylene	0.0005	0	ns	8	All nd except RRC-1 (0.00059)	12	All nd except EYC-1 (0.00164)	52	All nd
CCME Fraction 1 (C6-C10)	0.10	0	ns	8	All nd	12	All nd	52	All nd except ATR-DC-E (0.11)
CCME Fraction 2 (>C10-C16)	0.25	0	ns	8	All nd	12	All nd	52	All nd
Fraction 3 (C16-C34)	0.25	0	ns	8	All nd	12	All nd	52	All nd except MCC-1 (0.32)
Fraction 4 (C34-C50)	0.25	0	ns	8	All nd	12	All nd	52	All nd

nd = non-detect; ns = not sampled.

6.3 POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN WATER

Background

From 2001 to 2004, RAMP measured PAHs in water at a small selection of stations in the Athabasca River (*baseline* station ATR-DC and *test* station ATR-DD in fall from 2001 to 2004, and *test* stations ATR-FC and ATR-ER in 2001), in the Clearwater River (*baseline* station CLR-2 and *test* station CLR-1 seasonally in 2001 and in fall 2002 and 2003) and in the Christina River (*baseline* station CHR-2 in fall 2002 to 2003 and *test* station CHR-1 in fall 2002 to 2004). No further sampling was undertaken after 2004, because nearly all results (>99%) were below the then-commercially-available method detection limits of 20 ng/L (0.02 µg/L) for parent PAHs and 40 ng/L (0.04 µg/L) for alkylated PAHs. Readers are referred to the online RAMP water quality database for these earlier data.

Following recommendations from the RAMP 2010 Peer Review (AITF 2011) and increased interest in PAHs in water of the lower Athabasca region following publication of Kelly *et al.* (2009), RAMP re-initiated analysis of PAHs in waters for all sampling stations, beginning in spring 2011. This was technically possible because advances in commercially available analytical methods allowed measurement of parent and alkylated PAH species in water at method detection limits near or below 0.1 ng/L (=0.0001 µg/L) and a typical level of precision of 0.001 ng/L (=0.00001 µg/L).

Methods

PAHs were measured in water samples collected by RAMP from all water-quality sampling stations in spring, summer and fall 2011. Field sampling methods and QA/QC procedures have previously been described in Section 3.1.2 of this report.

Analyses were undertaken by AXYS Analytical Services Ltd. (Sidney, BC), the same laboratory that has undertaken analyses of PAHs in sediments for RAMP since such sampling began. Analysis followed AXYS method ML-021, which corresponds with US EPA methods 1625B or 8270C/D. Instrumental analysis was performed by low-resolution mass spectrometry (LRMS) using an RTX-5 capillary GC column. The LRMS was operated at a unit-mass resolution in the electron impact (EI) ionization mode, using multiple ion detection (MID) acquiring at least one characteristic ion for each target analyte and surrogate standard.

Both parent and alkylated PAH species were measured, with the specific list of analytes matching that of RAMP sediment analyses.

Analytical results from AXYS presented reporting limits (RL, equal to sample-specific detection limits) for each PAH species (ranging from approximately 0.008 to 0.4 ng/L); these were calculated for each sample tested based on various internal QA performance assessments undertaken with each analysis. Because these RLs were variable among tests, and because measurements in trip blanks exceeded RLs in some cases (typically in different analytical batches), data were subsequently blank-corrected to calculate project-wise, consistent, detection limits for each PAH species, to allow consistent comparisons of all PAH data collected by RAMP in 2011 and for use in the RAMP monitoring database. Following discussions with AXYS (G. Brooks, *pers. comm.* January 2011), project-wide DLs for each PAH species (or, in the case of alkylated forms, groups of species) were calculated using a blank-correction method, with DLs for each species set as equal to 2x the standard deviation of concentrations of that species measured in all project trip blanks.

Where mean RLs were greater than the blank-corrected DL, the RL was adopted as the project-wide DL. In most cases, the blank-corrected DL was higher than the mean RL, resulting in adoption of the blank-corrected DL as the project-wide DL. This resulted in an increase in detection limits for most species, typically of less than one order of magnitude. However, for some species (i.e., C1-biphenyl, naphthalene, C2-C4-naphthelenes, C1-C3 fluorenes and C2-C4-phenanthrenes), the DL increased by more than one order of magnitude, and for C2-biphenyl and C1-naphthelene, the DL increased by two orders of magnitude. Associated with this increase in project-wide DLs through blank-correction was an increase in number of non-detectable observations for all species. Details of this blank correction/DL adjustment appear in Appendix D.

This increase in DLs affected the reported results in two ways. In Section 5, total PAHs are reported as the sum of all PAH species calculated using 1x the project-wide DL, to be conservative (i.e., estimate on the high side) and to be consistent with other summation variables presented in this report (e.g., total PAHs in sediments). However, the large proportion of non-detectable PAH values in these water samples greatly increases the total PAH estimate relative to values calculated using ND=0xDL, and greatly reduces differences in reported total PAH values among samples analyzed.

In this section, total PAH results are presented using ND=0xDL, given a goal of this section is to examine patterns of PAH concentrations and composition among stations and seasons. Therefore, total PAH values discussed in this section are generally lower than those reported in Section 5.

Results

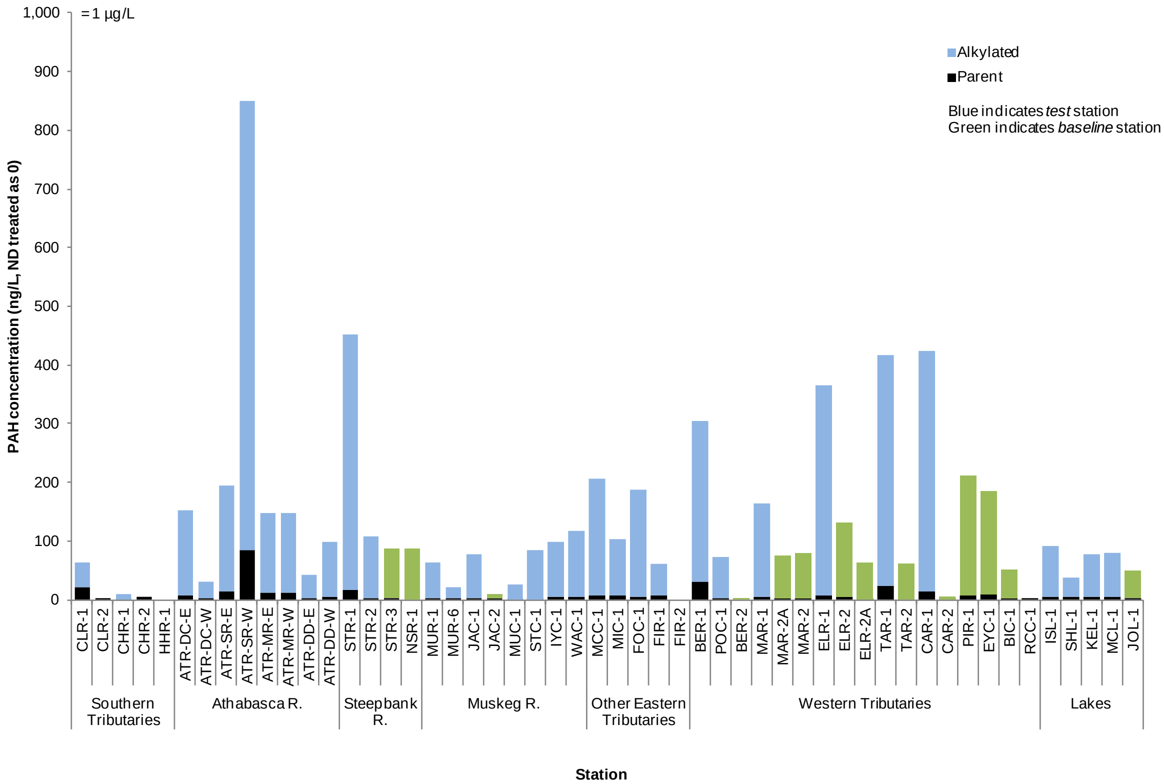
PAHs were measured in water at nearly all RAMP water quality stations in 2011, with total PAH values (using ND=0) in fall typically less than 200 ng/L (=0.2 µg/L) at all stations (Figure 6.3-1). Higher concentrations were observed at the mouths of several tributaries (i.e., *test* stations at the mouths of the Steepbank, Beaver, Tar, Ells and Calumet rivers and *baseline* stations at the mouths of Pierre River and Eymundson Creek), as well as one station on the Athabasca River mainstem, ATR-SR-W, upstream of the Steepbank River along the west bank, where a value of approximately 850 ng/L (0.85 µg/L) was measured. A small number of stations exhibited non-detectable concentrations of PAHs in fall 2011, including the upper Beaver River (*baseline* station BER-2), the North Steepbank River (*test* station NSR-1), High Hills River (*baseline* station HHR-1), and Red Clay Creek (*baseline* station RCC-1).

Alkylated PAHs dominated the species distribution at all stations, although differences in species distributions were apparent among stations (Table 6.3-1). All stations in the Athabasca River mainstem (including ATR-SR-W) exhibited very similar distributions, with highly alkylated (C4-) phenanthrenes dominating, followed by alkylated flouranthenes/pyrenes, benzoflouranthenes/pyrenes, chrysenes, and dibenzothiophenes (Table 6.3-1). Several stations in the upper Steepbank, upper Muskeg, upper MacKay and Tar watersheds and in regional lakes, exhibited highest concentrations of alkylated low-molecular-weight PAHs, particularly C2-biphenyls and C4-naphthelenes, in addition to high concentrations of C4-phenanthrenes and C4-flourenes/pyrenes, which were common at all stations.

Longitudinal trends were evident in all tributaries, with PAH concentrations lowest in upper watersheds and highest at tributary mouths (Figure 6.3-1). In the Athabasca River mainstem, concentrations were generally similar from upstream of the surface-mining area (ATR-DC-E/W) to the mouth of the Muskeg River, with the notable exception of ATR-SR-W, and then were somewhat lower at the "downstream of development" station, ATR-DD-E/W.

Seasonal measurements of PAHs in water also were made from spring to fall at several stations, namely *baseline* stations ATR-DC-E/W and *test* stations ATR-DD-E/W on the Athabasca River (spring/summer/fall), upper MacKay River (*baseline* station MAR-2A, summer/fall), upper Ells River (*baseline* station ELR-2A), Pierre River area *baseline* stations PIR-1, BIC-1 EYC-1, and RCC-1 (spring/summer/fall), and Johnson Lake (*baseline* station JOL-1, summer/fall). Generally, concentrations of total PAHs were substantially higher in spring and summer than fall (i.e., in spring, between 220 and 733 ng/L at ATR stations and 959 ng/L at EYC-1; in summer, above 1,500 ng/L at ATR stations and above 1,300 ng/L at EYC-1; and generally near or below 250 ng/L in spring or summer at all other stations).

Figure 6.3-1 Concentrations of total PAHs in water (nd treated as zero) at RAMP water quality sampling stations, September 2011.



Discussion

This dataset represents the first region-wide, high-resolution measure of PAHs in water that has been conducted directly on ambient waters rather than indirectly using passive samplers. Data collected through direct measurement of PAHs in ambient water samples should differ from those collected using passive samplers such as semi-permeable membrane devices (SPMDs) or polyethylene membrane devices (PMDs) in that they measure the particulate fraction of PAHs in the water column as well as the dissolved fraction. Measurement of the particulate as well as the dissolved fraction of PAHs should yield higher PAH concentrations than simply measuring the dissolved fraction alone, given most PAHs, especially the alkylated species that predominate in the lower Athabasca region, are strongly hydrophobic and typically associated with particulate organic matter (Burgess *et al.* 2003).

Indeed, relative to PMD-derived PAH data from the Athabasca River and its tributaries collected by Kelly *et al.* (2009), concentrations observed in RAMP samples in 2011 were typically higher: Kelly *et al.* (2009) measured concentrations of total PACs (polycyclic aromatic compounds, representing a similar suite of compounds as described by RAMP and others as PAHs) in the Athabasca River mainstem in summer 2008 of up to 135 ng/L, although concentrations were "usually less than 0.030 µg/L [30 ng/L]", while total PAH concentrations measured by RAMP at stations in the Athabasca River upstream and downstream of oil sands development in summer 2011 ranged from 1,546 to 1,860 ng/L. Differences in solubility/availability to PMDs may also explain differences in species profiles between those collected by Kelly *et al.* (2009) and RAMP in this study, as highly alkylated species most common in the RAMP samples (e.g., C4-phenanthrenes) were less strongly represented in the PMD data. As such, these datasets should be viewed as distinct put potentially complementary.

Total PAHs in the Athabasca River at stations ATR-DC and ATR-DD among all seasons showed a very strong (R^2=0.95) correlation with total organic carbon (TOC) (Figure 6.3-2); TOC itself correlated strongly with TSS (R^2=0.88) in these samples. The strong association with organic matter and similarity between upstream (DC) and downstream (DD) concentrations suggest a predominantly upstream source for these organic carbon-associated PAHs, consistent with observations that the large majority of the sediment load in the Athabasca River downstream of oil sands development originates upstream of Fort McMurray (Conly *et al.* 2002). However, downstream (DD) concentrations were somewhat higher than upstream concentrations (DC) in spring 2011, suggesting some influence of tributaries in the oil sands region on PAH concentrations in the Athabasca River, at least seasonally.

In contrast, correlations between total PAHs and either TOC or TSS were generally very weak in tributaries (R^2<0.10), particularly when two samples with very high TSS/TOC/PAH from Eymundson Creek (*baseline* station EYC-1) in spring and summer 2011 were removed from the dataset.

However, total PAHs in water did show a strong (R^2=0.77) correlation with total PAHs in sediments measured by RAMP at these stations (mean total PAH in sediments from 2009 to 2011 used to increase number of data pairs) (Figure 6.3-3). PAHs in water were lowest at stations with low PAHs in sediment, typically those in upper watersheds; PAHs in water were highest at locations with high PAHs in sediments, typically in lower watersheds. This correlation suggests that partitioning of PAHs from river sediments into overlying water may be the primary mechanism for waterborne PAH exposure in regional tributaries, consistent with assumptions or conclusions of several other studies, including Tetreault *et al.* (2003) and Colavecchia *et al.* (2004, 2006).

Collection of additional PAH data in water by RAMP in 2012 may help to clarify sources of within- and among-watershed variability observed in PAH concentrations.

Table 6.3-1 Concentrations of PAHs in water at water quality sampling stations in the RAMP FSA, September 2011.

				Southern Tributaries					Athabasca R.								Steepbank R.				Muskeg R.								Other Eastern Tributaries					Western Tributaries																	Lakes				
Parent/ Alkylated	PAH Species	Blank-corrected detection limit[1]	CCME WQ guideline	CLR-1	CLR-2 (B)	CHR-1	CHR-2 (B)	HHR-1 (B)	ATR-DC-E (B)	ATR-DC-W (B)	ATR-SR-E	ATR-SR-W	ATR-MR-E	ATR-MR-W	ATR-DD-E	ATR-DD-W	STR-1	STR-2	STR-3 (B)	NSR-1 (B)	MUR-1	MUR-6	JAC-1	JAC-2 (B)	MUC-1	STC-1	IYC-1	WAC-1	MCC-1	MIC-1	FOC-1	FIR-1	FIR-2 (B)	POC-1	BER-1	BER-2 (B)	MAR-1	MAR-2A (B)	MAR-2 (B)	ELR-1	ELR-2 (B)	ELR-2A (B)	TAR-1	TAR-2 (B)	CAR-1	CAR-2 (B)	PIR-1 (B)	EYC-1 (B)	BIC-1 (B)	RCC-1 (B)	ISL-1	SHL-1	KEL-1	MCL-1	JOL-1 (B)
P	Biphenyl	1.092	-								1.5			1.3	1.1			1.2				1.2								1.3		1.5			1.6				1.2				1.3		1.4				1.2		2.5		1.5	1.2	1.2
A	C1-Biphenyls	5.076	-															7.8	6.4	7.0						6.5				6.1		5.1						6.0					7.4	5.6							6.1		5.5	5.9	
A	C2-Biphenyls	49.033	-															70.2	61.3	67.2						62.2				56.8								57.5					71.1	54.4							60.0		50.8	54.2	
P	Naphthalene	14.130	1,100	19.3																															15.7																				
A	C1-Naphthalenes	12.241	-	19.7																															29.2																				
A	C2-Naphthalenes	4.342	-	7.0							7.5	12.7		6.4			4.5					4.9						6.0							13.0					5.0			4.4		6.6		4.6								
A	C3-Naphthalenes	3.141	-								6.0	8.8	3.5	5.9			6.1				3.5	3.3	3.5		5.0			5.9	7.4		3.9			3.9	9.8		5.4		3.9	13.1	5.9	3.5	8.9		11.4		6.2	6.0	5.6						
A	C4-Naphthalenes	5.552	-								5.7			7.4		8.4	13.0	13.1	10.5	12.3			6.4		7.2	10.5	10.7	11.9	8.5	10.6	13.0	9.6			9.6		13.1	8.9	7.4	26.7	10.1		18.5		15.2		9.8	8.4			11.4	9.2	9.2	10.4	
P	Acenaphthylene	0.164	-	0.5	0.2										0.2								0.2					0.2						0.2																					
P	Acenaphthene	0.434	5,800				1.1								0.5	0.5		1.0	0.8	0.7			1.1	0.6		0.9	0.5			0.8	0.8	0.8			0.6		0.5	0.9		0.8	0.7	0.6	1.4	0.5	0.6	0.5		0.4			0.7	0.8	0.8	1.0	
A	C1-Acenaphthenes	0.145	-														0.2						0.9								0.3				0.3					0.3															
P	Fluorene	0.241	3,000				0.5				0.3	0.7		0.3		0.2	0.2					0.4						0.3		4.4		2.5		0.3	0.5								0.5		0.5	0.2	0.3	0.3	0.3		0.2	0.7	0.4	0.3	0.4
A	C1-Fluorenes	4.491	-									4.9									8.6		8.1					5.6															6.6												
A	C2-Fluorenes	3.603	-						3.9		4.4	8.2		3.7			6.0						6.6				6.5		10.1		5.6			3.7	7.0		5.6		4.2	10.1	5.3	4.1	12.0		9.9		8.0	5.3	4.0						
A	C3-Fluorenes	15.857	-									17.0					18.2												19.7											21.4			16.7		20.7										
P	Phenanthrene	0.888	400	1.1			1.9		1.2	1.1	2.7	7.0	1.7	2.3		1.2	2.2				1.3	1.1	1.2	0.9	1.0		2.1	1.4	1.1			0.9		1.1	2.6		1.4	1.0		1.7	1.3		3.9		2.8		1.9	1.4	1.2		1.3	1.6	1.4	1.4	1.1
P	Anthracene	0.121	-	0.1			0.1			0.1	0.3	3.0	0.3	0.3	0.1	0.2	0.3										0.2														0.1		0.4		0.3										
A	C1-Phenanthrenes/Anthracenes	0.996	-						1.5	2.1	5.7	26.3	4.6	5.0	1.7	2.5	7.2	1.0			2.8	1.5	3.0	1.6	1.4	1.1	6.1	1.7		1.2	1.4	1.2		2.7	4.1		3.4		4.9	5.7	4.6	2.5	13.6		6.4		4.3	3.9	1.0			2.4	2.0	2.0	
A	C2-Phenanthrenes/Anthracenes	3.009	-						3.3		5.3	23.4	5.4	5.1		4.0	14.5				3.1		3.6				13.7	8.9	6.7	3.8	6.0			3.4	8.2		7.7		11.3	12.5	6.6	4.0	15.0		11.4		7.5	7.1							
A	C3-Phenanthrenes/Anthracenes	3.247	-						7.3		5.5	15.5	6.3	5.7		4.4	26.0						4.2				10.3	3.6	9.9	4.6	13.2			3.8	9.5		8.1		10.7	18.3	8.3	4.1	13.2		19.3		10.8	9.1							
A	C4-Phenanthrenes/Anthracenes	7.724	-						30.6	7.8	42.5	187.0	31.9	25.9	9.3	19.9	85.9				14.9		11.0						48.5		36.8	10.3		12.9	47.5		25.4		9.5	48.0	19.1	8.1	53.7		74.5		33.1	34.7	10.7			7.9			22.0
A	Retene (1-Methyl-7-isopropyl Phenanthrene)	2.071	-						3.8		19.9	2.1	2.4	8.0		2.8	9.4	4.0	2.6		2.2		3.4											2.2	8.3	2.9				4.4			3.7		15.1	3.7	4.5	13.6	3.5						17.3
P	Dibenzothiophene	0.191	-			0.3					0.7	6.3	0.6	0.4	0.2	0.4	0.9	0.3	0.3	0.3	0.2		0.3	0.3		0.2	0.2	1.9		0.3	0.4	0.3		0.3	0.5		0.3		0.2	0.4	0.2	0.2	1.1		0.6		0.5	0.4	0.2	0.6	0.3	0.5	0.4	0.5	0.3
A	C1-Dibenzothiophenes	0.146	-						0.5	0.5	2.4	26.3	2.5	1.6	0.8	1.3	5.5	0.5			0.9		1.4	0.8		0.2	0.5	3.6			1.5			1.5	2.2		3.1		0.6	5.7	3.9	2.3	8.4		3.6	0.2	3.2	1.5			0.2	1.2	0.7	0.6	0.2
A	C2-Dibenzothiophenes	1.559	-						5.4	1.7	6.1	55.2	8.0	5.4	3.5	4.9	23.6				3.7	2.8	5.2	1.8	3.2		9.6	5.0	12.6	1.7	13.8	2.7		5.0	8.4		13.3		4.4	26.5	14.2	8.5	23.5		23.8		14.2	8.9	1.7			2.6	1.8	1.6	
A	C3-Dibenzothiophenes	1.649	-	1.9					13.7	2.6	8.1	39.9	11.3	7.6	4.4	7.7	45.5				3.1		5.3	2.0	3.6	3.9	8.1	2.5	10.8	2.3		3.1		5.9	13.9		20.9		6.5	50.2	16.8	9.0	22.6		42.3		18.9	14.8	3.3			1.8	1.9		2.3
A	C4-Dibenzothiophenes	2.300	-	2.7		2.4			15.9	2.4	6.9	16.4	9.3	7.2	4.3	6.5	38.5						3.2				8.9	7.3	7.5		25.2	2.8		4.3	14.9		12.4		4.4	37.5	9.2	4.8	12.7		34.8		14.5	11.5	3.4						
P	Fluoranthene	0.508	40				0.9				0.9	2.0	0.6	0.7			0.6										0.5								0.8								0.6		0.6			0.7							
P	Pyrene	0.434	25	0.5			0.5		1.2	0.5	1.7	8.7	1.5	1.3	0.6	1.0	2.6				0.6						0.8	0.6	2.4	0.6	1.3	0.7		0.6	2.0		0.9		0.9	1.6	0.7		2.6		2.1		1.1	1.3							
A	C1-Fluoranthenes/Pyrenes	1.653	-	2.3					10.3	2.8	10.1	50.0	9.0	8.1	3.4	6.6	21.0				4.1	1.9	2.2		2.2		6.6	2.7	15.2	4.5	12.1	4.1		4.2	15.2		9.6		6.7	16.3	5.5	2.7	17.7		19.2		10.0	11.4	3.1			1.8			2.1
A	C2-Fluoranthenes/Pyrenes	1.989	-	4.0		3.1			18.6	4.1	13.8	54.4	13.4	12.1	5.1	8.5	36.7	2.1			5.9	2.1	3.4		2.5		7.1	8.2	16.1	2.6	20.2	5.0		6.7	25.6		13.3		3.3	23.0	7.8	3.7	19.2		34.2		17.0	14.4	5.0			2.3			
A	C3-Fluoranthenes/Pyrenes	1.143	-	2.3		2.7			14.7	2.3	8.5	30.4	9.1	8.4	3.5	4.9	29.9	1.6	1.4		4.2	1.3	2.1	1.6				8.2	14.7		16.2	4.3		4.0	23.1		8.1			16.1	5.1	2.2	11.4		26.8		16.0	9.2	3.0		1.4	1.3	1.4		
P	Benz[a]anthracene	0.081	18				0.2		0.1	0.1	0.8	10.9	0.9	0.3	0.1	0.3	1.0	0.1			0.1			0.1				0.2			0.2			0.1	0.3					0.2	0.1	0.1	2.0		0.5		0.2	0.3				0.1			0.1
P	Chrysene	0.226	-	0.4		0.4			1.8	0.5	2.3	16.3	2.3	1.6	0.7	1.2	5.1				0.8		0.3	0.3	0.3		1.2		2.2	0.3	1.8	0.7		0.7	2.6		1.4			2.6	1.0	0.5	4.4		3.1		1.7	1.7	0.4		0.4	0.5	0.3		0.3
A	C1-Benzo[a]anthracenes/Chrysenes	0.475	-	0.8		0.6			4.1	1.0	5.7	58.1	6.2	3.8	1.4	2.8	13.5				1.3		0.7	0.8			1.5	1.4	2.9		4.5	0.9		1.3	6.7		3.1			5.8	2.0	0.9	12.4		8.7		4.6	4.5	1.2			0.7			0.6
A	C2-Benzo[a]anthracenes/Chrysenes	0.704	-	1.0		1.0			6.1	1.0	5.3	44.6	5.9	3.9	1.4	3.4	13.7	0.8			1.2		0.7		1.0		3.8	0.8	3.7		5.0	1.9		1.5	8.4		4.0			6.0	2.1	0.8	9.6		10.8		5.2	4.4	1.0		4.6	2.0		0.8	1.4
P	Benzo[b,j,k]fluoranthene	0.190	-			0.2			0.9	0.4	1.5	5.7	1.0	1.1		0.4	1.4				0.4								0.5					0.2	1.0		0.3			0.6			0.9		0.8		0.5	1.3	0.2			0.2			0.2
P	Benzo[a]pyrene	0.184	15						0.3		1.0	11.5	0.8	0.5		0.3	1.0												0.2						0.6								1.9		0.5			0.4				0.1			
A	C1-Benzofluoranthenes/Benzopyrenes	0.922	-						4.6		5.9	53.3	5.4	4.3	1.3	1.5	10.4	2.4	1.6		1.3	0.9							2.8		2.3			1.6	6.9		1.0			2.2			7.0		8.7		5.9	5.2							
A	C2-Benzofluoranthenes/Benzopyrenes	0.747	-						2.6		3.1	31.2	2.9	2.1		1.9	5.9	2.0	0.8								0.8	28.7	1.5	1.7	1.5	1.8			3.7		1.0			1.5		0.8	4.5		4.7		4.2	1.9	0.9		1.6				1.2
P	Indeno[1,2,3-c,d]-pyrene	0.313	-						0.5		0.6	2.1	0.4	0.3			0.5	0.3																	0.5								0.5		0.4		0.3								
P	Dibenz[a,h]anthracene	0.109	-	0.1					0.1		0.3	3.5	0.3	0.1		0.1	0.3											0.3							0.2								0.6		0.2			0.2				0.1			
P	Benzo[g,h,i]perylene	0.170	-	0.2		0.2			0.6	0.2	1.1	6.9	0.8	0.5		0.3	1.2	0.7	0.6		0.2								0.4		0.4			0.3	1.0		0.3			0.4			1.4		1.0		1.0	0.7				0.2			
P	**Total Parent PAHs (ND=0)**	-	-	**22.2**	**0.2**	**1.1**	**5.2**	**0.0**	**6.7**	**3.1**	**15.6**	**84.6**	**11.0**	**11.0**	**3.7**	**6.0**	**17.4**	**3.6**	**1.7**	**1.0**	**3.7**	**2.8**	**3.1**	**2.2**	**1.2**	**1.1**	**5.5**	**5.0**	**6.8**	**7.7**	**4.9**	**7.4**	**0.0**	**3.9**	**30.5**	**0.0**	**5.0**	**1.8**	**2.4**	**8.2**	**4.1**	**1.4**	**23.6**	**0.5**	**15.4**	**0.7**	**7.6**	**9.1**	**3.6**	**0.6**	**5.6**	**4.9**	**4.7**	**4.4**	**3.5**
A	**Total Alkylated PAHs (ND=0)[2]**	-	-	**41.6**	**0.0**	**9.5**	**0.0**	**0.0**	**139.0**	**28.0**	**171.9**	**743.2**	**129.8**	**131.3**	**40.0**	**87.1**	**407.9**	**104.8**	**83.9**	**86.5**	**60.4**	**18.7**	**70.5**	**8.4**	**26.0**	**84.4**	**94.0**	**111.9**	**188.3**	**96.0**	**168.9**	**52.7**	**0.0**	**64.5**	**264.8**	**2.9**	**150.1**	**72.5**	**68.3**	**337.7**	**118.2**	**57.9**	**379.1**	**60.0**	**387.7**	**3.9**	**190.8**	**166.0**	**47.4**	**0.0**	**85.3**	**33.1**	**73.3**	**75.5**	**47.0**
P+A	**Total PAHs (ND=0)[2]**	-	-	**63.7**	**0.2**	**10.6**	**5.2**	**0.0**	**145.7**	**31.1**	**187.5**	**827.7**	**140.8**	**142.3**	**43.7**	**93.1**	**425.3**	**108.5**	**85.5**	**87.5**	**64.1**	**21.5**	**73.6**	**10.6**	**27.3**	**85.5**	**99.5**	**116.9**	**195.1**	**103.6**	**173.8**	**60.1**	**0.0**	**68.4**	**295.3**	**2.9**	**155.1**	**74.3**	**70.6**	**345.8**	**122.3**	**59.3**	**402.7**	**60.4**	**403.1**	**4.6**	**198.4**	**175.1**	**50.9**	**0.6**	**90.9**	**38.0**	**78.0**	**79.9**	**50.6**
P+A	Percent detectable values[1]	-	-	40%	2%	21%	16%	0%	60%	42%	79%	79%	67%	79%	47%	67%	81%	40%	23%	12%	51%	26%	56%	26%	23%	19%	49%	56%	53%	40%	56%	47%	0%	60%	86%	2%	58%	12%	37%	70%	53%	47%	91%	7%	84%	9%	67%	72%	47%	2%	30%	49%	33%	28%	35%

(B) = *Baseline* station (all other stations were *test* stations in 2011)

Blank cells indicate non-detectable values

[1] Project-wide, blank-corrected Detection Limit for each PAH species calculated as either lab-derived Reporting Limit or 2x standard deviation of trip blank measurements (see text).

[2] Total excludes retene (a specific C4-phenanthrene) unless retene value exceeds C4-phenanthrene value in a sample, in which case total includes retene but excludes C4-phenanthrene.

Figure 6.3-2 Relationship between total PAHs and total organic carbon (TOC) in water from the mainstem Athabasca River station located upstream (ATR-DC-E/W) and downstream (ATR-DD-E/W) of oil sands development, spring, summer, and fall, 2011.

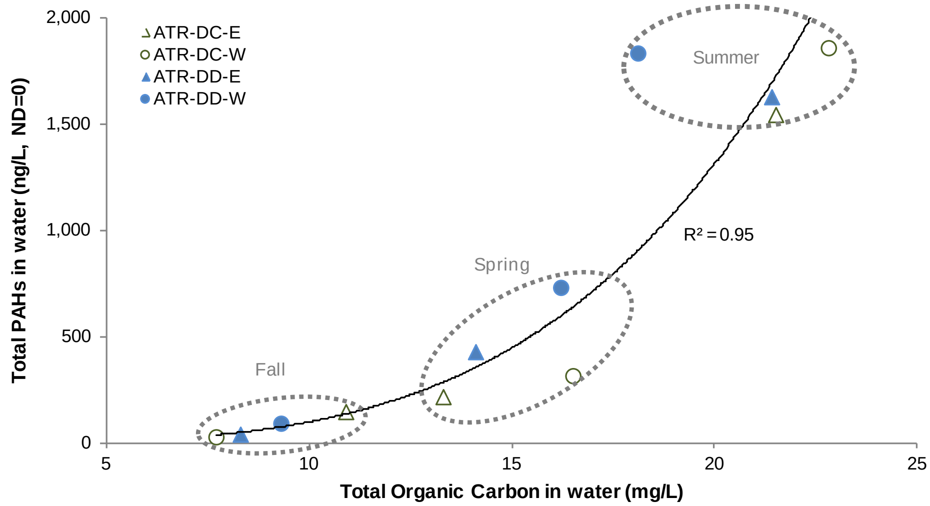
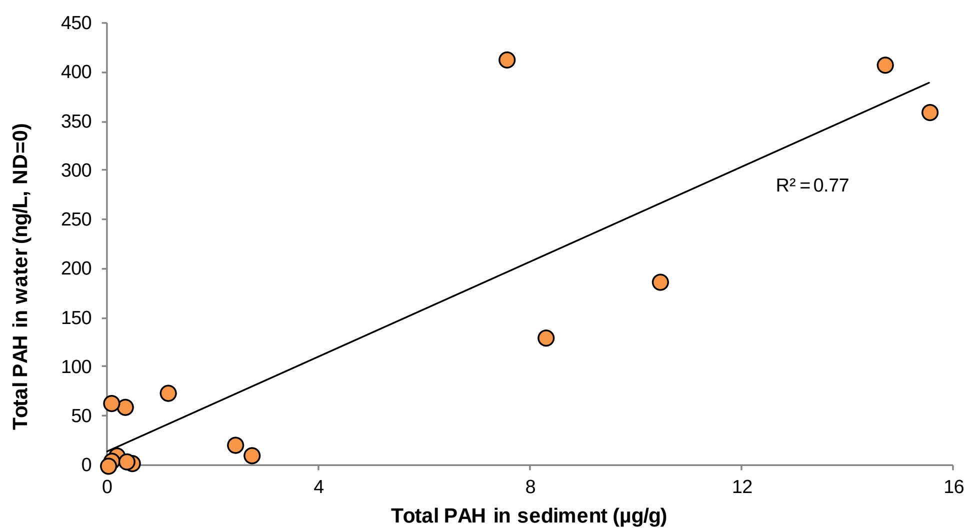


Figure 6.3-3 Relationship between total PAHs in water and total PAHs in sediment (fall 2009 to 2011 average) for stations on tributaries of the Athabasca River where paired data exist[1].



[1] Includes sediment data from stations CHR-D1, CHR-D2, CLR-D1, CLR-D2, POC-D1, JAC-D1, JAC-D2, MUR-D3, FOC-D1, FIR-D1, 1 BER-D2, ELR-D1, TAR-D1, CAR-D1, and CAR-D2.

6.4 NEXEN LAKES WATER QUALITY MONITORING

Nexen Inc. undertakes a bi-annual water quality monitoring program (the Program) at select lakes in the vicinity of their Long Lake Project. The Program is conducted to meet requirements stipulated under their Alberta Environmental Protection and Enhancement Act (EPEA) approval and to address community concerns. A total of nine lakes south of Fort McMurray were sampled for water quality in spring and fall 2011, in conjunction with the Nexen Wetlands Monitoring Program (Hatfield 2012). Results of the water quality program have historically been presented as part of the RAMP report since the Program began in 2000.

6.4.1 Summary of Field Methods and Sample Analysis

The 2011 Nexen lakes program consisted of spring and fall ambient water quality monitoring at each of nine lakes (Table 6.4-1 and Figure 6.4-1). Water quality stations were accessed via a pontoon-equipped helicopter in the spring and a combination of helicopter and Argo during the fall monitoring program. For each lake station, the helicopter landed near the edge of the lake and taxied out to the centre of the lake. This approach ensured surface waters at the sample collection point were not disturbed by rotor wash. When stations were accessed by ground, a personal inflatable boat (fish-cat) was used to access an offshore area of the lake for sampling.

Water quality sampling procedures in each lake followed RAMP's, as outlined in Section 3.1.2. All water samples were collected, preserved, and shipped according to protocols specified by consulting laboratories. All water quality samples taken in 2011 were analyzed for the RAMP standard variables (Table 3.1-4). All analyses were conducted by ALS Environmental Ltd. (Fort McMurray and Edmonton, Alberta), with the exception total and dissolved metals (including ultra-trace mercury) and naphthenic acids, which were analyzed by Alberta Innovates Technology Futures (AITF) in Vegreville, Alberta.

Table 6.4-1 Location of water quality stations for the Nexen Lakes Water Quality Monitoring Program, spring and fall 2011.

Waterbody	Station Name	UTM Coordinates (NAD83, Zone 12)	
		Easting	Northing
Canoe Lake	CANL-1	498900	6256861
Caribou Horn Lake	CARL-1	501305	6264200
Frog Lake	FRL-1	504521	6254100
Gregoire Lake	GRL-1	493510	6255110
Kiskatinaw Lake	KIL-1	499980	6265890
Rat Lake	RAL-1	507453	6251457
Sucker Lake	SUL-1	508396	6252302
Unnamed Lake One	UNL-1	502509	6249721
Unnamed Lake Two	UNL-2	500461	6255614

6.4.2 Analytical Approach

The analytical approach used in 2011 for the Program was based on the analytical approach described in Section 3.2.2 for the RAMP Water Quality component.

Development of Regional Water Quality Baseline Conditions

Determination of regional *baseline* concentrations for the Nexen lakes was conducted separately from the RAMP water quality dataset. The regional *baseline* range was defined from water quality data collected in the fall at all Nexen lakes between 2000 and 2008. All lakes sampled for the Program were considered to be *baseline* from 2000 to 2008 given operations at the Long Lake project did not start until 2008. This approach maximized the number of observations used to define regional *baseline* conditions against which observations from individual Nexen lakes could be compared.

Comparison to Historical Data and Water Quality Guidelines

Historical variability was presented for each water quality measurement endpoint, represented by minimum, maximum and median values, as well as the number of observations, at each station from 2000 to 2008 (fall observations only). All cases where concentrations of water quality variables exceeded relevant guidelines, including water quality measurement endpoints and any other water quality variables that were measured, also were reported.

Comparison to Regional Baseline Conditions

Descriptive statistics describing water quality characteristics for *baseline* years (2000 to 2008) for all lakes were calculated; the 5^{th}, 25^{th}, 50^{th} (median), 75^{th}, and 95^{th} percentiles were determined for comparison against station-specific data. The median rather than the mean was used as an indicator of typical conditions.

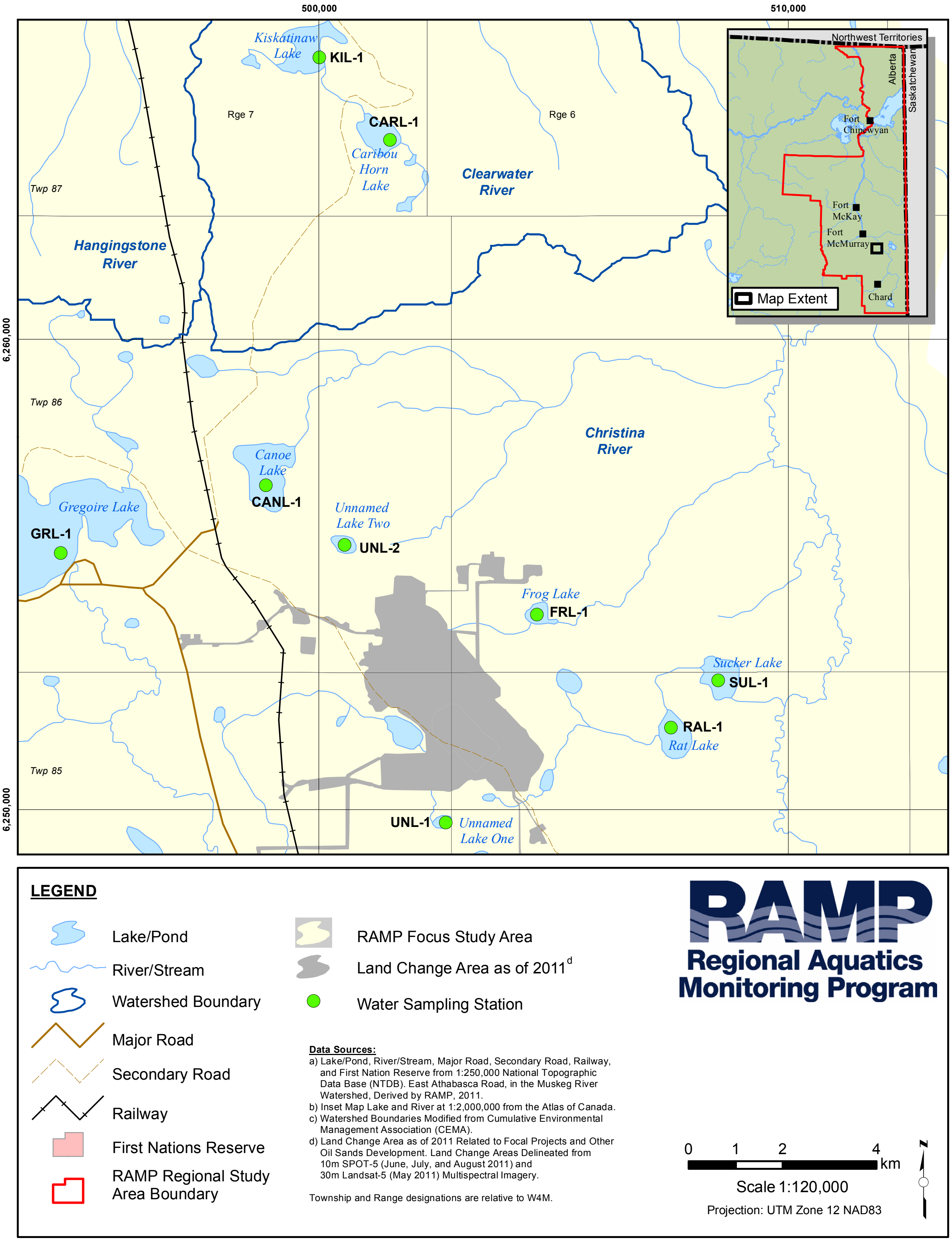
Data for the fifteen selected water quality measurement endpoints (Table 3.2-1) were presented graphically against regional *baseline* variability by presenting data for each station for all years of sampling to allow assessment of any temporal trends.

6.4.3 Water Quality Results

2011 Results Relative to Historical and Regional *Baseline* Concentrations Given the small number of observations from each lake, concentrations of some water quality measurement endpoints in fall 2011 exceeded previously-measured minimum or maximum concentrations for each lake (Table 6.4-2 to Table 6.4-10). Concentrations of water quality measurement endpoints were within historical ranges in spring and fall 2011 with the exception of (Table 6.4-2 to Table 6.4-10):

- total phenols, with concentrations that exceeded previously-measured maximum concentrations in spring at stations FRL-1 and GRL-1 and in fall at stations BIL-1 and POL-1;
- total phosphorous, with concentrations that exceeded previously-measured maximum concentrations in spring at stations CANL-1 and LOL-1;
- total nitrogen, with a concentration that exceeded the previously-measured maximum concentration in fall at station FRL-1;

Figure 6.4-1 Locations of water quality stations for the Nexen Lakes Water Quality Monitoring Program, spring and fall 2011.



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- total iron, with a concentration that exceeded the previously-measured maximum concentration in fall at station GRL-1;

- conductivity (570 µS/cm), with a value that exceeded the previously-measured maximum value (86µS/cm) in spring at station PUL-1. Conductivity decreased to 178 µS/cm in fall, which was still nearly two times greater than the range of previously-measured values;

- pH, which has been lower than the recommended guideline for the protection of aquatic life, increased by a factor of ten in fall 2011 at station UNL-1 to a neutral pH level; and

- dissolved and total phosphorous, with concentrations that exceeded previously-measured maximum concentrations at station UNL-1.

Concentrations of naphthenic acids in all lakes were below the detection limit of 1 mg/L in all years. In 2009, the detection limit for naphthenic acids was reduced to 0.2 mg/L, resulting in concentrations for naphthenic acids in fall 2009 and 2011 falling below the 5th percentile of the *baseline* range.

Generally, concentrations of water quality measurement endpoints in fall 2011 were within or below regional *baseline* concentrations for the Nexen lakes (Figure 6.4-2 and Figure 6.4-3).

Comparison of Water Quality Measurement Endpoints to Published Guidelines Concentrations of water quality measurement endpoints that exceeded water quality guidelines in fall 2011 were (Table 6.4-2 to Table 6.4-10):

- total nitrogen at stations BIL-1, CANL-1, CARL-1, FRL-1, RAL-1, SUL-1, UNL-1 and UNL-2;

- total mercury (ultra-trace) at stations CANL-1, CARL-1, FRL-1, GRL-1, KIL-1, RAL-1, SUL-1, UNL-1 and UNL-2;

- total phosphorus at stations FRL-1 and UNL-2; and

- total dissolved phosphorus and total and dissolved aluminum at station UNL-2.

Other Water Quality Guideline Exceedances The other exceedances of water quality guidelines in fall 2011 in the Nexen lakes were (Table 6.4-11):

- total iron at stations BIL-1, CARL-1, FRL-1, GRL-1, RAL-1, SUL-1, UNL-1, and UNL-2 and dissolved iron at stations BIL-1, UNL-1, and UNL-2;

- total phenols at all stations;

- sulphide at all stations; and

- total cadmium at station UNL-1.

Fall concentrations of total mercury (ultra-trace) exceeded the guideline at all stations with the exception of station BIL-1, although ultra-trace mercury was higher at station BIL-1 (4.5 ng/L) relative to past years. Contamination of the ultra-trace mercury samples was suspected given that the ultra-trace field-blank result was also above the guideline. Considerable efforts to resolve this issue with the laboratory were unable to definitively isolate the potential source of the contamination; possible sources of contamination were the de-ionized water, contaminated preservatives or air/water contamination from the field. As the samples were taken over the course of three separate sampling trips (September 18, September 21, and September 28), with three different modes of access (Argo, pontoon-helicopter, and truck), and all other analytes in the field blank measured less than 5x the detection limit, the most likely scenario is that the preservatives provided by the laboratory were contaminated. Therefore, concentrations of ultra-trace mercury in fall 2011 should be interpreted with caution (Hatfield 2012).

The other exceedances of water quality guidelines in spring 2011 in the Nexen lakes were (Table 6.4-11):

- pH at station UNL-1;
- total phosphorus at stations CANL-1, UNL-1, and UNL-2;
- total dissolved phosphorus at stations UNL-1 and UNL-2;
- total nitrogen at stations FRL-1, RAL-1, SUL-1, UNL-1, and UNL-2;
- total and dissolved aluminum at station UNL-2;
- total cadmium at stations KIL-1, UNL-1, and UNL-1;
- total iron at stations SUL-1, UNL-1, and UNL-2 and dissolved iron at station UNL-2;
- total phenols at stations CANL-1, CARL-1, FRL-1, KIL-1, RAL-1, UNL-1, and UNL-2; and
- sulphide at stations FRL-1, GRL-1, RAL-1, SUL-1, UNL-1, and UNL-2.

Ion Balance The ionic composition of water in all lakes in fall 2011 was dominated primarily by calcium bicarbonate, similar to previous sampling years (Figure 6.4-4 and Figure 6.4-5). In fall 2009, Canoe Lake had higher relative chloride levels than previously-measured, which persisted in 2011 (Figure 6.4-4). In 2006, Unnamed Lake 1 and Unnamed Lake 2 had ionic compositions that were very different from other lakes in the region; however in 2009 and 2011, the ionic composition of these lakes has become more similar to the other Nexen lakes (Figure 6.4-5).

Summary Water quality in the Nexen lakes in fall 2011 was similar to water quality observed during the period when these lakes were designated as *baseline*. Concentrations of most water quality measurement endpoints in the fall 2011 were within their regional *baseline* concentrations for the Nexen lakes. In addition, the ionic composition of water in all lakes in fall 2011 was similar to the dominant composition observed in previous monitoring years.

Table 6.4-2 Concentrations of water quality measurement endpoints, Canoe Lake (CANL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	6.9	<u>7.53</u>	4	6.8	7.3	7.4
Total Suspended Solids	mg/L	-	7	8	4	**<3**	2.5	19
Conductivity	µS/cm	-	<u>131</u>	<u>140</u>	4	83	89	102
Nutrients								
Total phosphorus	mg/L	0.05	0.0391	**0.0577**	4	0.035	**0.072**	**0.14**
Total dissolved phosphorus	mg/L	0.05	0.0192	0.0233	3	0.013	0.020	**0.065**
Total nitrogen*	mg/L	1.0	**1.201**	**1.221**	4	**1.1**	**1.3**	**1.4**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	4	0.061	<0.1	<0.1
Dissolved organic carbon	mg/L	-	<u>18.4</u>	<u>24</u>	4	20	22	23
Ions								
Sodium	mg/L	-	<u>10.7</u>	<u>10.8</u>	4	3	5	7
Calcium	mg/L	-	10.6	<u>11.7</u>	4	9.2	9.9	10.8
Magnesium	mg/L	-	<u>3.79</u>	<u>4.09</u>	4	3.1	3.2	3.5
Chloride	mg/L	230, 860	<u>16.1</u>	<u>15.6</u>	4	<1.0	1.4	5
Sulphate	mg/L	50, 100	1.26	0.81	4	0.8	2.2	2.5
Total Dissolved Solids	mg/L	-	101	<u>130</u>	4	46	105	110
Total Alkalinity	mg/L	-	39.9	41	4	36	42	43
Organic compounds								
Naphthenic acids	mg/L	-	0.43	0.1374	2	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.000503	0.000576	4	0.00023	0.00072	<0.01
Total aluminum	mg/L	0.1	0.0303	0.0151	4	0.014	0.0499	**0.11**
Dissolved aluminum	mg/L	0.1	<u>0.0122</u>	<u>0.0034</u>	1	0.00633	0.00633	0.00633
Total boron	mg/L	1.2	<u>0.026</u>	<u>0.0219</u>	4	0.015	0.0178	0.0193
Total molybdenum	mg/L	0.073	0.0000975	0.000148	4	<0.00002	<0.00006	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	**<u>10.9</u>**	<u>1.7</u>	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Sulphide	mg/L	0.002	**0.0053**	**0.0052**	3	**0.005**	**0.007**	**0.017**
Total Phenols	mg/L	0.004	**<u>0.0073</u>**	**<u>0.008</u>**	3	<0.001	<0.001	**0.004**

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

Table 6.4-3 Concentrations of water quality measurement endpoints, Caribou Lake (CARL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	7.41	<u>8</u>	3	7.2	7.7	7.8
Total Suspended Solids	mg/L	-	8	<u>4</u>	3	5	7	22
Conductivity	µS/cm	-	<u>151</u>	97.3	3	88	92.4	97.8
Nutrients								
Total phosphorus	mg/L	0.05	<u>0.0273</u>	0.041	3	0.037	0.039	0.048
Total dissolved phosphorus	mg/L	0.05	0.0079	0.0131	3	0.004	0.009	0.017
Total nitrogen*	mg/L	1.0	**1.001**	**1.031**	3	0.616	**1.1**	**1.2**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	3	<0.006	<0.006	0.2
Dissolved organic carbon	mg/L	-	20.7	24.7	3	18	22	26
Ions								
Sodium	mg/L	-	<u>4.4</u>	<u>4.3</u>	3	5.2	6	6
Calcium	mg/L	-	<u>19.3</u>	<u>19.8</u>	3	21.6	22	23.1
Magnesium	mg/L	-	<u>6.55</u>	<u>6.37</u>	3	7	7.4	7.56
Chloride	mg/L	230, 860	<0.5	<0.5	3	<1.0	1.1	2
Sulphate	mg/L	50, 100	1.8	1.86	3	1.3	3.4	16.1
Total Dissolved Solids	mg/L	-	126	122	3	97	138	180
Total Alkalinity	mg/L	-	81.7	78.5	3	74	77	94
Organic compounds								
Naphthenic acids	mg/L	-	0.30	0.0573	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.000423	0.000615	3	0.00028	0.0004235	<0.01
Total aluminum	mg/L	0.1	0.0356	<u>0.0193</u>	3	0.0343	0.0470	**0.116**
Dissolved aluminum	mg/L	0.1	<u>0.00616</u>	<u>0.00263</u>	1	0.00803	0.00803	0.00803
Total boron	mg/L	1.2	<u>0.0383</u>	<u>0.0332</u>	3	0.0113	0.0311	0.032
Total molybdenum	mg/L	0.073	0.0000878	0.0000926	3	0.00002	0.00002	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	<u>**9.3**</u>	<u>1.4</u>	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Sulphide	mg/L	0.002	<u>**0.0048**</u>	**0.0059**	2	**0.005**	**0.006**	**0.007**
Total Iron	mg/L	0.3	<u>0.0847</u>	**0.345**	2	0.24	**0.3235**	**0.407**
Total Phenols	mg/L	0.004	**0.007**	**0.0064**	2	<0.001	**0.0035**	**0.007**

[a] Sources for all guidelines are outlined in Table 3.2-5.
Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

Table 6.4-4 Concentrations of water quality measurement endpoints, Frog Lake (FRL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall Baseline (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	<u>7.47</u>	<u>7.97</u>	3	7.5	7.6	7.8
Total Suspended Solids	mg/L	-	<u>8</u>	<u>6</u>	3	3	3	5
Conductivity	µS/cm	-	<u>212</u>	<u>196</u>	3	178	180	181
Nutrients								
Total phosphorus	mg/L	0.05	**0.0546**	**0.0522**	3	0.035	0.042	**0.16**
Total dissolved phosphorus	mg/L	0.05	<u>0.0102</u>	<u>0.0107</u>	2	0.015	0.015	0.015
Total nitrogen*	mg/L	1.0	**<u>1.701</u>**	**1.591**	3	**1.3**	**1.3**	**1.6**
Nitrate+Nitrite	mg/L	-	<0.0710	<0.0071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	<u>26.9</u>	34.1	3	28	30	39
Ions								
Sodium	mg/L	-	<u>12.9</u>	<u>11.4</u>	3	7.5	8.0	9
Calcium	mg/L	-	24.2	<u>22.4</u>	3	24.2	24.3	24.5
Magnesium	mg/L	-	<u>7.91</u>	<u>6.58</u>	3	7.18	7.5	7.6
Chloride	mg/L	230, 860	<u>12.5</u>	<u>12</u>	3	<1.0	1	5
Sulphate	mg/L	50, 100	2.02	<u>0.67</u>	3	1.9	2.9	3.4
Total Dissolved Solids	mg/L	-	<u>212</u>	167	3	100	183	200
Total Alkalinity	mg/L	-	91.8	<u>78.2</u>	3	83	88	95
Organic compounds								
Naphthenic acids	mg/L	-	0.02	<1.0	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.000445	0.000462	3	0.00044	0.000427	<0.01
Total aluminum	mg/L	0.1	0.0275	0.0235	3	0.016	0.035	0.043
Dissolved aluminum	mg/L	0.1	<u>0.0125</u>	<u>0.00258</u>	1	0.00365	0.00365	0.00365
Total boron	mg/L	1.2	0.0458	0.0432	3	0.0375	0.0520	0.0696
Total molybdenum	mg/L	0.073	0.0001	<u>0.0000462</u>	3	0.00006	0.000074	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	**<u>6.6</u>**	<u>1.2</u>	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Total Phenols	mg/L	0.004	**0.0087**	**0.0093**	2	<0.001	**0.005**	**0.01**
Total Iron	mg/L	0.3	<u>0.142</u>	**<u>0.337</u>**	2	0.238	0.253	0.268
Sulphide	mg/L	0.002	**0.0077**	**<u>0.0056</u>**	2	**0.007**	**0.0085**	**0.01**

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

Table 6.4-5 Concentrations of water quality measurement endpoints, Gregoire Lake (GRL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	7.48	7.92	2	7.6	7.6	7.6
Total Suspended Solids	mg/L	-	10	7	2	<3	1.5	6
Conductivity	µS/cm	-	129	136	2	127	136.5	146
Nutrients								
Total phosphorus	mg/L	0.05	0.046	0.0275	2	0.021	0.023	0.025
Total dissolved phosphorus	mg/L	0.05	0.0109	0.0064	2	0.006	0.007	0.007
Total nitrogen*	mg/L	1.0	0.891	0.771	2	0.6	0.8	0.9
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	2	<0.1	<0.1	<0.1
Dissolved organic carbon	mg/L	-	11.1	11	2	11	11	11
Ions								
Sodium	mg/L	-	3.2	3.2	2	4	4	4
Calcium	mg/L	-	17.9	17.3	2	16.9	17.6	18.3
Magnesium	mg/L	-	4.83	4.44	2	4.5	4.7	4.9
Chloride	mg/L	230, 860	1.93	1.7	2	<1.0	1	3
Sulphate	mg/L	50, 100	4.5	5.32	2	6.4	6.6	6.7
Total Dissolved Solids	mg/L	-	92	97	2	96	108	120
Total Alkalinity	mg/L	-	62.7	59	2	53	59	64
Organic compounds								
Naphthenic acids	mg/L	-	<0.02	0.0639	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.00147	0.00105	2	0.000728	0.000914	<0.0011
Total aluminum	mg/L	0.1	0.0634	0.0335	2	0.021	0.0379	0.0548
Dissolved aluminum	mg/L	0.1	0.00513	0.00173	1	0.00279	0.00279	0.00279
Total boron	mg/L	1.2	0.0195	0.0197	2	0.0174	0.0180	0.0186
Total molybdenum	mg/L	0.073	0.000774	0.000698	2	0.000563	0.000652	0.00074
Total mercury (ultra-trace)	ng/L	5, 13	**7.6**	1.2	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Total Iron	mg/L	0.3	**0.336**	0.118	2	0.119	0.1275	0.142
Total Phenols	mg/L	0.004	**0.0101**	**0.0047**	1	<0.003	<0.003	<0.003

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; underlined values are outside of *baseline* range.

Table 6.4-6 Concentrations of water quality measurement endpoints, Kiskatinaw Lake (KIL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	<u>7.69</u>	<u>8</u>	3	7.7	7.8	7.8
Total Suspended Solids	mg/L	-	<3	3	3	<3	1	4
Conductivity	µS/cm	-	<u>154</u>	<u>158</u>	3	164	183	185
Nutrients								
Total phosphorus	mg/L	0.05	<u><0.001</u>	<u>0.0242</u>	3	0.025	0.029	**0.15**
Total dissolved phosphorus	mg/L	0.05	<u><0.001</u>	0.0079	2	0.008	0.010	0.011
Total nitrogen*	mg/L	1.0	<u><0.2</u>	**1.001**	3	0.776	**1.1**	**1.1**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	3	<0.006	<0.1	0.1
Dissolved organic carbon	mg/L	-	22.2	24.9	3	20	24	40
Ions								
Sodium	mg/L	-	<u>5.7</u>	<u>5.5</u>	3	6.2	7	7
Calcium	mg/L	-	21.4	<u>20.9</u>	3	21.2	22.7	24.1
Magnesium	mg/L	-	7.09	<u>6.46</u>	3	6.6	6.9	7.31
Chloride	mg/L	230, 860	<0.5	<0.5	3	<1.0	1.1	2
Sulphate	mg/L	50, 100	1.52	2.03	3	1.1	2.8	3.8
Total Dissolved Solids	mg/L	-	139	140	3	102	146	160
Total Alkalinity	mg/L	-	83.1	79.7	3	80	92	99
Organic compounds								
Naphthenic acids	mg/L	-	0.27	0.0616	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.000511	0.000542	3	0.00002	0.000442	<0.01
Total aluminum	mg/L	0.1	0.0304	0.0172	3	0.002	0.034	0.047
Dissolved aluminum	mg/L	0.1	<u>0.00609</u>	0.00224	1	0.00293	0.00293	0.00293
Total boron	mg/L	1.2	<u>0.0499</u>	<u>0.048</u>	3	<0.00008	0.040	0.0445
Total molybdenum	mg/L	0.073	0.0000818	0.0000912	3	<0.00002	0.000085	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	<u>**11.5**</u>	<1.2	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Total Phenols	mg/L	0.004	<u>**0.0082**</u>	**0.007**	2	<0.001	**0.0035**	**0.007**
Sulphide	mg/L	0.002	<u>**0.0086**</u>	<u>**0.049**</u>	2	**0.004**	**0.005**	**0.006**

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

Table 6.4-7 Concentrations of water quality measurement endpoints, Rat Lake (RAL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	<u>7.3</u>	<u>8.15</u>	3	7.7	7.7	7.9
Total Suspended Solids	mg/L	-	<u>7</u>	3	3	<1	4	6
Conductivity	µS/cm	-	<u>211</u>	<u>209</u>	3	204	206	208
Nutrients								
Total phosphorus	mg/L	0.05	<u>0.0349</u>	<u>0.0349</u>	3	0.042	0.045	0.11
Total dissolved phosphorus	mg/L	0.05	<u>0.0087</u>	<u>0.0127</u>	2	0.009	0.011	0.012
Total nitrogen*	mg/L	1.0	**1.091**	**1.191**	3	0.826	**1.3**	**1.4**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	18.9	22.4	3	18	18	26
Ions								
Sodium	mg/L	-	<u>8.3</u>	7.6	3	6.5	8	8
Calcium	mg/L	-	<u>28.3</u>	26.8	3	26.6	26.6	27
Magnesium	mg/L	-	<u>8.69</u>	<u>7.64</u>	3	7.83	8.0	8.3
Chloride	mg/L	230, 860	<u>2.48</u>	<u>2.58</u>	3	0.9	<1.0	2
Sulphate	mg/L	50, 100	<u>1.9</u>	<u>2.17</u>	3	2.7	4.4	4.6
Total Dissolved Solids	mg/L	-	147	160	3	113	167	180
Total Alkalinity	mg/L	-	<u>110</u>	101	3	100	103	109
Organic compounds								
Naphthenic acids	mg/L	-	0.41	0.1154	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	<u>0.000115</u>	0.000402	3	0.00039	0.00039	<0.01
Total aluminum	mg/L	0.1	<u>0.00595</u>	0.0162	3	0.0157	0.0160	0.033
Dissolved aluminum	mg/L	0.1	<u>0.00588</u>	<u>0.00107</u>	1	<0.001	<0.001	<0.001
Total boron	mg/L	1.2	0.0303	0.0311	3	0.023	0.0331	0.03406
Total molybdenum	mg/L	0.073	<u>0.0000474</u>	0.000091	3	0.0000688	0.00007	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	<u>**7.9**</u>	<u>1.4</u>	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Total Iron	mg/L	0.3	<u>0.188</u>	<u>**0.533**</u>	2	0.243	0.2785	**0.314**
Total Phenols	mg/L	0.004	<u>**0.009**</u>	<u>0.0038</u>	2	<0.001	0.0035	**0.007**
Sulphide	mg/L	0.002	<u>**0.0039**</u>	**0.0069**	2	**0.005**	**0.0065**	**0.008**

[a] Sources for all guidelines are outlined in Table 3.2-5.
Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

Table 6.4-8 Concentrations of water quality measurement endpoints, Sucker Lake (SUL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	<u>7.48</u>	<u>8.06</u>	4	7.7	7.8	7.9
Total Suspended Solids	mg/L	-	8	5	3	<1	4	8
Conductivity	µS/cm	-	199	187	4	187	215	219
Nutrients								
Total phosphorus	mg/L	0.05	<u>0.0365</u>	**0.06**	3	**0.054**	**0.084**	**0.11**
Total dissolved phosphorus	mg/L	0.05	<u>0.0094</u>	<u>0.029</u>	2	0.013	0.016	0.019
Total nitrogen*	mg/L	1.0	**1.461**	**1.381**	3	0.77	**1.5**	**1.9**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	4	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	22.7	25	3	19	20	25
Ions								
Sodium	mg/L	-	<u>1.9</u>	8.8	4	9.8	10	11
Calcium	mg/L	-	<u>10.7</u>	<u>21.5</u>	4	23	24.5	26.7
Magnesium	mg/L	-	<u>2.63</u>	<u>6.34</u>	4	6.8	7.6	8.3
Chloride	mg/L	230, 860	0.52	1.79	4	<1.0	1.4	2
Sulphate	mg/L	50, 100	<0.5	3.09	4	2.5	3.7	6
Total Dissolved Solids	mg/L	-	<u>94</u>	152	3	117	157	190
Total Alkalinity	mg/L	-	<u>38.6</u>	89.8	4	91	110	115
Organic compounds								
Naphthenic acids	mg/L	-	ns	0.1134	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	<u>0.000243</u>	0.000513	3	0.000409	0.0005	<0.01
Total aluminum	mg/L	0.1	<u>0.0629</u>	0.0135	3	0.01	0.0164	0.032
Dissolved aluminum	mg/L	0.1	<u>0.0106</u>	0.000708	1	<0.001	<0.001	<0.001
Total boron	mg/L	1.2	<u>0.0143</u>	0.0536	3	0.0441	0.0500	0.06852
Total molybdenum	mg/L	0.073	0.000072	0.000127	3	0.0000393	0.00006	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	<u>**12.1**</u>	<u>1.2</u>	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Total Iron	mg/L	0.3	**0.372**	**0.405**	2	0.185	**0.3235**	**0.462**
Sulphide	mg/L	0.002	<u><0.002</u>	**0.0064**	2	**0.004**	**0.0055**	**0.007**
Total Phenols	mg/L	0.004	<u>**0.011**</u>	**0.0055**	2	<0.001	<0.004	**0.008**

[a] Sources for all guidelines are outlined in Table 3.2-5.
Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.
ns = not sampled

Table 6.4-9 Concentrations of water quality measurement endpoints, Unnamed Lake One (UNL-1), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	<u>7.44</u>	**5.32**	4	**5.3**	**5.8**	6.4
Total Suspended Solids	mg/L	-	10	7	4	<1	4	22
Conductivity	µS/cm	-	<u>70</u>	<u>22.3</u>	4	23	25.2	39.2
Nutrients								
Total phosphorus	mg/L	0.05	0.0368	**<u>0.163</u>**	3	0.032	0.040	**0.12**
Total dissolved phosphorus	mg/L	0.05	<u>0.0081</u>	**<u>0.14</u>**	2	0.023	0.027	0.03
Total nitrogen*	mg/L	1.0	**<u>1.451</u>**	**1.181**	3	0.656	1.0	**1.3**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	3	<0.006	<0.1	<0.1
Dissolved organic carbon	mg/L	-	21.9	<u>29.4</u>	4	21	22	28
Ions								
Sodium	mg/L	-	<u>1.7</u>	<1.0	4	0.6	<1.0	<1.0
Calcium	mg/L	-	<u>10.9</u>	<u>2.4</u>	4	2.6	3.1	3.3
Magnesium	mg/L	-	<u>2.76</u>	0.72	4	0.7	0.8	0.9
Chloride	mg/L	230, 860	<0.5	<0.5	4	0.8	1	2
Sulphate	mg/L	50, 100	<0.5	<u>0.57</u>	4	0.8	2.2	2.7
Total Dissolved Solids	mg/L	-	<u>168</u>	<u>29.4</u>	4	21	22	28
Total Alkalinity	mg/L	-	<u>38.9</u>	<5.0	4	6	9	15
Organic compounds								
Naphthenic acids	mg/L	-	0.49	0.1315	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	<u>0.0000241</u>	0.000333	3	0.000292	0.00043	<0.01
Total aluminum	mg/L	0.1	<u>0.00943</u>	0.0951	3	0.058	0.081	0.097
Dissolved aluminum	mg/L	0.1	<u>0.00706</u>	<u>0.0696</u>	1	0.0749	0.0749	0.0749
Total boron	mg/L	1.2	0.0161	0.0103	3	<0.002	0.0084	0.0249
Total molybdenum	mg/L	0.073	<u>0.0000104</u>	<u>0.0000435</u>	3	0.0000463	0.00011	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	**<u>5.9</u>**	<u>2.2</u>	1	<1.2	<1.2	<1.2
Varaibles that exceeded CCME guidelines in Fall								
Dissolved Iron	mg/L	0.3	**<u>0.302</u>**	**<u>0.481</u>**	2	0.088	0.0582	0.284
Total Iron	mg/L	0.3	**0.309**	**<u>0.557</u>**	2	0.162	0.2415	**0.321**
Total Phenols	mg/L	0.004	**0.0111**	**<u>0.0125</u>**	2	<0.001	<0.005	**0.01**
Sulphide	mg/L	0.002	**<u>0.0029</u>**	**0.0072**	3	**0.004**	**0.004**	**0.008**
Total Cadmium	mg/L	-	<u><0.000002</u>	**0.000017**	3	<0.000006	<0.0006	**0.00022**

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; <u>underlined</u> values are outside of *baseline* range.

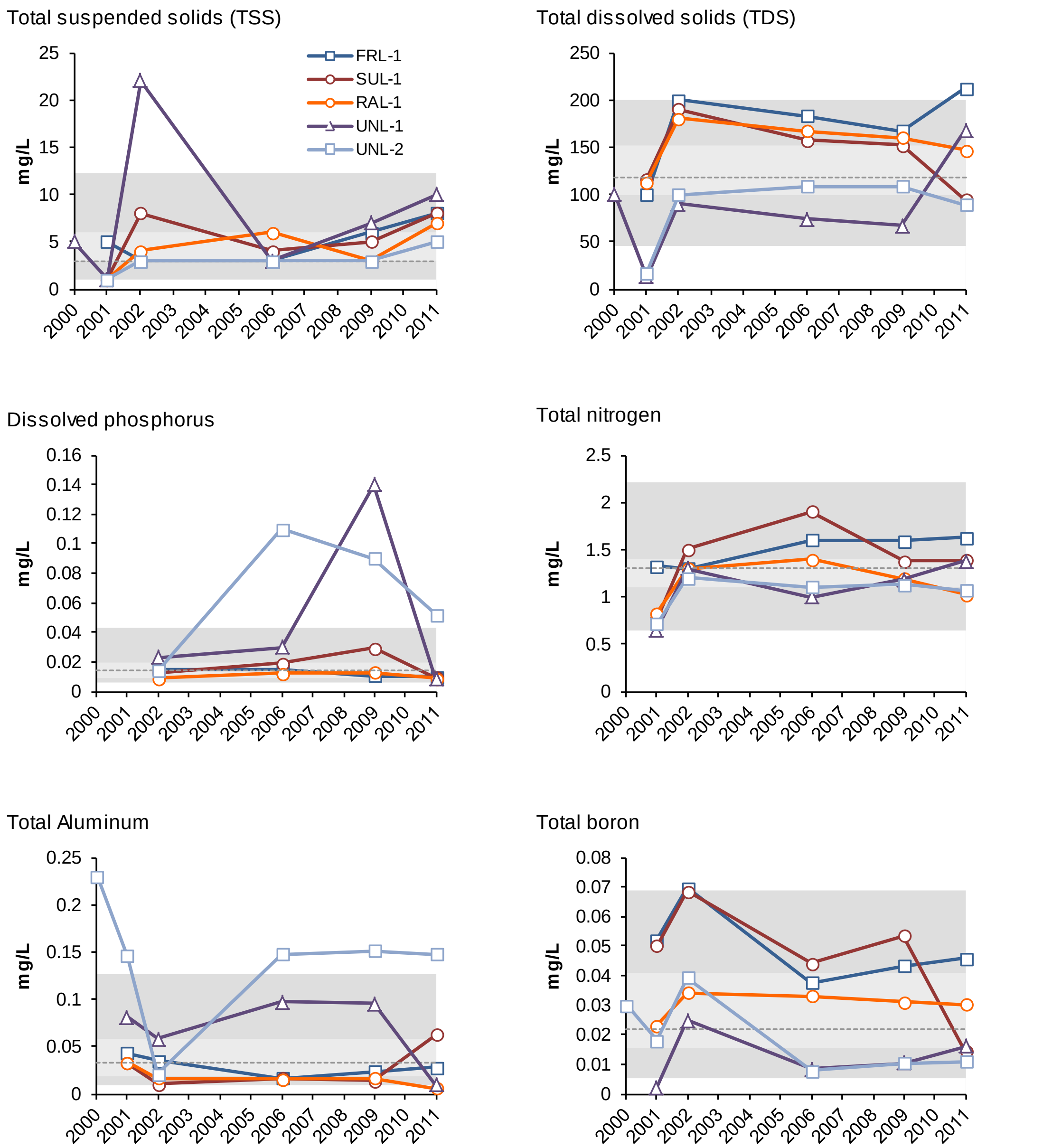
Table 6.4-10 Concentrations of water quality measurement endpoints, Unnamed Lake Two (UNL-2), fall 2011.

Analyte	Units	Guideline[a]	September 2011	September 2009	Fall *Baseline* (2000-2008)			
			Value	Value	n	Min	Median	Max
Physical variables								
pH	pH units	6.5-9.0	6.75	**5.69**	4	**5.6**	**5.9**	**6.22**
Total Suspended Solids	mg/L	-	5	<3	3	<1	<3	<3
Conductivity	µS/cm	-	22	33.7	4	34	35.7	41.5
Nutrients								
Total phosphorus	mg/L	0.05	**0.0624**	**0.102**	3	0.026	**0.112**	**0.14**
Total dissolved phosphorus	mg/L	0.05	**0.0519**	**0.09**	2	0.014	**0.062**	**0.11**
Total nitrogen*	mg/L	1.0	**1.141**	**1.131**	3	0.716	**1.1**	**1.2**
Nitrate+Nitrite	mg/L	-	<0.071	<0.071	4	<0.006	<0.1	0.1
Dissolved organic carbon	mg/L	-	35.4	36.6	4	25	30	39
Ions								
Sodium	mg/L	-	<1.0	<1.0	4	1	2	8.5
Calcium	mg/L	-	4.84	4.87	4	4.7	5.2	32
Magnesium	mg/L	-	1.39	1.27	4	1.4	1.5	8.1
Chloride	mg/L	230, 860	<0.5	<0.5	4	1	1.8	3
Sulphate	mg/L	50, 100	1.07	<0.5	4	1.2	2.9	6.2
Total Dissolved Solids	mg/L	-	89	109	3	17	100	109
Total Alkalinity	mg/L	-	7.4	<5.0	4	7	10	11
Organic compounds								
Naphthenic acids	mg/L	-	0.49	0.0477	1	<1.0	<1.0	<1.0
Selected metals								
Total arsenic	mg/L	0.005	0.000402	0.000405	4	0.00039	0.00077	<0.01
Total aluminum	mg/L	0.1	**0.148**	**0.151**	4	0.021	**0.147**	**0.23**
Dissolved aluminum	mg/L	0.1	**0.137**	**0.145**	1	**0.144**	**0.144**	**0.144**
Total boron	mg/L	1.2	0.011	0.0104	4	0.0077	0.024	0.0394
Total molybdenum	mg/L	0.073	0.0000513	0.0000798	4	0.0000333	0.000495	<0.001
Total mercury (ultra-trace)	ng/L	5, 13	**11.9**	1.6	1	<1.2	<1.2	<1.2
Variables that exceeded CCME guidelines in Fall								
Dissolved Iron	mg/L	0.3	**0.329**	**0.567**	2	0.206	345	**0.484**
Total Iron	mg/L	0.3	**0.364**	**0.599**	3	0.142	**0.516**	**0.85**
Total Phenols	mg/L	0.004	**0.0116**	**0.0089**	3	<0.001	0.002	**0.01**
Sulphide	mg/L	0.002	**0.0118**	**0.0067**	3	**0.005**	**0.006**	**0.009**
Total Cadmium	mg/L	-	0.000006	**0.0000094**	4	0.0000099	<0.0004	**0.00033**

[a] Sources for all guidelines are outlined in Table 3.2-5.

Values in **bold** are above the guideline; underlined values are outside of *baseline* range.

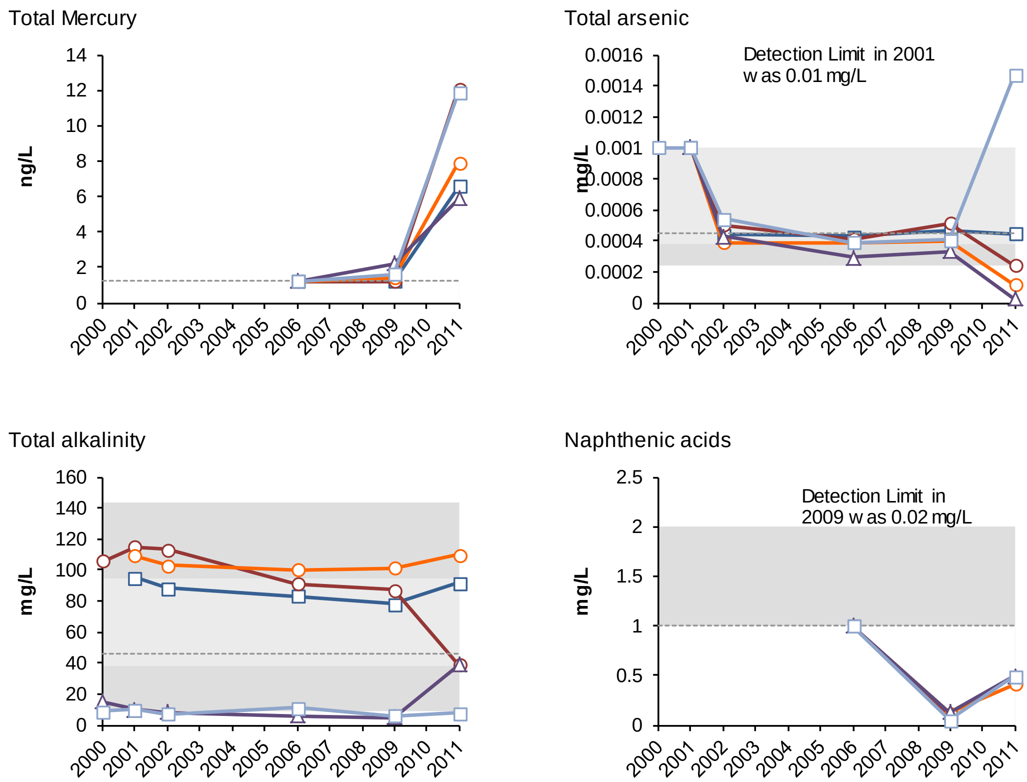
Figure 6.4-2 Selected water quality measurement endpoints in CANL-1,CARL-1, FRL-1, and RAL-1 lakes (fall data) relative to historical concentrations and regional fall *baseline* concentrations.



Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all stations from years when the stations were designated as *baseline* (2000 to 2006).

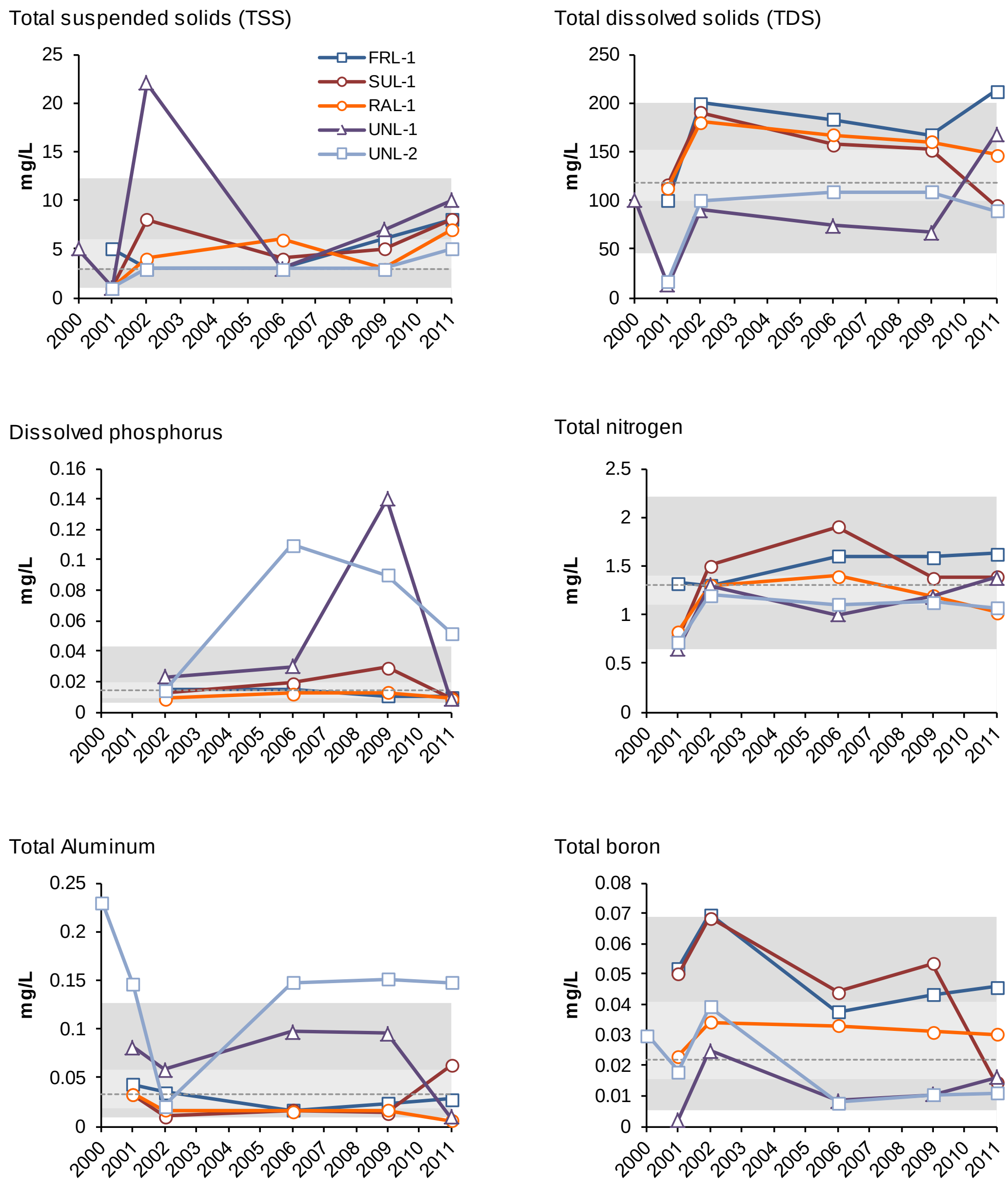
Figure 6.4-2 (Cont'd.)



Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all stations from years when the stations were designated as *baseline* (2000 to 2006).

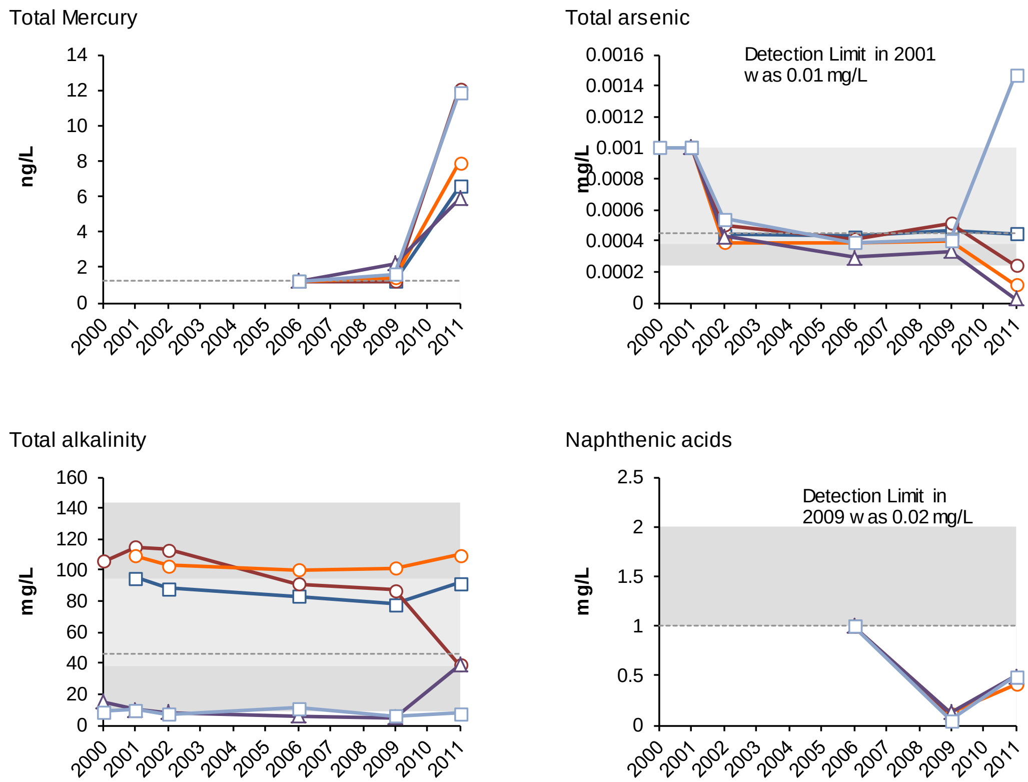
Figure 6.4-3 Selected water quality measurement endpoints in GRL-1, KIL-1, SUL-1, UNL-1 and UNL-2 lakes (fall data) relative to historical concentrations and regional fall *baseline* concentrations.



Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all stations from years when the stations were designated as *baseline* (2000 to 2006).

Figure 6.4-3 (Cont'd.)



Non-detectable values are shown at the detection limit.

[1] Regional *baseline* values reflect pooled results for all stations from years when the stations were designated as *baseline* (2000 to 2006).

Table 6.4-11 Water quality guideline exceedances in the Nexen lakes, 2011.

Variable	Units	Guideline[a]	CANL-1	CARL-1	FRL-1	GRL-1	KIL-1	RAL-1	SUL-1	UNL-1	UNL-2
Spring											
pH	pH units	6.5-9.0	-	-	-	-	-	-	-	5.78	-
Total phosphorus	mg/L	0.05	0.0599	-	-	-	-	-	-	0.204	0.0662
Total dissolved phosphorus	mg/L	0.05	-	-	-	-	-	-	-	0.19	0.0566
Total nitrogen	mg/L	1	1.321	-	1.231	-	-	1.411	1.071	1.141	1.001
Total aluminum	mg/L	0.1	-	-	-	-	-	-	-	-	0.161
Dissolved aluminum	mg/L	0.11	-	-	-	-	-	-	-	-	0.132
Total cadmium[b]	µg/L	0.007212	-	-	-	-	0.0000368	-	-	0.0000238	0.0000311
Total Iron	mg/L	0.3	-	-	-	-	-	-	0.418	0.341	0.386
Dissolved Iron	mg/L	0.3	-	-	-	-	-	-	-	-	0.337
Total Phenols	mg/L	0.004	0.0074	0.0053	0.0132	0.0086	0.0079	0.008	-	0.0118	0.0089
Sulphide	mg/L	0.0023	-	-	0.0062	-	-	0.0047	0.0044	0.0065	0.0062
Fall											
Total phosphorus	mg/L	0.05	-	-	0.0546	-	-	-	-	-	0.0624
Total dissolved phosphorus	mg/L	0.05	-	-	-	-	-	-	-	-	0.0519
Total nitrogen	mg/L	1	1.201	1.001	1.701	-	-	1.091	1.461	1.451	1.141
Total aluminum	mg/L	0.1	-	-	-	-	-	-	-	-	0.148
Dissolved aluminum	mg/L	0.11	-	-	-	-	-	-	-	-	0.137
Total Iron	mg/L	0.3	-	-	-	0.336	-	-	0.372	0.309	0.364
Dissolved Iron	mg/L	0.3	-	-	-	-	-	-	-	0.302	0.329
Total Phenols	mg/L	0.004	0.0073	0.007	0.0087	0.0101	0.0082	0.009	0.011	0.0111	0.0116
Sulphide	mg/L	0.0023	-	0.0048	0.0077	-	0.0086	0.0039	-	0.0029	0.0118
Total mercury	ng/L	5,13	10.9*	9.3*	6.6*	7.6*	11.5*	7.9*	12.1*	5.9*	11.9*

[a] Sources for all guidelines are outlined in Table 3.2-5.

[b] Guideline is hardness-dependent.

* Total mercury concentrations are likely elevated as a result of contamination.

Figure 6.4-4 Piper diagram of fall ion concentrations at stations CANL-1, CARL-1, GRL-1, and KIL-1.

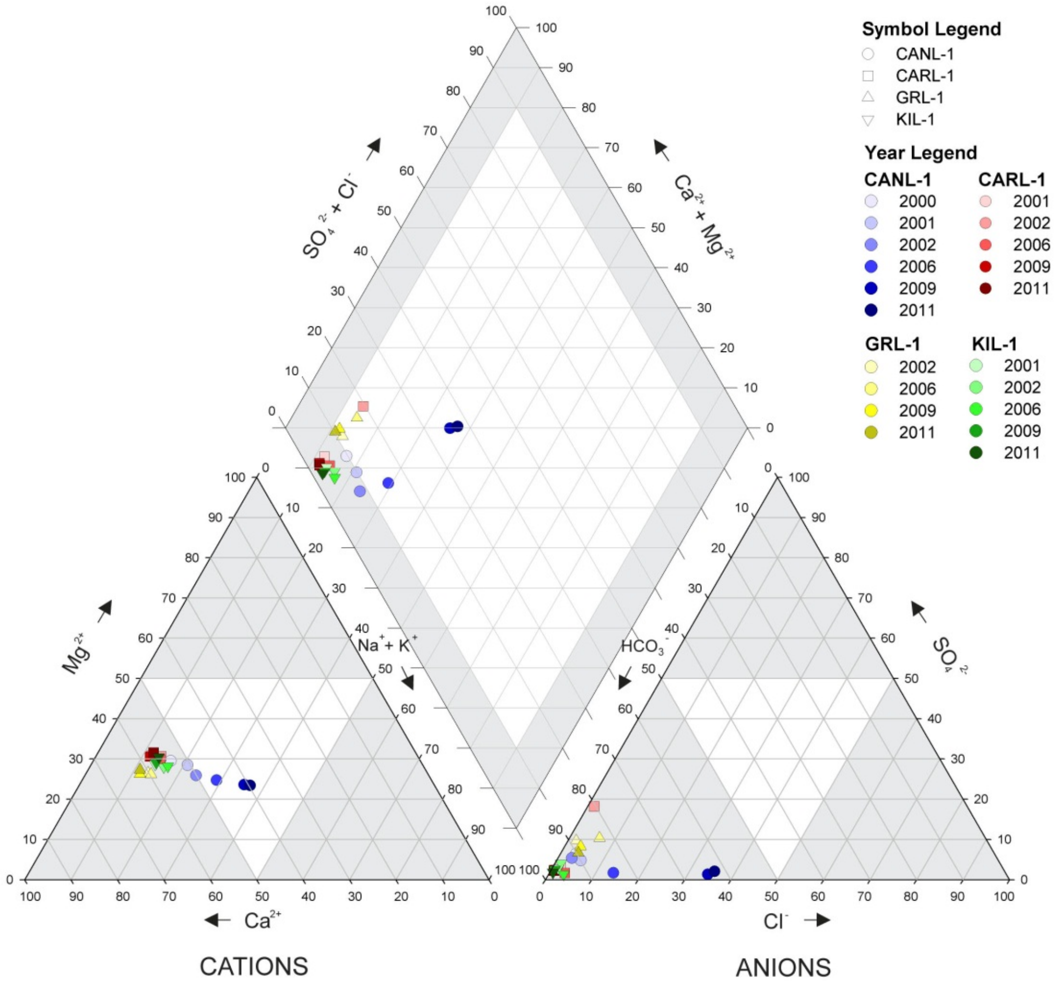
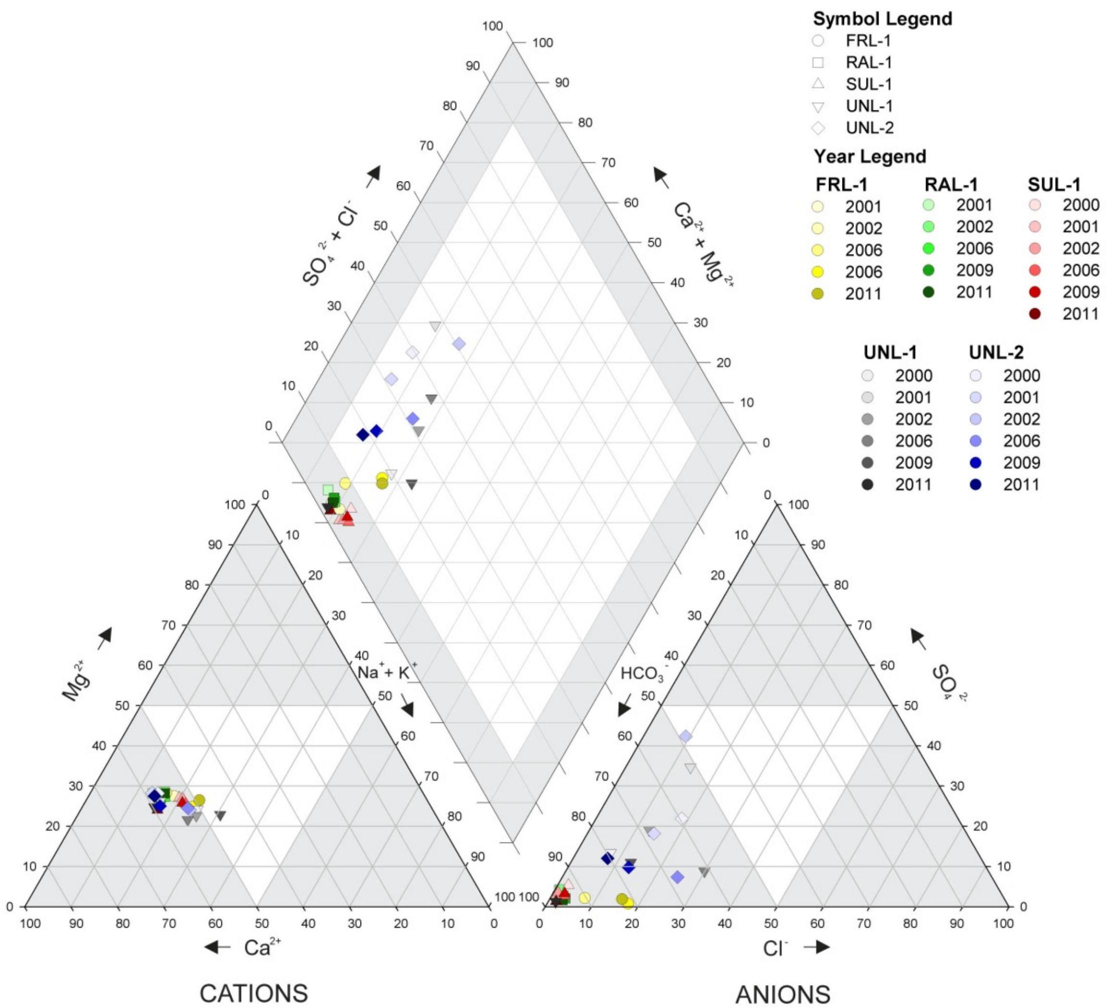


Figure 6.4-5 Piper diagram of fall ion concentrations at stations FRL-1, RAL-1, and SUL-1, UNL-1 and UNL-2.



6.5 CONSIDERATIONS FOR SAMPLING BENTHIC INVERTEBRATE COMMUNITIES IN THE MAINSTEM ATHABASCA RIVER

6.5.1 Introduction

The RAMP Benthic Invertebrate Communities component initiated sampling in the mainstem Athabasca River in 1997. Samples were collected in two general areas, upstream (sample area B near Donald Creek) and downstream (sample area A below Fort Creek) of oil sands development (see Figure 2.3 in Golder 1998). The survey in 1997 documented low to moderate total abundance and low taxonomic richness at all sampling locations. There were significant differences in the abundance between upstream and downstream locations and between sides of the mainstem channel. Differences in benthic invertebrate communities were considered to be a function of habitat differences among locations and were not considered evidence of any influence from oil sands development. The conclusion in 1997 was that high, natural among-location variability would make it difficult to detect changes in the benthic invertebrate community related to oil sands development.

Subsequent considerations of monitoring in the mainstem Athabasca River by RAMP have led to similar conclusions. The benthic invertebrate communities of the mainstem Athabasca River are dominated by chironomids and worms, which are generally tolerant of shifting sand environments (Barton and Smith 1984). The benthic invertebrate communities of the mainstem Athabasca River had between 70% and 85% of the fauna as chironomids and approximately 8% to 9% as worms in both upstream and downstream locations in 1997 (see Table 3.8 in Golder [1998]). Worms and chironomids tend to be among the more tolerant of the benthic fauna (Hynes 1960, Bode *et al.* 1996, Griffiths 1998). In addition, RAMP concluded that any immediate changes due to oil sands development would be first observed in the tributaries to the Athabasca River and would provide earlier evidence of any changes when they occur. The major tributaries to the Athabasca River include the Muskeg, Steepbank and MacKay rivers, which have riffle habitat near their confluences with the Athabasca River and; therefore, consist of more sensitive taxa dominated by Ephemeroptera, Plecoptera and Trichoptera. Taking these considerations into account, RAMP decided in 1998 to focus sampling effort on the tributaries to the Athabasca River rather than the mainstem Athabasca River.

The RAMP Benthic Invertebrate Communities component has undergone a scientific peer review four times since 1998 (Ayles 2004, AEMP 2011, Environment Canada 2011, and AITF 2011) and each review concluded that benthic invertebrate communities of the mainstem Athabasca River should be monitored in order for the sampling design to be considered robust and complete. Subsequent consideration by members of RAMP led to the conclusion that the mainstem Athabasca River should be included in the sampling design.

The objective of this study is to examine historical sampling that has been conducted on the mainstem Athabasca River near Fort McMurray, in part to determine which sampling gear will collect the most representative samples and to use the existing data as "pilot data" to assist in the development of a sampling program. This study includes:

- a review of the historical sampling programs;
- options for collecting benthic invertebrate community samples from the Athabasca River; and
- an analysis of variability of measurement endpoints for benthic invertebrate communities based on sampling natural substrates of the Athabasca River.

The assessment of variability of measurement endpoints can then be used to recommend adequate sample sizes and assist in developing an approach and design for future sampling.

6.5.2 Historical Data

Golder (2003) conducted a review of benthic invertebrate community surveys in the Athabasca River and tributaries in the vicinity of Fort McMurray. Golder (2003) identified a total of 78 locations in the mainstem Athabasca River, between Fort McMurray and Fort Creek (approximately, see Figures 1, 2 and 3 in Golder [2003]) that have been sampled using one or more different sampling techniques.

Depositional samples were collected using a 15 cm x 15 cm Ekman grab. Erosional samples were collected using Neill-Hess cylinders or Surber samplers. Depositional habitats (n=45) were sampled more frequently than erosional habitats (n=20). Golder (2003) identified that the limited working depth of the erosional sampling devices (≤ 0.6 m) resulted in erosional samples being collected from a narrow band of shallow water within a few meters of the shoreline. Golder (2003) further noted that depositional samples were usually collected further from shore in 1 to 3 m of water. Several locations (n=41) have been sampled using artificial substrates (rock-filled baskets) and one survey used an “airlift” device to sample benthos from the bottom of the river (Barton and Wallace 1980).

Golder (2003) identified and included data from the first year (1997) that RAMP conducted benthic sampling in the vicinity of Suncor’s Tar Island Dyke (as reported in Golder [1998]). That study involved the collection of six replicate Ekman samples from each of 12 sampling locations (three *baseline* and nine *test* locations adjacent to or downstream of the dyke). Samples were collected near shore and were accompanied by sediment samples for chemistry analysis and toxicity testing. The study was repeated in 2001 by Jacques Whitford (2002) and in 2004 and 2008 by Hatfield Consultants (Hatfield 2005, 2009b).

6.5.3 Options for Collecting Benthic Invertebrate Community Samples

Benthic invertebrate communities can be sampled using either artificial substrates (various designs) or from natural substrates. As outlined above, the benthic invertebrate community of the Athabasca River has been studied using both methods (Golder 2003). The Technical Guidance Document for the Environmental Effects Monitoring program for the metal mining sector was updated in 2011 with the recommendation that benthic invertebrate community samples in freshwater be collected from natural substrates so that densities of organisms can be estimated (Environment Canada 2011).

Environment Canada (2011) recognizes artificial substrates (various designs) as a valid alternative sampling approach for cases when natural substrates cannot be sampled or if there is a need to separate the effects of waterborne and sediment-associated contaminants. Artificial substrates can then be used in an “Investigation of Cause” phase of an EEM program (Hewitt *et al.* 2005).

Canada’s federal CABIN protocol (Reynoldson *et al.* 2004) involves the collection of benthos from shallower (nearshore) habitats using a D-framed kick net. The timed kick-net samples can be rapidly collected from either depositional or erosional habitat or some combination, which provides more flexibility. The use of the kick-net sampler has also been recognized in the United States (Flotermersch *et al.* 2006). Water levels in the

Athabasca River; however, can vary significantly from year to year and kick net samples collected from wadeable habitats may result in the periodic collection of samples from substrate that have only been wetted for a brief period, and may not produce a benthic sample that is representative of the river.

Neill-Hess cylinders are typically used to collect benthic organisms from shallow riffles. These devices have been used somewhat extensively in the mainstem Athabasca River, as per Golder (2003). Neill-Hess cylinder samples, like those collected with kick nets, may produce benthos that are not representative, for example, during periods of high flow, samples may be collected in shoreline habitat that is normally dry. Samples collected using Neil-Hess cylinders at erosional (riffle-like) habitats would be more likely to collect benthos that are considered sensitive to disturbance, such as Ephemeroptera, Plecoptera and Trichoptera, than other devices that collect benthos from depositional habitats (i.e., Ekman or Ponar grab).

Ekman and Ponar grabs are the conventional devices for sampling deeper depositional habitats, which is dominant in the Athabasca River. Ponar grabs are heavier and have not been used historically in the Athabasca River. Ekman grabs; however, have been used extensively (Golder 2003), although Ekman grabs are generally lighter and its effectiveness can be impacted by flows. To control for effects from flows, Ekman grabs have been typically used from pole mounts in the Athabasca River (Golder 2003). Ekman and Ponar grabs that collect benthos from depositional habitats are more likely to collect communities dominated by chironomids and oligochaete worms, groups that are not considered very sensitive to disturbance (Hynes 1960, Bode *et al.* 1996, Griffiths 1998).

6.5.4 Data Analysis

Data collected from sampling natural substrates of the mainstem Athabasca River from 1978 to 2005 were used in the analysis to determine appropriate sample size requirements; data from 1978 to 1999 were compiled by Golder (2003) on behalf of RAMP; and data from 1999 to 2005 were compiled from various sources, which include data as part of Suncor's assessment of the Athabasca River near the Tar Island Dyke and data collected from the Athabasca River Delta by RAMP. The data were used to explore the magnitude of variation in measurement endpoints of benthic invertebrate communities, among replicate locations within a reach (i.e., a discrete sampling area or an area normally ~10 m x 10 m, as per Environment Canada [2011]). Elliott (1977) suggested that the design of sampling programs can partly be determined by sample variability and sample sizes required to provide for a specified measure of precision in estimates of measurement endpoints. Elliott (1977), and then subsequently Environment Canada (2002, 2005, 2011), have recommended that environmental effects monitoring programs should collect enough samples so that measurement endpoints are estimated to within ~ ±20% of the true (but unknown) mean value within reaches. This analysis will determine the sample size required to estimate measurement endpoints as per Elliott (1977) to within 20% of the true mean values for samples collected using Neil-Hess cylinder and Ekman grab, for which there are adequate historical data available.

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

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

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

  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).

Precision

The number of samples required to obtain estimates of measurement endpoints that are within ± 20% of the true mean value within a reach was calculated from the following equation (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 (20% or D=0.2).

Sample sizes required to obtain within-reach estimates of measurement endpoints to within ±20% of their true mean values were calculate for each reach where replicate data were available. Visual assessment of relationships between required sample size and mean values of measurement endpoints were used to determine general sample sizes that would be relevant for sampling within reaches in the Athabasca River.

6.5.5 Results

Sample sizes required to achieve a precision of ±20% of the true mean value tended to decrease with an increase in the value of the measurement endpoint based on historical data (Figure 6.5-1, Figure 6.5-2). The required sample size depends on the abundance, richness, diversity and percent EPT that are expected. The studies carried out by Suncor normally involved the collection of six replicate samples within each of 12 reaches. Mean abundance of benthic organisms was approximately 100,000 per m^2 or greater when there were ~20 or more taxa per sample, diversity was >0.6 and EPT taxa consisted of approximately 60% or more of the fauna. Samples collected in the ARD were almost as variable as samples collected in the mainstem Athabasca River, with similar sample size requirements.

These data also suggested that six Neill-Hess cylinders would be adequately precise under the same circumstances as the Ekman grabs (i.e., when the mean abundance of benthic organisms is approximately 100,000 per m^2 or greater, richness is approximately 20 or more taxa per sample, diversity is 0.6 or greater, and percent EPT is greater than 60% [Figure 6.5-2]). A single sample using a Neill-Hess cylinder would be adequate when there are more than 25 taxa per sample and diversity is greater than 0.9, but would not be adequate for total abundance or percent EPT.

6.5.6 Discussion

The tendency for required sample sizes to decrease with increasing values of measurement endpoints is typical in freshwater environments (Downing 1979). Downing (1979) also demonstrated that smaller samplers are more efficient at estimating measurement endpoints. This analysis demonstrated that both Ekman grabs and Neill-Hess cylinders required almost the same number of samples in order to estimate each of the measurement endpoints with equal precision. The Ekman grab samples are five times smaller than the Neill-Hess cylinder samples and generally collect fewer organisms. The sand collected by the grab can also be relatively quick to wash and sort organisms. The collection and processing of six Ekman samples, then, would be less time consuming (and less expensive) than six Neill-Hess cylinder samples.

Other various considerations for selecting a sampling device are summarized in Table 6.5-1. The statistical efficiency of artificial substrates and kick-net samples has not been well studied (Downing 1979). Of the available samplers, the Ekman grab collects a sample of benthos that is less sensitive than the other samplers. Hatfield (2005, 2009b) identified the tolerant nature of the benthic invertebrate communities as one possible reason that changes have not been observed along the Tar Island Dyke. Artificial substrates can be built with any size and configuration to attract either depositional or erosional-type (i.e., sensitive) fauna; however, artificial substrates compared to more conventional methods, require at least two reach visits: one to install the apparatus and a second to collect it. Finally, the Ekman grab and Neill-Hess samples are quantitative, and are; therefore, more directly related to fish habitat (Environment Canada 2011). Kick-net samples are not quantitative in the “per-unit-area” sense; however, Environment Canada (2011) does consider a timed kick-net sample (i.e., numbers of organisms collected per unit time) to provide a measure of relative abundance, although there has been no calibration study to formally demonstrate the relationship.

Statistical rigour is necessary if the sampling program is driven by a requirement to detect changes of a specified magnitude. Environment Canada (2011) recommends that studies be designed to detect effects equal to ±2SD from the mean *baseline* condition. Sampling programs that involve less precise estimates of measurement endpoints will cause an underlying inflation of the effect size, where what appears to be an effect equal to 2SD, may in fact be as large as 3SD, with the increase masked by within-reach variability (Kilgour and Rosaasen 2008). It is; therefore, important to select a method and sample size that ensures precise within-reach estimates of mean measurement endpoint values.

Statistical considerations should not necessarily be the determining factor for gear selection. For instance, it would make sense to collect benthic samples from sensitive riffle habitats if there was assurance that they can be sampled on a routine basis. Riffle habitats will contain a broader selection of sensitive fauna that if affected by oil sands development will provide earlier warning than samples collected from sandy sediment regardless of the statistical inefficiencies. This analysis provides a general indication of the level of effort that might be considered if erosional riffle habitats are sampled within the mainstem Athabasca River. Despite the depositional nature of the lower Athabasca River, Golder (2003) demonstrated that various studies have collected erosional riffle samples throughout the mainstem Athabasca River between the town of Fort McMurray and Fort Creek and; therefore, it is recommended that RAMP consider the future collection of samples from riffle habitats using Neill-Hess cylinders or another similar apparatus. However, from a practical perspective, run/pool habitats are more common than riffles in the lower Athabasca River, which would require the use of an Ekman grab or similar sampler, recognizing that benthic communities would be dominated by more tolerant taxa.

The sampling design should be based on demonstrating that a valid EEM approach to sampling can be carried out. That is, the design should nest 5 to 6 reaches within an area and some number of stations within a reach (perhaps up to six samples, as per this analysis). Stations, as per Environment Canada (2011) need to be on the order of 10 m x 10 m long and separated spatially by a distance at least as great. Sample reaches within which stations are situated, should be relatively long to be consistent with the design of the sampling programs in tributary reaches (i.e., 2 to 3 km long). The USEPA (2006) uses a sampling reach that is approximately 500 m long for large rivers. Sampling reaches can be situated along the length of the Athabasca River to isolate and assess various point and non-point sources, as applicable.

Figure 6.5-1 Relationship between required sample size and mean of total abundance, richness, diversity and percent EPT for Ekman grab samples.

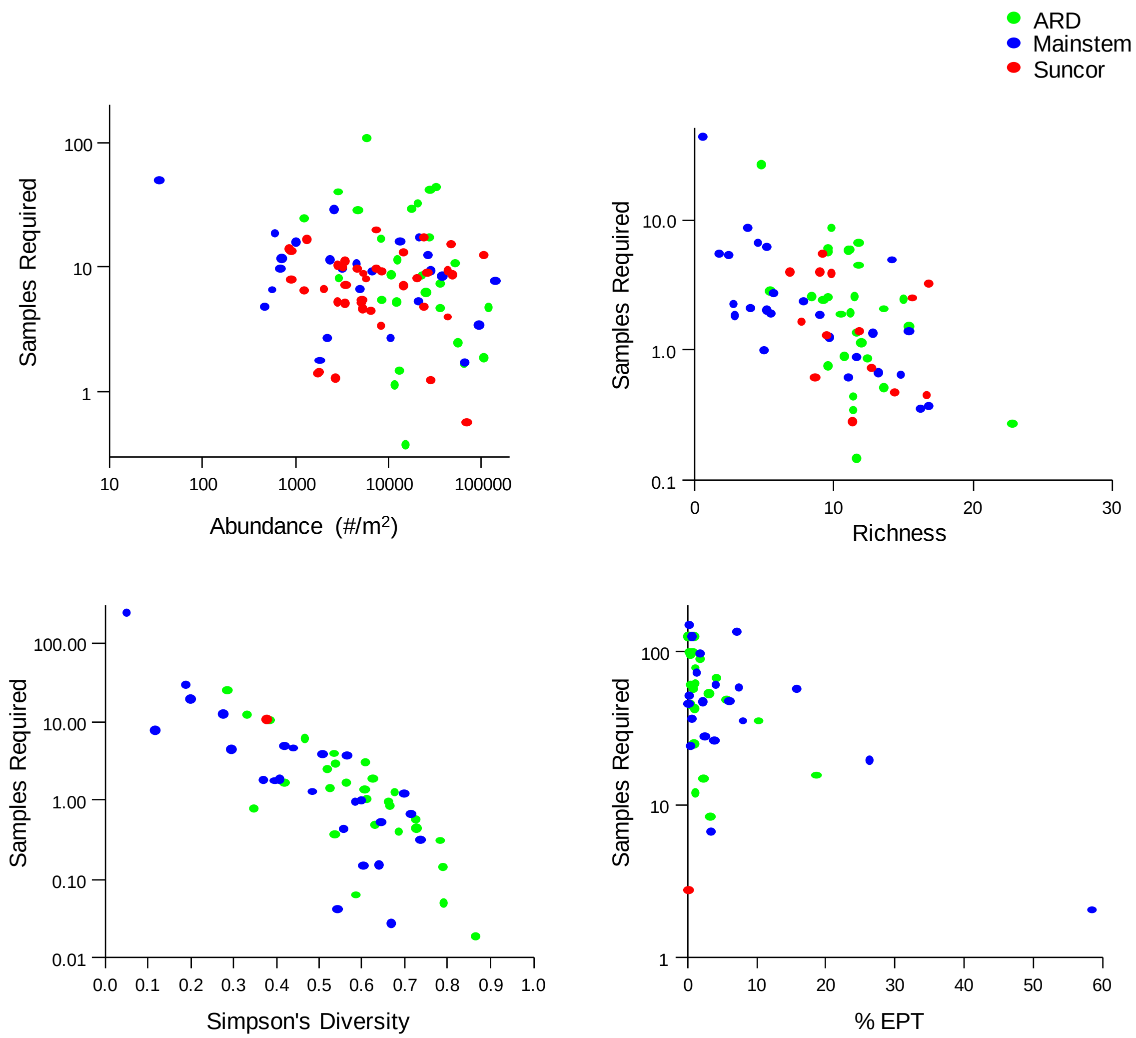


Figure 6.5-2 Relationship between required sample size and mean of total abundance, richness, diversity and percent EPT for Neill-Hess cylinder samples.

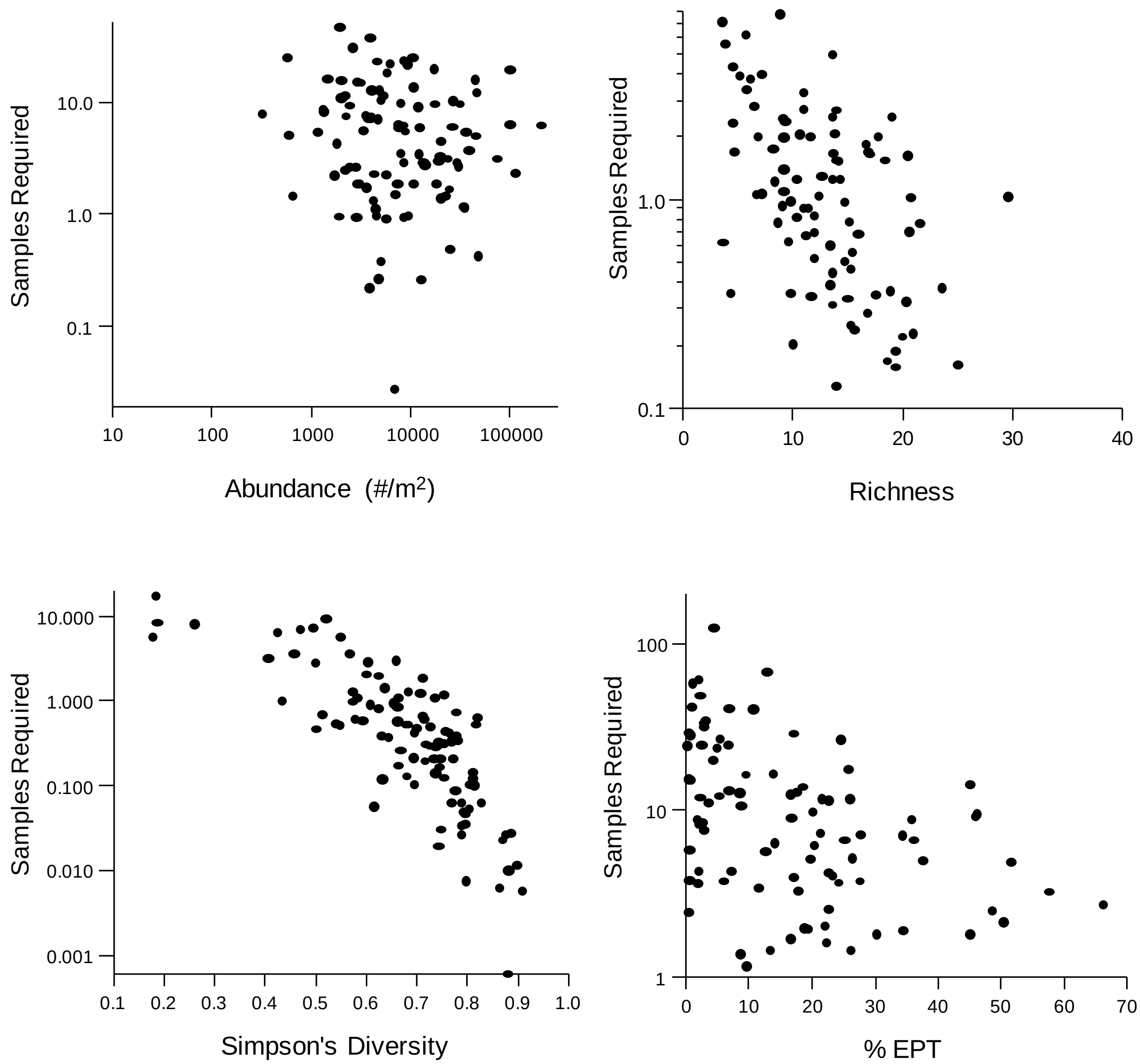


Table 6.5-1 Considerations for selecting a benthic sampling device for the mainstem Athabasca River.

Consideration	Sampler			
	Ekman	Neill-Hess	Artificial	Kick-Net
Statistical efficiency	Y	N	?	?
Samples sensitive habitat	N	Y	Y	Y
Samples a representative dominant habitat	Y	N	N	N
Samples same habitat from time to time	Y	N	Y	N
Single visit required	Y	Y	N	Y
Collects a quantitative sample	Y	Y	N	N

Note: “?” = not certain

6.6 VARIABILITY IN SEDIMENT QUALITY AND BENTHIC INVERTEBRATE COMMUNITIES IN FLETCHER CHANNEL

6.6.1 Introduction

The RAMP design for sampling benthic invertebrate communities in rivers involves the collection of a single sample at typically ten stations within a reach, with a given reach approximately two to four kilometers long (RAMP 2009b). Variations among stations in measurement endpoints of benthic invertebrate communities are then used to judge the significance of changes over time, or between *baseline* and *test* reaches, associated with oil sands development. Samples from the four channels of the Athabasca River Delta (ARD) (i.e., Fletcher, Big Point, Goose Island, and Embarras) have been sampled under a different design since sampling was initiated in 2002. Five replicate samples (Ekman grabs) are collected within a single reach within each ARD channel. A reach in the ARD has typically been 50 to 100 m in length, with individual samples separated by a distance of 10 to 20 m as the boat drifts with the current or is simply moved to make sure samples do not come from the exact same location. Variation among samples, within the ARD, is then used to test the significance of variations over time, potentially related to oil sands development. Based on historical decisions by RAMP, the sampling design is different between sampling on the tributaries to the Athabasca River and sampling in the ARD (i.e., difference in number of samples collected and the length of the reach), which has led to some concern that the small sample area may be leading to high variability in measurement endpoint values across years.

Abundance of benthic invertebrates in the channels of the ARD has typically varied from about 2,000 to 40,000 organisms per m^2 (see Section 5.1). Samples collected from two of the channels (Fletcher and Big Point) have historically produced estimates of total abundance that have been much higher (i.e., 60,000 to 100,000 organisms per m^2). Streams and rivers that are nutrient enriched can often produce numbers of organisms in excess of 100,000 per m^2. Samples collected in Fletcher Channel in fall 2010 averaged over 120,000 organisms per m^2, an observation that was atypical and requiring further investigation.

The objective of this pilot study was to explore the influence of sample area size on estimates of measurement endpoints for benthic invertebrate communities. During the sampling program in fall 2011, benthic samples were collected from Fletcher’s Channel at two spatial scales: (i) five samples were collected at the conventional spatial scale of a reach (reach FLC-1); and (ii) four new samples collected at four new stations, separated by a distance of 200 to 300 m (reach FLC-1A), which is more consistent with a reach length in tributaries. Sediment samples were collected concurrently for total metals. The results from this pilot study can be used to support the existing sampling design or to provide recommendations for modifications to the existing sampling design in the ARD.

6.6.2 Methods

6.6.2.1 Field

Sediment sample collection occurred on September 3, 2011 using an Ekman grab at each replicate location in Fletcher Channel (Figure 6.6-1). Single grabs for benthic invertebrate community analysis were washed through a box sieve with 220 µm mesh, preserved with 5 to 10% buffered formalin and stored separately in a white plastic polyethylene bottle. Samples collected for chemistry analysis were collected using a washed (metals free soap, hexane, acetone) Ekman grab.

6.6.2.2 Laboratory

Benthic samples were processed by Dr. Jack Zloty in a manner similar to that described in Section 3.1.3.2. Organisms were identified to lowest practical taxonomic level.

Sediment samples were analyzed by ALS Laboratories (Edmonton, Alberta) for particle size distribution (Wentworth scale), total organic carbon, and total metals.

6.6.2.3 Statistical Analyses

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

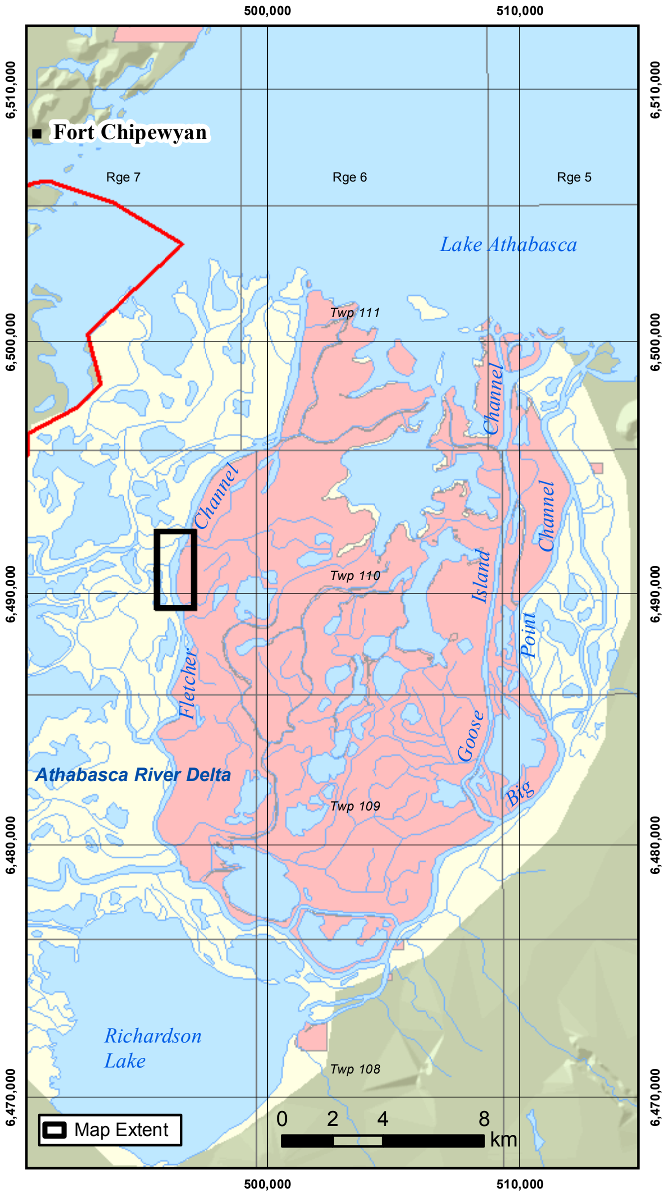
  $$\text{Evenness} = \frac{D}{D_{max}}$$

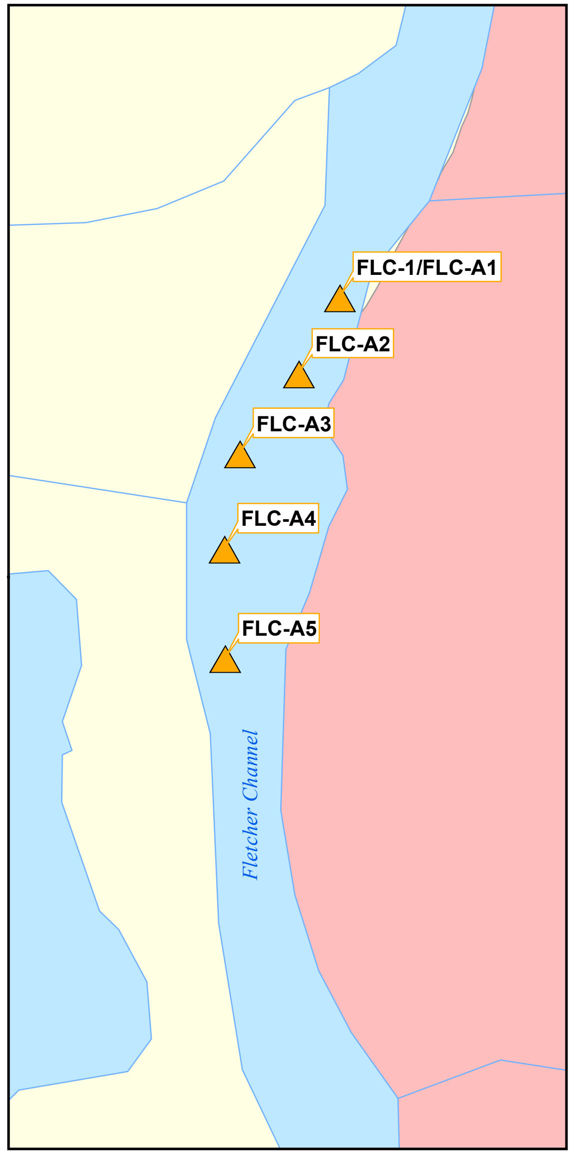
  $$D_{max} = 1 - \left(\frac{1}{S}\right)$$

  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).

Figure 6.6-1 Locations of benthic invertebrate community and sediment quality replicate samples collected from Fletcher Channel, Athabasca River Delta, September 2011.





Regional Aquatics Monitoring Program

LEGEND

- Lake/Pond
- River/Stream
- RAMP Regional Study Area Boundary
- First Nations Reserve
- RAMP Focus Study Area
- Replicate Benthic Invertebrate and 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.

Township and Range designations are relative to W4M.

0 0.25 0.5 1 km

Scale 1:20,000

Projection: UTM Zone 12 NAD83

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For sediments, total metals was calculated as the sum of all metals continuously measured by RAMP since 1997, including As, Ba, Be, Cd, Co, Cu, Pb, Hg, Mo, Ni, Se, Sr, Th, Ti, Sn, Ag, U, V and Zn.

Variance Analysis

Variance (S^2) was calculated for each measurement endpoint both among replicate stations at *test* reach FLC-1 (i.e., S_w^2), and among replicate stations at *test* reach FLC-1A (i.e., S_a^2). Differences in variances were tested using a simple variance-ratio *F*-test as per Zar (1984, p 123), with the following form:

$$F = \frac{S_a^{\ 2}}{S_w^{\ 2}}$$

The typical variance-ratio *F*-test has the larger of the two variances as the numerator. The among-station variance term was placed as the numerator to test whether there was a significant increase in variance caused by sampling at a larger spatial scale.

6.6.3 Results

Benthic invertebrate communities collected from *test* reaches FLC-1 and FLC-1A generally had low abundance, low diversity and was variable in composition among sampling locations. Tubificidae worms were present in all samples from *test* reach FLC-1, but were found in only one of four samples collected at *test* reach FLC-1A (Table 6.6-1). Bivalves (fingernail clams), Ceratopogonidae (sand fly larvae), Plecoptera (stoneflies), and Trichoptera (caddisflies) were found in only one sample from *test* reach FLC-1, and were not found in samples from *test* reach FLC-1A.

Differences in measurement endpoints of benthic invertebrate communities were not significantly greater in FLC-1A than FLC-1 (Table 6.6-2). F-ratios for abundance and richness were <1, indicating a greater degree of variation within *test* reach FLC-1 than among stations within *test* reach FLC-1A (Table 6.6-2). Higher variance in FLC-1 was driven by sample 3 (Table 6.6-1), which had high abundance (> 27,000 individuals per m^2), and a high number of taxa (13) compared to other samples in FLC-1 and FLC-1A. Simpson's Diversity, evenness and percent EPT each produced an F-ratio that was slightly greater than 1, indicating a potentially higher degree of variability in those measures when sampling at the reach scale. The F-ratios were; however, small enough that they were not significantly different, so no conclusion could be drawn regarding the influence of spatial scale on the variance of benthic invertebrate communities.

Sediment quality measured at each replicate (i.e., particle size and TOC) also was consistent between reaches (Table 6.6-3, Figure 6.6-2). Total metals, measured at five replicates along Fletcher Channel (i.e., along *test* reach FLC-1A), was similar among stations, and showed a clear correlation with particle size distribution, with total metals being highest at replicate FLC-1-1, which exhibited lowest percent sand (Figure 6.6-3). All component metals included in the total metals summary variable showed very strong correlation (i.e., $R^2 \geq 0.80$) with this summary variable except molybdenum ($R^2=0.71$), titanium ($R^2=0.58$), and metals with 40% or more non-detectable values (i.e., mercury, beryllium, cadmium, selenium, silver, thallium, tin).

Table 6.6-1 Summary of major taxon abundances and benthic invertebrate community measurement endpoints in replicate samples in *test* reaches FLC-1 and FLC-1A, September 2011.

Taxon	Percent Major Taxa Enumerated in Each Year								
	Reach FLC-1					Reach FLC-1A			
	1	2	3	4	5	2	3	4	5
Nematoda						25			
Tubificidae	82	100	48	72	100		100		
Bivalvia			2						
Ceratopogonidae			3						
Chironomidae	6		47	11		50			100
Ephemeroptera				11		25			
Plecoptera				6					
Trichoptera	12								
Benthic Invertebrate Community Measurement Endpoints									
Total Abundance (No./m^2)	738	43	27,676	781	130	174	43	0	87
Log Abundance	2.87	1.65	4.42	2.89	2.12	2.24	1.65	0	1.94
Richness	4	1	13	5	1	3	1	0	2
Log Richness	0.70	0.30	1.15	0.79	0.30	0.60	0.30	0	0.48
Simpson's Diversity	0.31	0.00	0.66	0.46	0.00	0.63	0	0	0.50
Evenness	0.42	0.00	0.71	0.57	0.00	0.94	0	0	1.00
% EPT	12	0	0	17	0	25	0	0	0
Log EPT	1.1	0	0	1.3	0.0	1.4	0	0	0

Table 6.6-2 Results of analysis of variance testing for differences in variability within and among test reaches FLC-1 and FLC-1A, September 2011.

Measurement Endpoint	Reach FLC-1		Reach FLC-1A		F-ratio	P-value
	Mean	SD	Mean	SD		
Abundance (#/m^2)	5,874	12,193	75.9	74.1	<0.001	0.995
Log Abundance	2.79	1.06	1.5	1.0	0.891	0.377
No. Taxa	4.80	4.90	1.5	1.3	0.069	0.801
Log No. Taxa	0.65	0.36	0.3	0.3	0.536	0.488
Simpson's Diversity	0.29	0.29	0.3	0.3	1.306	0.291
Evenness	0.34	0.33	0.5	0.6	2.928	0.131
%EPT	5.69	7.98	6.3	12.5	2.456	0.161
Log %EPT	0.47	0.65	0.4	0.7	1.198	0.310

Table 6.6-3 Sediment quality at benthic sampling locations (replicates) in Fletcher Channel, September 2011.

Sediment Variable	Reach FLC-1					Reach FLC-1A			
	1	2	3	4	5	2	3	4	5
Particle size distribution									
% Sand	78.6	91.4	70.6	94.6	97.6	91.0	95.4	99.1	89.3
% Silt	13.9	4.99	20.5	2.72	1.46	4.73	2.31	0.42	6.98
% Clay	7.52	3.63	8.91	2.67	0.97	4.29	2.33	0.49	3.72
Total organic carbon	0.68	0.83	1.26	0.12	<0.1	1.09	0.19	0.1	0.64
Total metals[1]	304	-	-	-	-	230	168	109	183

[1] Measured at one location at reach FLC-1, per standard RAMP protocol, and along the channel at spaced locations at reach FLC-1A.

Figure 6.6-2 Particle size distribution and total organic carbon in reaches FLC-1 and FLC-1A, September 2011.

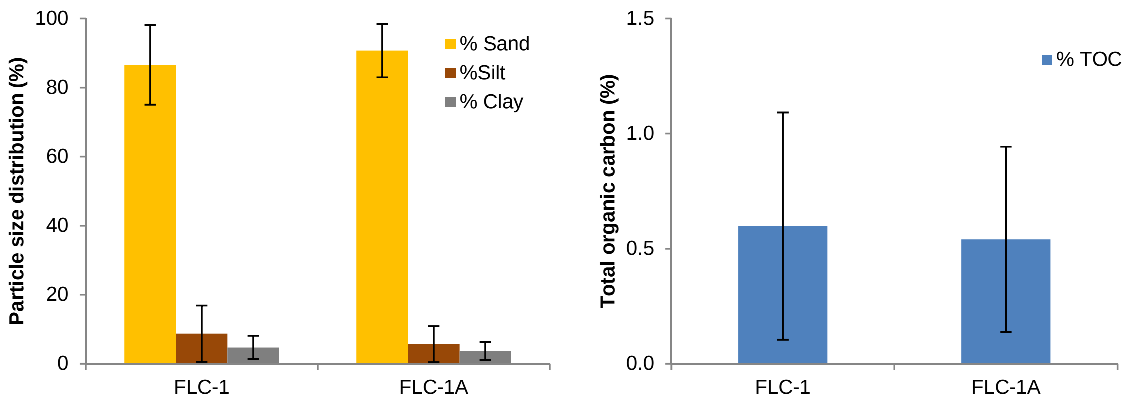
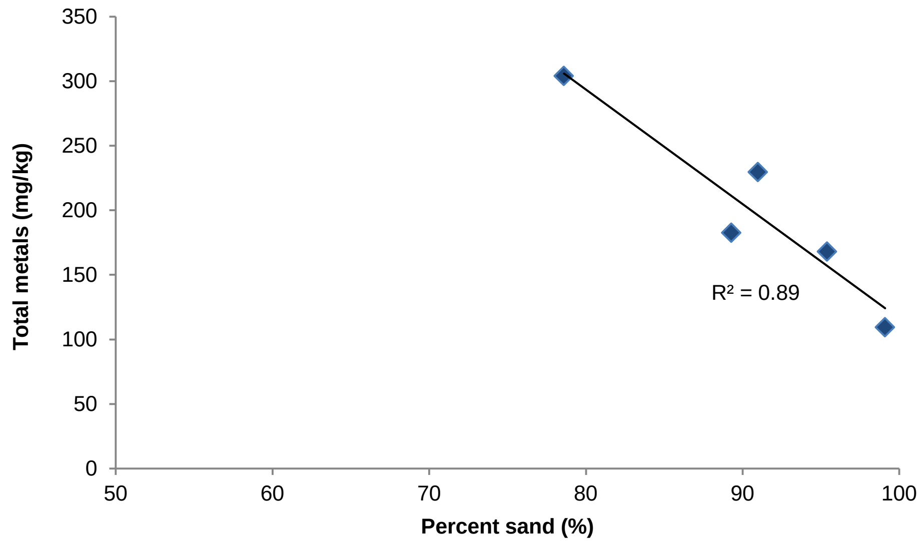


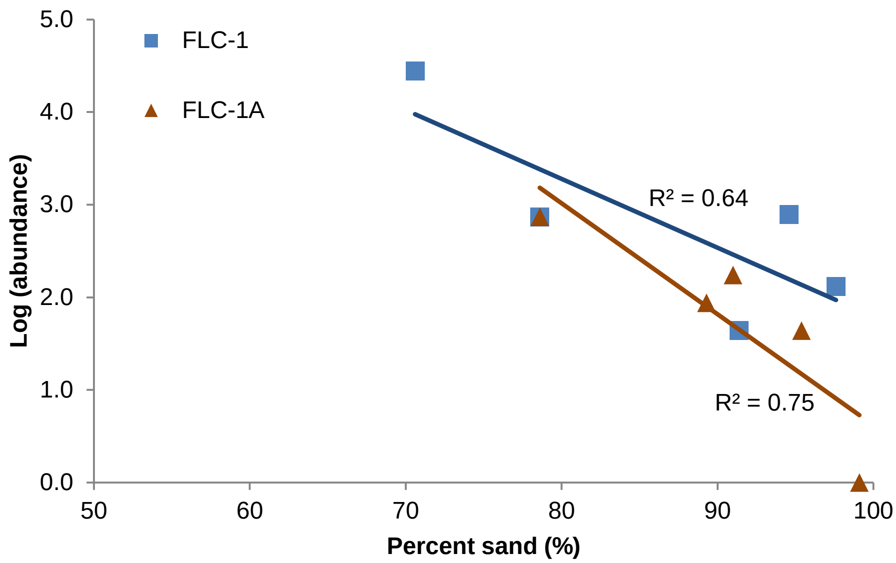
Figure 6.6-3 Relationship between particle size distribution (represented by %sand) and total metals along Fletcher Channel (reach FLC-1A), September 2011.



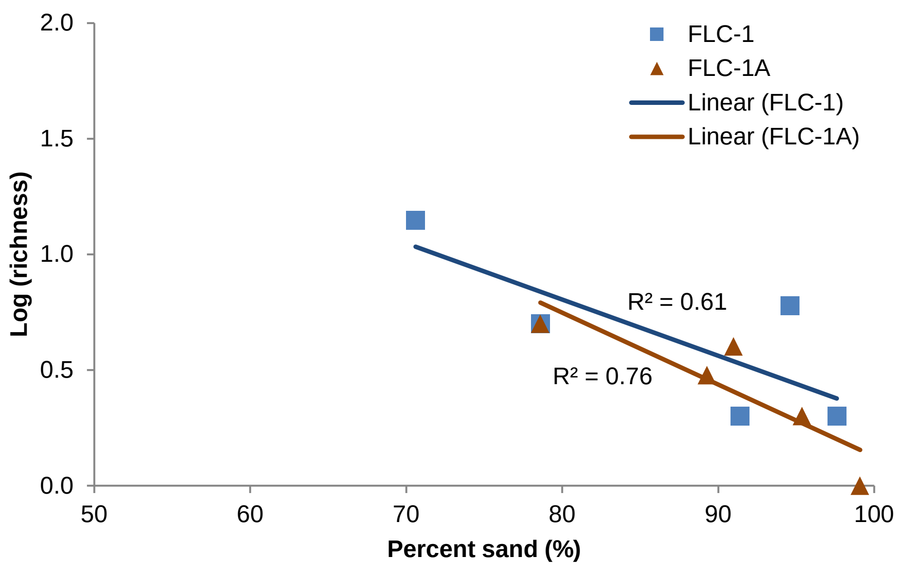
Benthic invertebrate community measurement endpoints also showed a correlation with particle size distribution, with highest abundance and richness found at the replicate station with the lowest %sand, and lowest abundance and richness (i.e., no organisms present) found at the replicate station with the greatest (>99%) proportion of sand (Figure 6.6-4).

Figure 6.6-4 Relationship between particle size distribution (represented by %sand) and benthic invertebrate abundance and richness, Fletcher Channel (reaches FLC-1 and FLC-1A), September 2011.

A. Percent sand vs. log (abundance)



B. Percent sand vs. log (richness)



6.6.4 Discussion and Recommendations

This study did not demonstrate a significant effect of spatial scale (i.e., sampling at the reach vs. station) on variation in estimates of measurement endpoints for benthic invertebrate communities. Although within-reach spatial heterogeneity of substrates, specifically substrate texture, appears to have been a driver of observed variability in benthic invertebrate measurement endpoints among replicates, these within-reach differences were consistent between station-based (FLC-1) and reach-based (FLC-1A) data collected in 2011. Spatial scale should have some influence on variance, with samples that are close together, *de facto*, having a greater likelihood of being similar than samples that are far apart (Borcard *et al.* 1992, Johnson and Goedkoop 2002, Lloyd *et al.* 2006, Grenouillet *et al.* 2008). Within the context of the reach (i.e., a length of watercourse that is between 2 and 4 km long) within the RAMP FSA, distances between samples (i.e., 100 to 200 m) may not be great enough to remove the tendency for samples to have similar fauna. Lloyd *et al.* (2006) concluded that the autocorrelation diminishes when samples are separated by considerably larger distances in large rivers (e.g., upwards of 10 km).

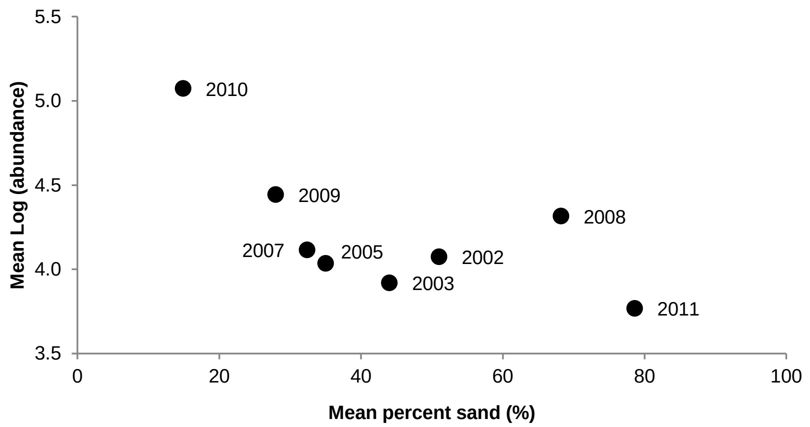
Substrate type (dominant particle size) appears to be a determinant of benthic invertebrate abundance within reaches. The channels of the ARD are generally turbid, with visibility < 1 m, with samples collected in 1 to 3 m of water, which makes it difficult to directly document specific micro-habitat conditions that are being sampled by any one grab. Other potential factors including the presence of large woody debris, and other structures within the channel, could influence local (micro-habitat) conditions that cause organic debris (and benthic invertebrates) to collect, which would then result in high within-station variability in abundance and other measurement endpoints.

Regardless, the results from this study further suggest that the high total benthic invertebrate abundance observed in Fletcher Channel in fall 2010 was not likely a function of samples being collected at the station scale rather than a reach-scale, given total abundance within *test* reach FLC-1 were almost as variable (and maybe more variable) as the abundance in *test* reach FLC-1A in 2011. This demonstrates that the abundance observed in fall 2010 was not a function of the exact location of *test* reach FLC-1, but would have likely been observed in a longer reach as well. Other factors that were not micro-scale-dependent were likely the cause of the observed variations in 2010 (RAMP 2011).

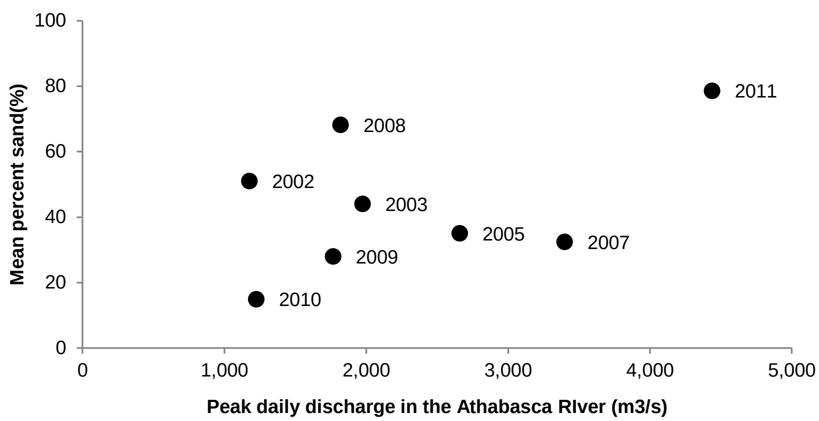
Exploration of historical benthos and sediment data collected by RAMP from Fletcher Channel since 2001 suggests that temporal variability in substrate texture may be an important determinant of benthic invertebrate abundance, as a general relationship is apparent between log-abundance and %sand measured in Fletcher Channel from 2002 to 2011, with the last two years exhibiting the lowest abundance and highest %sand (i.e., 2011) and the highest abundance and lowest %sand (i.e., 2010) (Figure 6.6-5). These data suggested that temporal variability rather than spatial variability in substrate type may have been the cause of the very high observed abundance in Fletcher Channel in 2010. The Athabasca River exhibited a near-historically-high freshet flow in late July 2011, which could have resulted in little deposition and/or considerable scour of fine particles to/from substrates of the river and delta (see Section 4). Comparison of peak (freshet) river flow in each year (at RAMP Station S24) with %sand and benthic invertebrate abundance in Fletcher Channel (Figure 6.6-5) suggests a flow-related influence on observed temporal variability in benthic invertebrate communities in Fletcher Channel since 2002, mediated at least in part by changes in sediment deposition and transport.

Figure 6.6-5 Relationships between particle size distribution and benthic invertebrate abundance in Fletcher Channel, and Athabasca River flow, 2002-2011.

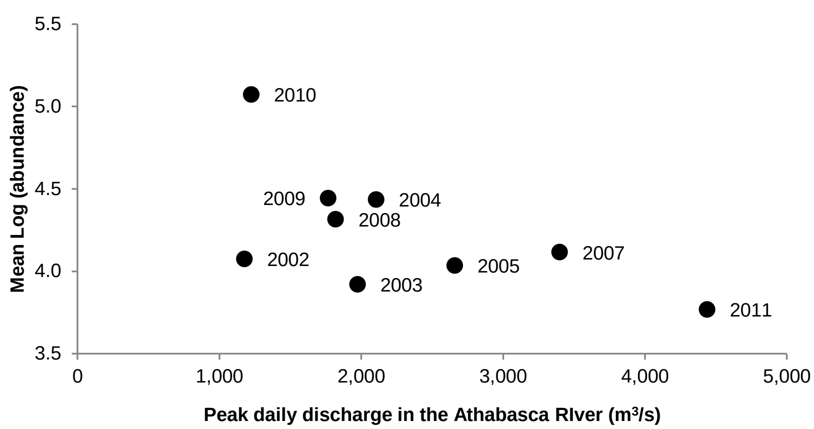
A. Mean percent sand vs. log (abundance) in Fletcher Channel



B. Peak Athabasca River discharge vs. mean percent sand in Fletcher Channel



C. Peak Athabasca River discharge vs. log (abundance) in Fletcher Channel



Results of this pilot study did not indicate that a modified experimental design for sampling the ARD channels at a larger spatial scale would enhance the RAMP sampling design for the Benthic Invertebrate Communities component. If the results had shown greater variance in measurement endpoints among replicate stations than within *test* reach FLC-1, there would have been support for sampling at the broader spatial scale. However, there was no statistical penalty for extending the length of the reach sampled in the ARD channels, and extending the length of the sampled reach would be more consistent with the scale at which inferences are intended (i.e., the channel). Hurlbert (1984) indicated that random sampling should be conducted at the same spatial scale at which inferences are being made.

These results also raised additional questions regarding deposition, scour and transport of sediments in delta channels, and the effect of these processes on sediment chemistry and biological communities, which merit further investigation.

6.7 *BASELINE* FISH REACH RECONNAISSANCE SURVEY

In response to a recommendation from the RAMP peer review (AITF 2011), a reconnaissance survey was conducted in September 2011 to identify additional *baseline* reaches for the RAMP slimy sculpin (*Cottus cognatus*) sentinel program. Two watercourses located upstream of oil sands development were evaluated regarding their similarity to current monitoring reaches, which includes two *test* reaches on the upper and lower Steepbank River, a *test* reach on the lower Muskeg River and a *baseline* reach on each of the Horse and Dunkirk rivers. The two candidate *baseline* watercourses included Buffalo Creek and an unnamed creek located approximately 80 km southwest of Fort McMurray and flow into the Athabasca River from the west (Figure 6.7-1).

Three criteria were established to determine whether these watercourses were suitable to incorporate into the slimy sculpin sentinel program:

- Adequate abundance of adult slimy sculpin (i.e., could support a sampling design of ≥ 20 male and 20 female sculpin);
- Habitat characteristics that were similar to current monitoring reaches in the sentinel fish program. Specific habitat characteristics suitable to slimy sculpin include fast flowing water and cobble substrate (BC CDC 2012); and
- Upstream of the influence of oil sands development, but within the McMurray Formation.

6.7.1 Methods

Buffalo Creek and Unnamed Creek were selected by reviewing topographical maps of the area (Figure 6.7-1). Creek selection was based primarily on size and access.

Fish Habitat

A quantitative assessment of fish habitat was conducted by collecting measurements of channel type (i.e., riffle, run, pool) and width, substrate composition (%), water velocity, instream cover, and *in situ* water quality variables. Visual estimates were conducted of areal coverage by substrate in standard size categories using the modified Wentworth classification system (Cummins 1962) and expressed as percentages. Water velocity was determined by measuring the time for a semi-submerged object to travel a known distance (2 m). A section of the creek was selected for flow measurements that were straight and clear of obstacles. Flow and depth measurements were repeated three times along the same transect and averaged. Photo documentation was collected for each watercourse.

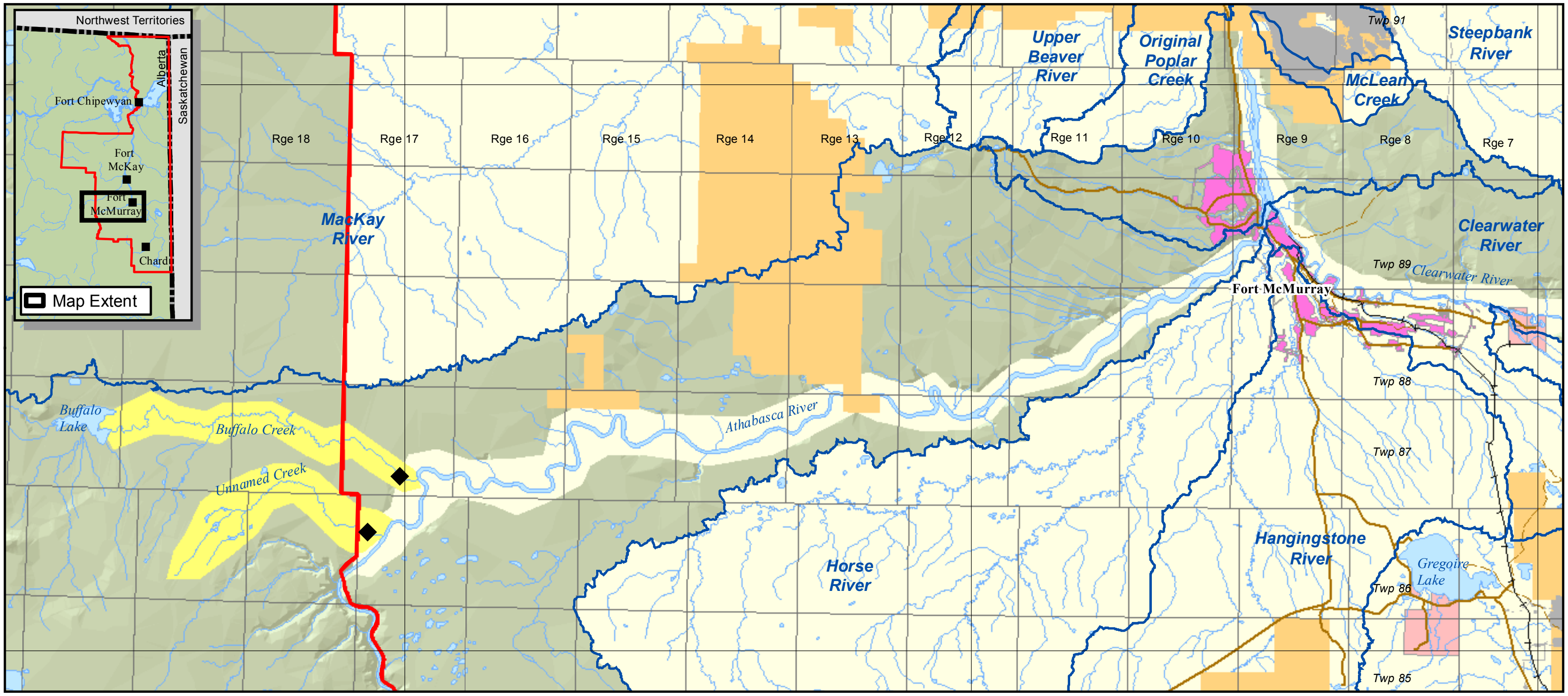
Near-surface measurements of pH, temperature (°C), and conductivity (µS/cm) were collected using a Hanna combo-tester. Dissolved oxygen levels (mg/L) were measured using a LaMotte Winkler titration kit (Code 5860).

Fish Inventory

A fish inventory was conducted on September 27, 2011 in each creek using a Smith-Root 12B-POW backpack electrofisher. The entire width of the creek was electrofished starting near the confluence with the Athabasca River moving upstream to minimize potential disturbance of fish and fish habitat during the sampling event. The section of each creek that was sampled was 40 times the wetted width or at least 150 m as defined by Peck *et al. (*2006) as the minimum level of effort to document 95% of the species available in a river reach. The reach lengths for this study were consistent with protocols used for the RAMP fish assemblage monitoring program, that were developed using USEPA EMAP fish assemblage sampling methods.

All fish were enumerated and measured for fork length (mm) and total weight (0.1 g). Sex and stage of maturity were recorded when discernable by external examination; fish were held in an aerated holding container and released at the end of the survey.

Figure 6.7-1 Location of baseline reconnaissance fish sampling reaches, 2011.



LEGEND

- Lake/Pond
- River/Stream
- Watershed Boundary
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area Boundary
- RAMP Focus Study Area
- Town of Fort McMurray
- Land Change Area as of 2011[d]
- 2011 Focal Projects
- Baseline Sampling Station

Data Sources:

a) Lake/Pond, River/Stream, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land Change Area as of 2011 Related to Focal Projects and Other Oil Sands Development. Land Change Areas Delineated from 10m SPOT-5 (June, July, and August 2011) and 30m Landsat-5 (May 2011) Multispectral Imagery.
e) Oil Sands Project Boundaries Derived from Alberta Energy Oil Sands Lease Agreements.

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

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6.7.2 Results

Fish Habitat

The lower portion of Buffalo Creek was uniform in habitat conditions. The reach had a moderate to high gradient, with fast flowing riffle habitat and shallow pools, and dominated by large boulder substrate (Figure 6.7-2). The average water depth of Buffalo Creek was 0.27 m with a velocity of 3.6 m/s. The wetted and bankfull widths of the creek were 5.0 m and 11.3 m, respectively (Table 6.7-1).

Unnamed Creek was similar to Buffalo Creek with a moderate to high gradient, with fast flowing riffle habitat and shallow pools and dominated by large boulders (Figure 6.7-3). The average depth of Unnamed Creek was 0.18 m with a velocity of 3.6 m/s. Wetted and bankfull widths were 1.9 m and 4.1 m, respectively (Table 6.7-1). Water quality variables were also similar between Buffalo and Unnamed creeks, with the exception of conductivity which was 2.5 times higher in Unnamed Creek (Table 6.7-1).

Table 6.7-1 Summary of habitat characteristics for Buffalo and Unnamed creeks, September 2011.

Watercourse	Buffalo Creek	Unnamed Creek
Sample date	Sept. 27, 2011	Sept. 27, 2011
Upstream UTM (NAD 83, 12 V)	401018 / 6265137	397893 / 6260304
Downstream UTM (NAD 83, 12 V)	401138 / 6265199	398084 / 6260212
Reach access	Helicopter	Helicopter
Habitat type	Riffle	Riffle
Fishing effort (secs)	1,243	1,021
Average water depth (m)	0.27	0.18
Average bankfull width (m)	11.3	4.1
Average wetted width (m)	5.0	1.9
Average velocity (m/s)	3.6	3.6
Dissolved oxygen (mg/L)	9.0	8.8
Conductivity (µs/cm)	266	607
pH	8.07	8.06
Water temperature (°C)	6.5	6.2

Fish Inventory

Table 6.7-2 provides a summary of fish captured in Buffalo and Unnamed creeks. A total of 30 fish were captured, 28 in Buffalo Creek and two in Unnamed Creek. Five species were captured in Buffalo Creek with lake chub as the most abundant species followed by white sucker, longnose sucker, spoonhead sculpin and burbot. Two species were caught in Unnamed Creek including lake chub and white sucker.

Table 6.7-2 Summary of fish species captured during the reconnaissance survey of Buffalo Creek and Unnamed Creek, September, 2011.

Watercourse	Species[1]	Fork Length (mm)	Weight (g)
Buffalo Creek	LNSC	123	21.4
	LNSC	161	53.8
	LNSC	78	7.5
	LKCH	54	1.0
	LKCH	48	1.2
	LKCH	57	1.6
	LKCH	57	2.9
	WHSC	76	5.2
	SPSC	92	8.5
	SPSC	47	1.4
	LKCH	52	1.3
	WHSC	58	2.1
	LKCH	54	1.6
	LNSC	54	1.8
	WHSC	49	2.0
	LKCH	59	2.1
	WHSC	49	1.4
	WHSC	48	1.6
	SPSC	49	0.9
	LNSC	53	1.5
	SPSC	53	1.6
	LNSC	51	1.6
	WHSC	46	1.6
	LKCH	52	1.3
	LKCH	53	1.8
	WHSC	44	1.0
	WHSC	42	0.9
	BURB	320	155.6
Unnamed Creek	LKCH	40	0.5
	WHSC	escaped	

[1] Species: LNSC-longnose sucker; LKCH-lake chub; WHSC-white sucker; SPSC-spoonhead sculpin; BURB-burbot.

6.7.3 Discussion

Based on the reconnaissance survey conducted in September 2011, Buffalo and Unnamed creeks were determined to be unsuitable for the RAMP slimy sculpin sentinel fish program. Both creeks were unsuccessful in meeting two of the three requirements necessary to be suitable *baseline* reaches for the program. Firstly, a viable population of adult slimy sculpin was not present in either creek. Despite both creeks appearing to have habitat conditions that would be suitable for sculpin, only a limited number of spoonhead sculpin were found in Buffalo Creek. Secondly, neither creek had habitat characteristics that were comparable to conditions found at monitoring reaches/watercourses currently in the program. Buffalo and Unnamed creeks are dominated by boulder with a moderate to high gradient compared to existing reaches that are dominated by cobble with low to moderate gradients (see sections 5.2 and 5.3).

The challenge for aquatic monitoring in the oil sands region is the limited availability of candidate *baseline* watercourses. Buffalo Creek and Unnamed Creek were thought to have potential; however, the current reconnaissance survey did not support their use for sentinel monitoring using slimy sculpin. Continued effort will be undertaken to identify other potential *baseline* watercourses in the future. Fortunately, RAMP has already designated the High Hills River as a new *baseline* watercourse for both the fish assemblage monitoring and sentinel monitoring program undertaken in 2011 and 2012, respectively.

Figure 6.7-2 Photo of Buffalo Creek taken near the mouth, facing upstream, September 2011.

Figure 6.7-3 Photo of Unnamed Creek taken near the mouth, facing upstream, September 2011.

7.0 INTEGRATION ANALYSIS OF RAMP DATA

7.1 INTRODUCTION

Over the last several years, RAMP has made an increasing effort to harmonize and integrate its monitoring components (i.e., water quality, sediment quality, benthic invertebrate communities and fish assemblages) with respect to space and time. Based on results presented in Section 5 of this report and past reports, it is apparent that there are likely some key environmental variables that are influencing temporal and spatial variability in monitoring data, specifically for aquatic biota (benthos and fish) of the region. In particular, several questions have been posed regarding the nature of these relationships, including:

1. What are the environmental variables that may drive changes in surface watercourses?
2. What variables may be causing any observed variability in the monitoring data?
3. Are observed changes in benthic invertebrate communities and fish assemblages associated with changes in water quality, sediment quality, or hydrology?
4. What variables may best explain spatial variability in data from year to year?

The objective of this section of the RAMP 2011 Technical Report is to present results of exploratory analyses conducted to evaluate the above questions using data collected by RAMP in 2011 and over time. The intent of the integration analysis was not to develop a definitive study of fish/benthos-habitat associations, but to identify possible relationships that would warrant further study to increase our understanding of the response of aquatic biota to environmental conditions occurring in the oil sands region.

7.2 METHODS

Analyses were conducted on two separate datasets: (i) temporal data, which focused on a subset of RAMP reaches from four watercourses that have a sufficiently-long time series for analyses (Table 7.2-1); and (ii) spatial data, which focused on all RAMP reaches that were sampled in 2011 (Table 7.2-2). The temporal dataset was used to explore the influences of physical and chemical variables over time on benthic invertebrate communities. The 2011 spatial dataset was used to explore the influences of physical and chemical variables on both benthic invertebrate communities and fish assemblages.

Table 7.2-1 Watercourses and RAMP reaches used to evaluate temporal relationships between aquatic biota and environmental variables.

Watershed	Hydrology Stations	Water Quality Stations	Benthic Invertebrate Reaches	Sampling Years
MacKay River	S26, S40	MAR-1, MAR-2A, MAR-2	MAR-E1, MAR-E2, MAR-E3	2000 to 2011
Steepbank River	S38	STR-1, STR-3	STR-E1, STR-E2	1998 to 2011
Ells River	S14A, S45	ELR-1, ELR-2, ELR-2A	ELR-D1, ELR-E2, ELR-E2A	1998 to 2011
Muskeg River	S7, S5, S5A	MUR-1, MUR-6	MUR-E1, MUR-D2, MUR-D3	1998 to 2011

Table 7.2-2 Watercourses and RAMP reaches used to evaluate spatial relationships between aquatic biota and environmental variables in 2011.

River	Water Quality Station	Benthic Reach	Sediment Quality Station	Fish Assemblage Reach	Hydrology Station	Sample date
Muskeg River	MUR-1	MUR-E1	-	MUR-F1	07DA008, S7	07-Sep-11
Muskeg River	-	MUR-D2	MUR-D2	MUR-F2	S5A, S33	15-Sep-11
Muskeg River	-	MUR-D3	MUR-D3	MUR-F3	S5	14-Sep-11
Jackpine Creek	JAC-1	JAC-D1	JAC-D1	JAC-F1	S2	14-Sep-11
Jackpine Creek	JAC-2	JAC-D2	JAC-D2	JAC-F2	S37	09-Sep-11
Steepbank River	STR-1	STR-E1	-	STR-F1	07DA006, S38	13-Sep-11
Steepbank River	STR-3	STR-E2	-	STR-F2	07DA006, S38	11-Sep-11
Tar River	TAR-1	TAR-D1	TAR-D1	TAR-F1	S15A, S19	08-Sep-11
Tar River	TAR-2	TAR-E2	-	TAR-F2	S34	12-Sep-11
MacKay River	MAR-1	MAR-E1	-	MAR-F1	07DB001, S26	14-Sep-11
MacKay River	MAR-2A	MAR-E2	-	MAR-F2	07DB001, S26	15-Sep-11
MacKay River	MAR-2	MAR-E3	-	MAR-F3	S40	11-Sep-11
Ells River	ELR-1	ELR-D1	ELR-D1	ELR-F1	S14	14-Sep-11
Ells River	ELR-2A	ELR-E2A	-	ELR-F2A	S45	12-Sep-11
Poplar Creek	POC-1	POC-D1	POC-D1	POC-F1	07DA007, S11	12-Sep-11
Beaver River	BER-2	BER-D2	BER-D2	BER-F2	07DA018, S39	06-Sep-11
Fort Creek	FOC-1	FOC-D1	FOC-D1	FOC-F1	S12	13-Sep-11

The following sections provide an overview of the data or measurement endpoints used in the integration analysis from all RAMP components.

Hydrology and Climate

Hydrologic and climate variables chosen for the integration analysis were factors that could potentially influence the habitat conditions for benthic invertebrate communities and fish assemblages and are generally variable from year to year or among watercourses. The following variables were included in the analysis:

Upstream Catchment Area The area of a watershed (ha) located upstream of each benthic invertebrate communities reach, which would influence the surface water conditions of that reach (temporal analysis only) (Table 7.2-3).

Table 7.2-3 Size (ha) of upstream catchment area for each benthic invertebrate reach included in the temporal dataset.

River	Benthic Reach	Upstream Catchment Area (ha)
Steepbank River	STR-E1	135,491
Steepbank River	STR-E2	60,347
Muskeg River	MUR-E1	143,256
Muskeg River	MUR-D2	140,149
Muskeg River	MUR-D3	36,879
Mackay River	MAR-E1	479,531
Mackay River	MAR-E2	356,078
Mackay River	MAR-E3	343,302
Ells River	ELR-D1	271,380
Ells River	ELR-E2	243,413
Ells River	ELR-E2A	242,616

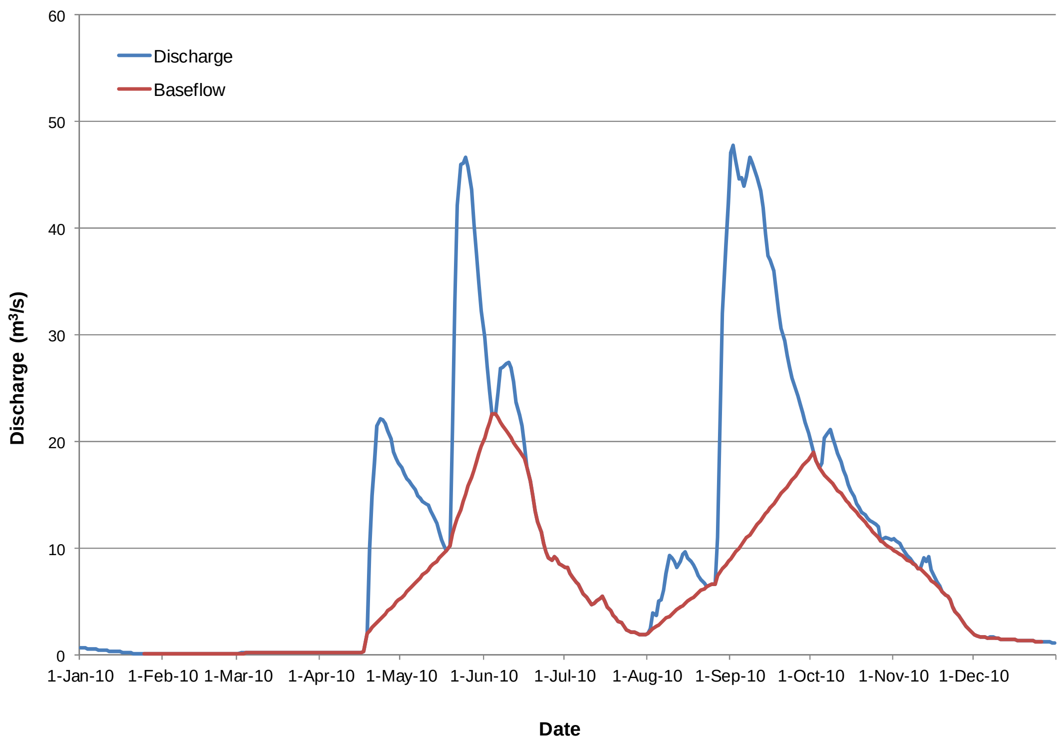
Flow Variables The following flow measurements were included in the integration analyses:

- Daily discharge - the daily discharge in m/s on the sampling date;
- Mean discharge in August - the average daily discharge in the month of August for all years;
- Peak flows in previous seven and thirty days - the maximum flow value for the seven and 30 days prior to the sampling date;
- Mean discharge since ice out - the average flow from May 1 to August 31; and
- Flow on sampling date as multiple of base flow - the discharge on the sampling date multiplied by the baseflow index described as follows.

The *baseflow index* (BFI) is a dimensionless variable that expresses the volume of baseflow as a fraction of the volume of total flow in a stream. The BFI is considered as a measure of the river's runoff which is derived from stored sources and, as a general catchment descriptor, has found many areas of application, including low flow estimation and groundwater recharge assessment (Tallaksen and van Lanen 2004). In catchments with high groundwater contribution to stream flow, BFI may be close to 1, but it is equal to zero for ephemeral streams. Estimates of baseflow and the baseflow index have been developed using a variety of methods. While these methods are approximations at best, they can provide an understanding of the general relationships between surface and subsurface flow contributions.

For the integration analysis, the baseflow index for all RAMP stations was estimated using a smooth minima separation method as described in Gustard *et al.* (1992). For the 2011 spatial analysis, the open-water BFI (May 1 to October 31) was calculated for each watercourse. Figure 7.2-1 provides a graphical example showing the separation of baseflow relative to total discharge at the RAMP Station S26 (MacKay River).

Figure 7.2-1 2010 discharge showing the continuous baseflow separation for RAMP Station S26 (MacKay River).



Water Quality

Water quality variables chosen for the integration analysis are generally limiting factors for benthic invertebrate communities and fish assemblages (i.e., increases/decreases in concentrations of these variables could influence suitable fish and benthic habitat conditions). The following variables were included in the analysis:

- Total Suspended Solids (TSS) – a variable strongly associated with other variables including total phosphorus and numerous metals;
- Alkalinity – an indicator of buffering capacity and acid sensitivity of waters;
- Conductivity – basic indicator of overall ion concentration;
- Total Kjeldahl nitrogen, total dissolved phosphorus – provides an indication of nutrient status;
- Dissolved organic carbon – dissolved organic matter in the water; and
- Dissolved oxygen – amount of oxygen available in the water to organisms.

Sediment Quality

Sediment quality variables included in the analysis were only available for depositional benthic invertebrate reaches, given sediment quality data are not collected in erosional reaches. The variables selected for the analysis included those that are indicators of a potential increase in development or are potentially toxic to benthos and fish, including the following:

- PAHs – sum of concentrations of all PAHs measured in a given sample, including parent and alkylated forms;
- Total metals – sum of all metals measured in a given sample (using all metals measured consistently by RAMP since 1997);
- Total organic carbon – an indicator of organic matter in sediment, including hydrocarbons; and
- Hydrocarbon Fractions 1 to 4 – indicators of the total hydrocarbon content of sediments, with each indicator (fraction) capturing hydrocarbon compounds of different molecular weights.

Benthic Invertebrate Communities

The following benthic invertebrate community measurement endpoints were included in the integration analyses:

- 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

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

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

  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).

Fish Assemblages

The following measurement endpoints of fish assemblages were included in the integration analyses:

- 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 measurement endpoint was computed for each reach following the calculation for Simpson's Diversity (D):

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

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 measurement endpoint was computed for each reach following the calculation for evenness (E) as per the EEM Technical Guidance Document (Environment Canada 2010), 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 ATI 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. 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. With this index, lower tolerance values imply a species that is more sensitive to disturbance.

Statistical Analyses

The temporal and spatial datasets were examined separately using three statistical tools: (i) Principal Components Analysis; (ii) Spearman rank correlation; and (iii) General Linear Models. The following section describes each of the three statistical tools.

A principal components analysis (PCA) (Tool 1) was used to explore the associations among variables across RAMP components. The PCA was carried out using measurement endpoints of benthic invertebrate communities (temporal and spatial data) and fish assemblages (spatial data only), hydrological variables (temporal and spatial data), water chemistry variables (temporal and spatial data), and sediment chemistry variables (spatial data only) (Table 7.2-4).

The data distributions for each variable were explored using probability plots prior to running the PCA. Variables that were identified as having somewhat non-normal distributions (across times and/or reaches) were $\log_{10}$-transformed. In most cases, log-transforming the data produced a more normal distribution. Normalizing the data was considered a necessary step in order to increase the linearity of relationships among variables, which is an assumption of the PCA.

PCAs were conducted for each component (i.e., hydrology, water chemistry, sediment chemistry, biology), with results used to identify subsets of variables that could be carried forward for the Spearman rank correlation analysis. Principal component axes that explained >10% of the total variance in a suite of variables were considered significant and used in the Spearman rank correlations (Jackson 1993). Pearson correlations (i.e., Pearson *r*-values) between individual variables and the "significant" PCA axes were calculated. Correlations between a variable and a PCA axis that were >|0.6| were considered strongly associated with an axis. Axis scores associated with the PCA of the hydrological data and water quality data were retained for the Spearman rank correlation analysis.

Spearman Rank Correlation (Tool 2) was used to quantify the degree of association between measurement endpoints of benthic invertebrate communities and fish assemblages (spatial analysis) and measures of physical and chemical habitat. Upstream catchment area and chlorophyll *a* (as an estimate of periphyton biomass) were used as additional predictors in the temporal dataset; upstream catchment area was used despite a poor correlation with the single axis in the hydrological PCA. Variables were considered strongly correlated when the Spearman correlation (i.e., r_s) was significant at 0.05. Spearman rank correlations were used because it is a non-parametric technique that can identify a relationship that may be either linear or non-linear monotonic (i.e., increasing or decreasing).

Table 7.2-4 List of variables within RAMP components used in the Principal Component Analysis of the temporal dataset and 2011 spatial dataset.

Component	Variable	Dataset	
		Temporal	Spatial
Hydrological Variables	Upstream catchment area	x	
	Daily discharge (m/s) = HYD1	x	x
	Average discharge/year for August = HYD2	x	x
	Peak flow in previous 7 days = HYD3	x	x
	Peak flow in previous 30 days = HYD4	x	x
	Average discharge since ice out = HYD9	x	x
	Flow on sample date as multiple of base flow = HYD10	x	
Water Quality	Total Suspended Solids	x	x
	Alkalinity	x	x
	Conductivity	x	x
	Total Kjeldahl nitrogen	x	x
	Total dissolved phosphorus	x	x
	Dissolved organic carbon	x	x
	Dissolved oxygen	x	x
Sediment Quality	PAHs		x
	Total metals		x
	TOC		x
	Hydrocarbon Fraction 1		x
	Hydrocarbon Fraction 2		x
	Hydrocarbon Fraction 3		x
	Hydrocarbon Fraction 4		x
Biological Measurement Endpoints	Benthic abundance	x	x
	Benthic richness	x	x
	Benthic diversity	x	x
	Benthic evenness	x	x
	Benthic percent EPT	x	x
	Fish abundance		x
	Fish richness		x
	Fish diversity		x
	Fish ATI value		x

General Linear (multiple regression) Model (Tool 3) was used to explore the associations between measurement endpoints of benthic invertebrate communities and the summary measures of physical (upstream catchment area, hydrology PC1 scores) and chemical (water quality PC1 and PC2 scores) habitat variables. This procedure assumes linear relationships, and identifies the variation explained by the predictors. A backward-stepwise procedure was used in this analysis to identify significant predictors. The analysis was carried out only for the erosional reaches in the temporal dataset because that was the only subset of data for which there were sufficient data that the incorporation of four or five predictors would not "over-explain" the variation in the response measurement endpoints resulting in erroneously significant multiple-regression models.

Scatterplots were performed on response measurement endpoints (benthic or fish) in relation to key variables identified in the Spearman rank correlation and/or the multiple regression model.

7.3 RESULTS

Principal Component Analysis

The results of the Principal Component Analysis are presented in Table 7.3-1.

Hydrologic variables in both the temporal and spatial datasets each produced a single PCA axis. All of the hydrologic variables in both datasets strongly covaried, with each variable having a correlation (*r* value) with the single PC axis >0.80. The high correlation of all hydrologic variables with one PC axis indicated that reaches with high daily discharges also had high discharges in August, high discharges in the previous seven and 30 days, high discharges since ice out, and high discharges on the day that benthic invertebrate samples were collected. The use of a single PC axis to describe flow conditions was justified by the PCA of the hydrologic data; therefore, for further analyses, either the single PC axis score or one of the actual measured variables can be used.

The PCA of the temporal water quality dataset resulted in two significant water quality PC axes. Nutrients (TKN, TDP, and DOC) were strongly positively correlated with the first axis, while alkalinity was strongly negatively correlated. The first axis indicated that reaches with higher concentrations of nutrient had lower alkalinity. Alkalinity and conductivity were strongly correlated with the second PC axis. The PCA of the 2011 spatial water quality dataset was somewhat similar to the PCA of the temporal dataset, with two PC axes each explaining >10% of the variation. Dissolved organic carbon (DOC), conductivity and alkalinity were strongly positively correlated with the first axis, indicating that those three variables covaried similarly to the second axis in the temporal dataset. Total dissolved phosphorus (TDP) was strongly correlated with the second axis of the 2011 spatial data, while total suspended solids were strongly associated with the third axis.

The PCA of the spatial sediment chemistry dataset produced two significant PC axes, with all measured analytes (PAH, metals, TOC and hydrocarbon fractions 1 to 4) covarying strongly with the first PC axis and hydrocarbon fraction 1 also correlating with the second PC axis, indicating concentrations of that variable were somewhat independent of the other variables.

The PCA of the biological measurement endpoints resulted in two axes in the temporal dataset and three axes in the 2011 spatial dataset. For the temporal dataset, total benthos abundance was the only measurement endpoint that correlated with the second PC axis, while the other benthic measurement endpoints correlated with the first PC axis (fish assemblage measurement endpoints were not included in the temporal dataset given the limited data available). The results indicated that total benthos abundance varied independently of the other benthic measurement endpoints (richness, diversity, evenness, percent EPT). For the 2011 spatial dataset, all measurement endpoints of benthic invertebrate communities were strongly correlated with the first PC axis, while measurement endpoints of fish assemblages had non-significant weak correlations with the first PC axis. Species richness and diversity of fish assemblages were strongly correlated with the second PC axis, while fish total abundance and the fish ATI value were strongly correlated with the third PC axis.

Spearman Rank Correlations and GLM

Spearman rank correlations are provided in Table 7.3-2; a summary of the results is provided in Table 7.3-3. Within the temporal-depositional dataset, benthic diversity, evenness and percent EPT tended to increase with WQ PC2 (alkalinity and conductivity), while percent EPT tended to be lower in reaches with larger upstream catchment areas (Figure 7.3-1). The regression model was similar in identifying a decrease in percent EPT with increasing upstream catchment area (Table 7.3-4). Within the temporal-erosional dataset, benthic total abundance varied positively with periphyton biomass and negatively with discharge (HYD PC1) (Figure 7.3-2). A similar result was observed using multiple regression of the HYD PC1 and the logarithm of periphyton biomass (Table 7.2-4). Benthic richness also varied positively with periphyton biomass (Figure 7.3-3). Spearman rank correlations indicated that percent EPT generally decreased with decreasing upstream catchment area in the temporal-erosional dataset and varied weakly-positively with WQ PC2 (alkalinity, conductivity) (Table 7.3-2). The parametric regression model indicated that percent EPT varied positively with periphyton biomass, though the relationship was weaker (Table 7.3-2, Figure 7.3-4).

Within the 2011 spatial-erosional dataset, there was only a single weak correlation between a benthic total abundance and WQ PC1 (i.e., alkalinity, conductivity, DOC) (Table 7.3-2, Figure 7.3-5). No measurement endpoints of fish assemblages in erosional reaches varied with any physical or chemical variable.

Within the 2011 spatial-depositional dataset, fish ATI and total abundance, and benthic evenness varied negatively with HYD PC1 (Table 7.3-2, Figure 7.3-6) indicating that the abundance and tolerance of fish assemblages were lower in reaches with higher flows. Benthic total abundance, richness, diversity and evenness were positively associated with WQ PC1 (i.e., alkalinity, conductivity, DOC) (Figure 7.3-7), while fish richness and diversity were negatively associated with WQ PC1 (Figure 7.3-8). These patterns indicated that benthic invertebrate communities were more abundant and diverse, while fish assemblages were less diverse in reaches that had higher concentrations of ions.

Within the 2011 spatial-depositional dataset, fish total abundance varied negatively with SQ PC1 (i.e., PAH, metals, TOC and hydrocarbon fractions 1 to 4) indicating that fish abundance decreased with increasing concentrations of PAHs, metals, TOC, and hydrocarbons in sediments.

Table 7.3-1 Principal Component Analysis of biotic measurement endpoints and physical and chemical summary variables within the temporal dataset and 2011 spatial dataset.

Component	Variable	Temporal Axis		Spatial Axis		
		1	2	1	2	3
Hydrology	Upstream catchment area	0.55				
	Log of HYD1	0.94		0.99		
	Log of HYD2	0.90		0.99		
	Log of HYD3	0.96		1.00		
	Log of HYD4	0.96		0.99		
	Log of HYD9	0.83		0.98		
	Log of HYD10	0.94		0.94		
	Percent of Variance Explained	86		96		
Water Chemistry	Log of TSS	0.37	0.29	0.04	-0.04	0.95
	Log of Alkalinity	-0.60	0.69	0.81	-0.47	-0.09
	Log of Conductivity	-0.55	0.75	0.71	-0.59	0.13
	Log of TKN	0.65	0.48	0.58	0.53	0.40
	Log of TDP	0.71	0.19	0.53	0.70	-0.24
	Log of DOC	0.74	0.36	0.80	0.47	-0.11
	Log of DO	-0.03	-0.41	-0.46	0.56	0.15
	Percent of Variance Explained	32	24	38	27	17
Sediment Chemistry	Log of PAH			0.88	-0.40	
	Log of Total Metals			0.62	0.53	
	Log of TOC			0.91	0.24	
	Log of HC Fraction 1			0.61	0.68	
	Log of HC Fraction 2			0.81	0.14	
	Log of HC Fraction 3			0.92	-0.36	
	Log of HC Fraction 4			0.88	-0.45	
	Percent of Variance Explained			66	19	
Biota	Log of Benthic Abundance	-0.12	0.95	0.83	0.09	-0.31
	Log of Benthic Richness	0.80	0.45	0.95	0.06	-0.20
	Benthic Diversity	0.95	-0.09	0.93	-0.18	0.29
	Benthic Evenness	0.86	-0.21	0.82	-0.24	0.45
	Log of % EPT	0.81	0.03	0.77	0.46	0.08
	Log of Fish Abundance			-0.19	0.30	0.68
	Log of Fish Richness			0.09	0.89	-0.30
	Fish Diversity			-0.10	0.93	-0.02
	Fish ATI			-0.15	0.35	0.71
	Percent of Variance Explained	59	23	42	24	16

Note: values are Pearson Correlations (r). Shading denotes values > |0.6| indicating a strong association with a PCA axis.

Table 7.3-2 Spearman rank correlations (r_s) between biotic measurement endpoints and physical and chemical summary variables within the temporal dataset and 2011 spatial dataset.

Dataset	Habitat	Response	Periphyton Biomass	Upstream Catchment Area	HYD PC1	WQ PC1	WQ PC2	WQ PC3	SQ PC1	SQ PC2
Temporal	Depositional	Benthic Abundance		0.20	0.06	0.27	-0.08			
		Benthic Richness		0.12	-0.09	-0.01	0.24			
		Benthic Diversity		-0.17	-0.22	-0.44	0.57			
		Benthic Evenness		-0.27	-0.18	-0.45	0.64			
		Benthic % EPT		-0.48	-0.26	-0.28	0.59			
	Erosional	Benthic Abundance	0.49	-0.07	-0.40	-0.24	0.22			
		Benthic Richness	0.33	-0.04	-0.17	-0.04	0.23			
		Benthic Diversity	-0.11	0.23	0.02	-0.11	-0.12			
		Benthic Evenness	-0.14	0.23	0.08	-0.01	-0.16			
		Benthic % EPT	0.29	-0.43	-0.09	0.02	0.13			
		Periphyton		-0.31	-0.10	0.01	-0.08			
Spatial	Depositional	Benthic Abundance			-0.22	0.65	-0.24	0.02	0.25	-0.05
		Benthic Richness			-0.26	0.72	-0.27	-0.03	0.20	0.08
		Benthic Diversity			-0.48	0.76	-0.42	-0.01	0.08	0.18
		Benthic Evenness			-0.67	0.80	-0.60	-0.07	0.03	0.23
		Benthic % EPT			-0.32	0.48	-0.08	-0.06	-0.31	0.25
		Fish Abundance			-0.65	0.14	-0.21	-0.14	-0.72	-0.15
		Fish Richness			0.22	-0.96	0.36	0.02	0.59	-0.25
		Fish Diversity			0.00	-0.79	0.45	0.57	0.12	-0.05
		Fish ATI			-0.72	0.07	-0.48	-0.43	-0.28	0.43
	Erosional	Benthic Abundance			-0.21	0.62	-0.30	0.45		
		Benthic Richness			-0.05	0.32	-0.10	0.42		
		Benthic Diversity			0.05	-0.55	0.40	-0.38		
		Benthic Evenness			0.15	-0.55	0.49	-0.38		
		Benthic % EPT			-0.43	-0.07	-0.18	-0.14		
		Fish Abundance			-0.52	-0.57	-0.23	-0.80		
		Fish Richness			0.12	0.50	0.01	0.60		
		Fish Diversity			0.62	-0.17	0.33	-0.05		
		Fish ATI			0.38	0.07	0.32	0.18		

Notes: values are Pearson Correlations (r). Values where p<0.05 are shaded to denote statistically significant relationships.

Table 7.3-3 Summary of Spearman rank correlations between biotic measurement endpoints and dominant variables of environmental PCA axes.

Temporal Analysis (no fish or SQ)

Biological Response	Discharge (HYD PC1)	Periphyton	Catchment	Alkalinity/ Conductivity (WQ PC2)
Erosional				
Benthos abundance	-	+	o	o
Benthos richness	o	+	o	o
Benthos diversity	o	o	o	o
Benthos evenness	o	o	o	o
Benthos - %EPT	o	+	-	o
Periphyton	o		-	o
Depositional				
Benthos abundance	o	na	o	o
Benthos richness	o	na	o	o
Benthos diversity	o	na	o	+
Benthos evenness	o	na	o	+
Benthos %EPT	-	na	o	+

2011 Spatial Analysis

Biological Response	Discharge (HYD PC1)	Alkalinity, Conductivity, DOC (WQ PC1)	TDP (WQ PC2)	TSS (WQ PC3)	SQ
Erosional					
Benthos abundance	o	+	o	o	na
Benthos richness	o	o	o	o	na
Benthos diversity	o	o	o	o	na
Benthos evenness	o	o	o	o	na
Benthos %EPT	o	o	o	o	na
Fish abundance	o	o	o	-	na
Fish richness	o	o	o	o	na
Fish diversity	o	o	o	o	na
Fish ATI	o	o	o	o	na
Depositional					
Benthos abundance	o	+	o	o	o
Benthos richness	o	+	o	o	o
Benthos diversity	o	+	o	o	o
Benthos evenness	-	+	o	o	o
Benthos %EPT	o	o	o	o	o
Fish abundance	-	o	o	o	-
Fish richness	o	-	o	o	o
Fish diversity	o	-	o	o	o
Fish ATI	-	o	o	o	o

na = sediment quality data are not collected at erosional reaches; periphyton was not sampled in depositional reaches.

Note: "o" denotes no significant correlation; "+" denotes a significant positive correlation; and "-" denotes a significant negative correlation.

Note: The temporal depositional dataset is only based on three reaches including *test* reaches MUR-D2, MUR-D3, and ELR-D1.

Table 7.3-4 Results of multiple regression analysis testing for the influences of physical and chemical variables on measurement endpoints of benthic invertebrate communities, using the temporal dataset.

Measurement Endpoint	Source	Type III SS	df	Mean Squares	F-Ratio	p-Value	Model R^2
Erosional							
Abundance	HYD PC1 + LogPeriphyton	5.060	2	2.530	17.66	**<0.001**	0.43
	Residual	6.733	47	0.143			
Richness	Periphyton	0.058	1	0.058	6.61	0.013	0.10
	Residual	0.501	57	0.009			
EPT	LogPeriphyton	0.150	1	0.150	4.81	0.032	0.08
	Residual	1.782	57	0.031			
Depositional							
Diversity	HYD PC1	0.036	1	0.036	4.86	**0.044**	0.24
	Residual	0.111	15	0.007			
Evenness	Upstream catchment area	0.032	1	0.032	4.44	**0.045**	0.14
	Residual	0.192	27	0.007			
EPT	Upstream catchment area	0.580	1	0.580	9.36	**0.005**	0.26
	Residual	1.674	27	0.062			

Note: **Bold** values denote significance at p=0.05.

Figure 7.3-1 Relationship between percent EPT (Ephemeroptera, Plecoptera and Trichoptera) and upstream catchment area (ha) in the temporal-erosional dataset.

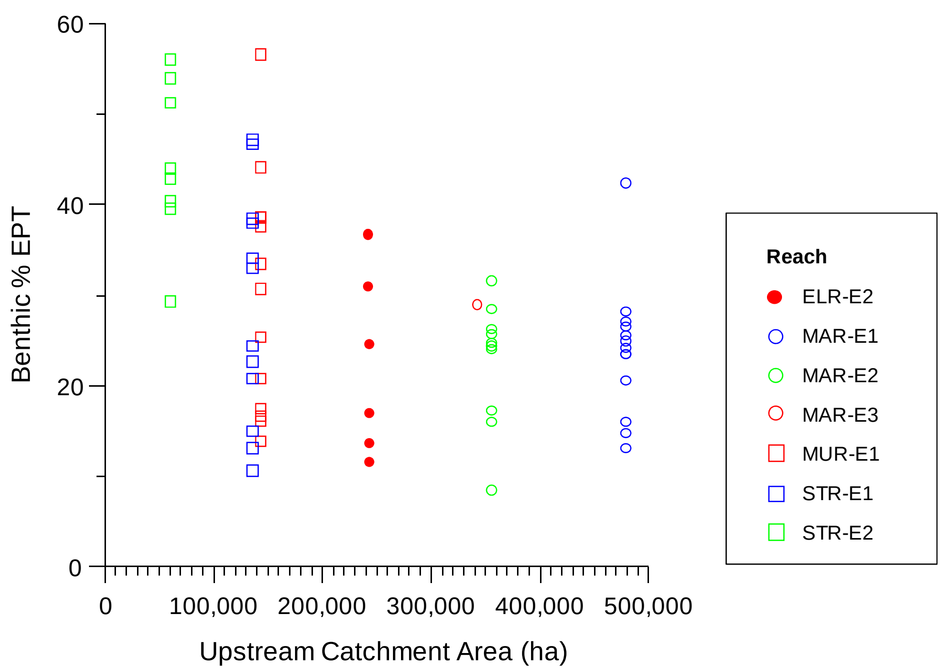
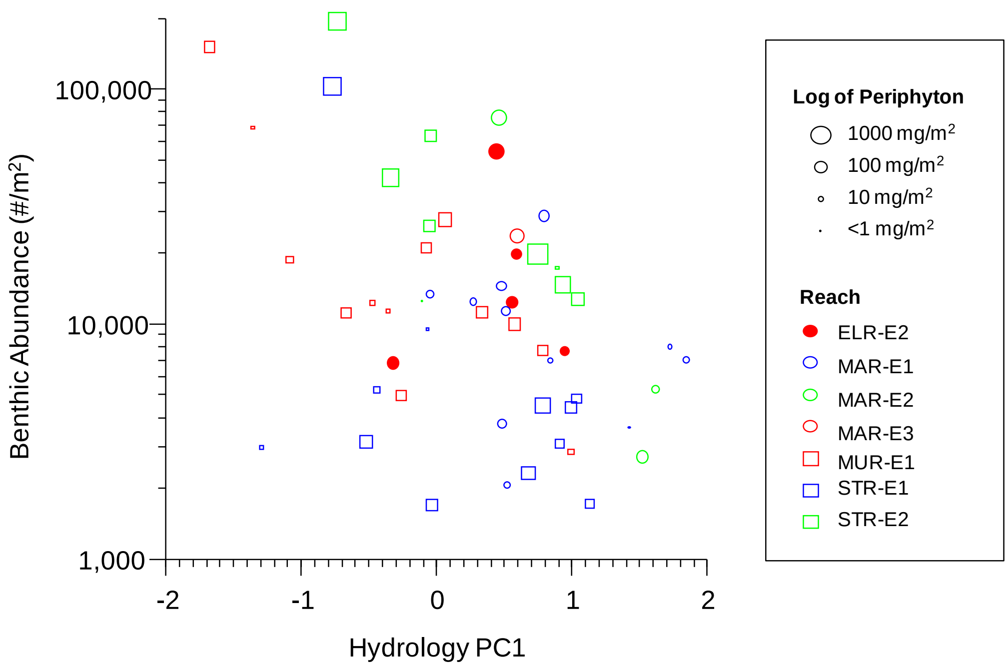


Figure 7.3-2 Relationship between total abundance of benthic invertebrate communities, HYD PC1 (discharge), and periphyton biomass in the temporal-erosional dataset.



Note: Periphyton biomass is indicated by the size of the symbols.

Figure 7.3-3 Relationship between benthic taxa richness and periphyton biomass in the temporal-erosional dataset.

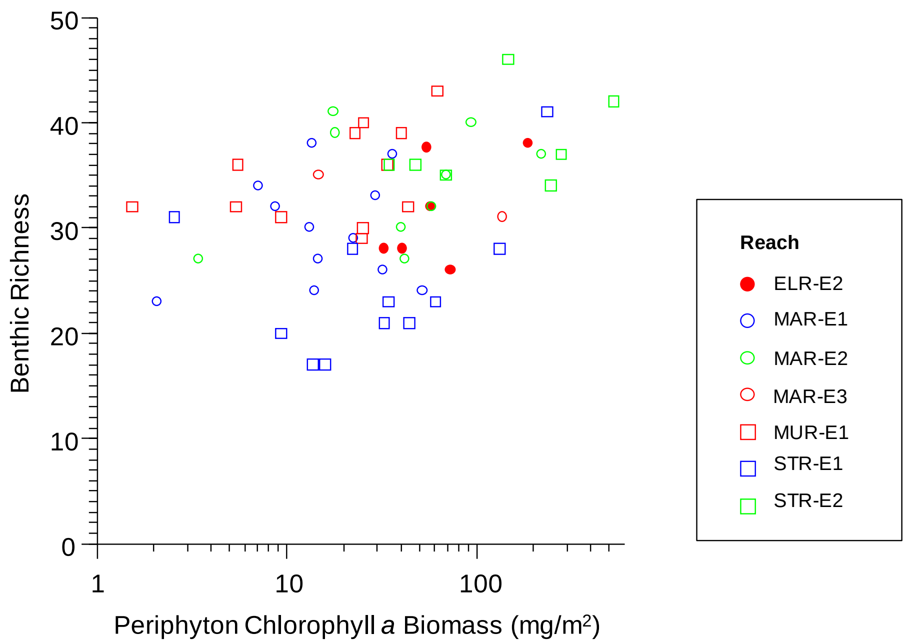


Figure 7.3-4 Relationship between percent EPT (Ephemeroptera, Plecoptera and Trichoptera) and periphyton biomass in the temporal-erosional dataset.

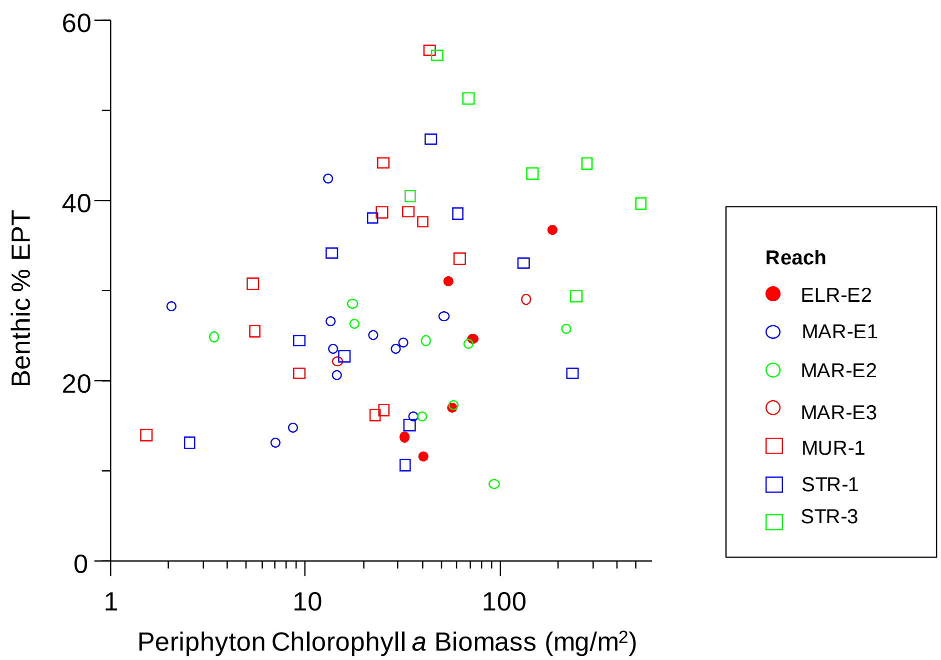


Figure 7.3-5 Relationship between benthic total abundance and dissolved organic carbon in the temporal dataset.

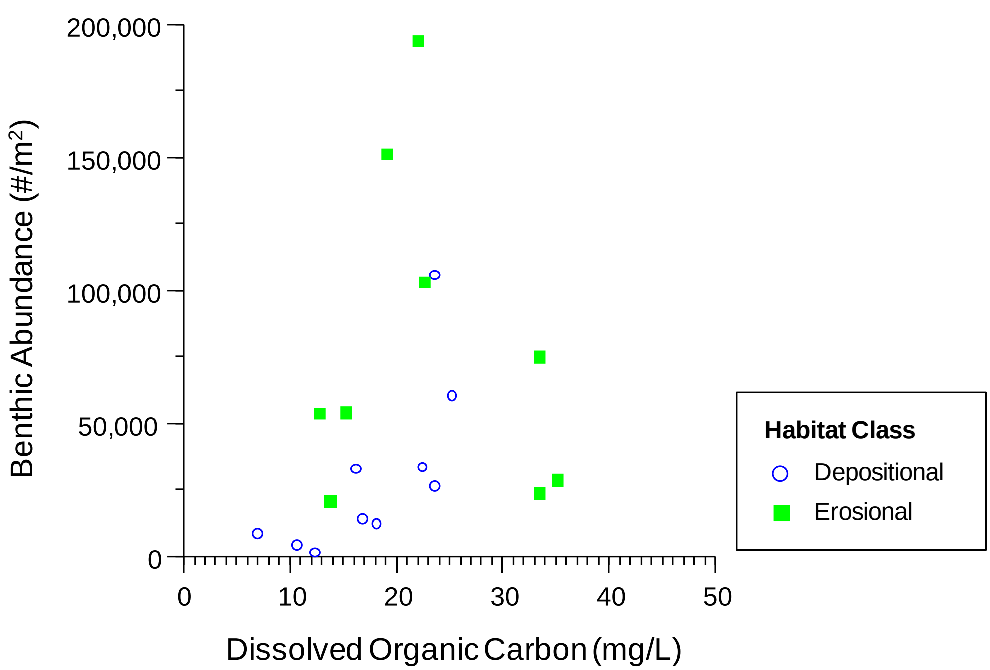


Figure 7.3-6 Relationship between the fish assemblage ATI value and discharge in the 2011 spatial dataset.

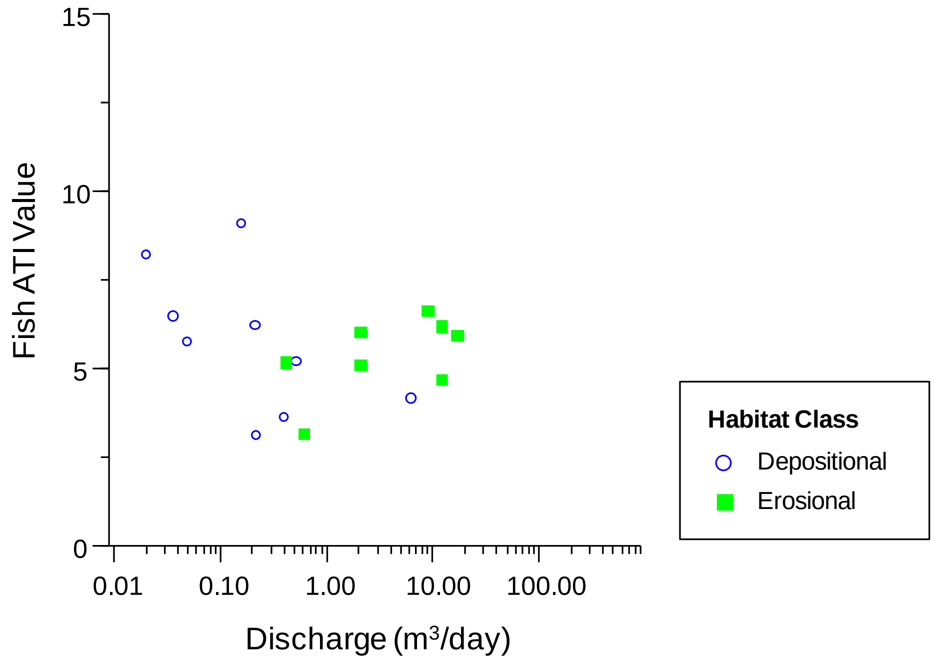


Figure 7.3-7 Relationship between benthic evenness and water quality PC1 (conductivity, alkalinity, DOC) in the 2011 spatial dataset.

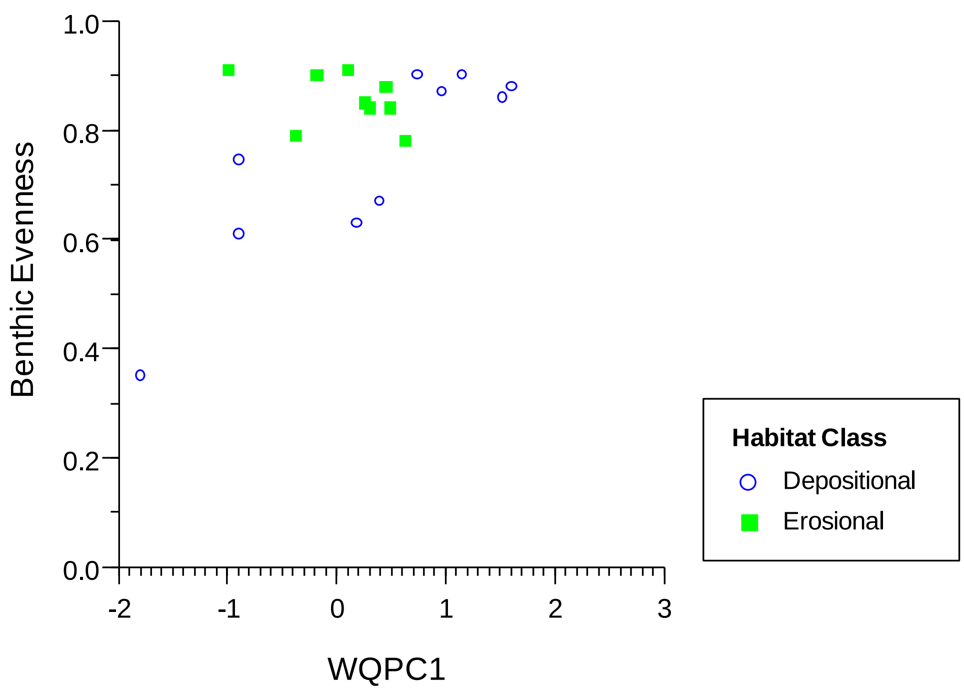
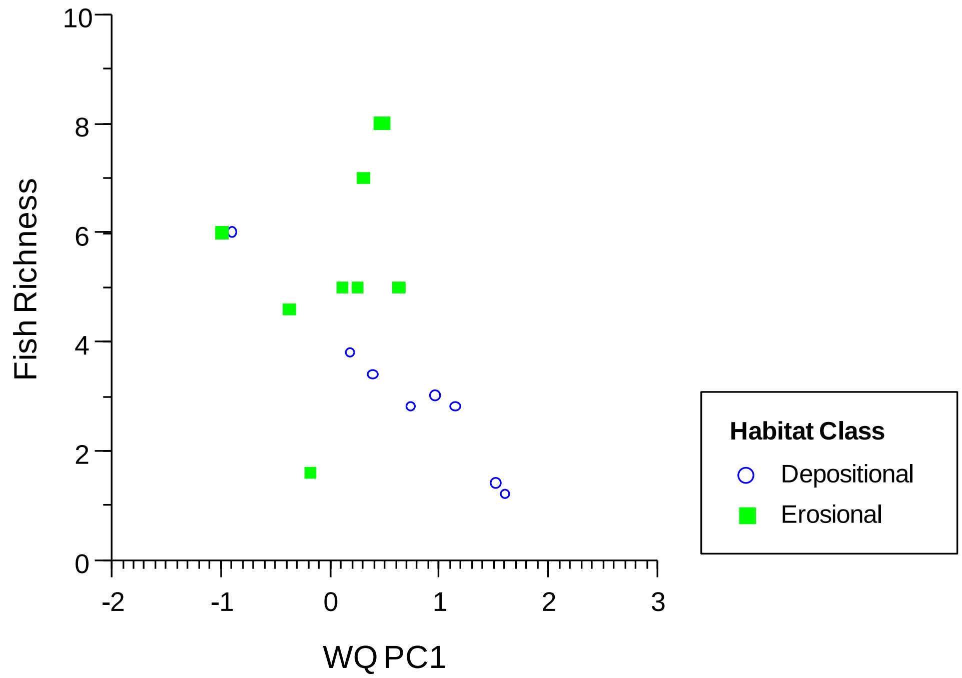


Figure 7.3-8 Relationship between fish species richness and water quality PC1 (conductivity, alkalinity, DOC) in the 2011 spatial dataset.



7.4 SYNTHESIS

Generally, strong relationships between variables describing benthic invertebrate communities and fish assemblages and environmental variables were limited. However, some patterns were observed for both benthos and fish.

There was a tendency for benthic invertebrate communities to be more abundant, rich and diverse during sampling periods or in rivers with low flows, which logically coincided with higher ion concentrations in water (conductivity, DOC, alkalinity). Similarly, benthic communities correlated positively with increasing periphyton biomass, which may reflect a response to increasing food source, particularly for grazing taxa such as Ephemeroptera and Plecoptera (among others), which also were found to increase with increasing periphyton. The increase in abundance associated with an increase in periphyton could also reflect an increase in hiding spaces; if periphyton was low, benthic invertebrates may be required to 'drift' downstream to places where cover is available or burrow into the sediment. Surprisingly, correlations between either benthic communities or periphyton biomass and concentrations of nutrients were very weak. As well, correlations between benthic invertebrate communities of depositional habitats and concentrations of hydrocarbons, metals and PAHs in sediment were also weak, suggesting that observed variations in benthos are related to other chemical or physical factors rather than oil sands-related chemicals.

Strong correlations between fish assemblages and environmental variables were also limited and sometimes in contradiction to results observed for benthic invertebrate communities. As with benthic evenness, fish ATI and total abundance in depositional reaches varied negatively with variables related to discharge; however, unlike benthic communities, fish richness and diversity were either not related (erosional reaches) or negatively associated (depositional reaches) with the water quality PC axis describing general ion concentrations. Interestingly, fish abundance was also lower in depositional reaches with higher sediment concentrations of hydrocarbons/metals; whereas no relationship was found with benthic communities that live on and within bottom sediments. It is possible that the negative correlations observed between fish abundance and flow/sediment quality are proximate and the relationship is more a function of difficulties in sampling small-bodied fishes in deeper pool/run depositional habitats using backpack/boat electrofishing gear. Likewise, lower fish abundance in erosional habitats with high TSS, may also reflect difficulties in observing and capturing fish by electrofishing under turbid water conditions or could indicate that fish are more abundant in clearer waters.

The comparisons were exploratory in nature and describe correlations between environmental variables and biologic measurement endpoints that warrant further investigation. However in general, strong relationships were not common and may be the result of several factors, including:

- Other environmental variables not included in the current analyses may influence biotic measurement endpoints strongly;
- Analysis of data from the region as a whole may have masked watershed-specific relationships;
- Relationships observed between variables and measurement endpoints may not be linear and there may be an optimum level of environmental conditions for biological communities;
- Some variability in biota and environmental variables had been removed *a priori* by conducting separate analyses for erosional and depositional habitats; and
- Given the many physiographic consistencies among regional watercourses, there may be more similarity than difference in environmental characteristics and biological communities within and among watersheds in many of the variables examined in this analysis.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The 2011 RAMP monitoring program results have been discussed in detail in sections 5 and 6. This section provides a summary of results for each component of RAMP. Based on results presented in Section 5, Table 8.1-2 provides a summary of the 2011 RAMP 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.

8.1 CLIMATE AND HYDROLOGY

8.1.1 Summary of 2011 Results

Hydrologic changes in the RAMP FSA in the 2011 water year (WY) were assessed as **Negligible-Low** in nine of 13 watersheds assessed. The exceptions to this were the Muskeg River, Tar River, Mills Creek, and Fort Creek watersheds in which at least one of the four measurement endpoints was classified as **Moderate** or **High** (Table 8.1-1). In the 2011 WY, the activities of focal projects and other oil sands developments contributing to hydrologic changes in the RAMP FSA, in order of decreasing hydrological effect, 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 2011 WY (Table 8.1-1). 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 percent change from *baseline* to *test* ranged from -0.3% (annual maximum daily discharge) to -1.9% (mean winter discharge) (Figure 8.1-1). 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 was no trend from 2004 to 2011 in changes from *baseline* to *test* in the four measurement endpoints (Figure 8.1-1).

Table 8.1-1 Summary assessment of the RAMP 2011 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	Moderate (+)	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	*not measured*	Negligible-Low
Hangingstone River	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low
Poplar Creek	Negligible-Low	*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%.

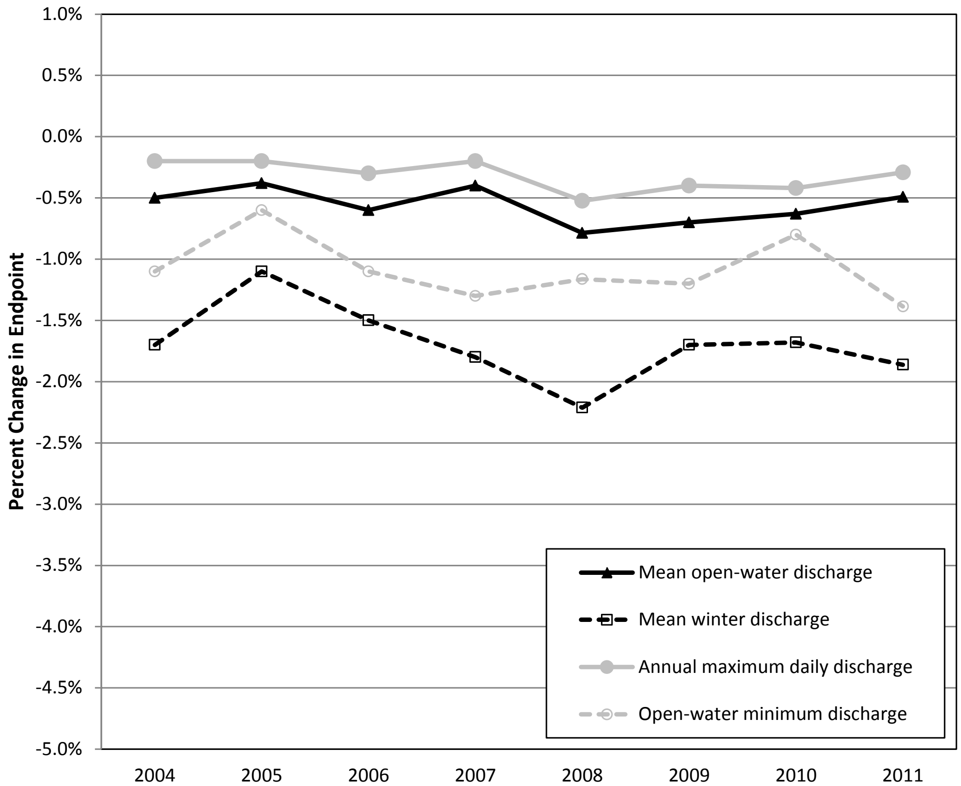
"not measured" means hydrologic information was not obtained for times of year for which the measurement endpoint is applicable.

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).

8.1.2 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 FSA 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 was installed further downstream in 2011 to monitor for potential effects of all oil sands developments. This station will be utilized in future reports to ensure a more complete assessment of the oil sands is conducted. In addition to a new location on the Athabasca River, a station was installed at the mouth of the Christina River and at additional locations within the RAMP FSA.

Figure 8.1-1 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 the 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 and 2011 analyses and reporting of the RAMP hydrology data. 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 2012 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.

8.1.3 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 the 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 8.1-2 Summary assessment of RAMP 2011 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]	Fish Assemblages[5]	Species	Subs. Fishers	General Cons.	
Athabasca River	Negligible-Low	Negligible-Low / Moderate	-	-	-	LKWH WALL	Negligible-Low High	Negligible-Low Moderate	-
Athabasca River Delta	-	-	Negligible-Low / Moderate	n/a	-	-	-	-	-
Muskeg River	High	Negligible-Low	Negligible-Low / Moderate	Negligible-Low	Negligible-Low / Moderate	-	-	-	-
Jackpine Creek	nm	Negligible-Low	Negligible-Low	Negligible-Low	Negligible-Low	-	-	-	-
Kearl Lake	nm	Negligible-Low	Moderate	n/a	-	-	-	-	-
Steepbank River	Negligible-Low	Moderate	Moderate	-	Negligible-Low	-	-	-	-
Tar River	High	Negligible-Low	Moderate	Moderate	-	-	-	-	-
MacKay River	Negligible-Low	Negligible-Low	Moderate / Negligible-Low	-	Negligible-Low	-	-	-	-
Calumet River	Negligible-Low	Negligible-Low	nm	nm	nm	-	-	-	-
Firebag River	Negligible-Low	Negligible-Low	nm	nm	nm	-	-	-	-
McClelland Lake	nm	n/a	Negligible-Low	n/a	-				
Johnson Lake	-	n/a	n/a	n/a	-				
Ells River	Negligible-Low	Negligible-Low	Negligible-Low	Moderate	Negligible-Low	-	-	-	-
Christina River	Negligible-Low	Negligible-Low	nm	nm	nm	-	-	-	-
Clearwater River	nm	Negligible-Low	Moderate	Negligible-Low	-	-	-	-	-
High Hills River	-	Negligible-Low	n/a	-	n/a				
Hangingstone River	Negligible-Low	-	-	-	-	-	-	-	-
Fort Creek	Moderate	Negligible-Low	High	Negligible-Low	Negligible-Low	-	-	-	-
Beaver River	-	Moderate	-	-	-	-	-	-	-
McLean Creek	-	Moderate	-	-	-	-	-	-	-
Mills Creek	High	Moderate	-	-	-	-	-	-	-
Isadore's Lake	nm	n/a	Negligible-Low	n/a	-				
Poplar Creek	Negligible-Low	Negligible-Low	Moderate	Negligible-Low	Negligible-Low	-	-	-	-
Shipyard Lake	-	n/a	Negligible-Low	n/a	-	-	-	-	-
Big Creek	-	Negligible-Low	-	-	-		-		-
Pierre River	-	Negligible-Low	-	-	-		-		-
Red Clay Creek	-	Negligible-Low	-	-	-		-		-
Eymundson Creek	-	Moderate	-	-	-		-		-
Stony Mountains	-	-	-	-	-		-		Negligible-Low
West of Fort McMurray	-	-	-	-	-		-		Negligible-Low
Northeast of Fort McMurray	-	-	-	-	-		-		Negligible-Low
Birch Mountains	-	-	-	-	-		-		Negligible-Low
Canadian Shield	-	-	-	-	-		-		Negligible-Low
Caribou Mountains	-	-	-	-	-		-		Negligible-Low

Legend and Notes

- Negligible-Low change
- Moderate change
- High change

"-" program was not completed in 2011.

nm - not measured in 2011.

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-MR-W, 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 all reaches in the Athabasca River Delta was assessed as Negligible-Low with the exception of Fletcher Channel, which was assessed as Moderate.

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 the middle reach of the MacKay River were assessed as Negligible-Low and benthic invertebrate communities at the lower reach were assessed as Moderate.

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

5 **Fish Populations (Fish Assemblages):** Classification based on exceedances of measurement from the regional variation in *baseline* reaches; see Section 3.2.4.3 for a detailed description of the classification methodology.

Note: Fish assemblages at the lower and upper reaches of the Muskeg River were assessed as Negligible-Low and fish assemblages at the middle reach were assessed as Moderate.

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

LKWH - lake whitefish; WALL - walleye.

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.

8.2 WATER QUALITY

8.2.1 Summary of 2011 Results

Water quality measured by RAMP at various waterbodies in fall 2011, especially in tributaries to the Athabasca River, was strongly influenced by low flows in September as a result of a dry summer, which generally caused an increase in concentrations of ions, total dissolved solids, pH, and conductivity across stations in the RAMP FSA.

The following waterbodies in 2011 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 of Mills Creek (a location of aggregate quarrying operations), as confirmed by RAMP data collected from this creek since 2010.
- **Steepbank River –** Increasing concentrations of several ions, total suspended solids, and some metals were observed at the lower station indicating a **Moderate** difference from regional *baseline* conditions because concentrations exceeded regional *baseline* concentrations and were higher than previously-measured at this station.
- **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.
- **Mills Creek –** Differences observed in water quality were classified as **Moderate** because of high concentrations of many ions and dissolved species that exceeded regional *baseline* concentrations.
- **Beaver River –** Differences observed in water quality were classified as **Moderate** because of high concentrations of many ions and dissolved species that exceeded regional *baseline* concentrations.
- **McLean Creek –** Differences observed in water quality were classified as **Moderate** because of high concentrations of many ions, which caused a shift in the ionic balance and exceeded regional *baseline* concentrations and high concentrations of dissolved species that exceeded regional *baseline* concentrations.
- **Eymundson Creek –** Differences observed in water quality were classified as **Moderate** because of high concentrations of many ions, metals and total suspended solids that exceeded regional *baseline* concentrations. In addition, water quality in this creek differed in ionic composition compared to other baseline stations in that area (Big Creek, Pierre River, Red Clay Creek), with a higher concentration of sulphate and less bicarbonate, which suggests a greater influence of groundwater.
- **Athabasca River –** *Test* station ATR-MR-W (upstream of the Muskeg River, west bank) exhibited water quality that showed **Moderate** differences from historical *baseline* conditions because of high TSS and particulate metals.

Aside from these localized changes, water quality in the RAMP FSA in 2011 was largely consistent with regional *baseline* conditions (Table 8.1-2).

8.2.2 Study Design Considerations

In 2011, analyses of naphthenic acids in water samples from RAMP stations by AITF and the University of Alberta indicated that the spatial heterogeneity of compounds captured by different methods may be as, or more, important than differences in magnitude of reported results. 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.

Beginning in spring 2011, analyses of water included both total recoverable hydrocarbons (TRH) and a potential future replacement, CCME Total Petroleum Hydrocarbons (TPH), which provides a more comprehensive and higher-resolution set of data describing hydrocarbons in water. The CCME TPH suite of analyses provided much more detailed and higher-resolution information regarding petroleum hydrocarbons than the existing TRH test; therefore, analysis of CCME TPH analytes should be continued in future RAMP sampling programs.

Total PAHs in tributary waters showed a strong correlation with total PAHs in sediments measured by RAMP at corresponding locations. PAHs in water were lowest at stations with low PAHs in sediment, typically those in upper watersheds; PAHs in water were highest at locations with high PAHs in sediments, typically in lower watersheds. This correlation suggests that partitioning of PAHs from river sediments into overlying water may be the primary mechanism for waterborne PAH exposure in regional tributaries, consistent with assumptions or conclusions of several other studies, including Tetriault *et al.* (2003) and Colavecchia *et al.* (2004, 2006).

8.2.3 Recommendations

The following recommendations are outlined to further improve monitoring conducted for the Water Quality component:

1. Continue to add *baseline* stations 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. Continue analyzing CCME 4-fraction Total Petroleum Hydrocarbons in water samples, with this suite of analytes replacing Total Recoverable Hydrocarbons;

4. Continue to analyze for PAHs in water to further clarify sources of within- and among-watershed variability observed in PAH concentrations.

8.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

8.3.1 Benthic Invertebrate Communities

8.3.1.1 Summary of 2011 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 were 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 were classified as **Moderate** because of the observed decrease over time in diversity, evenness, and percent EPT, all of which are typically associated with a negative change in benthic invertebrate communities. There has also been a high abundance of tubificid worms consistently over time in Fletcher Channel.

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 were assessed based on historical years in each lake, which was difficult in lakes with shorter sampling periods, such as Isadore's Lake. Similarly to 2010, 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.**

Rivers: Consistent with 2010, differences in measurement endpoints for benthic invertebrate communities in the lower *test* reach of Fort Creek were classified as **High** because decreases in abundance, richness, diversity, and evenness were below 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**:

- **Clearwater River –** Differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of the Clearwater River were classified as **Moderate** because of the significant decreases in abundance, richness, and percent EPT compared to the upper *baseline* reach.

- **Muskeg River –** Differences in measurement endpoints for benthic invertebrate communities at the upper *test* reach of the Muskeg River were classified as **Moderate** because of the decrease in taxa richness during the period that the reach was designated as *test* compared to the *baseline* period. In addition, there has been an increase in tubificid worms and a decrease in the number of mayflies, which may suggest degraded conditions.

- **Poplar Creek –** This was the fourth year of sampling for benthic invertebrate communities at 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. Consistent with 2010, differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of Poplar Creek were classified as **Moderate** because of significantly lower percent EPT compared to the upper *baseline* reach.

- **Tar River –** Differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of the Tar River were classified as **Moderate** because of the significantly large decreases in total abundance, taxa richness, diversity and evenness from the period when the reach as designated as *baseline* to the period when the reach became *test*. In addition, there was a dominance of tubificid worms in the benthic invertebrate community potentially indicating degraded conditions.

- **Steepbank River –** Differences in measurement endpoints of the benthic at the lower *test* reach of the Steepbank River were classified as **Moderate** because abundance, richness, percent EPT, and CA axis scores were significantly lower compared to the upper *baseline* reach. In addition, the reach was dominated by tolerant naidids, which could indicate degraded conditions, although there were more sensitive taxa present that were representative of good water quality.

- **MacKay River –** Differences in the values of measurement endpoints for benthic invertebrate communities at the lower *test* reach of the MacKay River were classified as **Moderate** because the percent EPT was significantly higher at the upper *baseline* reach compared to this reach and there was a significant decrease in total abundance and richness from the period when the reach was designated as *baseline* to the period when the reach became *test*.

Changes in the following reaches were classified as **Negligible-Low**:

- **Muskeg River –** Differences in measurement endpoints for benthic invertebrate communities in 2011 at the lower and middle *test* reaches of the Muskeg River were classified as **Negligible-Low** because the significant changes in some of the measurement endpoints did not imply a negative change to the benthic invertebrate community. The lower *test* reach had an increase in abundance, which could imply a negative change; however, the increase was coupled with a high relative abundance of sensitive taxa of mayflies, caddisflies, and stoneflies (EPT taxa). The middle *test* reach had an increase in percent EPT, reflecting good habitat conditions.

- **Jackpine Creek –** Differences in measurement endpoints of benthic invertebrate communities at the lower *test* reach of Jackpine Creek were classified as **Negligible-Low** because of the significant increase in taxa richness, diversity and evenness during the period when the reach became designated as *test*. In addition, values of some measurement endpoints (i.e., abundance, richness, and diversity) that exceeded the range of regional *baseline* conditions did not imply a negative change in the benthic invertebrate community.

- **MacKay River –** Differences in measurement endpoints of benthic invertebrate communities at the middle *test* reach of the MacKay River were classified as **Negligible-Low** because there were significant increases in richness, diversity, and percent EPT across time and no significant differences in measurement endpoints compared to the upper *baseline* reach. The benthic invertebrate community was diverse and contained a number of sensitive chironomid, mayfly, stonefly, and caddisfly taxa.

- **Ells River –** Differences in measurement endpoints for benthic invertebrate communities at the lower *test* reach of the Ells River were classified as **Negligible-Low** because the significant increase in richness did not imply a negative change in the benthic invertebrate community. It should be noted that there was a high relative abundance of tubificid worms and a low relative abundance of caddisflies, mayflies, and stoneflies, which might indicate a trend towards a degraded environment.

8.3.1.2 Study Design Considerations

The idea of sampling the mainstem Athabasca River was considered by the RAMP Technical Committee in 2011 and an analysis of previous surveys was conducted to determine the most effective sampling methods. Golder (2003) demonstrated that various studies have collected benthic samples in erosional riffle habitats throughout the mainstem Athabasca River between the town of Fort McMurray and Fort Creek; therefore, it is recommended that RAMP consider the future collection of samples from riffle habitats using Neill-Hess cylinders or another similar apparatus. From a practical perspective, run/pool habitat are more common than riffles in the lower Athabasca River, which would require the use of an Ekman grab or similar sampler, recognizing that benthic invertebrate communities would be dominated by more tolerant taxa.

The sampling design should be based on demonstrating that a valid EEM approach to sampling can be carried out. That is, the design should nest 5 to 6 reaches within an area and some number of stations within a reach (perhaps up to six samples, as per this analysis). Stations, as per Environment Canada (2011) need to be on the order of 10 m x 10 m long and separated spatially by a distance at least as great. Sample reaches within which stations are situated, should be relatively long to be consistent with the design of the sampling programs in tributary reaches (i.e., 2 to 4 km long). The USEPA (2006) uses a sampling reach that is approximately 500 m long for large rivers. Sampling reaches can be situated along the length of the Athabasca River to isolate and assess various point and non-point sources, as applicable.

The pilot study in Fletcher Channel of the ARD was conducted to explore the influence of sample area size on estimates of measurement endpoints for benthic invertebrate communities given the high abundance of benthos collected in 2010. This study did not demonstrate a significant effect of spatial scale (i.e., sampling at the reach vs. station) on variation in estimates of measurement endpoints for benthic invertebrate communities. Within-reach spatial heterogeneity of substrates, specifically substrate texture, appears to have been a driver of observed variability in benthic invertebrate measurement endpoints among replicates. The data suggest that temporal variability rather than spatial variability in substrate type may be the cause of the very high observed abundance in Fletcher Channel in 2010.

8.3.1.3 Recommendations

To further improve monitoring conducted for the Benthic Invertebrate Communities component, RAMP should evaluate whether sampling erosional habitat in the mainstem Athabasca River is feasible based on habitat availability. If so, consider sampling benthic invertebrate communities using a Neill-Hess cylinder; otherwise, sampling could be conducted in more abundant depositional habitat using a grab sampling device, recognizing that the benthic invertebrate communities in depositional habitat will be dominated by more tolerant species.

8.3.2 Sediment Quality

8.3.2.1 Summary of 2011 Results

Sediments in the RAMP FSA naturally contain concentrations of hydrocarbons and PAHs that may exceed environmental-quality guidelines.

In fall 2011, differences in sediment quality from regional *baseline* conditions were classified as **Moderate** at the lower *test* stations of the Tar and Ells rivers and **Negligible-Low** at all other sampling stations (Table 8.1-2), with concentrations of metals, hydrocarbons and PAHs in sediments generally within previously-measured concentrations throughout the RAMP FSA. The exceptions at stations on the Tar and Ells rivers are noted:

1. Concentrations of PAHs in the lower Ells River exceeded regional *baseline* concentrations, although were still within previously-measured concentrations at this station.
2. Concentrations of total metals and the predicted PAH toxicity of sediments in the lower Tar River exceeded regional *baseline* conditions, although both values were within previously-measured values for this station.

8.3.2.2 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.

8.4 FISH POPULATIONS

The 2011 RAMP Fish Populations component consisted of:

- fish inventories on the Athabasca and Clearwater rivers;
- fish assemblage monitoring on tributaries to the Athabasca and Clearwater rivers; and
- a fish tissue program on the Athabasca River.

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 program was initiated in 2011 following a two-year pilot study as a new approach to monitoring fish populations in the RAMP FSA. Fish assemblage monitoring was conducted at all tributary reaches sampled for benthic invertebrate communities.

8.4.1 Summary of 2011 Results

8.4.1.1 Fish Inventory

In 2011, the analysis of the Athabasca River and Clearwater River fish inventories focused on seasonal and spatial trends over time of catch per unit effort, fish condition, and age-frequency distributions for Key Indicator Resource (KIR) fish species.

Fish inventories on the Athabasca River and the Clearwater River are generally considered to be a community-driven activity, primarily suited for assessing general trends in abundance and population variables for KIR fish species, rather than detailed community structure.

As of 2011, current and historical fish inventory data from the Athabasca River indicated species-specific variability in relative abundance, age-frequency distributions, and condition of fish among years. Statistically significant differences were observed among years for condition in some 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 indicated that abnormalities observed in 2011 in all species were within the historical range and consistent with studies done prior to the major oil sands development in the upper Athabasca River, the ARD, and the Peace and Slave rivers.

In 2011, species richness in the Clearwater River was higher than all years in the spring, with the exception of 2007 and 2008; significantly higher than summer 2010; and less than fall 2010 but within the higher scale of the historical range (2003 to 2011).

The relative abundance of fish species in the Clearwater River was variable without any clear trends observed over time. Similarly, there has been no marked shift in species dominance from year to year. There have been no significant differences in condition of large-bodied KIR fish species in the Clearwater River across years. Condition can not necessarily be attributed to the environmental conditions in the capture location, as these populations are highly migratory throughout the region. In 2011, a shift towards a younger age-class was observed in northern pike and walleye. Although uncertain, this may reflect increasing fishing pressure on adult fish over the years within the Clearwater River causing a shift to a population dominated by younger individuals.

8.4.1.2 Fish Assemblage Monitoring

Fish assemblage monitoring characterizes changes in river reaches 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* or against regional *baseline* conditions. Differences within reaches are used to judge changes over time. 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 2011 results are provided below.

Differences in measurement endpoints (abundance, species richness, diversity, evenness, and the assemblage tolerance index) for fish assemblages were classified as **Negligible-Low** compared to regional *baseline* conditions in the following reaches:

- Muskeg River – lower reach;
- Poplar Creek;
- Tar River;
- Steepbank River;
- MacKay River;
- Muskeg River;
- Jackpine Creek; and
- MacKay River.

Differences in measurement endpoints for fish assemblages were classified as **Moderate** compared to regional *baseline* conditions at the middle *test* reach of the Muskeg River given that the median value of all measurement endpoints were below the range of variability for *baseline* reaches.

8.4.1.3 Fish Tissue

In 2011, the potential risk to human health related to fish consumption was assessed using individual samples of walleye and lake whitefish collected from the Athabasca River.

Measurement endpoints used in the assessment for the Athabasca River fish tissue program included metals and tainting compounds in fish tissue of both individual and composite samples. Potential human health risks from contaminated fish tissue were predicted from both individual and composite samples. In 2011, the mean concentration of mercury in lake whitefish was lower than previous years, with the exception of 2008, and the mean concentration of mercury in walleye was higher in 2011 compared to previous years, with the exception of 2003. The mean mercury concentration across all size classes of lake whitefish were below the Health Canada guideline for subsistence fishers indicating a **Negligible-Low** risk to human health. The mean mercury concentration of size classes of walleye greater than 300 mm exceeded the subsistence fishers guideline for consumption indicating a **High** risk to subsistence fishers and a **Moderate** risk to general consumers.

8.4.2 Recommendations

The following recommendations are outlined to further improve monitoring conducted for the Fish Populations component:

1. In response to community concerns regarding the health of fish in watercourses within the RAMP FSA, RAMP is continuing to collect data on fish abnormalities and working with a fish pathologist to develop a better

understanding of abnormalities in fish in Northern Alberta. RAMP is facilitating the analyses of fish with abnormalities submitted by community members and continues to find means to work with communities to assess fish health.

2. Based on the first year of the fish assemblage monitoring program, it was evident that there is value to the increased harmonization of the RAMP components in an effort to assess the surface watercourse conditions on a holistic basis. It is; therefore, recommended that RAMP continue this monitoring activity to gain more years of data to assess trends in fish assemblage measurement endpoints over time and in relation to water quality, hydrology, benthos, and sediment quality.

8.5 ACID-SENSITIVE LAKES

8.5.1 Summary of 2011 Results

There have been few changes in the chemistry of the 50 ASL component lakes (RAMP lakes) over the ten years of monitoring (2002 to 2011). In among-year comparisons utilizing the general linear model of ANOVA, DOC was the only measurement endpoint showing a significant change in a direction (decrease) indicative of acidification. The decrease in DOC in the RAMP lakes was determined to be more likely the result of other factors (e.g., changes in hydrological conditions) than the result of acidification. Other significant changes in the chemistry of the RAMP lakes included an increase in sodium and decrease in chloride. The significant trends in these relatively conservative variables also suggest the role of hydrology in controlling lake chemistry.

A critical load of acidity was calculated for each RAMP lake for 2002 to 2011 using the Henriksen steady state water chemistry model modified to include the contribution of organic anions as both strong acids and weak organic buffers. Critical loads were calculated using values of runoff derived from an isotopic mass balance technique (Gibson *et al.* 2010). Critical loads in 2011 ranged from -0.420 keq H^+/ha/yr to 4.54 keq H^+/ha/yr with a median CL of 0.566 keq H^+/ha/y. The lowest critical loads were found in lakes in the upland regions including the Stony Mountains, Birch Mountains, and Canadian Shield subregions. Lakes in the Stony Mountains, having the lowest critical loads, are the most acid-sensitive of the RAMP lakes.

The critical load of acidity for each individual lake was compared to the modeled rate of acid deposition in each catchment published in the Teck Frontier EIA (Teck 2011) and CEMA (2010). A maximum emissions scenario was assumed representing existing emissions sources as well as emissions from industrial sources that have been approved by the regulators. Acid input was expressed as the Net Potential Acid Input (PAI) which corrects for the N uptake by plants in the lake catchments (AENV 2007, CEMA 2004). A total of 11 (22%) of the 50 lakes had critical loads exceeded by the Net PAI. Seven of the 11 lakes were found in the Stony Mountains subregion.

The percent of RAMP 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 RAMP lakes reflects a bias in the RAMP ASL component design that preferentially selected the most poorly-buffered lakes for monitoring. The rates of critical load exceedance in the RAMP 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 the 50 individual RAMP lakes to detect changes that might indicate incipient acidification. As in previous years, all of the 11 significant trends in measurement endpoints were either small and within the range of analytical error or inconsistent with any reasonable acidification scenario. There were no significant decreases in Gran alkalinity in any of the 50 RAMP lakes.

Shewhart control charting was applied to the measurement endpoints in order to detect acidifying trends in ten individual lakes most at risk to acidification. The ten lakes were selected for control charting based on an acidification risk factor calculated from the ratio of potential acid input to the value of the critical load. The ten lakes were scattered throughout the oil sands region in the Stony Mountains (6), Birch Mountains (2), Northeast of Fort McMurray (1) and West of Fort McMurray (1) subregions. While the control charts showed a number of isolated exceedances of the two standard deviation limits in individual lakes, there was no suggestion of real trends in these lakes indicative of acidification. Concentrations of nitrates were highly variable and could range over three orders of magnitude within a lake.

Based on the analysis of among-year differences in concentrations of measurement endpoints, trend analysis and control plotting of measurement endpoints on individual lakes, there is no evidence to suggest that acidification is occurring in the RAMP lakes.

A summary of the state of the RAMP lakes in 2011 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 (in a direction indicative of acidification) for each lake. All six subregions were classified as having a **Negligible-Low** indication of incipient acidification.

8.6 INTEGRATION ANALYSIS OF RAMP DATA

Over the last several years, RAMP has made an increasing effort to harmonize and integrate its monitoring components (i.e., water quality, sediment quality, benthic invertebrate communities and fish assemblages) with respect to space and time. This harmonization provided an opportunity to undertake exploratory analyses to gain a better understanding of possible relationships between environmental variables and the observed temporal and spatial variability in benthic invertebrate communities and fish assemblages of the region. From this analysis, the following general patterns were observed:

- Benthic invertebrate communities tended to be more abundant, rich and diverse during periods of sampling or in rivers with low flows, which logically coincided with higher ion concentrations in water (conductivity, DOC, alkalinity);
- Benthic invertebrate community abundance tended to be more abundant with increasing periphyton biomass. This may reflect a response to increasing food availability, particularly for grazing taxa such as Ephemeroptera and Plecoptera (among others), which also were found to increase with increasing periphyton;
- Neither benthos nor periphyton correlated with nutrient concentrations nor sediment chemistry (PAHs, metals, hydrocarbons), suggesting the variation in benthos communities is related to other chemical or physical factors unrelated to oil sands chemicals;

- As with benthic evenness, fish abundance and the fish assemblage tolerance index (ATI) in depositional reaches varied negatively with variables related to discharge; however, unlike benthic communities, fish richness and diversity were either not related (erosional reaches) or negatively associated (depositional reaches) with general ion concentrations in water; and
- Fish abundance was lower in depositional reaches with higher sediment concentrations of hydrocarbons/PAHs/metals; however, it is possible that fish assemblages were more difficult to capture in deeper pool/run depositional habitats using backpack/boat electrofishing gear.

Generally, strong relationships between variables describing benthic invertebrate communities and fish assemblages and environmental variables were limited; however, the above correlations do suggest some areas that warrant further investigation. As well, future analyses will need to consider other potential factors that may play a role in the observed variation in aquatic biota of the region.

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10.0 GLOSSARY AND LIST OF ACRONYMS

10.1 GLOSSARY

Abundance	Number of organisms in a defined sampling unit, usually expressed as aerial coverage.
Acute	Acute refers to a stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.
Ageing Structures	Parts of the fish which are taken for ageing analyses. These structures contain bands for each year of growth or maturity which can be counted. Some examples of these structures are scales, fin rays, otoliths and opercula. Most ageing structures can be taken with minimal effect on the fish and vary according to fish species.
Alkalinity	A measure of water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates and hydroxides, and less significantly, borates, silicates, phosphates and organic substances. It is expressed as an equivalent of calcium carbonate. The composition of alkalinity is affected by pH, mineral composition, temperature and ionic strength. However, alkalinity is normally interpreted as a function of carbonates, bicarbonates and hydroxides. The sum of these three components is called total alkalinity.
ANCOVA	Analysis of covariance. ANCOVA compares regression lines, testing for differences in either slopes or intercepts (adjusted means).
ANOVA	Analysis of variance. An ANOVA tests for differences among levels of one or more factors. For example, individual sites are levels of the factor site. Two or more factors can be included in an ANOVA (e.g., site and year).
Baseline	*Baseline* is the term used in this report to describe aquatic resources and physical locations (i.e., stations, reaches, data) that are (in 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.

10.2 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
AEW	Alberta Environment and Water
AITF	Alberta Innovates Technology Futures
Albian	Albian Sands Energy Inc.
ALPAC	Alberta-Pacific Forest Industries Inc.
ALS	ALS Laboratory Ltd.
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
ARD	Athabasca River Delta
ASL	Acid Sensitive Lakes
ASRD	Alberta Sustainable Resource Development
ATI	Assemblage Tolerance Index
AWOS	Automated Weather Observing System
AWRI	Alberta Water 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 Analysis
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
CVAFS	Cold Vapor Atomic Fluorescence Spectraphotometry
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 Infrared
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
HC	Health Canada
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
LWD	Large woody debris
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
OSE	Oil Sands Exploration
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 Drainage
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
SWD	Small woody debris
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 Hydrocarbons
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WBEA	Wood Buffalo Environmental Association
WQI	Water Quality Index
WSC	Water Survey of Canada
WY	Water Year