3.0 2006 RAMP MONITORING ACTIVITIES

This section contains a description of RAMP monitoring conducted in 2006 and includes the following for each RAMP component:

- Summary of 2006 monitoring activities and field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, owners and operators of the 2006 focal projects, knowledge obtained from local communities, and other sources);
- Description of changes in monitoring network from the 2005 field program;
- Description of the challenges and issues encountered during 2006 and the means by which these challenges and issues were addressed;
- Summary of the component data that are now available;
- 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.

Monitoring activities for all RAMP components in 2006 were implemented according to the monitoring protocols, field methods, and SOPs for the RAMP components as outlined in the RAMP Technical Design and Rationale document (RAMP 2005b). Any changes in monitoring protocols, field methods, and SOPs from those contained in RAMP (2005b) are noted below.

Quality Assurance and Quality Control (QA/QC) procedures were employed throughout and for all aspects of the monitoring conducted under RAMP in 2006. Appendix B contains a detailed description of the QA/QC procedures used for RAMP monitoring in 2006.

All 2006 monitoring data collected under RAMP have been added to the RAMP database, which is located in the members' area of the RAMP website at www.ramp-alberta.org. The 2006 data tables are included on the CD-ROM accompanying the final 2006 technical report.

3.1 CLIMATE AND HYDROLOGY COMPONENT

3.1.1 Summary of 2006 Monitoring Activities

Monitoring activities in 2006 for the Climate and Hydrology component consisted of:

- Monitoring basic climate variables (combinations of air temperature, precipitation, snowfall, humidity, and barometric pressure) at five stations, as well as a variety of other climate variables at the Aurora Climate Station;

- Conducting regional snowcourse surveys in February, March and April 2006;
- Monitoring water levels and stream flows and collecting water samples for total suspended solids (TSS) analysis at:
  - 11 hydrometric stations in the Muskeg River basin;
  - 12 hydrometric stations on other Athabasca River tributaries north of Fort McMurray;
  - 3 hydrometric stations on other Athabasca River tributaries south of Fort McMurray; and
  - 1 hydrometric station on the Athabasca River;
- Monitoring winter discharges at fourteen and fifteen hydrometric stations in the winter season in early 2006 and winter season in late 2006, respectively; and
- Monitoring water levels at three lake/wetland stations.

Locations of RAMP-funded and RAMP co-funded climate and hydrometric stations monitored in 2006, as well as 2006 snowcourse survey sites, are shown in Figure 3.1-1. Stations are identified by station number only in Figure 3.1-1; the corresponding station names are provided in Table 3.1-1.

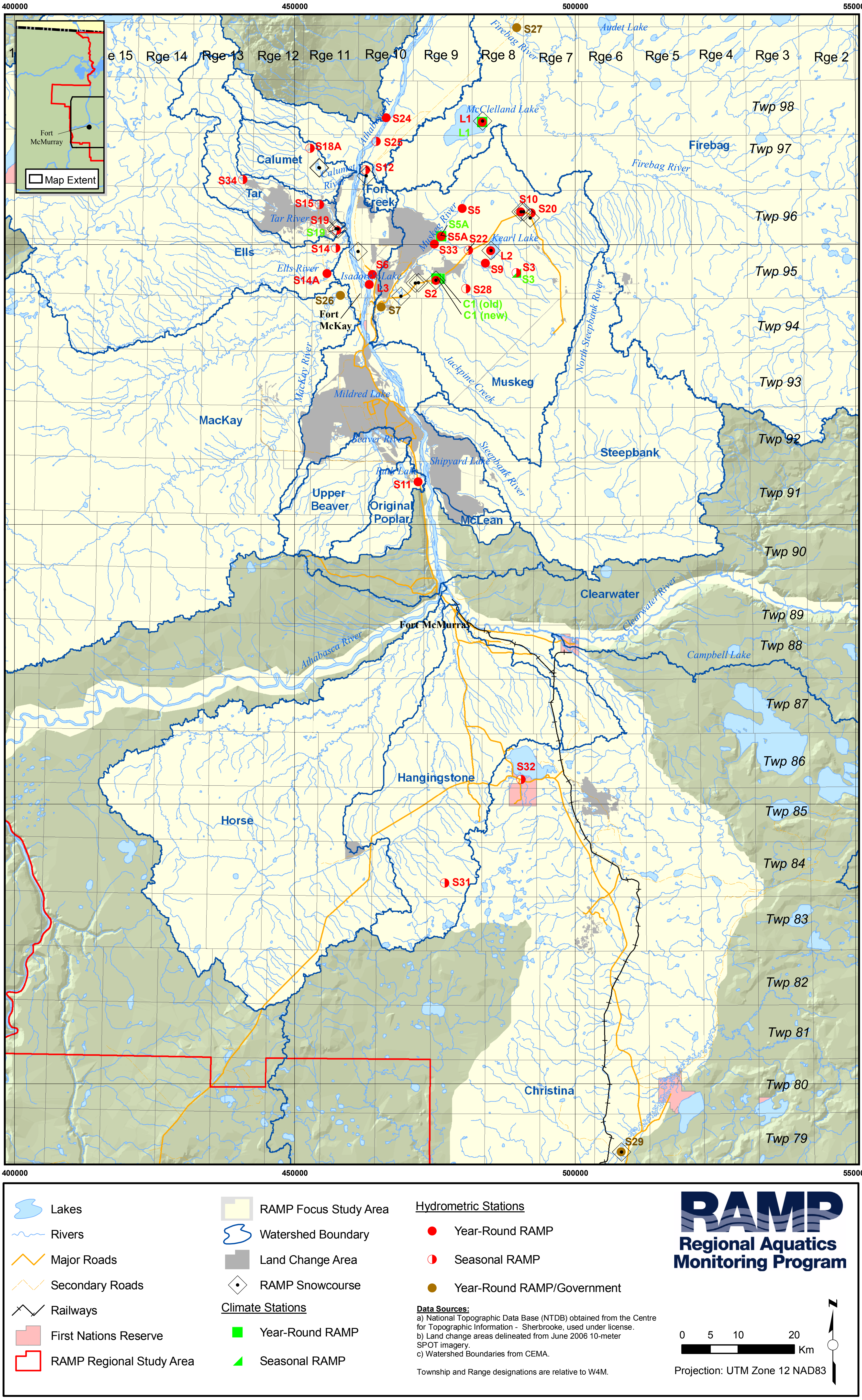
3.1.2 Summary of Field Methods

Field staff visited the climate and hydrometric stations routinely to check and maintain automated sensing equipment. Manual streamflow measurement procedures and standards used in the Climate and Hydrology component are based on recommendations by the Water Survey of Canada (WSC 2001), the United States Geological Survey (USGS 1982), the BC Ministry of Environment, Lands and Parks (BC MOELP 1998):

- 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.

For snowcourse surveys, a sampling site was established at each snowcourse survey site and snow depths were measured at 40 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.

Figure 3.1-1 Locations of RAMP climate and hydrology stations, and snowcourse survey sites, 2006.



K:\Data\Project\RAMP1245\GIS_MXD\Report\RAMP1245_D_CH_2007MAR12.mxd

Table 3.1-1 RAMP climate and hydrology stations operating in 2006.

No.	Name	UTM Coordinates[1]		Operating Season	Variables Measured
		Easting	Northing		
C1	Aurora Climate Station	475820[2]	6343952[2]	All year	Air temperature, precipitation, humidity, solar radiation, snow depth, wind speed and direction
		475230	6344049		
L1	McClelland Lake	483430	6371950	All year	Water level, discharge, air temperature, precipitation, humidity[3]
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	All year	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	All year	Level, discharge
S7	Muskeg River near Fort McKay (07DA008)	465408	6338944	Winter[4]	Level, discharge
S9	Kearl Lake Outlet	483980	6346750	All year	Level, discharge
S10	Wapasu Creek at Canterra Road	490272	6355942	All year	Level, discharge
S11	Poplar Creek at Highway 63 (07DA007)	471998	6307667	All year	Level, discharge
S12	Fort Creek at Highway 63	462600	6363400	Open-water	Level, discharge
S14	Ells River above Joslyn Creek	457310	6349466	Open-water	Level, discharge
S14A	Ells River at the CNRL Bridge	455748	6344947	All year	Level, discharge, water temperature
S15	Tar River near the Mouth	454390	6357209	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, precipitation
				All year	Precipitation
S20	Muskeg River Upland	492106	6355709	Open-water	Level, discharge
S22	Muskeg Creek near the Mouth	480970	6349071	Open-water	Level, discharge
S24	Athabasca River below Eymundson Creek	466313	6372760	All year	Level, discharge
S25	Susan Lake Outlet	464491	6368503	Open-water	Level, discharge
S26	MacKay River near Fort McKay (07DB001)	458120	6341037	Winter[4]	Level, discharge
S27	Firebag River near the mouth (07DC001)	489553	6388830	Winter[4]	Level, discharge
S28	Khahago Creek below Black Fly Creek	480489	6342185	Open-water	Level, discharge
S29	Christina River near Chard (07CE002)	508195	6187926	Winter[4]	Level, discharge
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
S34	Tar River above CNRL Lake	440729	6361689	All year[5]	Level, discharge

1 UTM coordinate datum is NAD83, Zone 12
2 First set of UTM coordinates are until March 7, 2006; second set of UTM coordinates are for after March 20, 2006.
3 Snowfall monitoring was added at station L1 in December 2006
4 Environment Canada monitors water level and discharge at these stations during the open-water season.
5 Winter monitoring began at station S34 in the fall of 2006.

3.1.3 Changes in Monitoring Network from 2005

3.1.3.1 New Monitoring Stations

Petro-Canada commissioned the reactivation of two discontinued RAMP stations in 2006: Fort Creek at Highway 63 (station S12) and Susan Lake Outlet (station S25). Both stations are intended to operate during the open-water season. Stations S12 and S25 were installed in April and May 2006, respectively, at what were believed to be the original station locations. It was subsequently recognized that the station S12 is so close to the mouth Fort Creek that it may occasionally be affected by backwater from the Athabasca River. This was likely not a problem for 2006, as Athabasca River water levels were relatively low during the summer and fall of 2006, but the station will be installed at a more upstream location in 2007.

Petro-Canada also commissioned the installation of new climate instrumentation at the McClelland Lake station (station L1) in the fall of 2006 to support lake water balance analyses. The sensors included a weighing-type year-round precipitation gauge and air temperature and humidity sensors.

3.1.3.2 Modified Stations

The Aurora Climate Station (station C1) was relocated approximately 600 m eastward in March 2006. Albian Sands commissioned the relocation to accommodate the development of the Jackpine mine. As a result, the March 7 through March 21 period is unavailable from the station C1 2006 record. A CDMA modem was installed at the station during its relocation to allow climate data to be downloaded remotely.

3.1.4 Challenges Encountered and Solutions Applied

The submerged pressure transducer at Athabasca River below Eymundson Creek (station S24) was destroyed during ice formation in fall 2006. A new transducer was installed after the ice cover had solidified to collect data during the winter, recognizing that the transducer would certainly be lost during spring breakup because the cable could not be buried in the frozen bank. A more permanent solution, possibly consisting of a bubbler-type station, should be considered for station S24 because of the frequent equipment damage or loss that has been experienced there due to ice movement.

The new weighing-type precipitation gauge for the McClelland Lake station (station L1) did not function after installation and was returned to the manufacturer for repair. In the interim, a temporary tipping-bucket rain gauge with a snow adapter was installed to collect precipitation data at the station.

3.1.5 Other Information Obtained

The following additional 2006 climate and hydrology information was obtained:

- Data from approximately 25 stations in the RAMP RSA maintained solely by the Meteorological Service of Canada (MSC) and the Water Survey of Canada (WSC);
- Water level, precipitation, and air temperature data from AENV's Christina Lake station; and
- Daily discharge information from CNRL's stations on the lower Tar and lower Calumet Rivers.

Some of the data obtained from the government agencies were provisional because the collecting organization had not completed its quality control procedures at the time the data were provided to RAMP.

3.1.6 Summary of Component Data Now Available

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

3.1.7 Analytical Approach

The analytical approach used in 2006 for the Climate and Hydrology component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2005b) and consisted of:

- Selecting hydrologic measurement endpoints;
- Developing criteria to be used in detecting changes in hydrologic measurement endpoints; and
- Detailed data analysis, consisting of tabular and graphical comparisons of 2006 hydrologic measurement endpoints, computed hydrologic baseline conditions, and selected criteria for determination of change in hydrologic conditions.

3.1.7.1 Selection of Hydrology Measurement Endpoints

The following measurement endpoints were used in the analysis of the 2006 hydrology data:

- Mean open-water (1 May to approximately 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 (RAMP 2005b), with emphasis on those measurement 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 more years of both baseline and operational data are available for watersheds containing focal projects.

3.1.7.2 Criteria for Determining Effects

The differences between operational and baseline 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 (RAMP 2005b). This is performed for all RAMP FSA watersheds with appropriate hydrometric stations, including watersheds that are designated as entirely *reference*. Unlike the other RAMP components, the methodology of the hydrologic analysis, described below, does not require comparison of measurement endpoints between *potentially influenced* and *reference* areas.

Table 3.1-2 Summary of RAMP data available for Climate and Hydrology component.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Mainstem																																									
Athabasca River below Eymundson Creek	S24																		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
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	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	2	2	2
Fort Creek at Highway 63	S12														2	2	2		2	2	2		2g	2g	2g														2	2	2
Ells River above Joslyn Creek	S14																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Ells River at the CNRL Bridge	S14A																																	2g	2g	2g	2g	2g	2g	2g	2g
Tar River near the Mouth	S15																		2	2	2		2	2	2		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	h	i	i					
Tar River Upland Tributary	S17																		2	2	2		2	2	2		2	2	2		2	2	2								
Upland Calumet River	S18																		2	2	2																				
Calumet River Upland Tributary	S18A																						2	2	2		2	2	2		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		2a	2a	2a		2a	2a	2a
Susan Lake Outlet	S25																						2	2	2														2	2	2
MacKay River near Fort McKay (07DB001)	S26		4	4	4		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
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4		4	4	4	2	4	4	4	2				2	4	4	4
Tar River above CNRL Lake	S34																																		2	2	2		2	2	2
Fort Creek Basin Snowcourse Survey															d																										
CNRL Area Snowcourse Survey																			d				d				d														
Clearwater River Tributaries																																									
Christina River near Chard (07CE002)	S29																					2	4a	4a	4a	2	4a	4a	4a	2	4	4	4	2	4	4	4	2	4	4	4
Hangingstone River at Highway 63	S30																						2	2	2																
Hangingstone Creek near the Mouth	S31																						2	2	2						2	2	2		2	2	2		2	2	2
Surmont Creek at Highway 31	S32																						2	2	2						2	2	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
i = barometric pressure, water temperature
j = rainfall, snowfall, air temperature, humidity

potentially influenced (blue)
reference (green)

Notes

snowfall monitoring added at station L1 in December 2006

Table 3.1-2 Cont'd.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Basin																																									
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	f
Alsands Drain	S1		2	2			2	2	2		2	2	2	2					2	2	2	2	2	2	2																
Jackpine Creek at Canterra Road	S2		2	2	2		2	2			2	2			2	2	2		2	2	2		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		2a	2a	2a		2a	2a	2a						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																																
Muskeg River above Stanley Creek	S5																										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River above Muskeg Creek	S5A		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i	2i
Muskeg River near Fort McKay (07DA008)	S7		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	2	2	2	2	2	2	2	2
Stanley Creek near the Mouth	S8											1	1		1	1	1		1	1	1		1	1	1		1	1	1												
Kearl Lake Outlet	S9						2	2	2		2e	2e	2e						2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2
Wapasu Creek at Canterra Road	S10										2	2	2						2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Albian Pond 3 Outlet	S13														2	2	2		2	2	2		2	2	2																
Muskeg River Upland	S20																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
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		2	2	2		2	2	2
Aurora Boundary Weir	S23																	2	2	2	2	2	2	2	2																
Khahago Creek below Black Fly Creek	S28																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Muskeg River at the Aurora/Albian Boundary	S33																										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
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																					
Wetlands and Lakes																																									
Isadore's Lake	L3													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Kearl Lake	L2										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
McClelland Lake	L1			2	2		2	2	2		2	2	2		2	2	2		2	2	2	1	2a	2a	2a	1	2a	2a	2a	1	2a	2a	2a	1	2a	2a	2a	2a	2a	2a	2c
Regional Data																																									
Wide-Area Snowcourse Survey																														d				d				d			
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
i = barometric pressure, water temperature
j = rainfall, snowfall, air temperature, humidity

(blue) potentially influenced
(green) reference

Notes

snowfall monitoring added at station L1 in December 2006

3.1.7.3 Detailed Analysis

Overall Approach

The analysis of the hydrologic data consisted of treating each watershed containing focal projects as both *reference* and *potentially influenced*. The observed hydrograph at a station was used as the operational case, and a baseline hydrograph for the station was generated using both land change information and water withdrawal and discharge information for the watershed. This approach isolates any influence of focal projects on the 2006 hydrograph from the effects of spatial and temporal variability. Additional details regarding this analytical approach are found in RAMP (2005b).

Estimation of Baseline Hydrographs

Baseline hydrographs are defined for this analysis as the hydrograph that would have be observed if no focal project activities had ever occurred upstream in the watershed. The baseline hydrograph may include the effects of activities from other development projects in the watershed, and so is not necessarily a naturalized hydrograph. The baseline hydrograph is derived for the purpose of assessing any incremental effects of focal projects.

Baseline hydrographs were estimated for the outlet of each major watershed by adding water withdrawals and subtracting water releases from the observed hydrographs as follows:

Baseline Hydrograph = Observed (Operational) Hydrograph

+ Natural runoff that would have occurred from land change areas which are closed-circuited;

- Incremental runoff that would have occurred from land change areas which are not closed-circuited or are being dewatered. Incremental runoff depth from these areas is assumed to 20% greater than runoff from areas of the catchment without land change

+ Water withdrawals from the watercourse in question by focal projects

- Water releases to the watercourse in question by focal projects

± Runoff from areas that have been diverted into (-) or out of (+) the watershed in question

- The difference between baseline and operational hydrographs on tributaries upstream of the station in question

The approach does not account for indirect effects of focal projects on streamflow, such as groundwater influences on surface water. It also does not account for the fact that an increase or decrease in catchment area affects the catchment responsiveness. In addition, the assumption of a 20% increase in runoff from land change areas that are not closed-circuited, while based on the professional judgment of members of the Climate and Hydrology subgroup under the RAMP Technical Program Committee, ignores the changes in runoff timing and catchment responsiveness that can be associated with activities that give rise to this type of land change designation, such as land clearing. Predicted effects during low flow periods are less robust than predicted effects during high flow periods. Monitoring reference catchments in RAMP provides a secondary basis for comparison. Considering these simplifications, however, the values estimated for the hydrologic measurement endpoints are appropriate for the objectives of this monitoring report in that the calculated measurement endpoints indicate the approximate magnitude of changes in the catchments.

3.2 WATER QUALITY COMPONENT

3.2.1 Summary of 2006 Monitoring Activities

Monitoring activities in 2006 for the Water Quality component were conducted in four ambient water sampling campaigns (Table 3.2-1). Rivers and lakes in the RAMP FSA were sampled to document water quality and assess any changes in water chemistry or quality that may be occurring due to focal projects or other factors affecting the natural environment.

Table 3.2-1 RAMP water quality sampling field campaigns, 2006.

Season	Duration
Winter	March 22 to 23
Spring	May 18 to 25
Summer	July 23 to 24*
Fall	September 6 to 23

* Due to logistical difficulties, Shipyard Lake was sampled on August 10, 2006.

Water quality sampling in 2006 focused on the Athabasca River and its major tributaries in the Athabasca oil sands region, as well as regionally important lakes and wetlands. Additional data were contributed by AENV and operators of individual focal projects for some locations. Water quality was examined at a total of 44 RAMP stations in 2006. Table 3.2-2 summarizes the location of the 2006 water quality sampling stations, seasonal distribution of the sampling effort, and water quality variables measured at each station, while Figure 3.2-1 indicates the locations of the water quality stations sampled in 2006. Sampling intensity was greatest during the fall campaign, with samples collected from all 2006 RAMP monitoring stations in that season (Table 3.2-2).

3.2.2 Summary of Field Methods and Sample Analysis

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

Field sampling involved collecting 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.

At all water quality stations, *in situ* measurements of dissolved oxygen (DO), temperature and conductivity were collected using an YSI Model 650 multi-probe water meter or a handheld thermometer (temperature), a handheld conductivity meter (conductivity) and a LaMott portable Winkler titration kit (dissolved oxygen).

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

Sampling methods were modified during winter in response to environmental conditions, and to account for and preclude any sampling error or contamination associated with the requisite use of secondary sample transfer vessels and ice augers. 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. Multiple holes were drilled for cross-channel composites 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 as required. All intermediate sampling equipment and final sample collection bottles were triple rinsed prior to final sample collection. All waterbodies sampled during the spring, summer and fall programs were clear of ice.

Four HOBO® Water Temp Pro automatic temperature sensor/data-loggers for collection of open-water temperature data were deployed during the spring sampling campaign (Table 3.2-4). Each sensor was attached to a steel rod anchored in the stream substrate in a pool or other deep area that was likely to contain water for the entire monitoring period. All sensors were programmed to collect temperature data at 15-minute intervals for the duration of their installation. Sensors remained in the water column until removal during the fall field campaign (Table 3.2-4).

All water samples were collected, filtered where appropriate (dissolved organic carbon only), preserved and shipped according to protocols specified by consulting laboratories, namely ALS in Fort McMurray, Alberta Research Council (ARC) in Vegreville, and HydroQual Laboratories (HydroQual) in Calgary. Samples were shipped via Greyhound or through the ALS outlet in Fort McMurray.

The OPTI lakes were sampled for water quality in conjunction with the Nexen Wetlands Monitoring Program. The 2006 OPTI Lakes program consisted of spring and fall ambient water sampling surveys at each of nine lakes (Table 3.2-5). Each water quality station was accessed via a pontoon helicopter in both the spring and fall monitoring programs. For each lake site, the helicopter landed near the edge of the lake and taxied out to the center of the lake. This approach ensured surface waters at the sample collection point were not disturbed by rotor wash.

Table 3.2-2 Summary of sampling for the RAMP 2006 Water Quality component.

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	W	S	S	F	
Athabasca River								
ATR-DC-CC	Athabasca River upstream of Donald Creek (cross-channel)	475020	6298154	1	-	-	1	Cross channel composite
ATR-DC-E	Athabasca River upstream of Donald Creek (east bank)	475120	6298154	-	-	-	1	East bank grab
ATR-DC-W	Athabasca River upstream of Donald Creek (west bank)	475102	6298152	-	-	-	1	West bank grab
ATR-DD-E	Athabasca River downstream of all development (east bank)	463627	6367714	1	1	1	1	East bank grab
ATR-DD-W	Athabasca River downstream of all development (west bank)	462604	6367557	1	1	1	1	West bank grab
ATR-FR	Athabasca River upstream of the Firebag River	478455	6400331	-	-	-	1	Cross channel composite
ATR-MR-E	Athabasca River upstream of the Muskeg River (east bank)	463504	6332230	-	-	-	1	East bank grab
ATR-MR-W	Athabasca River upstream of the Muskeg River (west bank)	463203	6332042	-	-	-	1	West bank grab
ATR-OF	Athabasca River at Old Fort (sampled monthly)	470205	6474330	12	12	12	12	AENV Sampling
ATR-SR-E	Athabasca River upstream of the Steepbank River (east bank)	470937	6319625	-	-	-	1	East bank grab
ATR-SR-W	Athabasca River upstream of the Steepbank River (west bank)	470785	6319199	-	-	-	1	West bank grab
ATR-UFM	Athabasca River upstream of Fort McMurray (monthly)	474901	6286327	13	11	13	11	AENV sampling
Tributaries to the Athabasca River (Eastern)								
FOC-1	Fort Creek	461525	6363115	-	6	6	7	Mid-channel grab
MCC-1	McLean Creek (mouth)	474637	6306051	-	6	6	9	Mid-channel grab
Steepbank River								
NSR-1	North Steepbank River	497380	6324549	-	-	-	1	Mid-channel grab
STR-1	Steepbank River (mouth)	470807	6319811	-	-	-	1	Mid-channel grab
STR-2	Steepbank River upstream of Suncor Millennium	485820	6309347	-	-	-	1	Mid-channel grab
STR-3	Steepbank River upstream of North Steepbank River	495076	6300011	-	1	1	1	Mid-channel grab
Muskeg River								
MUR-1	Muskeg River (mouth)	463473	6332409	-	-	-	1	Mid-channel grab
MUR-2	Muskeg River upstream of Canterra Road crossing	466569	6340506	4	4	4	4	Industry sampling
MUR-2	Muskeg River downstream of Canterra Road crossing	465545	6338322	15	15	15	14	AENV sampling
MUR-4	Muskeg River upstream of Jackpine Creek	474379	6349075	4	10	10	10	Industry sampling
MUR-5	Muskeg River upstream of Muskeg Creek	476043	6351800	10	10	10	10	Industry sampling
MUR-6	Muskeg River upstream of Wapasu Creek	492093	6355679	-	6	6	7	Mid-channel grab
Muskeg River Tributaries								
JAC-1	Jackpine Creek (mouth)	471935	6346300	-	-	-	1	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	481031	6349022	-	-	-	1	Mid-channel grab
SHC-1	Shelley Creek (mouth)	475117	6349244	-	-	-	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477375	6356665	-	-	-	1	Mid-channel grab
WAC-1	Wapasu Creek at Canterra Road crossing	490340	6355735	-	-	-	1	Mid-channel grab
Firebag River								
FIR-1	Firebag River (mouth)	479114	6400215	-	-	-	1	Mid-channel grab
FIR-2	Firebag River upstream of Suncor Firebag	531543	6354825	-	-	-	1	Mid-channel grab

Table 3.2-2 Cont'd.

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	W	S	S	F	
Tributaries to the Athabasca River (Western)								
BER-1	Beaver River (mouth)	463620	6330924	-	-	-	1	Mid-channel grab
CAL-1	Calumet River (mouth)	460816	6363196	-	-	-	1	Mid-channel grab
CAL-2	Calumet River (upper river)	453210	6367389	-	1	1	2	Mid-channel grab
ELR-1	Ells River (mouth)	459241	6351495	-	-	-	1	Mid-channel grab
ELR-2	Ells River (upstream)	455753	6344915	-	1	1	1	Mid-channel grab
MAR-1	MacKay River (mouth)	461601	6336007	-	-	-	1	Mid-channel grab
MAR-2	MacKay River upstream of Petro-Canada MacKay	444682	6314024	-	-	-	1	Mid-channel grab
POC-1	Poplar Creek (mouth)	473051	6308820	-	-	-	1	Mid-channel grab
TAR-1	Tar River (mouth)	458852	6353527	-	-	-	1	Mid-channel grab
TAR-2	Tar River upstream of CNRL Horizon	440261	6361800	-	1	1	2	Mid-channel grab
Tributaries to the Athabasca River (Southern)								
HAR-1	Hangingstone River upstream of Fort McMurray	478653	6276265	-	1	1	1	Mid-channel grab
Clearwater River								
CLR-1	Clearwater River upstream of Fort McMurray	480610	6283924	1	7	7	7	Mid-channel grab
CLR-2	Clearwater River upstream of Christina River	496294	6280422	-	6	6	7	Mid-channel grab
Christina River								
CHR-1	Christina River upstream of Fort McMurray	496646	6280035	-	-	-	1	Mid-channel grab
CHR-2	Christina River upstream of Janvier	511698	6192371	-	-	-	1	Mid-channel grab
Lakes and Wetlands								
ISL-1	Isadore's Lake	463361	6342764	-	-	16	16	Multi-location composite
KEL-1	Kearl Lake	485425	6349374	-	-	-	16	Multi-location composite
MCL-1	McClelland Lake	478202	6371301	-	-	-	16	Multi-location composite
SHL-1	Shipyard Lake	473481	6313037	-	-	16	16	Multi-location composite
	OPTI Lakes				5		5	Mid-lake grab
QA/QC[1]								
-				1	1	1	1	Trip & field blank, split, duplicate

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

Legend to Analytical Packages:

1. *RAMP standard (conventionals, major ions, nutrients, tot./dissolved metals, recoverable hydrocarbons, naphthenic acids, phenols)*
2. *RAMP standard + toxicity*
3. *RAMP standard + PAHs*
4. *RAMP standard + PAHs + toxicity*
5. *OPTI Lakes analytical package*
6. *Continuously-monitoring thermograph*
7. *RAMP standard + thermograph*
8. *RAMP standard + PAHs + thermograph*
9. *RAMP standard + toxicity + thermograph*
10. *RAMP standard + PAHs + toxicity + thermograph*
11. *AENV routine*
12. *AENV routine + RAMP standard*
13. *AENV routine + PAHs*
14. *AENV routine + DataSonde*
15. *AENV routine + PAHs + DataSonde*
16. *RAMP standard + chlorophyll-a*

Figure 3.2-1 RAMP water quality sampling locations, 2006.

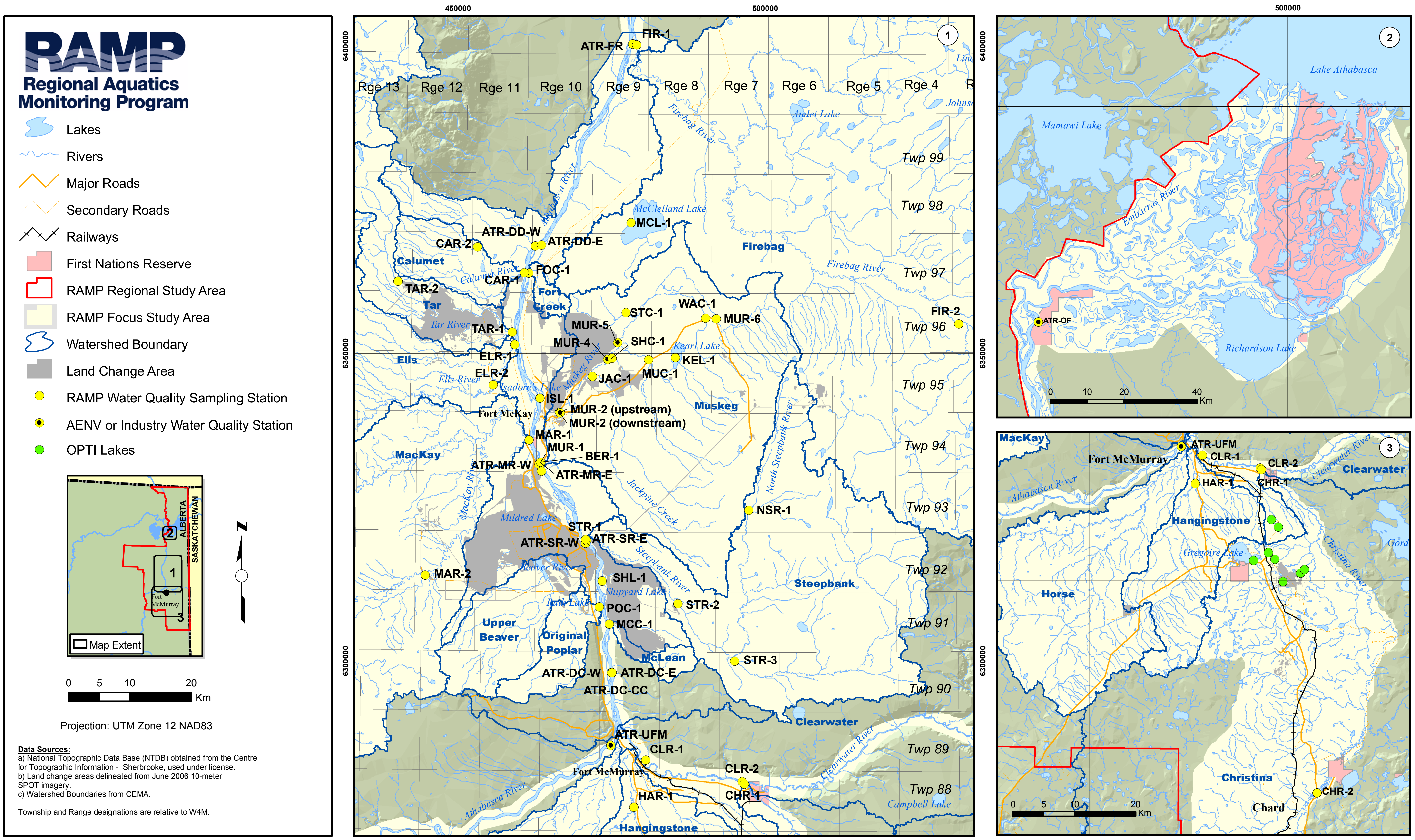


Table 3.2-3 RAMP water quality composite sample sub-groups.

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

Table 3.2-4 Locations of 2006 continuous water temperature monitoring stations.

Location	Installation Date	Removal Date
McLean Creek (station MCC-1)	May 18, 2006	September 15, 2006
Muskeg River (station MUR-6)	May 18, 2006	September 10, 2006
Clearwater River (station CLR-2)	May 18, 2006	September 9, 2006
Fort Creek (station FOC-1)	May 25, 2006	Lost

Table 3.2-5 OPTI Lakes sample station locations, 2006.

Waterbody	Site Name	UTM Coordinates (NAD83, Zone 12)	
		Easting	Northing
Canoe Lake	CANL-1	498465	6257522
Caribou Horn Lake	CARL-1	501172	6264481
Frog Lake	FRL-1	504481	6254151
Gregoire Lake	GRL-1	494505	6255428
Kiskatinaw Lake	KIL-1	499374	6266454
Rat Lake	RAL-1	507237	6251911
Sucker Lake	SUL-1	508291	6252929
Unnamed Lake One	UNL-1	502492	6249671
Unnamed Lake Two	UNL-2	500270	6255698

At each study lake, water quality grab samples were collected from approximately the center of the lake using the pontoon as a sampling platform. Samples were collected by direct fill, 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. At all water quality stations, supporting *in situ* water quality measurements of pH, dissolved oxygen, temperature and conductivity were collected using an YSI Model 85 or Model 86 multi-probe water meter, a Hach™ colourmetric kit (pH) and a LaMott™ portable Winkler titration kit (dissolved oxygen). All waterbodies sampled during the spring and fall sampling periods were clear of ice.

All water quality samples taken at the 44 RAMP stations in 2006 were analyzed for the RAMP standard variables (Table 3.2-6) in all sampling seasons (ALS for conventional water quality variables, organics/hydrocarbons, and ARC for total and dissolved metals, including ultra-trace total mercury). In addition:

- Samples collected from regional lakes were analyzed for chlorophyll *a* (ALS); and

- Water sampled from three stations during the fall sampling campaign (McLean Creek, station MCC-1, Tar River upstream, station TAR-2, and Calumet River upstream, station CAR-2) was analyzed for sublethal toxicity to aquatic organisms (Hydroqual) (Table 3.2-7).

3.2.3 Changes in Monitoring Network from 2005

The 2006 monitoring network for the Water Quality component was similar to the 2005 monitoring network with the following exceptions:

- Station ATR-DD (Athabasca River downstream of development) was sampled at the east and west bank, no cross-channel composite was collected;
- Chlorophyll *a*, previously sampled at all stations in winter and spring, was only sampled at RAMP lakes (Shipyard, Isadore's, McClelland, and Kearl Lakes) in summer and fall in 2006 following a decision of the RAMP Technical Program Committee; and
- The OPTI-Nexen lakes were surveyed in 2006.

3.2.4 Challenges Encountered and Solutions Applied

In 2005, thermographs that had been attached to a stone or cinder block and placed on the streambed were found to be at risk of becoming covered in sediment. In 2006 an effective solution to the problem was devised, and thermographs were attached to a length of steel rod which was anchored into the stream substrate.

3.2.5 Other Information Obtained

All sampling for the Water Quality component in 2006 was conducted by the RAMP implementation team, with the exception of:

- Three stations on the mainstem Muskeg River (stations MUR-2, MUR-4 and MUR-5) that were monitored by Syncrude and Albian Sands (Table 3.2-2); and
- Two stations on the mainstem Athabasca River (stations ATR-UFM, ATR-OF) and one station on the mainstem Muskeg River (station MUR-2) that were monitored by AENV (Table 3.2-2).

In addition, AENV 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. These supplemental data are provided to RAMP on an annual basis.

3.2.6 Summary of Component Data Now Available

The water quality data collected to date by RAMP are summarized in Table 3.2-8. Table 3.2-8 excludes data collected by AENV and industry partners.

Table 3.2-6 RAMP standard variables.

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

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

Table 3.2-7 Sublethal toxicity tests of ambient river water.

Group	Sublethal Toxicity Tests
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)*

3.2.7 Analytical Approach

The analytical approach used in 2006 for the Water Quality component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2005b) and consisted of:

- Selecting particular water quality variables as water quality measurement endpoints;
- Development of criteria to be used in detecting changes in water quality measurement endpoints;
- Updating of regional baseline data ranges for each water quality measurement endpoint;
- Tabular and graphical presentation of results comparing 2006 concentrations of water quality measurement endpoints, historical concentrations of each endpoint at each station, water quality regional baseline conditions, and selected criteria for determining of change in water quality; and
- Additional analyses, including an examination of winter water quality data and analysis of the semi-permeable membrane device (SPMD) pilot project implemented in summer 2006.

3.2.7.1 Selection of Water Quality Measurement Endpoints

Depending on the analytical package (Table 3.2-2) over 100 water quality variables can be analyzed in a RAMP water quality sample. A number of these variables were selected as water quality measurement endpoints for this 2006 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 (see RAMP [2005b] for a review of these EIAs and specific predictions of relevance to the RAMP Water Quality component);
- 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 (RAMP 2005a);
- Discussions among RAMP Component Managers about the importance of various water quality variables to assist in interpreting results of other RAMP components, particularly the Benthic Invertebrate Community component and the Fish Population component; and
- Discussions with RAMP Technical Program Committee regarding appropriate analytical strategies for the Water Quality component.

Table 3.2-8 Summary of RAMP data available for Water Quality component.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																									
Athabasca River upstream of Donald Creek (cross-channel)	ATR-DC-CC		1	1	1																				1				3				1	1	1	1	1	1			1
Athabasca River upstream of Donald Creek (east bank) [a]	ATR-DC-E								1								1				3				1				1				1	1	1	1	1				1
Athabasca River upstream of Donald Creek (middle)	ATR-DC-M																1																								
Athabasca River upstream of Donald Creek (west bank)[a]	ATR-DC-W								1								1				3				1				1				1	1	1	1	1				1
Athabasca River downstream of all development	ATR-DD																					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	1,1	1	1	1	1	1	1	1
Athabasca River upstream of the Embarras River (cross channel)	ATR-ER																1				3																				
Athabasca River upstream Fort Creek (cross channel)	ATR-1		1	1	1																																				
Athabasca River upstream Fort Creek (east bank) [a b]	ATR-FC-E								1								1				3				1				1								1				
Athabasca River upstream Fort Creek (middle)	ATR-FC-M																1																								
Athabasca River upstream Fort Creek (west bank) [a b]	ATR-FC-W								1								1				3				1				1								1				
Athabasca River upstream of the Firebag River	ATR-FR																								1				1				1				1				1
Athabasca River upstream of the Muskeg River (east bank) [a b]	ATR-MR-E								1								1				1				1				1				1				1				1
Athabasca River upstream of the Muskeg River (middle)	ATR-MR-M																1																								
Athabasca River upstream of the Muskeg River (west bank) [a b]	ATR-MR-W								1								1				1				1				1				1				1				1
Athabasca River at Old Fort (sampled monthly)[c]	ATR-OF													11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12					12	12	12	12
Athabasca River upstream of the Steepbank River (east bank)	ATR-SR-E																1				1				1				1				1				1				1
Athabasca River upstream of the Steepbank River (middle)	ATR-SR-M																1																								
Athabasca River upstream of the Steepbank River (west bank)	ATR-SR-W																1				1				1				1				1				1				1
Athabasca River upstream of Fort McMurray (monthly)[d]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11					13	11	13	11
Embarras River	EMR-1																												1												
Athabasca River Delta																																									
Big Point Channel [e]	ARD-1											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		6	6	9		6	6	9
McLean Creek (100 m upstream)	MCC-2											6	6																												
North Steepbank River	NSR-1																					1	1	1	1	1	1	1	1	1	1	1	1		1	1	1				1
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1				1	1			1				1				1				1				1
Steepbank River upstream of Suncor Millennium	STR-2																					1			1				1				1				1				1
Steepbank River upstream of North Steepbank River	STR-3																													1	1	1	1	1	1	1	1		1	1	1
Athabasca River Tributaries (Southern)																																									
Christina River upstream of Fort McMurray	CHR-1																					1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	3				1
Christina River upstream of Janvier	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	3				1
Clearwater River upstream of Fort McMurray	CLR-1																	3	8	8	8	1	7	7	8	1	7	7	8	1	7	7	7	1	7	7	7	1	7	7	7
Clearwater River upstream of Christina River	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8		6	6	7	1	7	7	7		6	6	7
Hangingstone River upstream of Fort McMurray	HAR-1																														1	1	1		1	1	3		1	1	1
Athabasca River Tributaries (Western)																																									
Beaver River (mouth)	BER-1																																1			1	1				1
Calumet River (mouth)	CAR-1																					1	1	1	2	1	1	1	2	1	1	1	2		1	1	2				1
Calumet River (upper river)	CAR-2																																		1	1	2		1	1	2
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11				1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2				1
Ells River (upstream	ELR-2														11	11	11	14												1	1	1	2		1	1	2		1	1	1
Firebag River (mouth)	FIR-1																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
Firebag River upstream of Suncor Firebag	FIR-2																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1
Fort Creek	FOC-1														7	7	9		6	6	7	1	6	6	7		6	6	7										6	6	7
MacKay River (mouth)	MAR-1								1								1				1	1			1				1				1				1				1
MacKay River upstream of Petro-Canada MacKay	MAR-2																					1			1	1	1	1	1				1				1				1
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1				1				1
Tar River (mouth)	TAR-1						1	1	1													1	1	1	2	1	1	1	2	1	1	1	1		1	1	1				1
Tar River upstream of CNRL Horizon	TAR-2																													1	1	1	1		1	1	1		1	1	2

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
16 = RAMP standard + chlorophyll a

Blue shading = potentially influenced
Green shading = reference

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

Table 3.2-8 Cont'd.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River																																									
Muskeg River (mouth)[f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1				1				1				1				1				1				1
Muskeg River upstream of Canterra Road crossing [f]	MUR-2									2	9	9	9	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Muskeg River downstream of Canterra Road crossing [g]	MUR-2					13	13	13	11	13	13	13	11	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14
Downstream of Alsands Drain	MUR-3																																								
Muskeg River upstream of Jackpine Creek [f g h]	MUR-4					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Muskeg River upstream of Muskeg Creek [f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Muskeg River upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9		6	6	9		6	6	9		6	6	7		6	6	9		6	6	9		6	6	7
Muskeg River Tributaries																																									
Alsands Drain (mouth) [f g h]	ALD-1					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	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				1				1
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1				1				1				1		1	1	1				1
Shelley Creek (mouth)	SHC-1								11				11,1																												1
Stanley Creek (mouth)	STC-1								11				11,1								1	1	1	1	1	1	1	1	1				1		1	1	1				1
Wapasu Creek at Canterra Road crossing	WAC-1					2			11	2			11,1																				1				1				1
Wetlands and Lakes																																									
Isadore's Lake	ISL-1							1									1			1	1												1			1	1			16	16
Kearl Lake	KEL-1							1									1			1	1				1	1			1			1	1			1	1				16
McClelland Lake	MCL-1																1			1	1				1																16
Shipyard Lake	SHL-1							1			1	1	1			1	1			1	1			1	1			1	1			1	1			1	1			16	16
Additional Sampling (Non-Core Programs)																																									
Unnammed Creek north of Ft. Creek (mouth)	UNC-1															1	1																								
OPTI Lakes	-																		5		5		5		5														5		5
Potential TIE	-																								√				√				√								
QA/QC																																									
Field and trip blanks, plus one split sample	-														1	1	1			1	1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	1	1	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
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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
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15 = AENV routine parameters + PAHs + DataSonde
16 = RAMP standard + chlorophyll a

Blue shading = potentially influenced
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[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the Delta)
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[e] In 1999, one composite samples was prepared with water from Big Point, Goose Island, Embarras and an unnamed side channel
[f] All testing, with the exception of thermographs, is conducted by individual industry
[g] AENV collects/collected nine samples throughout the year, although only three are/were analyzed for PAHs
[h] In 1999, MUR-4 was located upstream of Shelley Creek

Table 3.2-9 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;
- *conductivity*: basic indicator of overall ion concentration;
- *Total suspended solids (TSS):* a variable strongly associated with several other measured water quality variables, including total phosphorus, total aluminum and numerous other metals;
- *Dissolved phosphorus, total nitrogen and nitrate+nitrite:* indicators of nutrient status. Dissolved phosphorus rather than total phosphorus is included because it is the primary biologically available species of phosphorus and because total phosphorus levels are strongly associated with TSS (RAMP 2006);
- *Various ions (sodium, chloride, calcium, magnesium, sulphate):* indicators of ion balance, which could be affected by discharges or seepages from focal projects or by changes in the water table and changes in the relative influence of groundwater;
- *Total alkalinity:* an indicator of the buffering capacity and acid-sensitivity of waters;
- *Total dissolved solids (TDS) and dissolved organic carbon (DOC):* indicators of total ion concentrations and dissolved organic matter (particularly humic acids), respectively;
- *Total and dissolved aluminum:* aluminum is mentioned as a variable of interest in some oil sands EIAs, by CEMA, and in the RAMP 5-year report (Table 3.2-9). Total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with suspended solids (Golder 2003a). Dissolved aluminum more accurately represents biologically available forms of aluminum that may cause toxicity to aquatic organisms (Butcher 2001);
- *Total boron, total molybdenum, total strontium*: three metals found in predominantly dissolved form waters of the RAMP FSA (RAMP 2004) which may be indicators of groundwater influence in surface waters;
- *Total mercury (ultra-trace)*: a metal occurring naturally in the RAMP FSA that is of importance to fish tissue quality; 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 water quality measurement endpoints, 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 2006 were screened against Alberta acute and sublethal water quality guidelines for the protection of aquatic life (AENV 1999b) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2006). Variables for which no AENV or CCME guidelines exist were screened against applicable guidelines from other jurisdictions (e.g., British

Columbia) where appropriate. All values that exceeded these guidelines are reported explicitly in the body of the RAMP report.

- **Comparison to Natural Variation in Baseline Conditions**: RAMP 2006 data for each of the selected water quality measurement endpoints were assessed against a rigorously defined range of natural variability in concentration of each of these measurement endpoints.

Table 3.2-9 Potential key water quality measurement endpoints.

Group	RAMP (2005b) Variables Listed in EIAs (No. of projects)	CEMA Variables of Concern (CEMA 2004)	RAMP 5-year report (Golder 2003a)	Variables to Support other RAMP Components[1]	Additional Suggested Variables[2]
Physical Variables	Temperature (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 phosphorus (2)	Ammonia-N Total nitrogen Total phosphorus	Dissolved organic carbon Total Kjeldahl nitrogen Total phosphorus	Dissolved phosphorus Nitrate+nitrite	
Ions and Ion Balance	Chloride (2) Sulphide (2) Total dissolved solids (2)	Sodium Chloride Potassium **Fluoride** 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	Total strontium
Organics/ Hydrocarbons	Oil & grease (1) Naphthenic 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)	Naphthalene Biphenyl Acenapthene Acenaphthylene Fluorene Fluoranthene Alkyl-naphthalenes Alkyl-biphenyls Alkyl-acenaphthene Alkyl-benzo(a)anthracene Alkyl-fluorenes Alkyl-phenanthrenes Dibenzothiophene Alkyl-dibenzothiophenes	(None)	(None)	(None)
Effects-based Endpoints	Acute toxicity (1) Chronic toxicity (2)	Acute toxicity Chronic toxicity **Fish tainting**			

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

[1] Primarily benthic invertebrate communities and fish populations (inferred).

[2] Suggested by the RAMP Technical Program Committee, February 2006.

3.2.7.3 Development of Regional Water Quality Baselines

RAMP has adopted a regional baseline approach, in which individual observations may be compared against regional baseline data. In this approach, water quality data from all RAMP reference water quality stations (i.e., those upstream of any activities of focal projects) for all years of sampling (i.e., 1997 to 2006) were pooled 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 groups of stations exhibiting similar and consistent water quality characteristics. Similar approaches to consolidation and analysis of large water quality datasets are presented and discussed by Jones and Boyer (2002) and Güler *et al.* (2004). The analytical methodology was first used for RAMP water quality data analysis in the RAMP 2004 Technical Report (RAMP 2004) and is more fully described in RAMP (2004) and in the RAMP Technical Design and Rationale document (RAMP 2005b).

Detailed methods and results of the OCA of the RAMP water quality data are provided in Appendix D. Results of this analysis of the RAMP 1997 to 2006 dataset indicated three major groups of stations with similar water quality types (Table 3.2-10):

- Stations in tributary watersheds to the northeast and south of Fort McMurray, including the Muskeg, Steepbank, Firebag, and Clearwater-Christina rivers, as well as Kearl and McClelland lakes;
- Stations in tributary watersheds to the northwest of Fort McMurray, including the MacKay, Ells, Tar, Calumet, Poplar Creek, and Beaver rivers, Poplar Creek, as well as Fort Creek, McLean Creek, the Hangingstone River, and Isadore's and Shipyard lakes; and
- All stations in the Athabasca River and Athabasca River Delta.

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).

These groupings are generally consistent with groupings of water quality in the oil sands area by AOSERP (1985), and may be associated with patterns of underlying and surficial geology (AOSERP 1985). In addition, the groupings of stations into clusters in 2006 was generally consistent with the clusters defined in the 2005 analysis, with the exception of Isadore's and Shipyard lakes, which were grouped with the northeastern and southern tributaries in 2005. These results indicate that water quality data collected in 2006 were consistent with the water quality characteristics of each group.

Within each cluster, data from stations designated as *reference* (i.e., those stations located in areas of watersheds that are not being influenced by focal project activities) were pooled to develop descriptions of regional baseline water quality, against which RAMP data from stations designated as *potentially influenced* and *reference* were assessed. Table 3.2-11 lists the stations from which baseline data from 1997 to 2006 were pooled to develop these baseline descriptions. The numbers of observations in regional baseline datasets varied by cluster and by water quality measurement endpoint.

Determination of regional baseline concentrations for the OPTI lakes was conducted separately from the other RAMP water quality dataset. Instead of utilizing OCA to define groupings of stations exhibiting similar water quality, the regional baseline dataset was defined as all observations from fall sampling conducted from 2000 to 2006 for all OPTI lakes. As all waterbodies sampled for the OPTI lakes component are considered reference stations, this approach maximized the number of observations used to define regional baseline conditions against which observations from individual OPTI lakes could be compared.

Table 3.2-10 Classification of groups of RAMP water quality monitoring stations with similar water quality, from 1997 to 2006 data.

Waterbody	Total No. of Station/Year Combinations	Cluster		
		1	2	3
Athabasca River	**84**	**1**	**1**	**82**
Athabasca River Delta	**4**	**0**	**0**	**4**
Eastern tributaries	**24**	**12**	**11**	**1**
Firebag River	10	10	0	0
Fort Creek	5	1	4	0
McLean Creek	8	0	7	1
Unnamed Creek	1	1	0	0
Muskeg River	**54**	**35**	**18**	**1**
Muskeg River	22	14	7	1
Alsands Drain	1	0	1	0
Jackpine Creek	8	7	1	0
Muskeg Creek	9	5	4	0
Shelley Creek	2	0	2	0
Stanley Creek	7	5	2	0
Wapasu Creek	5	4	1	0
Steepbank River	**22**	**16**	**5**	**1**
Steepbank River	17	11	5	1
North Steepbank River	5	5	0	0
Western tributaries	**49**	**5**	**40**	**4**
Beaver River	4	0	4	0
Calumet River	7	0	7	0
Ells River	9	4	2	3
MacKay River	13	1	12	0
Poplar Creek	7	0	7	0
Tar River	9	0	8	1
Southern tributaries	**25**	**16**	**6**	**3**
Christina River	10	6	4	0
Clearwater River	12	10	0	2
Hangingstone River	3	0	2	1
Regional lakes	**26**	**18**	**8**	**0**
Isadore's Lake	5	2	3	0
Kearl Lake	8	8	0	0
McClelland Lake	5	5	0	0
Shipyard Lake	8	3	5	0
Total	**288**	**103**	**89**	**96**

Bold entries refer to sum of station-year combinations in each group of waterbodies.
Shaded entries denote the cluster designated for each waterbody.

Table 3.2-11 Regional baseline water quality data groups and station comparisons.

Regional Baseline Grouping (Cluster)	Baseline Stations Used for Regional Comparison[1]	Stations (2006) Compared with this Regional Baseline
1. Eastern and southern tributaries to the Athabasca River; Kearl Lake; McClelland Lake	FIR-1, FIR-2, FIR-2X, UNC-1, KEL-1, MCL-1, JAC-1, MUC-1, SHC-1, STC-1, WAC-1, MUR-5, MUR-6, CHR-1, CHR-2, CLR-1, CLR-2, STR-2, STR-3, NSR-1	FIR-1, FIR-2, KEL-1, MCL-1, JAC-1, MUC-1, SHC-1, STC-1, WAC-1, MUR-1, MUR-6, CHR-1, CHR-2, CLR-1, CLR-2, STR-1, STR-2, STR-3, NSR-1
2. Western tributaries to the Athabasca River; Fort Creek; McLean Creek; Hangingstone River; Isadore's Lake; Shipyard Lake	FOC-1, HAR-1, CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, TAR-1, TAR-2	FOC-1, MCC-1, ISL-1, SHL-1, HAR-1, BER-1, CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, POC-1, TAR-1, TAR-2
3. Athabasca River and Athabasca River delta	ATR-DC-CC, ATR-DC-CC-D, ATR-DC-E, ATR-DC-W, ATR-DC-M, ATR-UFM[2]	ATR-DC-E, ATR-DC-W, ATR-DC-CC, ATR-SR-E, ATR-SR-W, ATR-MR-E, ATR-MR-W, ATR-FR-CC, ATR-DD-E, ATR-DD-W

[1] See Table 3.2-8 for classification of station status by year. Where station status changed from reference to potentially influenced during 1997-2006, only baseline data were used to determine regional water quality characteristics.

[2] ATR-UFM data from the AENV dataset (1976-2004).

3.2.7.4 Tabular and Graphical Presentation of Results

Comparison to Water Quality Guidelines and Historical Data

Water quality data from fall 2006 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, at that station from 1997 to 2006. Concentrations of water quality variables that exceeded relevant guidelines were also reported.

Comparison to Natural Variation in Baseline Conditions

To allow a regional comparison, untransformed data from all baseline stations sampled by RAMP from 1997 to 2006 (fall only), for thirteen selected water quality measurement endpoints, were pooled from each cluster of similar stations (Table 3.2-10). Descriptive statistics describing natural water quality characteristics for each group were calculated; for each water quality cluster (Table 3.2-10), the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined for comparison against 2006 data. The number of observations for each of the thirteen selected water quality measurement endpoints varied by cluster (Table 3.2-12). 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 by presenting data for each station 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.

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). Piper diagrams were used to explore spatial differences and temporal changes in water quality.

Table 3.2-12 Number of observations for determination of baseline regional water quality.

Water Quality Measurement Endpoint	Number of observations (station-year combinations) for baseline regional water quality		
	Cluster 1	Cluster 2	Cluster 3
Total Suspended Solids (TSS)	98	36	66
Total Dissolved Solids (TDS)	98	36	30
Dissolved phosphorus	96	36	34
Total nitrogen	94	36	41
Total strontium	94	36	23
Total boron	95	36	29
Naphthenic acids	98	36	23
Calcium	95	36	23
Magnesium	95	36	23
Sodium	95	36	23
Potassium	95	36	23
Chloride	98	36	23
Sulphate	98	36	23

Trend Analysis

In addition to qualitative trend analysis using graphical means, statistical trend analysis was undertaken on water quality data for the Athabasca River, which has been monitored continuously by Alberta Environment since 1976. Trend analysis was undertaken on data from two stations: 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 (ARD), downstream of the Embarras River distributary. Trend analysis was conducted on data for the water quality measurement endpoints from the period of RAMP sampling (1997 to 2006), to assess trends potentially related to oil sands development during this time.

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, from which changes in water quality in the Athabasca River may be most likely expected. Therefore, for all other stations besides the three 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.

3.2.7.5 Additional Analyses

Winter Water Quality

RAMP has collected winter water quality data (December through March) with varying frequency in different watersheds since 1998, although sample collection in winter has frequently been impossible in some streams due to freezing of water to depth, particularly in smaller tributaries of the Athabasca River. Concerns were raised at the October 2006 RAMP Technical Program Committee meeting regarding the influence of *in situ* oil sands on groundwater and whether baseline winter water quality data had been collected with sufficient spatial scope and frequency to allow assessment of potential impacts in watersheds in which *in situ* projects were active. In response to these concerns, winter water quality data collected by RAMP were examined in those watersheds within the RAMP FSA that contain 2006 focal projects that are *in situ* oil sands operations; these are summarized below in Table 3.2-13.

The RAMP Technical Design and Rationale document (RAMP 2005b) summarized predictions made by environmental impact assessments for a number of oil sands developments. This summary of predictions was screened to determine specific issues and predictions related to winter water quality; however, no references specifically related to winter water quality data were found. Water quality predictions found in EIAs completed for *in situ* developments were related to: water quality variables related to ionic composition, including conductivity, total dissolved solids, alkalinity, and hardness; specific ions, including chloride, calcium, and magnesium; TSS; dissolved hydrocarbons; and general water quality.

Table 3.2-13 Summary of 2006 focal projects that are *in situ* oil sands operations.

Watershed	SAGD Oil Sands Development
Firebag River	Suncor Firebag
MacKay River	Petro-Canada Dover Vapex Pilot Petro-Canada MacKay River
Ells River	Deer Creek Joslyn SAGD
Steepbank River	Suncor Firebag
Muskeg River	Suncor Firebag
Clearwater-Christina	OPTI-Nexen Long Lake
Athabasca River	All of the above

From Table 2.2.1

Baseline winter data for these and other water quality variables, especially those with potentially significant groundwater associations (Section 3.2.7.1), were summarized in tables for the watersheds listed in Table 3.2-13. Summary data presented in these tables included the number of observations (n), the minimum and maximum observation, and the mean and coefficient of variation (CV) of the observations. Because the number of observations in all watersheds was low (n=1 to 6), descriptive statistics such as mean concentration and coefficient of variation should be interpreted with caution; these results are presented to provide some indication of variability over time at each station.

Baseline winter water quality data also were shown graphically for select water quality measurement endpoints, as described in Section 3.2.7.4. Where possible, data from stations within the same watershed were displayed on the same set of graphs to facilitate comparisons between stations. To provide context for winter concentrations relative to concentrations observed in other seasons, background shading corresponding to the 5th, 25th, 75th, and 95th percentile and median value of regional baseline fall concentrations are included. Fall concentrations for each station are also included on the graphs, and water quality guidelines are shown for relevant water quality variables.

Semi-Permeable Membrane Devices

In summer 2006, a pilot project using semi-permeable membrane devices (SPMDs) was implemented to explore the use of this technology for assessing levels of PAHs in RAMP rivers. SPMDs are sampling devices that mimic the bioconcentration of dissolved (potentially bioavailable) hydrophobic organic chemicals from aquatic ecosystems into the fatty tissue of organisms (Huckins *et al*. 2002). SPMDs consist of a segment of tubing containing a small amount of neutral lipid that accumulates nonpolar chemicals passing through the tubing membrane. These chemicals can then be extracted from the lipid and analyzed to provide data on organic contaminants in aquatic ecosystems. Because SPMDs are deployed in the field for days to months, they can provide a temporally integrated or time-weighted average concentration of the target chemicals (USGS 2004).

SPMDs were deployed for approximately four weeks (from the end of July to the end of August 2006) at three locations in the Muskeg River, representing a gradient of potential impacts of focal project activities on water quality. Upon retrieval from the river, SPMDs were shipped frozen to Environmental Sampling Technologies, Inc. (St. Joseph, Missouri) for extraction and clean-up. Laboratory analysis of parent and alkylated PAHs in the SPMD extract was conducted by AXYS Analytical Services in Sidney, B.C. Detailed methods and results are provided in Appendix D.

3.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

3.3.1 Benthic Invertebrate Community Component

3.3.1.1 Summary of 2006 Monitoring Activities

A total of 24 locations were sampled from 9 to 23 September 2006 for the Benthic Invertebrate Community component, comprising 20 river reaches and four lakes (Table 3.3-1, Figure 3.3-1). As in previous years, samples were collected in the dominant habitat type found in each reach (Table 3.3-1). Habitats were defined as being either depositional (dominated by fine sediment deposits and low to no current) or erosional (dominated by rocky substrates and frequent riffle areas). 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 (RAMP 2005b).

3.3.1.2 Summary of Field Methods and Sample Analysis

Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003a, RAMP 2005b). 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 grab was used, but the device was deployed using a rope and messenger from the surface.

In rivers, a total of 10 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

Figure 3.3-1 RAMP benthic invertebrate community and sediment quality sampling locations, 2006.

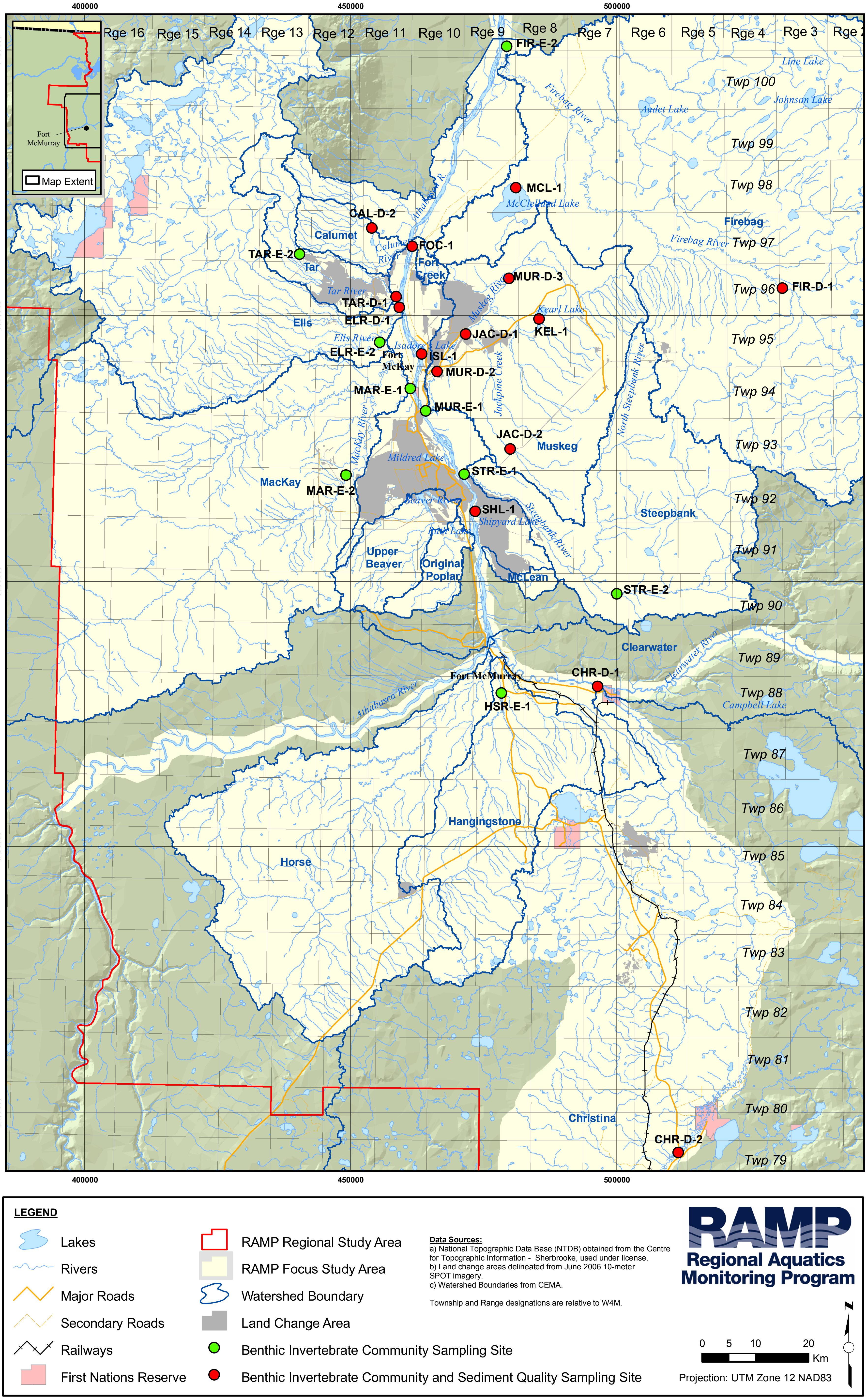


Table 3.3-1 Summary of sampling for the RAMP 2006 Benthic Invertebrate Community component.

Waterbody and Location	Habitat	Reach or Station	UTM Coordinates (NAD83, Zone 12)			
			Downstream Limit of Reach Sampled		Upstream Limit of Reach Sampled	
			Easting	Northing	Easting	Northing
Calumet River						
Upper reach	depositional[1]	CAL-D-2	453946	6366611	453930	636634
Christina River						
Lower Reach	depositional[1]	CHR-D-1	496458	6280200	497746	6278494
Upper Reach	depositional[1]	CHR-D-2	511620	6192391	510896	6192391
Ells River						
Lower Reach	depositional[1]	ELR-D-1	458760	6351600	459340	6351544
Upper Reach	erosional	ELR-E-2	455624	6344973	455129	6343613
Firebag River						
Lower Reach	depositional[1]	FIR-D-1	479342	6400412	479600	6397380
Upper Reach	erosional	FIR-E-2	531483	6354531	532083	6355087
Fort Creek						
Lower Reach	depositional[1]	FOC-1	461529	6363114	461559	6363096
Hangingstone River						
Lower Reach	erosional	HAR-E-1	478320	6278971	478141	6277633
Jackpine Creek						
Lower Reach	depositional[1]	JAC-D-1	471767	6346537	473013	6346268
Upper Reach	depositional[1]	JAC-D-2	480048	6325086	480789	6324249
MacKay River						
Lower Reach	erosional	MAR-E-1	461214	6336261	460464	6337497
Upper Reach	erosional	MAR-E-2	449198	6319902	448863	6318821
Muskeg River						
Lower Reach	erosional	MUR-E-1	463805	6332329	465206	6333179
Middle Reach	depositional[1]	MUR-D-2	466297	6339495	466589	6340499
Upper Reach	depositional[1]	MUR-D-3	480100	6357995	482143	6359808
Steepbank River						
Lower Reach	erosional	STR-E-1	471312	6320147	472617	6320288
Upper Reach	erosional	STR-E-2	500055	6297639	501195	6297645
Tar River						
Lower Reach	depositional[1]	TAR-D-1	458929	6353711	458672	6353574
Upper Reach	erosional	TAR-E-2	440584	6361040	439879	6362090
Lakes						
Kearl Lake	lake[1]	KEL-1	484753	6349944	484798	6349019
McClelland Lake	lake[1]	MCL-1	478202	6371301	477289	6369271
Shipyard Lake	lake[1]	SHL-1	473370	6313483	473531	6313395
Isadore's Lake	lake[1]	ISL-1	463295	6343035	463749	6343421

[1] Sediment quality sampling was conducted at these sites.

availability and approximately equal spacing. In lakes (i.e., Shipyard Lake, Kearl Lake, McClelland Lake, Isadores Lake), a total of 10 replicate samples were randomly selected from littoral areas based on a controlled depth range (0.5 to 3 m). Samples collected at depositional stations were sieved in the field using a 250-µm screen, preserved in 10% buffered formalin, and bottled for transport.

A series of physical measurements were recorded as supporting information from each replicate station:

- 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 – determined by measuring the time for a semi-submerged object to travel a known distance (2 m);
- Water depth at the benthic sample location – measured with a graduated device (pole or Hess cylinder);
- Amount of benthic algae at erosional stations (for chlorophyll *a* measurement) – obtained 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.

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. ALS Laboratory Group (ALS) conducted all laboratory analyses.

Dr. Jack Zloty in Summerland, BC, performed sorting and taxonomic identifications, as in previous years. 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 sub-sampled 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. Quality assurance and quality control (QA/QC) procedures related to benthic invertebrate sample processing are presented in Appendix B.

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

3.3.1.3 Changes in Monitoring Network from 2005

While there were plans to conduct benthic invertebrate community monitoring in the Athabasca River Delta (ARD) in 2006, very low water levels during the fall benthic invertebrate community sampling campaign made it impossible to access and collect any benthic invertebrate community samples in the ARD in 2006.

Only two samples instead of the ten samples usually taken in a stream reach could be collected from the lower erosional reach of the Muskeg River (MUR-E-1) because of unusually high flows during the field sampling campaign for the Benthic Invertebrate Community component. Water levels in riffles in the reach being sampled were almost always higher than the Neill-Hess sampler during the field sampling campaign, thereby making complete field sampling impossible.

The Sediment Quality component was harmonized with the Benthic Invertebrate Community component in 2006, with sediment samples being collected from the most downstream benthic station in depositional reaches (Section 3.3.2).

3.3.1.4 Challenges Encountered and Solutions Applied

In 2006, flow velocities were measured by determining the time for a semi-submerged object to pass a known distance (2 m). This approach was in contrast to previous years in which flow measurements were collected using electronic flow meters. The new, simpler approach to monitoring flow velocity was considered suitable for the purposes of the Benthic Invertebrate Community component because:

- Electronic devices had at times failed in previous years, providing incomplete datasets;
- The objective of flow velocity monitoring in the Benthic Invertebrate Community component is to provide an variable that could potentially explain some of the variation in indices of benthic invertebrate community composition, rather than to provide a detailed hydrologic measure of volume; and
- Field trials of the new method conducted in previous years had found a generally reasonable agreement between the two methods.

3.3.1.5 Other Information Obtained

No additional or supplementary information was obtained as part of the 2006 Benthic Invertebrate Community component.

3.3.1.6 Summary of Component Data Now Available

As of 2006, 1,605 benthic invertebrate community samples have been collected under RAMP. The distribution of stations and reaches and the time-series of data available are presented in Table 3.3-2. At least three years of data have been collected for each watershed in the RAMP FSA.

3.3.1.7 Analytical Approach and Methods

The analytical approach used in 2006 for the Benthic Invertebrate Community component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2005b) and consisted of:

- Selecting benthic invertebrate community measurement endpoints;

- Developing criteria to be used in detecting changes in benthic invertebrate community measurement endpoints; and
- Detailed data analysis, consisting of:
    - Analysis of variance testing for differences between upstream reference and downstream exposure reaches, and/or differences in time trends; and
    - Calculation of normal ranges of variability for indices of benthic community composition, and comparison of data from exposure reaches to determine how the communities compared to the natural background variability.

Selection of Benthic Invertebrate Community Measurement Endpoints

The following benthic invertebrate community measurement endpoints were calculated for each sample:

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

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

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

- Evenness, where

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

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

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

- Percent EPT taxa (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.

3.3.1.8 Criterion for Determining Effects

The criterion used for determining effects of focal projects on benthic invertebrate communities was whether or not the benthic invertebrate community measurement endpoints in a given site (i.e., river reaches and lakes) that is designated as *potentially influenced* exceed regional baseline conditions. The determination of regional baseline conditions is described below.

3.3.1.9 Detailed Data Analysis

Determination of Regional Baseline Conditions

An ordination (Correspondence Analysis [CA]) of the data was conducted to identify natural groupings of reaches among all the reaches that were designated as *reference* (Table 3.3-2). The technical aspects of the CA are documented in Appendix E; the main results are as follows:

- Depositional and erosional habitats grouped well in the analysis (RAMP 2005b) and justified the calculation of "normal ranges" for each of the benthic community indices for erosional and depositional reaches; and
- Neither bankfull width nor stream slope explained large amounts of variation in the benthic invertebrate community endpoints with the exception of a multivariate descriptor on the first CA axis.

On the basis of the results of the CA analysis, therefore, habitat type (i.e., erosional versus depositional) was used as the natural grouping on which regional baseline conditions were calculated.

Regional baseline conditions were defined as the normal range of variability for the measurement endpoints across all *reference* sites. The normal range of variability for the measurement endpoints was calculated as the mean value of the measurement endpoint (for a given habitat type) ± 2 standard deviations of the measurement endpoint values. These calculations were made separately for each measurement endpoint and for each habitat type.

Effects of Focal Projects on Benthic Invertebrate Communities

Possible effects of focal projects were evaluated by comparing benthic invertebrate community measurement endpoints in reaches designated as *potentially influenced* to upstream *reference* reaches and/or to pre-development conditions with analysis of variance (ANOVA). When necessary, the measurement endpoints were $\log_{10}$-transformed to meet assumptions of normality and homogeneity of variances. One-way ANOVAs were conducted for each benthic invertebrate community measurement endpoint with each reach-year combination as the factorial variable. Planned linear orthogonal contrasts (Hoke *et al*., 1990) were then used to identify differences between *reference* and *potentially influenced* reaches, between baseline and operational periods, and differences in time trends between lower *potentially influenced* reaches and upper *reference* reaches. Differences between *reference* reaches and reaches designated as *potentially influenced* were also evaluated for data collected in 2006 only. In all cases, the comparisons were tested against the residual error of the overall one-way ANOVA.

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

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

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
				W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Delta																																											
Athabasca River Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1				
Calumet River																																											
Lower Reach	1,2[1]	depositional	CAL-D-1																				2				1				1				1				1				
Upper Reach	1	depositional	CAL-D-2																												1				1				1				1,2
Christina River																																											
Lower Reach	1	depositional	CHR-D-1																								1				1				1				1				1,2
Upper Reach	1	depositional	CHR-D-2																								1				1				1				1				1,2
Clearwater River																																											
Downstream of Christina River	1	depositional	CLR-D-1																				1				1				1				1				1				
Upstream of Christina River	1	depositional	CLR-D-2																				1				1				1				1				1				
Ells River																																											
Lower Reach	1	depositional	ELR-D-1																												1				1				1				1,2
Upper Reach	1	erosional	ELR-E-2																												1				1				1				1
Firebag River																																											
Lower Reach	1	erosional	FIR-D-1																												1				1				1				1,2
Upper Reach	1	depositional	FIR-E-2																												1				1				1				1
Fort Creek																																											
Lower Reach	1[2]	depositional	FOC-D-1												2								1				1				1												1,2
Hangingstone River																																											
Lower Reach	1	erosional	HAR-E-1																																1				1				1
Jackpine Creek																																											
Lower Reach	1	depositional	JAC-D-1																								1				1				1				1				1,2
Upper Reach	1	depositional	JAC-D-2																												1				1				1				1,2
MacKay River																																											
Lower Reach	1	erosional	MAR-E-1																1				1				1				1				1				1				1
Upper Reach	1	erosional	MAR-E-2																								1				1				1				1				1
Muskeg River																																											
Lower Reach	1	erosional	MUR-E-1																1				1				1				1				1				1				1
Middle Reach	1	depositional	MUR-D-2																1				1				1				1				1				1				1,2
Upper Reach	1	depositional	MUR-D-3																								1				1				1				1				1,2
Steepbank River																																											
Lower Reach	1	erosional	STR-E-1																1				1				1				1				1				1				1
Upper Reach	1	erosional	STR-E-2																												1				1				1				1
Tar River																																											
Lower Reach	1[1]	depositional	TAR-D-1																				2				1				1				1				1				1,2
Upper Reach	1	erosional	TAR-E-2																												1				1				1				1

Type Legend:

1 = RAMP site

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

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

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

potentially influenced

reference

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

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

Table 3.3-2 (cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
				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
Wetlands and Lakes																																											
Isadore's Lake	1	lake	ISL-1																																								1,2
Kearl Lake	1	lake	KEL-1																				1				1				1				1				1				1,2
McClelland Lake	1	lake	MCL-1																								1				1												1,2
Shipyard Lake	1	lake	SHL-1																1				1				1				1				1				1				1,2
Historical Data																																											
Historical Data Review																1	1	1	1					1	1	1	1																
5-Year Summary Report																																											
Summary Report																								1	1																		
Locations No Longer in Sample Design																																											
Athabasca River																																											
Near Fort Creek (east bank)	1	depositional	ATR-B-A1 to A3				1																																				
(west bank)	1	depositional	ATR-B-A4 to A6				1																																				
Near Donald Creek (east bank)	1	depositional	ATR-B-B1 to B3				1																																				
(west bank)	1	depositional	ATR-B-B4 to B6				1																																				
Suncor near-field monitoring	2	depositional	-																				2																				
MacKay River																																											
200 m upstream of mouth	1	erosional	MAR-1								1																																
500 m upstream of mouth	1	erosional	MAR-2								1																																
1.2 km upstream of mouth	1	erosional	MAR-3								1																																
Muskeg River																																											
50 m upstream of mouth	1	erosional	MUR-1								1																																
200 m upstream of mouth	1	erosional	MUR-2								1																																
450 m upstream of mouth	1	erosional	MUR-3								1																																
Steepbank River																																											
50 m upstream of mouth	1	erosional	STR-1								1																																
150 m upstream of mouth	1	erosional	STR-2								1																																
300 m upstream of mouth	1	erosional	STR-3								1																																

Type Legend:

1 = RAMP site

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

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

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

potentially influenced

reference

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

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

3.3.1.10 Environmental Variables

A number of environmental variables, including physical substrate condition and water temperature, chemistry, and flow velocities, were measured at each site. These environmental variables were measured because they fundamentally influence the kinds of benthic invertebrate fauna found at a site. Where benthic invertebrate communities are shown to vary over time in a manner consistent with the development of focal projects, the variation may be attributed to changes in one or more of these environmental variables. While no attempt was made to relate observed variation in benthic invertebrate community measurement endpoints to variation in these environmental variables in a general sense across the 2006 benthic invertebrate community dataset, an examination of these potential associations was made if the criteria for determination of effect in benthic invertebrate communities (Section 0) were met.

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

- Dissolved oxygen is typically above concentrations considered critical for the protection of aquatic life (5.5 mg/L for warm-water biota; CCME, 2006). Concentrations below this guideline are indicative of potential risks to aquatic life, especially if those concentrations are observed during the day, which is the typical time of sampling for RAMP;

- Chlorophyll *a*, one of the environmental variables measured in erosional reaches was identified early in the AOSERP studies as a potential indicator of oil sands activity (Barton and Lock, 1979). Chlorophyll *a* can also be used to classify the nutrient status of a stream; for this report, concentrations of chlorophyll *a* below 70 mg/m^2, between 70 and 200 mg/m^2, and greater than 200 mg/m^2 are used to define oligotrophic, mesotrophic, and eutrophic conditions, respectively (from Dodds *et al.* 1998). In addition, the limits of the normal range of chlorophyll *a* values from reference reaches was determined (Appendix E) and is also provided in figures that illustrate trends over time in chlorophyll *a* values; and

- Differences in the conductivity of water among reaches can be used to infer differences in the overall water quality in those reaches.

3.3.2 Sediment Quality Component

3.3.2.1 Overview of 2006 Monitoring Activities

The Sediment Quality component was integrated with the Benthic Invertebrate Community component in 2006 in order to focus on depositional areas of sediment accumulation and to collect physical and chemical data that could be used to support the interpretation of benthic invertebrate community data. This shift in focus resulted from a decision of the RAMP Technical Program Committee in March 2006.

Sediment samples were collected from 6 to 23 September 2006 at the most downstream replicate sampling location in each depositional reach sampled for benthic invertebrate communities (total of eleven depositional reaches), as well as four regionally-important lakes and wetlands (Table 3.3-3, Figure 3.3-1). No sediment samples were collected in erosional reaches or in the Athabasca River mainstem.

3.3.2.2 Summary of Field Methods and Sample Analysis

Sediment sampling locations were identified from historical GPS coordinates recorded for benthic invertebrate community sampling locations or written descriptions from previous reports. Stations were accessed by helicopter, jet boat, or four-wheel drive vehicle.

At each station, sediment grabs were collected with a 6″ x 6″ Ekman dredge (0.023 m^2). Grab samples were transferred to a stainless steel pan; once sufficient sediment had been 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 cleaned with a metal-free soap (i.e., Liquinox), rinsed with hexane and acetone, and triple-rinsed with ambient water at each station prior to sampling.

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

Samples were shipped to analytical laboratories via Greyhound, Red Arrow, Purolator, or through the ALS Laboratory Group, Analytical Chemistry and Testing Services (ALS) drop-off depot in Fort McMurray. All chemical and physical (e.g., particle size, TOC) analyses were conducted by ALS (Edmonton, Alberta) except polycyclic aromatic hydrocarbons (PAHs), which were analyzed by AXYS Analytical Services Ltd. (AXYS; Sidney, British Columbia). Evaluation of sediment toxicity was undertaken by HydroQual Laboratories Ltd. (HydroQual; Calgary, Alberta).

Sediments were analyzed for the RAMP standard variables as well as sediment toxicity to aquatic organisms at all locations sampled (Table 3.3-4).

3.3.2.3 Changes in Monitoring Network from 2005

As indicated above, sediment quality monitoring in 2006 differed substantially from previous years:

- Sediment samples were collected at the most downstream benthic invertebrate community replicate sampling location, rather than at historical sediment sampling locations;
- Sediment sampling in erosional reaches was eliminated; and
- All sediment samples that were collected were assessed for sediment toxicity as well as being analyzed for the RAMP standard sediment quality variables in order to establish a new set of baseline data.

While there were plans to conduct benthic invertebrate community monitoring in the Athabasca River Delta (ARD) in 2006, very low water levels during the fall benthic invertebrate community sampling campaign made it impossible to access and collect any benthic invertebrate community samples in the ARD in 2006 and; therefore, no sediment sampling was conducted in the ARD in 2006.

Table 3.3-3 Summary of sediment quality sampling for RAMP, September 2006.

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12) Easting	Northing	Analytical Package
Tributaries to the Athabasca River (Eastern)				
FIR-D-1	Firebag River (lower reach)	479342	6400412	3
FOC-D-1	Fort Creek (lower reach)	461529	6363114	3
Tributaries to the Athabasca River (Western)				
CAL-D-2	Calumet River (upper reach)	453946	6366611	3
TAR-D-1	Tar River (lower reach)	458929	6353711	3
ELR-D-1	Ells River (lower reach)	458760	6351600	3
Tributaries to the Athabasca River (Southern)				
CHR-D-1	Christina River (lower reach)	496458	6280200	3
CHR-D-2	Christina River (upper reach)	511620	6192391	3
Muskeg River				
MUR-D-2	Muskeg River (middle reach)	466297	6339495	3
MUR-D-3	Muskeg River (upper reach)	480100	6357995	3
JAC-D-1	Jackpine Creek (lower reach)	471767	6346537	3
JAC-D-2	Jackpine Creek (upper reach)	480048	6325086	3
Regional Lakes				
KEL-1	Kearl Lake	484753	6349944	3
MCL-1	McClelland Lake	478202	6371301	3
SHL-1	Shipyard Lake	473370	63134483	3
ISL-1	Isadore's Lake	463295	6343035	3
QA/QC				
-	Two sets of split and duplicate samples			1
-	Two rinsate blanks			Metals, PAHs

Legend to Analytical Packages:

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

Table 3.3-4 RAMP sediment quality variables analyzed in 2006.

Group	Sediment quality Variable	
Physical variables	Percent sand	Percent clay
	Percent silt	Moisture content
Carbon content	Total inorganic carbon	
	Total organic carbon	
	Total carbon	
Total metals	Aluminum	Manganese
	Arsenic	Mercury
	Barium	Molybdenum
	Beryllium	Nickel
	Boron	Potassium
	Cadmium	Selenium
	Calcium	Silver
	Chromium	Sodium
	Cobalt	Strontium
	Copper	Thallium
	Iron	Uranium
	Lead	Vanadium
	Magnesium	Zinc
Organics	CCME 4-fraction total hydrocarbons:	
	- BTEX (Benzene, Toluene, Ethylene, Xylene)	
	- F1 (C6-C10)	
	- F2 (C10-C16)	
	- F3 (C16-C34)	
	- F4 (C34-C50)	
	- Total hydrocarbons (C6-C50)	
Target PAHs	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Dibenzothiophene
	Anthracene	Fluoranthene
	Benzo(a)anthracene/chrysene	Fluorene
	Benzo(a)pyrene	Indeno(c,d-123)pyrene
	Benzofluoranthenes	Naphthalene
	Benzo(g,h,i)perylene	Phenanthrene
	Biphenyl	Pyrene
Alkylated PAHs	C1-substituted acenaphthene	C1-substituted fluorene
	C1-substituted benzo(a)anthracene/chrysene	C2-substituted fluorene
	C2-substituted benzo(a)anthracene/chrysene	C3-substituted fluorene
	C1-substituted biphenyl	C1-substituted naphthalenes
	C2-substituted biphenyl	C2-substituted naphthalenes
	C1-substituted benzofluoranthene/ benzo(a)pyrene	C3-substituted naphthalenes
	C2-substituted benzofluoranthene/benzo(a)pyrene	C4-substituted naphthalenes
	C1-substituted dibenzothiophene	C1-substituted phenanthrene/anthracene
	C2-substituted dibenzothiophene	C2-substituted phenanthrene/anthracene
	C3-substituted dibenzothiophene	C3-substituted phenanthrene/anthracene
	C4-substituted dibenzothiophene	C4-substituted phenanthrene/anthracene
	C1-substituted fluoranthene/pyrene	1-methyl-7-isopropyl-phenanthrene (retene)[1]
	C2-substituted fluoranthene/pyrene	
	C3-substituted fluoranthene/pyrene	
Sublethal toxicity testing	Survival and growth of the amphipod *Hyalella azteca*	
	Survival and growth of *Chironomus tentans* midge larvae	

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

3.3.2.4 Challenges Encountered and Solutions Applied

Sediment samples for each depositional reach were originally planned as reach composites—that is, a small amount of sediment from each benthic invertebrate community replicate location would be collected and the composited sample submitted for analysis. This approach was found to be impractical to implement in the field due to the large amount of sediment required to be carried up down the reach. Instead, sediment samples were collected at the most downstream benthic replicate locations. However, both reach composites and downstream sediment samples were collected for three reaches. Data from these two types of samples were compared in order to determine if there were notable differences in sediment quality between the two types of sampling methods (Appendix F).

Particle size analysis was not possible at reach MUR-D-3 because of the high organic matter in the sediments collected at that reach.

3.3.2.5 Other Information Obtained

No additional sediment quality data for 2006 were obtained.

3.3.2.6 Summary of Component Data Now Available

Table 3.3-5 summarizes historical sediment quality sampling undertaken by RAMP since 1997. The RAMP sediment quality dataset now contains over 20,000 sediment quality observations collected between 1997 and 2006.

3.3.2.7 Analytical Approach

The analytical approach undertaken for the Sediment Quality component in 2006 differed from that of previous years, although some elements of the previous analytical approach were retained. The RAMP 2006 sediment quality analysis consisted of:

- Selecting particular sediment quality variables as sediment quality measurement endpoints, including predicted toxicity of sediments due to PAHs (calculated using an equilibrium-partitioning model);
- Tabular presentation of 2006 results comparing 2006 concentrations of the sediment quality measurement endpoints to concentrations previously observed within the reach, where data were available, as well as CCME sediment quality guidelines; and
- Analyzing the relationship between various sediment quality measurement endpoints and benthic invertebrate metrics, using correlation analysis.

Selection of Sediment Quality Measurement Endpoints

A subset of variables measured by the Sediment Quality component of RAMP was selected as the set of sediment quality measurement endpoints for tabular presentation of 2006 sediment quality results as well as for analysis of correlation with benthic invertebrate community measurement endpoints. The sediment quality measurement endpoints were chosen with guidance from:

- Sediment quality measurement endpoints listed in the EIAs of oil sands projects as being potentially affected by oil sands development activities (RAMP 2005b);
- Sediment quality variables of interest listed in the RAMP 5-year report (Golder 2003a);

Table 3.3-5 Summary of RAMP data available for the Sediment Quality component.

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca Delta / Lake Athabasca																																									
Comprehensive Delta Sampling[a]																																					1				
Delta composite[b]	ARD-1											3					3																								
Big Point Channel	BPC																				3				3				3												
Flour Bay	FLB-1																3																								
Fletcher Channel	FLC																				3				3				3												
Goose Island Channel	GIC																				3				3				3												
Athabasca River																																									
Athabasca River upstream of Donald Creek (east bank)[c]	ATR-DC-E				3				3								1				3				1				3				1				1				
Athabasca River upstream of Donald Creek (west bank)[c]	ATR-DC-W				3				3								1				3				1				3				1				1				
Athabasca River downstream of all development (east bank)	ATR-DD-E																								1				3				1				1				
Athabasca River downstream of all development (west bank)	ATR-DD-W																								1				3				1				1				
Athabasca River upstream of the Embarras River (cross channel)	ATR-ER																3				1				1				3				1				1				
Athabasca River upstream Fort Creek (east bank)[c d]	ATR-FC-E				3				3								1				3				1				3												
Athabasca River upstream Fort Creek (west bank)[c d]	ATR-FC-W				3				3								1				3				1				3												
Athabasca River upstream of mouth of Firebag River (east bank)	ATR-FR-E																								1				3				1				1				
Athabasca River upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1				1				
Athabasca River upstream of the Muskeg River (east bank)[c d]	ATR-MR-E								3								1				3				1				3				1				1				
Athabasca River upstream of the Muskeg River (west bank)[c d]	ATR-MR-W								3								1				3				1				3				1				1				
Athabasca River upstream of the Steepbank River (east bank)	ATR-SR-E																1				3				1				3				1				1				
Athabasca River upstream of the Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1				1				
Athabasca River upstream of Fort McMurray (monthly)	ATR-UFM																								1				3				1				1				
Athabasca River Tributaries (North of Fort McMurray)																																									
Calumet River (mouth)	CAR-1																								3								3								
Calumet River (upper river)	CAR-2																																				3				
Ells River (mouth)	ELR-1								1																3				3				3				1				
Ells River (upstream)	ELR-2																																3				1				
Firebag River (mouth)	FIR-1																								3				3				1				1				
Firebag River upstream of Suncor Firebag	FIR-2																								3				3				1				1				
Fort Creek (mouth)	FOC-1																1				1				3																
MacKay River (mouth)	MAR-1				1				1												3				3								3								
MacKay River upstream of Petro-Canada MacKay	MAR-2																				1				3								3								
McLean Creek (mouth)	MCC-1												3				3				1				3												3				
North Steepbank River	NSR-1																								3				3				1				1				
Poplar Creek (mouth)	POC-1				1																				3								3								
Steepbank River (mouth)	STR-1				1				1																3												3				
Steepbank River upstream of Suncor Millennium	STR-2				1																				3												3				
Steepbank River upstream of North Steepbank River	STR-3																																				3				
Tar River (mouth)	TAR-1								1																3				3				1				1				
Tar River upstream of CNRL Horizon	TAR-2																																1				1				
Athabasca River Tributaries (South of Fort McMurray)																																									
Christina River upstream of Fort McMurray	CHR-1																								1				3				3								
Christina River upstream of Janvier	CHR-2																								1				3				3								
Clearwater River upstream of Fort McMurray	CLR-1																				1				3				3												
Clearwater River upstream of Christina River	CLR-2																				1				3				3												
Hangingstone River upstream of Fort McMurray	HAR-1																																3				3				
Muskeg River																																									
Muskeg River (mouth)	MUR-1				1				1				3				1				1				3				3				3								
1 km upstream of mouth	MUR-1b																1												1												
Muskeg River upstream of Canterra Road crossing	MUR-2																1								3				3				3								
Muskeg River upstream of Jackpine Creek	MUR-4				1												1												1												
Muskeg River upstream of Muskeg Creek	MUR-5																1												1												
Muskeg River upstream of Wapasu Creek	MUR-6																1												1												
Muskeg River upstream of Stanley Creek	MUR-D2																								3				3				3								
Muskeg River Tributaries																																									
Jackpine Creek (mouth)	JAC-1				1																												3								
Stanley Creek (mouth)	STC-1																												1												
Benthic Invertebrate Community Component Sampling Locations																																									
Firebag River (lower reach)	FIR-D-1																																								3
Fort Creek	FOC-D-1																																								3
Calumet River (upper reach)	CAL-D-2																																								3
Tar River (lower reach)	TAR-D-1																																								3
Ells River (lower reach)	ELR-D-1																																								3
Christina River (lower reach)	CHR-D-1																																								3
Christina River (upper reach)	CHR-D-2																																								3
Muskeg River (middle reach)	MUR-D-2																																								3
Muskeg River (upper reach)	MUR-D-3																																								3
Jackpine Creek (lower reach)	JAC-D-1																																								3
Jackpine Creek (upper reach)	JAC-D-2																																								3
Wetlands and Lakes																																									
Isadore's Lake (composite)	ISL-1																				1																				3
Kearl Lake (composite)	KEL-1																				1												1								3
McClelland Lake (composite)	MCL-1																								1																3
Shipyard Lake (composite)	SHL-1																				1				3				1				3								3
Additional Sampling (Non-Core Programs)																																									
Potential TIE	-																				√																				
Testing inter-site variability (3 comp. samples)	-																1								1																
QA/QC																																									
One split and one duplicate sample	-																1				1				1				1				1				1				1

Legend

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

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

3 = standard sediment quality variables + toxicity testing

potentially influenced (blue)

reference (green)

Footnotes

[a] includes: ATR-OF (Athabasca River at Old Fort); ARD-2 (Athabasca River Delta); BEC (Big Eddy Channel); JFC (Jackfish Creek); EMR-1 (Embarras River [upper]); EMR-2 (Embarras River); CRC (Cree Creek); BPC (Big Point Channel); BPC-2 (Big Point Channel [upper]); FLC (Fletcher Channel); GIC (Goose Channel)

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

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

[d] Samples were collected downstream of tributary in 1998

√ = allowance made for potential TIE

- Results of correlation analysis of the RAMP 1997-2004 sediment quality dataset indicating significant inter-correlation of various variables;
- Discussions among RAMP Component Managers about the importance of various sediment quality variables in interpreting results of other RAMP components, particularly the Benthic Invertebrate Community component and the Fish Population component; and
- Discussions with RAMP Technical Program Committee regarding appropriate analytical strategies for the Sediment Quality component.

Table 3.3-6 presents variables listed from 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 chemical sorption;
- *Total organic carbon*: an indicator of organic matter in sediment, including hydrocarbons;
- *Total hydrocarbons (CCME fractions)*: Indicators of the total hydrocarbon content of sediments, with each indicator capturing hydrocarbon compounds of different molecular weights (specifically, number of carbon atoms);
- *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 (LMW) 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 (HMW) PAHs: a sum of concentrations of all PAHs with 4 to 6 benzene rings (including parent and alkylated forms) measured in a given sample;
  - Naphthalene: 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 (the methodology for calculating predicted PAH toxicity is presented in Appendix F);
- *Metals:* Only metals in sediment that exceeded CCME Interim Sediment Quality Guideline (ISQG) values (CCME 1999b) were presented, as metals in sediments are not listed in oil sands EIAs as being potentially affected by development (RAMP 2005b); and
- *Sublethal toxicity:* sublethal toxic effects of sediment on the survival and growth of *Hyalella azteca* or *Chironomus tentans*.

Table 3.3-6 Potential sediment quality measurement endpoints.

Group	EIA Review: Variables Listed in EIAs (No. of projects)	RAMP 5-year Report (Golder 2003a)	Variables to Support other RAMP Components[1]	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
Metals	(None)	Total metals	Total metals	(Metals that are high relative to sediment quality guidelines)
PAHs	General PAHs (4)	Naphthalene C1 Naphthalene	Total PAHs LMW PAHs (parent+alkylated)	LMW PAHs HMW PAHs Naphthalene Dibenzothiophenes Retene
Effects-based endpoints	Sublethal toxicity (1)		Sublethal toxicity	

[1] Primarily benthic invertebrate communities and fish populations (inferred).

3.3.2.8 Tabular Presentation of 2006 Sediment Quality Results

2006 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 2005 if there was a historically sampled station within the reach. Concentrations of any sediment quality measurement endpoint that exceeded relevant guidelines were reported in the tables.

3.3.2.9 Correlation with Benthic Invertebrate Metrics

Spearman's rank correlations were used to evaluate the relationship between benthic invertebrate community measurement endpoints and selected sediment quality measurement endpoints. Correlations of $r_s > |0.412|$ were indicative of statistically significant relationships for n=15 (number of depositional stations) (α=0.10, two-tailed test). Moderate correlations were defined as those with r_s between $|0.50|$ and $|0.75|$, while strong correlations were defined as those with r_s between $|0.75|$ and $|1.00|$. More detailed methods and results are provided in Appendix F.

3.4 FISH POPULATION COMPONENT

3.4.1 Overview of 2006 Monitoring Activities

The following monitoring studies were undertaken as part of the Fish Population component in 2006:

- Fish inventories on the Athabasca and Clearwater rivers (spring and fall sampling for both rivers);
- Tissue collection and chemical analysis for target fish species in the Clearwater River (fall sampling);
- Full-span fish fence program on the Muskeg River (spring);
- Sentinel fish species program using non-lethal sampling methods on the following Athabasca River tributaries: Muskeg, Steepbank, Horse and Dunkirk rivers (summer and fall sampling); and
- Sentinel fish species reconnaissance program (using non-lethal sampling methods) on the MacKay River (summer and fall sampling).

Table 3.4-1 lists the watercourses sampled and the target fish species for each of these monitoring studies, while 2006 sampling locations are presented in Figure 3.4-1. Common and scientific names for each fish species noted in this report are listed in Appendix G.

3.4.2 Summary of Field Methods

3.4.2.1 Athabasca River and Clearwater River Fish Inventories

In 2006, spring and fall inventories of the RAMP key indicator fish species were carried out on the Athabasca and Clearwater rivers. RAMP key indicator fish species (analogous to Key Indicator Resources, KIRs) that were the focus of this study were:

- Walleye (*Stizostedion vitreum*);
- Northern pike (*Esox lucius*);
- Longnose sucker (*Catostomus catostomus*);
- Lake whitefish (*Coregonus clupeaformis*);
- Goldeye (*Hiodon alosoides*); and
- Trout-perch (*Percopis omyscomaycus*).

Lake whitefish was excluded from some of the Athabasca fish inventory analyses due to field collection limitations associated with the species and biased sampling associated with the fall spawning run of this species.

Table 3.4-1 Summary of Fish Population component monitoring studies in 2006.

Watercourse	Fish Population Component Activity			
	Fish Fence	Fish Inventory	Fish Tissue	Sentinel Species
Athabasca River		spring and fall, fish community		
Clearwater River		spring and fall, fish community	fall, northern pike	
Muskeg River	spring, fish community			
Muskeg, Steepbank, Horse and Dunkirk rivers				summer and fall, slimy sculpin
MacKay River				summer and fall, reconnaissance

Spring sampling was conducted from 8 to 27 May, 2006. The survey focused primarily on the Athabasca River (8 days of effort), with a secondary effort on the Clearwater River (2 days of effort). Fall sampling was conducted from 11 to 29 September, 2006. This survey included six days of effort on the Athabasca River and three days on the Clearwater River. The locations of the 2006 Athabasca River fish inventories were in ten reaches of the Athabasca River specifically established by RAMP for the inventory program, a number of which have been sampled continuously since 1989 (i.e., pre-RAMP) (Figure 3.4-1, Table 3.4-2):

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

Sampling in the Clearwater River was conducted at three locations during the spring and fall sampling efforts (Figure 3.4-1, Table 3.4-2). Fish captured during the Clearwater River inventory were also used to support fish tissue monitoring studies (Section 3.4.2.2).

An effort was made in 2006 to enumerate all stunned fish, regardless of species or size, during the first 300 seconds of sampling in each river reach in order to enhance the scientific rigor of fish inventory monitoring studies. The basis for standardizing effort transects were:

- Variability observed in catch-per-unit effort results could be evaluated;
- The likelihood of change detection over time is increased;
- A more informed basis for a regular study design review is possible; and
- More efficient sampling programs, particularly on the Clearwater River, can be developed using information gathered on the basis of standardized measure of effort.

Figure 3.4-1 Location of sampling areas used for fish inventory, fish tissue, fish fence, and sentinel species monitoring studies in the RAMP Fish Population component, 2006.

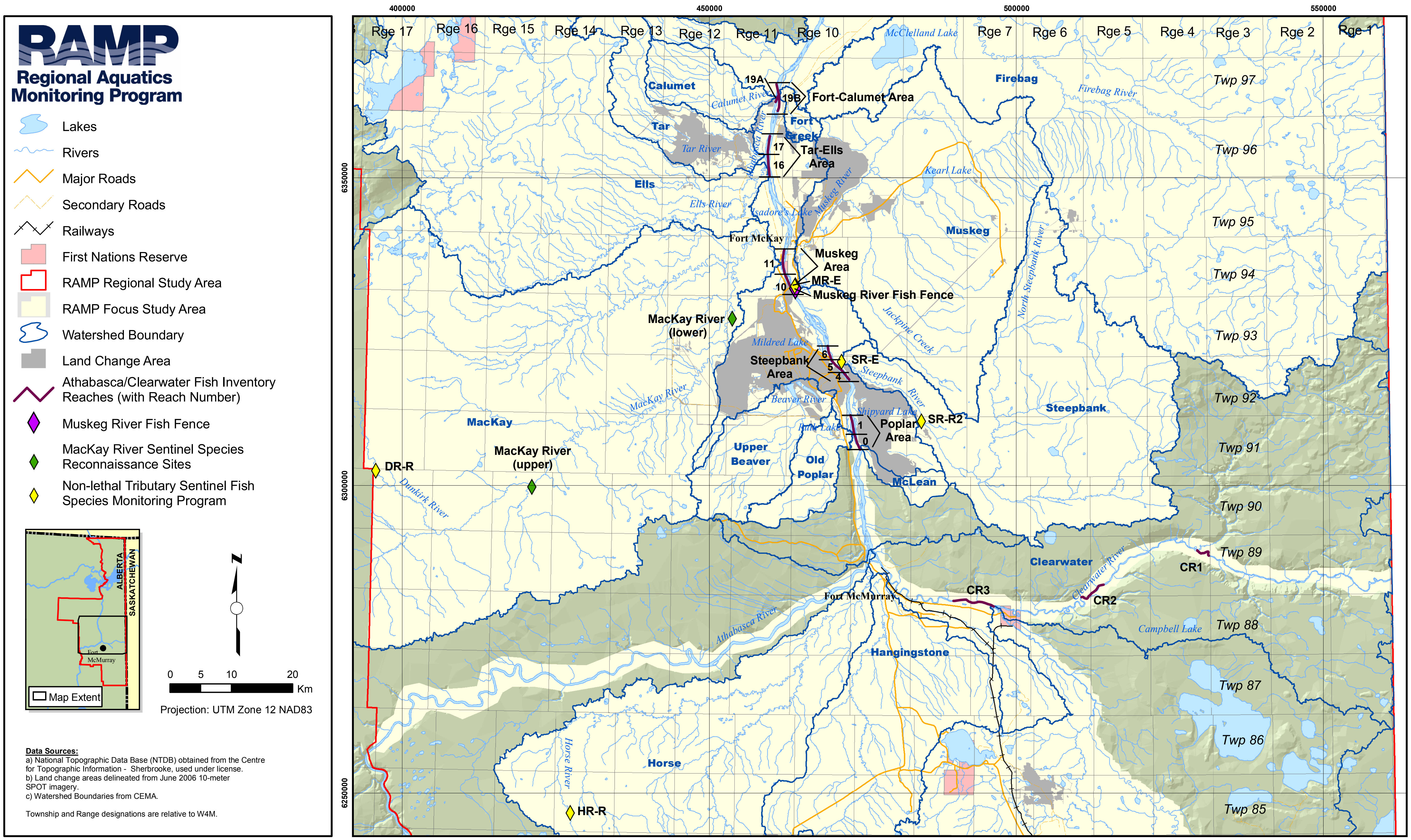


Table 3.4-2 Fish inventory sampling areas for Athabasca and Clearwater rivers, 2006.

Area	Reach Numbers	UTM Coordinates (NAD 83, Zone 12)	
		Upstream Boundary	Downstream Boundary
Athabasca River			
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	464129 E / 6331061 N	462060 E / 6338435 N
Tar-Ells Area	16 and 17	459859 E / 6350353 N	459913 E / 6356845 N
Fort-Calumet Area	19A	460824 E / 6362377 N	461417 E / 6363621 N
	19B	461181 E / 6360892 N	460999E / 6365205 N
Clearwater River	CR1	527711 E / 6290586 N	489943 E / 6281368 N
	CR2	514251 E / 6283905 N	510636 E / 6281851 N
	CR3	496363 E / 6280331 N	489812 E / 6281153 N

3.4.2.2 Clearwater River Fish Tissue Studies

Fish Collection and Sampling

Clearwater River tissue sampling studies in 2006 targeted northern pike. Fish sacrificed for tissue analysis were acquired from a sub-sample of fish captured during the fall Clearwater River inventory program (Section 3.4.2.1). Captured fish selected for tissue sampling were transferred to an onshore portable sampling station. All fish were held in coolers prior to dissection. Each fish underwent an external health assessment prior to dissection, and was measured for fork length (± 1.0 mm) and total weight (± 1.0 g). Tissue sampling was conducted for two types of analysis, as described below.

Tissue Analysis for Mercury A target of 25 northern pike was set for mercury tissue analysis, with specific targets of five fish, irrespective of sex, in each of five size classes of 100 mm increments in fork length from 200 mm to 700 mm. These size classes were selected based on typical size ranges of northern pike available in the fall, as observed during past fish inventory surveys (RAMP 2005a). This method:

- Ensured that the distribution of tissue samples represented a wide range of fish sizes and ages;
- Helped obtain a better understanding of tissue concentrations within the populations; and
- Allowed direct comparison with data from previous sampling efforts.

Fish tissue for mercury analysis was sampled non-lethally with a 4 mm biopsy punch (Acuderm Inc.), first used in 2005 (RAMP 2005a). During sampling, a few scales were removed and the dermal punch was positioned on the surface of the skin. The punch was then pushed straight in with moderate pressure and a twisting motion to penetrate the muscle. The twisting action and slight angular pressure was used upon extraction to assist in obtaining the muscle plug sample. The tissue plug was placed onto a clean glass slide for skin removal, and then into a pre-weighed 4 mL externally threaded, sterile cryovial using a clean dissecting probe and pair of tweezers. The tissue plug wet weight was then recorded for the calculation of total mercury concentration after analytical analysis. Following Baker *et al*. (2004), nexaband ("sterile crazy glue") was applied to help decrease the chance of inflection by closing the wound with something that acts as a waterproof bandage. Larger northern pike were immediately released into a calm marginal habitat after sampling to limit additional handling/confinement stress. Smaller northern pike were permitted to briefly recover in an aerated tank (e.g. cooler) prior to release. All sampling equipment was rinsed in hexane, then acetone, and 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 for analysis.

Comprehensive Tissue Analysis for Tainting Compounds and Metals Five male fish within the 450 mm to 500 mm fork length size class and five female fish within the 500 mm to 550 mm fork length size class previously sampled for mercury were sacrificed for a comprehensive suite of tainting compounds (organics) and metals. This length range was selected to minimize potential variability associated with size and age and to allow for direct comparison to previous surveys (RAMP 2005a). Muscle tissue was first removed from each fish for mercury analyses as described above. Muscle tissues were then removed from the left side of the fish to be used for assessing tainting compounds, and from the right side of the fish for assessing metals (RAMP 2005b). Minimum muscle tissue requirements per fish were 20 g (50 to 100 g is preferred) for tainting compounds analyses and 2 g (5 g is preferred) for metals analyses; tissue samples typically exceeded these weights. After dissection, liver weight (± 1.0 g) and gonad weight (± 1.0 g) were measured for each fish. An internal health assessment (Goede 1993) was conducted on each fish, and ageing structures (cliethra and fin rays) were collected and sent to North/South Consultants Inc. for analysis. Muscle samples collected for tainting compound analysis were individually wrapped in solvent-rinsed aluminum foil, and samples collected for metals analysis were individually wrapped in plastic wrap. All samples were labeled, stored on dry ice, and shipped via the Fort McMurray ALS office to ALS Laboratory Group (ALS) in Edmonton for chemical analysis.

Composite samples for female and male fish were prepared at ALS by combining an equal weight of muscle from five fish of each sex. All remaining tissue samples were archived at the testing laboratory for additional analyses if required. Individual muscle samples of fish from the Clearwater River were analyzed for mercury. Composite samples of fish from the Clearwater River were analyzed for:

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

Methods and detection limits used for chemical analyses for tainting compounds and metals are presented in Table 3.4-3.

In addition to the two types of tissue sampling described above, sub-samples of tissue were collected from sacrificed fish for Dr. Philip Fedorak at the University of Alberta to test an analytical method for detecting naphthenic acids.

Table 3.4-3 Methods of analyses and detection limits for metals and tainting compounds.

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

Note: Naphthalene was analyzed for three target compounds, 1-Methylnaphthalene, 2,6-Dimethylnaphthalene, 2,3,5-Trimethylnaphthalene, all with same detection limit and using the same method of analysis.

3.4.2.3 Muskeg River Fish Fence

The objectives of the 2006 Muskeg River fish fence were to:

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

Flow conditions in the Muskeg River during the 2006 sampling period were generally within the RAMP protocol for fence deployment in April 2006 (i.e., < 9 m^3/s, RAMP [2005b]) and the fence was deployed successfully.

Specifications for the major equipment items used for the deployment and operation of the Muskeg River fish fence are provided in Table 3.4-4. A number of smaller equipment items, such as dissection tools, fish measuring boards, construction tools, and first aid kits, were also used during field data collection.

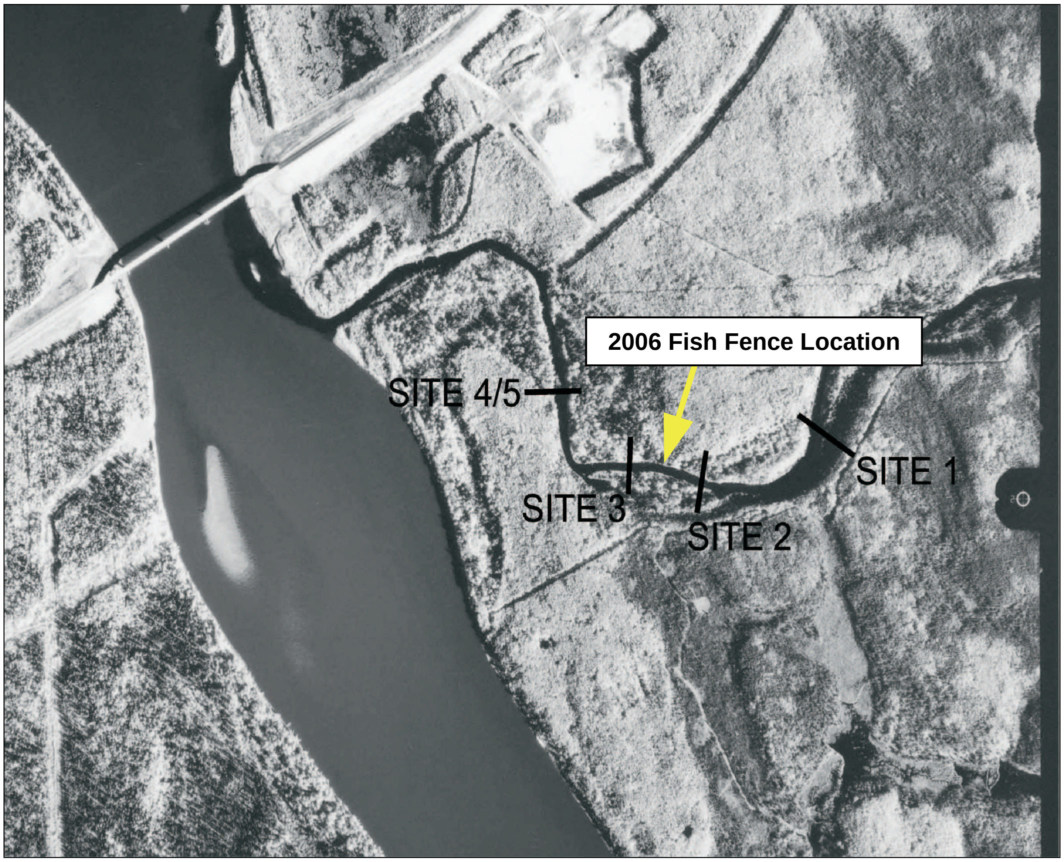
Table 3.4-4 Equipment used during the Muskeg River spring fish fence, April and May 2006.

Equipment Item	Model	Specifications
Global Positioning System (GPS)	Garmin 76	12 Channel
Water Quality measurement	YSI 85	DO, conductivity, temperature
pH Measurement	pHTestr2	pH Range of 0 to 14
Thermometer	Alcohol thermometer	Temperature Range -35 to 50 °C
Balance	UWE HS-7500	0 kg to 7.5 kg (±5.0 g)
	Kilotech KLB	0 kg to 5 kg (±1.0 g)
	UWE HS-3000	0 kg to 3 kg (±2.0 g)
	AM2501-SPL	0 kg to 12 kg (±25.0 g)
Fish fence components	—	
Floy tags	—	Specific to the RAMP program

Fish Fence Location and Construction

The Muskeg River fish fence was located mid-way between Sites 2 and 3 as shown in Figure 3.4-2; this location was selected on the basis of 2002 fish fence reconnaissance studies (Golder 2003b) and the 2003 fish fence deployment and operation (RAMP 2004). The selected location represents optimal hydraulic conditions, as well as cross-sectional depth profile, acceptable substrate features (e.g., a minimum of bitumen in the substrate matrix), and good access and safety characteristics. The site is located on the Muskeg River mainstem approximately 800 m upstream from its confluence with the Athabasca River (464049 E, 6332081 N, Zone 12, NAD83).

Figure 3.4-2 The Muskeg River, showing potential fish fence sites, and location of the 2003 and 2006 fence installation.



In order to capture the largest possible component of the spring spawning run and to increase the likelihood of capturing migrating Arctic grayling, the fish fence was installed as soon as possible after river ice-out and stream discharge fell below 10 m^3/s. Personnel from the Hatfield office in Fort McMurray monitored ice conditions in the lower Muskeg River daily to assist in determining the earliest date for fence installation. Helicopter support was used to transport the fish fence components and other equipment to the site on April 17, 2006, and installation of the fence began the same day. Installation was completed by April 19, 2006, and the fish fence was operational from April 19 to May 19, 2006.

The fish fence was constructed based on a design developed by Anderson and McDonald (1978), and Kristofferson et al. (1986). Wings of the fence consisted of sections of 96 vertical conduit pipes (1.8 m in height and 1.8 cm in diameter) held in place by two, three meter long, horizontal pieces of aluminum channel. Channels were supported by brackets attached to 2.1 m high x 5 cm diameter aluminum poles and "two by four" wooden A-frames, which were held in place by rock/sand-filled woven polyethylene bags. Conduit were spaced at 3.4 cm centres, leaving 1.6 cm of space between pipes. Upstream and downstream trap boxes, constructed of conduit and spruce "two by fours", were located on opposite sides of the river, and connected by a single centre wing. The traps were anchored in place by driving steel t-bar fence posts into the gravel bed on the upstream and downstream sides of the trap.

North/South Consultants Inc. assisted with the initial on-site installation of the fence in 2006. A view of the installed Muskeg River fish fence is shown in Figure 3.4-3.

Figure 3.4-3 View of full-span Muskeg River Fish Fence, Spring 2006.

Fish Sampling and Handling

A two-person crew monitored the fish fence daily. Efforts were made throughout the operation of the fish fence program to minimize the impact and stress caused by sampling activities. The two trap boxes were checked for fish four times every day between 0700 and 1900. The following species were captured at the fish fence in 2006:

- Lake whitefish, *Coregonus clupeaformis*;
- Mountain whitefish, *Coregonus williamsoni*;
- Longnose sucker, *Catostomus catostomus*;
- White sucker, *Catostomus commersoni*;
- Northern pike, *Esox lucius*;
- Arctic grayling *Thymallus arcticus*; and
- Walleye, *Stizostedion vitreum*.

Floy tags with a unique identification number (specific to the RAMP program) were inserted into the posterior end of the dorsal fin of captured sport fish (i.e., northern pike and walleye, but not Arctic grayling), as well as the first 50 white sucker and longnose sucker captured each day. The Floy tag number was recorded for all captured fish that were already tagged.

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

The following data were recorded from all fish recovered from the trap boxes:

- Species, life stage, sex and maturity (e.g. pre-spawning, ripe or post-spawning);
- Direction of capture (downstream trap, upstream trap);

- Fork length (± 1.0 mm);
- Fish weight (± 2.0 or 5.0 g) using an electronic hanging scale for all 'large' fish (>100 g) captured. A second hanging scale, with an accuracy of ± 5.0 g had to be used when the first hanging scale became inoperable); and
- Fish weight (± 0.1g) using a calibrated electronic balance for all 'small' fish (< 100 g) captured.

This information was recorded on field data sheets and later transferred to an electronic database for analysis.

External Pathological Index

Fish health was assessed by externally examining captured fish for abnormalities, disease and parasites. Eyes, gills, skin, fins, opercles, thymus, pseudobranchs, body form and parasites were assessed. All abnormalities were recorded by type and degree of severity and were assigned an index value ranging from 10 to 30; 0 indicated no signs of pathology (Appendix G). A pathological index (PI) for these external characteristics was calculated for each fish as the sum of the index values for all abnormalities. A mean index value was then calculated for each species.

Age Determination

Appropriate non-lethal aging structures (fin rays and scales) were collected from all captured fish except Arctic grayling using the protocols in MacKay et al. (1990). The aging structures were placed in scale envelopes and dried for age determination. In addition, the adipose fins on all captured Arctic grayling were clipped and archived in individually-labeled envelopes pending future DNA analysis, as required by ASRD.

North/South Consultants Inc. of Winnipeg analyzed all ageing structures from the fish fence program. Scales were used for ageing lake whitefish and mountain whitefish, while fin rays were used to age northern pike, white sucker, longnose sucker, and walleye. All collected ageing structures for species other than white sucker and longnose sucker were submitted for analysis. However, due to the large number of captured white sucker and longnose sucker, a weighted sub-sample (n=200) of collected age structures from each species was submitted for analysis based on the species-specific length frequency distribution of the captured fish. Furthermore, to ensure that the selected ageing structures would not be biased to any one period of the spawning run, ageing structures for a given length class were randomly selected from the pool of all ageing structures of the given length class collected over the entire period of operation of the fish fence.

Water Quality Measurements

Daily i*n situ* water quality measurements were taken throughout operation of the Muskeg River fish fence at a site immediately upstream of the fish fence. A YSI 85 meter or acceptable alternative was used to measure temperature, dissolved oxygen and specific conductance. pH was recorded using a hand-held probe or titration kit. Other environmental variables, such as general weather conditions and air temperature, were also recorded on a daily basis at the fish fence site. Water temperature was recorded between April 20 2006 and May 20, 2006 using a HOBO Water Temp Pro (H20-001) data logger that was installed on the right bank of the river between the fish fence wings. Average readings were generated every fifteen minutes and results were recorded in degrees Celsius (±0.2°C accuracy).

3.4.2.4 Non-Lethal Tributary Sentinel Fish Species Monitoring

Sentinel species monitoring in 2006 was carried out at a total of five sites on tributaries of the Athabasca River (Table 3.4-5, Figure 3.4-1). Two of these sites, lower Steepbank River (site SR-E) and Muskeg River (site MR-E) are designated as *potentially influenced,* while the remaining three sites, upper Steepbank River (site SR-R2), Horse River (site HR-R) and Dunkirk River (site DR-R), are designated as *reference*. Slimy sculpin (*Cottus cognatus*) was the sentinel species for non-lethal tributary sentinel fish species monitoring, with a target of 100 individuals to be captured per site for each sample period.

Table 3.4-5 Tributary sentinel fish species monitoring sites, 2006.

Watershed	Site Code	Location Description	UTM Coordinates (NAD83, Zone 12)
Steepbank River	SR-E (74 E/3)	Potentially influenced site in the vicinity of the Steepbank Mine, approximately 0.3 to 1.0 km upstream of the confluence with the Athabasca River.	Start:: 471255 E / 6320088 N Finish: 471631 E / 6320362 N
	SR-R2 (74 D/14)	Reference site approximately 15 km upstream of the of the confluence with the Athabasca River.	Start:: 484400 E / 6310590 N Finish: 484393 E / 6310494 N
Muskeg River	MR-E (74 E/4)	Potentially influenced site approximately 0.2 to 0.6 km upstream of the confluence with the Athabasca River.	Start:: 463831 E / 6332409 N Finish: 463839 E / 6332390 N
Horse River	HR-R (84 A/8)	Reference site approximately 140 km upstream of the confluence with the Athabasca River.	Start:: 427392 E / 6246802 N Finish: 427443 E / 6246822 N
Dunkirk River	DR-R (84 A/15)	Reference site approximately 25 km upstream of the confluence with the MacKay River.	Start:: 395710 E / 6302369 N Finish: 395770 E / 6302372 N

Fish Sampling and Handling

The two sampling campaigns for the 2006 non-lethal tributary sentinel species monitoring study were 14 to 18 August, 2006 and 1 to 4 October, 2006. All fish sampling was carried out by a two-person field crew using a Smith-Root 12B-POW battery-powered electrofishing unit and a standard dip net, which was deployed downstream of the anode prior to and during the application of electrical current. The dip net was fitted with a fine mesh net (0.125 in) to ensure that young-of-year fish could be captured. Fish sampling was conducted from one wetted bank to the other within each site until the 100 fish sentinel species target was reached or until conditions did not permit continued backpack electrofishing (i.e. water too deep).

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

Water Quality Measurements and Habitat Assessments

The August sampling campaign included habitat assessment at each site in addition to the fish sampling outlined above. Habitat assessment methods involved measuring and recording a range of variables relating to channel morphology, substrate, water quality, and stream cover similar to that outlined in Golder (2002a) and RIC (1999) (examples of the habitat assessment field data sheets are presented in Appendix G). Water quality variables included temperature, dissolved oxygen, and specific conductance and were measured either with a YSI multi-meter or combination of hand-held probes (temperature, conductivity) and titration kits (DO, pH). Basic water quality data were also collected during the October field campaign. A HOBO Water Temp Pro v2 data logger was deployed at each site in August 2006 and retrieved during the October 2006 sampling campaign to provide information on the thermal regime of the sampled site.

3.4.2.5 MacKay River Sentinel Fish Species Reconnaissance

The MacKay River sentinel fish species reconnaissance study was carried out on September 16, 2006. A range of habitat types were sampled in each of two sampling sites on the MacKay River, a lower site designated as *potentially-influenced* and an upper site designated as *reference* (Table 3.4-6, Figure 3.4-1).

Table 3.4-6 Location of MacKay River sentinel fish species reconnaissance sites.

Site	Designation	UTM Coordinate (NAD83, Zone 12)	
		Easting	Northing
Lower MacKay River	*potentially-influenced*	453731	6327177
Upper MacKay River	*reference*	421096	6299844

Sampling methods were designed to capture all species and size of fish using a Smith-Root 12B-POW battery-powered backpack electrofishing unit. Fish were captured during electrofishing using a standardized dip net with 0.125 inch mesh used in other RAMP sentinel fish program and fish inventories. During the fish sampling efforts, the dip net was positioned downstream of the electrofishing unit and current was applied to the water in 5 to 10 second bursts. An estimated surface area of about 2-4 m^2 was sampled with each burst, depending on factors such as water depth and conductivity.

All captured fish were identified and measured for 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 captured fish were revived in fresh water, with monitoring at regular intervals to ensure full recovery, and then released back into the watercourse near the original capture location.

In addition to the basic fish sampling outlined above, a general habitat assessment, including *in situ* water quality measurements (temperature, pH, conductivity, and dissolved oxygen) was conducted using the same procedures described above for sentinel species monitoring.

3.4.2.6 Fish Tag Return Assessment

Tagging of key indicator fish species has been regularly undertaken as part of the Fish Population component of RAMP since 1999. Recapture records are maintained by RAMP and the Alberta Ministry of Sustainable Resource Development (ASRD) and provide information on movements of tagged fish in the event a tag is returned by an angler. Data may include the tagging date and geographical location, as well as basic morphometric variables, 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 is 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.

3.4.3 Changes in Monitoring Network from 2005 Field Program

The location of the non-lethal tributary sentinel species monitoring program reference site on Steepbank River was moved approximately 7 km upstream from its historical location due to oil sands development activities that have resulted in land changes at the original site.

The Regional Lakes Program, where fish tissue from RAMP stakeholders or government partners is analyzed for mercury levels, was not conducted in 2006. No fish were available to RAMP for opportunistic analysis because the Index Netting (IN) program planned for Namur Lake by ASRD was not conducted in 2006.

3.4.4 Challenges Encountered and Solutions Applied

In general, field activities implemented under the 2006 Fish Population component were completed successfully.

There were several occasions during the spring Muskeg River fish counting fence study when discharge levels approached 9 m^3/s, which is the maximum flow allowed under the RAMP protocols for fish fence operation (RAMP 2005b). Some modifications to the fish fence were implemented, most notably the use of shore-anchored tether lines to maintain the stability of the structure. The fish fence partially collapsed during the night of May 7, 2006 (discharge 8.42 m^3/s), and was not operational for a short time on May 8. However, the fence was re-established by the end of the day on May 8, 2006. The impact of the event on accurate monitoring of fish migration was considered to be small, because the collapse occurred during a time of reduced fish movement and falling water temperatures (<5°C). Soon after this event, the number of fish moving upstream increased substantially with the highest daily counts reported between May 11 and 14, 2006.

Elevated water levels were encountered during the initial August attempt to conduct the MacKay River sentinel species reconnaissance study. The summer campaign for this study was; therefore, carried out in September 2006 to correspond with the timing of previous reconnaissance programs.

Temperature data loggers were deployed at each sentinel fish species survey site during the summer sampling program and removed later in the fall to gain insight into thermal regimes experienced by the different slimy sculpin populations. Detailed comparisons among sites were not possible as a result of air exposure of the data loggers during low water periods in mid-September.

3.4.5 Other Information Obtained

Fish samples were submitted to RAMP as part of the Fish Abnormalities program. In some cases, a tissue sample and age structure, as well as an external and internal health assessment was conducted.

3.4.6 Summary of Component Data Now Available

The Fish Population component data collected to date for the RAMP monitoring program is summarized in Table 3.4-7.

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

see symbol key at bottom

WATERBODY AND LOCATION	REACH	1997				1998				1999				2000				2001			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																					
Poplar Area	0/1[a]		1	1,5	1,5		1,6	1,5	1,3,6												
Steepbank Area	4/5/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Muskeg Area	10/11/12		1	1,5	1,5		1,6	1,5	1,3,6									7			6
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7			
Fort-Calumet Area	19A																				
	19B																				
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6												
Reference Area - upstream of Fort McMurray[c]			1																		
Radiotelemetry study region[d]					2	2			2						2	2	2	2	2		
Downstream of Suncor's Discharge	AR-SD												1,3								
Below Muskeg River	AR-MR												1,3								
Reference site upstream of Ft. McMurray STP																					
Reference site between STP and Suncor	AR-R												1,3								
Downstream of Developments (near Firebag R.)																					
Athabasca River Delta																					
Athabasca River Tributaries																					
Fort Creek (mouth)															1,8,5,9	1					
Historical Review of Tributary Fish Data																					
Clearwater River	CR1																				
Clearwater River	CR2																				
Clearwater River	CR3																				
Christina River[i]																					
Ells River																					
Upper and lower Ells River[h]													1,3								
Isadore's Lake																					
Kearl Lake																					
Mackay River																					
Lower reach (85 km section from bridge to mouth)[j]	MAR-1		1																		
Marguerite River Sentinel																					
McLean Creek																					
Mouth																					
Upstream of mouth (100 m)																					
Muskeg River																					
Lower 35 km below Jackpine Creek confluence				1			4						1,3		2,8	2	2	2	2	1	6
Mouth (within 1 km of confl. with Athabasca R.)	MR-E												1,3						4		3
Reference sites (Steepbank, Horse and Dunkirk R.)	SR-R																3				3
	HR-R,																3				3
	DR-R																3				3
Upper Muskeg River (near Wapasu Ck. Confluence)																					
Muskeg River Tributaries																					
Alsands Drain																					
Jackpine Creek (accessable areas of lower creek)															8					1	
Shelley Creek																					
Muskeg Creek (Canterra road crossing)[e]																					
Stanley Creek																					
Wapasu Creek (mouth or Canterra road)[e]																					
Regionally Important Lakes																					
Various lakes in water/air emissions pathway																					
Poplar Creek																					
Shipyard Lake																					
Steepbank River																					
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																	
Vicinity of Steepbank Mine	SR-E												1,3								3
Original Sentinel reference site on Steepbank River[g]	SR-EC												1,3				3				3
Reference site in vicinity of Bitumen Heights	SR-R												1,3								
New Sentinel Reference site on Steepbank River	SR-R2																				
Sentinel reference sites (Horse and Dunkirk R.)	HR-R, DR-R																3				3

WATERBODY AND LOCATION	REACH	2002				2003				2004				2005				2006			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																					
Poplar Area	0/1[a]		1				1		1		1		1		1		1		1		1
Steepbank Area	4/5/6		1		10,6		1		1,6		1		1		1		1,6		1		1
Muskeg Area	10/11/12		1		10,6		1		1,6		1		1		1		1,6		1		1
Tar-Ells Area	16/17		1				1		1		1		1		1		1		1		1
Fort-Calumet Area	19A														1		1		1		1
	19B						1												1		1
Reference Area - about 200 km upstream[b]	5/6																				
Reference Area - upstream of Fort McMurray[c]																					
Radiotelemetry study region[d]																					
Downstream of Suncor's Discharge	AR-SD				10,3				10												
Below Muskeg River	AR-MR				10,3				10												
Reference site upstream of Ft. McMurray STP					3				10												
Reference site between STP and Suncor	AR-R				3				10												
Downstream of Developments (near Firebag R.)									10,6												
Athabasca River Delta																					
Athabasca River Tributaries																					
Fort Creek (mouth)																					
Historical Review of Tributary Fish Data																					
Clearwater River	CR1						1		1		1		1		1		1		1		1,6
Clearwater River	CR2						1		1		1				1				1		1,6
Clearwater River	CR3						1	10	1		1				1				1		1,6
Christina River[i]													1				1				
Ells River																					
Upper and lower Ells River[h]											4a		3a			1	3				
Isadore's Lake																					
Kearl Lake																					
Mackay River																					
Lower reach (85 km section from bridge to mouth)[j]	MAR-1		1					10			4a				4a						3a
Marguerite River Sentinel																					
McLean Creek																					
Mouth																					
Upstream of mouth (100 m)																					
Muskeg River																					
Lower 35 km below Jackpine Creek confluence				1	6							1	6								
Mouth (within 1 km of confl. with Athabasca R.)	MR-E		4		4		4						3						4	3	3
Reference sites (Steepbank, Horse and Dunkirk R.)	SR-R												3								
	HR-R,												3							3	3
	DR-R												3							3	3
Upper Muskeg River (near Wapasu Ck. Confluence)			1,4		1,4																
Muskeg River Tributaries																					
Alsands Drain																					
Jackpine Creek (accessable areas of lower creek)				1								1									
Shelley Creek																					
Muskeg Creek (Canterra road crossing)[e]			1,4		1,4																
Stanley Creek																					
Wapasu Creek (mouth or Canterra road)[e]			1,4		1,4																
Regionally Important Lakes																					
Various lakes in water/air emissions pathway									6				6								
Poplar Creek																					
Shipyard Lake																					
Steepbank River																					
Steepbank Mine baseline fisheries reach (1995)[f]	AF014																				
Vicinity of Steepbank Mine	SR-E												3							3	3
Original Sentinel reference site on Steepbank River[g]	SR-EC												3								
Reference site in vicinity of Bitumen Heights	SR-R																				
New Sentinel Reference site on Steepbank River	SR-R2																			3	3
Sentinel reference sites (Horse and Dunkirk R.)	HR-R, DR-R												3							3	3

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
3a = sentinel fish reconnaisance
4 = fish fence
4a = fish fence reconnaisance
5 = fish habitat association
6 = fish tissue
7 = winter fish habitat sampling
8 = spawning survey
9 = benthic drift survey
10 = IBI Assessment - Test program
N/A = site unnamed

[blue] potentially influenced
[green] 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.

3.4.7 Analytical Approach

The analytical approach used in 2006 for the Fish Population component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2005b) and consisted of:

- Selecting fish population measurement endpoints;
- Developing criteria to be used in detecting changes in fish population measurement endpoints; and
- Detailed data analysis, consisting of statistical analyses and tabular and graphical presentations of 2006 results for the Fish Population component.

3.4.7.1 Selection of Fish Population Measurement Endpoints

The measurement endpoints selected for the Fish Population component were specific to each study undertaken:

- **Athabasca River and Clearwater River Fish Inventories** A review of the available dataset from the RAMP fish inventory studies indicated that relative abundance (as measured by CPUE) and percent species composition were the fish population measurement endpoints that were most appropriate for use in analyzing monitoring results;
- **Clearwater River Fish Tissue Study** The fish population measurement endpoints selected were a range of metals (including mercury) and tainting compounds (PAHs) in fish muscle tissue;
- **Muskeg River Fish Fence Study** The following fish population measurement endpoints were used for large-bodied fish species captured at the Muskeg River fish fence: relative abundance of migrants (fence count data by species); length/age-frequency; percent composition (relative to all fish captured); condition factor; sex ratio; onset and peak timing of spawning runs; residency time in the spawning tributary (out-migration was monitored); and
- **Sentinel Species Monitoring** Fish population measurement endpoints selected for RAMP non-lethal sentinel species monitoring on the Athabasca River and selected tributaries are summarized in Table 3.4-8 and based on Environment Canada's Environmental Effects Monitoring (EEM) guidelines developed for the metal mining and pulp and paper sectors (Environment Canada 2002, 2005).

3.4.7.2 Criteria for Determining Effects

The criteria used for determining effects on fish populations were also specific to each study undertaken within the Fish Population component.

Athabasca River and Clearwater River Fish Inventories

As indicated previously in Table 1.4-1, the RAMP fish inventory activity is considered to be a stakeholder-driven activity that is best suited for assessing general trends in abundance and population variables for large-bodied species. It is not specifically designed for assessing environmental effects of focal project activities and there are therefore no effects criteria applied to the Athabasca River and Clearwater River Fish Inventory studies for 2006.

Table 3.4-8 Fish population measurement endpoints for non-lethal sentinel species monitoring.

Indicator	Non-lethal Sentinel Monitoring
Growth	▪ *Length / weight of young of year at end of growth period ▪ Size of 1+ fish ▪ Size at age
Reproduction	▪ Abundance of young of year ▪ Young of year survival
Condition	▪ *Body weight vs. length (k)
Survival	▪ Age frequency distribution (if possible) ▪ *Length frequency distribution

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

Clearwater River Fish Tissue Study

There are three sets of effects criteria used in analysis of the results of the Clearwater River Fish Tissue Study.

First, 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 Aboriginal 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, updated April 2006); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000).

Health Canada guidelines for chemical contaminants in fish are designed for the average fish consumer; mercury (as total mercury) is the only contaminant evaluated in the current study that has a guideline. The Health Canada guideline for methylmercury for subsistence consumers represents a more stringent guideline. 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 USEPA criteria also provide criteria for several contaminants for different exposure scenarios such as 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.

Second, 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 3.4-9, along with

Table 3.4-9 Concentrations of metals that have lethal, sublethal or no effect on freshwater fish.

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

Data obtained from Jarvinen and Ankley 1999.
- = No data.
[1] Methylated forms of mercury.

information regarding the studies from which these thresholds were derived, including the endpoints evaluated, tissue type, species, life stage and/or fish size, exposure route and duration of exposure. Only the most relevant studies are 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, are excluded. Data derived from acute exposures are only included for contaminants where few data exist.

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

Muskeg River Fish Fence Study

The use of a fish counting fence as a monitoring tool for RAMP is relatively recent and is in part due to the success achieved in with the Muskeg River fish fence in 2003. While data from fish fences are best suited for assessing time trends in abundance and population variables for each spawning species, the high level of natural annual variability common in spawning run strength means it is necessary to collect a large number of sampling years before observed trends and possible effects of development activities can be described with confidence. Therefore, no effects criteria are applied to the results of the 2006 Muskeg River fish fence study.

Sentinel Species Monitoring

The selected criteria for determination of change in measurement endpoints selected for use in non-lethal sentinel species studies were based on Environment Canada's Environmental Effects Monitoring (EEM) criteria (Environment Canada [2002, 2005]):

- Non-lethal approach
    - *Condition factor at exposed site ±10% difference from reference site*

3.4.7.3 Detailed Data Analysis

All statistical analyses of the Fish Population component data were conducted using Microsoft Excel (Excel 2000) and SYSTAT 10 (SPSS 2000).

Athabasca River and Clearwater River Fish Inventories

All fish captured during the Athabasca River and Clearwater River fish inventories were summarized by KIR species composition (percent of total catch) and relative abundance (catch per unit effort - CPUE).

More detailed analyses were conducted on KIR species with sufficiently large sample sizes. When possible, multi-year comparisons of inventory data from both the Athabasca River and Clearwater River were made. The key analyses were as follows.

First, a temporal comparison of the ratio of captured walleye and northern pike abundance above and below the corresponding legal size limits was conducted so as to provide an index of recruitment to the sport fishery and a means to gain insight into overall survival of these two species. While fork length is the standard measure of walleye and northern pike length used in RAMP fish population studies, the ASRD size regulations for the Athabasca River in the Northern Boreal Zone 3 are given in total length (legal walleye ≥ 430 mm; legal northern pike ≥ 630 mm). Using regression equations for each species, approximations of the appropriate minimum fork length size were calculated at 370 mm for walleye and 600 mm for northern pike. These corresponded extremely well to length size-classes already used in the length-frequency distributions.

Second, an analysis of fish condition was conducted, restricted to fish collected in the spring for all species except lake whitefish for which fall data were used. To be consistent with the analyses of past years, 2006 analyses were restricted to fish of the following species-specific minimum lengths: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; and longnose sucker >350 mm. Fish condition was estimated for each species by the relationship of total body weight versus fork length ($\log_{10}$ data). Potential differences in condition among years (1997-2006) were tested using Analysis of Covariance (ANCOVA). An external pathology index (Golder 2003b) was calculated for each fish (Appendix G). Historical external pathology index results were tabulated to assess evidence of trends in external fish health.

Clearwater River Fish Tissue Studies

Scatterplots were used to initially assess the relationships between mercury concentrations in northern pike and whole-organism indices. Spearman 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 $r_s > |0.75|$. Linear regression was used to further evaluate significant rank correlations. Assumptions of regression models were tested and if necessary were performed using $\log_{10}$-transformed or ranked data. Analyses were also conducted on the temporal dataset to determine whether mercury concentrations have changed over time, and to assess the required frequency of fish tissue studies. Finally, fish tissue chemistry data for northern pike from the Clearwater River were compared to the various effects criteria listed above in Section 3.4.7.2 to assess potential effects on humans and fish.

Muskeg River Fish Fence Study

For each species, analysis of variance (ANOVA) was used to compare fork length between sexes. Estimates of size-at-age (fork length vs. age) and condition (body weight vs. fork length) between sexes were evaluated using Analysis of Covariance (ANCOVA). An assumption of the ANCOVA model is that the slopes of the regression lines are equal between areas. Therefore, differences in slopes were tested prior to conducting the ANCOVA. Generally, ANCOVA is fairly robust even when slopes are not equal, so slopes were considered different when $p < 0.01$ (Paine 1998). Data were $\log_{10}$ transformed where appropriate. In addition, graphical and tabular presentations were made of species-specific and, in some cases, sex-specific recapture rates, residence times, and condition factors.

Sentinel Species Monitoring Studies

Data generated from the summer and fall sampling campaigns were tested for differences between the *reference* and *potentially influenced* sampling sites. Three types of analyses were conducted.

For testing for possible differences in population distribution, sculpin length-frequency distributions were generated using 2 mm length classes and then compared using the

Kolmogorov-Smirnov test (K-S test)(α = 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.

For testing for possible differences in growth, sculpin lengths and weights were $\log_{10}$-transformed and compared among sites using ANOVA (α = 0.05).

For testing for possible differences in energy storage, sculpin condition factor was compared among sites using ANCOVA (α = 0.05), where weight represented the dependent variable, site the independent variable, and length the covariate. The first step was to compare slopes of length-weight regressions from different populations, and the second step was to compare the intercepts of the regressions.

Fish Tag Return Assessment

A spatial presentation of tag return information (location tagged and location recaptured) was prepared for the tag returns received in 2006.

3.5 ACID-SENSITIVE LAKES

3.5.1 Overview of 2006 Monitoring Activities

As in previous years, the 2006 Acid-Sensitive Lakes (ASL) component consisted of monitoring 50 lakes and ponds within and beyond the RAMP RSA for water quality variables during late August and early September 2006. The locations of each sampled lake are presented in Figure 3.5-1, while the date of lake sampling, the UTM coordinate of each lake and the tertiary watershed in which each lake is located are presented in Table 3.5-1. The unique ID number listed in Table 3.5-1 is that ascribed to each lake by the NO_xSO_x Monitoring Working Group (NSMWG) lake sensitivity mapping program (WRS 2004).

3.5.2 Summary of Field Methods

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

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.

Figure 3.5-1 Location of RAMP acid-sensitive lakes surveyed in 2006.

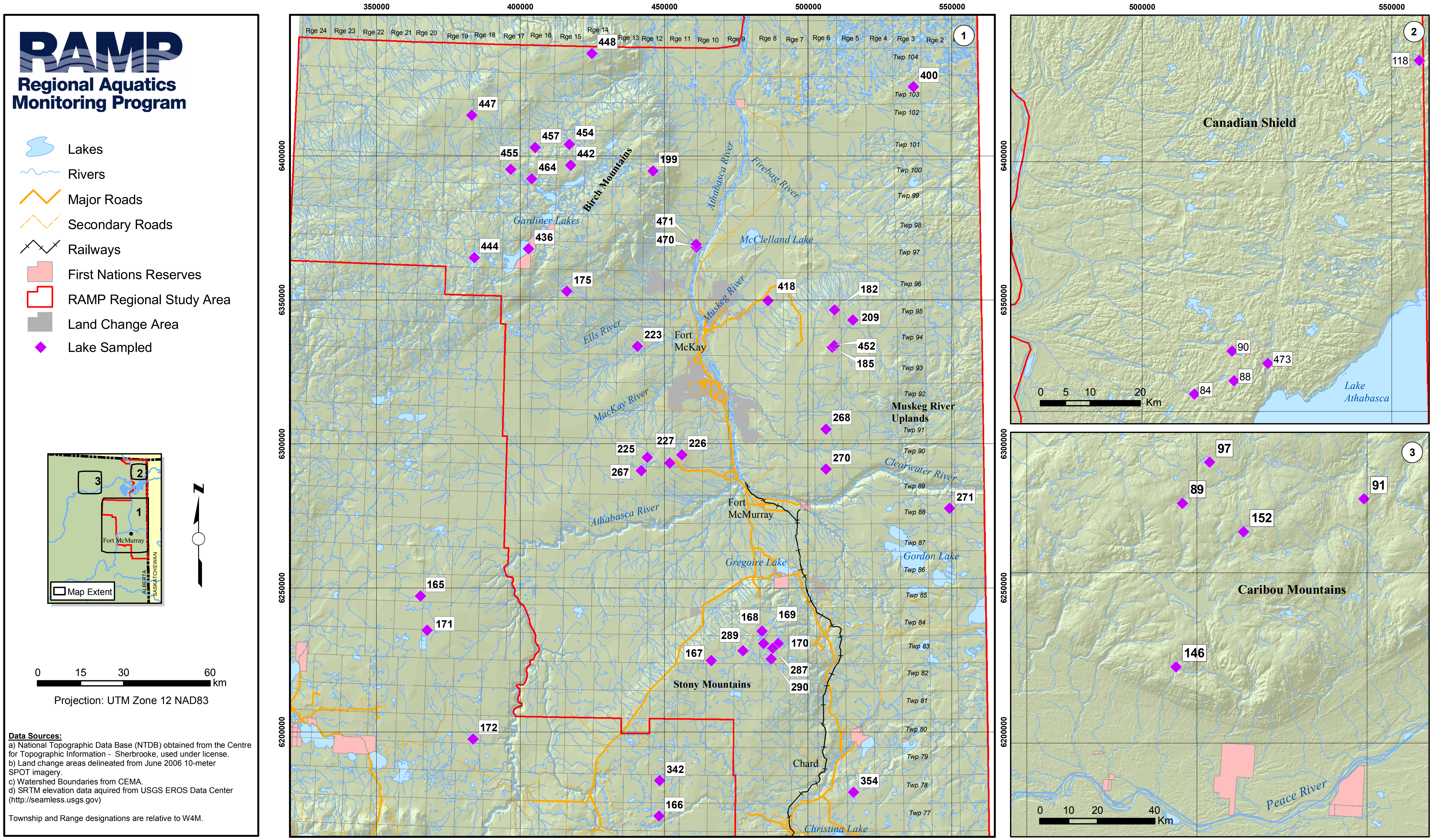


Table 3.5-1 Lakes sampled in 2006 for the Acid-Sensitive Lakes component.

Lake Identification			UTM Coordinates		Sampling Date
Unique ID[1]	Name	Tertiary Watershed	E	N	m/d
Stony Mountains Sub-Region					
168	A21	7CE	483819	6235130	08/25
169	A24	7CE	484387	6230872	08/25
170	A26	7CE	489502	6230877	08/25
167	A29	7CE	466180	6224950	08/25
166	A86	7CE	448014	6170896	08/25
287	25		487594	6229281	08/25
289	27		477248	6228400	08/25
290	28		487068	6225576	08/25
342	82		448271	6183205	08/25
354	94		515689	6179207	08/25
Birch Mountains Sub-Region					
436	L18/Namur		402704	6368016	08/23
442	L23/Otasan		417321	6396959	08/23
444	L25/Legend		383849	6364923	08/23
447	L28		382996	6414339	08/23
448	L29/Clayton	7KE/7KF	424694	6435790	08/23
454	L46/Bayard		416941	6404239	08/23
455	L47		396500	6395456	08/23
457	L49		404995	6403111	08/23
464	L60		403796	6392247	08/23
175	P13	7DA	416003	6353212	09/01
199	P49	7DA	446002	6394961	09/01
Northeast of Fort McMurray Sub-Region					
452	L4 (A-170)		508990	6334305	08/25
470	L7		461006	6368512	
471	L8		460931	6369481	08/25
400	L39/E9/A-150		536495	6424234	08/25
268	E15		506092	6305335	08/25
182	P23	7DA	509000	6346712	08/28
185	P27	7DA	508300	6333712	09/01
209	P7	7DC	515399	6343212	09/01
270	4		506113	6291421	08/25
271	6		549064	6277789	08/25
418	Kearl		485939	6349881	08/25
West of Fort McMurray Sub-Region					
165	A42	7CC	365015	6247322	08/30
171	A47	7CC	367321	6235430	08/30
172	A59	7PA	383467	6197733	08/30
223	P94	7BD	440557	6334112	08/30
225	P96	7BD	444002	6295513	08/30
226	P97	7DA	456002	6296463	08/30
227	P98	7CC	451762	6293513	08/30
267	1		441917	6290884	08/30
Caribou Mountains Sub-Region					
146	E52/ Fleming	7JF	243692	6522556	08/25
91	O-1/E55	7PC	298955	6571856	08/25
97	O-2/E67	7PA	253582	6582654	08/25
152	E59/Rocky Island	7JF	263546	6562225	08/25
89	E68 Whitesand	7PA	245596	6570610	08/25
Canadian Shield Sub-Region					
473	A301		525150	6559733	08/28
118	L107/Weekes	7MD	555469	6620456	08/28
84	L109/Fletcher	7NA	510321	6553552	08/28
88	O-10	7NA	518279	6556260	08/28
90	R1	7NA	517889	6562197	08/28

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

Subsamples of 150 mL were taken from the composite samples for phytoplankton taxonomy and 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 and the zooplankton samples were sent to Environment Canada for analysis.

The water quality samples were analyzed for the water quality variables listed in Table 3.5-2.

Table 3.5-2 Water quality variables analyzed in 2006 in lake water sampled under the ASL component.

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

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 laboratory. Quality control samples were analyzed for all variables listed in Table 3.5-2 (Appendix B).

3.5.3 Changes in Monitoring Network from 2005

There were no changes in the ASL monitoring network in 2006.

3.5.4 Challenges Encountered and Solutions Applied

There were no exceptional challenges encountered in implementing field activities under the ASL component in 2006.

3.5.5 Other Information Obtained

AENV collected additional samples from each lake surveyed in the ASL component (Table 3.5-1) during the 2006 ASL field season. These water samples were sent to ARC Vegreville for analysis for both total and dissolved metals. In addition, AENV provided the results of seasonal sampling conducted for CEMA on ten of the lakes listed in Table 3.5-1. These data were used to assess the natural variability in water quality in these lakes.

3.5.6 Summary of Component Data Now Available

The selection of lakes sampled during the eight years of the ASL component is summarized in Table 3.5-3.

Table 3.5-3 Summary of lakes sampled during RAMP, 1999 to 2006.

NO_x-SO_x GIS No.	Original RAMP Designation	1999	2000	2001	2002	2003	2004	2005	2006
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	+							
310	A300			+					

Note: Lakes sampled during the 2006 field component have been shaded.

3.5.7 Analytical Approach

The analytical approach used in 2006 for the ASL component was in accordance with the overall analytical approach outlined in the RAMP Technical Design and Rationale (RAMP 2005b) and consisted of:

- Selecting ASL measurement endpoints;
- Developing criteria to be used in detecting changes in ASL measurement endpoints; and
- Detailed data analysis of 2006 results.

3.5.7.1 Measurement Endpoints

The measurement endpoints for the ASL component in 2006 were:

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

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

3.5.7.2 Criteria for Determining Effects

Criteria for determining changes in the ASL measurement endpoints were stated in the RAMP Technical Design and Rationale document (RAMP 2005b) as follows:

> *A significant impact on a lake from acid deposition is concluded if a significant change is noted in one or more measurement endpoints beyond natural variability. These endpoints include 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 P<0.05 that is directly attributable to increased deposition of acidifying substances. Natural variability is measured as the variance of the measurement endpoint.*

3.5.7.3 Details of Data Analysis

Primary Analyses

The emphasis in the data analysis was placed on the detection and evaluation of potential trends in the ASL measurement endpoints in the RAMP ASL lakes that would indicate incipient changes in the buffering capacity and acid sensitivity of the lakes according to the criteria for determining effects described above. In this regard, three specific data analyses were conducted.

Between-Year Comparison of Endpoint Parameters: An Analysis of Variance (ANOVA) was conducted to determine whether there have been any significant changes in the concentrations of the ASL measurement endpoints in the 50 RAMP lakes, as a group, during the five years when all 50 lakes were sampled. Any observed changes were discussed in relation both to acidification and natural variability.

Trends in ASL Measurement Endpoints: Potential trends in the ASL measurement endpoints were examined for the 31 lakes that have been monitored for at least seven consecutive years. The analysis involved trend analysis using the Mann-Kendall non-parametric test (Gilbert 1987). Estimates of analytical error (determined as the standard deviation of the analysis at each concentration) were incorporated in the analyses to evaluate the validity of any trends observed in ASL measurement endpoints. Significant trends observed in the analyses were considered in relation to the natural variability in each ASL measurement endpoint. The natural variability in measurement endpoints was determined from the between-year variability observed in the ASL component data record and the within-year variability obtained from an on-going seasonal water quality study conducted by AENV on ten of the RAMP ASL lakes.

Calculation of Critical Loads of Acidity and Comparison to Modeled Potential Acid Input: The critical loads (CL), in units of keq H+/ha/y, is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology and represents a measure of a lake's sensitivity to acidification. CLs for the RAMP lakes in 2006 were calculated using the Henriksen steady state water chemistry model (Henriksen and Posch 2001; Henriksen *et al*. 1992; Forsius *et al*. 1992; Rhim 1995) modified for the effects of organic acids on buffering and acid sensitivity (RAMP 2005a; WRS 2006).

In 2006, the runoff to each lake, a term in the Henriksen model, was calculated both from traditional hydrometric methods and from analysis of heavy isotopes of oxygen (^{18}O) and (^{2}H) in each lake. In the latter technique, the natural evaporative enrichment of ^{18}O and ^{2}H in the lakes is used to partition water losses between evaporation and liquid outflow and hence derive an estimate of runoff (Gibson 2002; Gibson et al. 2002; Gibson and Edwards 2002). This technique utilizes a completely different set of assumptions from the hydrometric method which extrapolates water yields from one or more gauged catchments to the ungauged lake catchments. Potential inaccuracies in the hydrometric method, especially in low-relief catchments, have long been recognized (WRS 2004). The isotopically derived values of runoff were taken from a recent study by Bennett et al. (2006, submitted). Critical loads were calculated using both estimates of runoff and the values compared.

The critical loads for each lake were compared with levels of the Potential Acid Input (PAI) to each lake basin taken as the modeled rate of acid deposition (planned development case) for each lake published in the Kearl Lake EIA (Imperial Oil 2005). As listed values of PAI for most EIAs are unavailable for lakes in the Caribou Mountains and the Shield region, they were estimated from the air modeling study reported for the Long Lake EIA (OPTI/Nexen 2002). In both regions the values of the PAI corresponded to background values (no industrial input) determined from RELAD modeling conducted by Alberta Environment in 2002.

Supporting Analyses

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

- Update of the ASL database, calculation of summary statistics, identification of lakes with unusual chemical characteristics and comparisons of the chemistry of the RAMP lakes in 2006 to the range of chemical characteristics of lakes within the Athabasca oil sands region;
- Analysis of metals in the individual RAMP lakes with emphasis on those (e.g., aluminum) that are known to increase with acidification. Extreme values of individual metals and exceedances of Alberta and CCME water quality guidelines for metals (CCME 2006, AENV 1999b) were identified in individual lakes and in regions within the study area; and
- Estimates of the seasonal variability in water quality variables in ten of the ASL lakes were updated with the 2006 data and summary statistics were calculated.

Update of the ASL Database, Summary Statistics and Comparisons of RAMP ASL Lake Chemistry to Regional Lake Chemistry The chemical data from all years of the ASL component were tabulated and summarized statistically. Box plots were drawn of selected variables in the 2006 data to show the range of each variable and existence of outliers. A Piper plot was prepared for the 2006 data to characterize the RAMP ASL lakes by their major ion chemistry. As in 2005, the chemical characteristics of the RAMP ASL lakes in 2006 were compared to those of 450 regional lakes reported in the NSMWG lake sensitivity mapping study (WRS 2004). Comparisons involved:

- Examination of the ranges, medians and mean values of key chemical variables for 2006 in the RAMP lakes relative to the regional dataset;
- Graphical presentation of both datasets in box plots; and
- Statistical comparison of chemical variables between the RAMP ASL lakes and the regional dataset.

Analysis of Metal Concentrations in the RAMP ASL Lakes The total and dissolved metal fractions from five years of monitoring by AENV (2001, 2003, 2004, 2005 and 2006) were tabulated and summarized statistically to establish baseline concentrations for each metal. Lakes having extreme mean metal concentrations were identified as those exceeding the 95^{th} percentile concentration for individual metals; exceedances of the Alberta and CCME surface water quality guidelines were also identified.