3.0 2008 RAMP MONITORING ACTIVITIES

This section contains a description of RAMP monitoring conducted in 2008 and includes the following for each RAMP component:

- Summary of 2008 monitoring activities and field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, owners and operators of the 2008 focal projects, knowledge obtained from local communities, and other sources);
- Description of changes in the monitoring network from the 2007 program;
- Description of the challenges and issues encountered during 2008 and the means by which these challenges and issues were addressed;
- Summary of the component data that are now available; and
- A description of the approach used for analyzing the RAMP data, including:
  - A description and explanation of the measurement endpoints that were selected;
  - A description and explanation of the criteria that were used to assess whether or not changes in the selected measurement endpoints have occurred; and
  - A description of the statistical, graphical, or other analyses that were performed on the monitoring data to assess whether or not changes in the selected measurement endpoints have occurred.

Monitoring activities for all RAMP components in 2008 were implemented according to the monitoring protocols, field methods, and Standard Operating Procedures (SOPs) for the RAMP components as outlined in the RAMP Technical Design and Rationale (RAMP 2009). Any changes in monitoring protocols, field methods and SOPs from those contained in RAMP (2009) 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 2008. Appendix B contains a detailed description of the QA/QC procedures used for RAMP monitoring in 2008.

All 2008 monitoring data collected under RAMP have been added to the RAMP database which is located in the RAMP member's area website. The 2008 data tables are included on the CD-ROM accompanying the final 2008 technical report.

3.1 CLIMATE AND HYDROLOGY

3.1.1 Overview of 2008 Activities

Monitoring for the Climate and Hydrology component for 2008 included (Table 3.1-1):

- monitoring a set of climate variables at the Aurora and Horizon Climate stations;
- monitoring a sub-set of climate variables at five other stations, with air temperature and precipitation monitored at two and four of these stations respectively;
- monitoring water temperature at ten stations;
- conducting regional snowcourse surveys in February, March and April;

- monitoring water level and streamflow, and collecting water samples for total suspended solids (TSS) analysis[1] at:
  - o 11 hydrometric stations in the Muskeg River basin;
  - o 16 hydrometric stations on other Athabasca River tributaries north of Fort McMurray;
  - o three hydrometric stations on Athabasca River tributaries south of Fort McMurray; and
  - o one hydrometric station on the Athabasca River;
- monitoring winter discharges at 18 of the streamflow stations;
- monitoring water levels at three lake / wetland stations; and
- integrating regional climatic and hydrometric monitoring data collected by government agencies, the Wood Buffalo Environmental Association (WBEA) and oil sands operators into the RAMP database.

Locations of 2008 RAMP climate stations and snowcourse survey sites are shown in Figure 3.1-1, and 2008 hydrometric stations that were funded in whole or in part by RAMP are shown in Figure 3.1-2. Station names, station locations, and variables measured are provided in Table 3.1-1. Names of the government stations are provided in Appendix C.

3.1.2 Field Methods

3.1.2.1 General

Field staff visited the climate and hydrometric stations routinely (i.e., ten times in 2008 for year-round stations and five times during the period of operation of seasonal stations) to check and maintain automated sensing equipment and to make manual streamflow and water level measurements. These measurements are necessary for the development, refinement, or adjustment of a stage-discharge relationship, which is used to convert continuously recorded water levels to discharge.

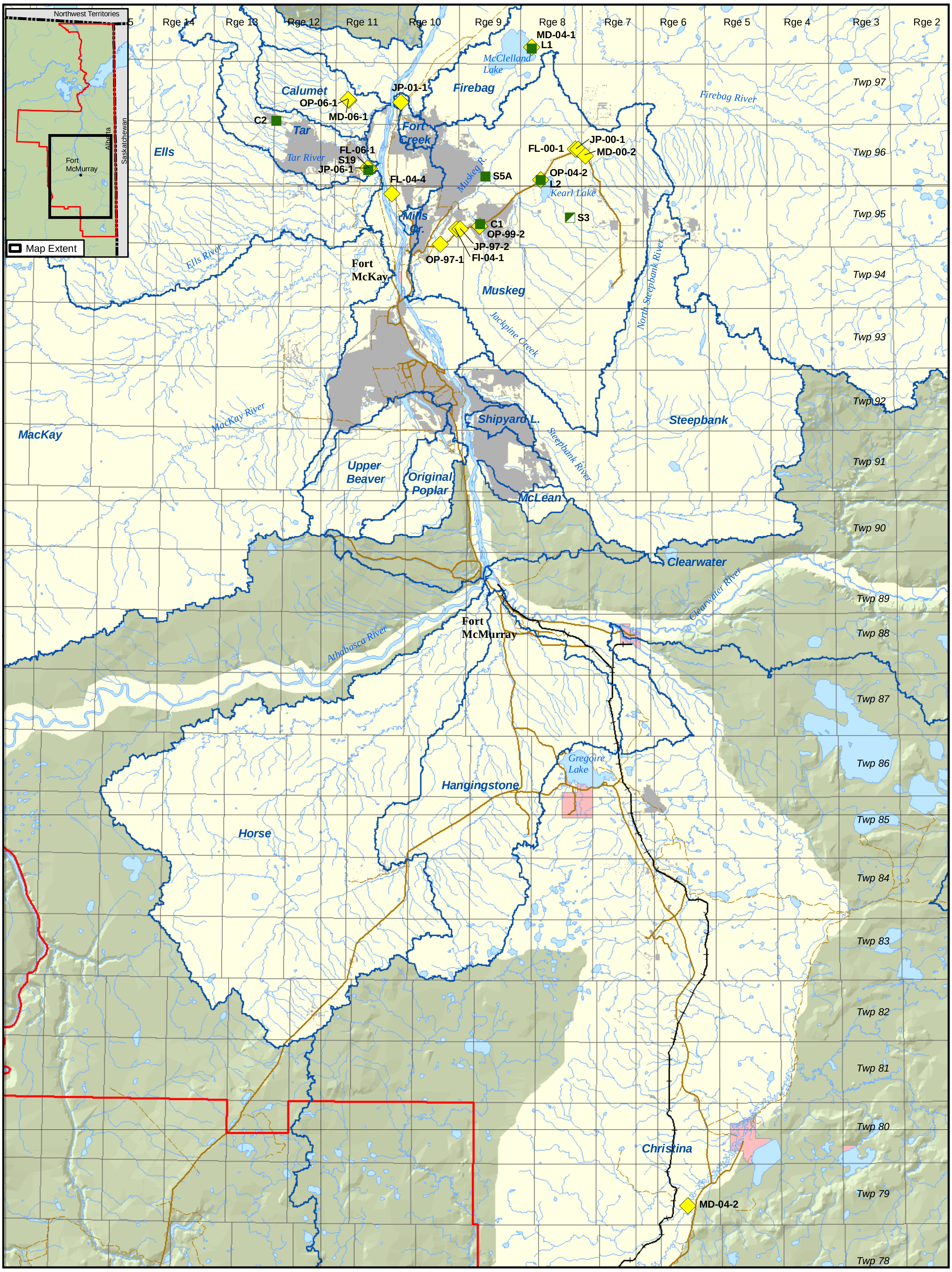
3.1.2.2 Streamflow Measurement

Streamflow measurement procedures and standards are based on recommendations by the Water Survey of Canada (WSC 2001), the United States Geological Survey (USGS 1982), the BC Ministry of Environment, Lands and Parks (BC MOELP 1998). Streamflow measurement locations were accessed by wading or from an overhead bridge or boat. Measurement standards are summarized below:

- Number of verticals: 20, or at a spacing of 0.05 m in small streams;
- Number of readings in the vertical for an open-water measurement: one at 60% of the depth below the surface for depths of 1.1 m or less; otherwise one at 20% and one at 80% of the depth;
- Number of readings in the vertical for a measurement under ice: one at 60% of the depth below the surface for depths of 1.0 m or less; otherwise one at 20% and one at 80% of the depth; and
- Velocity averaging: At least 20 seconds for electromagnetic meters; 45 seconds for mechanical meters.

[1] TSS was sampled five times during the open-water season. Water levels were recorded at 15-minute intervals and converted to streamflow. In some of the small streams in winter, where it was expected that the stream could freeze to depth, depth sensors were removed and monthly flow measurements were made during the winter season.

Figure 3.1-1 Locations of RAMP climate stations and snowcourse survey sites, 2008.



LEGEND

- Lake/Pond
- River/Stream
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area as of 2008
- Watershed Boundary

Climate Stations

- Year-Round RAMP
- Seasonal RAMP
- Active RAMP Snowcourse

Data Sources:
a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, First Nation Reserve, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (May, July and August 2008) Multispectral Imagery.

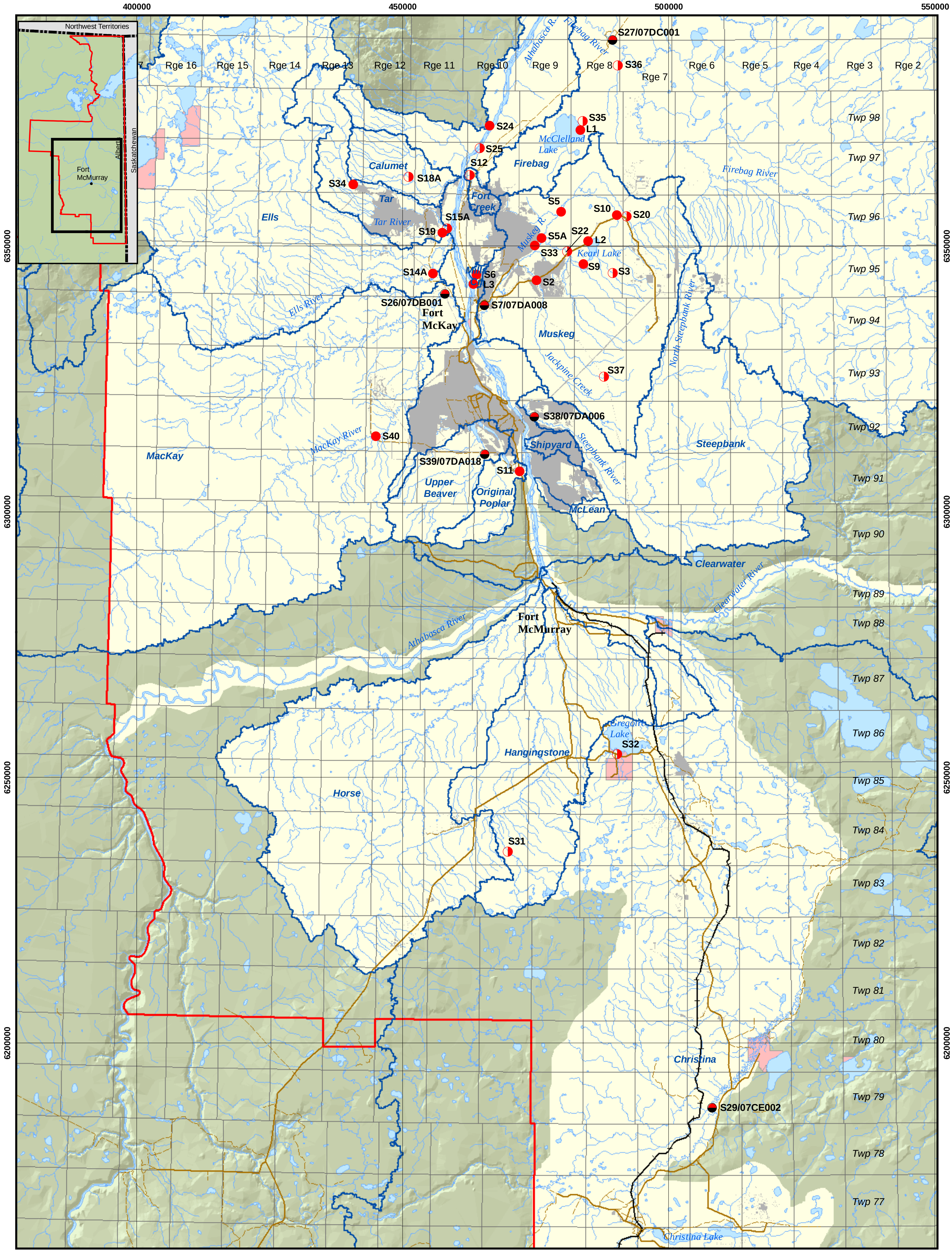
Township and Range designations are relative to W4M.

RAMP
Regional Aquatics Monitoring Program

0 5 10 20 Km
Scale 1:650,000
Projection: UTM Zone 12 NAD83

K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_D_Climate_20090406.mxd

Figure 3.1-2 Locations of RAMP and government hydrometric stations, 2008.



LEGEND

- Lake
- River
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area as of 2008
- Watershed Boundary

Hydrometric Stations

- Year-Round RAMP
- Seasonal RAMP
- Year-Round RAMP/Government

Data Sources:
a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, First Nation Reserve, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (May, July and August 2008) Multispectral Imagery.

Township and Range designations are relative to W4M.

RAMP
Regional Aquatics Monitoring Program

0 5 10 20 Km
Scale 1:750,000
Projection: UTM Zone 12 NAD83

K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_E_Hydro_20090420.mxd

Table 3.1-1 RAMP climate and hydrometric stations operating in 2008.

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

1 UTM coordinate datum is NAD83.

2 Station began operating in September 2008.

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

Details of the measurement procedures used for the Climate and Hydrology component are provided in the RAMP Design and Rationale Document (RAMP, 2009). Quality assurance and quality control procedures are provided in Appendix B of this technical report.

For snowcourse surveys, a sampling plot was established at each snowcourse survey site and snow depths were measured at 40 locations within the plot. At least four samples were measured for snow density. Snow depth and the sample mass were recorded for each density sample to allow calculation of the snow water equivalent and snow density.

3.1.3 Changes in Monitoring Network from 2007

3.1.3.1 New Monitoring Stations

The Horizon Climate Station (Station C2) was established on the west side of the Athabasca River in the Tar River watershed (Figure 3.4-1) to mirror the Aurora Climate Station (Station C1) on the east side. The station was constructed in summer 2008 and began operating in September 2008.

Two streamflow stations were established downstream of McClelland Lake. McClelland Lake Outlet below McClelland Lake (Station S35) measures the outflow from the lake and uses a combined depth-velocity sensor to partially compensate for poor hydraulic conditions typical of this location which is characterized by lack of a well-defined channel. McClelland Lake Outlet above Firebag River (Station S36) monitors the runoff from the entire catchment surrounding McClelland Lake. Data from Station S36 will support estimation of lake inflows and other components of lake water balance.

Three new *baseline* stations were established at locations upstream of development. Station S38, Steepbank River near Fort McMurray (07DA006) and Station S39, Beaver River above Syncrude (07DA018) are operated by WSC from March to October and by RAMP during the winter. Station S40, MacKay River at Petro-Canada Bridge, was established as a year-round station in the fall of 2007 and monitors water level, discharge, and water temperature.

3.1.3.2 Modified Stations

The following stations were modified in 2008:

- A new weighing-style precipitation gauge was installed at the Kearl Lake station (station L2) to more accurately determine the year-round precipitation in this area;
- Stations S5A (Muskeg River above Muskeg Creek), S33 (Muskeg River at the Aurora/Albian Boundary), and S34 (Tar River above CNRL Lake) were upgraded with new equipment to provide for remote download capability; and
- Station S34 (Tar River above CNRL Lake) was relocated 50 meters downstream of its previous location to a more hydraulically-favorable river section.

3.1.3.3 Discontinued Stations

Station S28, Khahago Creek below Black Fly Creek, was discontinued after the 2007 open-water season due to encroaching development from the Shell Jackpine Mine Project.

3.1.4 Challenges Encountered and Solutions Applied

The tipping-bucket rain gauge at Station S3, Iyinimin Creek above Kearl Lake, was knocked over (cause unknown) between the May and June 2008 visits. During the June 2008 visit, the cable connecting the rain gauge to the datalogger was inadvertently unplugged and no data were collected until the problem was corrected during the August 2008 visit; the problems encountered at this station resulted in a loss of data for 97 days in total between May and August.

At Station S14A, Ells River at the CNRL Bridge, a faulty datalogger resulted in loss of data for nine days during the winter months of 2008. While the issue was resolved on the first field visit after the malfunction, an unknown trigger caused this problem to replicate twice more before the winter season had ended resulting in a loss of data for 63 days in total. The spring 2008 ice run destroyed the depth sensor at the same station.

At Station S18A, Calumet River Upland Territory, the datalogger enclosure was knocked down between the May and June 2008 visits and filled with water; this short-circuited the datalogger and resulted in data loss. A replacement transducer/datalogger device was installed but a programming error resulted in additional data loss; the problems encountered at this station resulted in data loss for the entire open water period.

3.1.5 Other Information Obtained

Climate and hydrometric information collected by other organizations was obtained and has been incorporated into the RAMP database. These agencies include the Meteorological Service of Canada (MSC) and the WSC (both agencies of Environment Canada), Alberta Environment (AENV), and the WBEA. Some of the data obtained are provisional indicating that the collecting organization had not completed its quality control procedures at the time the data were provided to RAMP. Provisional data are flagged as such in the RAMP database and replaced with the final data at the end of each sampling period.

3.1.6 Summary of Component Data Now Available

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

3.1.7 Analytical Approach

3.1.7.1 Overall Approach

The analysis of the hydrologic data consisted of treating each watershed containing focal projects as both *baseline* and *test*. The observed hydrograph at a station was used as the *test* 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 the influence of focal projects on the 2008. Additional details regarding this analytical approach are found in RAMP (2009).

3.1.7.2 Analytical Approach for 2008

The RAMP 2008 hydrology analysis consisted of the following steps:

- Estimation of the 2008 *baseline* hydrographs;
- Review and selection of hydrologic measurement endpoints and calculation of endpoint values from the *baseline* and observed, *test* hydrographs; and
- Application of criteria to be used in assessing change in the hydrologic measurement endpoints.

Table 3.1-2 Summary of RAMP data available for the Climate and Hydrology component, 1997 to 2008.

see symbol key at bottom

Location	Station Number	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Climate Stations																																																	
Aurora Climate Station	C1	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h
Horizon Climate Station	C2																																																h
McClelland Lake	L1																						a	a	a		a	a			a	a	a						c	c	cg	i	i	i	i	i	i	i	i
Kearl Lake	L2																																												i	i	i	i	i
Iyinimin Creek above Kearl Lake	S3						a	a	a		a	a	a						a	a	a		a	a	a		a								a	a			a	a	a			c			c	c	c
Muskeg River above Muskeg Creek	S5A																					e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e	e
Mills Creek at Highway 63	S6														e	e	e																																
Kearl Lake Outlet	S9										e	e	e																																				
Calumet River near the Mouth	S16																						h	h	h	cf	cf	cf	cf	f	cf	cf	cf	cf	cf	f													
Tar River Lowland Tributary near the Mouth	S19																						a	a	a		a	a	a		a	a	a		a	a	a	c	c	c	c	c	c	c	c	c	c	c	c
Christina River near Chard	S29																						a	a	a		a	a	a		a	a	a																
Muskeg River Basin Snowcourse Survey			d				d				d				d				d																														
Fort Creek Basin Snowcourse Survey															d																																		
CNRL Area Snowcourse Survey																			d				d				d																						
Wide-Area Snowcourse Survey																														d				d				d				d				d			
Athabasca River Tributaries																																																	
Mills Creek at Highway 63	S6		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	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	2	2	2	2	2t	2t	2t
Fort Creek at Highway 63	S12														2	2	2		2	2	2		2	2	2														2	2	2		2	2	2		2	2	2
Ells River above Joslyn Creek	S14																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2				
Ells River at CNRL Bridge	S14A																																2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2t	2	2t	2t	2t
Tar River near the Mouth	S15																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2								
Tar River near the Mouth	S15A																																										2	2	2		2t	2t	2t
Calumet River near the Mouth	S16																		2	2	2		2	2	2		2t	2t	2t		2	2	2t																
Tar River Upland Tributary	S17																		2	2	2		2	2	2		2	2	2		1	1	1																
Upland Calumet River	S18																		2	2	2																												
Calumet River Upland Tributary	S18A																						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Susan Lake Outlet	S25																						2	2	2														2	2	2		2	2	2		2	2	2
MacKay River near Fort McKay (07DB001)	S26		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Tar River above CNRL Lake	S34																																		2	2	2		2	2	2	2	2	2	2	2	2t	2t	2t
McClelland Lake Outlet at McClelland Lake	S35																																														2	2	2
McClelland Lake Outlet above Firebag River	S36																																														2	2	2
Steepbank River near Fort McMurray (07DA006)	S38		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4
Beaver River above Syncrude (07DA018)	S39		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4
MacKay River at Petro-Canada Bridge	S40																																													2	2t	2t	2t
Athabasca River Mainstem																																																	
Athabasca River below Eymundson Creek	S24																		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Legend

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

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

Test (downstream of focal projects) [blue shading]
Baseline (upstream of focal projects) [green shading]

Table 3.1-2 (Cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Basin																																																	
Alsands Drain	S1		2	2			2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2																								
Jackpine Creek at Canterra Road	S2		2	2	2		2	2			2	2			2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	2t
Iyinimin Creek above Kearl Lake	S3		2	2	2		2	2	2		2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Blackfly Creek near the Mouth	S4		2	2	2		2	2	2																																								
Muskeg River above Stanley Creek	S5																										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River above Muskeg Creek	S5A		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2t	2t	2t	2t	2t	2t	2t	2t	2t	2	2	2	2	2	2t	2t	2t
Muskeg River near Fort McKay (07DA008)	S7		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Stanley Creek near the Mouth	S8											1	1		1	1	1		1	1	1		1	1	1		1	1	1																				
Kearl Lake Outlet	S9						2	2	2		2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Wapasu Creek at Canterra Road	S10		2								2	2	2						2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Albian Pond 3 Outlet	S13														2	2	2		2	2	2		2	2	2																								
Muskeg River Upland	S20																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Shelley Creek near the Mouth	S21																		1	1	1		1	1	1		1	1	1																				
Muskeg Creek near the Mouth	S22																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Aurora Boundary Weir	S23																	2	2	2	2	2	2	2	2																								
Khahago Creek below Black Fly Creek	S28																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2				
Muskeg River at the Aurora/Albian Boundary	S33																										2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
East Jackpine Creek near the 1300 m Contour	S37																																												2		2	2	2
Muskeg River High Water Gauging				3				3				3				3				3																													
Jackpine Creek High Water Gauging				3				3												3																													
Clearwater River Mainstem																																																	
Clearwater River above Christina River (07CD005)			4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4
Clearwater River at Draper (07CD001)		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Clearwater River Tributaries																																																	
Christina River near Chard (07CE002)	S29																					2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Hangingstone River at Highway 63	S30																						2	2	2																								
Hangingstone Creek near the Mouth	S31																						2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Surmont Creek at Highway 881	S32																						2	2	2						2	2	2		2	2	2		2	2	2		2	2	2		2t	2t	2t
Wetlands																																																	
McClelland Lake	L1			2	2		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2	2	2	2	2		2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Kearl Lake	L2										1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1t	1t	1t	1t	1t
Isadore's Lake	L3													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Regional Data																																																	
Compilation of Environment Canada data																																		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Compilation of WBEA data																																										√	√	√	√	√	√	√	√

Legend

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

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

Test (downstream of focal projects) [blue]
Baseline (upstream of focal projects) [green]

3.1.7.3 Estimation of 2008 Baseline Hydrographs

2008 *baseline* hydrographs are defined for this analysis as the hydrograph that would have been observed in 2008 had there been no focal projects in the watershed. The 2008 *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 change due to focal projects.

2008 *baseline* hydrographs were estimated for the outlet of each major watershed by adding water withdrawals, subtracting water releases and accounting for land-use changes within the watershed of the 2008 observed hydrographs. The computation of the 2008 *baseline* hydrograph for the outlet of a given watercourse is:

2008 *Baseline* Hydrograph = 2008 Observed, *test* Hydrograph

+ water withdrawals in 2008 by focal projects

- water releases in 2008 by focal projects

+ natural runoff that would have occurred within the watershed in 2008, but did not occur due to closed-circuited land resulting from focal projects or areas where runoff is intercepted by focal projects

- incremental runoff from areas that were cleared and areas that were dewatered within the watershed as of 2008

- the difference between observed hydrographs and estimated *baseline* hydrographs on tributaries upstream of the station in question (particularly when considering the mainstem of the Athabasca River).

The above approach does not account for indirect factors, 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. An attempt was made to obtain a more reliable relationship between natural and cleared-land runoff response using data collected at the Shell Jackpine and Petro-Canada Fort Hills project sites, but the results were highly variable and inconclusive. Therefore the estimate of a 20% increase was retained for this analysis.

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 as measured at the mouth of the major watercourses in the RAMP FSA. The monitoring of *baseline* catchments in RAMP provides a secondary basis for comparison.

3.1.7.4 Review, Selection, and Generation of Hydrologic Measurement Endpoints

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

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

These measurement endpoints are hydrologic measurement endpoints used in various oil sands project EIAs (RAMP 2009), can be computed from one year of data, and were selected for the analysis of the 2008 data. Values for each of these four measurement endpoints were calculated for the observed (*test*) and *baseline* hydrographs and a percent change in the measurement endpoints between the *test* and *baseline* values was calculated.

3.1.7.5 Classification of Results

In the current report, the percent change in the hydrologic measurement endpoints calculated between the *test* and *baseline* hydrographs were used for classifying hydrologic results as follows: ± 5% - Negligible-Low; ± 15% - Moderate; > 15% - High. These ranges were derived from criteria for determining effects on hydrologic measurement endpoints in a number of EIAs prepared for oil sands projects (RAMP 2009). In past years, the category Negligible-Low consisted of two separate categories of Negligible (± 2%) and Low (± 5%); however, they were combined in 2008 as it was recognized that the uncertainty in hydrologic variables, based on instrumentation precision and standard hydrometric techniques is at least ± 5%, which therefore represents the lowest level of change that can realistically be detected.

3.2 WATER QUALITY COMPONENT

3.2.1 Summary of 2008 Monitoring Activities

Monitoring activities in 2008 for the Water Quality component were conducted in four sampling campaigns: winter (March 25 to 26); spring (May 12 to 14, May 20); summer (July 14 to 26); and fall (September 3 to 12).

Water quality sampling in 2008 focused on the Athabasca River and its major tributaries in the RAMP FSA, as well as regionally-important lakes and wetlands. Additional data were contributed by AENV and operators of individual projects for some locations (primarily on the Muskeg River). Water quality was sampled at 45 RAMP stations in 2008. Table 3.2-1 summarizes the location of 2008 water quality sampling stations, seasonal distribution of the sampling effort, and water quality variables measured at each station; Figure 3.2-1 indicates the locations of the water quality stations sampled in 2008. Sampling intensity was greatest during the fall campaign, with samples collected from all 2008 RAMP monitoring stations in that season. RAMP's standard protocol for newly-established water quality stations is to sample seasonally for three years and then to sample once in the fall (Table 3.2-1).

3.2.2 Summary of Field Methods and Sample Analysis

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

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

Table 3.2-1 Summary of sampling for the RAMP 2008 Water Quality component.

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	Winter	Spring	Summer	Fall	
Athabasca River								
ATR-DC-E	Athabasca River upstream of Donald Creek (east bank)	475083	6298296	1	-	-	1	East bank grab
ATR-DC-W	Athabasca River upstream of Donald Creek (west bank)	474779	6298286	1	-	-	1	West bank grab
ATR-DD-E	Athabasca River downstream of all development (east bank)	463856	6367949	1	1	1	1	East bank grab
ATR-DD-W	Athabasca River downstream of all development (west bank)	463409	6368232	1	1	1	1	West bank grab
ATR-FR	Athabasca River upstream of the Firebag River	478251	6400119	-	-	-	1	Cross channel composite
ATR-MR-E	Athabasca River upstream of the Muskeg River (east bank)	463617	6332029	-	-	-	1	East bank grab
ATR-MR-W	Athabasca River upstream of the Muskeg River (west bank)	463202	6331847	-	-	-	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)	470958	6319634	-	-	-	1	East bank grab
ATR-SR-W	Athabasca River upstream of the Steepbank River (west bank)	470795	6319195	-	-	-	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	461584	6363103	-	-	-	7	Mid-channel grab
MCC-1	McLean Creek (mouth)	474629	6306033	-	-	-	2	Mid-channel grab
Steepbank River								
NSR-1	North Steepbank River	497420	6324279	-	-	-	1	Mid-channel grab
STR-1	Steepbank River (mouth)	471314	6320162	1	-	-	1	Mid-channel grab
STR-2	Steepbank River upstream of Suncor Millennium	485826	6309338	-	-	-	1	Mid-channel grab
STR-3	Steepbank River upstream of North Steepbank River	495681	6299523	-	-	-	1	Mid-channel grab
Muskeg River and Muskeg River Tributaries								
MUR-1	Muskeg River (mouth)	463469	6332410	-	-	-	1	Mid-channel grab
MUR-2	Muskeg River upstream of Canterra Road crossing	466576	6340478	4	4	4	4	Industry sampling
MUR-2	Muskeg River downstream of Canterra Road crossing	465545	6338322	15	15	15	14	AENV sampling
MUR-4	Muskeg River upstream of Jackpine Creek	474379	6349075	4	10	10	10	Industry sampling
MUR-5	Muskeg River upstream of Muskeg Creek	476043	6351800	10	10	10	10	Industry sampling
MUR-6	Muskeg River upstream of Wapasu Creek	492115	6355705	-	-	-	7	Mid-channel grab
IYC-1	Iyinimin Creek (mouth)	489427	6345181	-	-	-	1	Mid-channel grab
JAC-1	Jackpine Creek (mouth)	474995	6344038	-	-	-	1	Mid-channel grab
JAC-2	Jackpine Creek (upper river)	480023	6325019	-	-	-	1	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	480992	6349024	1	1	1	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477377	6356653	-	-	-	1	Mid-channel grab
WAC-1	Wapasu Creek at Canterra Road crossing	490293	6355914	-	-	-	1	Mid-channel grab
Firebag River								
FIR-1	Firebag River (mouth)	478967	6400063	-	-	-	1	Mid-channel grab
FIR-2	Firebag River upstream of Suncor Firebag	531528	6354782	-	-	-	1	Mid-channel grab

Table 3.2-1 (Cont'd.)

Station Identifier and Location		UTM Coordinates (NAD83, Zone 12)		Analytical Package by Season				Sample Type
		Easting	Northing	Winter	Spring	Summer	Fall	
Tributaries to the Athabasca River (Western)								
BER-1	Beaver River (mouth)	463651	6330926	-	-	-	1	Mid-channel grab
BER-2	Beaver River (upper river)	534448	6311273	1	1	1	1	Mid-channel grab
CAR-1	Calumet River (mouth)	460816	6363192	-	-	-	1	Mid-channel grab
CAR-2	Calumet River (upper river)	454093	6367001	-	-	-	1	Mid-channel grab
ELR-1	Ells River (mouth)	459238	6351491	-	-	-	1	Mid-channel grab
ELR-2	Ells River (upstream)	455743	6344940	-	-	-	1	Mid-channel grab
MAR-1	MacKay River (mouth)	461236	6336307	1	1	1	1	Mid-channel grab
MAR-2	MacKay River upstream of Petro-Canada MacKay	444682	6314024	1	1	1	1	Mid-channel grab
POC-1	Poplar Creek (mouth)	473071	6308822	-	-	-	1	Mid-channel grab
TAR-1	Tar River (mouth)	458538	6353542	-	-	-	1	Mid-channel grab
TAR-2	Tar River upstream of CNRL Horizon	440260	6361788	-	-	-	1	Mid-channel grab
Tributaries to the Athabasca River (Southern)								
HAR-1	Hangingstone River upstream of Fort McMurray	478653	6276270	-	-	-	1	Mid-channel grab
Clearwater River								
CLR-1	Clearwater River upstream of Fort McMurray	479431	6284197	-	-	-	1	Mid-channel grab
CLR-2	Clearwater River upstream of Christina River	496122	6280509	-	-	-	1	Mid-channel grab
Christina River								
CHR-1	Christina River upstream of Fort McMurray	496551	6280111	-	-	-	1	Mid-channel grab
CHR-2	Christina River upstream of Janvier	511834	6192351	-	-	-	1	Mid-channel grab
Lakes and Wetlands								
ISL-1	Isadore's Lake	463455	6343973	-	-	16	16	Mid-lake grab
KEL-1	Kearl Lake	485049	6350170	-	-	-	16	Mid-lake grab
MCL-1	McClelland Lake	478491	6371451	-	-	-	16	Mid-lake grab
SHL-1	Shipyard Lake	473330	6313525	-	-	16	16	Mid-lake grab
QA/QC[1]								
-				1	1	1	1	Trip and field blanks, split, duplicate

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

Legend to Analytical Packages:

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

Field sampling involved collecting either 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 single grab samples in lakes and wetlands.

Grab samples were collected by submerging each sample bottle to a depth of approximately 30 cm, uncapping and filling the bottle, and recapping at depth. The only exception to this was the oil and grease sample, which was taken from the surface of the water. The ultra-trace mercury bottle was triple-rinsed using this procedure prior to the final sample collection, following guidance from the analytical laboratory[2].

A composite sample was collected at one station on the Athabasca River upstream of the Firebag River (ATR-FR), where an average concentration of monitored variables was desired given the water quality is uniform due to greater mixing unlike stations further upstream. The composite was collected through combining a series of 2 L grabs collected at spaced intervals (Table 3.2-2) 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, ultra-trace mercury bottles were triple-rinsed prior to sample collection, all other bottles were not triple-rinsed.

Table 3.2-2 RAMP water quality composite sample sub-groups.

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

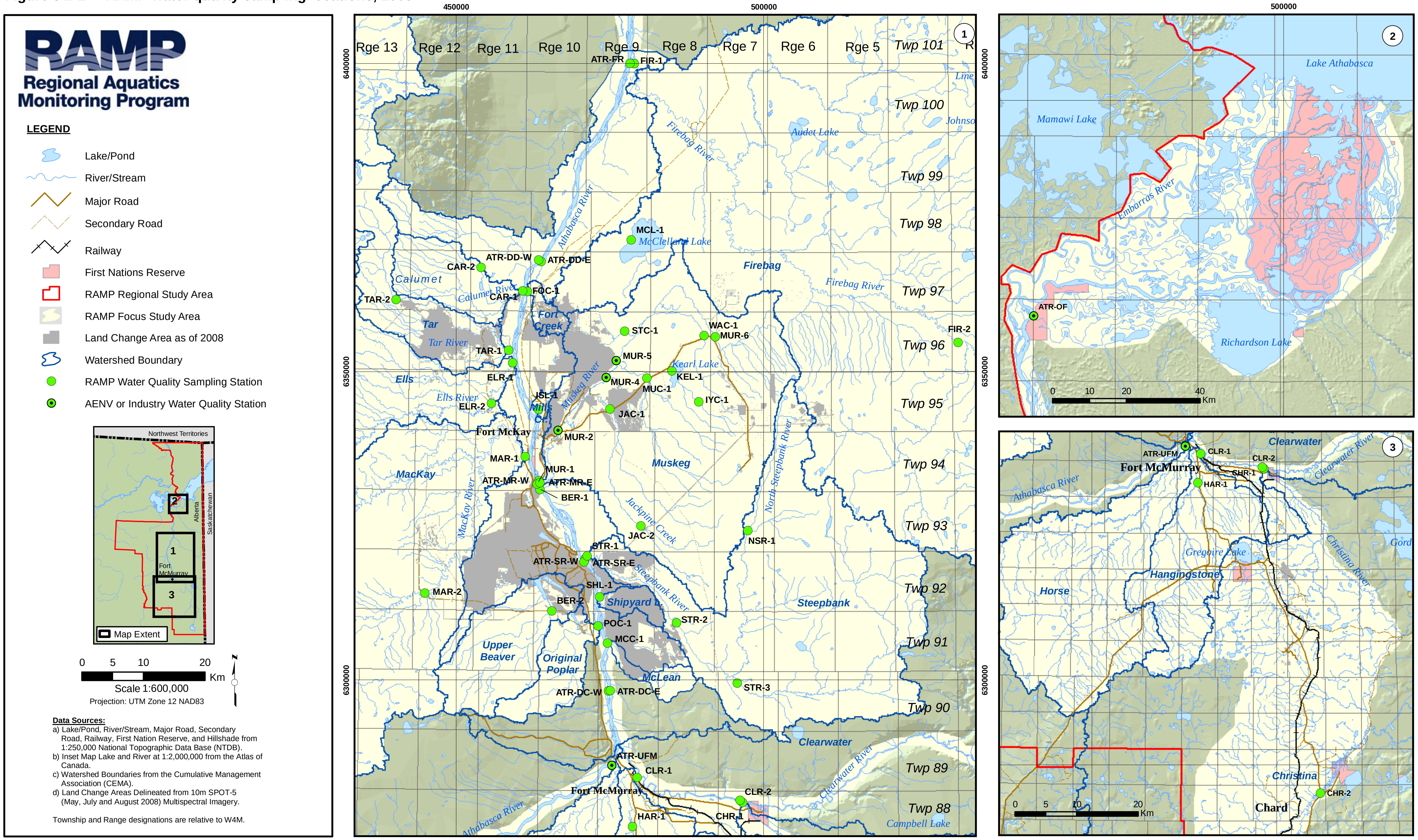
Samples taken at mouths of tributaries were collected approximately 100 m upstream of the confluence where possible to avoid influences of mainstem water on sampled water quality at each station. Similarly, stations located on river mainstems near tributaries were sampled approximately 100 m upstream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

Sampling methods were modified during winter in response to environmental conditions, and to account for and preclude any sampling error or contamination associated with the requisite use of secondary sample transfer vessels and ice augers (all waterbodies sampled during other seasons were free of ice). Water was collected through holes in the river/lake ice drilled using a gas-powered auger. For grab samples, one hole was drilled at the estimated stream thalweg. Samples were collected from approximately 0.2 m below the bottom of the ice layer using a triple-rinsed polymer bucket. Water was transferred to individual sample bottles and then preserved as required. All intermediate sampling equipment was triple-rinsed prior to final sample collection.

Two HOBO® Water Temp Pro automatic temperature sensor/dataloggers for collection of open-water temperature data were deployed during the spring sampling campaign (Table 3.2-3). Locations were selected because of concern regarding potential abnormal changes in water temperature in these tributaries during the open water period. Each sensor was attached to a steel rod anchored in the stream substrate in a pool or other deep area that was expected 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.

[2] All other bottles are no longer triple-rinsed prior to the final sample collection as the bottles are certified clean from the analytical lab.

Figure 3.2-1 RAMP water quality sampling locations, 2008.



K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_F_Water_20090312.mxd

Table 3.2-3 Locations of 2008 continuous water temperature monitoring stations.

Location	Installation Date	Removal Date	Comments
Fort Creek (station FOC-1)	May 20, 2008	Sept 10, 2008	in the water when removed
Muskeg River upstream of Wapasu Creek (station MUR-6)	May 12, 2008	Sept 10, 2008	in the water when removed

All water samples were collected (dissolved organic carbon was filtered), preserved and shipped according to protocols specified by consulting laboratories. All water quality samples taken in 2008 were analyzed for the RAMP standard variables (Table 3.2-4) in all sampling seasons (ALS in Fort McMurray for conventional water quality variables, organics/hydrocarbons, and Alberta Research Council in Vegreville (ARC-Vegreville) 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 one station during the fall sampling campaign (McLean Creek, station MCC-1) was analyzed by Hydroqual Laboratories in Calgary for sublethal toxicity to aquatic organisms using the following three tests: algal growth inhibition, using the freshwater alga, *Pseudokirchneriella subcapitata*[3]; invertebrate survival and reproduction, using the cladoceran, *Ceriodaphnia dubia*; and fish early life-stage survival and growth, using fathead minnows *(Pimephales promelas)*.

3.2.3 Changes in Monitoring Network from 2007

The 2008 monitoring network for the Water Quality component was the same as the 2007 monitoring network with the following exceptions:

- Beaver River (upper river), station BER-2, was added to serve as a *baseline* station for the lower Beaver River and Poplar Creek *test* stations;
- Jackpine Creek (upper river), station JAC-2, was added to serve as a *baseline* station for the lower Jackpine Creek *test* station (station JAC-1) and to add water quality sampling to the already existing sediment and benthic stations at this location;
- Mid-Christina River, station CHR-2A, was removed from the program given the differences between water quality at this station and Christina River upstream of Janvier (station CHR-2) were not significantly different; and
- Shelley Creek station (SHC-1) was not sampled based on program design.

3.2.4 Challenges Encountered and Solutions Applied

Access to certain sites on the Athabasca River was difficult due to out of date navigational charts, and slower and more cautious boating was needed to ensure safety.

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[3] This species was formerly known as *Selanastrum capricornutum.*

Table 3.2-4 RAMP standard water quality variables.

Group	Water Quality Variable	
Conventional variables	Colour	Total dissolved solids (TDS)
	Dissolved organic carbon (DOC)	Total hardness
	pH	Total organic carbon
	Conductivity	Total suspended solids
	Total alkalinity	
Major ions	Bicarbonate	Potassium
	Calcium	Sodium
	Carbonate	Sulphate
	Chloride	Sulphide
	Magnesium	
Nutrients	Nitrate + nitrite	Phosphorus – total
	Ammonia nitrogen	Phosphorus – 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, ultra-trace[1] (Hg)
	Barium (Ba)	Molybdenum (Mo)
	Beryllium (Be)	Nickel (Ni)
	Bismuth (Bi)	Selenium (Se)
	Boron (B)	Silver (Ag)
	Cadmium (Cd)	Strontium (Sr)
	Calcium (Ca)	Thallium (Tl)
	Chlorine (Cl)	Thorium (Th)
	Chromium (Cr)	Tin (Sn)
	Cobalt (Co)	Titanium (Ti)
	Copper (Cu)	Uranium (U)
	Iron (Fe)	Vanadium (V)
	Lead (Pb)	Zinc (Zn)

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

3.2.5 Other Information Obtained

Sampling for the Water Quality component in 2008 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 sampled by Syncrude and Albian Sands (Table 3.2-1); 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 sampled by AENV (Table 3.2-1).

In addition, AENV collects continuous year-round dissolved oxygen monitoring data on the Muskeg River upstream of Stanley Creek (AENV station D2 at RAMP station MUR-4, Figure 3.2-1) and at station MUR-2 with DataSonde probes purchased by RAMP. These supplemental data are provided to RAMP on an annual basis.

3.2.6 Summary of Component Data Now Available

Water quality data collected to date by RAMP are summarized in Table 3.2-5. Table 3.2-5 does not include data collected by AENV and RAMP industry members.

3.2.7 Analytical Approach

The analytical approach used in 2008 for the Water Quality component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2009) and consisted of:

- Review and selection of particular water quality variables as water quality measurement endpoints;
- Review and selection 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; and
- Tabular and graphical presentation of results comparing 2008 concentrations of water quality measurement endpoints, historical concentrations of each endpoint at each station, water quality regional *baseline* conditions, and selected criteria for determining change in water quality.

3.2.7.1 Review and Selection of Water Quality Measurement Endpoints

Depending on the analytical package (Table 3.2-1) over 70 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 2008 technical report; the selection of the measurement endpoints was guided by the following:

- Water quality measurement endpoints used in the EIAs of oil sands projects (see RAMP [2009] 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 1997-2007 water quality dataset indicating significant inter-correlation of various water quality variables, particularly metals (RAMP 2008);
- 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 within the RAMP Technical Program Committee regarding appropriate analytical strategies for the Water Quality component.

Table 3.2-6 presents the water quality variables listed in these various sources.

The final list of water quality measurement endpoints are the following:

- *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 3.2-6). Total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with TSS (Golder 2003a). Dissolved aluminum more accurately represents biologically available forms of aluminum that may be toxic to aquatic organisms (Butcher 2001);
- *Total boron, total molybdenum, total strontium*: three metals found in predominantly dissolved form in waters of the RAMP FSA (RAMP 2004) and which may therefore be indicators of groundwater influence in surface waters;
- *Total arsenic and total mercury (ultra-trace)*: metals of potential importance to the health of aquatic life and human health, which may originate from natural and anthropogenic sources; 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 3.2.7.3.

Table 3.2–5 Summary of RAMP data available for the Water Quality component. (Page 1 of 2)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																	
Upstream of Fort McMurray (grab)[a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1												
(west bank)[b]	ATR-DC-W								1								1
(east bank)[b]	ATR-DC-E								1								1
(middle)	ATR-DC-M																1
Upstream of the Steepbank River (middle)	ATR-SR-M																1
(west bank)	ATR-SR-W																1
(east bank)	ATR-SR-E																1
Upstream of the Muskeg River (middle)	ATR-MR-M																1
(west bank)[b c]	ATR-MR-W								1								1
(east bank)[b c]	ATR-MR-E								1								1
Upstream Fort Creek (cross channel)	ATR-1		1	1	1												
(west bank)[b c]	ATR-FC-W								1								1
(east bank)[b c]	ATR-FC-E								1								1
(middle)	ATR-FC-M																1
Downstream of all development (cross channel)	ATR-DD																
(east bank)	ATR-DD-E																
(west bank)	ATR-DD-W																
Upstream of mouth of Firebag River	ATR-FR																
Upstream of the Embarras River (cross channel)	ATR-ER																1
Embarras River	EMR-1																
At Old Fort (grab)[d]	ATR-OF													11	11	11	11
Athabasca River Delta																	
Big Point Channel[e]	ARD-1											1					1
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1											6	7		6	6	9
(100 m upstream)	MCC-2											6	6				
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1
(upstream of Project Millennium)	STR-2																
(upstream of Nt. Steepbank)	STR-3																
North Steepbank River (upstream of P.C. Lewis)	NSR-1																
Fort Creek (mouth)	FOC-1														7	7	9
Muskeg River																	
Mouth[f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1
Upstream of Canterra Road Crossing[f]	MUR-2									2	9	9	9	10	10	10	10
AENV sampling[g]						13	13	13	11	13	13	13	11	15	15	15	14
Downstream of Alsands Drain	MUR-3																
Upstream of Jackpine Creek[f g h]	MUR-4					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10
Upstream of Muskeg Creek[f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10
Upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9

Waterbody and Location	Station	2001				2002				2003				2004			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																	
Upstream of Fort McMurray (grab)[a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11
Upstream Donald Creek (cross channel)	ATR-DC-CC								1				3				1
(west bank)[b]	ATR-DC-W				3				1				1				1
(east bank)[b]	ATR-DC-E				3				1				1				1
(middle)	ATR-DC-M																
Upstream of the Steepbank River (middle)	ATR-SR-M																
(west bank)	ATR-SR-W				1				1				1				1
(east bank)	ATR-SR-E				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																
(west bank)[b c]	ATR-MR-W				1				1				1				1
(east bank)[b c]	ATR-MR-E				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1																
(west bank)[b c]	ATR-FC-W				3				1				1				
(east bank)[b c]	ATR-FC-E				3				1				1				
(middle)	ATR-FC-M																
Downstream of all development (cross channel)	ATR-DD					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3
(east bank)	ATR-DD-E																
(west bank)	ATR-DD-W																
Upstream of mouth of Firebag River	ATR-FR								1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER				3												
Embarras River	EMR-1												1				
At Old Fort (grab)[d]	ATR-OF	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																	
Big Point Channel[e]	ARD-1				1								1				1
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1		6	6	9	1	6	6	7		6	6	7		6	6	9
(100 m upstream)	MCC-2																
Steepbank River (mouth)	STR-1				1	1			1				1				1
(upstream of Project Millennium)	STR-2					1			1				1				1
(upstream of Nt. Steepbank)	STR-3													1	1	1	1
North Steepbank River (upstream of P.C. Lewis)	NSR-1					1	1	1	1	1	1	1	1	1	1	1	1
Fort Creek (mouth)	FOC-1		6	6	7	1	6	6	7		6	6	7				
Muskeg River																	
Mouth[f]	MUR-1				1				1				1				1
Upstream of Canterra Road Crossing[f]	MUR-2	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling[g]		15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14
Downstream of Alsands Drain	MUR-3																
Upstream of Jackpine Creek[f g h]	MUR-4	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek[f g]	MUR-5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6		6	6	9		6	6	9		6	6	7		6	6	9

Waterbody and Location	Station	2005				2006				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																	
Upstream of Fort McMurray (grab)[a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	11	13	11	13
Upstream Donald Creek (cross channel)	ATR-DC-CC	1	1	1	1	1			1				1				
(west bank)[b]	ATR-DC-W	1	1	1	1				1				1	1			1
(east bank)[b]	ATR-DC-E	1	1	1	1				1				1	1			1
(middle)	ATR-DC-M																
Upstream of the Steepbank River (middle)	ATR-SR-M																
(west bank)	ATR-SR-W				1				1				1				1
(east bank)	ATR-SR-E				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																
(west bank)[b c]	ATR-MR-W				1				1				1				1
(east bank)[b c]	ATR-MR-E				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1																
(west bank)[b c]	ATR-FC-W				1												
(east bank)[b c]	ATR-FC-E				1												
(middle)	ATR-FC-M																
Downstream of all development (cross channel)	ATR-DD	1,1	1	1	1												
(east bank)	ATR-DD-E					1	1	1	1	1	1	1	1	1	1	1	1
(west bank)	ATR-DD-W					1	1	1	1	1	1	1	1	1	1	1	1
Upstream of mouth of Firebag River	ATR-FR				1				1				1				1
Upstream of the Embarras River (cross channel)	ATR-ER																
Embarras River	EMR-1																
At Old Fort (grab)[d]	ATR-OF	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Athabasca River Delta																	
Big Point Channel[e]	ARD-1																
Athabasca River tributaries (Eastern)																	
McLean Creek (mouth)	MCC-1		6	6	9		6	6	9				9				1
(100 m upstream)	MCC-2																
Steepbank River (mouth)	STR-1				1				1				1	1			1
(upstream of Project Millennium)	STR-2				1				1				1				1
(upstream of Nt. Steepbank)	STR-3	1	1	1	1		1	1	1		1	1	1				1
North Steepbank River (upstream of P.C. Lewis)	NSR-1		1	1	1				1				1				1
Fort Creek (mouth)	FOC-1						6	6	7				7		6	6	7
Muskeg River																	
Mouth[f]	MUR-1				1				1				1				1
Upstream of Canterra Road Crossing[f]	MUR-2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling[g]		15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	15
Downstream of Alsands Drain	MUR-3																
Upstream of Jackpine Creek[f g h]	MUR-4	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek[f g]	MUR-5	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6		6	6	9		6	6	7				7		6	6	7

Legend

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

Footnotes

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

(blue) Test (downstream of focal projects)
(light green) Baseline (upstream of focal projects)
(dark green) Baseline, but excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities.

√ = allowance made for potential TIE

Table 3.2–5 (Cont'd.) (Page 2 of 2)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Muskeg River Tributaries																																																	
Alsands Drain (mouth) [f g h]	ALD-1					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10																
Jackpine Creek (mouth) [g]	JAC-1					13	13	13	11	13	13	13	11,1				1				1				1				1				1				1				1				1				1
(upper)	JAC-2																																																1
Shelley Creek (mouth)	SHC-1								11				11,1																												1				1				
Muskeg Creek (mouth)	MUC-1								11,2				11,1				1				1				1				1				1		1	1	1				1				1	1	1	1	1
Stanley Creek (mouth)	STC-1								11				11,1								1	1	1	1	1	1	1	1	1				1		1	1	1				1				1				1
Iyinimin Creek (mouth)	IYC-1																																											1	1				1
Wapasu Creek (Canterra Road Crossing)	WAC-1					2			11	2			11,1																				1				1				1				1				1
Athabasca River tributaries (Western)																																																	
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1				1				1				1				1
Beaver River (mouth)	BER-1																																1			1	1				1				1				1
(upper)	BER-2																																													1	1	1	1
MacKay River (mouth)	MAR-1								1								1				1	1			1				1				1				1				1				1	1	1	1	1
(upstream of P.C. MacKay)	MAR-2																					1			1	1	1	1	1				1				1				1				1	1	1	1	1
Ells River (mouth)	ELR-1						1	1	1						11	11	11	11				1	1	1	2	1	1	1	2	1	1	1	2	1	1	1	2				1				1				1
(upstream of CNRL Lease 7)	ELR-2														11	11	11	14												1	1	1	2		1	1	2		1	1	1		1	1	1				1
Tar River (mouth)	TAR-1						1	1	1													1	1	1	2	1	1	1	2	1	1	1	1		1	1	1				1				1				1
(upstream of CNRL Horizon)	TAR-2																													1	1	1	1		1	1	1		1	1	2		1	1	2				1
Calumet River (mouth)	CAR-1																					1	1	1	2	1	1	1	2	1	1	1	2		1	1	2				1				1				1
Calumet River (upstrream of CNRL Horizon)	CAR-2																																		1	1	2		1	1	2	1	1	1	2				1
Firebag River (mouth)	FIR-1																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1				1				1
(upstream of Suncor Firebag)	FIR-2																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				1				1				1
Athabasca River tributaries (Southern)																																																	
Clearwater River (upstream of Fort McMurray)	CLR-1																	3	8	8	8	1	7	7	8	1	7	7	8	1	7	7	7	1	7	7	7	1	7	7	7		7	7	7				1
(upstream of Christina River)	CLR-2																	3	8	8	8	1	7	7	8	1	7	7	8		6	6	7	1	7	7	7		6	6	7		7		7				1
Christina River (upstream of Fort McMurray)	CHR-1																					1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	1				1	1			1				1
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	1				1	1			1				1
(mid)	CHR-2A																																									1			1				
Hangingstone River (upstream of Ft. McMurray)	HAR-1																														1	1	1		1	1	1		1	1	1		1	1	1				1
Wetlands (Lakes)																																																	
Kearl Lake (composite)	KEL-1							1									1			1	1				1	1			1			1	1			1	1				16			16	16				16
Isadore's Lake (composite)	ISL-1							1									1			1	1												1			1	1			16	16			16	16			16	16
Shipyard Lake (composite)	SHL-1							1			1	1	1			1	1			1	1			1	1			1	1			1	1			1	1			16	16			16	16			16	16
McClelland Lake (composite)	MCL-1																1			1	1				1																16				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		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	1	1	1	1,1	1	1	1	1,1

Legend

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

Footnotes

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

Test (downstream of focal projects) [blue]
Baseline (upstream of focal projects) [light green]
Baseline, but excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities. [dark green]

√ = allowance made for potential TIE

Table 3.2-6 Potential water quality measurement endpoints.

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

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

[1] Primarily Benthic Invertebrate Community and Fish Population Components (inferred).

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

3.2.7.2 Development of Regional Water Quality Baselines

RAMP uses a regional *baseline* approach, in which individual observations are compared against regional *baseline* data. In this approach, water quality data from all RAMP *baseline* water quality stations for 1997 to 2008 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 is more fully described in the RAMP Technical Design and Rationale document (RAMP 2009).

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 2008 dataset indicated three major groups of stations with similar water quality types (Table 3.2-7):

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

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). Where multiple years of data from a station fell across different clusters, data from all years for that station were placed in a single cluster that either: (i) represented the most years of data; or (ii) included other stations from the watershed within which that station was located.

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 2008 was generally consistent with the clusters defined in the 2007 analysis, with the exception of Hangingstone, Ells and MacKay rivers, which were grouped with the northwest tributaries in 2007. These results indicate that *baseline* water quality data collected in 2008 were consistent with the water quality characteristics of each group.

Within each cluster, data from stations designated as *baseline* (i.e., those stations located in areas of watersheds that are not being influenced by focal project activities) were pooled to develop descriptions of regional *baseline* water quality, against which RAMP data from stations designated as *test (i.e.,* downstream of focal project activities*)* and *baseline* were assessed. Table 3.2-8 lists the stations from which *baseline* data from 1997 to 2008 were pooled to develop these *baseline* descriptions. The numbers of observations in regional *baseline* datasets varied by cluster and by water quality measurement endpoint.

3.2.7.3 Tabular and Graphical Presentation of Results

Comparison to Water Quality Guidelines and Historical Data

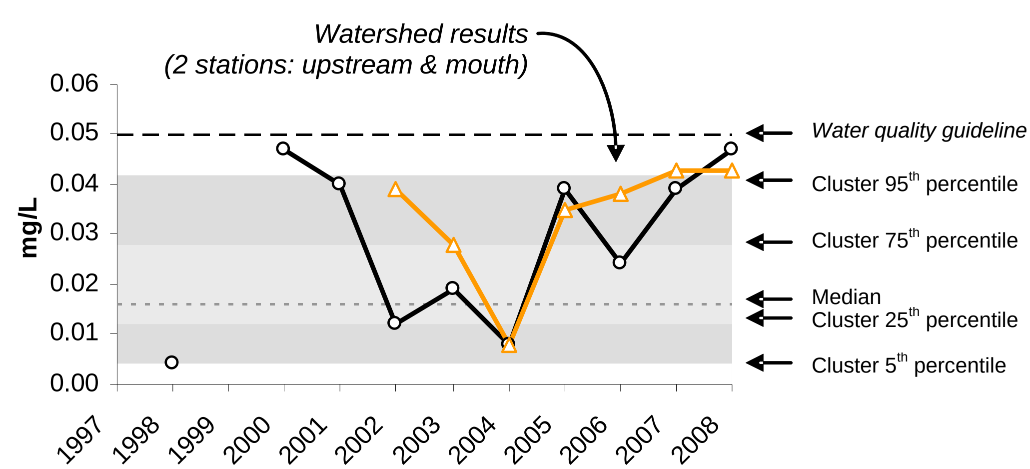
Water quality data from fall 2008 for each water quality measurement endpoint were tabulated for each station sampled. Historical variability was presented for each water quality measurement endpoint, represented by minimum, maximum and median values observed, as well as number of observations, at that station from 1997 to 2008 (fall observations only). All cases in which concentrations of water quality variables—including water quality measurement endpoints and any other monitored water quality variables—that exceeded relevant guidelines were also reported.

Comparison to Natural Variation in Baseline Conditions

To allow a regional comparison, untransformed data for fifteen of the 21 water quality measurement endpoints from all *baseline* stations sampled by RAMP from 1997 to 2008 (fall only) were pooled from each cluster of similar stations (Table 3.2-7). Descriptive statistics describing natural water quality characteristics for each group were calculated; for each water quality cluster (Table 3.2-7), the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined for comparison against station-specific data. The number of observations varied by cluster for each of the fifteen selected water quality measurement endpoints (Table 3.2-9). The median rather than the mean was used as an indicator of typical conditions; given water quality data are characteristically positively skewed.

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

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



[1] in this case, dissolved phosphorus at MacKay River stations MAR-1 (*test*) and MAR-2 (*baseline*)

Table 3.2-7 Classification of groups of RAMP water quality monitoring stations with similar water quality, from 1997 to 2008 data.

Waterbody	Total Number of Station/Year Combinations	Cluster		
		1	2	3
Athabasca River	**102**	**6**	**0**	**96**
Athabasca River Delta	**5**	**0**	**0**	**5**
Eastern Tributaries	**32**	**14**	**15**	**3**
Firebag River	14	14	0	0
Fort Creek	7	0	7	0
McLean Creek	10	0	8	2
Unnamed Creek	1	0	0	1
Regional Lakes	**34**	**16**	**17**	**1**
Isadore's Lake	7	0	7	0
Kearl Lake	10	9	0	1
McClelland Lake	7	7	0	0
Shipyard Lake	10	0	10	0
Muskeg River	**87**	**45**	**41**	**1**
Muskeg River mainstem	43	15	27	1
Alsands Drain	1	0	1	0
Jackpine Creek	11	10	1	0
Muskeg Creek	11	6	5	0
Shelley Creek	3	0	3	0
Stanley Creek	9	6	3	0
Iyinimin Creek	2	2	0	0
Wapasu Creek	7	6	1	0
Southern Tributaries	**36**	**25**	**1**	**10**
Christina River	15	10	0	5
Clearwater River	16	14	0	2
Hangingstone River	5	1	1	3
Steepbank River	**30**	**23**	**5**	**2**
North Steepbank River	7	7	0	0
Steepbank River	23	16	5	2
Western Tributaries	**70**	**15**	**45**	**10**
Beaver River	7	0	7	0
Calumet River	11	0	11	0
Ells River	13	7	2	4
MacKay River	17	8	7	2
Poplar Creek	9	0	9	0
Tar River	13	0	9	4
Total	**396**	**144**	**124**	**128**

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

Shaded entries denote the cluster designated for each waterbody.

Table 3.2-8 Regional baseline water quality data groups and station comparisons.

Regional Baseline Grouping (Cluster)	Baseline Stations Used in Creating Regional Comparison[1]	Stations (2008) Compared Against this Regional Baseline
1. Eastern and southern tributaries to the Athabasca River, plus Kearl Lake, McClelland Lake, Ells and MacKay rivers	FIR-1, FIR-2, FIR-2X, KEL-1, MCL-1, JAC-1, MUC-1, SHC-1, STC-1, WAC-1, MUR-5, MUR-6, CLR-1, CLR-2, STR-2, STR-3, NSR-1, IYC-1, ELR-1, ELR-2, MAR-1, MAR-2	FIR-1, FIR-2, KEL-1, MCL-1, JAC-1, JAC-2, MUC-1, STC-1, MUR-1, MUR-6, CHR-1, CHR-2, CLR-1, CLR-2, STR-1, STR-2, STR-3, NSR-1, IYC-1, WAC-1
2. Several western tributaries to the Athabasca River, plus Fort Creek, McLean Creek, Isadore's Lake, Shipyard Lake, Hangingstone River	FOC-1, CAR-1, CAR-2, TAR-1, TAR-2, BER-2	FOC-1, MCC-1, ISL-1, SHL-1, BER-1, BER-2, CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, POC-1, TAR-1, TAR-2, HAR-1
3. Athabasca River and Athabasca River Delta, Unnamed Creek	ATR-DC-CC, ATR-DC-CC-D, ATR-DC-E, ATR-DC-W, ATR-DC-M, ATR-UFM[2], UNC-1	ATR-DC-E, ATR-DC-W, ATR-SR-E, ATR-SR-W, ATR-MR-E, ATR-MR-W, ATR-FR-CC, ATR-DD-E, ATR-DD-W

[1] See Table 3.2-5 for classification of station status by year. Where station status changed from *baseline* to *test* during 1997-2008, only *baseline* data were used in the determination of regional water quality characteristics.

[2] ATR-UFM data are from the AENV dataset (1976-2007).

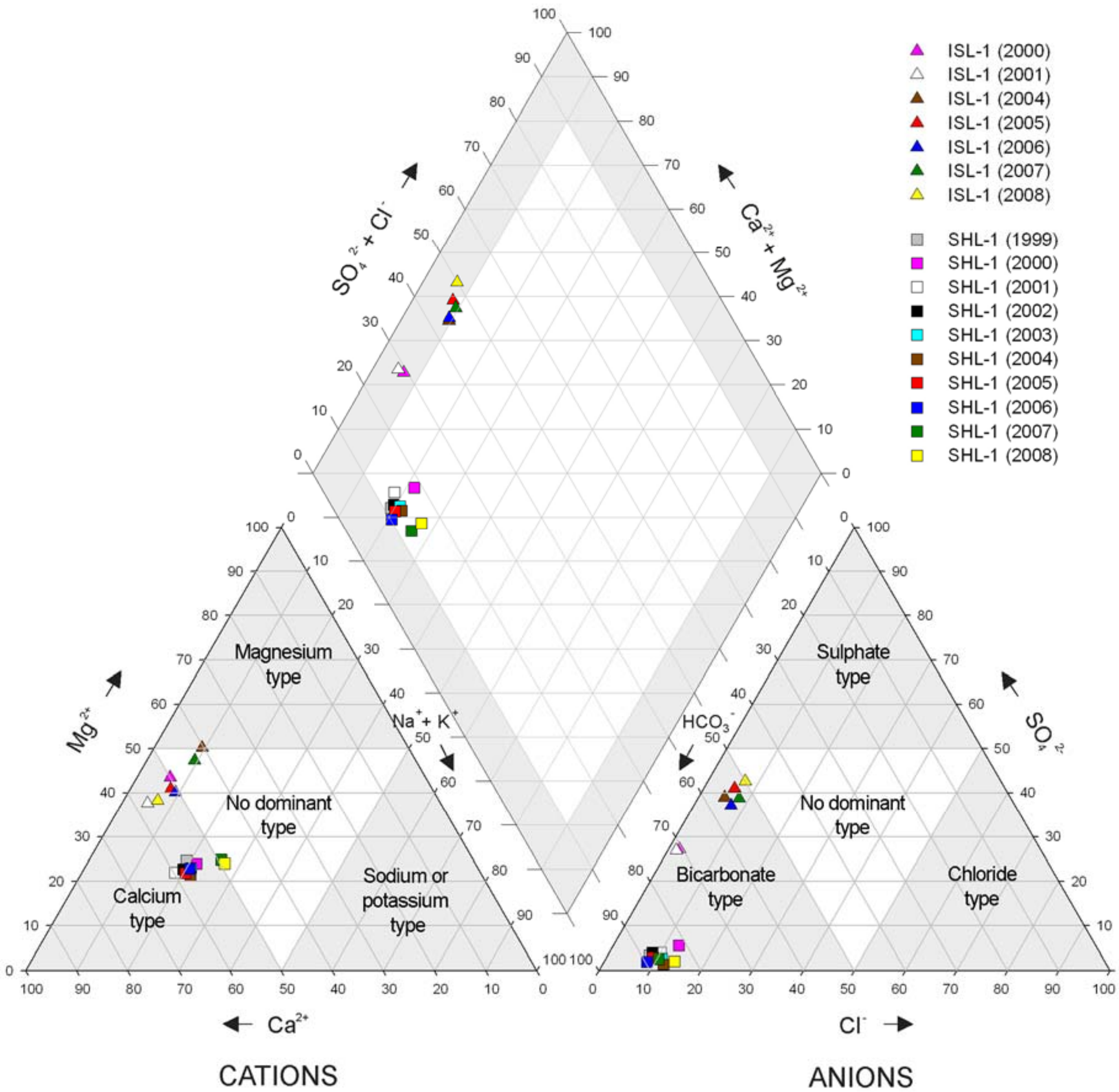
Table 3.2-9 Number of observations for determination of baseline regional water quality.

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)	112	20	28
Total Dissolved Solids (TDS)	112	20	28
Dissolved phosphorus	109	20	28
Total nitrogen	108	20	28
Total strontium	109	20	28
Total boron	109	20	28
Total Mercury (ultra-trace)	67	17	14
Total Arsenic	112	20	28
Naphthenic acids	112	20	28
Calcium	109	20	28
Magnesium	109	20	28
Sodium	109	20	28
Potassium	109	20	28
Chloride	112	20	28
Sulphate	112	20	28

Ion Balance

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

Figure 3.2-3 Example Piper diagram, illustrating relative ion concentrations in waters from Isadore's Lake and Shipyard Lake (1997 to 2008)



Trend Analysis

Statistical trend analysis was undertaken on water quality data for the Athabasca River, which has been monitored continuously by Alberta Environment since 1976. Trend analysis was undertaken on data from: Athabasca River upstream of Fort McMurray (station ATR-UFM, approximately 100 m upstream of the Horse River); and Athabasca River at Old Fort (station ATR-OF), located near the head of the Athabasca River Delta, downstream of the Embarras River tributary. Trend analysis was conducted on specific water quality measurement endpoints (Section 3.2.7.1), including total suspended solids, total dissolved solids, dissolved phosphorus, total nitrogen, total boron, naphthenic acids, total strontium, calcium, chloride, magnesium, potassium, sodium, sulphate and total arsenic, from the period of RAMP sampling (1997 to 2008), to assess trends potentially related to development between the two stations during this time period. Trend analysis also was conducted on the water quality measurement endpoints at those sampling stations where there were at least seven consecutive years of fall water quality data. A Mann-Kendall trend analysis was conducted using the program WQStat Plus, with a level of significance of α=0.05. Values were not flow-averaged before trend analysis, given a lack of concurrent hydrometric data for most sampling stations.

Regional Analysis of Water Quality

In addition to watershed-level analyses, this report includes regional-level analyses of water quality, based on comparisons of water quality in different regional groups (clusters) of water quality stations described above. Specific comparisons include those between historical regional *baseline* data and regional *baseline* data collected in 2008, and between data from *test* stations and regional *baseline* data from 2008 and historically. Results of these comparisons are included in Section 6.

3.2.7.4 Classification of Results

Two criteria for classifying water quality results were used:

- **Comparison to Water Quality Guidelines**: All water quality data collected by RAMP in 2008 in any season were screened against Alberta acute and chronic water quality guidelines for the protection of aquatic life (AENV 1999b) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2007). Variables for which there are no AENV or CCME guidelines were screened against applicable guidelines from other jurisdictions where appropriate (Table 3.2-10). All values that exceeded these guidelines are reported explicitly in the body of the RAMP report.
- **Comparison to Natural Variation in *Baseline* Conditions**: 2008 water quality data for each of the selected water quality measurement endpoints were assessed against a rigorously defined range of natural variability in concentration of each of these measurement endpoints.

Summary indicators of water quality also were based on comparisons with regional *baseline* conditions. Water quality at each RAMP monitoring station in fall 2008 was summarized into a single index value, ranging from 0 to 100, using an approach based on the CCME Water Quality Index[4]. This index is calculated using comparisons of observed water quality against user-specified benchmark values, such as water quality guidelines or background concentrations. It considers three factors: (i) the percentage of variables with values that exceed a given user-specified benchmark; (ii) the percentage of comparisons that exceed a given user-specified benchmark; and (iii) the degree to which observed values exceed user-specified benchmark values.

Index calculations for RAMP water quality data used regional *baseline* conditions, calculated and described in Section 3.2.7.2, as the benchmarks for comparison. Specifically, individual water quality observations were compared to the 95th percentiles of *baseline* concentrations (for the appropriate water quality station cluster) for each water quality variable.

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

Table 3.2-10 Water quality guidelines used to screen data collected by the RAMP Water Quality Component, 2008.

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

[1] CCME (2007).

[2] AENV (1999).

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

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

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

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

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

e: for inorganic mercury

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

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

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

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

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

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

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

Variables included in calculation of the water quality index included all RAMP water quality measurement endpoints (Section 3.2.7.1) (except nitrate+nitrite, which was excluded because of autocorrelation with total nitrogen, which was included in index calculations). Index values were calculated for all *baseline* and *test* stations. Calculation of water quality index values for all stations sampled by RAMP in fall since 1997 (n=374) yielded index values ranging from 49.4 to 100.

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

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

This classification scheme, based on similarity to regional *baseline* conditions, differs somewhat from that used by CCME to classify water quality based on water-quality guidelines. Specifically, only three categories were used (versus five used by CCME), to ensure consistency with classification schemes used for other RAMP components. A classification of "Negligible-Low" difference from baseline in this classification, corresponds with CCME guideline-based index classes "Good" and "Excellent"; RAMP classification of "Moderate" difference from baseline generally corresponds with CCME class "Fair"; and RAMP classification of "High" difference from baseline corresponds with CCME classes "Marginal" and "Poor".

3.3 BENTHIC INVERTEBRATE COMMUNITIES AND SEDIMENT QUALITY

3.3.1 Benthic Invertebrate Community Component

3.3.1.1 Summary of 2008 Monitoring Activities

Benthic invertebrates were collected from September 3 to 12, 2008. A total of 196 samples were collected from 18 river reaches, and four lakes (Figure 3.3-1, Table 3.3-1). As in previous years, river reach samples were collected in the dominant habitat type found in each reach (Table 3.3-1). Habitats were defined as being either depositional (dominated by fine sediment deposits and low to no current) or erosional (dominated by rocky substrates and frequent riffle areas).

3.3.1.2 Summary of Field Methods

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

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

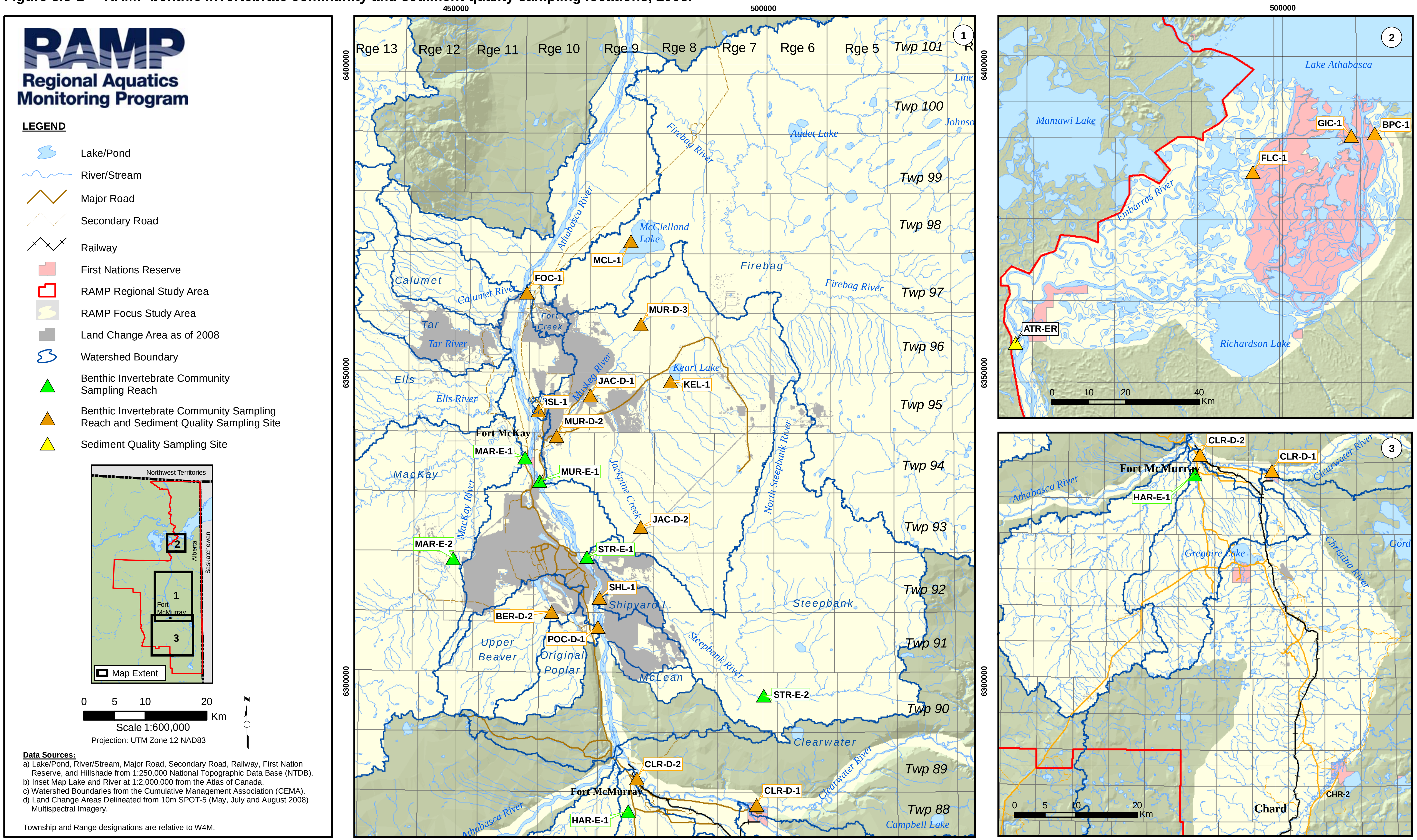
Table 3.3-1 Summary of sampling for the RAMP 2008 Benthic Invertebrate Community component.

Waterbody and Location	Habitat[1]	Reach or Station	UTM Coordinates (NAD 83, Zone 12)			
			Downstream Limit of Reach		Upstream Limit of Reach	
			Easting	Northing	Easting	Northing
Athabasca River Delta						
Goose Island Channel	depositional	BPC	510963	6496226	510934	6496382
Big Point Channel	depositional	FLC	496445	6491625	496509	6491770
Fletcher Channel	depositional	GIC	508179	6495947	508014	6495925
Beaver River						
Upper Reach	depositional	BER-D-2	465552	6311273	465199	6310949
Clearwater River						
Lower Reach	depositional	CLR-D-1	479431	6284197	481529	6283309
Upper Reach	depositional	CLR-D-2	498883	6279869	501149	6279678
Fort Creek						
Lower Reach	depositional	FOC-1	461573	6363104	461592	6363115
Hangingstone River						
Lower Reach	erosional	HAR-E-1	477994	6278877	478135	6277658
Jackpine Creek						
Lower Reach	depositional	JAC-D-1	471874	6346383	473072	6346337
Upper Reach	depositional	JAC-D-2	480023	6325019	480788	6324627
MacKay River						
Lower Reach	erosional	MAR-E-1	461236	6336307	460339	6337159
Upper Reach	erosional	MAR-E-2	449586	6319959	448856	6318805
Muskeg River						
Lower Reach	erosional	MUR-E-1	463613	6332486	464933	6332691
Middle Reach	depositional	MUR-D-2	466388	6339835	466565	6340316
Upper Reach	depositional	MUR-D-3	480101	6357967	482144	6359802
Poplar Creek						
Lower Reach	depositional	POC-D-1	473071	6308822	472701	6308767
Steepbank River						
Lower Reach	erosional	STR-E-1	471318	6320166	472387	6319900
Upper Reach	erosional	STR-E-2	500036	6297643	500996	6207509
Lakes[2]						
Kearl Lake	lake	KEL-1	484917	6348686		
McClelland Lake	lake	MCL-1	478122	6370897		
Shipyard Lake	lake	SHL-1	473589	6313227		
Isadore's Lake	lake	ISL-1	463646	6343448		

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

[2] UTM coordinates of first station

Figure 3.3-1 RAMP benthic invertebrate community and sediment quality sampling locations, 2008.



K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_G_BenSed_20090312.mxd

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

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

Laboratory Methods

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

Dr. Jack Zloty in Summerland, BC performed sorting and taxonomic identifications, as in previous years. Samples were sieved in the laboratory using a 250-µm mesh sieve to remove the preservative and any remaining fine sediments. The material retained by the sieve was elutriated using a flotation technique to separate organic material from sand and gravel, and invertebrates from organic material. Samples containing bitumen were treated with paint thinner to remove hydrocarbons prior to sorting. Inorganic material was scanned under a magnifying lens and any remaining invertebrates were removed before discarding. The remaining organic material was separated into coarse and fine size fractions using a 1-mm sieve. The fine size fraction of large samples was sub-sampled using a modification of the method described by Wrona *et al*. (1982) in which fine materials were scanned for invertebrates with the aid of a dissecting microscope at a magnification of 6X to 10X. All sorted material was preserved for random checks of removal efficiency. QA/QC procedures related to sample processing for benthic invertebrate communities are discussed in Appendix B.

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

3.3.1.3 Changes in Monitoring Network from 2007

Beaver River Upper Reach (*baseline* reach BER-D-2) and Poplar Creek Lower Reach (*test* reach POC-D-1) were sampled for the first time in 2008.

3.3.1.4 Challenges Encountered and Solutions Applied

Only seven benthic samples were collected from Poplar Creek Lower Reach (*test* reach POC-D-1) because of time constraints in the field.

3.3.1.5 Other Information Obtained

No additional or supplementary information was obtained as part of the 2008 Benthic Invertebrate Community component.

3.3.1.6 Summary of Component Data Now Available

As of 2008, 2,031 benthic invertebrate community samples have been collected under RAMP. The distribution of stations and reaches, and the time-series of data available for individual locations are presented in Table 3.3-2.

3.3.1.7 Analytical Approach and Methods

The analytical approach used in 2008 for the Benthic Invertebrate Community component was based on the analytical approach described in the RAMP Technical Design and Rationale (RAMP 2009) and consisted of:

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

Selection of Benthic Invertebrate Community Measurement Endpoints

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

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

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

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

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				2007				2008			
				W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Delta																																																			
Athabasca River Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1								1,1				1,1
Calumet River																																																			
Lower Reach	1,2[1]	depositional	CAR-D-1																				2				1				1				1				1												
Upper Reach	1	depositional	CAR-D-2																												1				1				1				1,2								
Christina River																																																			
Lower Reach	1	depositional	CHR-D-1																								1				1				1				1				1,2				1				
Middle Reach	1	erosional	CHR-E-2A																																												1				
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												1
Upstream of Christina River	1	depositional	CLR-D-2																				1				1				1				1				1												1
Ells River																																																			
Lower Reach	1	depositional	ELR-D-1																												1				1				1				1,2				1				
Upper Reach	1	erosional	ELR-E-2																												1				1				1				1								
Firebag River																																																			
Lower Reach	1	erosional	FIR-D-1																												1				1				1				1,2				1				
Upper Reach	1	depositional	FIR-E-2																												1				1				1				1				1				
Fort Creek																																																			
Lower Reach	1	depositional	FOC-D-1												2								1				1				1								1,2				1,2				1,2				1,2
Hangingstone River																																																			
Lower Reach	1	erosional	HAR-E-1																																1				1				1				1				1
Jackpine Creek																																																			
Lower Reach	1	depositional	JAC-D-1																								1				1				1				1				1,2				1				1
Upper Reach	1	depositional	JAC-D-2																												1				1				1				1,2				1				1
MacKay River																																																			
Lower Reach	1	erosional	MAR-E-1																1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	MAR-E-2																								1				1				1				1				1				1				1
Muskeg River																																																			
Lower Reach	1	erosional	MUR-E-1																1				1				1				1				1				1				1				1				1
Middle Reach	1	depositional	MUR-D-2																1				1				1				1				1				1				1,2				1,2				1,2
Upper Reach	1	depositional	MUR-D-3																								1				1				1				1				1,2				1,2				1,2
Steepbank River																																																			
Lower Reach	1	erosional	STR-E-1																1				1				1				1				1				1				1				1				1
Upper Reach	1	erosional	STR-E-2																												1				1				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 station

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

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

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

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Baseline, but excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities.

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

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

Table 3.3-2 (Cont'd.)

see symbol key at bottom

WATERBODY AND LOCATION	TYPE	HABITAT	STATION	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008			
				W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S		F	W	S	S	F
Beaver River																																																			
Lower Reach	1	depositional	BER-D2																																																1
Poplar Creek																																																			
Lower Reach	1	depositional	POC-D1																																																1
Wetlands and Lakes																																																			
Isadore's Lake	1	lake	ISL-1																																						1,2				1,2				1,2
Kearl Lake	1	lake	KEL-1																				1				1				1				1				1				1,2				1,2				1,2
McClelland Lake	1	lake	MCL-1																								1				1												1,2				1,2				1,2
Shipyard Lake	1	lake	SHL-1																1				1				1				1				1				1				1,2				1,2				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 station

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

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

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

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Baseline, but excluded from Regional Baseline calculations because of upstream non-RAMP oil-sands activities.

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

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

- 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. In situations where S = 1 (i.e., only one taxon was identified in a sample), evenness was set to 1; and

- Percent EPT (Ephemeroptera, Plecoptera, Trichoptera).

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

3.3.1.8 Detailed Data Analysis

Determination of Regional Baseline Conditions

An ordination of the data was conducted using Correspondence Analysis (CA) to identify natural groupings of reaches among all the reaches that were designated as *baseline (*Table 3.3-2). The axes of the results of the Correspondence Analysis are also used as benthic invertebrate community measurement endpoints. The technical aspects of the CA are documented in Appendix E.

Depositional and erosional habitats each grouped well in the analysis and justified the calculation of "normal ranges" for each of the benthic community measurement endpoints for erosional and depositional reaches. On the basis of these results, 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 measurement endpoints across all *baseline* sites. The normal range of variability for measurements endpoints was calculated as between the 5^{th} percentile and 95^{th} percentile of the measurement endpoint values. These calculations were made separately for each measurement endpoint and for each habitat type.

Evaluating Potential Changes in Benthic Invertebrate Communities

Possible changes in benthic invertebrate communities were evaluated by comparing benthic invertebrate community measurement endpoints in reaches designated as *test* to upstream *baseline* reaches and/or to pre-development conditions with analysis of variance (ANOVA). When necessary, the measurement endpoints were $\log_{10}$-transformed to meet assumptions of normality and homogeneity of variances. One-way ANOVAs were conducted for each benthic invertebrate community measurement endpoint with each reach-year (or lake-year, as relevant) combination as the factorial variable. Planned linear orthogonal contrasts (Hoke *et al*. 1990) were then used to identify differences between *baseline* and *test* reaches (or lakes), between *baseline* and *test* periods, and differences in time trends between lower *test* reaches and upper *baseline* reaches (or lakes, as appropriate). Differences between reaches designated as *baseline* and reaches designated as *test* were also evaluated for data collected in 2008 only. In all cases, the comparisons were tested against the residual error of the overall one-way ANOVA.

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

The statistical power associated with these various hypothesis testing procedures is quite high with an error-degrees-of-freedom that is frequently > 100. The ability to detect differences is quite substantive, with the detectable effect sizes much less than the within-reach-standard deviation (i.e., small differences, Cohen 1977, Kilgour *et al.* 1998). Statistically significant differences; therefore, may be minor, subtle, or otherwise trivial. As additional aids to interpreting statistical significance we; therefore, examined the nature of the difference to determine if the difference was consistent with a "negative" impact. A reduction in taxa richness, Simpson's Diversity, Evenness and % EPT would each be considered a negative change or difference. Abundance might increase or decrease with an impact. Excessively high abundances (i.e., on the order of 100's of thousands of organisms per m^2) would be considered a negative impact if the fauna was dominated by one or a few taxa (see Kilgour *et al*. 2005), and might be consistent with a nutrient enrichment effect (Lowell *et al*. 2003). In addition, we tested whether non-effect-related variation was significant. This was determined by testing the "remainder" variation, which is based on the remaining treatment sums of squares, left over after considering the specific effects-based contrasts. A significant "remainder" test indicates that there is a considerable amount of noise in the data and can put into question other contrasts that may be statistically significant, but that do not account for as much of the total variation (DFO and EC 1995).

3.3.1.9 Environmental Variables

A number of environmental variables, including physical substrate condition and water temperature, chemistry, and flow velocities were measured at each site. These environmental variables were measured because they 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. An examination of these potential associations was made if the criteria for determination of effect in benthic invertebrate communities were met.

In addition, some general conclusions about the condition of a reach 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 2007). Concentrations below this guideline are indicative of potential risks to aquatic life, especially if those concentrations are observed during the day, which is the typical time of sampling for RAMP; and

- Chlorophyll *a*, one of the environmental variables measured in erosional reaches, was identified early in the Alberta Oil Sands Environmental Research Program (AOSERP) studies as a potential indicator of oil sands activity (Barton and Lock 1979). 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 reaches designated as *baseline* was determined (Appendix E) and is provided in figures that illustrate trends over time in chlorophyll *a* values.

3.3.1.10 Classification of Results

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

Measured changes were classified as Negligible-Low, Moderate and High on the basis of (i) the strength of the statistical signal from a reach (lake), and (ii) whether values produced by the reach (lake) tend to fall within or outside the normal range of variation for reaches (lakes) in a *baseline* condition (Table 3.3-3). Strong statistical signals are considered here to be differences that are statistically significant ($p < 0.05$), and that are about as strong (or stronger) as the background "noise" in reach-year variations (see Section 3.3.1.8 for a discussion of how the "noise" is assessed). There are seven benthic community metrics being assessed. If any one of those metrics produces a strong signal of an effect, then this criterion will be considered to have been met. Allowing any one of the seven measurement endpoints to trigger this criterion assumes that each measurement endpoint represents an attribute of the community that is important. The second criterion will be considered to be met (producing a "yes" in Table 3.3-3) if any measurement endpoint has fallen outside of the normal range of variation of *baseline* conditions for three years in a row. The criterion will also be considered to be met when values for three of the seven metrics fall outside the normal range of variation within the current year. This is particularly relevant for the assessment of waterbodies (reaches or lakes) for which there is not at least a three-year data record within RAMP.

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

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

3.3.2 Sediment Quality

3.3.2.1 Overview of 2008 Program

Sediment samples were collected from 3 to 12 September 2008 at the most downstream replicate sampling location in each depositional reach sampled for benthic invertebrate communities (total of 12 depositional reaches), one site in the Athabasca River that was not sampled for benthic invertebrates, and four regionally-important lakes (Table 3.3-4, Figure 3.3-1).

3.3.2.2 Summary of Field Methods and Sample Shipping and Analysis

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

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

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

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

Sediments were analyzed for the RAMP standard sediment quality variables (Table 3.3-5), as well as sediment toxicity to aquatic organisms at all locations sampled.

3.3.3 Changes in Monitoring Network from 2007

Four additional stations were sampled in 2008 as compared to 2007: stations BER-D-2; POC-D-1; CLR-D-1; and CLR-D-2. BER-D-2 was the only new station added in 2008 and was sampled to provide *baseline* data for comparison to data from *test* station POC-D-1.

3.3.4 Challenges Encountered and Solutions Applied

A sediment sample submitted for analysis of CCME four-fraction hydrocarbon analysis was only analyzed by ALS Environmental for the volatile fraction (i.e., BTEX: benzene, toluene, ethylene and xylene), rather than all hydrocarbon fractions, despite submission of correct chain-of-custody forms with an appropriate analytical request. Follow-up with the laboratory confirmed that this error was caused by miscoding of the analytical requirements for this sample following sample log-in, but before analysis. This missing analysis was not noticed by the RAMP implementation team until data analysis began and after the remaining quantity of this sample had been discarded by the lab.

To reduce the possibility of this occurring in the future, all data will be screened upon receipt (not only upon sample submission) to confirm all analyses were properly completed. The RAMP implementation team also has requested that analytical laboratories keep remaining sediment samples until at least January of the following year, to reduce the risk of analyses not being completed.

3.3.5 Other Information Obtained

No additional sediment quality information for 2008 was obtained.

Table 3.3-4 Summary of sampling for the RAMP Sediment Quality component, September 2008.

Station Identifier and Location		UTM Coordinates (NAD83, Zone12) Easting	Northing	Analytical Package
Athabasca River				
ATR-ER	Athabasca River at Embarras River	468117	6471259	3
Athabasca Delta				
FLC-1	Fletcher Channel	496445	6491625	3
GIC-1	Goose Island Channel	508179	6495947	3
BPC-1	Big Point Channel	510963	6496226	3
Tributaries to the Athabasca River (Eastern)				
FOC-1	Fort Creek	461573	6363104	3
Tributaries to the Athabasca River (Western)				
BER-D-2	Beaver River (upper reach)	463651	6311273	3
POC-D-1	Poplar Creek	473071	6308822	
Tributaries to the Athabasca River (Southern)				
CLR-D-1	Clearwater River (lower reach)	498883	6279869	1
CLR-D-2	Clearwater River (upper reach)	479431	6284197	3
Muskeg River				
MUR-D-2	Muskeg River (middle reach)	466388	6339835	3
MUR-D-3	Muskeg River (upper reach)	480101	6357967	3
JAC-D-1	Jackpine Creek (lower reach)	471874	6346383	3
JAC-D-2	Jackpine Creek (upper reach)	480023	6325019	3
Regional Lakes				
KEL-1	Kearl Lake	484924	6348678	3
MCL-1	McClelland Lake	478491	6371451	3
SHL-1	Shipyard Lake	473328	6313523	3
ISL-1	Isadore's Lake	463455	6343973	3
QA/QC				
-	Two sets of split and duplicate samples			1
-	One rinsate blank			Metals, PAHs

Legend to Analytical Packages:

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

Table 3.3-5 RAMP standard sediment quality variables.

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

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

3.3.6 Summary of Component Data Now Available

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

3.3.7 Analytical Approach

The analytical approach undertaken for the sediment quality component in 2008 was generally similar to that of recent previous years, and consisted of:

- Review and selection of particular sediment quality variables as sediment quality measurement endpoints, including predicted toxicity of sediments due to PAHs (calculated using an equilibrium-partitioning model);
- Tabular presentation of 2008 results, comparing 2008 concentrations of the sediment quality measurement endpoints to concentrations previously observed within the reach, where data were available, and sediment quality guidelines; and
- Analysis of the relationship between various sediment quality measurement endpoints and benthic invertebrate community measurement endpoints, using correlation analysis.

These steps are described in detail below.

3.3.7.1 Selection of Sediment Quality Measurement Endpoints

A number of sediment quality variables were selected as sediment quality measurement endpoints for the 2008 technical report; the selection of the measurement endpoints was guided by information obtained from a number of sources (Table 3.3-7):

- Sediment quality measurement endpoints listed in the environmental impact assessments of oil sands projects as being potentially affected by oil sands development activities (RAMP 2009);
- Sediment quality variables of interest listed in the RAMP 5-year report (Golder 2003a);
- Results of correlation analysis of the RAMP 1997-2004 sediment quality dataset indicating significant inter-correlation of various sediment quality variables;
- Discussions among RAMP Component Managers about the importance of various sediment quality variables to interpretation of other RAMP components (e.g., benthic invertebrate communities, fish populations); and
- Discussions with RAMP Technical Program Committee members, regarding approaches and strategies for the sediment quality component.

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

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

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

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006*				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																																	
Upstream of Fort McMurray (cross channel)	ATR-UFM																								1				3				1																
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				3				3								1				3				1				3				1																
(east bank)[a]	ATR-DC-E				3				3								1				3				1				3				1																
Upstream of Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1																
(east bank)	ATR-SR-E																1				3				1				3				1																
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								3								1				3				1				3				1																
(east bank)[a b]	ATR-MR-E								3								1				3				1				3				1																
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				3				3								1				3				1				3																				
(east bank)[a b]	ATR-FC-E				3				3								1				3				1				3																				
Testing inter-site variability (3 composite samples)	-																1								1																								
Downstream of all development (west bank)	ATR-DD-W																								1				3				1																
(east bank)	ATR-DD-E																								1				3				1																
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1																
(east bank)	ATR-FR-E																								1				3				1																
Upstream of the Embarras River	ATR-ER																3				1				1				3				1				1								1				3
Athabasca Delta / Lake Athabasca																																																	
Delta composite[c]	ARD-1											3					3																																
Big Point Channel	BPC																				3				3				3								1								1				3
Goose Island Channel	GIC																				3				3				3								1								1				3
Fletcher Channel	FLC																				3				3				3								1								1				3
Flour Bay	FLB-1																3																																
Athabasca River Tributaries (South of Fort McMurray)																																																	
Clearwater River (upstream of Fort McMurray)	CLR-1/CLR-D-1																				1				3				3																				3
(upstream of Christina River)	CLR-2																				1				3				3																				3
Christina River (upstream of Fort McMurray)	CHR-1																								1				3				3																
(upstream of Janvier)	CHR-2																								1				3				3																
(benthic reach at mouth)	CHR-D-1																																								3				1				
benthic reach at upper Christina River)	CHR-D-2																																								3								
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																3				3												
Athabasca River Tributaries (North of Fort McMurray)																																																	
McLean Creek (mouth)	MCC-1												3				3				1				3												3												
Beaver River	BER-D-2																																																3
Poplar Creek (mouth)	POC-1/POC-D-1				1																				3								3																3
Steepbank River (mouth)	STR-1				1				1																3												3												
(upstream of Suncor Project Millennium)	STR-2				1																				3												3												
(upstream of North Steepbank)	STR-3																																				3												
North Steepbank River (upstream of P.C. Lewis)	NSR-1																								3				3				1				1												
MacKay River (mouth)	MAR-1				1				1												3				3								3																
(upstream of Petro-Canada MacKay)	MAR-2																				1				3								3																

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)
2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus,* Hyalella azteca)
3 = standard sediment quality + toxicity testing
√ = allowance made for potential TIE
* Sediment program integrated with Benthic Invertebrate Community component in 2006.

Footnotes

[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the ARD Delta)
[b] Samples were collected downstream of tributary in 1998
[c] In 1999, one composite sample was collected from Big Point Goose Island, Embarras and an unnamed side channel

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

Table 3.3-6 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005				2006*				2007				2008			
		W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River Tributaries (North of Fort McMurray) (cont'd)																																																	
Ells River (mouth)	ELR-1								1																3				3				3				1												
(benthic reach at mouth)	ELR-D-1																																								3				3				
(upstream of CNRL Lease 7)	ELR-2																																3				1												
Tar River (mouth)	TAR-1								1																3				3				1				1												
(benthic reach at mouth)	TAR-D-1																																								3								
(upstream of CNRL Horizon)	TAR-2																																1				1												
Calumet River (mouth)	CAR-1																								3								3				3												
(upstream of CNRL)	CAR-2																																				3												
(benthic reach at upper Calumet)	CAR-D-2																																								3								
Fort Creek (mouth)	FOC-1																1								3																								
(benthic reach at mouth)	FOC-D-1																																				3				3				3				3
Firebag River (mouth)	FIR-1																								3				3				1				1												
(benthic reach at mouth)	F1R-D-1																																								3				1				
(upstream of Suncor Firebag)	FIR-2																								3				3				1				1												
Muskeg River																																																	
Mouth	MUR-1				1				1				3				1				1				3				3				3																
1 km upstream of mouth	MUR-1b																1												1																				
Upstream of Canterra Road Crossing	MUR-2																1								3				3				3																
Upstream of Jackpine Creek	MUR-4				1												1												1																				
Upstream of Muskeg Creek	MUR-5																1												1																				
Upstream of Stanley Creek	MUR-D-2																								3				3				3																
Upstream of Wapasu Creek	MUR-6																1												1																				
(benthic reach - downstream of Jackpine Creek)	MUR-D-2																																								3				3				3
(benthic reach - upstream of Stanley Creek)	MUR-D-3																																								3				3				3
Muskeg River Tributaries																																																	
Jackpine Creek (mouth)	JAC-1				1																												3																
(benthic reach at mouth)	JAC-D1																																								3				1				3
(benthic reach at upper Jackpine Creek)	JAC-D2																																								3				1				3
Stanley Creek (mouth)	STC-1																												1																				
Wetlands																																																	
Kearl Lake (composite)	KEL-1																				1												1								3				3				3
Isadore's Lake (composite)	ISL-1																				1																				3				3				3
Shipyard Lake (composite)	SHL-1																				1				3				1				3								3				3				3
McClelland Lake (composite)	MCL-1																								1																3				3				3
Additional Sampling (Non-Core Programs)																																																	
Potential TIE	-																				√																												
QA/QC																																																	
One split and one duplicate sample	-																1				1				1				1				1				1				1				1				1

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)
2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus, Hyalella azteca*)
3 = standard sediment quality + toxicity testing
√ = allowance made for potential TIE
* Sediment program integrated with Benthic Invertebrate Community component in 2006.

Footnotes

[a] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the ARD Delta)
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Baseline (upstream of focal projects)
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Table 3.3-7 Potential sediment quality measurement endpoints.

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

1 Primarily Benthic Invertebrate Community component (inferred).

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

- *Total hydrocarbons (CCME fractions)*: Indicators of the total hydrocarbon content of sediments, with each indicator (fraction) capturing hydrocarbon compounds of different molecular weights (specifically, number of carbon atoms), based on methods presented by CCME (2001);
- *Various PAH measurement endpoints,* including*:*
  - *Total PAHs:* a sum of concentrations of all PAHs measured in a given sample, including parent and alkylated forms;
  - *Total parent PAHs:* a sum of concentrations of all non-alkylated PAHs measured in a given sample;
  - *Total alkylated PAHs:* a sum of concentrations of all alkylated PAHs measured in a given sample;
  - *Naphthalene:* a volatile, low-molecular-weight PAH that may cause toxicity when dissolved in water;
  - *Total dibenzothiophenes:* a sulphonated PAH (parent and alkylated forms) that is associated with bitumen (i.e., petrogenic);
  - *Retene:* an alkylated phenanthrene generated through decomposition of plant materials (i.e., biogenic rather than petrogenic); and
  - *Predicted PAH toxicity:* an estimate of the cumulative toxicity of all PAHs in a sediment sample (the methodology for calculating predicted PAH toxicity is presented in Appendix F);

- *Metals:* With the exception of total arsenic (see below), only metals in sediment that exceeded CCME Interim Sediment Quality Guideline (ISQG) values (CCME 2002) were presented, as metals in sediments are not listed in oil sands EIAs as being potentially affected by development (RAMP 2009);

- *Total arsenic:* In analyses of sediment quality in the Athabasca River Delta (Section 5.1) and in regional analyses of sediment quality in tributaries (Section 6), data for total arsenic in sediments are presented, given recent stakeholder concerns regarding arsenic in regional sediments; and

- *Sublethal toxicity:* sublethal toxic effects of whole sediment samples on the survival and growth of the amphipod (seed-shrimp) *Hyalella azteca* or the midge *Chironomus tentans.*

3.3.7.2 Tabular Presentation of 2008 Sediment Quality Results

2008 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 2008 at the historically-sampled station within the reach. Concentrations of any sediment quality measurement endpoint and any metal that exceeded relevant guidelines were also reported.

3.3.7.3 Correlation with Benthic Invertebrate Community Measurement Endpoints

Spearman's rank correlations were used to evaluate the relationship between benthic invertebrate community measurement endpoints (i.e., abundance, diversity, evenness, taxa richness, and Ephemeroptera, Plecoptera and Trichoptera [EPT] values) and selected sediment quality measurement endpoints. Correlations were calculated for all depositional stations, sampled at the lowest (most downstream) end of the reach. Correlations greater than r_s of $|0.283|$ were indicative of statistically-significant relationships for n=48 (number of depositional stations) (α=0.10, two-tailed test). Moderate correlations were defined as those ranging from $|0.50|$ to $|0.75|$, while strong correlations were defined as those ranging from $|0.75|$ to $|1.00|$.

3.3.7.4 Classification of Results

Sediment quality in each depositional benthic-invertebrate sampling reach in fall 2008 was summarized using the CCME Sediment Quality Index calculator, (http://www.ccme.ca/ourwork/water.html?category_id=103). This index uses an identical calculation to that developed by CCME for water quality (see Section 3.2.7.4), also yielding a single index value ranging from 0 to 100.

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

Index calculations for RAMP sediment quality data used regional *baseline* conditions, calculated and described in Section 3.2.7.4, as benchmarks for comparison. Specifically, 5th or 95th percentiles of *baseline* values for all variables included in the index were used as benchmarks against which individual water quality observations were compared. All sediment quality data collected by RAMP since 1997 at stations classified as *baseline* was used to develop *baseline* ranges of sediment quality.

Seventy-eight sediment-quality variables were included in calculation of the index, including total and fractional hydrocarbons, all parent and alkylated PAH species, all metals measured consistently in sediments by RAMP since 1997, and sediment-toxicity endpoints. For hydrocarbons and metals, data were compared against the 95th percentile of *baseline* data, while for sediment-toxicity endpoints, data were compared against the 5th percentile. Index values were calculated for all *baseline* and *test* stations. For all sediment-quality station observations from 1997 to 2008 (n=243), sediment quality index values of 45.7 to 100 were calculated.

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

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

3.4 FISH POPULATION COMPONENT

3.4.1 Overview of 2008 Monitoring Activities

The following monitoring activities were conducted in 2008 for the Fish Population component:

- Spring, summer, and fall fish inventories on the Athabasca River and spring and fall fish inventories on the Clearwater River;
- Tissue analyses and health evaluations on target fish species in the Athabasca River (fall sampling); and
- Tissue analyses on target fish species in two regional lakes: Gardiner (Buffalo) Lake and Big Island Lake (fall sampling).

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

A fish fence planned for spring 2008 on the lower Muskeg River could not be implemented due to prohibitively high water levels during the scheduled installation period (April/May). Measured peak discharge on the river at the beginning of May was 35 m^3/s, which exceeded the safe installation discharge criterion of 9 m^3/s. The fish fence intended to be a repeat of the one carried out in 2006 (postponed in 2007 due to high discharge levels), is scheduled to be implemented in spring 2009, pending assessment of seasonal water levels at that time.

3.4.2 Summary of Field Methods

3.4.2.1 Fish Inventories

Athabasca River and Clearwater River Fish Inventories

In 2008, spring, summer (Athabasca River only) and fall inventories of the following RAMP key indicator fish species (analogous to Key Indicator Resources, KIRs) were carried out on the Athabasca and Clearwater rivers:

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

Table 3.4-1 Summary of 2008 Fish Population component monitoring activities.

Watercourse	Fish Population Component Monitoring Activity	
	Fish Inventory	Fish Tissue
Athabasca River	Spring, summer, and fall: fish community	Fall: walleye, lake whitefish
Clearwater River	Spring and fall: fish community	
Gardiner Lake (Regional Lake)		Fall: walleye, northern pike, lake whitefish
Big Island Lake (Regional Lake)		Fall: walleye, northern pike, lake whitefish

The allocation of sampling effort for the fish inventories was:

- Spring sampling was conducted between May 12 and May 29, 2008, with seven days of sampling on the Athabasca River and two days of sampling on the Clearwater River;
- Summer sampling was conducted on the Athabasca River between July 23 and August 1, 2008, with seven days of sampling; and
- Fall sampling was conducted between September 22 and October 3, 2008, with seven and three days of sampling on the Athabasca and Clearwater rivers respectively. The fall survey on the Athabasca River took seven days of effort and three days of effort on the Clearwater River.

Sampling on the Athabasca River was implemented within ten reaches specifically established by RAMP for the fish inventory program, all of which have been sampled annually since 1997, and a number of which have been sampled continuously since 1989 by Syncrude Canada Ltd. (Figure 3.4-1, Table 3.4-2). Lake whitefish and walleye captured during the fall survey at the Muskeg, Steepbank and Poplar areas were also used to support fish tissue monitoring studies (Section 3.4.2.2). These ten reaches fall within key areas of the river:

- 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 areas (i.e., CR1, CR2, and CR3) during the spring survey (Figure 3.4-1, Table 3.4-2). However, due to boat motor malfunction and extremely low water levels, reaches CR1B (downstream section of reach CR1) and CR2C (downstream section of area CR2) were not completed in the fall survey.

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

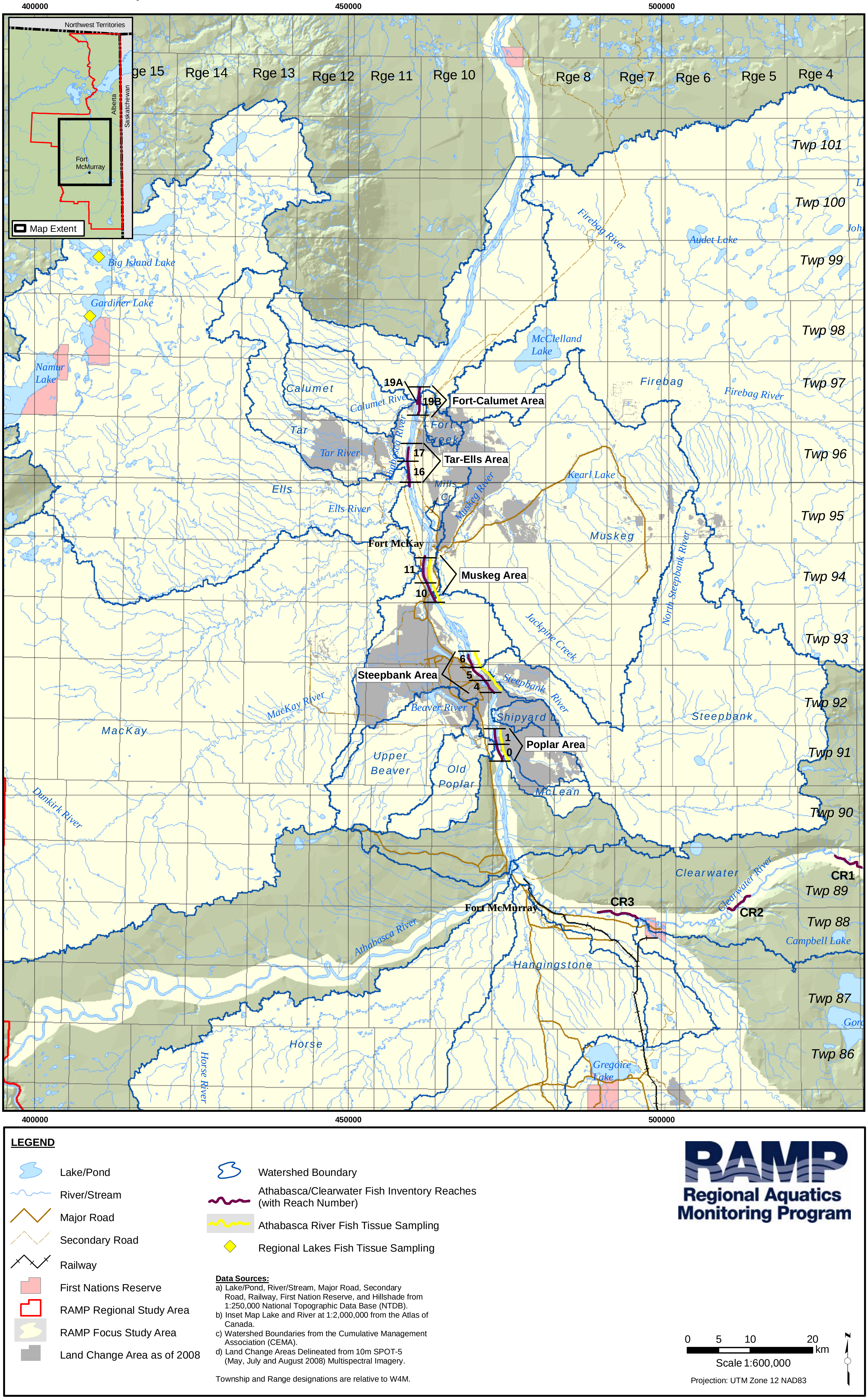
Fish were sampled using a Smith-Root model SR-18 electrofishing boat equipped with a 5.0 GPP electrofishing unit, configured with two anode boom arrays and multiple dropper cables. The boat's hull acted as the cathode. Stunned fish were captured with dip nets and held in an on-board flow-through live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

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

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

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

Figure 3.4-1 Location of areas of fish inventory and fish tissue monitoring activities for the 2008 RAMP Fish Population component.



K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_H_Fish_20090317.mxd

Table 3.4-2 Fish inventory sampling locations on the Athabasca and Clearwater rivers, 2008.

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

* Reaches not completed in fall 2008; coordinates taken from spring sampling program.

Adults and larger juvenile walleye, northern pike, longnose sucker, and white sucker were sampled for aging structures and walleye and northern pike were fixed with RAMP Floy tags prior to their live release. Floy tags were inscribed with a discrete ID number and a contact phone number to facilitate tracking in the event of a recapture during future inventories, and to encourage anglers to report them. Aging structures were also collected for flathead chub, as requested by CEMA for instream flow needs (IFN) research and assessment. Aging structures were collected non-lethally according to procedures outlined in MacKay *et al*. (1990), as follows:

- Longnose sucker and white sucker – two leading rays from left pectoral fin;
- Northern pike and walleye – two leading rays from left pelvic fin;
- Walleye and lake whitefish (tissue program) – otoliths and two leading rays from left pelvic fin; and
- Flathead chub – two leading rays from left pectoral fin and scales.

Aging structures were dried and stored in labeled coin envelopes. Spring samples were shipped for analyses to North/South Consultants, and fall samples are being held pending future analyses. All fish were released in the same area of the river where they were captured.

3.4.2.2 Fish Tissue Studies

Athabasca River Tissue Study

The 2008 fish tissue study on the Athabasca River targeted walleye and lake whitefish. Tissue samples were acquired from fish captured in the Muskeg, Steepbank and Poplar areas of the Athabasca River in September 2008 (Figure 3.4-1). Muscle tissue was collected non-lethally for mercury analysis, and lethal dissections were performed for internal health assessments and the collection of tissue for analyses of tainting compounds (organics) and metals.

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

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

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

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

The condition of each external structure was evaluated according to type and was assigned an associated index code and HAI value representing degree of severity ranging from 0 to 30, where 0 indicated no signs of pathology (Adams *et al.* 1993, also Appendix G). A mean HAI score was then calculated for each species by summing the index values for all individuals of each species and dividing by the total number of fish per species.

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

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

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

The distribution of fish captured for tissue analysis for tainting compounds is provided in Table 3.4-3. Because of difficulties capturing female walleye within the targets size class, fish from other size classes were also included to ensure sufficient tissue for analyses (Table 3.4-3).

Table 3.4-3 Sex/length combinations of walleye and lake whitefish captured for fish tissue analyses of metals and organics, Athabasca River 2008.

Species	Sex	Size Class	Number Captured
Walleye	Male	450-500 mm (target)	4
		550-600 mm	1
	Female	500-550 mm (target)	1
		450-500 mm	2
		600-650 mm	1
Lake whitefish	Male	400-450 mm	5
	Female	400-450 mm	5

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

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

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

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

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

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

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

Regional Lakes Tissue Studies

In 2008, tissue studies were performed on a sacrificed subsample of fish captured during Alberta Sustainable Resource Development's (ASRD's) fish population surveys on the following two regional lakes:

- Gardiner (Buffalo) Lake (target species: walleye, northern pike, lake whitefish); and
- Big Island Lake (target species: walleye, northern pike, and lake whitefish).

Sampling in both lakes took place between September 9 and September 19, 2008 during the Fall Walleye Index Netting (FWIN) program conducted by ASRD. Targets of 30 walleye, 30 northern pike, and 30 lake whitefish were set for mercury tissue analysis, with specific targets of five fish (irrespective of sex) in each of six size classes of 100 mm increments in fork length from 200 mm to 800 mm. These six length classes were selected in order to ensure consistency with those size classes targeted in the fall during past tissue programs for these species on other regional lakes. These classes were originally selected based on typical size ranges observed for each species during past fall lake inventories, and were therefore considered to be representative of a wide range of fish sizes and ages within the population of each species.

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

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

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

3.4.2.3 Fish Tag Return Assessment

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

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

3.4.3 Changes in Monitoring Network from 2007

2008 Fish Population component monitoring activities differed from those carried out during 2007 in the following ways:

- The Muskeg River fish fence program was planned for spring 2008, but not implemented due to prohibitively high water levels (the 2007 fish fence was also cancelled due to high water levels);
- No sentinel species programs were conducted in 2008, sentinel species sampling is scheduled for 2009;
- Regional Lakes fish tissue programs were implemented on Gardiner Lake and Big Island Lake in 2008 as compared to Namur (Moose) and Gregoire (Willow) lakes in 2007; and
- The fall 2008 Clearwater River fish inventory was not fully completed due to safety issues concerning low water levels and boat motor malfunctions.

3.4.4 Challenges Encountered and Solutions Applied

Most monitoring activities implemented under the 2008 Fish Population component were completed successfully without significant difficulties. However, high water flows on the Muskeg River in spring 2008 prohibited implementation of the Muskeg River fish fence program. In addition, Low water levels and boat motor malfunctions in October 2008 prevented completion of the fall Clearwater River fish inventory.

Table 3.4-4 Methods of analyses and detection limits for mercury, metals, and tainting compounds in Athabasca River fish tissues, 2008.

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[2]	0.05	EPA 3540/8270-GC/MS
Thiophene	0.01	EPA 5021/8260-Headspace GC/MS
Toluene	0.01	EPA 5021/8260-Headspace GC/MS

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

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

The Muskeg River fish fence, planned for spring 2008, could not be implemented due to prohibitively high water levels during the scheduled installation period (April/May). Discharge on the river at the beginning of May was recorded at 35 m^3/s, which exceeded the safe installation discharge criterion of 9 m^3/s. The fish fence, which was intended to be a repeat of the one carried out in 2006 (cancelled in 2007), is scheduled to be implemented in spring 2009, pending assessment of seasonal water levels at that time.

Fish inventory sampling in the Clearwater River was completed at all three planned reaches (i.e., CR1, CR2, and CR3) in spring 2008. However, due to very low water levels and boat motor malfunctions, sampling during the fall program (October, 2008) was only partially completed at CR1 and CR2. The low water levels prohibited safe navigation of all reaches and boat motor malfunctions prohibited adequate time to complete the sampling program within the scheduled dates. However, sections of the CR1 and CR2, historically dominant in KIR species abundance were completed (i.e., CR1A, CR2A and CR2B).

3.4.5 Other Information Obtained

To provide the RAMP fish group with a more thorough understanding of the fish species distribution, diversity and relative abundance in the RAMP FSA historical fish data were compiled from the ASRD Fisheries Management Information System (FMIS), AOSERP, and various reports, and summarized. Maps of relative abundance and species richness were completed to assess fish community assemblages in the RAMP FSA. The results of this study are provided in Appendix G.

3.4.6 Summary of Component Data Now Available

Fish Population component data collected to date by RAMP are summarized in Table 3.4-5.

3.4.7 Analytical Approach

The analytical approach used in 2008 for the Fish Population component was based on the analytical approach described in the RAMP Technical Design and Rationale document (RAMP 2009) and consisted of:

- selecting fish population measurement endpoints;
- conducting detailed analysis on fish population measurement endpoints, including statistical analyses and tabular/graphical presentations; and
- selecting and using criteria to assess change in fish population measurement endpoints.

3.4.7.1 Selection of Fish Population Measurement Endpoints

The measurement endpoints selected to evaluate Fish Population component data were specific to each study undertaken.

Fish Inventories

The following measurement endpoints were used to analyze fish inventory results from the Athabasca and Clearwater rivers:

- Percent species composition (relative to all fish captured);
- Relative abundance (catch-per-unit-effort – CPUE);
- Length-frequency distributions;

- Condition factor;
- Incidence of external health anomalies; and
- Recruitment to the sport fishery (Athabasca River only).

Fish Tissue Studies

Measurement endpoints used to analyze fish tissue results from the Athabasca River included whole-organism metrics (fork length, body weight, and age), incidence of external/internal health anomalies, and all metals (including mercury) and tainting compounds measured (Table 3.4-4).

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

3.4.7.2 Detailed Data Analysis

Detailed analyses were performed on measurement endpoints calculated from the Fish Population component data; all analyses were conducted using Microsoft Excel 2003, SYSTAT 10 (SPSS 2000) and WQStatPlus.

Fish Inventories

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

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

Species Composition and Relative Abundance (CPUE) All fish captured in the Athabasca River and Clearwater River fish inventories were summarized by percent species composition (relative to total abundance for all species), and relative abundance for each species (catch per unit effort - CPUE). These measurement endpoints were calculated for all combined areas on a river, for each season. Species composition and CPUE were also calculated for each area (see Table 3.4-2), and for each season. Temporal comparisons were graphically presented in order to compare species composition between 1997 and 2008 for each of the large-bodied KIR species, for each season (with the exception of lake whitefish, given insufficient data) and statistically analyzed for significant trends using WQStatPlus ($\alpha = 0.1$).

Age-Frequency Distributions Age-frequency distributions (i.e., number of fish per age class) were calculated for two species, walleye and northern pike, captured during the Athabasca River and Clearwater fish inventories (spring and fall combined). Age classes were divided into one year increments for each of the species. Age-frequency distributions were displayed graphically for each year in order to evaluate trends in dominant age classes over time.

Length-Frequency Distributions Length-frequency distributions (i.e. number of fish per fork length class) were calculated for each large-bodied KIR species captured during the Athabasca River and Clearwater River fish inventories (spring and fall combined). Length classes were divided into 25 mm increments for goldeye and 50 mm increments for walleye, longnose sucker, white sucker, and northern pike. Length-frequency distributions were displayed graphically for each year in order to evaluate trends in dominant length classes over time.

Table 3.4-5 Summary of RAMP data available for the Fish Population component.

		1997				1998				1999				2000				2001				2002				2003				2004				2005				2006				2007				2008			
WATERBODY AND LOCATION	**REACH**	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F
Athabasca River																																																	
Poplar Area	0/1[a]		1	1,5	1,5		1,6	1,5	1,3,6														1								1		1		1		1		1		1		1		1		1		1,6
Steepbank Area	4[a]/5[a]/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		1		1,6		1		1		1		1		1		1,6
Muskeg Area	10/11		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		1		1,6		1		1		1		1		1		1,6
Tar-Ells Area	16/17		1	1,5	1,5		1,6	1	1,3,6									7					1								1		1		1		1		1		1		1		1		1		1
Fort-Calumet Area	19[a]																																						1		1		1		1		1		1
CNRL/TrueNorth Area (Fort/Asphalt reaches)																							1																										
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6																																								
Reference Area - upstream of Fort McMurray[c]			1																																														
Radiotelemetry study region[d]					2		2		2						2	2	2	2	2																														
Downstream of Suncor's Discharge	AR-SD												1,3												10,3				10															3	3				
Below Muskeg River	AR-MR												1,3												10,3				10															3	3				
Reference site upstream of Ft. McMurray STP																									3				10															3	3				
Reference site between STP and Suncor	AR-R												1,3												3				10															3	3				
Downstream of Development (near Firebag River)																													10,6															3	3				
Athabasca River Tributaries																																																	
Fort Creek (mouth)															1,8,5,9	1																																	
Historical Review of Tributary Fish Data																																																	
Clearwater River	CR1																										1		1		1		1,6		1		1		1		1,6		1		1,6		1		1
Clearwater River	CR2																										1		1		1				1				1		1,6		1				1		1
Clearwater River	CR3																										1	10	1		1				1				1		1,6		1				1		1
Christina River[i]																																	1																
Ells River																																																	
Upper Ells River[h]													1,3																		4		3		4		3							3	3				
Lower Ells River[h]													1,3																		4		3		4		3							3	3				
Mackay River																																																	
Lower reach (85 km section from bridge to mouth)[j]	MAR-1		1																				1					10			4																		
Muskeg River																																																	
Lower 35 km below Jackpine Creek confluence				1			4						1,3		2,8	2	2	2	2	1	6			1	6							1	6							1	6								
Mouth (within 1 km of confluence with Athabasca River)	MR-MT												1,3						4		3		4		4		4						3						4		3								
Reference sites (Steepbank, Horse and Dunkirk rivers)																	3				3												3								3								
Upper Muskeg River (near Wapasu Creek Confluence)																							1,4		1,4																								
Muskeg River Tributaries																																																	
Alands Drain																																																	
Jackpine Creek (accessable areas of lower creek)															8					1				1								1																	
Shelley Creek																																																	
Muskeg Creek (Canterra road crossing)[e]																							1,4		1,4																								
Stanley Creek																																																	
Wapasu Creek (mouth or Canterra road)[e]																							1,4		1,4																								
Steepbank River																																																	
Steepbank Mine baseline fisheries reach (1995)[f]	AF014			1																																													
Vicinity of Steepbank Mine	SR-MN												1,3								3												3							3	3								
Reference site in vicinity of Bitumin Heights	SR-R												1,3																																				
Setinel reference site[g]	SR-EC												1,3				3				3												3							3	3								
Sentinel reference sites (Horse and Dunkirk R.)																	3				3												3							3	3								
Regionally-Important Lakes																																																	
Various lakes in water/air emissions pathway																													6				6											6	6				6

Legend

1 = fish inventory

2 = radiotelemetry; 1997-1998 walleye, lake whitefish (Athabasca River)
2000-2001: longnose sucker, northern pike, Arctic grayling (Athabasca River and Muskeg River)

3 = sentinel fish monitoring; 1998-1999: longnose sucker (Athabasca River)
2002-2008: trout-perch (Atha. River); slimy sculpin (Muskeg, Steepbank)

4 = fish fence: aluminum counting fence (large bodied fish); small-mesh fyke nets (small bodied fish)

5 = fish habitat association

6 = fish tissue: walleye and lake whitefish (Athabasca River); northern pike (Muskeg River),
northern pike (Clearwater River), northern pike, walleye and lake whitefish (lakes)

7 = winter fish habitat sampling

8 = spawning survey

9 = benthic drift survey

10 = IBI Assessment - Test program

Footnotes

[a] Reaches include east and west banks

[b] Reference area upstream of Fort McMurray; includes a 22 km section extending 1 km upstream of the Duncan Creek Confluence downstream to Iron Point

[c] Reference area upstream of Fort McMurray. It was investigated as a potential reference area for longnose sucker sentinel species monitoring but found to be inadequate due to habitat differences and concerns about longnose sucker mobility.

[d] Radiotelemetry region includes the area 60 km upstream of Fort McMurray to 250 km downstream of Fort McMurray.

[e] small bodied fish inventory done by fish fence (fyke net) to record fish movements in and out of watercourse. Needs to be done prior to Kearl Project.

[f] Located from 3 to 11 km upstream of the confluence with the Athabasca River.

[g] Reference site located approximately 21 km upstream of confluence with Athabasca River; sampling done by Environment Canada, NWRI, Burlington, Ontario

[h] In 2004 the Ells River was evaluated as a potential reference site for sentinel species (slimy sculpin) monitoring on the Muskeg and Steepbank Rivers. Several sites were sampled but no slimy sculpin were captured. Hence, the site was determined not to be suitable as a reference site for this species. In 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers.

[i] Reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing.

[j] In 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers.

Test (downstream of focal projects)

Baseline (upstream of focal projects)

Condition Factor Fish condition was evaluated over time as a measure of change in energy storage for all large-bodied KIR species captured during the Athabasca River and Clearwater River fish inventories. In order to be consistent with past analyses, 2008 analyses were restricted to fish of the following species-specific minimum lengths: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; longnose sucker >350 mm; and white sucker >350 mm.

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

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

- Fish condition (or "fatness") was compared among years (1997 to 2008) for each season using analysis of covariance (ANCOVA; α = 0.05), where body weight (log_{10} transformed) as the dependent variable, site, as the independent variable, and fork length (log_{10} transformed), as the covariate. The first step in the analysis was to compare slopes of length-weight regressions from different populations, and the second step was to compare the intercepts of the regressions;
- Fulton's Condition Factor was calculated as K= (body weight/fork length^3 x 10^5), and used in tabular and graphical presentations showing condition for each species, per season, over time; and
- Length-at-age and weight-at-age comparisons were made between areas with aging data for KIR species from the spring inventory using analysis of covariance (ANCOVA; α = 0.05), where fork length or body weight represented the dependent variable, site the independent variable, and age the covariate.

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

- Percentage of anomalies was calculated relative to total number of fish captured during each season;
- Key types of anomalies were identified; and
- Mean annual HAI scores were calculated for each large-bodied KIR species and compared graphically over time.

Recruitment to the Sport Fishery Fish captured during the Athabasca River inventory were used to estimate recruitment of walleye and northern pike to the sport fishery. The ratios of under-size to legal-size fish were calculated and compared over time (1997 to 2008) for each species. Although fork length is the standard length measure used in RAMP fish population studies, ASRD legal catch size limits for the Athabasca River in the Northern Boreal Zone 3 are given in total length (walleye ≥ 430 mm; northern pike ≥ 630 mm). Using regression equations for each species, the associated fork length limits were estimated to be 370 mm for walleye and 600 mm for northern pike.

Fish Tissue Studies

Measurement endpoints calculated from data collected during the fish tissue programs on the Athabasca River and regional lakes (i.e., Gardiner and Big Island lakes) were used to evaluate trends in fish health and chemical concentrations.

Whole-organism Metrics Whole-organism metrics (i.e., fork length, body weight, age) were reported along with fish sex and stage for walleye and lake whitefish collected during the tissue program on the Athabasca River. These metrics were also reported for fish collected during tissue programs on Gardiner and Big Island lakes; ageing structures were not analyzed for lake whitefish.

Incidences of Health Anomalies Incidences of anomalies observed during external and internal health assessments were reported for walleye and lake whitefish collected and dissected during the fish tissue program on the Athabasca River.

Mercury Mercury results were reported for fish collected during tissue programs on the Athabasca River and Gardiner and Big Island lakes. Scatterplots were then used to initially assess relationships between mercury concentrations and whole-organism metrics for each species and sex combination. Spearman's rank correlations (two-tailed, $\alpha = 0.05$) were then used to statistically evaluate the significance of these relationships. Spearman's Rank Correlations with correlation coefficients (r_s) greater than the critical r_s (dependent on sample size, α=0.10, two-tailed test) were indicative of statistically significant relationships. Moderate correlations were defined as those ranging from $|0.50|$ to $|0.75|$, while strong correlations were defined as those ranging from $|0.75|$ to $|1.00|$. Linear regression was used to further evaluate significant rank correlations. Assumptions of regression models were tested and, if necessary, analyses were performed using $\log_{10}$-transformed or ranked data. Mercury concentrations among years (2002, 2003, 2005 and 2008) for the Athabasca River study were compared graphically and statistically using analysis of covariance (ANCOVA; α=0.05), with mercury concentration ($\log_{10}$ transformed) as the dependent variable, year as the independent variable, and fork length ($\log_{10}$ transformed) as the covariate. The first step in the analysis was to compare slopes of length-weight regressions from different populations, and the second step was to compare the intercepts of the regressions.

Mercury concentrations in fish tissue samples from all three waterbodies sampled in the RAMP 2008 program (i.e., Athabasca River, Gardiner Lake and Big Island Lake) were standardized to fish weight and compared to weight-standardized fish tissue mercury concentrations from lakes in the region (Grey *et al.* 1995, Golder 2004, RAMP 2003, RAMP 2004, RAMP 2008) to assess temporal and spatial comparisons.

Total Metals and Organic Compounds Results for total metals and tainting compounds were reported for walleye and lake whitefish collected during the Athabasca River fish tissue program.

Fish Tag Return Assessment

A spatial presentation of tag return information (location tagged and location recaptured) was prepared for the tag returns received in 2008.

3.4.7.3 Classification of Results

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

Fish Inventories

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

Fish Tissue Studies

Metals (including mercury) and tainting compounds measured in fish collected from the Athabasca River were used to evaluate potential risk to human health, fish, and palatability (tainting).

Mercury in fish collected from Gardiner Lake and Big Island Lake was used to evaluate potential risk to human health and fish health.

Potential Risk to Human Health To assess potential risk to human health due to ingestion of fish tissues, fish tissue data were screened against the following criteria (Table 3.4-6):

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

Mercury is the only RAMP fish tissue study endpoint that currently has a Health Canada consumption guideline, both for general and subsistence consumers. USEPA criteria exist for a larger number of RAMP fish tissue measurement endpoints, and are risk-based values that take into account the toxicity (including carcinogenicity) of the contaminant, body weight of the consumer, and exposure rate. National USEPA criteria have been developed for both recreational (general) and subsistence consumers, and are available for arsenic, selenium, and mercury. Regional USEPA criteria apply to general adult exposure, and exist for several total metals, mercury, and toluene, tainting compound.

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

Table 3.4-6 Criteria used for evaluating potential risk of fish consumption to human health.

RAMP Fish Tissue Measurement Endpoint[1]	Units	Health Canada		National USEPA[4]		Region III USEPA[5]
		General[2]	Subsistence[3]	Recreational	Subsistence	Risk-based Criteria
Total Metals						
Antimony (Sb)	mg/kg	nc	nc	nc	nc	0.54
Arsenic (As)	mg/kg	nc	nc	0.026	0.00327	0.0021
Barium (Ba)	mg/kg	nc	nc	nc	nc	270
Beryllium (Be)	mg/kg	nc	nc	nc	nc	2.7
Boron (B)	mg/kg	nc	nc	nc	nc	120
Cadmium (Cd)	mg/kg	nc	nc	nc	nc	1.4
Chromium (Cr)	mg/kg	nc	nc	nc	nc	4.1
Copper (Cu)	mg/kg	nc	nc	nc	nc	54
Iron (Fe)	mg/kg	nc	nc	nc	nc	410
Lithium (Li)	mg/kg	nc	nc	nc	nc	27
Manganese (Mn)	mg/kg	nc	nc	nc	nc	190
Mercury (Hg)[6]	mg/kg	0.5	0.2	0.4	0.049	0.14
Molybdenum (Mo)	mg/kg	nc	nc	nc	nc	6.8
Nickel (Ni)	mg/kg	nc	nc	nc	nc	27
Selenium (Se)	mg/kg	nc	nc	20	2.457	6.8
Silver (Ag)	mg/kg	nc	nc	nc	nc	6.8
Strontium (Sr)	mg/kg	nc	nc	nc	nc	810
Thallium (Tl)	mg/kg	nc	nc	nc	nc	0.095
Tin (Sn)	mg/kg	nc	nc	nc	nc	810
Vanadium (V)	mg/kg	nc	nc	nc	nc	1.4
Zinc (Zn)	mg/kg	nc	nc	nc	nc	410
Tainting Compounds						
Toluene	mg/kg	nc	nc	nc	nc	110

[1] Endpoints listed are for variables that have human health criteria under Health Canada or National USEPA.

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

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

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

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

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

nc – no criterion.

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

Summary indicators of 2008 fish tissue mercury results were developed for determining risk to human based on the exceedances of subsistence fisher and general consumer consumption guidelines, and criteria outlined in the RAMP Technical Design and Rationale Document (RAMP 2009). Summary indicators of fish tissue results were classified taking into account the consumption differences between general consumers and subsistence fishers and the variance in mercury concentrations across size classes of individual fish to accurately assess the risk to human health in relation to the amount of fish consumed and in the size of fish consumed. Table 3.4-7 provides the classification of results for risk to human health for subsistence fishers and general consumers. The classification will specify the corresponding size class for each species for which fish tissue studies were conducted in 2008 (i.e., walleye, lake whitefish and northern pike); selected size classes for fish tissue studies are outlined in Section 3.4.2.2. A Moderate classification is not defined for subsistence fishers given that the consumption guideline is low due to larger quantities of fish consumed by this group which poses a higher risk to human health.

Table 3.4-7 Classification of fish tissue results for risk to human health.

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

Potential Risk to Fish Health To assess potential risk to fish health, fish tissue data were screened against minimum lethal (survival) and non-lethal (growth and reproduction) effects and no-effects thresholds derived from laboratory-based studies summarized in Jarvinen and Ankley (1999). These criteria were only available for some of the RAMP fish tissue measurement endpoints, including several total metals and mercury, but not for any of the tainting compounds. The thresholds were developed based on ranges of fish tissue residue concentrations linked to both effects and a lack of effects on both sublethal (e.g. growth) and lethal (survival) measurement endpoints; the lowest (i.e., most conservative) concentrations were used to evaluate risk. The thresholds are presented in Table 3.5-1, along with information regarding the studies from which they were derived, including the measurement endpoints evaluated, tissue type, species, life stage and/or fish size, exposure route, and duration of exposure. Only thresholds derived from the most relevant studies were used to screen the RAMP fish tissue data; those derived from studies on small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, were excluded. Effects concentrations associated with acute exposures were only included for contaminants where few other data existed.

Summary indicators of 2008 fish tissue metal results were developed for determining risk to fish health. The classification of the summary indicators, based on the sublethal and lethal effects thresholds of metals in fish, were developed in the RAMP Technical Design and Rationale Document (RAMP 2009) to provide an overview of the health of fish tissue in relation to the risk to human health. Summary indicators were classified using the following scheme and provided for each watershed where fish tissue studies were conducted in 2008:

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

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

Summary indicators of 2008 fish tissue tainting compound results were developed for determining the potential influence of compounds on fish palatability. The classification of the summary indicators, based on exceedances of tainting compound guidelines, were developed in the RAMP Technical Design and Rationale Document (RAMP 2009) to provide an overview of the health of fish tissue in relation to the risk to human health. Summary indicators were classified using the following scheme and provided for each watershed where fish tissue studies were conducted in 2008:

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

3.5 ACID-SENSITIVE LAKES

The 2008 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 2008. The locations of each lake are presented in Figure 3.5-1, along with each lake’s acid-sensitivity based on three separate classification systems using (i) Gran alkalinity, (ii) pH, and (iii) the critical load.

Table 3.5-1 Criteria used for evaluating potential risk to fish health based on concentrations of metals that have lethal, sublethal, or no effects on freshwater fish.

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

- = no data; [1] methylated forms of mercury

Table 3.5-1 (Cont'd.)

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

- = no data; [1] methylated forms of mercury

Table 3.5-2 presents the three classification systems and the number of lakes that are classified as highly acid-sensitive, moderately acid-sensitive, of low acid-sensitivity and least acid-sensitive.

Table 3.5-2 Acid sensitivity criteria for Alberta lakes.

Acid Sensitivity Category	Gran Alkalinity[1] (µeq/L)	No. of Lakes in Alkalinity Categories	pH[1] (Units)	No. of Lakes in each pH Category	Critical[2] Load (CL) Keq H^+/ha/y	No. of Lake in each CL Category
High Sensitivity	Negative to 199	28	4.0 to 6.49	19	<0.249	30
Moderate Sensitivity	200 to 399	10	6.5 to 6.99	13	0.250 to 0.499	13
Low Sensitivity	400 to 799	8	7.0 to 7.49	10	0.500 to 0.999	4
Least Sensitive	> 800	4	> 7.5	8	>1.00	3

[1] Sources: Erickson 1987; Saffron and Trew 1996; [2]CASA 1996.

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

The date of lake sampling, the UTM coordinates of each lake and the tertiary watershed in which each lake is located are presented in Table 3.5-3. The unique ID number listed in Table 3.5-3 is that ascribed to each lake by the NO_xSO_x Monitoring Working Group (NSMWG) lake sensitivity mapping program (WRS 2004).

3.5.1 Summary of Field Methods

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

Water samples were collected from the euphotic zone (defined as twice the Secchi disk depth) 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).

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.

Table 3.5-3 Lakes sampled in 2008 for the Acid-Sensitive Lakes component.

Lake Identification			UTM Coordinates (NAD83, Zone12)		Sampling Date m/d
Unique ID[1]	Original Name	AENV Designation	Easting	Northing	
Stony Mountains Sub-Region					
168	A21	SM 10	483819	6235130	08/29
169*	A24	SM 9	484387	6230872	09/05
170	A26	SM 6	489502	6230877	08/29
167	A29	SM	466180	6224950	09/05
166*	A86	SM 7	448014	6170896	08/29
287*	25	SM 8	487594	6229281	08/29
289	27	SM	477248	6228400	09/05
290	28	SM	487068	6225576	09/05
342	82	SM 2	448271	6183205	08/29
354	94	SM 1	515689	6179207	08/29
Birch Mountains Sub-Region					
436	L18/Namur	BM 2	402704	6368016	08/28
442	L23/Otasan	BM 9	417321	6396959	08/28
444	L25/Legend	BM 1	383849	6364923	08/28
447	L28	BM 6	382996	6414339	08/28
448*	L29/Clayton	BM 7	424694	6435790	08/28
454	L46/Bayard	BM 8	416941	6404239	08/28
455	L47	BM 4	396500	6395456	08/28
457	L49	BM 5	404995	6403111	08/28
464	L60	BM 3	403796	6392247	08/28
175*	P13	BM 10	416003	6353212	09/05
199*	P49	BM 11	446002	6394961	09/05
Northeast of Fort McMurray Sub-Region					
452	L4 (A-170)	NE 1	508990	6334305	09/06
470	L7	NE 2	461006	6368512	09/06
471	L8	NE 3	460931	6369481	09/06
400	L39/E9/A-150	NE 4	536495	6424234	09/05
268	E15	NE 5	506092	6305335	09/05
182	P23	NE 6	509000	6346712	09/05
185*	P27	NE 7	508300	6333712	09/05
209	P7	NE 8	515399	6343212	09/05
270	4	NE 9	506113	6291421	09/05
271*	6	NE 10	549064	6277789	09/05
418*	Kearl	NE 11	485939	6349881	09/06
West of Fort McMurray Sub-Region					
165	A42	WF 1	365015	6247322	08/29
171	A47	WF 2	367321	6235430	08/29
172	A59	WF 3	383467	6197733	08/29
223*	P94	WF 4	440557	6334112	09/05
225	P96	WF 5	444002	6295513	09/05
226	P97	WF 6	456002	6296463	09/05
227	P98	WF 7	451762	6293513	09/05
Caribou Mountains Sub-Region					
146	E52/ Fleming	CM 1	243692	6522556	09/03
91	O-1/E55	CM 5	298955	6571856	09/03
97	O-2/E67	CM 4	253582	6582654	09/03
152	E59/Rocky Island	CM 2	263546	6562225	09/03
89	E68 Whitesand	CM 3	245596	6570610	09/03
Canadian Shield Sub-Region					
473	A301	S 4	525150	6559733	09/05
118	L107/Weekes	S 1	555469	6620456	09/05
84	L109/Fletcher	S 2	510321	6553552	09/05
88	O-10	S 5	518279	6556260	09/05
90	R1	S 3	517889	6562197	09/05

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

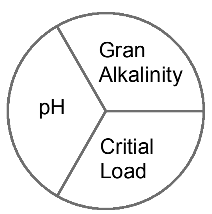
Figure 3.5-1 Location and acid sensitivity of RAMP acid-sensitive lakes sampled in 2008.

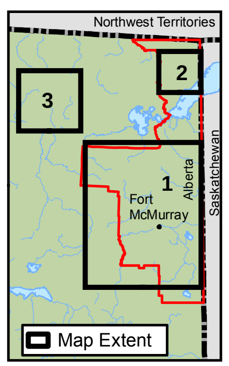
RAMP
Regional Aquatics Monitoring Program

LEGEND

- Lake/Pond
- River/Stream
- Major Road
- Secondary Road
- Railway
- First Nations Reserve
- RAMP Regional Study Area
- RAMP Focus Study Area
- Land Change Area as of 2008
- Watershed Boundary

Acid Sensitivity Category





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

0 10 20 40 km

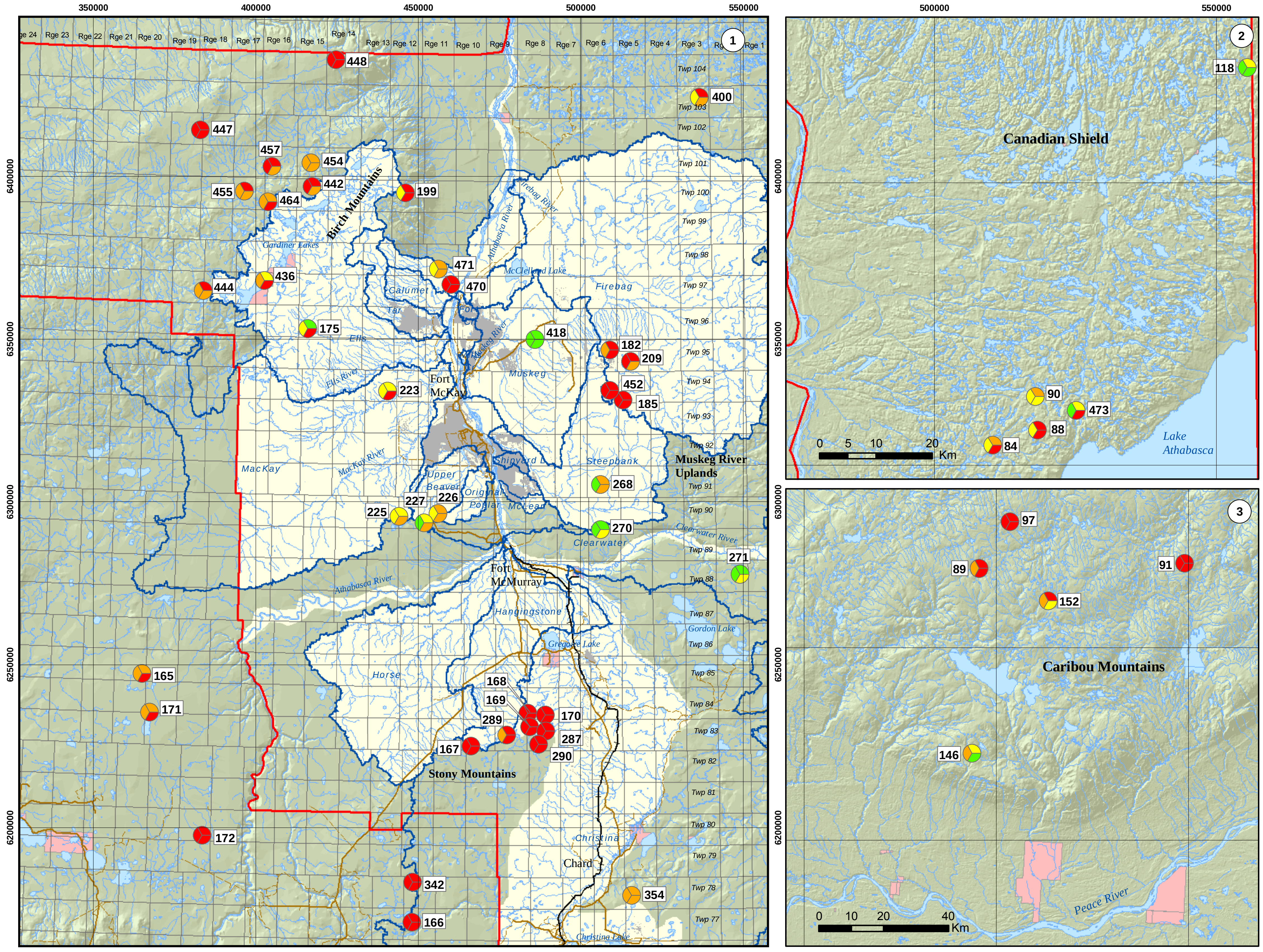
Scale 1:1,300,000

Projection: UTM Zone 12 NAD83

Data Sources:
a) Lake/Pond, River/Stream, Major Road, Secondary Road, Railway, First Nation Reserve, and Hillshade from 1:250,000 National Topographic Data Base (NTDB).
b) Inset Map Lake and River at 1:2,000,000 from the Atlas of Canada.
c) Watershed Boundaries from the Cumulative Management Association (CEMA).
d) Land Change Areas Delineated from 10m SPOT-5 (May, July and August 2008) Multispectral Imagery.

Township and Range designations are relative to W4M.

K:\Data\Project\RAMP1393\GIS_MXD\E_TechReport\RAMP1393_I_ASL_20090312.mxd



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 from each lake as vertical hauls through the euphotic zone, using a #20 mesh (63 µm), conical plankton net. Zooplankton samples were preserved in approximately 5% formalin after anaesthetizing in soda water. Plankton samples were archived at AENV and the zooplankton samples were sent to Environment Canada for analysis. The water samples were analyzed for the water quality variables listed in Table 3.5-4.

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 3.5-4 (Appendix B).

Table 3.5-4 Water quality variables analyzed in 2008 in lake water sampled under the ASL component.

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

3.5.2 Changes in Monitoring Network from 2007

Logistical difficulties prevented one lake (Lake 267, AENV WF 8) in the West of Fort McMurray Sub-Region being sampled in 2008.

3.5.3 Challenges Encountered and Solutions Applied

There were no exceptional challenges encountered in implementing field activities under the ASL component in 2008.

3.5.4 Other Information Obtained

AENV collected additional samples from each lake surveyed in the ASL component (Table 3.5-3) during the 2008 field season. These water samples were sent to the Alberta Research Council, 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 3.5-3. These data were used to assess the natural within-year variability in water quality in these lakes and are reported in Appendix H.

3.5.5 Summary of Component Data Now Available

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

3.5.6 Analytical Approach

The analytical approach used in 2008 for the ASL component was in accordance with the overall analytical approach outlined in the RAMP Technical Design and Rationale (RAMP 2009) and consisted of:

- selecting ASL measurement endpoints;
- developing criteria to be used in detecting changes in ASL measurement endpoints; and
- detailed data analysis of 2008 results.

3.5.6.1 Measurement Endpoints

The measurement endpoints for the ASL component in 2008 were as follows:

- 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).

3.5.6.2 Details of Data Analysis

Primary Analyses

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

Between-Year Comparisons of Measurement Endpoints An Analysis of Variance (ANOVA) was conducted to determine whether there have been any significant changes in the concentrations of the ASL measurement endpoints in the 50 RAMP lakes, as a group, during the seven years when all 50 lakes were sampled (2002-2008). An ANOVA was run after testing for the homogeneity of the variance of each variable between years. When the variance of a variable was found to be non-homogeneous, a non-parametric test (Kruskal-Wallis one-way analysis of variance) was applied to detect changes in the median concentrations. Tukey's post-hoc test was used to examine individual differences in mean values between years when the ANOVA indicated significant differences. Any observed changes were discussed in relation both to acidification and natural variability.

Table 3.5-5 Summary of lakes sampled during RAMP, 1999 to 2008.

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

Calculation of Critical Loads of Acidity and Comparison to Modeled Potential Acid Input The critical loads (CL), in units of keq H+/ha/y, is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology; it represents a measure of a lake's sensitivity to acidification. CLs for the RAMP lakes in 2008 were calculated using the Henriksen steady state water chemistry model (Henriksen and Posch 2001; Henriksen *et al*. 2003; Forsius *et al*. 1992; Rhim 1995) modified for the effects of organic acids on buffering and acid sensitivity (RAMP 2005; WRS 2006).

As in previous years, the runoff to each lake, a term in the Henriksen model, was calculated both from traditional hydrometric methods and from analysis of heavy isotopes of oxygen (^{18}O) and (^{2}H) in each lake. In the latter technique, the natural evaporative enrichment of ^{18}O and ^{2}H in the lakes is used to partition water losses between evaporation and liquid outflow and hence derive an estimate of runoff (Gibson 2002, Gibson *et al*. 2002, Gibson and Edwards 2002). This technique utilizes a different set of assumptions from the hydrometric method which extrapolates water yields from one or more gauged catchments to the ungauged lake catchments. Potential inaccuracies in the hydrometric method, especially in low-relief catchments, have long been recognized (WRS 2004). The isotopically derived values of runoff were taken from a recent study by Bennett *et al.* (2008). Critical loads were calculated using both estimates of runoff and the values 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 Total E&P Joslyn North Mine Project EIA (Deer Creek Energy 2006). As listed values of PAI are generally unavailable for lakes in the Caribou Mountains and the Shield region, they were estimated from background PAI values (no industrial input) determined from RELAD modeling conducted by Alberta Environment in 2002.

Trends in Measurement Endpoints in Individual Lakes Potential trends in the ASL measurement endpoints were examined for the 31 lakes that have been monitored for at least eight consecutive years. The analysis involved trend analysis using the Mann-Kendall non-parametric test (Gilbert 1987). Estimates of analytical error (determined as the percent error of the analysis reported by the laboratory at each concentration) were incorporated in the analyses to evaluate the validity of any trends observed in ASL measurement endpoints.

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 2008 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 2007, AENV 1999b) were identified; and
- Estimates of the seasonal variability in water quality variables in ten of the ASL lakes were updated with the 2008 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 years of the ASL component were tabulated and summarized statistically. Lakes with unusual chemical characteristics were identified based on exceedances of the 5th and 95th percentiles in values of measurement endpoints. Using multivariate principal components analysis and Piper plots, the ASL lakes were categorized and grouped according to lake chemistry. The chemical characteristics of the RAMP ASL lakes were compared to those of 450 regional lakes reported in the lake sensitivity mapping study produced for the NOxSOx Management Working Group (NSMWG; WRS 2004). Comparisons involved:

- Examination of the ranges, medians and mean values of key chemical variables for 2008 in the RAMP lakes relative to the regional dataset;
- Graphical presentation of both datasets in box plots; and
- Statistical comparison of chemical variables between the RAMP ASL lakes and the regional dataset.

Principal Components Analysis of the Regional Lake Database and the RAMP ASL Data Principal Components Analysis (PCA) was applied to the NSMWG regional lake database in order to group the lakes into specific lake types or categories based on lake chemistry. PA was also applied to the RAMP Lakes which were then classified according to lake type.

Analysis of Metal Concentrations in the RAMP ASL Lakes The total and dissolved metal fractions from seven years of monitoring by AENV (2001, 2003-2008) were tabulated and summarized statistically to establish *baseline* concentrations for each metal. Lakes having extreme mean metal concentrations were identified as those exceeding the 95th percentile concentration for individual metals; exceedances of the Alberta and CCME surface water quality guidelines were also identified.

Trends in ASL Measurement Endpoints in Individual Lakes In addition to the Mann Kendall analyses described above, key measurement endpoints (pH, Gran alkalinity, sulphate, sum of base cations and nitrates, dissolved organic carbon) were charted in Shewhart control plots for ten lakes deemed most at risk to acidification. These control plots are extremely helpful in detecting trends before significant change has occurred. Ten lakes were selected for control charting on the basis of a high ratio of PAI to the value of the critical load; the greater this ratio in a lake, the greater is the risk for acidification. The control plots follow standard analytical control chart theory where control limits representing two and three standard deviations are plotted on the graphs with the points and the mean value (Gilbert 1987). The lines at two standard deviations represent warning limits while the lines at three standard deviations identify distinct outliers. A trend in the value of a measurement endpoint is often assumed if three consecutive points fall on the same side outside of the two standard deviation warning limits or one point outside of the three standard deviation control limit.

3.5.6.3 Classification of Results

A summary of the state of the ASL lakes in 2008 with respect to the potential for acidification was prepared for each physiographic subregion by examining deviations from the mean chemical concentrations of the measurement endpoints for each lake within each subregion. The measurement endpoint and the relevant trend that is indicative of acidification are as follows: Gran alkalinity (downwards); pH (downwards); sum base cations (upwards); nitrates (upwards); dissolved organic carbon (downwards); sulphate (upwards); aluminum (upwards).

For each lake, the mean and standard deviation were calculated for each measurement endpoint over all the monitoring years. The number of lakes in 2008 within each subregion having measurement endpoint values greater than two standard deviations (above or below the mean as indicated above) was calculated. The number of such endpoint-lake exceedances was expressed as a percentage of the total number of lake-endpoint combinations for each subregion. The results were classified as follows:

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