3.0 2004 RAMP MONITORING PROGRAM

This section contains descriptions of the RAMP monitoring program conducted in 2004 for each RAMP component, and includes the following:

- overview of the 2004 program;
- detailed description of field methods;
- description of any other information obtained (i.e., information from regulatory agencies, the oil sands operators, knowledge obtained from local communities, and other sources);
- description of changes in monitoring network from the 2003 field program;
- description of the challenges and issues encountered during 2004 and the means by which these challenges and issues were addressed; and
- summary of the component data that is now available.

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

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

Quality Assurance and Quality Control (QA/QC) procedures were employed throughout and for all aspects of the 2004 RAMP monitoring program; Appendix B contains a detailed description of the QA/QC procedures used.

In addition, all RAMP data now resides in a MYSQL relational database which may be found in the members area of the RAMP website at www.ramp-alberta.org; the 2004 data tables are therefore not included in the appendices of this report. Appendix C of this report, however, contains a summary description of the RAMP database.

3.1 CLIMATE AND HYDROLOGY

3.1.1 Overview of 2004 Program

The climate and hydrology monitoring program for 2004 included the following:

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

- conducting the first RAMP regional snow course surveys in February, March and April;
- monitoring water levels and stream flows and collecting water samples for total suspended solids (TSS) analysis at:
  - eleven hydrometric stations in the Muskeg River basin;
  - ten hydrometric stations on other Athabasca River tributaries north of Fort McMurray;
  - three hydrometric stations on other Athabasca River tributaries south of Fort McMurray; and
  - one hydrometric station on the Athabasca River.
- monitoring winter discharges at nine of the hydrometric stations in winter 2003-2004, and ten stations in winter 2004-2005, compared to five stations in winter 2002-2003;
- monitoring water levels at three wetland stations;
- integrating regional climatic and hydrometric monitoring data collected by government agencies into the RAMP database; and
- installing a new hydrometric station on the Ells River.

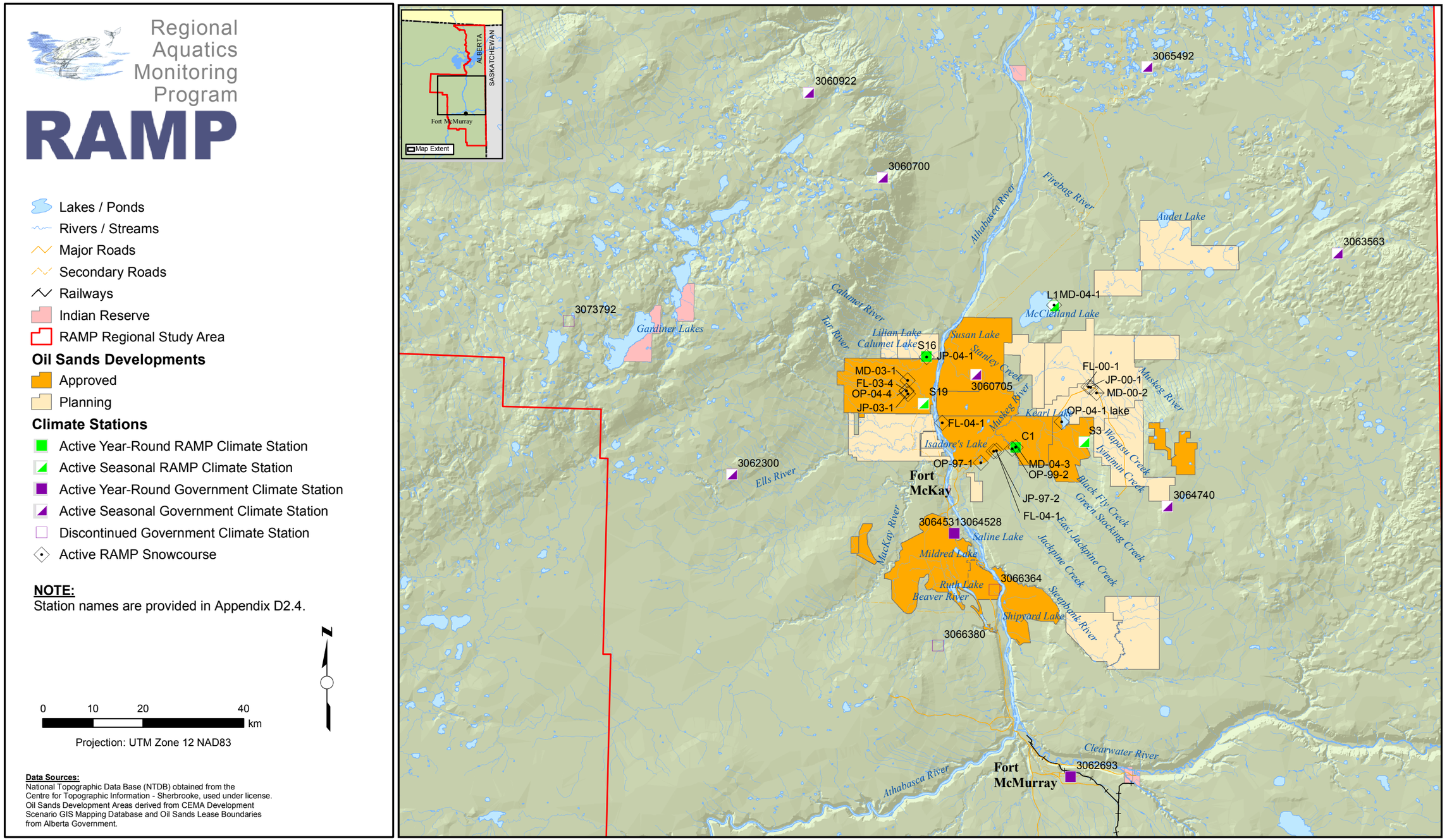
Locations of RAMP and federal and provincial government active and discontinued climate stations, and 2004 snowcourse survey sites, are shown in Figure 3.1-1 for the area north of Fort McMurray and Figure 3.1-2 for the area south of Fort McMurray. Locations of RAMP and government hydrometric stations, both currently active and discontinued, are shown in Figure 3.1-3 for the area north of Fort McMurray and Figure 3.1-4 the area south of Fort McMurray. Non-RAMP stations are identified by station number only on Figures 3.1-1 to 3.1-4; the corresponding station names are provided in Appendix D.

3.1.2 Field Methods

3.1.2.1 General

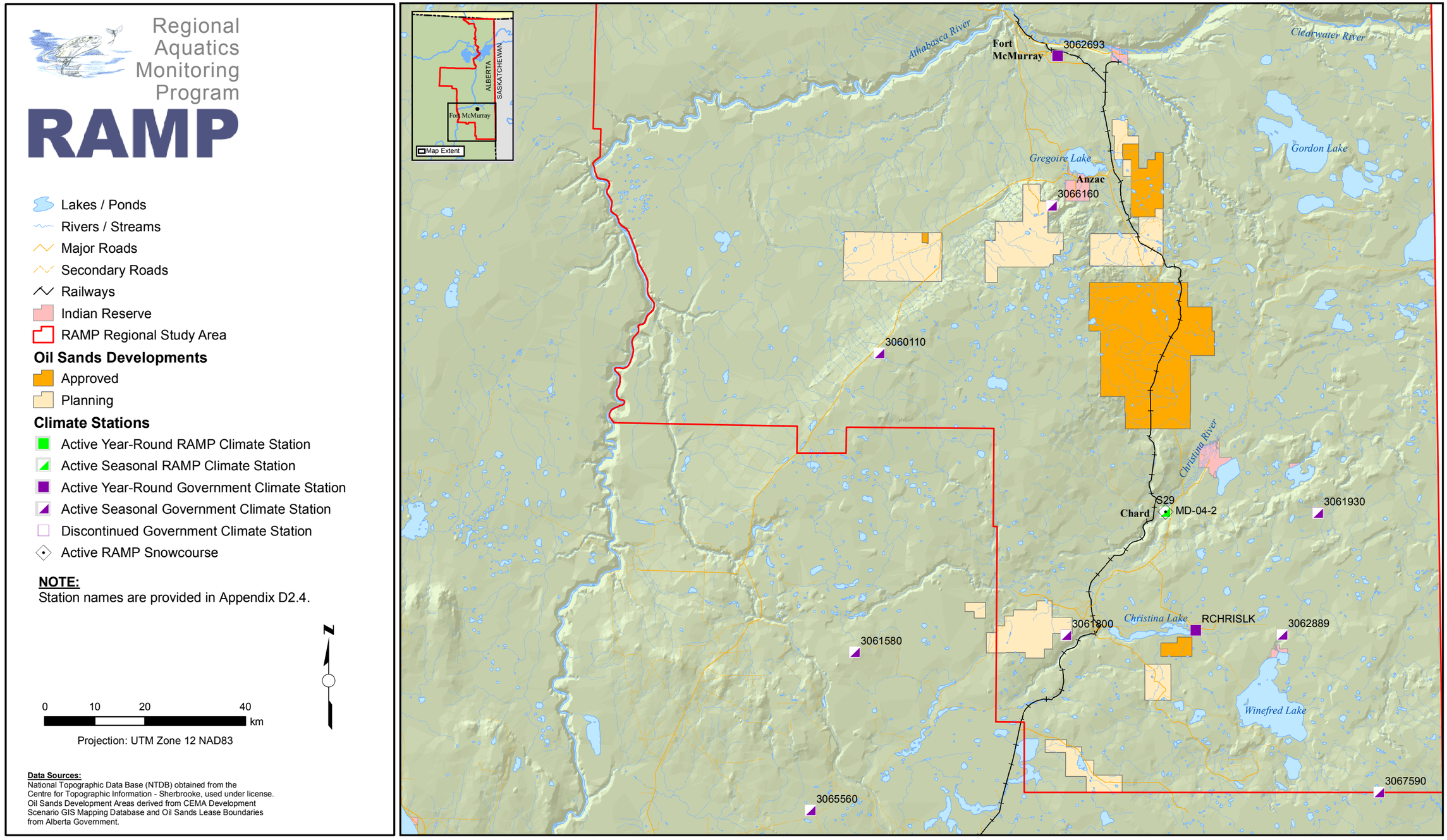
Field staff visited the climate and hydrometric stations routinely to check and maintain automated sensing equipment and to make manual streamflow measurements. Manual streamflow measurements are necessary for the development of a stage-discharge relationship, which is used to convert continuously recorded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

Figure 3.1-1 Locations of active and discontinued climate stations, and 2004 snowcourse survey sites, north of Fort McMurray.



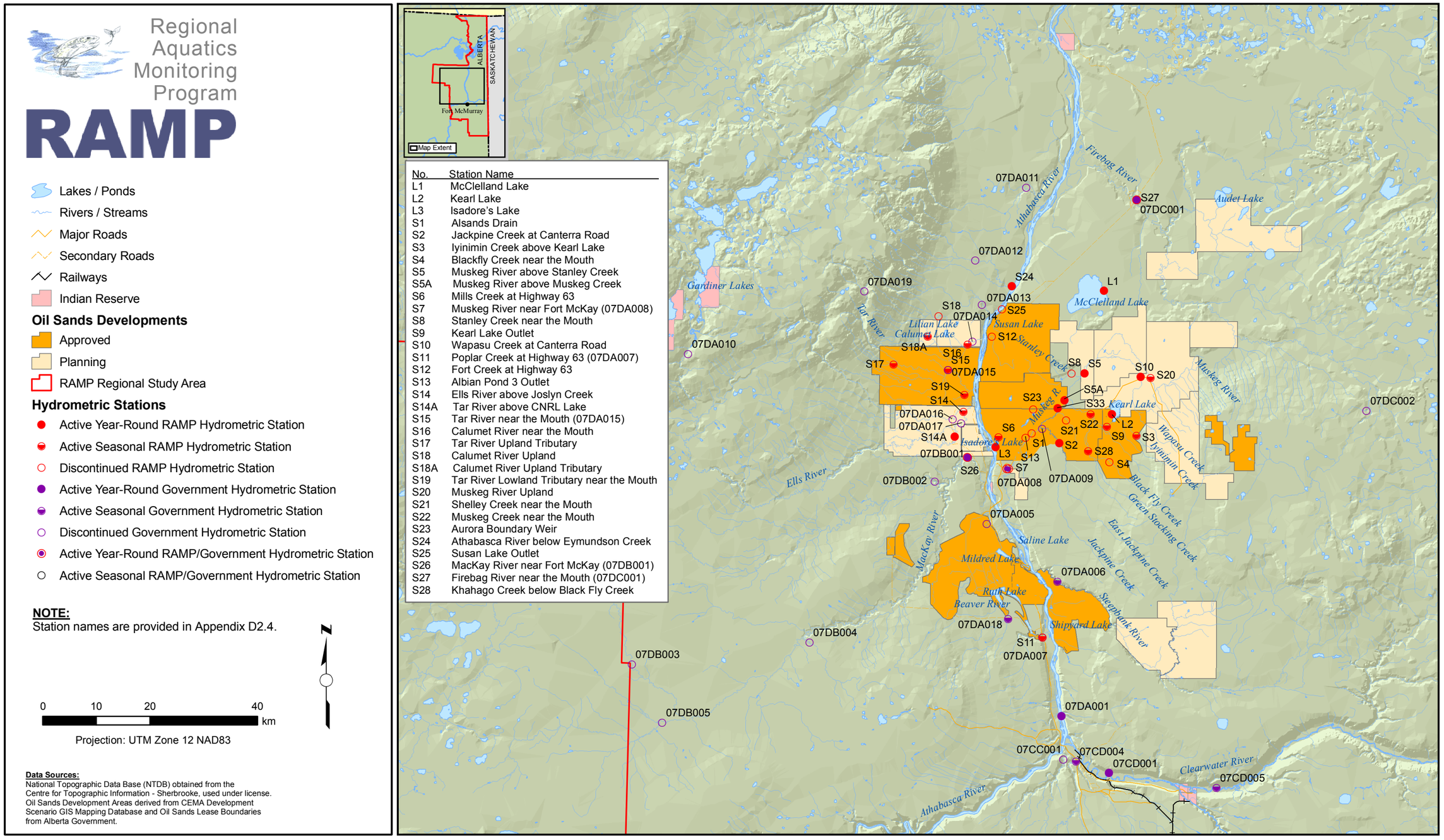
RAMP1110\GIS\2004ClimateN.MXD

Figure 3.1-2 Locations of active and discontinued climate stations, and 2004 snowcourse survey sites, south of Fort McMurray.



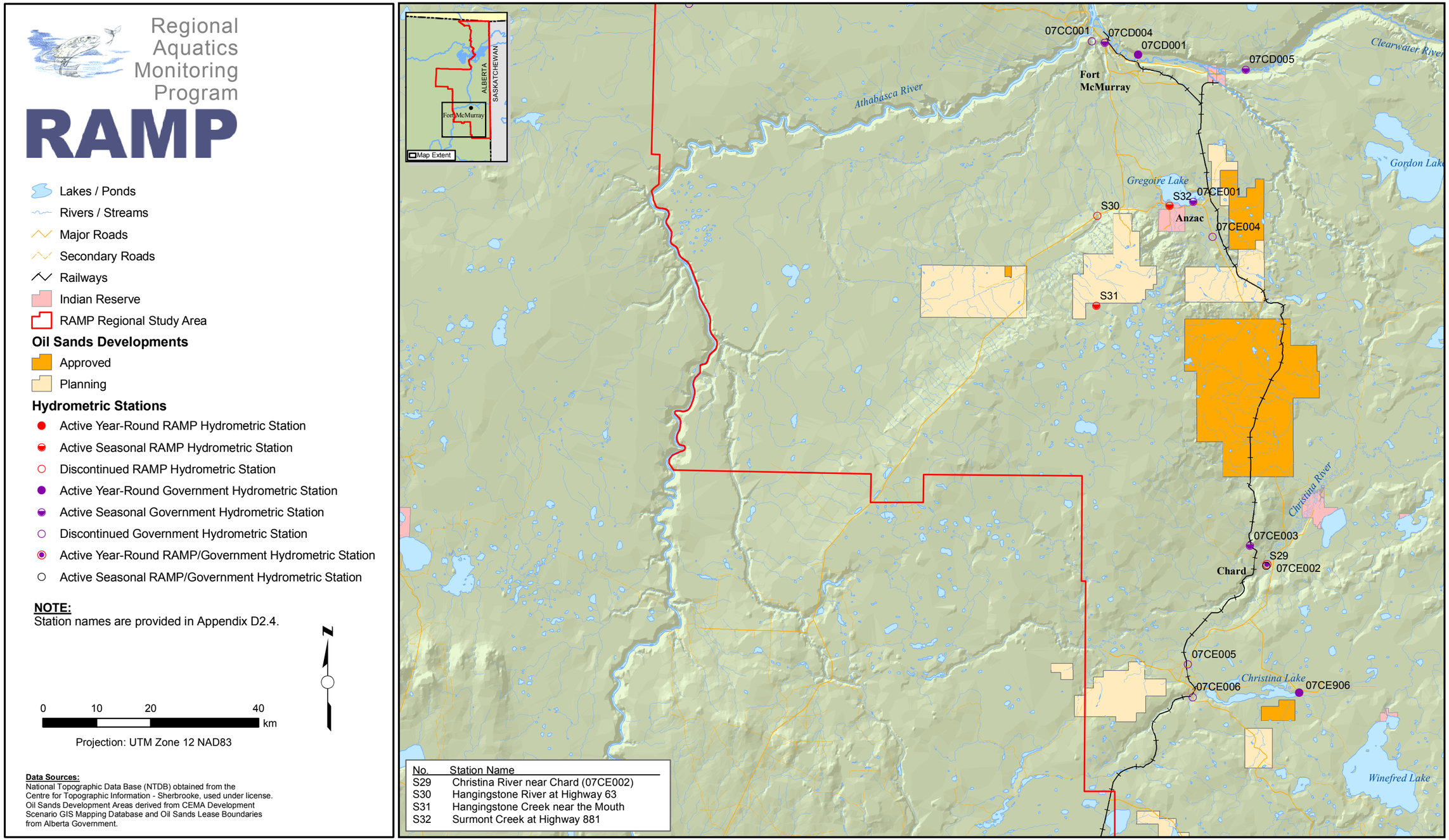
RAMP1110\GIS\2004ClimateS.MXD

Figure 3.1-3 Locations of active and discontinued hydrometric stations north of Fort McMurray.



RAMP1110\GIS\2004HydrologyN.MXD

Figure 3.1-4 Locations of active and discontinued hydrometric stations south of Fort McMurray.



RAMP1110\GIS\2004HydrologyS.MXD

Table 3.1-1 RAMP climate and hydrometric stations operating in 2004.

No.	Name	UTM Coordinates		Operating Season	Parameters Measured
		Easting	Northing		
C1	Aurora Climate Station	475820	6343952	All year	Air temperature, rainfall, humidity, solar radiation, snow on the ground, wind speed and direction
L1	McClelland Lake	483430	6371950	All year Open-water	Water level, discharge Rainfall
L2	Kearl Lake	484935	6349023	All year	Water level
L3	Isadore's Lake	463297	6342987	All year	Water level
S2	Jackpine Creek at Canterra Road	475132	6343680	Open-water	Level, discharge
S3	Iyinimin Creek above Kearl Lake	489491	6345029	Open-water	Level, discharge, rainfall
S5	Muskeg River above Stanley Creek	479820	6356551	All year	Level, discharge
S5A	Muskeg River above Muskeg Creek	476100	6351600	All year	Level, discharge, barometric pressure, water temperature
S6	Mills Creek at Highway 63	463829	6344743	Open-water	Level, discharge
S7	Muskeg River near Fort McKay (07DA008)	465408	6338944	Winter*	Level, discharge
S9	Kearl Lake Outlet	483980	6346750	Open-water	Level, discharge
S10	Wapasu Creek at Canterra Road	490272	6355942	All year	Level, discharge
S11	Poplar Creek at Highway 63 (07DA007)	471998	6307667	Open-water	Level, discharge
S14	Ells River above Joslyn Creek	457310	6349466	Open-water	Level, discharge
S15	Tar River near the Mouth	454390	6357209	Open-water	Level, discharge
S16	Calumet River near the Mouth	458087	6361908	Open-water	Level, discharge, rainfall, snowfall, air temperature, water temperature
S17	Tar River Upland Tributary	444331	6358256	Open-water	Level, discharge
S18a	Calumet River Upland Tributary	452702	6367295	Open-water	Level, discharge
S19	Tar River Lowland Tributary near the Mouth	457502	6352663	Open-water	Level, discharge, rainfall
S20	Muskeg River Upland	492106	6355709	Open-water	Level, discharge
S22	Muskeg Creek near the Mouth	480970	6349071	Open-water	Level, discharge
S24	Athabasca River below Eymundson Creek	466313	6372760	All year	Level, discharge
S26	MacKay River near Fort McKay (07DB001)	458120	6341037	Winter*	Level, discharge
S27	Firebag River near the mouth (07DC001)	489553	6388830	Winter*	Level, discharge
S28	Khahago Creek below Black Fly Creek	480489	6342185	Open-water	Level, discharge
S29	Christina River near Chard (07CE002)	508195	6187926	Winter*	Level, discharge Rainfall
S31	Hangingstone Creek near the mouth	476713	6235953	Open-water	Level, discharge
S32	Surmont Creek at Highway 31	490310	6254473	Open-water	Level, discharge
S33	Muskeg River at the Aurora/ Albian Boundary	474876	6350204	All year	Level, discharge

* Environment Canada monitors water level and discharge at these stations during the open-water season.

3.1.2.2 Streamflow Measurement

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

- Number of verticals: 20, or at a spacing of 0.1 m in small streams;
- Number of readings in the vertical for an open-water measurement: one at 60% of the depth below the surface for depths of 1.1 m or less; otherwise one at 20% and one at 80% of the depth;
- Number of readings in the vertical for a measurement under ice: one at 60% of the depth below the surface for depths of 1.0 m or less; otherwise one at 20% and one at 80% of the depth. At one vertical, a set of at least five readings over the range of depth to obtain a velocity profile; and
- Velocity averaging: At least 20 seconds for electromagnetic meters; 45 seconds for mechanical meters.

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

3.1.2.3 Snow Course Surveys

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

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

3.1.3 Changes in Monitoring Program from 2003

3.1.3.1 Regional Snowcourse Survey

A regional snowcourse survey was initiated in 2004. In previous years, snow surveys have been made at a variety of locations, depending on immediate needs, but have typically been focused on one area each year. The regional survey is designed to monitor general snow conditions over the entire oil sands area. Sixteen sites were selected, as shown in Figure 3.1-1 and Figure 3.1-2, to obtain representative coverage over the variety of terrain and vegetation types in the region. It is intended that the same sites be monitored each year for at least five years to capture year-to-year variability. Three measurements were made in 2004, approximately at the beginning of February, March, and April, to monitor snowpack changes approaching the spring melt and to ensure that the maximum snowpack would be captured.

3.1.3.2 New and Reactivated Monitoring Stations

Deer Creek Energy requested that the Ells River station above Joslyn Creek (S14) be moved to the new road crossing of the Ells River, 6 km downstream of its original location, and converted to a year-round station. The RAMP Climate and Hydrology subgroup members agreed with that request, provided that the existing station is operated for three years in parallel with the new station to provide a basis for comparison of the two records. Accordingly monitoring equipment was temporarily installed at a new station on the Ells River at the CNRL Bridge (S14A), on October 30. A permanent installation will be made after regulatory approvals are obtained.

Two stations south of Fort McMurray, Hangingstone Creek near the Mouth (S31) and Surmont Creek at Highway 881 (S32) were reactivated to provide information on small catchments south of Fort McMurray.

3.1.3.3 Discontinued Stations

Stanley Creek near the mouth (S8) and Shelley Creek near the mouth (S21) were discontinued in 2004, following a recommendation in the 2003 RAMP report. At both stations, hydraulic conditions were so adverse (poorly defined streams, densely vegetated muskeg, numerous beaver dams) that continuous discharge measurements had never been obtained at either station.

Two stations on the CNRL lease, the Tar River near the mouth (S15) and the Tar River Lowland Tributary near the mouth (S19), were expected to be discontinued in 2004 because of advancing development. However, the development did not advance to the stage that the stations had to be removed and they remained operational throughout 2004. It is anticipated that these two stations will be discontinued in 2005, and replaced with other stations in the vicinity of the CNRL lease.

3.1.4 Challenges Encountered and Solutions Applied

Monitoring equipment at RAMP stations on the Christina River near Chard (07CE002) (S29) and the MacKay River near Fort McKay (07DB001) (S26) was destroyed by ice during the spring of 2004. In each stream, there is a WSC station, consisting of a stilling well and bubbler-style depth sensor, in close proximity to the RAMP station. WSC operates its station and makes manual discharge measurements only during the open-water season, but keeps the bubbler operating during the winter to prevent freezing. An arrangement was made with WSC to provide RAMP with the water levels measured at its station during the winter. That information, combined with manual discharge measurements by RAMP during routine winter visits, enables the collection of data more reliably than using the RAMP station. This approach may be adopted at other similar stations if it proves to be successful at the Christina and MacKay River stations.

The datalogger at the C1 climate station malfunctioned in November, due to unknown causes, shortly after a routine data download. The problem was recognized during the next visit in early December, and several return visits were made immediately to diagnose and correct the problem. After the last visit, the system appeared to be functioning normally, but when the connected computer lost power, the data collection program was erased. In January, when it was recognized that the system was still not working, a technician from Campbell Scientific visited the site to test all of the equipment. Since that time, the data collection has been working properly.

3.1.5 Other Information Obtained

Climate and hydrometric information collected by federal and provincial agencies was obtained and has been incorporated into the RAMP database. These agencies include the Meteorological Service of Canada (MSC) and WSC (both agencies of Environment Canada), Alberta Environment and Alberta Sustainable Resource Development. Some of the data obtained was provisional because the collecting organization had not completed its quality control procedures at the time the data was provided to RAMP. Provisional data is flagged in the RAMP database. Provisional data obtained in previous years has been updated in the RAMP database.

3.1.6 Summary of Component Data Now Available

The climate and hydrology data collected to date for the RAMP program is summarized in Table 3.1-2. The table includes data collected by government agencies at combined government / RAMP stations.

3.1.7 Analytical Approach

The analytical framework presented in Section 1.4 and Figure 1.4-1 was generally followed for analysis of the hydrologic data. Some adjustments to the framework were made to accommodate the differences between hydrologic and biological data. The RAMP 2004 hydrology analysis included the following major elements:

- Selection of hydrology measurement endpoints;
- Development of criteria to be used in detecting changes in hydrology measurement endpoints; and
- Detailed data analysis, consisting of:
  - Designation of watersheds to be used to represent baseline and operation conditions for the purposes of assessing hydrologic effects; and
  - Tabular and graphical presentation of 2004 results comparing 2004 hydrology measurement endpoints, hydrologic baseline conditions, and selected criteria for determination of change in hydrologic conditions.

These elements are described in detail below.

3.1.7.1 Selection of Hydrology Measurement Endpoints

The following measurement endpoints were selected for the analysis of the 2004 data:

- mean open-water (1 May to 31 October) season discharge;
- mean winter (1 November to 31 March) discharge;
- annual maximum daily discharge; and
- open-water season minimum daily discharge.

These endpoints were selected based on a review of measurement endpoints used in various oil sands project EIAs (Appendix A), with emphasis on those endpoints that can be computed from one year of data. Additional endpoints, such as the 1:10 year flood flow or the 7Q10 low flow, may be added to the analysis in future years when multiple years of both baseline and operational data for reference and exposed watersheds are available.

3.1.7.2 Criteria for Determining Effects

The differences between actual and naturalized hydrographs were compared to the various sets of criteria for determining effects on hydrologic measurement endpoints in the EIAs that were prepared for oil sands projects (Appendix A).

3.1.7.3 Detailed Analysis

Reference and Exposed Watersheds

Evaluating environmental effects for hydrology using the reference and exposed watershed approach poses several challenges:

- Natural variability from year to year and from one watershed to another is large relative to the magnitude of potential effects.

- Measurement uncertainty for hydrometric monitoring is large relative to the magnitude of potential effects. Accuracy of discharge hydrographs under good conditions is often considered to be in the range of ±5% to ±10%. In many of the streams in the oil sands region, where flow measurement conditions are much less than ideal due to beaver dams, aquatic vegetation, and poorly defined stream channels, measurement uncertainty is even greater.

- Measurement endpoints used in several of the project EIAs included parameters such as 1 in 10 year high and low flows. Estimating the values of these parameters with any confidence requires close to ten years of stationary data (i.e. data that does not exhibit a trend). The pre-development record at most of the stations is much shorter than ten years. Streamflows measured in catchments that are experiencing ongoing development can not be expected to be stationary. Other EIAs included 1:50 year and 1:100 year discharges as endpoints; those parameters would require substantially longer periods of record to evaluate.

The approach adopted to deal with these difficulties was to measure environmental effects directly, using each watershed potentially affected by development as both a reference and an exposed watershed simultaneously. The observed hydrograph at a selected station was used as the operational case, and a "naturalized" hydrograph (defined and derived as discussed below) was used as the baseline case. Thus any influence effect of development was isolated from the effects of spatial and temporal variability.

Table 3.1-2 Summary of RAMP Data Available for the Climate and Hydrology Component.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1995				1996				1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Wide-Area Snowcourse Survey																																						d			
Athabasca River Tributaries																																									
Mills Creek at Highway 63	S6										2	2	2		2	2	2		2	2	2		2e	2e	2e		2	2	2		2	2	2		2	2	2		2	2	2
Poplar Creek at Highway 63 (07DA007)	S11		2	2	2		2	2	2			2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Fort Creek at Highway 63	S12																						2	2	2		2	2	2		2g	2g	2g								
Ells River above Joslyn Creek	S14																										2	2	2		2	2	2		2	2	2		2	2	2
Tar River near the Mouth	S15																										2	2	2		2	2	2		2	2	2		2	2	2
Calumet River near the Mouth	S16																										2	2	2		2h	2h	2h		2h	2h	2h	h	2h	2h	2h
Tar River Upland Tributary	S17																										2	2	2		2	2	2		2	2	2		2	2	2
Calumet River Upland Tributary	S18																										2	2	2		2	2	2		2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19																										2	2	2		2a	2a	2a		2a	2a	2a		2a	2a	2a
Susan Lake Outlet	S25																														2	2	2								
MacKay River near Fort McKay (07DB001)	S26		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4		4	4	4	2	4	4	4
Joslyn Creek near Fort McKay (07DA016)																																									
Fort Creek Basin Snowcourse Survey																							d																		
CNRL Area Snowcourse Survey																											d				d				d						
Athabasca River Mainstem																																									
Athabasca River below Eymundson Creek	S24																										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River Basin																																									
Alsands Drain	S1			2	2		2	2	2		2	2			2	2	2		2	2	2	2					2	2	2	2	2	2	2								
Jackpine Creek at Canterra Road	S2			2	2		2	2	2		2	2	2		2	2			2	2			2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Iyinimin Creek above Kearl Lake	S3		2	2	2		2	2	2		2	2	2		2a	2a	2a		2a	2a	2a						2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a
Blackfly Creek near the Mouth	S4		2	2	2		2	2	2		2	2	2		2	2	2																								
Muskeg River above Stanley Creek	S5																																		2	2	2	2	2	2	2
Muskeg River above Muskeg Creek	S5A			2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e
Muskeg River near Fort McKay (07DA008)	S7		4	4	4		4	4	4		4	4	4		4	4	4	4	4	4	4		4	4	4		4	4	4	2	4	4	4	2	2	2	2	2	4	4	4
Stanley Creek near the Mouth	S8																			1	1		1	1	1		1	1	1		1	1	1		1	1	1				
Kearl Lake Outlet	S9														2	2	2		2e	2e	2e						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
Albian Pond 3 Outlet	S13																						2	2	2		2	2	2		2	2	2								
Muskeg River Upland	S20																										2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth	S21																										2	2	2		2	2	2		2	2	2				
Muskeg Creek near the Mouth	S22																										2	2	2		2	2	2		2	2	2		2	2	2
Aurora Boundary Weir	S23																									2	2	2	2	2	2	2	2								
Khahago Creek below Black Fly Creek	S28																										2	2	2		2	2	2		2	2	2		2	2	2
Muskeg River at the Aurora/Albian Boundary	S33																																		2	2	2	2	2	2	2

Legend

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

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

exposed
reference

Table 3.1-2 (cont'd)

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1995				1996				1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Wide-Area Snowcourse Survey																																						d			
Muskeg River Basin (con'td)																																									
Aurora Climate Station	C1		f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Muskeg River Basin Snowcourse Survey											d				d				d				d				d														
Muskeg River High Water Gauging												3				3				3				3				3													
Jackpine Creek High Water Gauging												3				3												3													
Clearwater River Mainstem																																									
Clearwater River above Christina River ((07CD005)		4	4	4	4	4	4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
Clearwater River at Draper (07CD001)		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Clearwater River Tributaries																																									
Christina River near Chard (07CE002)	S29																													2	4a	4a	4a	2	4a	4a	4a	2	4a	4a	4a
Hangingstone River at Highway 63	S30																														2	2	2								
Hangingstone Creek near the Mouth	S31																														2	2	2						2	2	2
Surmont Creek at Highway 881	S32																										2	2	2		2	2	2						2	2	2
Wetlands																																									
McClelland Lake	L1											2	2		2	2	2		2	2	2		2	2	2		2	2	2	2a	2a	2a	2a	2a	2a	2a	2a	1	2a	2a	2a
Kearl Lake	L2																		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isadore's Lake	L3																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Regional Data																																									
Compilation of Environment Canada data																																									

Legend

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

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

exposed
reference

Calculation of Naturalized Flow Hydrographs

Naturalized flow hydrographs are defined for this analysis as the hydrograph that would have occurred at the station if no oil sands development had occurred in the watershed. The naturalized hydrograph may include the effect of other non-oil sands related activities in the watershed, and so may in fact not be naturalized as that term is normally defined. However, this definition suffices for the purposes of assessing any incremental effects of oil sands developments.

The computation of the naturalized hydrograph is as follows:

Naturalized Hydrograph	=	Observed Hydrograph
	+	natural runoff that would have occurred from active oil sands development areas, or that is intercepted by development
	-	incremental runoff from areas that are cleared and areas that are dewatered
	+	water withdrawals from the watercourse in question by oil sands development activities
	-	water releases to the watercourse in question by oil sands development activities
	-	the difference between naturalized and observed hydrographs on tributaries upstream of the station in question

Naturalized hydrographs were derived for the outlet of each major watershed by adding water withdrawals and subtracting water releases from the observed hydrographs. Changes in catchment area due to stream diversions and the isolation of developed areas were considered by assuming that the daily discharge was increased or decreased in direct proportion to the changes in catchment area that remains not hydrologically isolated by oil sands development activities. Incremental runoff depth from cleared and dewatering areas was assumed for this analysis to be 50% of the runoff depth on natural portions of the catchment. That assumption is believed to be conservatively large. Changes in the rate and timing of runoff would also occur but are not considered in this analysis.

The approach does not account for indirect effects of oil sands development on streamflow, such as groundwater influences on surface water. Therefore the current philosophy of monitoring some reference catchments should continue in order to provide a secondary basis for comparison.

The assumption that changes in the runoff hydrograph are directly proportional to catchment area changes is obviously a simplification. The catchments are not homogeneous, and therefore removing part of the contributing area may have a large or small effect, depending on whether the removed portion of the catchment was more or less productive than the average. In addition, an increase or decrease in catchment area

affects the catchment responsiveness. Flood peaks, for example, will normally not be doubled by doubling the size of the catchment.

Considering the simplifications involved in the analytical approach, the values estimated for the various endpoints in the hydrologic component of this report should be considered as estimates appropriate for the objectives of this monitoring report. The reported measurement endpoints indicate the approximate magnitude of changes in the catchments. The same approach, but with a more detailed analysis including hydrologic modeling, could be used to provide a more accurate assessment of effects should that be required.

3.2 WATER QUALITY

3.2.1 Overview of 2004 Program

The 2004 RAMP water quality program included five ambient water sampling programs on rivers and lakes in the RAMP FSA to document water quality and assess any changes in water chemistry or quality that may be occurring due to oil sands development or other factors affecting the natural environment. Specific timing of seasonal sample programs in 2004 appears in Table 3.2-1, below.

Table 3.2-1 RAMP water quality sampling field campaigns, 2004.

Season	Duration
Winter 1	February 3, 2004
Winter 2	March 15 to March 18, 2004
Spring	May 15 to May 19, 2004
Summer	July 25 to July 30, 2004
Fall[1]	September 8 to September 20, 2004

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

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

Discrete water quality sampling in 2004 was focused on the Athabasca River and its major tributaries in the Athabasca oil sands region, as well as regionally important lakes and wetlands. Sampling was conducted by RAMP, with data also contributed from Alberta Environment (AENV) and individual oil sands operators for some locations. Water quality was examined at a total of 46 stations in 2004. Table 3.2-2 summarizes water quality sampling stations, frequency of seasonal sampling, and water quality parameters measured at each station, while Figure 3.2-1 indicates the locations of the water quality stations sampled in 2004.

Table 3.2-2 Summary of the RAMP 2004 water quality program.

See key at end of table, following page.

Station identifier and location		UTM Coordinates		Analytical package by season				Sample type
		Easting	Northing	W	S	S	F	
Athabasca River mainstem								
ATR-UFM	Upstream of Fort McMurray (monthly)	475330	6286105	11	13	11	13	*AENV sampling*
ATR-DC-CC	Upstream of Donald Creek	475020	6298154	-	-	-	1	Cross channel composite
ATR-DC-W	Upstream of Donald Creek	475102	6298152	-	-	-	1	West bank grab
ATR-DC-E	Upstream of Donald Creek	475120	6298154	-	-	-	1	East bank grab
ATR-SR-W	Upstream of the Steepbank River	470785	6319199	-	-	-	1	West bank grab
ATR-SR-E	Upstream of the Steepbank River	470937	6319625	-	-	-	1	East bank grab
ATR-MR-W	Upstream of the Muskeg River	463203	6332042	-	-	-	1	West bank grab
ATR-MR-E	Upstream of the Muskeg River	463504	6332230	-	-	-	1	East bank grab
ATR-DD	Downstream of all development	463709	6367819	1,1	1	1	3	Cross channel composite
ATR-FR	Upstream of the Firebag River	478455	6400331	-	-	-	1	Cross channel composite
ATR-ER	Upstream of the Embarras River			-	-	-	1	Cross channel composite
ATR-OF	At Old Fort (sampled monthly)	470205	6474330	12	12	12	12	*AENV Sampling*
EMR-1	Embarras River			-	-	-	1	Mid-channel grab
Athabasca River Delta								
ARD-1	Big Point Channel [e]	511903	6494506	-	-	-	1	Cross channel composite
Tributaries to the Athabasca River (Eastern)								
MCC-1	McLean Creek (mouth)	474637	6306051	-	6	6	9	Mid-channel grab
Steepbank River								
STR-1	Steepbank River (mouth)	470807	6319811	-	-	-	1	Mid-channel grab
STR-2	Steepbank River (u/s of Millennium)	485820	6309347	-	-	-	1	Mid-channel grab
STR-3*	Steepbank R. (u/s of N. Steepbank R.)	495076	6300011	1	1	1	1	Mid-channel grab
NSR-1	North Steepbank R. (u/s of P.C. Lewis)	497380	6324549	1[NS]	1	1	1	Mid-channel grab
Muskeg River								
MUR-1	Mouth	463473	6332409	-	-	-	1	Mid-channel grab
MUR-2	Upstream of Canterra Road crossing	466569	6340506	4	4	4	4	*Industry sampling*
MUR-2	Downstream of Canterra Rd. crossing			15	15	15	14	*AENV sampling*
MUR-4	Upstream of Jackpine Creek	474379	6349075	4	10	10	10	*Industry sampling*
MUR-5	Upstream of Muskeg Creek	476043	6351800	10	10	10	10	*Industry sampling*
MUR-6	Upstream of Wapasu Creek	492093	6355679	-	6	6	9	Mid-channel grab
Muskeg River Tributaries								
JAC-1	Jackpine Creek (mouth)	471935	6346300	-	1	1	1	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	481031	6349022	1[NS]	1	1	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477375	6356665	1[NS]	1	1	1	Mid-channel grab
WAC-1	Wapasu Creek (Canterra Rd. crossing)	490340	6355735	-	-	-	1	Mid-channel grab

Table 3.2-2 (cont'd.)

Station identifier and location		UTM Coordinates		Analytical package by season				Sample type
		Easting	Northing	W	S	S	F	
Tributaries to the Athabasca River (Eastern)								
Firebag River								
FIR-1	Firebag River (mouth)	479114	6400215	1	1	1	1	Mid-channel grab
FIR-2	Firebag River (u/s of Suncor Firebag)	531543	6354825	1	1	1	1	Mid-channel grab
Tributaries to the Athabasca River (Western)								
POC-1	Poplar Creek (mouth)	473051	6308820	-	-	-	1	Mid-channel grab
BER-1	Beaver River (mouth)	463620	6330924	-	-	1	1	Mid-channel grab
MAR-1	MacKay River (mouth)	461601	6336007	-	-	-	1	Mid-channel grab
MAR-2	MacKay River (u/s of P.C. MacKay)	444682	6314024	-	-	-	1	Mid-channel grab
ELR-1	Ells River (mouth)	459241	6351495	1	1	1	2	Mid-channel grab
ELR-2*	Ells River (upstream of CNRL Lease 7)	455753	6344915	1[NS]	1	1	2	Mid-channel grab
TAR-1	Tar River (mouth)	458852	6353527	1	1	1	1	Mid-channel grab
TAR-2*	Tar River (upstream of CNRL Horizon)	441968	6360675	1[NS]	1	1	1	Mid-channel grab
CAR-1	Calumet River (mouth)	460816	6363196	1[NS]	1	1	2	Mid-channel grab
Tributaries to the Athabasca River (Southern)								
HAR-1*	Hangingstone R. (u/s of Ft. McMurray)	478653	6276265	1[NS]	1	1	3	Mid-channel grab
Clearwater River								
CLR-1	Clearwater River (u/s of Fort McMurray)	480610	6283924	1	7	7	7	Mid-channel grab
CLR-2	Clearwater River (u/s of Christina R.)	496294	6280422	1	7	7	7	Mid-channel grab
Christina River								
CHR-1	Christina River (u/s of Fort McMurray)	496646	6280035	1	1	1	3	Mid-channel grab
CHR-2	Christina River (upstream of Janvier)	511698	6192371	1	1	1	3	Mid-channel grab
Lakes and Wetlands								
KEL-1		485425	6349374	-	-	1	1	Multi-location composite
ISL-1		463361	6342764	-	-	1	1	Multi-location composite
SHL-1		473481	6313037	-	-	1	1	Multi-location composite
Additional Sampling (Non-Core Programs)								
-				-	-	-	-	Not undertaken
QA/QC[1]								
-				1,1	1	1	1	N/A

* New station in 2004.
NS Not sampled – waterbody frozen to depth at time of survey.
1 Results of the RAMP QA/QC program for water quality are presented in Appendix B.
A Legend to Analytical Packages:

1. RAMP standard (conventionals, major ions, nutrients, tot./diss. metals, rec. HC, napth. acids)
2. RAMP standard + toxicity
3. RAMP standard + PAHs
4. RAMP standard + PAHs + toxicity
5. OPTI Lakes analytical package (2002)
6. Continuously-monitoring thermograph
7. RAMP standard + thermograph
8. RAMP standard + PAHs + thermograph
9. RAMP standard + toxicity + thermograph
10. RAMP standard + PAHs + toxicity + thermograph
11. AENV routine
12. AENV routine + RAMP standard
13. AENV routine + PAHs
14. AENV routine + DataSonde
15. AENV routine + PAHs + DataSonde

All water quality samples were analyzed for the RAMP standard variables in all sampling seasons except station ATR-UFM (Athabasca River upstream of Fort McMurray), which instead was analyzed for AENV routine parameters in winter, spring, summer and fall, and additionally for PAHs in the spring and fall programs. Both RAMP and AENV water quality parameter suites were collected from the Athabasca River near Old Fort (ATR-OF). Additionally, chronic toxicity and PAHs in water were analyzed from the fall sampling program at a number of stations.

3.2.2 Field Methods

3.2.2.1 Discrete Field Sampling

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

Composite samples were collected at stations where average concentrations of monitored variables were desired, including lentic waterbodies (i.e., lakes or wetlands) and selected stations along the Athabasca River. Composites were collected through combining a series of 2 L grabs collected at regularly spaced intervals (Table 3.2-3) into a triple-rinsed polymer bucket. Samples were removed from the composite bucket with a clean glass vessel and transferred to laboratory-supplied sample bottles. Caution was taken to ensure that the composite sample remained covered when not in use and that no contaminants were introduced during the course of sub-sampling. As with single grabs, all sample bottles were triple-rinsed prior to sample collection.

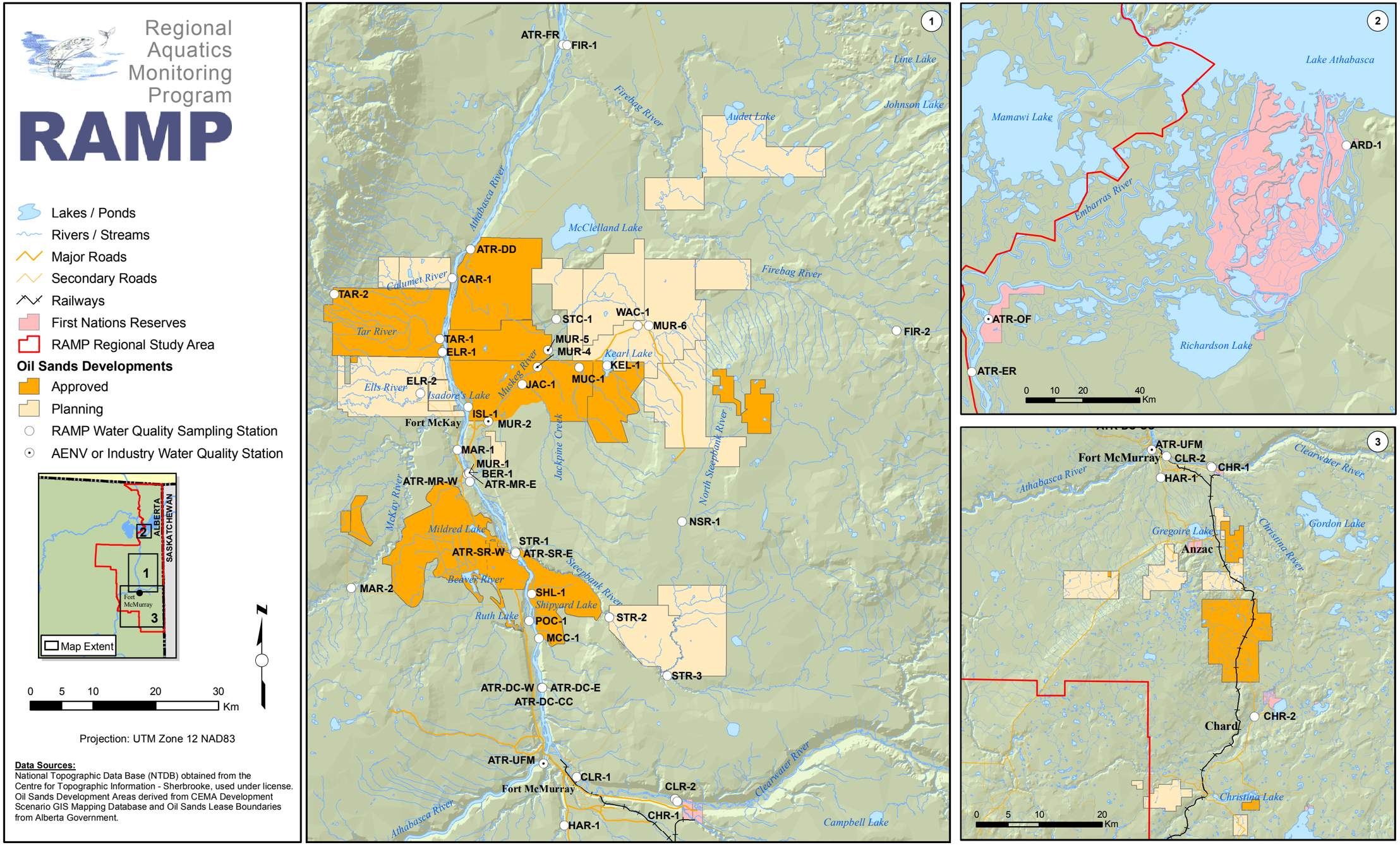
Table 3.2-3 RAMP water quality composite sample sub-groups.

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

At all water quality stations, *in situ* measurements of dissolved oxygen (DO), temperature and conductivity were collected using a YSI Model 85 multi-probe water meter and/or a handheld thermometer (temperature), a handheld conductivity meter (conductivity) and a LaMott portable Winkler titration kit (dissolved oxygen). Most dissolved oxygen measurements during the 2004 program were determined through Winkler titration due to concerns with measurement accuracy of the YSI 85 DO probe.

Samples taken at mouths of tributaries were collected approximately 100 m upstream of its confluence where possible to avoid influences of mainstem water on sampled water quality at each station. Similarly, stations located on river mainstems near influent tributaries were sampled approximately 100 m upstream of the influent tributary confluence.

Figure 3.2-1 RAMP water quality sampling locations, 2004.



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Sampling methods were modified during winter in response to environmental conditions, and to account for and preclude any sampling error or contamination associated with the requisite use of secondary sample transfer vessels and ice augers. Water was collected through holes in the river/lake ice drilled using a gas-powered auger. For stations designated as single grab, one hole was drilled at the estimated stream thalweg. For stations where cross-channel composites were collected, multiple holes were drilled following guidelines outlined in Table 3.2-3.

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

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

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, snowmobile and/or four-wheel drive vehicle. Detailed descriptions of location and access to all stations, including specific geographic coordinates, are included in the RAMP database (www.ramp-alberta.org).

3.2.2.2 Continuous Monitoring

As part of the spring water quality program RAMP deployed five HOBO Water Temp Pro automatic temperature sensor/data-loggers for collection of open-water temperature data. Each sensor was attached to a section of rebar which was then pounded into the substrate in a pool or other deep area that was likely to contain water for the entire monitoring period. Sensors were cabled to the bank to ensure equipment retrieval. This deployment methodology was instituted in 2004 after observing that some sensors attached to cinder blocks during the 2003 program were buried as a result of sediment loading.

All sensors were programmed to collect temperature data at 15-minute intervals for the duration of their installation. Sensors remained in the water column until removal during the fall field program, as shown in Table 3.2-4.

Table 3.2-4 Locations of continuous water temperature monitoring stations, May to September 2004.

Location	Installation Date	Removal Date
Clearwater River mouth (CLR-1)	May 19, 2004	September 20, 2004
Upper Clearwater River (CLR-2)	May 19, 2004	September 20, 2004
McLean Creek (MCC-1)	May 17, 2004	September 18, 2004
Upper Muskeg River (MUR-6)	May 20, 2004	September 17, 2004

Alberta Environment collects continuous year-round dissolved oxygen monitoring data on the Muskeg River upstream of Stanley Creek (Station D2) with a DataSonde continuous water quality monitoring probe purchased by RAMP, as well as at station MUR-2.

3.2.2.3 Sample Shipment and Analysis

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

Samples were shipped via Greyhound or through the ETL/MRRT collaborative drop depot in Fort McMurray. RAMP standard water quality variables and poly-aromatic hydrocarbons (PAHs) were analyzed by ETL (Table 3.2-5, Table 3.2-6). Metals (dissolved and total, including ultra-trace total mercury) were measured by ARC (Table 3.2-7). Chronic toxicity of water to aquatic organisms was evaluated by HydroQual (Table 3.2-8).

Table 3.2-5 RAMP conventional water quality variables.

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

Table 3.2-6 RAMP target and alkylated PAH compounds.

Group	Polyaromatic hydrocarbon (PAH)	
Target PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(b&k)fluoranthene	Indeno(c,d-123)pyrene
	Benzo(a)pyrene	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	Pyrene
Alkylated PAHs	C1-substituted acenaphthene	
	C1-substituted benzo(a)anthracene/chrysene	
	C2-substituted benzo(a)anthracene/chrysene	
	C1-substituted biphenyl	
	C2-substituted biphenyl	
	C1-substituted benzo(b or k)fluoranthene/methyl benzo(a)pyrene	
	C2-substituted benzo(b or k)fluoranthene/benzo(a)pyrene	
	C1-substituted dibenzothiophene	
	C2-substituted dibenzothiophene	
	C3-substituted dibenzothiophene	
	C4-substituted dibenzothiophene	
	C1-substituted fluoranthene/pyrene	
	C1-substituted fluorene	
	C2-substituted fluorene	
	C1-substituted naphthalenes	
	C2-substituted naphthalenes	
	C3-substituted naphthalenes	
	C4-substituted naphthalenes	
	C1-substituted phenanthrene/anthracene	
	C2-substituted phenanthrene/anthracene	
	C3-substituted phenanthrene/anthracene	
	C4-substituted phenanthrene/anthracene	
	1-methyl-7-isopropyl-phenanthrene (retene)	

Table 3.2-7 RAMP total and dissolved metals.

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

[1] Total mercury (Hg) measured to ultra-trace levels (0.000006 mg/L, or 0.6 ng/L)

Table 3.2-8 Chronic toxicity assessment of ambient river water.

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

3.2.2.4 Seasonal Differences in Analyses

Sampling intensity was greatest during the fall program, with samples collected from at all active RAMP monitoring stations (Table 3.2-2). During the fall, additional water quality analyses supplemental to the RAMP standard variables were collected at stations on the Athabasca River, Christina River, Hangingstone River, McLean Creek, Ells River, Calumet River and Muskeg River (Table 3.2-9).

Table 3.2-9 Fall 2004 analyses conducted by RAMP and supplemental to the RAMP standard suite of variables.

Station location	ID	Supplemental analyses	
		PAHs	Chronic Toxicity
Athabasca River d/s of all development	ATR-DD	√	-
Lower Christina River	CHR-1	√	-
McLean Creek	MCC-1	-	√
Muskeg R. u/s of Canterra Rd. crossing	MUR-2	√	√
Muskeg R. upstream of Jackpine Ck.	MUR-4	√	√
Muskeg R. upstream of Muskeg Ck.	MUR-5	√	√
Muskeg R. upstream of Wapasu Ck.	MUR-6	-	√
Lower Ells River	ELR-1	-	√
Ells River u/s of CNRL Lease 7	ELR-2	-	√
Calumet River	CAR-1	-	√

3.2.3 Changes in Monitoring Network from 2003 Field Program

Station location and methodology were largely consistent with 2003 efforts; however, the following variations were present in the 2004 program:

- New baseline stations were established and sampled seasonally on the lower Hangingstone River (HAR-1), the upper Tar River (TAR-2), the upper Ells River (ELR-2), and the upper Steepbank River (STR-3, upstream of the North Steepbank River);
- No sampling was conducted on the Athabasca River upstream of Fort Creek (ATR-FC), Fort Creek (FOC-1) or McClelland Lake (MCL-1), due to the withdrawal of True North Energy Ltd. from RAMP in 2003;
- PAH sampling was not conducted on the Athabasca River upstream of Donald Creek (ATR-DC-CC, cross-channel composite), at either of the Clearwater River stations (CLR-1, CLR-2), or in the upper Christina River (CHR-2);
- Toxicity sampling was conducted on McLean Creek (MCC-1), on the Muskeg River upstream of Wapasu Creek (MUR-6), and on the upper Ells River (ELR-2);
- Only fall and not summer sampling was not conducted on Beaver River (BER-1);
- Winter, spring and summer sampling was dropped from the upper MacKay River (MAR-2);
- Toxicity sampling was not conducted on the Tar River (TAR-1);
- Spring and summer sampling was added to Jackpine Creek (JAC-1) and Muskeg Creek (MUC-1);
- Winter sampling was dropped and summer sampling was added to Kearl Lake (KEL-1);
- Sampling at Isadore's Lake was re-instituted (summer and fall); and
- Chlorophyll *a* was analyzed at all RAMP standard water quality stations for 2004.

3.2.4 Challenges Encountered and Solutions Applied

In 2004, large fluctuations in day and nighttime temperatures in data collected by continuous monitoring thermographs in McLean Creek and the upper and lower Clearwater strongly suggests that these thermographs were exposed to air for varying periods of time during the open-water monitoring season, specifically:

- McLean Creek: July 1 to September 18 (removal date);
- Upper Clearwater: August 1 to September 20 (removal date); and
- Lower Clearwater: August 8 to August 15.

Each sensor was attached to a section of rebar, which was pounded into the streambed. Care was taken to ensure that the sensor was located near the substrate in the stream thalweg; however, due to the wide, naturally occurring fluctuations in water depth, which characterize many of the watercourses in the Athabasca oil sands region, this approach appears insufficient for the collection of meaningful data from the study watercourses.

The 2004 site selection process was based upon alignment with water and sediment quality stations. It is recommended that in 2005, a reconnaissance of these watercourses be undertaken to determine whether there are alternative locations more likely to provide the necessary wetted depth for full open-water season data collection that can be accessed safely when thermographs are established in the spring. This investigation will be undertaken in conjunction with regularly scheduled spring water quality sampling. Further, it is recommended that thermographs be re-positioned as part of summer water quality sampling program to ensure an adequate water depth is achieved for the entire temperature-monitoring program.

3.2.5 Other Information Obtained

All data collection for the 2004 water quality program was conducted by the RAMP implementation team, with the exception of three stations on the Muskeg River mainstem (MUR-2, MUR-4 and MUR-5) that were monitored by industry (i.e., Syncrude Canada Ltd. and Albian Sands Ltd.) and three stations on the Athabasca (ATR-UFM, ATR-OF) and Muskeg rivers (MUR-2) monitored by AENV (Table 3.2-2).

3.2.6 Summary of Component Data Now Available

As a supporting activity to the 2004 field program, the RAMP implementation team input all water quality data collected by RAMP since its inception in 1997 into a relational database with consistent structure and formats. This dataset includes over 42,000 water quality observations from 1997 to 2004, and facilitated comprehensive and comparative analysis of water quality in the RAMP area since 1997, as described in Section 3.2.7.

Table 3.2-10 summarizes historical water quality sampling undertaken by RAMP since 1997, excluding data collected by AENV and industry partners.

3.2.7 Analytical Approach

In accordance with the overall analytical approach used for the preparation of this report (Section 1.4), the RAMP 2004 water quality analysis included the following major components:

- Selection of particular water quality variables as water quality measurement endpoints;
- Development of criteria to be used in detecting changes in water quality measurement endpoints;

- Designation of stations to be used as baselines for water quality conditions through the establishment of regional baseline values for each water quality measurement endpoint;

- Tabular and graphical presentation of 2004 results comparing 2004 concentrations of the water quality measurement endpoints, water quality baseline conditions, and selected criteria for determination of change in water quality; and

- Specification of additional analyses to be conducted including trend analysis.

These components are described in detail below.

3.2.7.1 Selection of Water Quality Measurement Endpoints

RAMP collects data for over 100 water quality variables at some stations in a given sampling event. A number of these variables were selected as water quality measurement endpoints for the purpose of this 2004 technical report; the selection of the measurement endpoints was guided by information obtained from the following sources:

- Water quality measurement endpoints used in the EIAs of oil sands projects (Appendix A):

- A draft list of water quality variables of concern in the lower Athabasca region developed by CEMA (2004);

- Water quality variables of interest listed in the RAMP 5-year report (Golder 2003a);

- Results of correlation analysis of the RAMP 1997-2004 water quality dataset indicating significantly inter-correlation of various water quality variables (particularly metals) (Appendix E);

- Discussions among RAMP Component Managers about the importance of various water quality variables to interpretation of other RAMP components, particularly fish and benthic invertebrate communities; and

- Discussions with RAMP Technical Subcommittee members, during and in relation to a meeting held in Edmonton in mid-February 2005 to discuss analytical strategies for this report.

Table 3.2-11 presents variables listed in these various sources. The final list of water quality measurement endpoints used in this report, and reasons for their inclusion, are:

- *pH:* an indicator of acidity;

- *Total suspended solids:* a variable strongly associated with several other measured variables, including total phosphorous, total aluminum and numerous other metals;

- *Dissolved phosphorous, total nitrogen and nitrate-nitrite:* indicators of nutrient status (note that dissolved phosphorous rather than total phosphorous is included because it is the primary biologically available species of phosphorous and because total phosphorous levels are strongly associated with total suspended solids [Appendix E]);

- *Various ions (sodium, chloride, sulphate):* indicators of ion balance, which could be affected by oil sands-related discharges or seepages;

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

- *Total dissolved solids and dissolved organic carbon:* 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 3.2-11); given total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with suspended solids (Golder 2003a), dissolved aluminum also was assessed, as it more accurately represents biologically available forms of aluminum that may cause toxicity to aquatic organisms (Butcher 2001);

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

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

In addition to the above variables, overall ionic composition at each station was assessed graphically using Piper diagrams, as discussed in Section 3.2.7.4, below.

3.2.7.2 Criteria for Determining Effects

Two criteria for determining water quality effects were used:

- **Comparison to Water Quality Guidelines**: All water quality data collected by RAMP in 2004 were screened against Alberta acute and chronic water quality guidelines for the protection of aquatic life (AENV 1999) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2002). All values that exceeded these guidelines are reported explicitly in the body of the RAMP report.

- **Comparison to Natural Variation in Baseline Conditions**: The concentration in 2004 of each of the selected water quality measurement endpoints was assessed against a rigorously defined natural condition of concentration of the measurement endpoint. The definition of the natural condition is explained immediately below.

Table 3.2-10 Summary of Available RAMP Water Quality Data.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																	
Upstream of Fort McMurray (grab) [a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1																				1				3				1
(west bank) [b]	ATR-DC-W								1								1				3				1				1				1
(east bank) [b]	ATR-DC-E								1								1				3				1				1				1
(middle)	ATR-DC-M																1																
Upstream of the Steepbank River (middle)	ATR-SR-M																1																
(west bank)	ATR-SR-W																1				1				1				1				1
(east bank)	ATR-SR-E																1				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																1																
(west bank) [b c]	ATR-MR-W								1								1				1				1				1				1
(east bank) [b c]	ATR-MR-E								1								1				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1		1	1	1																												
(west bank) [b c]	ATR-FC-W								1								1				3				1				1				
(east bank) [b c]	ATR-FC-E								1								1				3				1				1				
(middle)	ATR-FC-M																1																
Downstream of all development (cross channel)	ATR-DD																					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3
Upstream of mouth of Firebag River	ATR-FR																								1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER																1				3												
Embarras River	EMR-1																												1				
At Old Fort (grab) [d]	ATR-OF													11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																																	
Big Point Channel [e]	ARD-1											1					1				1								1				1
Athabasca River tributaries (Eastern)																																	
McLean Creek (mouth)	MCC-1											6	7		6	6	9		6	6	9	1	6	6	7		6	6	7		6	6	9
(100 m upstream)	MCC-2											6	6																				
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1				1	1			1				1				1
(upstream of Project Millennium)	STR-2																					1			1				1				1
(upstream of Nt. Steepbank)	STR-3																													1	1	1	1
North Steepbank River (upstream of P.C. Lewis)	NSR-1																					1	1	1	1	1	1	1	1	1	1	1	1

Legend

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

Footnotes

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

exposed
reference

Table 3.2-10 (cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River																																	
Mouth [f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1				1				1				1				1
Upstream of Canterra Road Crossing [g]	MUR-2									2	9	9	9	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling [f]						13	13	13	11	13	13	13	11	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14
Downstream of Alsands Drain	MUR-3																																
Upstream of Jackpine Creek [f g h]	MUR-4					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek [f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9		6	6	9		6	6	9		6	6	7		6	6	9
Muskeg River Tributaries																																	
Alsands Drain (mouth) [f g h]	ALD-1					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Jackpine Creek (mouth) [f]	JAC-1					13	13	13	11	13	13	13	11,1				1				1				1				1				1
Shelley Creek (mouth)	SHC-1								11				11,1																				
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1				1				1				1
Stanley Creek (mouth)	STC-1								11				11,1								1	1	1	1	1	1	1	1	1				1
Wapasu Creek (Canterra Road Crossing)	WAC-1					2			11	2			11,1																				1
Athabasca River tributaries (Western)																																	
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1
Beaver River (mouth)	BER-1																																1
MacKay River (mouth)	MAR-1								1								1				1	1			1				1				1
(upstream of P.C. MacKay)	MAR-2																					1			1	1	1	1	1				1
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11				1	1	1	2	1	1	1	2	1	1	1	2
(upstream of CNRL Lease 7)	ELR-2														11	11	11	14												1	1	1	2
Tar River (mouth)	TAR-1						1	1	1													1	1	1	2	1	1	1	2	1	1	1	1
(upstream of CNRL Horizon)	TAR-2																													1	1	1	1
Calumet River (mouth)	CAR-1																					1	1	1	2	1	1	1	2	1	1	1	2
Fort Creek (mouth)	FOC-1														7	7	9		6	6	7	1	6	6	7		6	6	7				
Firebag River (mouth)	FIR-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

Legend

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

Footnotes

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

exposed
reference

Table 3.2-10 (cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River tributaries (Southern)																																	
Clearwater River (upstream of Fort McMurray)	CLR-1																	3	8	8	8	1	7	7	8	1	7	7	8	1	7	7	7
(upstream of Christina River)	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8		6	6	7
Christina River (upstream of Fort McMurray)	CHR-1																					1	1	1	3	1	1	1	3	1	1	1	3
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	1
Hangingstone River (upstream of Ft. McMurray)	HAR-1																														1	1	1
Wetlands (Lakes)																																	
Kearl Lake (composite)	KEL-1							1									1			1	1				1	1			1			1	1
Isadore's Lake (composite)	ISL-1							1									1			1	1												1
Shipyard Lake (composite)	SHL-1							1			1	1	1			1	1			1	1			1	1			1	1			1	1
McClelland Lake (composite)	MCL-1																1			1	1				1								
Additional Sampling (Non-Core Programs)																																	
Unnammed Creek north of Ft. Creek (mouth)	UNC-1															1	1																
OPTI Lakes	-																		5		5		5		5								
Potential TIE	-																								√				√				√
QA/QC																																	
Field and trip blanks, plus one split sample	-														1	1	1			1	1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1

Legend

1 = standard water quality parameters (conventionals, major ions, nutrients, t. & d. metals, recoverable hydrocarb. and naph. acids)
2 = standard w.q. + chronic toxicity testing (*Selenastrum capricornutum, Ceriodaphnia dubia,* fathead minnow)
3 = standard w.q. + PAHs
4 = standard w.q. + chronic tox testing + PAHs
5 = standard w.q. for OPTI lakes (routine paramters and arsenic)
6 = thermograph
7 = thermograph + standard w.q.
8 = thermograph + standard w.q. + PAHs
9 = thermograph + standard w.q. + chronic tox. testing
10 = thermograph + standard w.q. + chronic tox testing + PAHs
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13 = AENV routine parameters + PAHs
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Footnotes

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[d] Monthly sampling for nutrients and conventional parameters; quarterly sampling for total and dissolved metals
[e] In 1999, one composite samples was prepared with water from Big Point, Goose Island, Embarras and an unnamed side channel
[f] AENV collects/collected nine samples throughout the year, although only three are/were analyzed for PAHs
[g] All testing, with the exception of thermographs, is conducted by individual industry
[h] In 1999, MUR-4 was located upstream of Shelley Creek
√ = allowance made for potential TIE

exposed
reference

Table 3.2-11 Potential key water quality water quality measurement endpoints.

Analyte group	EIA review: Variables listed in EIAs (n=13 projects)	CEMA "Variables of Concern" (draft, 2004)[1]	RAMP 5-year report (Golder 2003)	Variables to support other RAMP components[2]	Additional suggested variables[3]
Physical variables	Temperature (3) Total suspended solids (9) Dissolved oxygen (3) Conductivity (1) pH (1)	(None)	pH Total suspended solids	Temperature Dissolved oxygen pH Total suspended solids Conductivity	
Nutrients	Ammonia-N (1) Total nitrogen (2) Total phosphorous (2)	Ammonia-N Total nitrogen Total phosphorous	Dissolved organic carbon Total Kjeldahl nitrogen Total phosphorous	Dissolved phosphorous Nitrate+nitrite	
Ions and Ion Balance	Chloride (2) Sulphide (2) Total dissolved solids (2)	Sodium Chloride Potassium **Flouride** Sulphate	Total dissolved solids Sulphate Total alkalinity	Total alkalinity Hardness	Carbonate Bicarbonate Magnesium Calcium
Dissolved and Total Metals	Aluminum (3) Arsenic (2) Barium (2) Boron (1) Cadmium (3) Chromium (3) Copper (3) Iron (2) Manganese (2) Mercury (2) Molybdenum (1) Selenium (1) Silver (1) Zinc (1)	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	
Organics/ Hydrocarbons	Oil & grease (1) Napthenic acids (1) Total phenolics (2)	Oil & grease Total hydrocarbons Naphthenic acids **Toluene** **Xylene**	(None)	(None)	(None)
PAHs	Benzo(a)anthracene (3) Benzo(a)pyrene (2) Misc. PAHs (3)	Napthelene Biphenyl Acenapthene Acenaphtylene Flourene Fluoranthene Alkyl-napthelenes Alkyl-biphenyls Alkyl-acenapthene Alkyl-benzo(a)anthracene Alkyl-flourenes Alkyl-phenanthrenes Dibenzothiophene Alkyl-dibenzothiophenes	(None)	(None)	(None)
Effects-based end-points	Acute toxicity (1) Chronic toxicity (2)	Acute toxicity Chronic toxicity **Fish tainting**			

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

[1] Includes variables not necessarily related to oil sands operations.

[2] Primarily fish and benthos (inferred).

[3] Suggested by members of the RAMP Technical Subcommittee, February 2005.

3.2.7.3 Designation of RAMP Stations as Water Quality Baselines

Each water quality station was designated as either a baseline or operational station (Table 3.2-10). Discussions of the ability of the RAMP program to detect effects often have been framed by considerations of statistical power, a testable statistical concept used to assess the likelihood that the result of a statistical test is neither a false positive nor a false negative. However, while power is valuable concept for environmental studies involving biological end-points such as benthic invertebrate abundance or fish health, its application to the RAMP water quality program is problematic for the following reasons:

- *Repeated water quality measurements are not true replicates:* Samples collected from the same station over time are not replicates, as these samples are not collected from the same "population" of data (samples collected from the same river also may be auto-correlated due to downstream flow);

- *Water quality data typically are highly variable and not normally distributed:* Even if one accepts pseudo-replicated year-to-year measurements as true replicates, water quality data typically are highly variable and positively skewed (i.e., many low values with a few very high values), meaning that the number of annual replicates required to provide sufficient power for hypothesis-testing may be high—higher than the standard n=3 years of baseline data currently collected by RAMP;

- *Sufficient numbers of replicates must exist for both baseline and exposed observations:* To test with sufficient statistical power, comparisons of data between baseline and exposed stations require sufficient replication in both treatments, meaning that possible changes in water quality at exposed stations cannot be statistically assessed until sufficient post-development data exist, slowing the feedback between monitoring results and management decisions based on these results; and

- *Achieving sufficient "depth" may sacrifice "breadth":* Collection of potentially large numbers of replicate (or pseudo-replicate) samples at specific stations to achieve acceptable statistical power may require re-allocation of monitoring efforts from abbreviated sampling at many stations to intensive sampling at a few stations, reducing the geographic coverage of the RAMP water quality program.

Regional Baselines: Alternatives to Power-Based Designs

An alternative to power-based experimental and analytical designs for environmental studies involves the definition of regional baseline characteristics, developed from numerous observations in unaffected areas, against which individual observations may be assessed. Examples of such approaches include the British River Invertebrate Prediction and Classification System (RIVPACS) (Wright *et al.* 1997), the Australian River Assessment System (AUSRIVAS) (http://ausrivas.canberra.edu.au/), and the Reference Condition Approach (RCA) developed by Environment Canada (Reynoldson *et al*. 1998).

These approaches use large amounts of data collected from numerous unaffected waterbodies to define and predict the structure of invertebrate communities in natural streams, against which individual observations collected from locations potentially affected by development may be compared.

In these models, the likelihood of a new sample being assigned as a false negative or false positive is minimized through rigorous definition of natural baseline conditions. The conceptual foundation of these regional bioassessment techniques—i.e., assessment of individual samples against a rigorously defined natural condition—was adapted for analysis of RAMP 2004 water quality data. Specifically, fall 2004 water quality results were assessed against representative regional baseline conditions, which were defined from pooled RAMP fall water quality data from 1997 to 2004 from baseline stations with similar water quality characteristics. Groups of RAMP baseline stations with similar water quality characteristics were developed objectively using multivariate data reduction and clustering techniques, as described generally in this section and in detail in Appendix E.

This regional baseline comparison approach has the following advantages:

- Individual observations may be assessed against a robustly defined regional baseline, providing greater assurance that any observed values outside this range of baseline values may actually represent change outside the range of natural variability, allowing prompt follow-up or management response;

- Instead of comparing observations against three (pseudo-replicated) years of baseline data, individual observations are compared against many baseline observations collected over several years that encompass a range of natural conditions;

- Water quality at stations lacking a directly comparable baseline station may still be assessed against regionally defined baseline conditions; and

- The broad geographic scope of the RAMP program is an advantage in data analysis rather than a limitation.

Potential disadvantages of using this regional baseline approach include:

- Potential pooling of water quality data from stations with divergent water quality characteristics; and

- Potential pooling of data from watersheds exhibiting narrow natural variability with watersheds exhibiting wide natural variability.

Both of these potential disadvantages relate to the risk of overstating the range of natural variability against which annual data are assessed. The risk that stations with divergent water quality will be pooled was addressed through grouping of data using Objective Classification Analysis (OCA), which involved multivariate data reduction of the RAMP total metals, dissolved metals and major ions dataset using Principal Component Analysis (PCA), followed by application of hierarchical and k-means clustering algorithms to define meaningful, internally consistent groups of stations from the RAMP 1997-2004 fall dataset that exhibit consistently similar water quality characteristics

(Appendix E). Similar approaches to consolidation and analysis of large water quality datasets are presented and discussed by Jones and Boyer (2002) and Güler *et al.* (2004).

The latter issue—that watersheds exhibiting low natural variability in water quality would be pooled with those that exhibit high natural variability—was addressed through presentation of summarized monitoring results from 1997-2004 for all key variables of interest for all stations monitored as well as graphical comparisons of results to water quality group ranges.

Development and Assessment of Regional Baseline Data for Water Quality

Detailed methods and results of the Objective Classification Analysis of RAMP water quality data are provided in Appendix E. Results of this analysis indicated three major groups of stations with similar water quality types (Table 3.2-12), namely:

- All stations in the Athabasca River mainstem and delta;
- Stations in tributary watersheds generally to the northwest of Fort McMurray, including the MacKay, Ells, Tar, Calumet, Poplar Creek, Beaver River, and McLean Creek; and
- Stations in tributary watersheds to the northeast and south of Fort McMurray, including the Muskeg, Steepbank, Clearwater-Christina, Firebag, Fort Creek and regional lakes (i.e., Isadore's, Kearl, Shipyard and McClelland).

For many stations included in the cluster analysis, samples from different years clustered closely together, indicating that water quality at these stations was consistent at specific locations across years of sampling (i.e., spatial variation was more important than temporal variation in defining cluster membership).

No specific stations or station-year combinations clustered separately from all other stations in hierarchical cluster analysis, indicating a general similarity of water quality characteristics among all stations.

These groupings are generally consistent with results of similar cluster-based analyses of water quality in the oil sands area by AOSERP (1985), and generally consistent with patterns of underlying and surficial geology (AOSERP 1985).

From these clusters, data from baseline stations (i.e., those located in watersheds where oil sands development has not yet occurred) were pooled to develop descriptions of regional water quality, against which RAMP data from potentially exposed and baseline stations were assessed. Table 3.2-13 lists the station-year from which from 1997 to 2004 RAMP data were pooled to develop these baseline descriptions and which stations were compared against these baselines. Numbers of observations in regional baseline data sets ranged from n=16 (Cluster 1: Athabasca River mainstem) to n=158 (Cluster 3: Eastern and southern tributaries and regional lakes).

Table 3.2-12 Classification of groups of RAMP water quality monitoring stations with similar water quality, from 1997 to 2004 data.

Waterbody	Total No. of Station/Year Combinations	Cluster		
		1	2	3
Athabasca River mainstem	**63**	**1**	**62**	**0**
Athabasca River delta	4	0	4	0
Eastern tributaries	**17**	**8**	**0**	**9**
Firebag River	6	6	0	0
Fort Creek	4	1	0	3
McLean Creek	6	0	0	6
Unnamed Creek	1	1	0	0
Muskeg River	**38**	**27**	**0**	**11**
Muskeg River	17	12	0	5
Alsands Drain	1	0	0	1
Jackpine Creek	6	5	0	1
Muskeg Creek	6	4	0	2
Shelley Creek	1	0	0	1
Stanley Creek	4	4	0	0
Wapasu Creek	3	2	0	1
Steepbank River	**14**	**10**	**1**	**3**
Steepbank River	11	7	1	3
N. Steepbank River	3	3	0	0
Western tributaries	**29**	**2**	**1**	**26**
Beaver River	2	0	0	2
Calumet River	3	0	0	3
Ells River	5	2	1	2
MacKay River	9	0	0	9
Poplar Creek	5	0	0	5
Tar River	5	0	0	5
Southern tributaries	**15**	**10**	**1**	**4**
Christina River	6	3	0	3
Clearwater River	8	7	1	0
Hangingstone River	1	0	0	1
Regional lakes	**19**	**16**	**0**	**3**
Isadore's Lake	3	2	0	1
Kearl Lake	6	6	0	0
McClelland Lake	4	4	0	0
Shipyard Lake	6	4	0	2
Total	**199**	**74**	**69**	**56**

Table 3.2-13 Regional baseline water quality data groups and station comparisons.

Regional baseline grouping (Cluster)	Baseline stations used for regional comparison	Stations (2004) compared with this regional baseline
1. Athabasca River mainstem and delta	ATR-UFM, ATR-DC-CC, ATR-DC-W, ATR-DC-E, ATR-DC-M **n=16 station-year observations** (n=6 for ultra-trace mercury)	ATR-SR-W, ATR-SR-E, ATR-MR-W, ATR-MR-E, ATR-FC-W ATR-FC-E, ATR-DD, ATR-FR ATR-ER, ARD-1, plus all baseline stations to left
2. Western tributaries to the Athabasca River	MAR-1 (1998-2001), MAR-2, ELR-1, ELR-2, TAR-1 (1998-2004), TAR-2, CAR-1 **n=50 observations** (n=30 for ultra-trace mercury)	MCC-1, POC-1, MAR-1, BER-1, plus all baseline stations to left
3. Eastern and southern tributaries to the Athabasca River; regional lakes	CLR-1, CLR-2, CHR-1, CHR-2, HAR-1, STR-2, STR-3, NSR-1, FOC-1, FIR-1, FIR-2X, FIR-2, MUR-5 (1998-2003), MUR-6, SHC-1, MUC-1, STC-1 (1998-2003), WAC-1, KEL-1, ISL-1 (1998), MCL-1, UNC-1 **n = 158 observations** (n=78 for ultra-trace mercury)	STR-1, MUR-1, MUR-2, MUR-4, MUR-5, ALD-1, JAC-1, STC-1, ISL-1, SHL-1 plus all baseline stations to left

3.2.7.4 Tabular and Graphical Presentation of Results

Comparison to Water Quality Guidelines

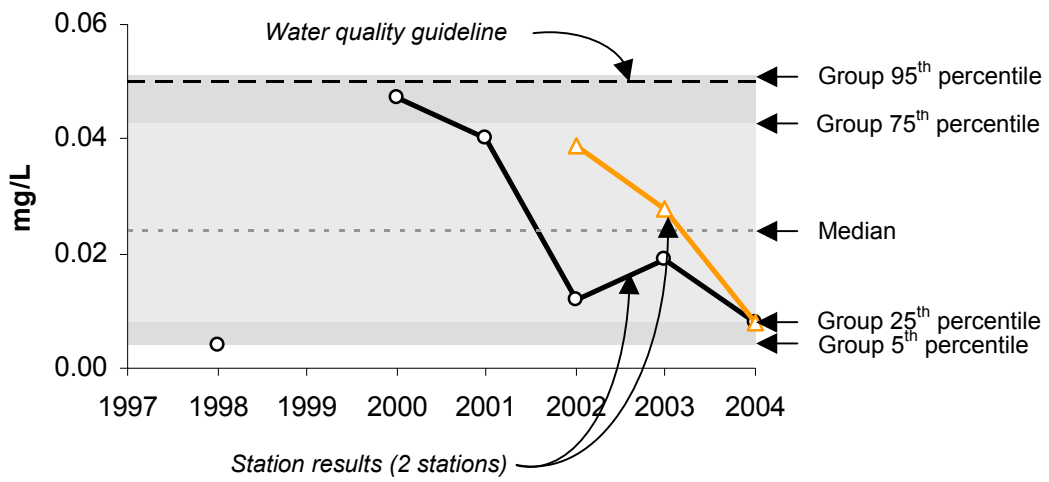
Water quality data from fall 2004 for each water quality measurement endpoint were tabulated for each station sampled. Historical variability was presented for each water quality measurement endpoint, represented by minimum, maximum and median values observed (as well as number of observations) from 1997 to 2003 at that station. Concentrations of any water quality measurement endpoint that exceeded relevant guidelines were noted and, as indicated above, all values that exceeded these guidelines were also reported.

Comparison to Natural Variation in Baseline Conditions

To allow regional comparison, untransformed data from all baseline stations sampled by RAMP from 1997 to 2004 (fall only), for all water quality measurement endpoints, were pooled from each cluster of similar stations (Table 3.2-12); descriptive statistics describing natural water quality characteristics for each group were calculated. For each water quality cluster (Table 3.2-12), the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined, for comparison against 2004 data. The median rather than the mean was used as an indicator of typical conditions, given water quality data are characteristically positively skewed.

Data for a subset of the water quality measurement endpoints were presented graphically in the context of relevant regional variability, as shown in the example graph below (Figure 3.2-2). Data for each station were presented for all years of sampling by RAMP, to allow assessment of any temporal trends. 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.

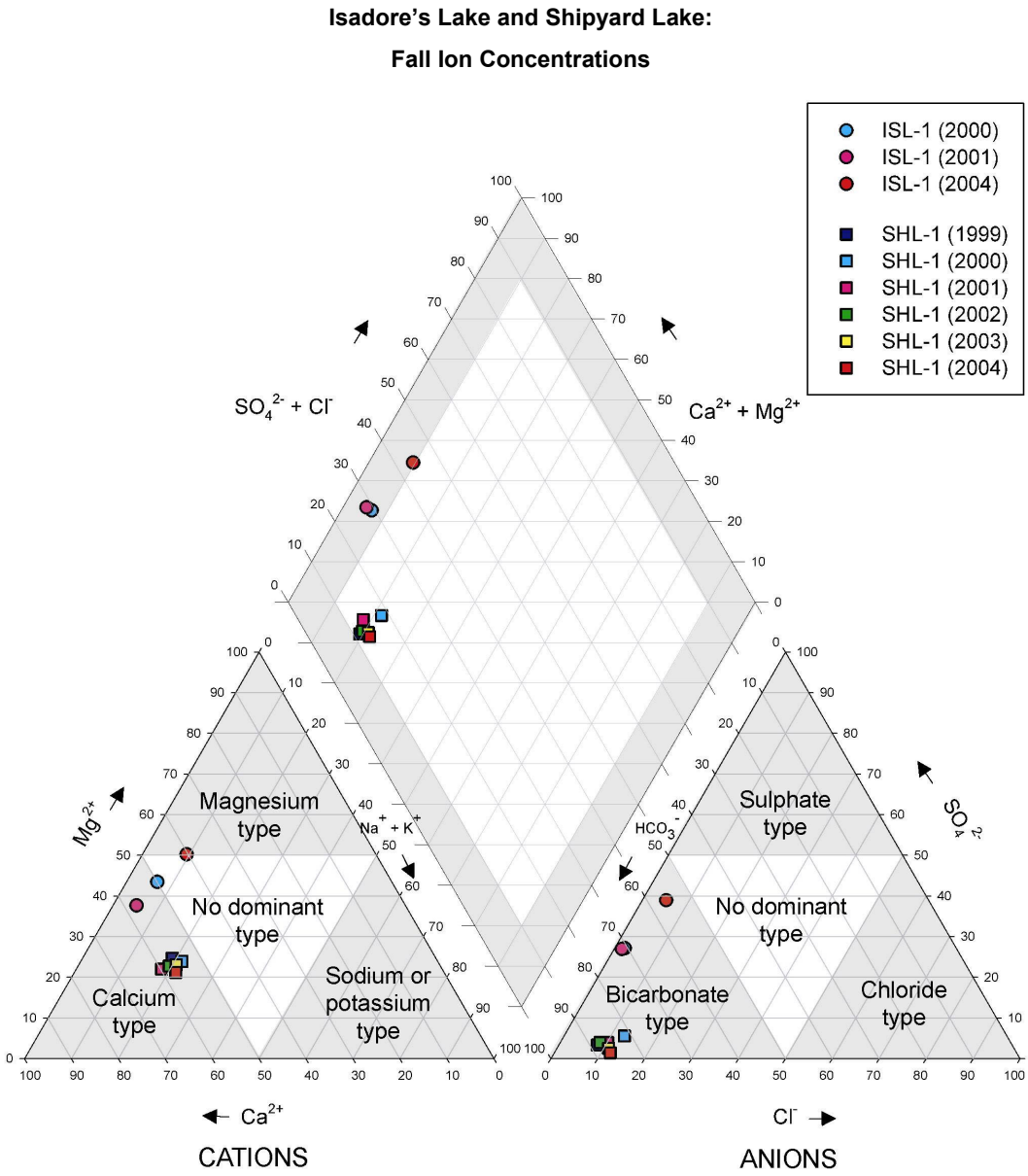
Figure 3.2-2 Example of comparison of data from a specific RAMP station[1] against regional baseline data and water quality guidelines.



[1] In this case, dissolved phosphorous at MacKay River stations MAR-1 and MAR-2.

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

Figure 3.2-3 Example Piper diagram, illustrating ion concentrations in waters from Isadore's Lake and Shipyard Lake, collected by RAMP, 1997 to 2004.



Trend Analysis

In addition to qualitative trend analysis using graphical means, statistical trend analysis was undertaken on water quality data for the Athabasca River mainstem, which has been monitored continuously by Alberta Environment since 1976. Two stations were studied: Athabasca River upstream of Fort McMurray (ATR-UFM, approximately 100 m upstream of the Horse River); and Athabasca River at Old Fort (ATR-OF), located near the head of the Athabasca River Delta, downstream of the Embarras River distributary.

Temporal trends were tested using Mann-Kendall's test (Sen's slope), a non-parametric statistical technique that evaluates the correlation of chemical concentrations with time. These analyses were undertaken using *WQ Stat Plus* v.1.56, a statistical package specifically designed to assess trends in water quality (NIC 2003).

Statistical trend analysis was not undertaken on RAMP data from tributaries to the Athabasca River sampled by RAMP, partly due to typically insufficient sample sizes (numbers of years of data), and partly because changes in water quality in these smaller tributaries due to oil sands and other anthropogenic activities are not expected to necessarily occur incrementally, but rather step-wise, which would not necessarily be captured by statistical assessment of incremental trends in water quality. By contrast, incremental changes in water quality may be postulated in the Athabasca River, given its large volume relative to its tributaries (Figure 1.3-1), from which changes in water quality in the Athabasca River mainstem may be most likely expected. Therefore, for all other stations besides the two AENV long-term monitoring stations on the Athabasca mainstem, any trends in water quality in key variables of interest were assessed qualitatively by graphical means.

3.3 SEDIMENT QUALITY

3.3.1 Overview of 2004 Program

Objectives of the 2003 RAMP sediment monitoring program included assessment of baseline sediment quality and identification of any potential effects related to oil sands development or other factors in rivers and lakes in the RAMP study area.

Sediment quality monitoring stations were selected to provide data related to ongoing and anticipated developments in the oil sands region. Stations were located upstream, downstream, and in the vicinity of existing oil sands developments, to allow for comparisons of sediment quality between these areas. Sediments were also collected from waterbodies in areas under consideration for development to provide baseline sediment quality data, which would provide an indication of the background levels and natural variability of chemicals in sediments in undeveloped areas.

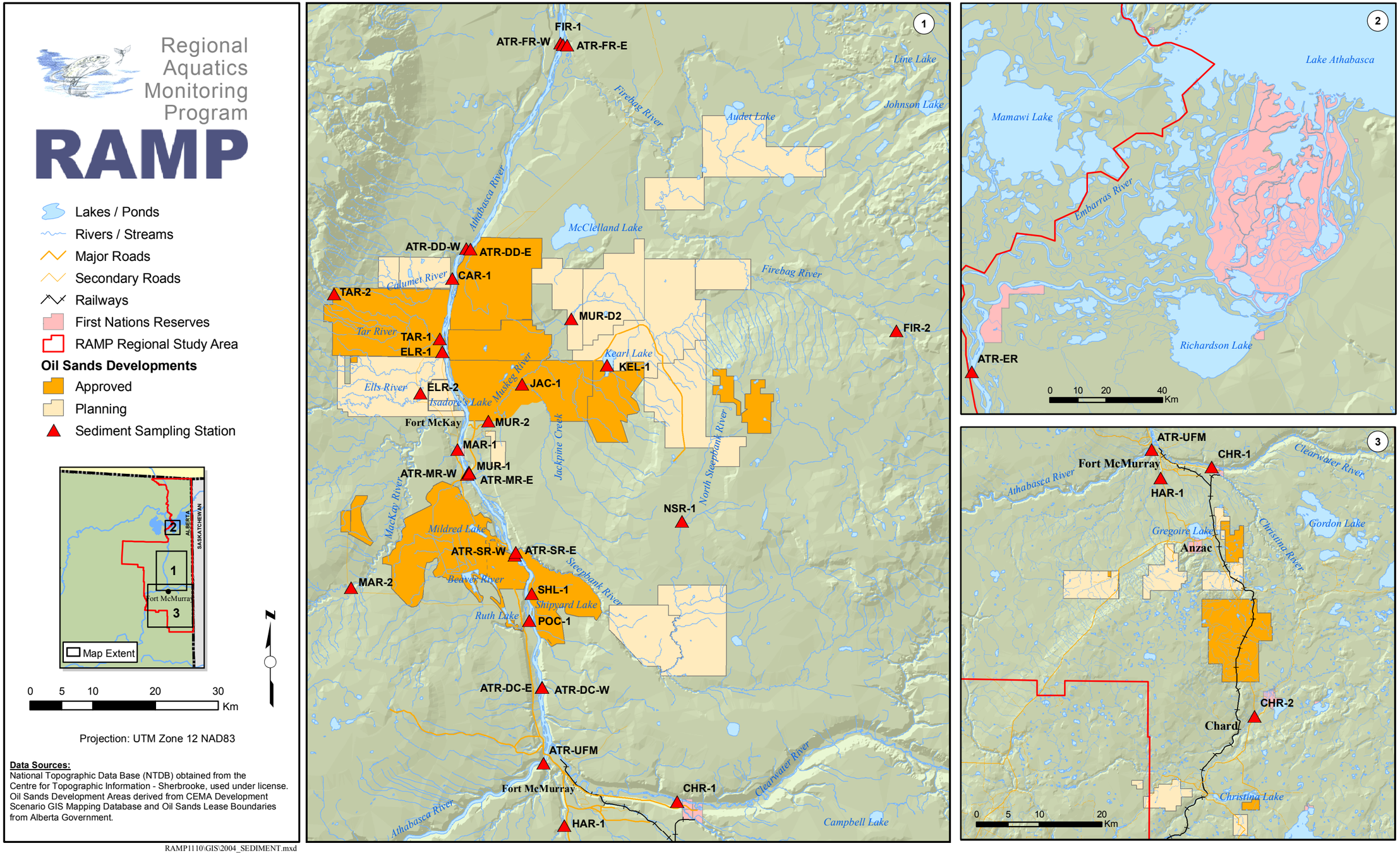
Sediment samples were collected by RAMP from 33 stations located along the Athabasca River and its major tributaries in the oil sands region, and from regionally important lakes and wetlands (Figure 3.3-1). Stations sampled and variables analyzed at each station are summarized in Table 3.3-1.

3.3.1.1 Athabasca River Mainstem and Delta Stations

In the Athabasca River mainstem, sediment samples were collected from east and west bank locations (i.e., any location between the dry bank and 25% of the total cross-sectional wetted width), approximately 100 m upstream from the following tributaries (listed in upstream-downstream order):

- Donald Creek;
- Steepbank River;

Figure 3.3-1 RAMP sediment quality sampling locations, September 2004.



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- Muskeg River;
- Downstream of all development (near the outlet of Susan Lake); and
- Firebag River.

Additionally, sediments were collected from the Athabasca River upstream of Fort McMurray, approximately 100 m upstream of the confluence of the Horse River (east bank), and in the lower reaches of the Athabasca River shortly upstream of the Embarras River distributary. No sediment sampling was scheduled or undertaken in the Athabasca River Delta in 2004.

3.3.1.2 Other Waterbodies

Sediment samples were collected from center channel locations of stations located along Athabasca River tributaries, where water depth and velocity allowed for safe sample collection. Stations located on the upper Clearwater and Christina rivers and all Muskeg River stations (excluding the mouth) were either too deep or fast-flowing to allow for cross-channel samples to be collected; at these stations, individual grab samples were collected at regularly spaced intervals perpendicular to the bank.

Sediment samples also were collected from Shipyard and McClelland lakes.

3.3.2 Field Methods

3.3.2.1 Discrete Field Sampling

The 2004 sediment quality field program was implemented from September 8 to September 20, concurrent with the fall water quality program. Sediment samples were collected from depositional zones at each station. At several sampling locations in tributaries to the Athabasca, substrates were predominantly erosional rather than depositional. At these locations, sampling was conducted where depositional sediments were found. Historical sampling locations were identified from 2003 GPS coordinates or written descriptions from previous reports, and followed a general rule-of-thumb followed by the previous RAMP implementation team of sampling approximately 100 m upstream of river confluences. Stations were accessed by helicopter, jet boat, canoe or four-wheel drive vehicle.

At each station, 4 to 6 grabs were collected with a 6″ x 6″ Ekman dredge (0.023 m^2). Grab samples were transferred to a stainless steel pan; once sufficient sediment had been colleted for analysis, all samples were homogenized in the pan into a single composite sample with a stainless steel spoon. To minimize potential for sample contamination, pans, spoons, and the dredge were rinsed with hexane and acetone, cleaned with a solvent, metal-free soap (i.e., Liquinox), then triple-rinsed with ambient water at each station prior to sampling.

Homogenized samples were transferred into labeled, sterilized glass jars for chemical analyses, and/or to resealable plastic bags for toxicological analysis. All samples were stored on ice prior to and during shipment to analytical laboratories.

Table 3.3-1 Summary of RAMP sediment quality program, September 2004.

Station identifier and location		UTM Coordinates		Analytical package[A] / Season			
		Easting	Northing	W	S	S	F
Athabasca River mainstem							
ATR-UFM	Upstream of Fort McMurray (cross channel)	475330	6286105	-	-	-	1
ATR-DC-W	Upstream of Donald Creek (west bank)	475102	6298152	-	-	-	1
ATR-DC-E	Upstream of Donald Creek (east bank)	475120	6298154	-	-	-	1
ATR-SR-W	Upstream of Steepbank River (west bank)	470785	6319199	-	-	-	1
ATR-SR-E	Upstream of Steepbank River (east bank)	470937	6319625	-	-	-	1
ATR-MR-W	Upstream of Muskeg River (west bank)	463203	6332042	-	-	-	1
ATR-MR-E	Upstream of Muskeg River (east bank)	463504	6332230	-	-	-	1
ATR-DD-W	Downstream of all development (west bank)	463065	6367951	-	-	-	1
ATR-DD-E	Downstream of all development (east bank)	463707	6367819	-	-	-	1
ATR-FR-W	Upstream of Firebag River (west bank)	478031	6400586	-	-	-	1
ATR-FR-E	Upstream of Firebag River (east bank)	478459	6400329	-	-	-	1
ATR-ER	Upstream of the Embarras River	468288	6468175	-	-	-	1
Tributaries to the Athabasca River (Eastern)							
NSR-1	North Steepbank River (upstream of PC-Lewis)	497380	6324549	-	-	-	1
Muskeg River							
MUR-1	Muskeg River (mouth)	463473	6332409	-	-	-	3
MUR-1B	1 km upstream of mouth			-	-	-	1
MUR-2	Upstream of Canterra Road Crossing	466569	6340506	-	-	-	3
MUR-4	Upstream of Jackpine Creek	474379	6349075	-	-	-	1
MUR-5	Upstream of Muskeg Creek	476043	6351800	-	-	-	1
MUR-D2	Upstream of Stanley Creek	479759	6356751	-	-	-	3
MUR-6	Upstream of Wapasu Creek	492093	6355679	-	-	-	1
Muskeg River Tributaries							
JAC-1	Jackpine Creek (mouth)	471935	6346300	-	-	-	3
Firebag River							
FIR-1	Firebag River (mouth)	479114	6400215	-	-	-	1
FIR-2	Firebag River (upstream of Suncor Firebag)	531543	6354825	-	-	-	3

Table 3.3-1 (cont'd.)

Station identifier and location		UTM Coordinates		Analytical package[A] / Season			
		E	N	W	S	S	F
Tributaries to the Athabasca River (Southern)							
Christina River							
CHR-1	Christina River (mouth)	496646	6280035	-	-	-	3
CHR-2	Christina River (upstream of Janvier)	511698	6192371	-	-	-	3
HAR-1*	Hangingstone River (upstream of Ft. McMurray)	478653	6276265	-	-	-	3
Tributaries to the Athabasca River (Western)							
Ells River							
ELR-1	Ells River (mouth)	459241	6351495	-	-	-	1
ELR-2*	Ells River (upstream of CNRL Lease 7)	455753	6344915	-	-	-	3
Tar River							
TAR-1	Tar River (mouth)	458852	6353527	-	-	-	1
TAR-2*	Tar River (upstream of CNRL Horizon)	441968	6360675	-	-	-	1
CAR-1	Calumet River (mouth)	460816	6363196	-	-	-	3
POC-1	Poplar Creek (mouth)	473051	6308820	-	-	-	3
Regional Lakes							
SHL-1	Shipyard Lake (composite)	473481	6313037	-	-	-	3
KEL-1	Kearl Lake (composite)	485425	6349374	-	-	-	1
Additional sampling (Non-core programs)							
-	Potential TIE			-	-	-	-
Quality Assurance/Quality Control							
-	2x split samples, duplicate samples, rinseate blanks			-	-	-	1

* New station in 2005.

[A] Legend to Analytical Packages:

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

2 = Sediment toxicity (Chironomus tentans, Hyalella azteca).

3 = RAMP standard + toxicity

3.3.2.2 Sample Shipping and Analysis

Samples were shipped to analytical laboratories via Greyhound or through the ETL/MMRT collaborative drop depot in Fort McMurray. All chemical analyses of sediment were undertaken by Enviro-Test Laboratories Ltd. (ETL, Edmonton, AB) except polycyclic aromatic hydrocarbons (PAHs), which were analyzed by AXYS Analytical Services Ltd. (AXYS, Sidney, BC). Evaluation of sediment toxicity was undertaken by HydroQual Laboratories Ltd. (Calgary, AB).

Table 3.3-2 summarizes physical, chemical and toxicological variables assessed in the RAMP 2003 sediment program.

Due to very high amounts of plant material in sediment collected from station KEL-1 (Kearl Lake), particle size analysis was not possible at this station.

Table 3.3-2 RAMP sediment quality parameters analyzed in 2003.

Group	Sediment quality variable	
Physical variables	Percent sand	Percent clay
	Percent silt	Moisture content
Carbon content	Total inorganic carbon	
	Total organic carbon	
	Total carbon	
Total metals	Aluminum	Manganese
	Arsenic	Mercury
	Barium	Molybdenum
	Beryllium	Nickel
	Boron	Potassium
	Cadmium	Selenium
	Calcium	Silver
	Chromium	Sodium
	Cobalt	Strontium
	Copper	Thallium
	Iron	Uranium
	Lead	Vanadium
	Magnesium	Zinc
Organics	AEP Tier 1 total hydrocarbons:	
	Total recoverable hydrocarbons	
	Total volatile hydrocarbons (C5-C10)	
	Total extractable hydrocarbons (C11-C30)	
	CCME 4-fraction total hydrocarbons:*	
	BTEX (Benzene, Toluene, Ethylene, Xylene)*	
	F1 (C6-C10)*	
	F2 (C10-C16)*	
	F3 (C16-C34)*	
	F4 (C34-C50)*	

Table 3.3-2 (cont'd.)

Group	Sediment quality variable	
Target PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(a)pyrene	Indeno(c,d-123)pyrene
	Benzofluoranthenes	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	Pyrene
Alkylated PAHs	C1-substituted acenaphthene	
	C1-substituted benzo(a)anthracene/chrysene	
	C2-substituted benzo(a)anthracene/chrysene	
	C1-substituted biphenyl	
	C2-substituted biphenyl	
	C1-substituted benzofluoranthene/ benzo(a)pyrene	
	C2-substituted benzofluoranthene/benzo(a)pyrene	
	C1-substituted dibenzothiophene	
	C2-substituted dibenzothiophene	
	C3-substituted dibenzothiophene	
	C4-substituted dibenzothiophene	
	C1-substituted fluoranthene/pyrene	
	C2-substituted fluoranthene/pyrene	
	C3-substituted fluoranthene/pyrene	
	C1-substituted fluorene	
	C2-substituted fluorene	
	C3-substituted fluorene	
	C1-substituted naphthalenes	
	C2-substituted naphthalenes	
	C3-substituted naphthalenes	
	C4-substituted naphthalenes	
	C1-substituted phenanthrene/anthracene	
	C2-substituted phenanthrene/anthracene	
	C3-substituted phenanthrene/anthracene	
	C4-substituted phenanthrene/anthracene	
	1-methyl-7-isopropyl-phenanthrene (retene)[1]	
Chronic toxicity testing	Survival and growth of the amphipod *Hyallela azteca*	
	Survival and growth of *Chironomus tentans* midge larvae	

* New analyte in 2005 (see Section 3.3.2).
[1] Any summations of Total PAH did not include retene, as it is also accounted for in total C4-substituted phenanthrene/anthracene.

3.3.3 Changes in Monitoring Network from 2003 Field Program

Relative to 2003, key changes to the sampling program included:

- Addition or removal of several sampling stations and a reduced toxicity testing program, based on the prescribed RAMP 10-year study design (RAMP 2002);
- Elimination of sublethal toxicity testing using the earthworm Lumbriculus variegates, primarily because survival results were not useable due to persistent problems with organism breakage in sandy sediments;
- Addition of CCME Total Hydrocarbon measurement end-points ("four-fraction"), due to their more detailed breakdown of compound types relative to Alberta Tier 1 variables used previously by RAMP, and the presence of associated CCME soil quality guidelines for assessment of results (with the intention of undertaking only CCME analyses in future RAMP programs, should data comparisons undertaken in this report indicate that results of these methods are comparable);
- Additional QA/QC in the field through additional cleaning of sampling gear in the field at each station using non-metal laboratory soaps (in addition to acetone/hexane rinses and rinsing with ambient water); and
- Enhanced assessment of QA/QC practices though collection of field rinseate blanks, to assess cleanliness of sediment sampling equipment (see Appendix B).

3.3.4 Challenges Encountered and Solutions Applied

Water flows in the Athabasca River mainstem during the fall sediment sampling program in September 2004 were high relative to previous years (please see Section 4); at most locations, the river's wetted width extended fully from bank to bank. This contrasted with previous years, where the river's wetted width at each sampling location was much smaller than its bankfull width. As a result, sediment samples from east and west banks were collected in different locations in 2004 than in 2003 and likely also in previous years exhibiting different river discharges. Additionally, the higher flows in the Athabasca River likely reduced deposition of finer suspended sediments, which were noted overlying layers of sand in 2003; analysis of 1997 to 2004 RAMP data (Appendix E) indicates that finer sediments exhibit higher concentrations of metals and organic compounds than coarser sediments.

To address this issue, care was taken to ensure that sediments sampled along each bank of the Athabasca River were samples of river sediment rather than slumping bank materials. Aside from this, little could be done to reduce this potentially confounding effect on station and sediment variability between years, highlighting one of the limitations of monitoring sediment in the Athabasca River mainstem for the assessment of temporal trends.

3.3.5 Other Information Obtained

No additional sediment quality data for 2005 were available for inclusion in this analysis.

3.3.6 Summary of Component Data Now Available

As a supporting activity to the 2004 field program, all sediment quality data collected by RAMP since 1997 were input into a relational database with consistent structure and formats. This data set, which includes over 12,000 sediment quality observations from 1997 to 2004, facilitated comprehensive and comparative analysis of sediment quality in the RAMP area since 1997, as described in Section 3.2.7.

Table 3.3-3 summarizes historical sediment quality sampling undertaken by RAMP since 1997, excluding data collected by AENV and industry partners.

3.3.7 Analytical Approach

Analysis of the RAMP sediment quality data set built upon results of previous studies by RAMP and others, and followed a similar conceptual approach to that used by the 2004 Water Quality component (see Section 3.2.7, above). The RAMP 2004 sediment quality analysis included the following major components:

- Selection of particular sediment quality variables as sediment quality measurement endpoints, including predicted toxicity of sediments due to PAHs, calculated using an equilibrium-partitioning model;
- Development of criteria to be used in detecting changes in sediment quality measurement endpoints;
- Designation of stations to be used as baselines for sediment quality conditions through the establishment of regional baseline values for each sediment quality measurement endpoint;
- Tabular and graphical presentation of 2004 results comparing 2004 concentrations of the sediment quality measurement endpoints, sediment quality baseline conditions, and selected criteria for determination of change in sediment quality; and
- Specification of additional analyses to be conducted including trend analysis.

These components are described in detail below.

3.3.7.1 Selection of Sediment Quality Measurement Endpoints

RAMP collects approximately 80 sediment quality variables at each station, and collected over 3,200 measurements of sediment quality in 2004. A number of these variables were selected as sediment quality measurement endpoints for presentation and discussion in the body of this report, drawn from the following sources:

- Sediment quality measurement endpoints listed in the environmental impact assessments of oil sands projects as being potentially affected (Appendix A);

- Sediment quality variables of interest listed in the recent RAMP 5-year report (Golder 2003a);

- Results of correlation analysis of the RAMP 1997-2004 sediment quality dataset indicating significant inter-correlation of various variables (Appendix F);

- Discussions among RAMP Component Managers about the importance of various sediment quality variables to interpretation of other RAMP components, particularly fish and benthos; and

- Discussions with RAMP Technical Subcommittee members, during and in relation to a meeting held in Edmonton in mid-February 2005 to discuss analytical strategies for this report.

Table 3.3-4 presents variables listed in these various sources. Final sediment quality measurement endpoints selected for use in this report, and reasons for their inclusion, are as follows:

- *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 contaminant sorption;

- *Total organic carbon*: an indicator of organic matter in sediment, including hydrocarbons;

- *Total hydrocarbons (CCME and Alberta Tier 1)*: Indicators of the total hydrocarbon content of sediments, with each measurement endpoint capturing hydrocarbon compounds of different molecular weights (more specifically, numbers of carbon atoms) (both CCME and Alberta Tier 1 data are presented this year for comparison);

- *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 Low-Molecular Weight PAHs: a sum of concentrations of all PAHs with 1 to 3 benzene rings (including parent and alkylated forms) measured in a given sample;

    - Total High-Molecular Weight PAHs: a sum of concentrations of all PAHs with 4 to 6 benzene rings (including parent and alkylated forms) measured in a given sample;

    - Naphthelene: a volatile, low-molecular-weight PAH that may cause toxicity when dissolved in water;

    - Retene: an alkylated phenanthrene generated through decomposition of plant materials (i.e., not associated with petroleum sources);

- Total dibenzothiophenes: a sulphonated PAH (parent and alkylated forms) that is associated with bitumen (i.e., petrogenic); and

- Predicted PAH toxicity: an estimate of the cumulative toxicity of all PAHs in a sediment sample (discussed further below);

- *Metals:* given metals in sediments are not listed in oil sands EIAs as being potentially affected by development, only metals in sediment that exceeded CCME ISQG values were presented; and

- *Chronic toxicity:* sublethal toxic effects of sediment on the survival and growth of amphipods or midge larvae.

Predicting Potential Toxicity of PAH Mixtures in Sediments

In situ toxicity of sediment PAHs to aquatic organisms was estimated using an equilibrium partitioning approach. This approach assumes that the equilibrium distribution of PAHs among sediment solids, porewater, and associated hydrophobic material is determined by the relative affinity of individual PAH species for these components. This affinity can be described by an appropriate partition coefficient; for example, the partitioning of a chemical species between organic carbon and water is described by K_{oc}.

Bioavailability and toxicity to aquatic organisms is assumed to increase with aqueous PAH concentration. Thus, overall toxicity of the sediment PAH assemblage is related to the solubility and toxicity of individual PAH species within the assemblage, and is assumed to result from the additive effects of individual PAH molecules (Neff *et al.* 2005).

Methods and constants (e.g., K_{ow}, freshwater solubility and toxicity for various PAH species) used to estimate cumulative PAH toxicity in sediment were adapted from Neff *et al.* (2005). For PAH included in the RAMP analytical dataset, constants for the following PAHs were unavailable: benzo(b/k)fluoranthene, C1- and C2-substituted benzofluoranthene/pyrenes, C2- and C3-substituted fluoranthene/pyrenes, dimethyl- and methyl-biphenyl, and methyl acenaphthene, and were excluded from the analysis. However, the exclusion of these species was not expected to significantly influence the estimated toxicity (B. Fowler, Axys Anatytical Ltd., *pers. comm.* February 2005).

Sediment toxicity was estimated for each station and sampling event for which PAH concentrations were available. Individual sediment PAH concentrations (mg PAH species/kg sediment) were normalized to total recoverable hydrocarbon (TRH) concentration of that sediment sample, to account for variation in overall hydrocarbon content among stations. Concentrations of individual PAH species in porewater were estimated according to the equation $C_w = C_s/K_{ow}$, where C_w is the aqueous concentration of PAH, C_s is the normalized concentration of sediment PAH, and K_{ow} is the octanol-water partition coefficient for the individual PAH species.

Table 3.3-3 Historical sediment quality sampling by RAMP, 1997 to 2004.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																	
Upstream of Fort McMurray (cross channel)	ATR-UFM																								1				3				1
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				3				3								1				3				1				3				1
(east bank)[a]	ATR-DC-E				3				3								1				3				1				3				1
Upstream of Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1
(east bank)	ATR-SR-E																1				3				1				3				1
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								3								1				3				1				3				1
(east bank)[a b]	ATR-MR-E								3								1				3				1				3				1
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				3				3								1				3				1				3				
(east bank)[a b]	ATR-FC-E				3				3								1				3				1				3				
Testing inter-site variability (3 comp. samples)	-																1																
Downstream of all development (west bank)	ATR-DD-W																								1				3				1
(east bank)	ATR-DD-E																								1				3				1
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1
(east bank)	ATR-FR-E																								1				3				1
Upstream of the Embarras River	ATR-ER																3				1				1				3				1
Athabasca Delta / Lake Athabasca																																	
Delta composite[c]	ARD-1											3					3																
Big Point Channel	BPC																				3				3				3				
Goose Island Channel	GIC																				3				3				3				
Fletcher Channel	FLC																				3				3				3				
Flour Bay	FLB-1																3																
Athabasca River Tributaries (South of Fort McMurray)																																	
Clearwater River (upstream of Fort McMurray)	CLR-1																				1				3				3				
(upstream of Christina River)	CLR-2																				1				3				3				
Christina River (upstream of Fort McMurray)	CHR-1																								1				3				3
(upstream of Janvier)	CHR-2																								1				3				3
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																3
Athabasca River Tributaries (North of Fort McMurray)																																	
McLean Creek (mouth)	MCC-1												3				3				1				3								
Poplar Creek (mouth)	POC-1				1																				3								3
Steepbank River (mouth)	STR-1				1				1																3								
(upstream of Project Millennium)	STR-2				1																				3								
(upstream of Nt. Steepbank)	STR-3																																
North Steepbank River (upstream of P.C. Lewis)	NSR-1																								3				3				1
MacKay River (mouth)	MAR-1				1				1												3				3								3
(upstream of P.C. MacKay)	MAR-2																				1				3								3

Legend

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

2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus, Hyalella azteca*)

3 = standard s.q. + toxicity testing

exposed

reference

Footnotes

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

[b] Samples were collected downstream of tributary in 1998

[c] In 1999, one composite sample was collected from Big Point, Goose Island, Embarras and an unnamed side channel

√ = allowance made for potential TIE

Table 3.3-3 (cont'd)

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Tributaries (North of Fort McMurray) (cont'd)																																	
Ells River (mouth)	ELR-1								1																3				3				3
(upstream of CNRL Lease 7)	ELR-2																																3
Tar River (mouth)	TAR-1								1																3				3				1
(upstream of CNRL Horizon)	TAR-2																																1
Calumet River (mouth)	CAR-1																								3								3
Fort Creek (mouth)	FOC-1																1				1				3								
Firebag River (mouth)	FIR-1																								3				3				1
(upstream of Suncor Firebag)	FIR-2																								3				3				1
Muskeg River																																	
Mouth	MUR-1				1				1				3				1				1				3				3				3
1 km upstream of mouth	MUR-1b																1												1				
Upstream of Canterra Road Crossing	MUR-2																1								3				3				3
Upstream of Jackpine Creek	MUR-4				1												1												1				
Upstream of Muskeg Creek	MUR-5																1												1				
Upstream of Stanley Creek	MUR-D2																								3				3				3
Upstream of Wapasu Creek	MUR-6																1												1				
Muskeg River Tributaries																																	
Jackpine Creek (mouth)	JAC-1				1																												3
Shelley Creek (mouth)	SHC-1																																
Muskeg Creek (mouth)	MUC-1																																
Stanley Creek (mouth)	STC-1																												1				
Wapasu Creek (Canterra Road Crossing)	WAC-1																																
Wetlands																																	
Kearl Lake (composite)	KEL-1																				1												1
Isadore's Lake (composite)	ISL-1																				1												
Shipyard Lake (composite)	SHL-1																				1				3				1				3
McClelland Lake (composite)	MCL-1																								1								
Additional Sampling (Non-Core Programs)																																	
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																																
Potential TIE	-																				√												
QA/QC																																	
One split and one duplicate sample	-																1				1				1				1				1

Legend

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

2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus, Hyalella azteca*)

3 = standard s.q. + toxicity testing

exposed

reference

Footnotes

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

[b] Samples were collected downstream of tributary in 1998

[c] In 1999, one composite sample was collected from Big Point, Goose Island, Embarras and an unnamed side channel

√ = allowance made for potential TIE

Table 3.3-4 Potential key sediment quality measurement endpoints[1].

Analyte group	EIA review: Variables listed in EIAs (n=13 projects)	RAMP 5-year report (Golder 2003)	Variables to support other RAMP components[2]	Additional suggested variables
Physical variables	(None)	(None)	Particle size distribution	
Carbon content	(None)	(None)	Total organic carbon	Total inorganic carbon Total organic carbon
Total Hydrocarbons	(None)	TRH	CCME F1, F2 Tier 1 TEH	CCME F1-F4+BTEX Tier 1 TVH, TEH, TRH
Metals	(None)	Total metals	Total metals	(Metals that are high relative to SQGs)
PAHs	General PAHs (4)	Naphthelene C1 Naphthelene	Total PAHs LMW PAHs (parent+alkylated)	LMW PAHs HMW PAHs Naphthelene Dibenzothiophenes Retene
Effects-based end-points	Chronic toxicity (1)		Chronic toxicity	

[1] All variables currently are monitored by RAMP except those in **bold**.
[2] Primarily benthos (inferred).

K_{ow} values were used as surrogates for K_{oc} values (organic carbon-water partition coefficients), given they are readily available and relatively accurate for most RAMP PAH species. K_{oc} values for most non-polar organic chemicals are related to and tend to be lower than the comparable K_{ow}; thus, use of K_{ow} provides a conservative (lower) estimate of toxicity.

The toxicity contributed by each PAH species in a given sample was estimated from its predicted concentration in porewater and its known toxicity in aqueous phase, to generate a hazard quotient (HQ). These HQs then were summed for all compounds in the sample to generate a hazard index (HI), which described predicted toxicity of sediments to aquatic organisms. HIs were determined for the entire RAMP historical

dataset (1997-2004). Hazard indices greater than 1 indicate PAH concentrations in excess of toxicity values—i.e., a potential toxic effect of sediments on aquatic organisms.

3.3.7.2 Criteria for Determining Effects

Two criteria for determining sediment quality effects were used:

- **Comparison to Sediment Quality Guidelines:** All sediment quality data collected by RAMP in 2004 were screened against CCME Interim Sediment Quality Guidelines (ISQG) (CCME 2002). All values that exceeded these guidelines were reported explicitly in the body of the RAMP report; and

- **Comparison to Natural Variation in Baseline Conditions:** The concentration in 2004 of each of the selected sediment quality measurement endpoints was assessed against a rigorously defined natural condition of concentration of the measurement endpoint. The definition of the natural condition is explained immediately below.

3.3.7.3 Establishment of Regional Baseline Values for Comparison

Given similar concerns regarding the analytical power of RAMP Water and Sediment Quality components, the analytical approach for the 2004 Sediment Quality component followed that of the 2004 Water Quality component, namely assessment of 2004 data against the range of natural variability defined by representative regional baseline data collected by RAMP from 1997 to 2004. The background and rationale for this regional baseline approach are presented in Section 3.2.7, above.

Groups of RAMP baseline stations with similar sediment quality characteristics were determined using multivariate data reduction and iterative clustering techniques, described in detail in Appendix F. This Objective Classification Analysis (OCA) involved multivariate data reduction of sediment metals and PAH datasets using Principal Component Analysis (PCA), followed by application of hierarchical and k-means clustering algorithms using derived metals and PAH Principal Components as well as other sediment characteristics (i.e., particle size distribution, inorganic and total organic carbon, and total recoverable hydrocarbons,), to define meaningful, internally consistent clusters of from the RAMP 1997-2004 dataset that exhibit consistently similar sediment quality (Appendix F).

Results of Objective Classification Analysis of RAMP sediment quality data indicated four major groups of stations with similar sediment quality types (Table 3.3-5), namely:

- All stations in the Athabasca River mainstem and delta;

- All regional lakes;

- All tributaries to the Athabasca River except stations in the lower Muskeg River; and

- Lower Muskeg River stations MUR-1 (mouth) and MUR-1B (1 km upstream of the mouth).

Given lower Muskeg River stations MUR-1 and MUR-1B are not considered baseline stations, this fourth cluster was not used to describe regional baseline. Reasons for the separate clustering of these lower Muskeg River stations are discussed with these results in Section 5.3.3.

Clustering of RAMP station-year data using sediment quality data was not as clear as was the case for water quality. For many stations included in the cluster analysis, particularly those on the Athabasca River mainstem, samples from the same stations for different years did not cluster closely together, indicating that many stations did not exhibit consistent and characteristic sediment quality across years (i.e., in many cases, variation among years within the historical dataset was larger than spatial variation among stations).

Table 3.3-5 Classification of groups of RAMP sediment monitoring stations with similar sediment quality, from 1997 to 2004 data.

Waterbody	Total # of Station-Year Combinations	Cluster			
		1	2	3	4
Athabasca River mainstem	**66**	**1**	**62**	**41**	**25**
Athabasca River delta	12	0	0	12	0
Eastern tributaries	**12**	**0**	**0**	**3**	**9**
Firebag River	6	0	0	0	6
Fort Creek	2	0	0	2	0
McLean Creek	4	0	0	1	3
Muskeg River	**25**	**7**	**3**	**3**	**12**
Muskeg River	22	7	2	3	10
Jackpine Creek	2	0	0	0	2
Stanley Creek	1	0	1	0	0
Steepbank River	**7**	**0**	**0**	**0**	**7**
Steepbank River	4	0	0	0	4
N. Steepbank River	3	0	0	0	3
Western tributaries	**23**	**0**	**0**	**10**	**26**
Calumet River	2	0	0	1	1
Ells River	5	0	0	1	4
MacKay River	8	0	0	4	4
Poplar Creek	3	0	0	2	1
Tar River	5	0	0	2	3
Southern tributaries	**13**	**0**	**0**	**2**	**11**
Christina River	6	0	0	1	5
Clearwater River	6	0	0	1	5
Hangingstone River	1	0	0	0	1
Regional lakes	**19**	**0**	**7**	**2**	**0**
Isadore's Lake	3	0	0	1	0
Kearl Lake	6	0	2	0	0
McClelland Lake	4	0	2	0	0
Shipyard Lake	6	0	3	1	0
Total	**167**	**7**	**10**	**73**	**77**

From these clusters, data from baseline stations (i.e., those located in watersheds where oil sands development has not yet occurred) were pooled to develop descriptions of regional sediment quality against which 2004 RAMP data were assessed. Athabasca River stations showed high variability in membership among clusters and no baseline data for the Athabasca River delta cluster (i.e., all delta stations are downstream of development). However, given the physical linkage between the river mainstem and delta, these stations were grouped together for comparative purposes. Table 3.3-6 lists the station-year from which from 1997 to 2004 RAMP data were pooled to develop these baseline descriptions and which stations were compared against these baselines. Numbers of observations in regional baseline data sets ranged from n=3 (Cluster 2: Regional lakes) to n=45 (Cluster 3: Athabasca River tributaries) (Table 3.3-6).

Table 3.3-6 Regional baseline sediment quality data groups and station comparisons.

Regional baseline grouping (Cluster)	Baseline stations used for regional comparison	Stations (2004) compared with this regional baseline
1. Athabasca River mainstem and delta	ATR-UFM, ATR-DC-CC, ATR-DC-W, ATR-DC-E, ATR-DC-M **n=13 station-year observations**	ATR-SR-W, ATR-SR-E, ATR-MR-W, ATR-MR-E, ATR-FC-W ATR-FC-E, ATR-DD, ATR-FR ATR-ER, ARD-1, plus all baseline stations to left
2. Regional lakes	KEL-1, MCL-1 **n=3 observations**	SHL-1, plus all baseline stations to left
3. Athabasca River tributaries	FIR-1, FIR-2, FIR-2X, FOC-1, MUR-5 (to 2003), MUR-6, CHR-1, CHR-2, CLR-1, CLR-2, HAR-1, STR-2, NSR-1, CAR-1, ELR-1, ELR-2, MAR-1 (1998-2001), MAR-2, POC-1 (1997-1998), TAR-1 (1998-2003), TAR-2 **n=45 observations** (n=32 for total PAHs)	JAC-1, MUR-1, MUR-2, MUR-D2, POC-1, TAR-1, plus all baseline stations to left

3.3.7.4 Tabular and Graphical Presentation of 2004 Sediment Quality Results

Comparison to Sediment Quality Guidelines

2004 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 2003 at that station. Concentrations of any sediment quality measurement endpoint that exceeded relevant guidelines were noted and, as indicated above, all values that exceeded these guidelines were also reported.

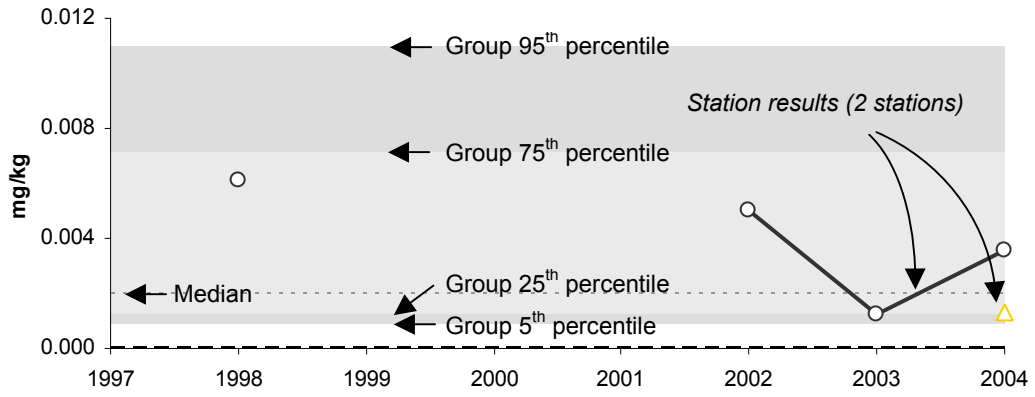
Comparison to Natural Variation in Baseline Conditions

To allow regional comparison, untransformed data from all baseline stations sampled by RAMP from 1997 to 2004, for all sediment quality measurement endpoints, were pooled from each cluster of similar stations; descriptive statistics describing natural sediment quality characteristics for each group were calculated. For each cluster, the 5th, 25th, 50th (≡median), 75th, and 95th percentiles were determined, for comparison against 2004 data. Data for a subset of the sediment quality measurement endpoints (namely, Total PAHs, Total Recoverable Hydrocarbons, and naphthalene) were presented graphically in the context of relevant regional variability, as shown in the example graph below (Figure 3.3-2). Data for each station were presented for all years of sampling by RAMP, to allow assessment of any temporal trends. To allow more sensitive assessment of any temporal trends, hydrocarbon concentrations were normalized to organic carbon content and expressed as mg/kg organic carbon. 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.

Trend Analysis

Given the short time period for which sediment quality data are available, and typically high data variability, any trends in sediment quality in key variables of interest were assessed qualitatively by graphical means.

Figure 3.3-2 Example of comparison of data from a specific RAMP station[1] against regional baseline data and sediment quality guidelines.



[1] In this case, naphthelene at Ells River stations ELR-1 and ELR-2.

3.4 BENTHIC INVERTEBRATE COMMUNITIES

3.4.1 Overview of 2004 Program

A total of 28 locations were sampled in 2004 for the Benthic Invertebrate Community component, comprising 23 river reaches, including one (Hangingstone River) newly established in 2004, three stations in the Athabasca River Delta and two lakes (Figure 3.4-1, Table 3.4-1). As in previous years, samples were collected in the dominant habitat type found in each reach (Table 3.4-1). Habitats were defined as being either depositional (dominated by fine sediment deposits and low to no current) or erosional (dominated by rocky substrates and frequent riffle areas). Most tributaries in the study area are predominately depositional, with some variation within watercourses.

3.4.2 Field Methods

Field Sampling

The benthic invertebrate community field program was conducted from September 8 to 22, 2004. Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003a). A Neill-Hess cylinder (0.093-m^2 opening and 210-µm mesh) was used for collection of invertebrates in erosional areas. In depositional habitats, a pole-mounted Ekman grab (0.023 m^2, 6″ x 6″) was used for invertebrate collection. In lakes greater than 1 m deep, the 6″ x 6″ Ekman dredge was used, but the device was deployed using a rope and messenger from the surface.

In rivers, a total of 15 replicate samples (using the Ekman or Neill-Hess depending on habitat type) were collected from within pre-established reaches. Reaches were typically 2 to 4 km long. Samples were selected randomly from within the reach, based on habitat availability and approximately equal spacing. In lakes and wetlands (i.e., Shipyard Lake, Kearl Lake, McClelland Lake), a total of 5 replicate samples were randomly selected based on a controlled depth range (1.5 to 3 m). For the stations in the Athabasca River Delta, five replicate samples were collected. Samples collected at depositional stations were sieved in the field using a 250-µm screen, preserved in 10% buffered formalin, and bottled for transport. Dr. Jack Zloty in Calgary, AB, performed sorting and taxonomic identifications, as in previous years.

At depositional stations, an additional Ekman grab sample was collected for laboratory analysis of total organic carbon (TOC as a dry weight percentage) and particle size (% sand, silt and clay, as dry weight). At erosional stations benthic algae scrapings were collected for chlorophyll a determination. All laboratory analyses were conducted by EnviroTest Laboratories Ltd. (ETL).

A series of physical measurements were recorded as supporting information from each replicate station. These measurements are identical to those recorded in previous RAMP sampling years:

- wetted and bankfull channel widths – visual estimate (for rivers/streams only); field water quality measurements – dissolved oxygen, conductivity, temperature (YSI85 multi-meter) and pH (WTW Set 2 pH meter). All instruments calibrated according to manufacturers instructions;

- current velocity – Marsh-McBirney current velocity meter or a Swoffer Model 2100 current velocity measurement;

- water depth – measured from the graduated wading rod associated with each current velocity meter;

- amount of benthic algae at erosional stations (for chlorophyll a measurement) – obtained through scraping of a 2 cm x 2 cm square from three randomly selected cobbles and combined into one composite sample per station;

- substrate particle size distribution (erosional stations only) – visual estimates of areal coverage by particles in standard size categories using the modified Wentworth classification system (Cummins 1962) and expressed as percentages;

- geographical position – using a hand-held Magellan Global Positioning System (GPS) unit; and

- general station appearance.

Laboratory Methods

Benthic 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 subsampled using a method based on that described by Wrona *et al*. (1982). Invertebrates were removed from the detritus under a dissecting microscope. All sorted material was preserved for random checks of removal efficiency.

Invertebrates were identified using recognized taxonomic keys (Brooks and Kelton 1967; Teskey 1969; Edmunds *et al*. 1976; Oliver and Roussel 1983; Currie 1986; Wiederholm 1986; McCafferty and Randolph 1988; Stewart and Stark 1988; Brinkhurst 1989; Pennak 1989; Clifford 1991; Merritt and Cummins 1996; Westfall and May 1996; Wiggins 1996; Zloty and Pritchard 1997; Epler 2001). Animals were identified to the lowest practical level, typically genus with the exception of Oligochaeta, which were identified to family. Small, early-instar or damaged specimens were identified to the lowest level possible, generally to family.

Quality assurance and quality control (QA/QC) procedures related to benthic invertebrate sample processing are discussed in Appendix B. Five percent of the total number of samples collected during the field program was re-sorted to evaluate sorting efficiency.

Table 3.4-1 Summary of benthic invertebrate community sampling program for 2004.

Waterbody and Location	Habitat	Station	UTM Coordinates			
			Easting		Northing	
			Min.	Max.	Min.	Max.
Athabasca River						
Athabasca Delta	depositional	FLC,GIC,BPC	496607	511824	6491521	6494584
Calumet River						
Lower reach near mouth	depositional	CAL-D-1-15	458197	459931	6361950	6362770
Upper reach	depositional	CAL-D-16-20	453923	454035	6366527	6366603
Clearwater River						
Downstream of Christina River	depositional	CLR-D-1-15	479635	481252	6282704	6284473
Upstream of Christina River	depositional	CLR-D-16-30	498440	501154	627840	6279917
Christina River						
Lower reach near mouth	depositional	CHR-D-1-15	495920	497647	6278654	6280506
Upper reach at Janvier	depositional	CHR-D-16-30	510434	511783	6191563	6192328
Ells River						
Lower reach near mouth	depositional	ELR-D-1-15	458455	459182	6350846	6351671
Upper Reach	erosional	ELR-E-1-15	455146	455809	6343484	6344746
Firebag River						
Lower reach near mouth	erosional	FIR-E-1-15	476269	479795	6397267	6400855
Upper reach	depositional	FIR-D-1-15	531088	532257	6354524	6354992
Hangingstone River						
Lower reach near mouth	erosional	HAR-E-1-15	478008	478463	6278221	6279799
Jackpine Creek						
Lower reach near mouth	depositional	JAC-D-1-15	471640	473534	6326296	6346435
Upper reach	depositional	JAC-D-16-30	479970	480852	6324358	6325103
MacKay River						
Lower reach near mouth	erosional	MAR-E-1-15	453577	460381	6337496	6339051
Upper reach	erosional	MAR-E-16-30	448539	449407	6318277	6319660
Muskeg River						
Lower reach near mouth	erosional	MUR-E-1-15	463718	465833	6332043	6334168
Lower to middle reach	depositional	MUR-D-1-15	466562	466775	6339617	6340834
Upstream of Stanley Creek	depositional	MUR-D-16-30	479702	482153	6356958	6359466
Steepbank River						
Lower reach near mouth	erosional	STR-E-1-15	471273	472037	6319815	6320176
Upper reach	erosional	STR-E-16-30	500098	501279	6297165	6297436
Tar River						
Lower reach near mouth	depositional	TAR-D-1-15	457893	458581	6353179	6353512
Upper reach	erosional	TAR-E-1-15	441852	442423	6360468	6360898
Kearl Lake						
Kearl Lake	lake	KRL-1-10	484914	486141	484914	486141
Shipyard Lake						
Shipyard Lake	lake	SHL-1-10	473603	473651	473603	473651

3.4.3 Changes in Monitoring Program from 2003

The Lower Reach of the Hangingstone River was added as part of the 2004 sampling program. In addition, the upper reach of the Steepbank River was sampled in this 2004 survey, for the first time.

3.4.4 Challenges Encountered and Solutions Applied

All proposed sampling areas were sampled as proposed.

3.4.5 Other Information Obtained

No additional or supplementary information was obtained as part of the 2004 Benthic Invertebrate Community component.

3.4.6 Summary of Component Data Now Available

As of 2004, 1,120 benthic community samples have been collected under the RAMP. The distribution of sites, and the time-series of data available for individual water bodies is presented in Table 3.4-2. Three years of baseline data have now been collected for the Athabasca River Delta, two lakes (Kearl and McClelland) and several tributaries (Calumet River, Christina River, Clearwater River, Ells River, MacKay River, Steepbank River, Tar River). Operational data are available to begin testing for effects on the Muskeg River (upper, mid and lower reaches), Jackpine Creek (lower reach), MacKay River (lower reach), Steepbank River (lower reach) and Tar River (lower reach).

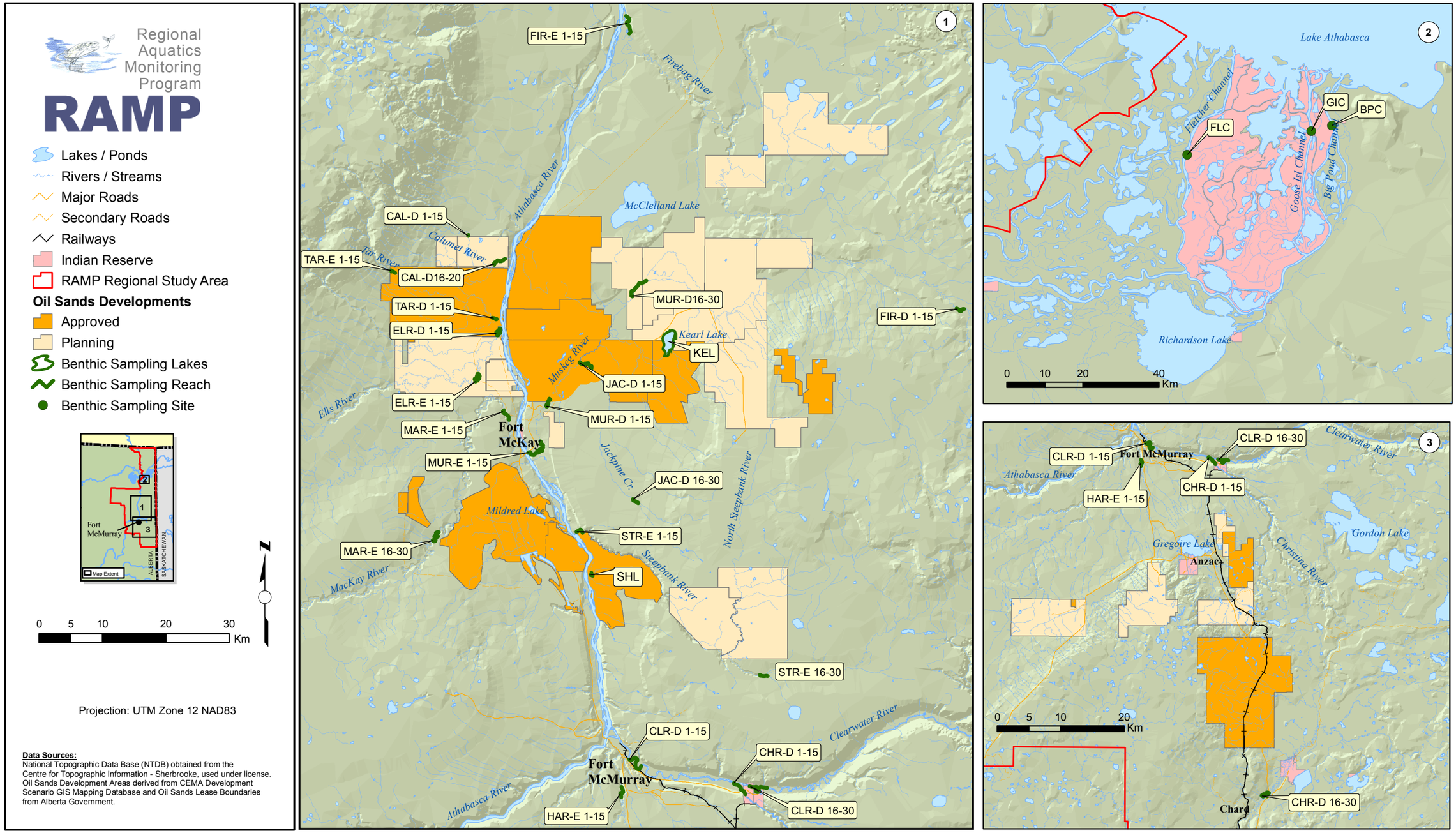
3.4.7 Analytical Approach and Methods

The RAMP 2004 benthic invertebrate community analysis included the following major components:

- Selection of benthic invertebrate community measurement endpoints;
- Development of criteria to be used in detecting changes in benthic invertebrate community measurement endpoints; and
- Detailed data analysis, consisting of:
  - Designation of stations used as baseline stations for benthic invertebrate community conditions through the establishment of regional baseline values; and
  - Tabular and graphical presentation of 2004 results comparing 2004 concentrations of the benthic invertebrate community measurement endpoints, benthic invertebrate community baseline conditions, and selected criteria for determination of change in benthic invertebrate communities.

These components are described in detail below.

Figure 3.4-1 2004 benthic invertebrate community sampling locations.



RAMP1110\GIS\2004_BENTHOS.MXD

3.4.7.1 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,

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

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

- Evenness, where,

$$\text{Evenness} = \frac{D}{D_{max}} \qquad [2]$$

$$D_{max} = 1 - \left(\frac{1}{S}\right) \qquad [3]$$

  and S is the total number of taxa in the sample. In situations where S = 1 (i.e., only one taxon was identified in a sample), evenness was set to 1; and

- Percent EPT (Ephemeroptera, Plecoptera, Trichoptera).

Abundance, richness, diversity, evenness, and percent EPT were determined for each sample and then averaged to reach or lake level. The indices were computed for all RAMP data dating from 1998 onward to evaluate trends in these measures over time.

3.4.7.2 Criteria for Determining Effects

The criterion used for determining effects on benthic invertebrate communities was exceedance of the regional range of variability for the selected measurement endpoints based on baseline mean and standard deviation, with regional range defined as $\bar{X} \pm 2SD$.

Based on similarities in fauna, across years, those groupings were used to calculate regional ranges of variability for the select indices of composition based on the mean and standard deviation (i.e., regional range was estimated as $\bar{X} \pm 2SD$). That approach to estimating the normal range of variability is consistent with the recommended approach in the Five-Year report (Golder, 2003), but differing in that ranges were produced for clusters of reaches here, and only for individual reaches in the Five-Year summary. What this approach does not do is take into account trends in the baseline condition over time. The Muskeg (lower through to upper reaches), the MacKay River (lower reach since 2002), Steepbank River (lower reach since 1998) and Tar River (lower reach, 2004) are designated as exposed to oil sands developments. All other reaches are considered (at this time) to be in a reference condition. Variations in indices of benthic community composition in exposed reaches were evaluated relative to variations in reaches considered to be in a reference condition as in Table 3.4-2.

Table 3.4-2 Summary of RAMP Data Available for the Benthic Invertebrate Coomunity Component.

see symbol key at bottom

WATERBODY AND LOCATION	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
			W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																		
Near Donald Creek (west bank)	depositional	ATR-B-B4 to B6				1																												
Near Donald Creek (east bank)	depositional	ATR-B-B1 to B3				1																												
Near Fort Creek (west bank)	depositional	ATR-B-A4 to A6				1																												
Near Fort Creek (east bank)	depositional	ATR-B-A1 to A3				1																												
Suncor near-field monitoring	depositional	-																				2												
Athabasca Delta	depositional	FLC,GIC,BPC																								1				1				1
Calumet River																																		
Lower reach near mouth	depositional	CAL-D-1-15																				2				1				1				1
Upper reach	depositional	CAL-D-16-20																												1				1
Clearwater River																																		
Downstream of Christina River	depositional	CLR-D-1-15																				1				1				1				1
Upstream of Christina River	depositional	CLR-D-16-30																				1				1				1				1
Christina River																																		
Lower reach near mouth	depositional	CHR-D-1-15																								1				1				1
Upper reach at Janvier	depositional	CHR-D-16-30																								1				1				1
Ells River																																		
Lower reach near mouth	depositional	ELR-D-1-15																								1				1				1
Upper Reach	erosional	ELR-E-1-15																												1				1
Firebag River																																		
Lower reach near mouth	erosional	FIR-E-1-15																												1				1
Upper reach	depositional	FIR-D-1-15																												1				1
Fort Creek																																		
Lower reach near mouth	depositional	FOC-D-1-5												2								1				1				1				
Hangingstone River																																		
Lower reach near mouth	erosional	HAR-E-1-15																																1
Jackpine Creek																																		
Lower reach near mouth	depositional	JAC-D-1-15																								1				1				1
Upper reach	depositional	JAC-D-16-30																												1				1

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

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

exposed
reference

Table 3.4-2 (cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004			
			W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
MacKay River																																		
200 m upstream of mouth	erosional	MAR-1								1																								
500 m upstream of mouth	erosional	MAR-2								1																								
1.2 km upstream of mouth	erosional	MAR-3								1																								
Lower reach near mouth	erosional	MAR-E-1-15																1				1				1				1				1
Upper reach	erosional	MAR-E-16-30																								1				1				1
Muskeg River																																		
50 m upstream of mouth	erosional	MUR-1								1																								
200 m upstream of mouth	erosional	MUR-2								1																								
450 m upstream of mouth	erosional	MUR-3								1																								
Lower reach near mouth	erosional	MUR-E-1-15																1				1				1				1				1
Lower to middle reach	depositional	MUR-D-1-15																1				1				1				1				1
Upstream of Stanley Creek	depositional	MUR-D-16-30																								1				1				1
Steepbank River																																		
50 m upstream of mouth	erosional	STR-1								1																								
150 m upstream of mouth	erosional	STR-2								1																								
300 m upstream of mouth	erosional	STR-3								1																								
Lower reach near mouth	erosional	STR-E-1-15																1				1				1				1				1
Upper reach	erosional	STR-E-16-30																												1				1
Tar River																																		
Lower reach near mouth	depositional	TAR-D-1-15																				2				1				1				1
Upper reach	erosional	TAR-E-1-15																												1				1
Kearl Lake																																		
Kearl Lake	lake	KRL-1-10																				1				1				1				1
McClelland Lake																																		
McClelland Lake	lake	MCL-1-10																								1				1				
Shipyard Lake																																		
Shipyard Lake	lake	SHL-1-10																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										

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

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

exposed
reference

3.4.7.3 Detailed Data Analysis

Taxonomic and water/sediment quality summaries were generated for all river and lake samples collected in 2004, averaged across sample locations for each reach/lake. The distribution of abundance across taxa was also averaged for each sample reach or lake. The percent of the total samples represented by the EPT taxa (Ephemeroptera – mayflies, Plecoptera – stoneflies, and Trichoptera – caddisflies) was also determined for each sampling location.

Determination of Regional Baseline Conditions

Correspondence Analysis (CA) was used to identify natural groupings of study reaches that were designated as reference. These natural groupings were then used to identify regional baseline conditions for different groupings of systems and habitat types (Appendix G contains details of the CA approach used for this RAMP component).

The results of the CA of baseline sites from the entire RAMP program (1998–2004) are shown in Figure 3.4-2. The only natural grouping of sites that was apparent in the ordination was between erosional and depositional habitats, and separation occurred mostly along the first CA axis. Depositional sites tended to be dominated by the Tabanidae, Tubificidae, Ostrocoda, Coleoptera, Ceratopogonidae, and Chironomidae. By comparison, erosional sites tended to be dominated by EPT taxa (Ephemeroptera, Plecoptera, Trichoptera), the Enchytraeidae, Empididae, and Hydracarina.

Additional CAs were conducted on depositional and erosional reference reaches separately, but still found very little natural grouping of sites within either habitat type. Thus, baseline conditions were defined in terms of habitat type only; that is, erosional versus depositional habitats.

The taxon scores and eigenvalues generated from the CA on reference reaches were used to calculate site scores for reaches where there is current potential for effects from oil sands development (i.e., Lower Reach of the Muskeg River, Lower to Mid Reach of the Muskeg River, Lower Reach of the Steepbank River, Lower Reach of the MacKay River, Lower Reach of Jackpine Creek, and Lower Reach of the Tar River). Patterns in community composition over time in exposed reaches were compared visually to expected baseline conditions for the different habitat types.

These were plotted graphically by reach with baseline conditions appropriate to the reach habitat type overlaid on the figure for comparison. Baseline conditions were derived based on habitat type (erosional versus depositional) and are summarized in Table 3.4-3. All data were plotted as means ± 2 standard deviations (SD), representing the range about the mean over which approximately 95% of observations can be expected to lie.

Effects of Oil Sands Development on Benthic Invertebrate Communities

Possible effects of oil sands development were evaluated by comparing benthic measurement endpoints in exposed reaches to upstream reference reaches and/or to pre-development conditions with analysis of variance (ANOVA). When necessary, dependent variables (measurement endpoints) were $\log_{10}$-transformed to meet assumptions of normality and homogeneity of variances. One-way ANOVAs were conducted for each benthic community index with each reach-year combination as the

Figure 3.4-2 Correspondence analysis of benthic invertebrate taxon abundances in reference reaches of RAMP, 1998 – 2004.

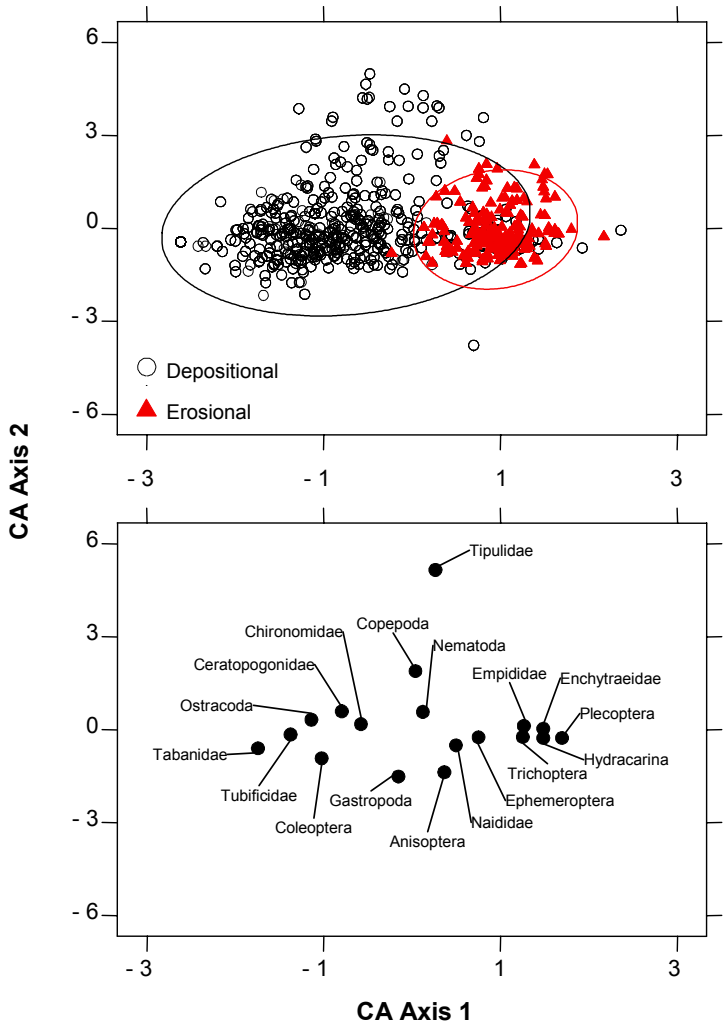


Table 3.4-3 Baseline conditions of benthic community indices in erosional and depositional habitats.

Index	Erosional habitats			Depositional Habitats		
	Mean	SD	N	Mean	SD	N
Total abundance (#/m^2)	20,001	27,149	197	22,086	30,533	445
Richness	30.6	7.8	197	11.3	7.0	445
Simpson's Diversity	0.847	0.086	197	0.628	0.231	445
Evenness	0.878	0.089	197	0.743	0.213	445
EPT (%)	26.1	17.9	197	2.9	10.4	445

factorial variable. Planned comparisons were then used to identify differences between reference and exposed reaches, between designated baseline and operational periods, and changes over time. A comparison that tested for the interaction between reference and exposed reaches and trends over time made it possible to evaluate if temporal patterns differed between the reference and exposed reaches in a system. We also evaluated differences between reference and exposed reaches for data collected in 2004 only. In all cases, the comparisons were tested against the residual error of the omnibus one-way ANOVA.

Habitat types between reference and exposed reaches were not always the same; in these cases we expected that trends over time should be the same in both reference and exposed reaches unless oil sands development was influencing the downstream reach different from the upstream reach.

Note that the three channels of the Athabasca River Delta are considered potentially exposed to oil sands development; however, due to the unique nature of the deltaic environment there are no reference reaches are available. Consequently, it was not possible to test for differences in measurement endpoints for the three channels of the Athabasca River Delta.

3.5 FISH POPULATIONS

3.5.1 Overview of 2004 Program

In 2004, RAMP conducted the following monitoring of fish populations in the oil sands region:

- fish inventory on the Athabasca River (spring and fall sampling), the Clearwater River (spring and fall sampling), and the Muskeg/Jackpine River (summer/fall);
- reconnaissance level fish inventory on the Christina River (fall);
- tissue collection and chemical analysis for target fish species in the Clearwater River, Muskeg/Jackpine River, and one regionally important lake (Winefred Lake);
- sentinel fish species program on the Muskeg, Steepbank, Horse and Dunkirk rivers; as well as a sentinel species reconnaissance survey on the Ells River; and
- fish fence reconnaissance survey on the Ells and MacKay rivers.

Table 3.5-1 lists the watercourses sampled and the target fish species for each component of the 2004 RAMP Fisheries Component program. The locations of sampling sites for the 2004 fisheries program elements are shown in Figure 3.5-1. Common and scientific names for each fish species noted in this report are listed in Appendix H.

Table 3.5-1 Tasks, sampling sites, timing and target species for 2004 RAMP fish program.

Waterbody	2004 RAMP Fisheries Program Activity					
	Fish Inventory	Fish Tissue	Sentinel Species	Fish Fence Reconn.	Sentinel Reconn.	Reconn. Inventory
Winifred Lake		FALL ▪ walleye, ▪ lake whitefish ▪ northern pike				
Athabasca River	SPRING & FALL ▪ fish community					
Clearwater River	SPRING & FALL ▪ fish community	FALL ▪ walleye ▪ northern pike				
Christina River						FALL ▪ fish community
Muskeg / Jackpine River	SUMMER ▪ fish community	FALL ▪ walleye ▪ northern pike	FALL ▪ slimy sculpin			
Steepbank River			FALL ▪ slimy sculpin			
Ells River				SPRING ▪ assessed physical conditions	FALL ▪ small-bodied fish species	
MacKay River				SPRING ▪ assessed physical conditions		
Horse River			FALL ▪ slimy sculpin			
Dunkirk River			FALL ▪ slimy sculpin			

3.5.2 Field Methods

3.5.2.1 Fish Inventory

Athabasca River and Tributary

Overview The RAMP Athabasca River and tributary fish inventory is conducted to provide data on geographic and temporal variations in fish species composition, relative abundance, size and condition factor. In 2004, spring and fall inventories were carried out to augment existing fish presence and abundance data for key fish indicator species (i.e., Key Indicator Resources) in the oil sands region of the Athabasca River. The key fish indicator species are (CEMA 2001):

- walleye (*Sander vitreus*);
- northern pike (*Esox lucius*);

- lake whitefish (*Coregonus clupeaformis*);
- longnose sucker (*Catostomus catostomus*);
- goldeye (*Hiodon alosoides*); and
- trout-perch (*Percopis omyscomaycus*).

Inventories were conducted by personnel from Syncrude, Suncor, CNRL, OPTI/Nexen and Alberta Sustainable Resource Development as an in-kind contribution to RAMP.

Fish Sampling and Handling Spring sampling was conducted between May 4 and May 27, 2004. The survey focused primarily on the Athabasca River mainstem (8 days effort), with a secondary effort on the Clearwater River (2 days effort).

The fall program was implemented from September 21 to September 30, 2004. This survey included five days of effort on the Athabasca River mainstem and one day on the Clearwater River. Fish captured during the Clearwater River component of the inventory were also used to support fish tissue monitoring studies outlined in Section 3.5.3.2.

In 2004, Athabasca River sampling focused on 10 reaches specifically established by RAMP for the inventory program (Table 3.5-2, Figure 3.5-1). The ten reaches have been re-sampled each year (1997-2004) and are located in four sections of the Athabasca River near major tributary confluences. The four areas are: the Poplar Area (Reaches 0 and 1), Steepbank Area (Reaches 4 to 6), Muskeg Area (Reaches 10 to 12), and the Tar-Ells Area (Reaches 16 and 17). Sampling in the Clearwater River was conducted at three locations in the Fort McMurray region (Figure 3.5-1) during the spring sampling effort. Low water conditions and a number of technical difficulties limited the fall sampling to only one of the three Clearwater reaches (CR1 in the upper watershed). Sampling was conducted in areas conducive to boat electrofishing, primarily shallow river margins.

Table 3.5-2 Athabasca River and tributary fish inventory sampling locations, 2004.

Site Name	Reach Numbers	UTM Coordinates (NAD 83, zone 12V)	
		Upstream Boundary	Downstream Boundary
Poplar Area	0 and 1	474627 E / 6305817 N	473052 E / 6311432 N
Steepbank Area	4, 5 and 6	472838 E / 6317197 N	469314 E / 6322688 N
Muskeg Area	10, 11 and 12	463967 E / 6331391 N	463253 E / 6341314 N
Tar-Ells Area	16 and 17	459859 E / 6350353 N	459913 E / 6356845 N
Clearwater River	na	527711 E / 6290586 N	489943 E / 6281368 N

na = not applicable

Fish sampling was carried out using a Smith-Root model SR-18 electrofishing boat with a 5.0 GPP electrofishing unit configured with two anode boom arrays with multiple dropper-cables. The boat hull acted as the cathode. Stunned fish were captured with dip-nets and held in an on-board flow-through live well. Fish observed, but not captured, were enumerated by species and recorded as observed fish. Seine netting (at

select sites in the Clearwater River) was also conducted during the spring inventory (5-m long net). Seining was conducted where the bottom habitat was deemed suitable for walking.

Large-bodied fish were measured for fork length (±1 mm) and weight (±10 g) and an external pathology examination was conducted to assess the presence of abnormalities, disease and/or parasites. Sex and state of maturity were recorded when discernible by external examination. Small-bodied species (e.g., forage fish) were measured for fork length only. Prior to live release, key indicator species of sufficient size were fixed with RAMP Floy tags; each was inscribed with a contact phone number to encourage anglers to report their catch. Non-lethal ageing structures were collected for captured fish following procedures outlined in MacKay *et al*. (1990). Ageing structures were archived.

Muskeg River/Jackpine Creek Fish Inventory

Fish were collected in the Muskeg River from August 6 to 8, 2004. Sampling methods were designed to sample all sizes of fish. Sampling was conducted using a Smith-Root 2.5 GPP portable boat electrofishing unit deployed in a 12′ inflatable zodiac-type boat. Baited Gee-type minnow traps were set overnight at one site and checked daily for two days. Fish collected during electrofishing were captured using a hand net. Current was applied to the water in 5 to 10 second bursts and sampling was concentrated along the shoreline areas. An area of river approximately 10 to 15 square metres was sampled for each burst.

Fish were collected in Jackpine Creek from August 4 to 6, 2004. Again, sampling methods were designed to capture all sizes of fish. Sampling was conducted using a Smith-Root 12B-POW battery-powered backpack electrofishing unit. Fish collected during electrofishing were captured using a hand net positioned downstream of the electrofishing unit. Current was applied to the water in 5-10 second bursts and sampling was concentrated along the shoreline areas. An area of river approximately 2-4 m^2 was sampled for each burst. Baited Gee-type minnow traps were also used in the Jackpine inventory and were set overnight at one site and checked daily for two days.

All captured fish from the Muskeg and Jackpine were identified and measured for fork length (± 1 mm), and the majority of fish were measured for wet weight (± 0.1 g) using a calibrated electronic balance. Fish were examined externally for signs of injury, abnormalities, parasitism or disease. Fish were then revived in a bucket of fresh water and released at or near the point of capture. All fish were monitored during the holding period to ensure full recover before being released.

A limited number of northern pike captured during the Muskeg River inventory were sacrificed for tissue analysis. Fish tissue methods are described below in Section 3.5.3.2.

Christina River Reconnaissance Fish Inventory

A reconnaissance fish inventory was conducted on a section of the Christina River to assess its suitability for baseline data collection to support future resource development impact determinations. Fish sampling was carried out over a two-day period from September 21 to 22, 2004 upstream and downstream of the Hwy. 881 bridge crossing.

UTM coordinates for the upstream and downstream boundaries (NAD 83, Zone 12) of the sampling area on the Christina River are as follows:

Downstream Boundary:	510936 E / 6191767 N
Upstream Boundary:	512015 E / 6192252 N

Sampling was conducted using a Smith-Root 2.5 GPP portable boat electrofishing unit deployed from a 12′ inflatable zodiac-type boat. Fish collected during electrofishing were captured using a hand net. Current was applied to the water in 5 to 10 second bursts and sampling was concentrated along the shoreline areas. An area of river approximately 10 to 15 square metres was sampled for each burst. In addition to the electrofishing, eight baited Gee-type minnow traps were set overnight at different sites with in the sampling area.

All captured fish from the Christina River were identified and measured for fork length (± 1 mm), and wet weight (± 0.1 g) using a calibrated electronic balance. Fish were examined externally for signs of injury, abnormalities, parasitism or disease. Fish were then revived in a bucket of fresh water and released at or near the point of capture. All fish were monitored during the holding period to ensure full recover before being released.

3.5.2.2 Fish Tissue

The RAMP fish tissue program is conducted to measure the levels of chemicals, including metals and organic tainting compounds, present in fish populations of the Athabasca oil sands region, and to identify any potential risks to humans, fish, and wildlife.

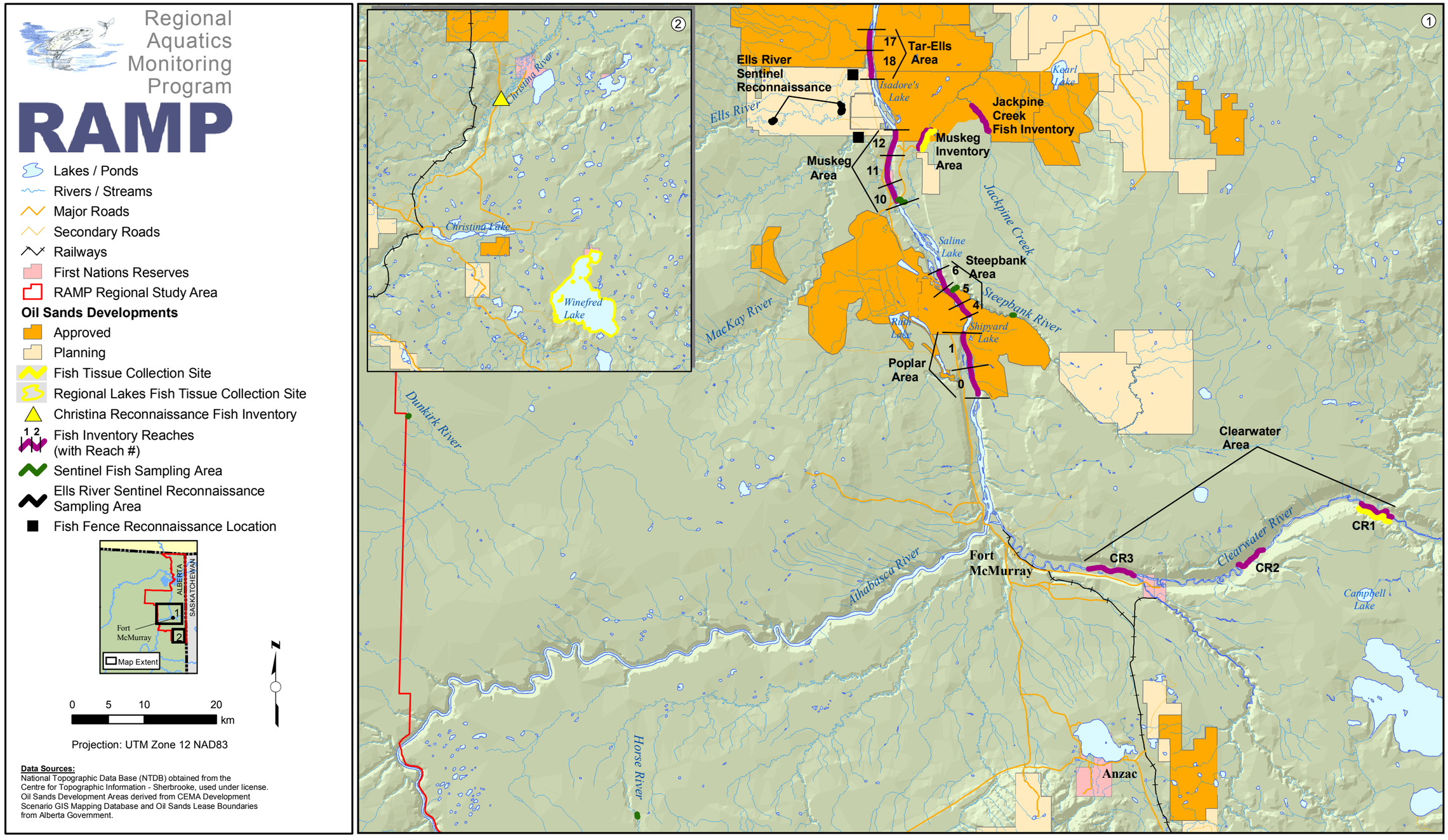
In 2004, fish sampling for tissues was conducted in the Clearwater River and the Muskeg River, as well as Winefred Lake. Lake collections were conducted under the Regional Lakes component of the RAMP Fish Tissue Program. Regional lake sampling was initiated to address community concerns regarding the safe consumption of fish from recreational, subsistence or commercial fisheries in regionally important lakes connected to the Athabasca River, or located in the zone of airborne oil sands emissions. Tissue collection and analyses occurs on an opportunistic basis, when sampling is conducted by other agencies or programs.

Fish species targeted for the Clearwater and Muskeg Rivers included walleye and northern pike. For Winefred Lake, tissues from lake whitefish, walleye and northern pike were collected and analyzed.

Fish Collection and Sampling

Clearwater River and Muskeg River Fish sacrificed for tissue analysis were acquired from a sub-sample of fish captured during the inventory work on the Clearwater and Muskeg Rivers as described above (see Section 3.5.3.1). Fish that met the species and length requirements for tissue analyses (Table 3.5-3) were transferred to an onshore portable sampling station and held in coolers prior to dissection.

Figure 3.5-1 Location of fish population component sampling areas (inventory, tissue programs, sentinel species program, reconnaissance), 2004.



RAMP1110\GIS\2004_FISH.MXD

For each selected fish species, up to 25 individuals were targeted for mercury tissue analyses on the basis of size. The objective was to collect tissues for mercury analysis from five fish of each sex from each of five predetermined size classes for each species (Table 3.5-3). Size classes were used to ensure an equal distribution of tissue samples were collected from a wide range of fish sizes and ages; this approach helped obtain a better understanding of tissue concentrations within the populations being assessed, and allowed direct comparison with data from previous sampling efforts. Size classes were selected based on typical size ranges of fish available in the fall, as observed during past fish inventory surveys (RAMP 2003). In addition to the size ranges of fish selected for mercury analysis, sub-samples of male and female fish within a narrow size class from each species were targeted for a more comprehensive suite of organics and metals analyses (Table 3.5-3). This range was selected to remove potential variability associated with size and age, and to allow for direct comparison to previous surveys (RAMP 2003).

Table 3.5-3 Target fork length classes for the selection of fish for the RAMP fish tissue program, Clearwater and Muskeg Rivers, 2004.

Species	Target Size Classes for Mercury Analysis (mm) (5 fish per class)					Target Size Classes for Composite Samples	
	1	2	3	4	5	Female	Male
Walleye	200-300	301-400	401-500	501-600	601-700	500-550	450-500
Northern pike	200-300	301-400	401-500	501-600	601-700	500-550	450-500

Mercury concentration was measured in all fish selected for tissues analysis, while a more comprehensive suite of metals and tainting compounds analyses was completed on composite samples prepared for each species and sex. Composite sample sizes of five walleye and five northern pike from each sex were targeted during field operations.

A sub-sample of sacrificed fish were selected for an inter-laboratory examination of the suitability of implementing a non-lethal biopsy needle sample collection methodology for mercury analysis in future fish tissue programs (see description below for further details).

Each fish was measured for fork length (± 1.0 mm), total weight (± 1.0 g) and underwent an external health assessment prior to dissection. For each fish, muscle tissue was removed for mercury analyses. Additional muscle tissues were targeted from five males and females per species for composite samples. Muscle tissues were removed from the left side of the fish following procedures outlined in the RAMP protocol for fish health assessment for organic chemicals (Golder 1999), and from the right side of the fish according to the RAMP fish health assessment protocol for metals (Golder 1999). Minimum muscle tissue requirements per fish were set at 20 grams for organics analyses and two grams for metals analyses; for most fish, these minimum weights were well exceeded. Muscle samples collected for organics analyses were individually wrapped in solvent-rinsed aluminum foil and samples collected for metals analyses were individually wrapped in plastic wrap. All samples were labeled, stored on dry ice, and shipped to Enviro-Test Laboratories (ETL Edmonton) for analysis and compositing.

After dissection, carcass weight (i.e., internal organs removed; ± 1.0 g), liver weight (± 1.0 g) and gonad weight (± 1.0 g) were measured for each fish. Tissue chemistry sample weights were added to the fish carcass weight. An internal health assessment (Goede 1993) was conducted on each fish and ageing structures, consisting of otoliths and pectoral fin rays were collected. Ageing structures were sent to North Shore Environmental Services (Ontario) for analysis.

Regional Lakes The Regional Lakes program was initiated in 2002 to provide a mechanism for opportunistic testing to quantify potential mercury, and possibly other chemicals, in fish tissues collected from lakes located within the RAMP study area. The Regional Lakes protocol developed by the RAMP Fisheries Sub-group is provided in Appendix H.

Laboratory protocols for the 2004 program were revised based on feedback from the RAMP Technical Sub-Committee meeting (held 25-26 March, 2004); namely, previous programs involved the individual testing of the three largest fish caught per species, while the remaining specimens were analyzed as composite samples, each consisting of five fish. All samples were tested for total mercury concentration only. The current program involves measurement of mercury in individual fish from several size classes, as depicted in Table 3.5-4.

Table 3.5-4 2004 Revised target size classes for RAMP regional lakes opportunistic sampling programs.

Species	Target Size Classes for Mercury Analysis (mm) (5 fish per class)				
	1	2	3	4	5
Walleye	200-300	301-400	401-500	501-600	601-700
Lake whitefish	350-400	401-450	451-500	501-550	551-600
Northern Pike	200-300	301-400	401-500	501-600	601-700

In 2004, fish tissues from lake whitefish, walleye, and northern pike were collected by the Alberta Department of Sustainable Resource Development (ASRD) from fish sacrificed during their annual Fall Walleye Index Netting (FWIN) program in Winefred Lake. A sub-sample of the fish captured were selected for tissue testing to ensure the size ranges observed for each species were well represented; as with the Clearwater River tissues program, this approach provided mercury bioaccumulation data on a population scale.

All fish were captured using scientific multi-gang gill nets. Efforts were made to collect a minimum of 10 fish from each of the target species. Fork length and weight were measured and sex and maturity of fish were also reported as part of the FWIN program (ASRD 2005 in preparation).

The tail sections (between the last rib and end of the caudal peduncle) of the Winefred Lake fish were collected on-site by ASRD, placed on ice and transported to Fort McMurray where they were stored in the Hatfield deep-freeze unit before being shipped to ETL for dissection and analysis. Dissection instructions were provided to the laboratory to ensure skinless, interior tissue samples were collected from each specimen.

Non-Lethal Biopsy Pilot Study In 2004, RAMP initiated a non-lethal fish tissue biopsy pilot study in response to technical sub-committee concerns regarding potential effects of lethal monitoring activities on fish populations. The goal of this investigation was to evaluate whether tissues from target species (i.e., walleye and northern pike) could be acquired for analysis of mercury using a non-lethal sampling methodology similar to those employed by Baker *et al* (2004); this publication observed that mortalities and long-term sublethal effects on fish associated with the tissue biopsy technique were low.

A sub-sample of fish captured and sacrificed in support of the Clearwater River tissues program was used for this pilot study. In addition to the mercury tissue samples secured from these specimens for analysis by ETL, two additional tissue samples were collected and shipped frozen to Flett Research, Winnipeg for mercury analysis; one sample consisted of a minimum of 10 g of tissue collected using standard RAMP dissection methods outlined above, while the second consisted of 50 mg of tissue collected using the biopsy procedure.

Biopsy tissue plugs were collected by inserting the inner cannula of the biopsy needle at an oblique angle beneath a scale and into the dorsal musculature. The outer barrel, which possesses a sharp leading edge, was then extended over the inner needle to cut and capture a small tissue sample. The needle was then removed with the enclosed tissue sample secured within the cannula. Once removed from the fish, the needle was re-engaged, allowing the tissue sample to be collected with a clean pair of tweezers and transferred to a 4 ml externally threaded, sterile cryovial. A minimum of two biopsy plugs were composited to attain the minimum 50 mg sample weight.

All sampling equipment was rinsed in hexane, then acetone, then triple-rinsed with deionized water after each fish to avoid cross contamination. All samples were placed in a cooler on dry ice directly after collection, transported and held in the Hatfield deep-freeze in Fort McMurray before being shipped on dry ice to Flett Research in Winnipeg.

Chemical Analysis of Tissue Samples

Composite samples were prepared at ETL by combining an equal weight of muscle from five fish for each size class. Remaining tissue samples were archived frozen at the testing laboratory pending further analyses.

Individual muscle samples of fish from the Clearwater River, Muskeg River, and Winefred Lake were analyzed for mercury. Composite samples from the Clearwater River fish were also analyzed for mercury and the following:

- Metals: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, vanadium, and zinc.

- Tainting Compounds (PAHs): thiophene, toluene, M+P-xylenes, o-xylene, 1,3,5-tribmethylbenzene, and naphthalene. There are fourteen compounds that are known to have the potential to taint fish muscle (described in Golder 2002), but only these six analytes can be measured effectively.

Analyses were conducted on a wet weight basis. The methods and detection limits used for chemical analyses are presented in Table 3.5-5.

Table 3.5-5 Methods of analyses and detection limits for metals and tainting compounds.

Analyte	Detection Limit(mg/kg)	Method of Analysis
Metals		
Aluminum (Al)	4	EPA 200.3/200.8-ICPMS
Antimony (Sb)	0.04	EPA 200.3/200.8-ICPMS
Arsenic (As)	0.2	APHA 3114 C-AAS – Hydride
Barium (Ba)	0.08	EPA 200.3/200.8-ICPMS
Beryllium (Be)	0.2	EPA 200.3/200.8-ICPMS
Boron (B)	2	EPA 200.3/200.8-ICPMS
Cadmium (Cd)	0.08	EPA 200.3/200.8-ICPMS
Calcium (Ca)	10	EPA 200.3/200.7-ICPOES
Chromium (Cr)	0.2	EPA 200.3/200.8-ICPMS
Cobalt (Co)	0.08	EPA 200.3/200.8-ICPMS
Copper (Cu)	0.08	EPA 200.3/200.8-ICPMS
Iron (Fe)	2	EPA 200.3/200.7-ICPOES
Lead (Pb)	0.04	EPA 200.3/200.8-ICPMS
Lithium (Li)	0.5	EPA 200.3/200.8-ICPMS
Magnesium (Mg)	2	EPA 200.3/200.7-ICPOES
Manganese (Mn)	0.04	EPA 200.3/200.7-ICPOES
Mercury (Hg)	0.01	EPA 200.3/200.8-ICPMS
Molybdenum (Mo)	0.04	EPA 200.3/200.8-ICPMS
Nickel (Ni)	0.08	EPA 200.3/200.8-ICPMS
Phosphorus (P)	2	EPA 200.3/200.7-ICPOES
Potassium (K)	2	EPA 200.3/200.7-ICPOES
Selenium (Se)	0.2	APHA 3114 C-Auto Continuous Hydride
Silver (Ag)	0.08	EPA 200.3/200.8-ICPMS
Sodium (Na)	2	EPA 200.3/200.7-ICPOES
Strontium (Sr)	0.04	EPA 200.3/200.8-ICPMS
Thallium (Tl)	0.04	EPA 200.3/200.8-ICPMS
Tin (Sn)	0.08	EPA 200.3/200.8-ICPMS
Titanium (Ti)	0.05	EPA 200.3/200.7-ICP-OES
Vanadium (V)	0.08	EPA 200.3/200.8-ICPMS
Zinc (Zn)	0.2	EPA 200.3/200.8-ICPMS
Tainting Compounds (PAHs)		
1,3,5-Trimethylbenzene	0.02	EPA 5021/8240-Headspace GC/MS
M+P-Xylenes	0.02	EPA 5021/8240-Headspace GC/MS
Naphthalene	0.02	EPA 5021/8240-Headspace GC/MS
o-Xylene	0.02	EPA 5021/8240-Headspace GC/MS
Thiophene	0.02	EPA 5021/8240-Headspace GC/MS
Toluene	0.02	EPA 5021/8240-Headspace GC/MS
Toluene d8	0.02	EPA 5021/8240-Headspace GC/MS
1,2-Dichloroethane d4	0.02	EPA 5021/8240-Headspace GC/MS
4-Bromofluorobenzene	0.02	EPA 5021/8240-Headspace GC/MS

Data were not presented for naturally occurring elements such as potassium, phosphorus, magnesium, and sodium that are not associated with oil sands activities, or with adverse effects on humans, fish, or wildlife through fish consumption.

In addition to the conventional analyses listed above, tissue samples collected for the non-lethal biopsy pilot study were analyzed for total mercury using cold vapor atomic fluorescence spectrophotometry (CVAFS) at Flett Research Ltd. in Winnipeg. Freeze-dried biopsy samples were transferred to 20 x 150 mm acid cleaned Pyrex culture tubes and digested in 10 mL of a 2.5:1 mixture of sulfuric and nitric acid at 180o C for a period of 6 h in an aluminum hotblock. The samples were cooled to room temperature, 200 µL of BrCl was added, and then made up to 25 mL with deionized water. Analysis of digests was by CVAFS using a Brooks Rand II Hg fluorometer according to EPA Method 1631 protocol (U.S. EPA, 2001b) using a single gold trap. Peak areas were determined with Spectra-Physics 4200 integrator.

3.5.2.3 Sentinel Species

Sentinel species monitoring measures morphological changes occurring in a designated species of fish deemed a good indicator of, and/or particularly susceptible to, changes in environmental quality. The slimy sculpin was selected as the sentinel species for RAMP for various reasons including its limited home range and relative abundance in the project area.

The overall design of the RAMP sentinel species monitoring program is based on the environmental effects monitoring requirements currently in place for the mining and pulp and paper sectors in Canada (Environment Canada 2004). In particular, this involves fish sampling at designated exposed and reference sites. Exposed sites are defined as occurring in the vicinity of, or downstream of, current oil sands developments. These sites are not necessarily exposed to specific oil sands outputs (e.g., industrial discharges), but have the potential to be affected by oil sands operations due to their location. Reference sites occur either in the same watercourses, but upstream of oil sands development, or in other drainages outside the oil sands development area (Golder 2002).

Muskeg/Steepbank Monitoring

Monitoring Sites In 2004, sentinel species monitoring was carried out in a number of tributaries of the Athabasca River. Previous sentinel fish studies were conducted in the Athabasca River tributaries under RAMP in 1999, 2000 and 2001. To maximize comparison of data collected in 2004 with previous studies, fish were collected at the sites listed below in Table 3.5-6 (two exposed sites and three reference sites).

In previous years, the RAMP sentinel species program has used a lethal sampling approach where fish are sacrificed to acquire the necessary data. A non-lethal sampling approach, based on the work of Gray *et al*. (2002), was introduced for the 2004 sentinel species monitoring program. This approach involves the collection of growth data from populations of sculpin at the RAMP exposed and reference sites by non-lethally sampling a minimum of 100 fish at each location twice during the annual growth period. Rather than conduct internal health assessments and calculate organ-somatic indices, the two-sampling period approach was used to assess external growth characteristics (length, weight, and condition factor) of young-of-year fish between emergence and winter ice-cover.

Table 3.5-6 Sampling locations for the tributary sentinel fish species monitoring program, 2004.

Watershed	Site Code	General Location	UTM Coordinates (NAD27)
Muskeg River	MR-E (74 E/4)	Exposed site approximately 0.2 to 0.6 km upstream of the confluence with the Athabasca River	S: 463693 E / 6332507 N F: 463982 E / 6331862 N
Steepbank River	SR-E (74 E/3)	Exposed site in the vicinity of the Steepbank Mine, approximately 0.3 to 1.0 km upstream of the confluence with the Athabasca River	S: 471049 E / 6319993 N F: 471721 E / 6320375 N
	SR-R (74 D/14)	Reference site approximately 16 km upstream of the confluence with the Athabasca River	S: 479342 E / 6316444 N F: 479593 E / 6316461 N
Horse River	HR-R (84 A/8)	Reference site approximately 140 km upstream of the confluence with the Athabasca River	S: 427070 E / 6246983 N F: 427129 E / 6247010 N
Dunkirk River	DR-R (84 A/15)+	Reference site approximately 25 km upstream of the confluence with the MacKay River	S: 395890 E / 6302384 N F: 395852 E / 6302398 N

Note: table reprinted from Table 3.25 in the RAMP 2001 annual report; S - reach start, F - reach finish

Fish Sampling and Handling The two sampling periods for the 2004 sentinel species monitoring program were August 5-12, 2004 and an eight day period between October 12-22, 2004. All fish sampling was carried out by a two or three-person crew using a Smith-Root 12B-POW battery-powered electrofishing unit and a portable pole seine, which was deployed downstream of the anode prior to and during the application of electrical current. The pole seine was fitted with a fine mesh net (1/8 inch) to ensure that young-of-year sculpin were captured. Fish sampling was concentrated in areas that were considered optimum slimy sculpin habitat (i.e., moderated to fast flow, with gravel/cobble/boulder substrate). All sculpin captured were enumerated by life history stage, measured for fork length (± 1.0 mm) and weight (± 0.01 g) using an electronic balance that was calibrated prior to each measurement. An external pathology examination was also performed. The fish were then revived in a bucket of fresh water for eventual release back into the river. All fish were monitored at regular intervals to ensure full recovery prior to being released.

In order to provide supplemental data on age classes and assist with species determinations, ten sculpin were sacrificed from each of the five monitoring sites during the October sampling effort. Fish identification, including DNA analysis, was carried out by Wayne Roberts from the University of Alberta Museum of Zoology. Otoliths were extracted from all fish and archived for future ageing.

In addition to the basic fish sampling outlined above, the August sampling effort included habitat assessments and determination of sculpin densities at each monitoring site. These activities were carried out to evaluate inter-site comparability. The habitat assessment involved measuring and recording a range of parameters relating to channel morphology, substrate, water quality, and fish cover as outlined in Golder (1997) and RIC (1999). Water quality parameters were measured with a YSI Model 85 multi-meter, and included temperature, dissolved oxygen, and specific conductance/conductivity.

Sculpin densities were determined by removing fish from within a representative area of stream channel enclosed by upstream and downstream full-span block nets. Enclosure areas were relatively large (568 to 1,325 m^2) to ensure a representative sample of habitat conditions at each site. Due to time constraints, only single-pass electrofishing was undertaken at each site; the number of fish captured during this effort was assumed to equal the total fish population present within the blocked area. In support of this method a preliminary two-pass approach was attempted at one site, but no fish were captured during the second pass.

Ells River Sentinel Species Reconnaissance

Fish sampling for the Ells River sentinel species reconnaissance was carried out from September 8 to 10, 2004. A range of habitat types was sampled during the field program. The UTM coordinates of the sampling sites on the Ells River are provided below in Table 3.5-7. Effort 1 was located in the upstream sampling are while Efforts 2-5 were conducted in the downstream areas (see Figure 3.5-1, Page 3-79).

Table 3.5-7 UTM coordinates (Zone 12, NAD 83) for sampling sites and fish sampling methods used for Ells River sentinel species reconnaissance.

	Start		Finish		
Effort	Easting	Northing	Easting	Northing	Method
1	446474	6343425	445982	6343242	Backpack Electrofishing
2	455688	6345051	455606	6344677	Backpack Electrofishing
3	455455	6345661	455688	6345051	Backpack Electrofishing
4	455455	6345661	455688	6345051	Minnow Trapping
5	455606	6344677	455771	6344561	Backpack Electrofishing

Sampling methods were designed to capture all sizes of fish. The majority of sampling was conducted using a Smith-Root 12B-POW battery-powered backpack electrofishing unit. Fish were captured during electrofishing using a two-metre wide portable pole seine with a 1/8″ mesh suitable for use by one person. The lower edge of the pole seine was weighted with lead weights to keep it on the substrate.

During the fish sampling efforts, the pole seine was positioned approximately three metres downstream of the electrofishing unit. Current was applied to the water in 5-10 second bursts. An estimated area of river about 2-4 m^2 was sampled at a given time. A number of baited Gee-type minnow traps were set overnight in the downstream sampling area on the Ells River.

All captured fish were identified and measured for fork length (± 1 mm) and wet weight (± 0.1 g) using a calibrated electronic balance. Fish were examined externally for signs of injury, abnormalities, parasitism or disease. Fish were revived in a bucket of fresh water and released at or near the point of capture. All fish were monitored at regular intervals to ensure full recovery prior to being released.

3.5.2.4 Fish Fence Reconnaissance

The successful operation of the 2003 Muskeg River fish fence has prompted RAMP to investigate whether there are other waterbodies in the study area that may be suitable for similar studies. On April 23, 2004 an advanced reconnaissance of potential fish fence sites was conducted on the Ells River (hydrology station S14) and the MacKay River (hydrology station S26) in conjunction with regularly scheduled RAMP hydrometric field activities.

Examinations of channel morphology, flow, and substrate characteristics were undertaken to assess whether the sites were suitable for deployment of a fish fence under site-specific freshet conditions. Historical RAMP hydrographs from each of these stations were also consulted to determine the range of flows typically experienced during the proposed spring operation period. Coordinates for each site area are provided in Table 3.5-8.

Table 3.5-8 Location information for fish fence reconnaissance sites, Spring 2004.

Waterbody	RAMP Hydrology Station	UTM Coordinates (Zone 12, NAD 83)
MacKay River	S26	E 458016 / N 6341022
Ells River	S14	E 457260 / N 6349701

Site suitability was evaluated based on whether the observed conditions were suitable for deployment of a fish fence utilizing the same system and hardware as the 2003 Muskeg River fence. The 2003 fence consisted of vertical conduit pipes held in place by sections of aluminum channel, each 3 m in length, and supported by "two by four" wooden A-frames. Upstream and downstream trap boxes positioned against steel t-bars acted as capture reservoirs for migrating fish. Rock and sand filled polyethylene bags were used to provide further stabilization to the fence (Figure 3.5-2).

Figure 3.5-2 Muskeg river fish fence, May 2003.

The MacKay River site was selected as a candidate for fish fence deployment due to its close proximity to existing hydrometric monitoring stations (RAMP and WSC), which provide historical flows valuable for this assessment, and because it would allow field crews to access the site by vehicle on a daily basis.

The location of the Ells River reconnaissance site was selected to capitalize on the required crew presence for RAMP hydrometric monitoring. However, existing hydrologic data for this site suggests discharge may be too high to ensure integrity of a fish fence with a design similar to that used on the Muskeg River in 2003. Access to this site is by helicopter only.

3.5.2.5 Fish Tag Return Assessment

Since the inception of RAMP in 1999, tagging of key indicator fish species has been regularly undertaken as part of various fish program activities, including inventories and the operation of fish fences. Records have been kept by RAMP and the Alberta Ministry of Sustainable Resource Development (ASRD) that provide data on individual fish tagged during these programs. Data include the tagging date and geographical location, as well as basic morphometric parameters, such as fish length and weight.

RAMP fish tags provide a contact phone number that anglers can use to report catch information to ASRD. This information can in-turn be compared to data compiled at the time of tagging and used for subsequent analysis. In general, capture information has been limited to the tag number, species and a description of the geographical location of where the fish was caught.

3.5.3 Changes in Monitoring Network from 2003 Field Program

There were no changes in the monitoring network for fish program elements that were common to both 2003 and 2004 (i.e., Athabasca fish inventory and tissue sampling).

There were several reconnaissance level elements included in the 2004 fish program that could potentially result in modification of the monitoring network. These included the Ells River sentinel species monitoring reconnaissance, the fish fence reconnaissance conducted on the Ells River and the MacKay River, and Christina River reconnaissance fish inventory. Results of these studies presented in this document will be assessed by the RAMP Technical Subcommittee and changes to the monitoring design and network will be implemented if appropriate.

3.5.4 Challenges Encountered and Solutions Applied

In general, field activities implemented under the 2004 RAMP fish program were completed successfully. However, two of the component elements, the Clearwater fish inventory and the Christina River reconnaissance fish inventory, were not fully implemented due to technical and weather issues. Water levels in the Christina River were in excess of bankfull depth and flow velocity was relatively high during the reconnaissance inventory field program. Under these conditions the catch efficiency of the boat electrofishing unit and minnow traps deployed was reduced significantly. Low water levels and technical difficulties with the boat electrofishing unit resulted in only

one of the three standard reaches on the Clearwater River being sampled during the fall field program.

Spoonhead and slimy sculpin coexist in a number of watersheds in the oil sands region (e.g., Steepbank River and Muskeg River). These species are enumerated during RAMP inventory work on Athabasca River tributaries (e.g., Muskeg River and Jackpine Creek in 2004), and the slimy sculpin is the target species in the sentinel species monitoring program. In 2004, RAMP field crews experienced difficulties trying to identify live sculpins based on conventional diagnostic features (e.g., small pores on the chin, length of the lateral line, and presence of small spines on the pre-operculum). All field crews included at least one member with extensive experience in the identification of small-bodied fish species present in the oil sands region. Difficulties identifying sculpin species in the field may be partially related to a limited understanding of habitat preferences, natural variability in commonly used diagnostic features, and in some cases, hybridization. Misidentification of sculpin species has undoubtedly occurred during past RAMP fisheries field programs.

In response to the sculpin identification problems experienced during the 2004 field program, Hatfield has been working with Wayne Roberts, a sculpin authority from the Museum of Zoology at the University of Alberta, to identify which watersheds in the RAMP study area contain both slimy and spoonhead sculpin species, and to generate a set of protocols that can be used to accurately identify these to species in the field. It is intended that these protocols be available for use during the 2005 RAMP field program.

3.5.5 Other Information Obtained

Since RAMP's inception in 1997, numerous fish of various species have been tagged to provide supplementary information on movement patterns and general life history. In most instances, RAMP Floy tags have been attached to fish during inventory and fish fence programs. These tags are colour-coded and inscribed with a contact phone number to encourage angles to report capture information. Tagging and recapture data are compiled by the Alberta Ministry of Sustainable Resource Development (SRD) from angler reports and results of RAMP fish sampling activities.

In order to supplement the range of RAMP fisheries data gathered and analyzed during the 2004 program, SRD has supplied a summary of fish tagging and recapture information for the years 1999 to 2004. This information and the associated analysis are presented in a subsequent section of the report.

3.5.6 Summary of Component Data Now Available

The Fisheries Population component data collected to date for the RAMP program is summarized in Table 3.5-9.

3.5.7 Analytical Approach

The RAMP 2004 fisheries component analysis included the following major elements:

- Selection of fisheries population measurement endpoints;

- Development of criteria to be used in detecting changes in fisheries population measurement endpoints; and

- Detailed data analysis, consisting of statistical analyses and tabular and graphical presentations of 2004 results for the fisheries population component.

These elements are described in detail below.

3.5.7.1 Selection of Fisheries Population Measurement Endpoints

The measurement endpoints selected for the fisheries population component were specific to each study undertaken within the fisheries population component itself.

Fish Inventory Studies

With respect to the fish inventory studies, the possible measurement endpoints by key indicator species that considered were:

- Relative abundance (catch per unit effort);

- Length-frequency;

- Age-frequency;

- Percent composition; and

- Condition factor.

Based on a review of the available data set from the RAMP fish inventory program it was determined that relative abundance (CPUE) and percent composition were the endpoints best suited for application to analysis of monitoring results.

Fish Tissue Studies

With respect to the fish tissue studies, the measurement endpoints selected were a range of metals (including mercury, particularly for the regional lakes fish tissue studies) and tainting compounds (PAHs) in fish muscle tissue.

Sentinel Species Monitoring

With respect to sentinel species monitoring on Athabasca tributaries, the selected measurement endpoints depend on the sampling approach but were essentially taken from the Environment Canada guidelines for the mining and pulp and paper sectors in Canada:

- *Lethal sampling approach:* Condition factor; Relative gonad size (Gonad Somatic Index); Relative liver size (Liver Somatic Index); and

- *Non-lethal approach:* Condition factor.

Table 3.5-9 Summary of RAMP Data Available for the Fisheries Population Component.

see symbol key at bottom

WATERBODY AND LOCATION	REACH	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																	
Poplar Area	0/1[a]		1	1,5	1,5		1,6	1,5	1,3,6														1								1		1
Steepbank Area	4/5/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1
Muskeg Area	10/11/2012		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7					1								1		1
CNRL/TrueNorth Area (Fort/Asphalt reaches)																							1										
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6																								
Reference Area - upstream of Fort McMurray[c]			1																														
Radiotelemetry study region[d]					2		2		2						2	2	2	2	2														
Downstream of Suncor's Discharge	AR-SD												1,3												10,3				10				
Below Muskeg River	AR-MR												1,3												10,3				10				
Reference site upstream of Ft. McMurray STP																									3				10				
Reference site between STP and Suncor	AR-R												1,3												3				10				
Downstream of Developments (near Firebag R.)																													10,6				
Athabasca River Delta																																	
Athabasca River Tributaries																																	
Fort Creek (mouth)														1,8,5,9		1																	
Historical Review of Tributary Fish Data																																	
Clearwater River	CR1																														1		1
Clearwater River	CR2																														1		
Clearwater River	CR3																											10			1		
Christina River [i]																																	1
Muskeg River																																	
Lower 35 km below Jackpine Creek confluence				1			4						1,3		2,8	2	2	2	2	1	6			1	6							1	6
Mouth (within 1 km of confl. with Athabasca R.)	MR-MT												1,3						4		3		4		4		4						3
Reference sites (Steepbank, Horse and Dunkirk R.)																	3				3												3
Upper Muskeg River (near Wapasu Ck. Confluence)																							1,4		1,4								
Muskeg River Tributaries																																	
Alands Drain																																	
Jackpine Creek (accessable areas of lower creek)															8					1				1								1	
Shelley Creek																																	
Muskeg Creek (Canterra road crossing)[e]																							1,4		1,4								
Stanley Creek																																	
Wapasu Creek (mouth or Canterra road)[e]																							1,4		1,4								
Regionally Important Lakes																																	
Various lakes in water/air emissions pathway																													6				6
Kearl Lake																																	
Isadore's Lake																																	

Legend

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

N/A = site unnamed

exposed
reference

Footnotes

[a] Reaches include east and west banks
[b] Reference area upstream of Fort McMurray; includes a 22 km section extending 1 km upstream of the Duncan Creek Confluence downstream to Iron Point
[c] Reference area upstream of Fort McMurray. It was investigated as a potential reference area for longnose sucker sentinel species monitoring but found to be inadequate due to habitat differences and concerns about longnose sucker mobility.
[d] Radiotelemetry region includes the area 60 km upstream of Fort McMurray to 250 km downstream of Fort McMurray.
[e] small bodied fish inventory done by fish fence (fyke net) to record fish movements in and out of watercourse. Needs to be done prior to Kearl Project.
[f] Located from 3 to 11 km upstream of the confluence with the Athabasca River.
[g] Reference site located approximately 21 km upstream of confluence with Athabasca River; sampling done by Environment Canada, NWRI, Burlington, Ontario
[h] In 2004 the Ells River was evaluated as a potential reference site for sentinel species (slimy sculpin) monitoring on the Muskeg and Steepbank Rivers. Several sites were sampled but no slimy sculpin were captured. Hence, the site was determined not to be suitable as a reference site for this species. In 2004 a fish fence reconnaissance was carried out on the Ells and MacKay Rivers.
[i] Reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing.
[j] In 2004 a fish fence reconnaissance was carried out on the Ells and MacKay Rivers.

Table 3.5-9 (cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	REACH	1997				1998				1999				2000				2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Steepbank River																																	
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																													
Vicinity of Steepbank Mine	SR-MN												1,3								3												3
Reference site in vicinity of Bitumin Heights	SR-R												1,3																				
Setinel reference site[g]	SR-EC												1,3				3				3												3
Sentinel reference sites (Horse and Dunkirk R.)																	3				3												3
Shipyard Lake																																	
McLean Creek																																	
Mouth																																	
Upstream of mouth (100 m)																																	
MacKay River																																	
Lower reach (85 km section from bridge to mouth) [j]	MAR-1		1																				1					10			4		
Tar River																																	
Mouth																																	
Ells River																																	
Upper and lower Ells River[h]													1,3																		4		3
Poplar Creek																																	
Gregoire River - OPTI (non core program)																																	

Legend

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

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reference

Footnotes

[a] Reaches include east and west banks
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[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.
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[f] Located from 3 to 11 km upstream of the confluence with the Athabasca River.
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[i] Reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing.
[j] In 2004 a fish fence reconnaissance was carried out on the Ells and MacKay Rivers.

3.5.7.2 Criteria for Determining Effects

The criteria used for determining effects on fisheries populations were also specific to each study undertaken within the fisheries population component itself.

Fish Inventory Studies

Because the fish inventory studies are generally considered to be a stakeholder-driven activity that is best suited for assessing trends in abundance and population parameters for large-bodied species, rather than fish community structure, it was determined that, in order to establish criteria for detecting and assessing change in the designated measurement endpoints, it would be necessary to determine the range of variability in each parameter over the maximum number of sampling years. Once the extent of variability is estimated appropriate criteria for determining change in the measurement endpoints can be formulated and the overall monitoring approach can be refined.

Fish Tissue Studies

Effects on Human Health To assess potential effects of ingestion of fish tissue on human health, fish tissue data were screened against the following criteria:

- Health Canada Guidelines for chemical contaminants in fish (CFIA 2003) and for exposure of Indian and Inuit residents to methylmercury in the Canadian environment (Health Canada 1978, as cited in Lockhart *et al*. 1995);
- Region III USEPA risk-based criteria for consumption of fish tissue for recreational and subsistence fishers (USEPA 2003); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000).

The Health Canada guidelines for chemical contaminants in fish are designed for the average fish consumer; the only contaminant evaluated in the current study that has a guideline is mercury (as total mercury). The Health Canada guideline for methylmercury for Indian and Inuit residents represents a more stringent criterion for subsistence fish consumers. The regional and national USEPA criteria, which are risk-based criteria that take into account the toxicity (including carcinogenicity) of the contaminant, body weight of the consumer, and exposure rate, include criteria for a larger number of contaminants. The national criteria also provide criteria for several contaminants for different exposure scenarios (e.g., recreational and subsistence fishers). The Health Canada guideline for subsistence fishers is less conservative (four times higher) than the USEPA screening value for subsistence fishers. Because the USEPA criterion for subsistence fishers is based on more recent toxicology data and models, it is the more pertinent of the two criteria.

Effects on Fish and Wildlife To assess potential effects on fish health, fish tissue data were compared to the lowest tissue residue concentrations linked to effects (or a lack of effects). Effects thresholds were derived from laboratory-based studies summarized in Jarvinen and Ankley (1999); these effects thresholds relate tissue residues to sublethal and lethal effects for aquatic organisms exposed to a number of inorganic and organic chemicals. The full range of effects (or no effects) thresholds are presented in

Table 3.5-10, along with information regarding the studies that these thresholds were derived from, including the endpoints evaluated, tissue type, species, life stage and/or fish size, exposure route and duration of exposure. Only the most relevant studies were used for effects threshold assessment by RAMP. Studies for small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, were excluded. Data derived from acute exposures were only included for contaminants where there was a paucity of data.

To assess potential effects on wildlife that consume fish, fish tissue data were compared to CCME criteria for avian and mammalian piscivores (CCME 2001b). Mercury (as methylmercury) was the only contaminant analyzed that had a criterion.

Effects on Palatability Elevated concentrations of tainting compounds can result in decreased palatability of fish due to presence of an undesirable odor or flavor. To assess potential tainting of fish tissues, concentrations of tainting compounds were compared to criteria developed by Jardine and Hrudey (1988). Tainting compounds present at concentrations above 1 mg/kg are believed to result in a detectable undesirable odor or taste.

Sentinel Species Monitoring

For the sentinel species studies, the selected criteria for determination of change in measurement endpoints were based on Environment Canada's Environmental Effects Monitoring (EEM) criteria:

- Lethal sampling approach
  - Condition factor at exposed site ± 10% difference from reference site
  - Relative gonad size at exposed site ± 25% difference from non-exposure site
  - Relative liver size at exposed site ± 25% difference from reference site
- Non-lethal approach
  - Condition factor at exposed site ± 10% difference from reference site

3.5.7.3 Detailed Data Analysis

Fish Inventory

Athabasca River and Tributary All fish captured during the inventory were summarized by species composition (i.e., percent of total catch) and relative abundance (i.e., catch-per-unit-effort [CPUE]). Data for fish collected during the limited beach seining efforts on the Clearwater River were included in length-frequency analyses for the 2004 inventory.

Where sample sizes permitted, more detailed analyses were conducted on key fish indicator species. When possible, multi-year comparisons of inventory data from both the Athabasca River and Clearwater River were made. All detailed analyses were conducted using SYSTAT® 10 statistical software (SPSS 2000). The following population parameters were examined:

- length-frequency distribution;
- mean condition factor; and
- mean external pathology index.

Table 3.5-10 Concentrations of metals that have lethal, sublethal or no effect on freshwater fish (data obtained from Jarvinen and Ankley 1999).

Variable	Endpoint		Effects 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
Barium	-	-	-	-	-	-	-	-
Cadmium	Survival	no effects	0.02 - 2.8	muscle	rainbow trout, brook trout	150 -200 g, adult	water, ip injection	210 - 455
		effects	0.14 - 0.7	whole body	rainbow trout, brook trout	5 - 15 g	water	29 - 30
	Growth	no effects	0.09 - 2.8	muscle, whole body	rainbow trout, brook trout	3.1 g, 5 g, adult	water	30 - 455
		effects	0.12 - 0.96	muscle, whole body	rainbow trout, Atlantic salmon	3.1 g, alevin	water	92 - 210
	Reproduction	no effects	0.4	muscle	rainbow trout	adult	water	455
		effects	0.6	muscle	rainbow trout	adult	water	455
Chromium	-	-	-	-	-	-	-	-
Copper	Survival	no effects	0.5 - 3.4	muscle	rainbow trout, brook trout	embryo-adult-juvenile	water	0.33 - 720
		effects	0.5	muscle	rainbow trout	138 g	water	0.33
	Growth	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
	Reproduction	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
Iron	-	-	-	-	-	-	-	-
Lead	Survival	no effects	4.0	carcass	rainbow trout	under-yearlings (6.5 g)	water	224
Manganese	-	-	-	-	-	-	-	-
Mercury[1]	Survival	no effects	1.91 - 35.0	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, juvenile, fingerling, yearling-adult, adult	ip injection, oral, water	15 -273
		effects	3.7 - 31	whole body, muscle	rainbow trout, brook trout northern pike	10 - 20 mm, subadult (100 - 150 g), yearling-adult, adult	ip injection, oral, water	186 - 273
	Growth	no effects	2.28 - 29.0	whole body, muscle	rainbow trout	fingerling, juvenile	oral, water	24 - 105
		effects	8.6 - 35.0	whole body, muscle	rainbow trout	fingerling	oral	84 - 105
	Reproduction	no effects	9.2	muscle	brook trout	yearling-adult	water	273
		effects	23.5	muscle	brook trout	yearling-adult	water	273
Nickel	Survival	no effects	0.82 - 58.0	muscle	rainbow trout, carp	15 g, 150 - 200 g	water	5 - 180
		effects	118.1	muscle	carp	15 g	water	4
Selenium	Survival	no effects	0.28 - 3.1	whole body, carcass	rainbow trout, chinook salmon, largemouth bass	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	water, oral	28 - 308
		effects	0.92 - 2.5	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, .fingerling-juvenile	water, oral	28 - 168
	Growth	no effects	0.08 - 1.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	oral	60 - 308
		effects	0.32 - 2.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, fingerling-juvenile, juvenile	oral	60 -168
Silver	Survival	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
	Growth	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
Strontium		-	-	-	-	-	-	-
Tin		-	-	-	-	-	-	-
Titanium		-	-	-	-	-	-	-
Vanadium	Survival	no effects	5.33	carcass	rainbow trout	juvenile	oral	84
	Growth	no effects	0.02	carcass	rainbow trout	juvenile	oral	84
		effects	0.41	carcass	rainbow trout	juvenile	oral	84
Zinc	Survival	no effects	60	whole body	Atlantic salmon	juvenile	water	80
	Growth	no effects	60	whole body	Atlantic salmon	juvenile	water	80

- = no data

[1] methylated forms of mercury

Comparison of length-frequency distributions among years (1997-2004) was based on data collected from spring and fall inventories (i.e., no summer data were used). High numbers of lake whitefish are only present in the oil sands region of the Athabasca River during the fall spawning migration. Accordingly, length-frequency analyses for lake whitefish was limited to fall inventory data only. Differences in length-frequency distributions among years for each species were compared separately using the G-test for independence for two-way frequency tables (Sokal and Rohlf 1981). G or the log-likelihood ratio is distributed approximately as X^2. Tables of standardized deviates (year-by-length class) were also examined to identify any obvious pattern in distributions over time.

With the exception of lake whitefish, analysis of condition was restricted to data for fish collected in the spring. Fall data were used for lake whitefish. To be consistent with past years, analyses were restricted to fish of a minimum length: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; and longnose sucker >350 mm. For each species, fish condition was estimated by the relationship of total body weight versus fork length ($\log_{10}$ data). Potential differences in condition among years (1997-2004) were initially tested using Analysis of Covariance (ANCOVA). However, for some species when the full ANCOVA model (i.e., test of slopes) was conducted, there was a high number of fish that exhibited studentized residual values > 4.0. Given these results, the residual values for each fish derived from the ANCOVA model were saved and these data were used to test for differences in condition among years using the non-parametric Kruskall-Wallis test (similar to ANOVA). This approach avoided the potential problems associated with arbitrarily omitting high numbers of fish from the analyses based on residual values, and potentially biasing the results of the test. For graphical purposes, Fulton's Condition Factor was also calculated using the following equation: $K=(\text{body weight}/\text{fork length}^3 \times 10^5)$.

An external pathology index (Golder 2003b) was calculated for each fish (Appendix H). Historical index results were tabulated to assess evidence of trends in external fish health.

Muskeg River/Jackpine Creek Fish Inventory Analysis of data generated from the Muskeg/Jackpine fish inventory was consistent with that applied to the Athabasca and Clearwater inventory data. Again, when possible the analysis included multi-year comparisons.

Christina River Reconnaissance Fish Inventory Due to high, fast-flowing water conditions in the Christina during the inventory period, fish catches were very low. Therefore, no statistical analysis of the catch data was possible.

Fish Tissue Studies

Statistical Analysis Scatterplots were used to initially assess the relationships between mercury concentrations in fish and whole-organism parameters. Rank correlations were then used to evaluate relationships between these variables for each species and sex combination. The significance of a correlation was determined using critical values of Spearman's correlation coefficient (r_s). A correlation was described as moderate if $|0.50| > r_s < |0.75|$ and strong if $r_s > |0.75|$. If significant rank correlations were observed, linear regression was used to further evaluate the relationship. Assumptions of regression models were tested and if necessary regressions were performed using

log_{10}-transformed or ranked data. All statistical analyses were performed using SYSTAT 10 (SPSS 2000).

Statistical analysis was also conducted on the data generated from the non-lethal biopsy pilot study. The objective of the analysis was to provide an inter-laboratory comparison, as well as a comparison of the two analytical procedures used by Flett Research Ltd. Mercury concentrations measured by the two laboratories used in the biopsy study were analyzed using the Wilcoxon paired-sample test, a nonparametric counterpart to the paired-sample t-test (Zar 1983). This procedure required the calculation of differences in measured mercury concentration for each individual northern pike, which were ranked (i.e., lowest to highest) and affixed a sign (plus or minus) based on the difference. The next step involved the summation of the ranks with the same sign, which was compared to the critical value $T_{0.05,(2),10}$ (T = 8). If the absolute value of either rank sum was less than the critical value for mercury concentrations as measured between the two analytical laboratories or by sampling method, they were determined to be significantly different at $\alpha = 0.05$.

Screening of Potential Effects Tissue chemistry data for the Clearwater River, Muskeg River, and Winefred Lake were compared to several criteria to assess potential effects on humans, fish, and piscivorous wildlife.

Sentinel Species Monitoring

Muskeg/Steepbank Monitoring

Data Analysis As indicated above, the intent of the non-lethal sentinel species initiative was to generate interpretable data on population/age distribution, energy use and energy storage for fish sampled at reference and exposed sites in order to achieve the monitoring objectives established for the lethal sampling approach. The intent is to assess and compare these three parameters for populations with similar age class structure at the reference and exposed sites in an effort to detect potential effects of exposure to oil sands activities and/or other factors.

Data generated from the two field sampling efforts were tested for differences between reference and exposed sites.

Population Distribution Sculpin length frequency distributions were broken into 2-mm size classes and compared using the two-sample Kolmogorov-Smirnov test (K-S test) ($\alpha = 0.05$).

The following conditions were considered when applying the K-S test to the sample data:

- The test is limited to comparing two samples at a time;
- There were differences in frequencies within a particular size range; and
- The test assesses both the shape and position of distributions.

Comparisons were made within the Steepbank River at exposed versus reference sites, and among systems by comparing reference sites on the Horse and Dunkirk rivers with the Muskeg River exposed site and the Steepbank exposed site.

Growth Sculpin lengths and weights were log-transformed and compared among sites using ANOVA ($\alpha = 0.05$), with Bonferroni adjusted post-hoc multiple comparisons for differences between sites.

Energy Storage Sculpin condition factor (i.e., "fatness") was analyzed among sites using analysis of covariance (ANCOVA; $\alpha = 0.05$) in which weight represented the dependent variable, site the independent, and length the covariate (plus the interaction term). The first step in an ANCOVA analysis (beyond assessment of issues surrounding normality) involves comparing slopes of length-weight regressions from different populations with the second being assessment of the intercepts. For graphical purposes, Fulton's Condition Factor was also calculated, as $K=(\text{body weight}/\text{fork length}^3 \times 10^5)$.

3.5.7.4 Fish Tag Return Assessment

To date, no systematic analysis of the capture information has been carried out. Therefore, as part of the 2004 fish program a preliminary assessment and presentation of tagging data was prepared.

3.6 ACID SENSITIVE LAKES

3.6.1 Overview of 2004 Program

As in 2003, the 2004 Acid-Sensitive Lakes (ASL) program consisted of monitoring 50 lakes and ponds in the oil sands region for water quality parameters during late August and early September (Table 3.6-1). Interpretation of the water quality data was more detailed than in previous years and included:

- Comparisons of the chemical characteristics of the RAMP lakes to the general characteristics of lakes within the oil sands region;
- Calculations of organic anion concentrations and charge densities of dissolved organic materials in each lake;
- The analysis of the contribution of strong acid anions to the acid-base status in each lake;
- Analysis of the degree of buffering attributable to weak organic anions in each lake;
- Calculations of critical loads of acidity for each lake and comparison with modelled PAI; and
- Analysis of potential trends in water quality parameters that would indicate increased acidification.

Table 3.6-1 Name, location and date of sampling of lakes in 2004 for the acid sensitive lake program.

Lake Identification			UTM Coordinates		Sampling Date
Unique ID[1]	Name	Tertiary Watershed	E	N	m/d 00:00
Stony Mountains Sub-Region					
168	A21	7CE	483819	6235130	08/25 18:30
169	A24	7CE	484387	6230872	08/25 18:16
170	A26	7CE	489502	6230877	08/25 17:32
167	A29	7CE	466180	6224950	08/25 13:48
166	A86	7CE	448014	6170896	08/25 12:05
287	25		487594	6229281	08/25 16:45
289	27		477248	6228400	08/25 11:31
290	28		487068	6225576	08/25 13:48
342	82		448271	6183205	08/25 11:25
21	94				08/25 10:20
Birch Mountains Sub-Region					
436	L18/Namur		402704	6368016	08/26 09:55
442	L23/Otasan		417321	6396959	08/26 13:45
444	L25/Legend		383849	6364923	08/26 11:13
447	L28		382996	6414339	08/26 16:45
448	L29/Clayton	7KE/7KF	424694	6435790	08/26 17:30
454	L46/Bayard		416941	6404239	08/26 15:00
455	L47		396500	6395456	08/26 12:10
457	L49		404995	6403111	08/26 12:45
464	L60		403796	6392247	08/26 15:50
175	P13	7DA	416003	6353212	09/01 14:05
199	P49	7DA	446002	6394961	09/01 13:40
North East of Fort McMurray Sub-Region					
452	L4 (A-170)		508990	6334305	08/31 14:15
470	L7		461006	6368512	08/31 15:15
471	L8		460931	6369481	08/30 16:58
400	L39/E9/A-150		536495	6424234	08/30 14:34
268	E15		506092	6305335	08/31 16:00
182	P23	7DA	509000	6346712	09/01 10:45
185	P27	7DA	508300	6333712	09/01 10:00
209	P7	7DC	515399	6343212	09/01 11:45
270	4		506113	6291421	08/31 17:18
271	6		549064	6277789	08/27 15:38
4182	Kearle				08/31 14:40

Table 3.6-1 (cont'd.)

Lake Identification			UTM Coordinates		Sampling Date
Unique ID[1]	Name	Tertiary Watershed	E	N	m/d 00:00
West of Fort McMurray Sub-Region					
165	A42	7CC	365015	6247322	08/27 12:40
171	A47	7CC	367321	6235430	08/27 13:30
172	A59	7PA	383467	6197733	08/27 11:45
223	P94	7BD	440557	6334112	09/01 14:45
225	P96	7BD	444002	6295513	09/01 15:20
226	P97	7DA	456002	6296463	09/01 16:00
227	P98	7CC	451762	6293513	09/01 16:15
267	1		441917	6290884	08/27 10:00
Caribou Mountains Sub-Region					
146	E52/ Fleming	7JF	243692	6522556	08/28 11:05
91	O-1/E55	7PC	298955	6571856	08/28 14:40
97	O-2/E67	7PA	253582	6582654	08/28 13:40
152	E59/Rocky Island	7JF	263546	6562225	08/28 12:20
89	E68 Whitesand	7PA	245596	6570610	08/28 13:00
Canadian Shield Sub-Region					
473	A301				08/29 14:45
118	L107/Weekes	7MD	555469	6620456	08/29 09:45
84	L109/Fletcher	7NA	510321	6553552	08/29 15:50
88	O-10	7NA	518279	6556260	08/29 16:35
90	R1	7NA	517889	6562197	08/29 13:46

[1] Unique identification number derived from the Lake Sensitivity Mapping Program conducted by NSMWG (WRS 2004).

3.6.2 Methods

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

Water samples were collected from the euphotic zone at a single deep-water site in each major basin of each lake using weighted Tygon tubing and were then combined to form a single composite sample for chemical analysis. When the euphotic zone extended to the lake bottom, sampling was restricted to depths greater than 1 m above the lake bottom. In shallow lakes (< 3 m deep), composite samples were created from five to ten – 1 L grab samples collected at 0.5 m depth along a transect dictated by wind direction (upwind to downwind shore).

The euphotic zone was defined as twice the Secchi disk depth. In previous years, 1% light penetration was determined with a LiCor quantum sensor and found to correlate reasonably well with twice the Secchi depth. Vertical profiles of dissolved oxygen, temperature, conductivity and pH were measured at the deepest location using a field-calibrated water quality meter. Secchi depth was also recorded. Samples for chemical analysis were stored on ice and were shipped to the Limnology Laboratory, University of Alberta, Edmonton, within 48 hours of collection.

Subsamples of 150 mL volume were taken from the euphotic zone composite samples for phytoplankton taxonomy. These samples were preserved using Lugol's solution. One or two replicate zooplankton samples were also collected in each lake as vertical hauls through the euphotic zone, using a #20 mesh (63 µm), conical plankton net. Zooplankton samples were preserved in approximately 5% formalin after anaesthetizing in club soda. Plankton samples are being stored at AENV.

The date of lake sampling, the latitude and longitude of each lake and the tertiary watershed in which each lake was found are presented in Table 3.6-2. The unique ID number is that ascribed to each lake by the NOxSOx Monitoring Working Group (NSMWG) lake sensitivity mapping program (WRS 2004). The locations of each lake relative to the major oil sands developments are indicated in Figure 3.6-1.

The water quality samples were analyzed for the following parameters:

- pH
- turbidity
- colour
- total suspended solids (TSS)
- total dissolved solids (TDS)
- dissolved organic carbon (DOC)
- dissolved inorganic carbon (DIC)
- conductivity
- total alkalinity (fixed point titration to pH 4.5)
- Gran alkalinity
- bicarbonate
- Gran bicarbonate
- chloride
- sulphate
- calcium
- potassium
- sodium
- magnesium
- iron
- silicon
- total dissolved nitrogen (TDN)
- ammonia
- nitrite + nitrate
- total Kjeldahl nitrogen (TKN)
- total nitrogen (TN)
- total phosphorus (TP)
- total dissolved phosphorus (TDP)
- chlorophyll *a*

All samples were also analyzed for a suite of 29 metals and trace elements at ARC Vegreville. As part of the QA/QC program, one blind field blank was collected using deionized water from the Limnology Laboratory, University of Alberta. Split samples were additionally assessed by the University of Alberta lab. Quality control samples were analyzed for all parameters listed above (Appendix B).

Table 3.6-2 Summary of lakes sampled during the RAMP program, 1999 to 2004.

NOx-SOx GIS No.	Original RAMP Designation	ASL Data Available					
		1999	2000	2001	2002	2003	2004
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 L.					+	+
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	+					
474	A300			+			

3.6.3 Changes in Monitoring Program Network from 2003

There were no changes in the field program from 2003.

3.6.4 Challenges and Solutions Applied

The principal challenge encountered in implementing the field program was that of poor weather which delayed completion of the lake and pond sampling for a month.

3.6.5 Other Information Obtained

Alberta Environment provided total and dissolved metals analyses on the RAMP lakes. These samples were collected at the same time as the RAMP samples during the 2004 field season. The inclusion and analysis of these data follow recommendations of the Peer Review Committee.

3.6.6 Summary of Component Data Now Available

The ASL program within RAMP has evolved over the 6 years since its initiation. In general, the number of lakes monitored has increased to the current total of 50. For a variety of reasons, largely logistical, a number of lakes that were monitored in the initial stages of the program have been dropped. The selection of lakes sampled during the six years of the program is summarized in Table 3.6-2. Lakes sampled during the 2004 field program have been shaded.

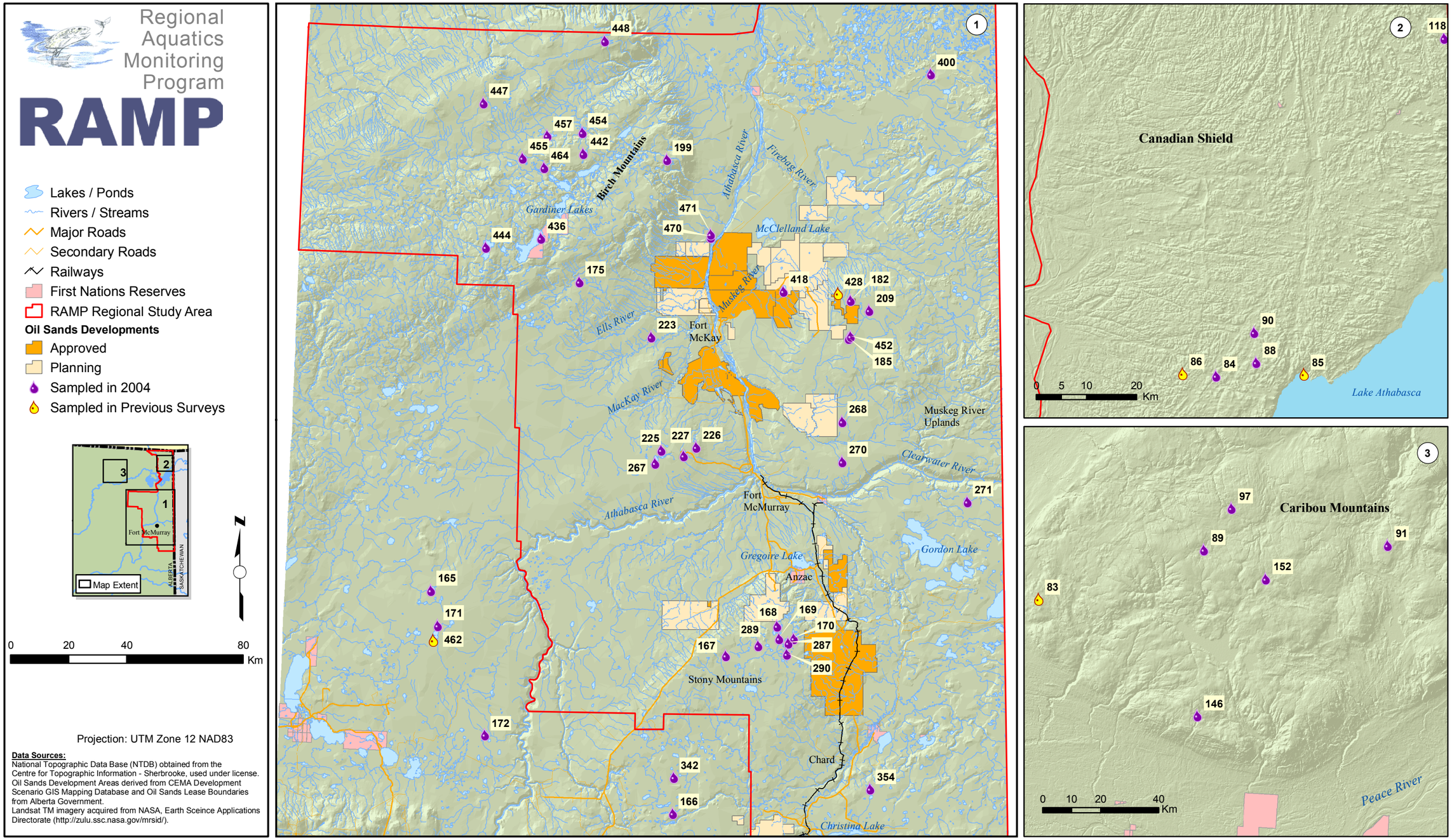
3.6.7 Analytical Approach

3.6.7.1 Selection of Measurement Endpoints

In accordance with the overall analytical approach used for the preparation of this report (Section 1.4), analyses of the 2004 ASL monitoring data involved the determination of an assessment endpoint, measurement endpoints, and the criteria to be used for determining potential effects on regional lakes from oil sands developments. Based on the definitions of Suter (1993), the assessment endpoint for the ASL component has been assumed as the proportion of regional lakes that are adversely affected by acidic deposition from oil sands developments. The following measurement endpoints were considered for the ASL component:

- the critical load of acidity;
- pH;
- Gran alkalinity;
- base cation concentrations;
- nitrate plus nitrite concentrations; and
- DOC and aluminum concentration.

Figure 3.6-1 Location of acid-sensitive lakes surveyed in 2004.



At this point in the RAMP program, the critical load of acidity is considered to be the principal measurement endpoint for the ASL component. The other potential measurement endpoints listed above are known to be affected during acidification but, as the data on these other measurement endpoints are limited to only 3 to 6 years, there is little ability yet to distinguish between natural variability and real trends in these parameters that might indicate acidification.

Sulphate was not included in the list of measurement endpoints. Unlike most shield lakes including those in eastern Canada, sulphate and acidity (H^+) in Alberta lakes are poorly correlated because of the abundance of neutral sulphate compounds in wet deposition (AEP 1990; Lau 1982; Legge 1988). In fact, sulphate correlates better with calcium than with H^+. The poor correlation between sulphate and H^+ in the RAMP lakes was demonstrated in the 2003 RAMP report (Section 8.4.2).

3.6.7.2 Criteria for Determining Effects

Criteria for determining changes in the ASL measurement endpoints in the oil sands region were as follows:

- Any measurement of the critical load of acidity of a particular lake that was exceeded by the measured or modeled value of the potential acid input to that lake (PAI) was considered as potentially affected by acid deposition. On a regional basis, the criteria was set as an increase in at least 10 % (five lakes) of the 50 RAMP lakes having such exceedances.

- A significant change in any of the other measurement endpoints beyond natural variability that included a reduction of lake pH, Gran alkalinity, critical load or base cation concentrations or an increase in nitrates or aluminum concentrations. A significant change is defined as a statistically significant change at $\alpha<0.05$ that is directly attributable to increased deposition of acidifying substances. Natural variability is measured as the variance of the parameter. However, as indicated above, in many cases sufficient data may not be available to determine natural variability.

The analysis of the ASL data was expanded from 2003 to include recommendations of the PRC and to utilize the measurement endpoints and associated criteria developed for the ASL component. The data analysis included the following items, of which the second and third items have been described in greater detail in Appendix I:

- Chemical characterization of the RAMP lakes and comparisons of these lakes to the range of chemical characteristics of lakes within the oil sands region. Lakes with unusual chemistry were identified.

- Determination of organic anion concentrations, charge densities and strong acid anions concentrations in each lake and the relationships of each to DOC and pH.

- Determination of the degree of buffering attributable to weak organic anions and the decrease in acid neutralizing capacity attributed to strong organic acid anions in each lake.

- Calculation of the critical loads of acidity (CL) for each lake for 2003 and 2004 for comparison with the modeled PAI. These CL calculations involved a modification of the standard Henriksen model to incorporate the effects of weak and strong organic anions in each lake. The same process is being applied to the entire database of regional lakes by the NOxSOx Management Working Group (NSMWG).

- Analysis of potential trends in acid-sensitive lake parameters (measurement endpoints) in the context of the criteria for assessing change in the measurement endpoints defined above.

3.6.7.3 Details of Data Analysis

Comparison of RAMP Lake Chemistry to Regional Lake Chemistry

The chemical characteristics of the lakes were compared to those of 460 regional lakes reported in the NSMWG lake sensitivity mapping study (WRS 2004). The NSMWG report included historical data for each lake from the following field surveys:

- Erikson's survey of Alberta Lakes conducted in 1983-1987 (Erikson 1987);

- Saffran and Trew's survey of 109 lakes in 1995 (Saffran and Trew 1996);

- Preston McEachern's study of the Caribou Lakes in 1997 (WRS 2003);

- Water quality surveys conducted by Alberta-Pacific Forest Industries in 1998 and 1999 (WRS 2003);

- A pond water survey conducted for the NSMWG (WRS 2003); and

- Previous RAMP surveys.

Comparisons involved:

- Examination of the ranges and median values and mean values of key chemical parameters in the RAMP lakes relative to the regional data set; and

- Graphical presentation of major ions of both data sets in Piper diagrams.

The mean concentrations of the parameters in the two lake populations were compared statistically using Student's T tests after appropriate transformations to ensure normality and homogeneity of variances.

Chemical characteristics of the RAMP lakes were also compared to those of the regional lake database diagrams in Piper diagrams. A Piper diagram is a multivariate graphical technique that permits the cation and anion compositions of many samples to be represented on a single graph in which major groupings in the data can be visually discerned. The diagram displays the relative concentrations of the major cations and anions on two separate tri-linear plots together with a central diamond plot where the points from the two tri-linear plots are projected. The central diamond shaped field is used to show the overall chemical characteristics of the water (Freeze and Cherry 1979).

Determination of Weak Organic Anion Concentrations, Charge Densities, and Strong Acid Anions Concentrations in Each Lake

Weak organic acid concentrations were calculated by two methods: anion deficit and a calibration of the organic acid dissociation equations of Oliver *et al*. (1983). The anion deficit method is based on the principle of electoneutrality in which the charges on cations and anions in any solution must be balanced. In coloured waters, a fraction of the inorganic cations are balanced by organic anions, the products of dissociated organic acids. By subtracting the inorganic anions from the cations the anionic deficit can be used as an estimate of the concentration of dissociated organic anion A^-:

$$[A^-] = [Ca^{2+}] + 2\,[Mg^{2+}] + [Na^+] + [K^+] + [K^+] + [NH_4^+] + 3[Al^{3+}] + [H^+]$$

$$-2[SO_4^{2-}] - [Cl^-] - [NO_3^-] - [F^-] - [HCO_3^-] - 2\,[CO_3^-]$$

where all ions are expressed in µeq/L. The charge density is expressed as the organic anion concentration divided by the DOC in units of µeq A- /mg C and represents the number of dissociated carboxyl groups per mg of DOC at the pH of the sample.

The determination of A^- by anionic deficit requires an estimate of bicarbonate concentrations. These are not the bicarbonate concentrations generally reported by the laboratories but must be calculated by equilibrium relationships and DIC measurements. The bicarbonate normally quoted by the laboratory is really the titration bicarbonate and is in error in humic lakes because weak organic anions (and aluminum) are titrated at the same time as the bicarbonate. The titration bicarbonate, then, overestimates the real bicarbonate concentration.

Bicarbonate was determined from ionization fractions (α) representing the fractions of the bicarbonate, carbonate and carbonic acid species in solution:

$$\alpha_{HCO3} = ([H^+]/K_1 + 1 + K_2/[H^+])^{-1}$$

$$\alpha_{CO3} = ([H^+]^2/K_1K_2 + [H^+]/K_2 + 1)^{-1}$$

$$\alpha_{H2CO3} = (1 + K_1\,[H^+] + K_1K_2\,/[H^+]^2)^{-1}$$

K_1 and K_2 are constants (pK_1 = 6.464 and pK_2 = 10.49). The constants were taken from Stumm and Morgan (1981) for water at a temperature of 10 ^{0}C and having a low ionic strength.

The model of Oliver *et al*. (1983) is based on the single mass action coefficient model of organic acid dissociation proposed by Perdue *et al*. (1980). In the Oliver *et al*. (1983) model, concentrations of dissociated organic ions at a given pH are estimated from the equilibrium equation:

$$[A\text{-}] = K\,[CT] / (K + H^+)$$

where K is a mass action quotient and CT is the total concentration of acidic functional groups (total acidity) determined from base titrations of purified humic and fulvic acids to pH 7-8. CT is a function of DOC expressed as:

$$C_T = m\,[DOC].$$

where m is the number of equivalents of carboxyl units per mg of DOC or the carboxyl content.

The dissociation behaviour of purified humic and fulvic acids was studied by titrating the two isolates with NAOH to pH 7.0 with CO2 excluded. The measured pH and known equivalents of base titrant were then used to develop a formula relating pK to pH:

$pK = a + b\,(pH) + c\,(pH)^2$, where a, b, and c are constants.

Once the dissociation behaviour of the humic materials is known, the organic ion concentration can be calculated from at the DOC content and pH of the sample.

The method of Oliver *et al*. (1983) has been widely applied by calibrating the parameters of the model to particular sets of lakes and conditions (Lazerte and Dillon 1984; Driscoll *et al*. 1989; Wilkinson *et al*. 1992; Kortelainen 1992). In all cases, the A^- estimated from the ion deficit and field measurements of DOC and pH were used in the calibration process to generate the constants a, b and c.

For this study, a calibration process was followed based on the Oliver *et al*. (1983) equations. Examination of these equations indicated that $[A^-]$ is proportional to the DOC content and a non-linear, in particular, an exponential function of pH. This knowledge was used to fit A^-, as calculated from the anion deficit, to an appropriate function of DOC and pH. Using non-linear regression (SYSTAT 11©), the data were fitted to an equation of the form:

$A^- = a\ DOC\ \exp(b*pH)$.

The charge density was calculated for each RAMP lake and compared to literature values.

Strong acid anions (A^-_{SA}) in the RAMP lakes were analyzed by the method suggested by Cantrell *et al*. (1990), Munson and Guerini (1993) and Kortelainen (1993). Gran alkalinity typically underestimates the charge balance alkalinity where the discrepancy is proportional to the DOC content. The calculation of the charge balance alkalinity (ANC_{CB}) is based on electroneutrality principles where ANC_{CB} is equivalent to the sum of strong bases minus the sum of strong acid anions (Stumm and Morgan 1981):

$$ANC_{CB} = 2[Ca^{2+}] + 2\,[Mg^{2+}] + [Na^+] + [K^+] + [NH_4^+] + 3[Al^{3+}] + [H^+]$$
$$- 2[SO_4^{2-}] - [Cl^-] - [NO_3^-] - [F^-]$$

The concentration of strong organic acids is then calculated from:

$A^-_{SA} = ANC_{CB} - ANC_{gran}$.

The concentration of strong organic acids was then regressed on DOC to obtain an equation of the form

$A^-_{SA} = f*DOC + g$, where f and g are constants.

The concentration of strong organic acids (A^-_{SA}) is equivalent to the decrease in ANC attributable to these organic acids.

Calculation of the Buffering Attributable to Weak Organic Acids

The ANC or buffering attributable to the weak organic acids (ANC_{org}) was calculated by the method of Roila *et al*. (1994):

$$ANC_{org} = ANC_{gran} - [HCO_3] + [H^+]_{sample} - [H^+]_{endpoint}$$

Where ANC_{gran} is the measured Gran Alkalinity, $[HCO_3]$ is the bicarbonate concentration calculated using DIC and the pH, $[H^+]_{sample}$ is the initial hydrogen concentration of the sample and $[H^+]_{end}$ is the hydrogen concentration at the end point (equivalence point) of the titration. A model of the same for A- above was then derived from the non-linear regression of ANC_{org} on pH and DOC:

$ANC_{org} = c\ DOC\ \exp(d*pH)$, where c and d are constants.

Calculation of Critical Loads of Acidity to the RAMP Lakes

The critical load, in units of keq H+/ha/y, is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology. The PAI is defined as the sum of the wet and dry deposition of sulphur and nitrogen oxides minus the wet and dry deposition of base cations. Exceedances of the critical load by the PAI in a lake imply a potential for acidification. Critical loads of acidity were calculated for each lake using the Henriksen's steady state water chemistry model (Henriksen and Posch 2001; Henriksen *et al*. 1992; Forsius *et al*. 1992; Rhim 1994). In the normal Henriksen model the critical load for a lake is calculated as:

$$CL = ([BC]^*_0 - [ANC_{lim}]) .Q$$

where:

- CL in the critical loading level of acidity;
- $[BC]^*_0$ is the pre-industrial (original) non-marine base cation concentration in the lake assumed, equivalent to the current base cation concentrations;
- Q is the mean annual catchment runoff calculated from regional analysis of flow data collected from over 40 hydrometric stations monitored by the Water Survey of Canada; and
- ANC is the critical value for the acid neutralizing capacity in the water for a given indicator organism. ANC_{lim} was assumed to be 75 µeq/L based on discussions in WRS(2004).

The equation states that the critical load is equivalent to the acid neutralizing capacity (ANC) or alkalinity generated within the lake catchment (acid consuming processes) minus a critical chemical threshold of ANC (ANC_{lim}) required to protect a selected biological indicator. The alkalinity generating processes are represented by the original or historical export of base cations from the catchment (weathering). By including Q, the runoff, in the equation, both ANC generation and the critical chemical threshold are expressed in terms of a flux (mass/time).

Following a new approach initiated by the NSMWG, the original Henriksen model was modified to account for both the buffering of weak organic anions and the lowering of ANC attributable to strong organic acids. The modified model assumed that DOC, with its associated buffering from weak organic acids (ANC_{org}) and reduction of ANC from strong organic acids (SA_{org}), was exported from the catchment basin to the lake in the same way that we assume the export of base cations (carbonate alkalinity). The relationships developed above between ANC_{org} and DOC and pH, and between SA_{org} and DOC were then substituted into the Henriksen equation.

Thus:

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

where,

$ANC_{org} = c\ DOC\ \exp(d*pH)$; and

$SA_{org} = f\ *DOC$, as derived above for the population of RAMP lakes.

The critical loads of acidity were then calculated for both 2003 and 2004. The critical loads were compared with levels of PAI for each lake basin. The PAI used for the comparison was that generated, under a cumulative effects scenario, for the most recent impact assessment conducted in the oil sands region. Exceedances of the critical load in a lake imply a potential for acidification.

Analysis of Trends of the ASL Measurement Endpoints

Potential trends in the measurement endpoints (critical load of acidity, pH, Gran alkalinity, base cation concentrations, nitrates, DOC and aluminum concentrations were examined over the six-year monitoring period. The analysis involved graphic presentation of the data as a function of time and trend analysis using the Mann-Kendall non-parameteric test (Gilbert 1987). This test calculates the differences between successive measurements of a parameter and assigns each positive difference (increase in the parameter) a value of +1 and each negative difference (decrease in the parameter) a value of -1. The Mann-Kendall statistic, S, is calculated as the number of positive differences minus the number of negative differences. S is then compared to tables to determine the probability of attaining a specified magnitude of S for n observations. If S is large and positive, the values of the parameter taken later in time tend to be greater than those taken earlier. If S is large and negative, the values of the parameter taken later in time tend to be less.