3.0 2005 RAMP MONITORING PROGRAM

This section contains descriptions of the RAMP monitoring program conducted in 2005 for each RAMP component, and includes the following:

- Overview of the 2005 program;
- Detailed description of field methods;
- Description of any other information obtained (i.e., information from regulatory agencies, the oil sands operators, knowledge obtained from local communities, and other sources);
- Description of changes in monitoring network from the 2004 field program;
- Description of the challenges and issues encountered during 2005 and the means by which these challenges and issues were addressed; and
- Summary of the component data that is now available.

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

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

Quality Assurance and Quality Control (QA/QC) procedures were employed throughout and for all aspects of the 2005 RAMP monitoring program; Appendix B contains a detailed description of the QA/QC procedures used.

In addition, all RAMP data now resides in a MYSQL relational database which may be found in the members' area of the RAMP website at www.ramp-alberta.org; the 2005 data tables are included on the CD-ROM accompanying the final 2005 technical report.

3.1 CLIMATE AND HYDROLOGY

3.1.1 Overview of 2005 Program

The climate and hydrology monitoring program for 2005 included the following:

- Monitoring climate at five stations, including temperature and precipitation at most stations, as well as a variety of other climate variables at the Aurora Climate Station;
- Conducting the RAMP regional snow course surveys in February, March and April;

- Monitoring water levels and stream flows and collecting water samples for total suspended solids (TSS) analysis at:
    - 12 hydrometric stations in the Muskeg River basin;
    - 10 hydrometric stations on other Athabasca River tributaries north of Fort McMurray;
    - 3 hydrometric stations on other Athabasca River tributaries south of Fort McMurray; and
    - 1 hydrometric station on the Athabasca River;
- Monitoring winter discharges at thirteen of the hydrometric stations in the winters of 2004-2005 and 2005-2006, compared to nine stations in winter 2003-2004 and five stations in winter 2002-2003;
- Monitoring water levels at three lake / wetland stations;
- Integrating regional climatic and hydrometric monitoring data collected by government agencies into the RAMP database;
- Completing construction and installation of a permanent bubbler-type hydrometric station on the Ells River;
- Installing a new hydrometric station in the headwaters of the Tar River; and
- Replacing the streamflow measurement weir on Mills Creek at Highway 63.

Locations of RAMP and federal and provincial government active and discontinued climate stations, and 2005 snowcourse survey sites, are shown in Figure 3.1-1. Stations are identified by station number only in Figure 3.1-1; the corresponding station names are provided in Table 3.1-1.

3.1.2 Field Methods

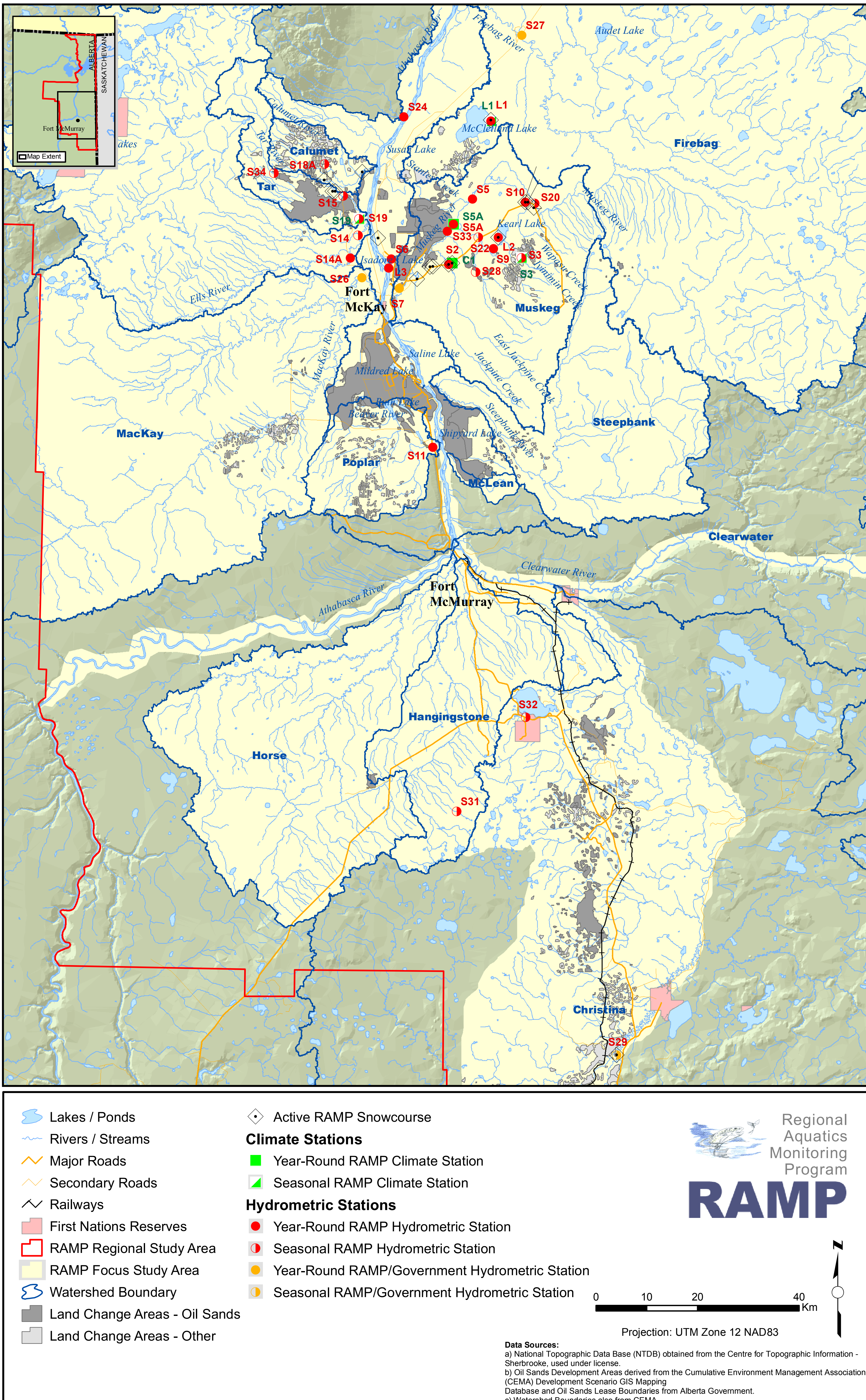
3.1.2.1 General

Field staff visited the climate and hydrometric stations routinely to check and maintain automated sensing equipment and to make manual streamflow measurements. Manual streamflow measurements are necessary for the development and 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).

Figure 3.1-1 Locations of RAMP climate and hydrology stations, and snowcourse survey sites, 2005.



G:\DATA\PROJECTS\RAMP1166\GIS\RAMP1166_D_ClimateHydro_2006APR20.mxd

Table 3.1-1 RAMP climate and hydrology stations operating in 2005.

No.	Name	UTM Coordinates[1]		Operating Season	Parameters Measured
		Easting	Northing		
C1	Aurora Climate Station	475820	6343952	All year	Air temperature, rainfall, humidity, solar radiation, snow on the ground, wind speed and direction
L1	McClelland Lake	483430	6371950	All year	Water level, discharge
				Open-water	Rainfall
L2	Kearl Lake	484935	6349023	All year	Water level
L3	Isadore's Lake	463297	6342987	All year	Water level
S2	Jackpine Creek at Canterra Road	475132	6343680	All year	Level, discharge
S3	Iyinimin Creek above Kearl Lake	489491	6345029	Open-water	Level, discharge, rainfall
S5	Muskeg River above Stanley Creek	479820	6356551	All year	Level, discharge
S5A	Muskeg River above Muskeg Creek	476100	6351600	All year	Level, discharge, barometric pressure, water temperature
S6	Mills Creek at Highway 63	463829	6344743	All year	Level, discharge
S7	Muskeg River near Fort McKay (07DA008)	465408	6338944	Winter[2]	Level, discharge
S9	Kearl Lake Outlet	483980	6346750	All year	Level, discharge
S10	Wapasu Creek at Canterra Road	490272	6355942	All year	Level, discharge
S11	Poplar Creek at Highway 63 (07DA007)	471998	6307667	All year	Level, discharge
S14	Ells River above Joslyn Creek	457310	6349466	Open-water	Level, discharge
S14A	Ells River at the CNRL Bridge	455748	6344947	All year	Level, discharge, water temperature
S15	Tar River near the Mouth	454390	6357209	Open-water	Level, discharge
S16	Calumet River near the Mouth	458087	6361908	All year[3]	Precipitation, air 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, rainfall
				Winter	Snowfall
S20	Muskeg River Upland	492106	6355709	Open-water	Level, discharge
S22	Muskeg Creek near the Mouth	480970	6349071	Open-water	Level, discharge
S24	Athabasca River below Eymundson Creek	466313	6372760	All year	Level, discharge
S26	MacKay River near Fort McKay (07DB001)	458120	6341037	Winter[2]	Level, discharge
S27	Firebag River near the mouth (07DC001)	489553	6388830	Winter[2]	Level, discharge
S28	Khahago Creek below Black Fly Creek	480489	6342185	Open-water	Level, discharge
S29	Christina River near Chard (07CE002)	508195	6187926	Winter[2]	Level, discharge
S31	Hangingstone Creek near the mouth	476713	6235953	Open-water	Level, discharge
S32	Surmont Creek at Highway 31	490310	6254473	Open-water	Level, discharge
S33	Muskeg River at the Aurora/Albian Boundary	474876	6350204	All year	Level, discharge
S34	Tar River above CNRL Lake	440729	6361689	Open-water	Level, discharge

[1] UTM coordinate datum is NAD83.

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

[3] Station S16 was discontinued in 2005; however, measurements of precipitation continued until May 1 and air temperature until October 11.

Measurements were made by wading or from a bridge or a boat. Measurement standards are summarized briefly below:

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

Details of the measurement procedures used for the Climate and Hydrology component are provided in Appendix C.

3.1.2.3 Snow Course Surveys

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

At each snow course site, a sampling site was established and snow depths were measured at 40 locations at a 10 m spacing. At least four samples were taken for density measurements using an Adirondack snow density gauge. Snow depth and the sample mass were recorded for each density sample to allow calculation of the snow water equivalent and snow density.

3.1.3 Changes in Monitoring Program from 2004

3.1.3.1 New and Upgraded Monitoring Stations

CNRL commissioned the installation of a new hydrometric station on the Tar River near the upstream boundary of Oil Sands Lease 18. Monitoring equipment was installed at the new station, station S34 (Tar River above CNRL Lake) on April 26, 2005. Due to the upstream location of the station, its watershed is expected to remain undeveloped for the foreseeable future. Therefore, the establishment of the station is consistent with recommendations in the RAMP Technical Design and Rationale Report (RAMP 2005b), which noted the scarcity of hydrometric monitoring stations in reference watersheds.

Station S14A (Ells River at the CNRL Bridge) was installed as a temporary installation in October 2004. A permanent installation comprising a bubbler-style depth sensor was completed in October 2005 after regulatory approvals were obtained. The bubbler-style sensor is expected to be more resistant to damage by ice and wildlife and therefore more reliable, and more economical to repair if damaged, than the submerged pressure transducers used at other RAMP hydrometric stations.

The flow measurement weir for Station S6 (Mills Creek) was replaced in 2005 following recommendations in previous RAMP reports, which noted that the weir was in poor condition, leaking and leaning downstream. The treated plywood and timber pile weir was replaced with steel piles and sheet steel.

3.1.3.2 Discontinued Stations

Station S16 (Calumet River near the Mouth) was discontinued following a decision by CNRL to replace station S16 with a new station operated outside of the RAMP program.

Station S17 (Tar River Upland Tributary) was discontinued because adverse hydraulic conditions (poorly defined stream, numerous beaver dams) precluded reliable continuous discharge measurements, and because of significant mine developments in the immediate vicinity. The station was replaced by station S34 as discussed above.

3.1.3.3 Formalized Quality Assessments

Since 2003, quality assessments have been applied to each manual streamflow measurement and to the annual record collected at each hydrometric station, to assist in interpretation and use of the data and to provide information useful for planning changes to the monitoring network. The quality assessment has been based largely on personal judgment of the consultant team. In late 2005, that assessment process was formalized to provide more consistent and repeatable results. One matrix of indicators was developed for streamflow measurements and a second for the annual record at each station. The matrices are provided in Appendix C.

3.1.4 Challenges Encountered and Solutions Applied

Submerged pressure transducers at two year-round RAMP stations, station S14A (Ells River at the CNRL Bridge) and station S24 (Athabasca River below Eymundson Creek) were destroyed during the ice breakup of spring 2005. The transducers were replaced during the subsequent field visit.

The datalogger at the Aurora C1 climate station malfunctioned in November 2004 and was repaired by Campbell Scientific on January 19, 2005. The equipment has been working properly since that time.

Spring discharges and water levels were higher in 2005 than usual, affecting the activities in this component. RAMP consultant team members visited the hydrometric stations between April 22 and April 29, 2005 to install and activate the open-water season stations and make routine streamflow measurements. High flows were observed at all sites except on the Athabasca River. The spring flood this year was estimated to be in the range of a 1:5 year flood in the Muskeg River basin, and a 1:3 year flood on the Ells River and western tributaries. At many stations the 2005 data included the highest spring values recorded to date. Some stations where flow is usually easily measured by wading were impossible to wade due to high stage and high flow velocities. Access to some stations was not possible due to the high water levels. Where possible, measurements were made at alternate locations, from bridges or boats. Flows were also high during the summer and in September, as discussed in Section 4.

Beaver dams complicated data capture, access and measurements, particularly at station S5A (Muskeg River above Muskeg Creek), station S9 (Kearl Lake Outlet), and station S18A (Calumet River Upland Tributary). Station S9 equipment was moved downstream approximately 50 m, to avoid variable backwater conditions.

Rating curves at some stations may have shifted due to channel changes that occurred during the high discharges this year. Continued stage-discharge measurements should detect the magnitude and direction of any changes in the rating curves.

Equipment at station S11 (Poplar Creek at Highway 63) and station S7 (Muskeg River near Fort McKay) was damaged or stolen by vandals. More robust station enclosures will be considered for new stations and possibly for some of the more accessible existing stations.

3.1.5 Other Information Obtained

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

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

The RAMP 2005 hydrology analysis consisted of the following major elements:

- Selection of hydrology measurement endpoints;
- Development of criteria to be used in detecting changes in hydrology measurement endpoints; and
- Detailed data analysis, consisting of:
    - Designation of watersheds to be used to represent baseline and operation conditions for the purposes of assessing hydrologic effects; and
    - Tabular and graphical presentation of 2005 results comparing 2005 hydrology measurement endpoints, hydrologic baseline conditions, and selected criteria for determination of change in hydrologic conditions.

These elements are described in detail below.

3.1.7.1 Selection of Hydrology Measurement Endpoints

The following measurement endpoints were selected for the analysis of the 2005 data:

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

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

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005			
		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																																					
Mills Creek at Highway 63	S6		2	2	2		2	2	2		2	2	2		2e	2e	2e		2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
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
Fort Creek at Highway 63	S12														2	2	2		2	2	2		2g	2g	2g												
Ells River above Joslyn Creek	S14																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Ells River at CNRL Bridge	S14a																																	2	2	2	2
Tar River near the Mouth	S15																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
Calumet River near the Mouth	S16																		2	2	2		2h	2h	2h		2h	2h	2h	h	2h	2h	2h	h	i	i	
Tar River Upland Tributary	S17																		2	2	2		2	2	2		2	2	2		2	2	2				
Upland Calumet River	S18																		2	2	2																
Calumet River Upland Tributary	S18A																						2	2	2		2	2	2		2	2	2		2	2	2
Tar River Lowland Tributary near the Mouth	S19																		2	2	2		2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a
Susan Lake Outlet	S25																						2	2	2												
MacKay River near Fort McKay (07DB001)	S26		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4	2	4	4	4	2	4	4	4	2	4	4	4
Firebag River near the Mouth (07DC001)	S27		4	4	4		4	4	4		4	4	4		4	4	4		4	4	4	2	4	4	4		4	4	4	2	4	4	4	2			
Tar River above CNRL Lake	S34																																		2	2	2
Fort Creek Basin Snowcourse Survey															d																						
CNRL Area Snowcourse Survey																			d				d				d										
Athabasca River Mainstem																																					
Athabasca River below Eymundson Creek	S24																		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Muskeg River Basin																																					
Alsands Drain	S1		2	2			2	2	2		2	2	2	2					2	2	2	2	2	2	2												
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
Iyinimin Creek above Kearl Lake	S3		2	2	2		2a	2a	2a		2a	2a	2a						2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a		2a	2a	2a
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
Muskeg River above Muskeg Creek	S5A		2	2	2		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e	2e
Muskeg River near Fort McKay (07DA008)	S7		4	4	4		4	4	4	4	4	4	4		4	4	4		4	4	4	2	4	4	4	2	2	2	2	2	4	4	4	2	2	2	2

Legend

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

Footnotes

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

potentially influenced - oil sands
potentially influenced - other
reference

Table 3.1-2 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997 W	1997 S	1997 S	1997 F	1998 W	1998 S	1998 S	1998 F	1999 W	1999 S	1999 S	1999 F	2000 W	2000 S	2000 S	2000 F	2001 W	2001 S	2001 S	2001 F	2002 W	2002 S	2002 S	2002 F	2003 W	2003 S	2003 S	2003 F	2004 W	2004 S	2004 S	2004 F	2005 W	2005 S	2005 S	2005 F
Muskeg River Basin (con'td)																																					
Stanley Creek near the Mouth	S8											1	1		1	1	1		1	1	1		1	1	1		1	1	1								
Kearl Lake Outlet	S9						2	2	2		2e	2e	2e						2	2	2		2	2	2		2	2	2		2	2	2	2	2	2	2
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
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
Shelley Creek near the Mouth	S21																		2	2	2		2	2	2		2	2	2								
Muskeg Creek near the Mouth	S22																		2	2	2		2	2	2		2	2	2		2	2	2		2	2	2
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
Muskeg River at the Aurora/Albian Boundary	S33																										2	2	2	2	2	2	2	2	2	2	2
Aurora Climate Station	C1	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f	f
Muskeg River Basin Snowcourse Survey			d				d				d				d				d																		
Muskeg River High Water Gauging				3				3				3				3				3																	
Jackpine Creek High Water Gauging				3				3												3																	
Clearwater River Tributaries																																					
Christina River near Chard (07CE002)	S29																					2	4a	4a	4a	2	4a	4a	4a	2	4a	4a	4a	2			
Hangingstone River at Highway 63	S30																						2	2	2												
Hangingstone Creek near the Mouth	S31																						2	2	2						2	2	2		2	2	2
Surmont Creek at Highway 881	S32																						2	2	2						2	2	2		2	2	2
Wetlands																																					
McClelland Lake	L1			2	2		2	2	2		2	2	2		2	2	2		2	2	2	1	2a	2a	2a	1	2a	2a	2a	1	2a	2a	2a	1	2a	2a	2a
Kearl Lake	L2										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Isadore's Lake	L3													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Regional Data																																					
Wide-Area Snowcourse Survey																														d				d			
Compilation of Environment Canada data		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Legend

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

Footnotes

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

potentially influenced - oil sands
potentially influenced - other
reference

These endpoints were selected based on a review of measurement endpoints used in various oil sands project EIAs (RAMP 2005b), with emphasis on those endpoints that can be computed from one year of data. Additional endpoints, such as the 1:10 year flood flow or the 7Q10 low flow, may be added to the analysis in future years when multiple years of both baseline and operational data are available for watersheds with areas designated as *potentially influenced-oil sands*.

3.1.7.2 Criteria for Determining Effects

The differences between operational and baseline hydrographs were compared to the various sets of criteria for determining effects on hydrologic measurement endpoints in the EIAs that were prepared for oil sands projects (RAMP 2005b).

3.1.7.3 Detailed Analysis

Overall Approach

Evaluating hydrologic effects using hydrologic comparisons between areas designated as *reference* and areas designated as *potentially influenced-oil sands* poses several challenges:

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

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

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

The approach adopted to deal with these challenges was to measure hydrologic effects directly, treating each watershed potentially affected by development as both *reference* and *potentially influenced-oil sands*. The observed hydrograph at a selected station was used as the operational case, and a baseline hydrograph was derived as discussed below. Thus any influence of oil sands development was isolated from the effects of spatial and temporal variability.

Estimation of Baseline Hydrographs

Baseline hydrographs are defined for this analysis as the hydrograph that would have occurred at the station if no oil sands development had occurred in the watershed. The baseline hydrograph may include the effect of other non-oil sands related activities in the watershed, and so is not necessarily a naturalized hydrograph. The baseline hydrograph is derived for the purpose of assessing any incremental effects of oil sands developments.

The baseline hydrograph is estimated as follows:

Baseline Hydrograph = Observed (Operational) Hydrograph

- \+ Natural runoff that would have occurred from active oil sands development areas, or that is intercepted by oil sands development
- \- Incremental runoff from areas that are cleared and areas that are dewatered
- \+ Water withdrawals from the watercourse in question by oil sands development activities
- \- Water releases to the watercourse in question by oil sands development activities
- ± Runoff from areas that have been diverted into (-) or out of (+) the watershed in question
- \- The difference between baseline and operational hydrographs on tributaries upstream of the station in question

Baseline hydrographs were estimated for the outlet of each major watershed by adding water withdrawals and subtracting water releases from the observed hydrographs. Changes in catchment area due to stream diversions and the isolation of oil sands-developed areas were considered recognizing the difference in runoff response between upland and lowland areas. Incremental runoff depth from cleared and dewatering areas was estimated using the assumption that runoff from those areas would be 20% greater than runoff from the natural portion of the catchment.

The approach does not account for indirect effects of oil sands development on streamflow, such as groundwater influences on surface water. It does not account for the fact that an increase or decrease in catchment area affects the catchment responsiveness. Flood peaks, for example, will normally not be doubled by doubling the size of the catchment. In addition, the assumption of a 20% increase in runoff from cleared and dewatering areas is somewhat arbitrary, and ignores the changes in runoff timing and catchment responsiveness that are also associated with clearing. As a result, the predicted effects on low flow, in particular, are weak. Therefore the current philosophy of monitoring some reference catchments should continue in order to provide a secondary basis for comparison.

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

3.2 WATER QUALITY

3.2.1 Overview of 2005 Program

The 2005 RAMP water quality program included five ambient water sampling programs on rivers and lakes in the RAMP FSA to document water quality and assess any changes in water chemistry or quality that may be occurring due to oil sands development or other factors affecting the natural environment. Specific timing of seasonal sampling programs in 2005 appears in Table 3.2-1, below.

Table 3.2-1 RAMP water quality sampling field campaigns, 2005.

Season	Duration
Winter 1	January 28, 2005
Winter 2	March 15 to March 18, 2005
Spring	May 24 to June 2, 2005
Summer	July 19 to August 1, 2005
Fall[1]	September 7 to September 24, 2005

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

Generally, stations were selected to serve one of three purposes: to provide baseline data for characterization of natural variability prior to development; to measure water quality near to and downstream from existing oil sands developments; or, to act as an upstream baseline station for comparison with areas possibly affected by oil sands development. Further details regarding the rationale of each sampling station are found in RAMP (2005b).

Discrete water quality sampling in 2005 was focused on the Athabasca River and its major tributaries in the Athabasca oil sands region, as well as regionally important lakes and wetlands. Sampling was conducted by RAMP, with data also contributed from Alberta Environment (AENV) and individual oil sands operators for some locations. Water quality was examined at a total of 45 stations in 2005. Table 3.2-2 summarizes water quality sampling stations, frequency of seasonal sampling, and water quality variables measured at each station, while Figure 3.2-1 indicates the locations of the water quality stations sampled in 2005.

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

3.2.2 Field Methods

3.2.2.1 Discrete Field Sampling

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

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

At all water quality stations, *in situ* measurements of dissolved oxygen (DO), temperature and conductivity were collected using a YSI Model 85 multi-probe water meter and/or a handheld thermometer (temperature), a handheld conductivity meter (conductivity) and a LaMott portable Winkler titration kit (dissolved oxygen). Most dissolved oxygen measurements during the 2005 program were determined through Winkler titration due to concerns with measurement accuracy of the YSI 85 DO probe.

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

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

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

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

Table 3.2-2 Summary of sampling for the RAMP 2005 Water Quality component.

See key at end of table, following page.

Station Identifier and Location		UTM Coordinates		Analytical Package by Season				Sample Type
		Easting	Northing	W	S	S	F	
Athabasca River								
ATR-UFM	Upstream of Fort McMurray (monthly)	475330	6286105	11	13	11	13	*AENV sampling*
ATR-DC-CC	Upstream of Donald Creek	475020	6298154	-	-	-	1	Cross channel composite
ATR-DC-W	Upstream of Donald Creek	475102	6298152	-	-	-	1	West bank grab
ATR-DC-E	Upstream of Donald Creek	475120	6298154	-	-	-	1	East bank grab
ATR-SR-W	Upstream of the Steepbank River	470785	6319199	-	-	-	1	West bank grab
ATR-SR-E	Upstream of the Steepbank River	470937	6319625	-	-	-	1	East bank grab
ATR-MR-W	Upstream of the Muskeg River	463203	6332042	-	-	-	1	West bank grab
ATR-MR-E	Upstream of the Muskeg River	463504	6332230	-	-	-	1	East bank grab
ATR-DD	Downstream of all development	463709	6367819	1,1	1	1	1	Cross channel composite
ATR-DD-W	Downstream of all development (west bank)			1	1	1	1	
ATR-DD-W	Downstream of all development (east bank)			1	1	1	1	
ATR-FR	Upstream of the Firebag River	478455	6400331	-	-	-	1	Cross channel composite
ATR-ER	Upstream of the Embarras River			-	-	-	-	Cross channel composite
ATR-OF	At Old Fort (sampled monthly)	470205	6474330	12	12	12	12	*AENV Sampling*
EMR-1	Embarras River			-	-	-	-	Mid-channel grab
Athabasca River Delta								
ARD-1	Big Point Channel	511903	6494506	-	-	-	-	Cross channel composite
Tributaries to the Athabasca River (Eastern)								
MCC-1	McLean Creek (mouth)	474637	6306051	-	1[a]	1[a]	2[a]	Mid-channel grab
Steepbank River								
STR-1	Steepbank River (mouth)	470807	6319811	-	-	-	1	Mid-channel grab
STR-2	Steepbank River (u/s of Millennium)	485820	6309347	-	-	-	1	Mid-channel grab
STR-3	Steepbank R. (u/s of N. Steepbank R.)	495076	6300011	NS	1	1	1	Mid-channel grab
NSR-1	North Steepbank R. (u/s of P.C. Lewis)	497380	6324549	NS	1	1	1	Mid-channel grab
Muskeg River								
MUR-1	Mouth	463473	6332409	-	-	-	1	Mid-channel grab
MUR-2	Upstream of Canterra Road crossing	466569	6340506	4	4	4	4	*Industry sampling*
MUR-2	Downstream of Canterra Rd. crossing			15	15	15	14	*AENV sampling*
MUR-4	Upstream of Jackpine Creek	474379	6349075	4	10	10	10	*Industry sampling*
MUR-5	Upstream of Muskeg Creek	476043	6351800	10	10	10	10	*Industry sampling*
MUR-6	Upstream of Wapasu Creek	492093	6355679	-	6	6	7	Mid-channel grab
Muskeg River Tributaries								
JAC-1	Jackpine Creek (mouth)	471935	6346300	-	-	-	1	Mid-channel grab
MUC-1	Muskeg Creek (mouth)	481031	6349022	-	-	-	1	Mid-channel grab
STC-1	Stanley Creek (mouth)	477375	6356665	NS	1	1	1	Mid-channel grab
WAC-1	Wapasu Creek (Canterra Rd. crossing)	490340	6355735	-	-	-	1	Mid-channel grab

Table 3.2-2 (Cont'd.)

Station Identifier and Location		UTM Coordinates		Analytical Package by Season				Sample Type
		Easting	Northing	W	S	S	F	
Tributaries to the Athabasca River (Eastern)								
Firebag River								
FIR-1	Firebag River (mouth)	479114	6400215	1	1	1	1	Mid-channel grab
FIR-2	Firebag River (u/s of Suncor Firebag)	531543	6354825	1	1	1	1	Mid-channel grab
Tributaries to the Athabasca River (Western)								
POC-1	Poplar Creek (mouth)	473051	6308820	-	-	-	1	Mid-channel grab
BER-1	Beaver River (mouth)	463620	6330924	-	-	1	1	Mid-channel grab
MAR-1	MacKay River (mouth)	461601	6336007	-	-	-	1	Mid-channel grab
MAR-2	MacKay River (u/s of P.C. MacKay)	444682	6314024	-	-	-	1	Mid-channel grab
ELR-1	Ells River (mouth)	459241	6351495	1	1	1	2	Mid-channel grab
ELR-2	Ells River (upstream of CNRL Lease 7)	455753	6344915	NS	1	1	1	Mid-channel grab
TAR-1	Tar River (mouth)	458852	6353527	NS	1	1	1	Mid-channel grab
TAR-2	Tar River (upstream of CNRL Horizon)	440261	6361800	NS	1	1	1	Mid-channel grab
CAR-1	Calumet River (mouth)	460816	6363196	NS	1	1	2	Mid-channel grab
CAR-2*	Calumet River (upper river)			NS	1	1	2	
Tributaries to the Athabasca River (Southern)								
HAR-1	Hangingstone R. (u/s of Ft. McMurray)	478653	6276265	NS	1	1	1	Mid-channel grab
Clearwater River								
CLR-1	Clearwater River (u/s of Fort McMurray)	480610	6283924	1	7	7	7	Mid-channel grab
CLR-2	Clearwater River (u/s of Christina R.)	496294	6280422	1	7	7	7	Mid-channel grab
Christina River								
CHR-1	Christina River (u/s of Fort McMurray)	496646	6280035	1	1	1	1	Mid-channel grab
CHR-2	Christina River (upstream of Janvier)	511698	6192371	1	1	1	1	Mid-channel grab
Lakes and Wetlands								
KEL-1		485425	6349374	-	-	1	1	Multi-location composite
ISL-1		463361	6342764	-	-	1	1	Multi-location composite
SHL-1		473481	6313037	-	-	1	1	Multi-location composite
QA/QC[1]								
-				1	1	1	1	N/A

Note: NS indicates not sampled – waterbody frozen to depth at time of survey.

[a] Thermograph not installed due to technical oversight.

* New station in 2005.

[1] Results of the RAMP QA/QC program for water quality are presented in Appendix B.

Legend to Analytical Packages:

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

Figure 3.2-1 RAMP water quality sampling locations, 2005.

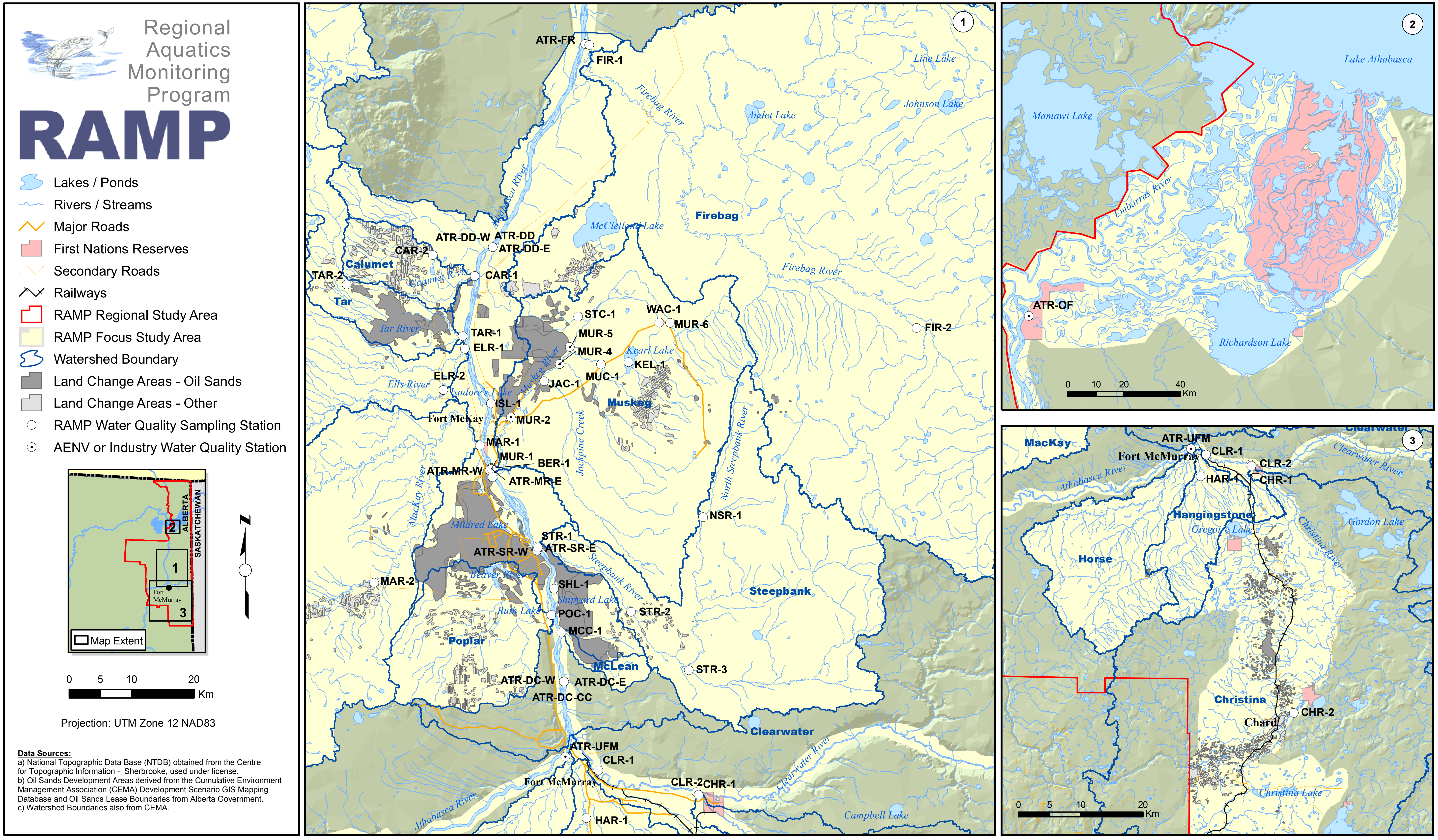


Table 3.2-3 RAMP water quality composite sample sub-groups.

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

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

3.2.2.2 Continuous Monitoring

As part of the spring water quality program RAMP deployed three HOBO Water Temp Pro automatic temperature sensor/data-loggers for collection of open-water temperature data. Each sensor was attached to a stone or cinder block and deployed in a pool or other deep area that was likely to contain water for the entire monitoring period. Sensors were cabled to the bank to ensure equipment retrieval.

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

Table 3.2-4 Locations of continuous water temperature monitoring stations, May to September 2005.

Location	Installation Date	Removal Date
Clearwater River mouth (CLR-1)	May 28, 2005	September 14, 2005
Upper Clearwater River (CLR-2)	May 27, 2005	September 13, 2005
Upper Muskeg River (MUR-6)	May 25, 2005	September 08, 2005

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

3.2.2.3 Sample Shipment and Analysis

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

Samples were shipped via Greyhound or through the ETL outlet in Fort McMurray. RAMP conventional water quality variables and organics/hydrocarbons were analyzed by ETL (Table 3.2-5). Metals (dissolved and total, including ultra-trace total mercury) were measured by ARC (Table 3.2-6). Sublethal toxicity of water to aquatic organisms was evaluated by HydroQual (Table 3.2-7).

3.2.2.4 Seasonal Differences in Analyses

Sampling intensity was greatest during the fall program, with samples collected from all active RAMP monitoring stations (Table 3.2-2). During the fall, additional samples were collected for analysis of sublethal toxicity at the following stations: McLean Creek (MCC-1); lower and upper Ells River (ELR-1 and ELR-2); and lower and upper Calumet River (CAR-1 and CAR-2).

3.2.3 Changes in Monitoring Network from 2004 Field Program

Station location and methodology were largely consistent with 2004 efforts; however, the following variations were present in the 2005 program:

- Following the spring sampling campaign, station TAR-2 (Tar River, upstream) was relocated to an undisturbed location several kilometers further upstream, given the area surrounding the river at the 2004 location had recently been logged and therefore no longer was a suitable reference location;
- A thermograph was not deployed at station MCC-1 in 2005, due to technical oversight;
- Chlorophyll *a* was immediately filtered and frozen on the day the sample was collected by the Enviro-Test laboratory in Fort McMurray, to meet sample holding times and provide better assurance that chlorophyll synthesis or degradation did not occur following sample collection; and
- A new monitoring station was established in the upper Calumet River (CAR-2).

3.2.4 Challenges Encountered and Solutions Applied

In fall 2005, thermographs that had been deployed on the Clearwater River in spring were covered in sediment at the time of retrieval. Each sensor had been attached to a stone or cinder block and placed on the streambed, with care taken to ensure that the sensor was located near the stream thalweg. However, this approach appears insufficient for the collection of meaningful data from the study watercourses.

The 2004-2005 site selection process for thermograph placement was based upon alignment with water and sediment quality stations. It is recommended that in 2006, a reconnaissance of these watercourses be undertaken to determine whether there are alternate locations for the thermographs that are more likely to provide the necessary wetted depth for full open-water season data collection, and that can be accessed safely in both spring and fall. This investigation would be undertaken in conjunction with regularly scheduled spring water quality sampling. It is also suggested that the thermographs be deployed on an anchored buoy line at a standard depth below the surface. This would ensure the units remain positioned in the water column and collect temperature data throughout the open-water season.

Table 3.2-5 RAMP conventional water quality variables.

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

Table 3.2-6 RAMP total and dissolved metals.

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

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

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

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

In 2004, the 48-hour holding time (between sampling and laboratory analysis) for chlorophyll *a* samples was exceeded frequently because the consulting laboratory subcontracted these analyses to a laboratory in Winnipeg. To address this holding time concern, 2005 chlorophyl *a* samples were filtered at the Enviro-Test laboratory in Fort McMurray and frozen prior to shipment. This approach increased the maximum allowable holding time to 28-days, ensuring all holding restrictions were satisfied. An assessment of this change in holdings times on resulting chlorophyll *a* data was undertaken for this report, as discussed in Section 3.2.7.5.

Due to a test set-up oversight at the consulting toxicology laboratory (HydroQual), a fathead minnow sublethal bioassay was not conducted for station MCC-1 (McLean Creek) in September 2005.

3.2.5 Other Information Obtained

All data collection for the 2005 water quality program was conducted by the RAMP implementation team, with the exception of three stations on the Muskeg River mainstem (MUR-2, MUR-4 and MUR-5) that were monitored by industry (i.e., Syncrude Canada Ltd. and Albian Sands Energy Inc.) and three stations on the Athabasca (ATR-UFM, ATR-OF) and Muskeg rivers (MUR-2) monitored by AENV (Table 3.2-2).

3.2.6 Summary of Component Data Now Available

All water quality data collected by the RAMP implementation team in 2005 were entered into the RAMP relational database, which includes all RAMP water quality data collected since its inception in 1997, in consistent structure and formats. This dataset now includes over 52,000 water quality observations from 1997 to 2005, and facilitated comprehensive and comparative analysis of water quality in the RAMP area since 1997, as described in Section 3.2.7.

Table 3.2-8 summarizes historical water quality sampling undertaken by RAMP since 1997, excluding data collected by AENV and industry partners.

3.2.7 Analytical Approach

In order to address the objectives of RAMP generally and of the RAMP Water Quality component specifically, a mix of analytical approaches is used. Specific approaches have changed over time, as the volume of data for given and previous years has increased (Table 3.2-9). RAMP's current approach uses a tiered, nested design of control/impact (upstream/downstream) designs, nested within gradient designs, all nested within a regional assessment design, which allows hypothesis testing at project, watershed and regional scales.

In accordance with the overall analytical approach used for the preparation of this report (Section 1.6), the RAMP 2005 water quality analysis included the following major components:

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

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

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005			
		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 (grab) [a]	ATR-UFM	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11	13	11				
Upstream Donald Creek (cross channel)	ATR-DC-CC		1	1	1																				1				3				1	1	1	1	1
(west bank) [b]	ATR-DC-W								1								1				3				1				1				1	1	1	1	1
(east bank) [b]	ATR-DC-E								1								1				3				1				1				1	1	1	1	1
(middle)	ATR-DC-M																1																				
Upstream of the Steepbank River (middle)	ATR-SR-M																1																				
(west bank)	ATR-SR-W																1				1				1				1				1				1
(east bank)	ATR-SR-E																1				1				1				1				1				1
Upstream of the Muskeg River (middle)	ATR-MR-M																1																				
(west bank) [b c]	ATR-MR-W								1								1				1				1				1				1				1
(east bank) [b c]	ATR-MR-E								1								1				1				1				1				1				1
Upstream Fort Creek (cross channel)	ATR-1		1	1	1																																
(west bank) [b c]	ATR-FC-W								1								1				3				1				1								1
(east bank) [b c]	ATR-FC-E								1								1				3				1				1								1
(middle)	ATR-FC-M																1																				
Downstream of all development (cross channel)	ATR-DD																					1,1	1	1	3	1,1	1	1	3	1,1	1	1	3	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																1				3																
Embarras River	EMR-1																												1								
At Old Fort (grab) [d]	ATR-OF													11	11	11	11	11	11	11	11	12	12	12	12	12	12	12	12	12	12	12	12				
Athabasca River Delta																																					
Big Point Channel [e]	ARD-1											1					1				1								1				1				
Athabasca River tributaries (Eastern)																																					
McLean Creek (mouth)	MCC-1											6	7		6	6	9		6	6	9	1	6	6	7		6	6	7		6	6	9		6	6	9
(100 m upstream)	MCC-2											6	6																								
Steepbank River (mouth)	STR-1		1	1	1		1	1	1	1							1				1	1			1				1				1				1
(upstream of Project Millennium)	STR-2																					1			1				1				1				1
(upstream of Nt. Steepbank)	STR-3																													1	1	1	1	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		1	1	1
Muskeg River																																					
Mouth [f]	MUR-1		1	1	1	13	13,1	13,1	11,1	13	13,6	13,6	11,7				1				1				1				1				1				1
Upstream of Canterra Road Crossing [f]	MUR-2									2	9	9	9	10	10	10	10	10	10	10	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AENV sampling [g]						13	13	13	11	13	13	13	11	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14	15	15	15	14
Downstream of Alsands Drain	MUR-3																																				
Upstream of Jackpine Creek [f g h]	MUR-4					13	13	13	11	13	13,6	13,6	11,7	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10	4	10	10	10
Upstream of Muskeg Creek [f g]	MUR-5					13	13	13	11	13,2	13,9	13,9	11,9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Upstream of Wapasu Creek	MUR-6					2			2	2	9	9	9		6	6	9		6	6	9		6	6	9		6	6	7		6	6	9		6	6	9

Legend

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

Note: Beginning in 2003, volatile hydrocarbons (VOCs) will be measured at some locations on the Muskeg, Tar, Ells and Steepbank Rivers

Footnotes

[a] Two samples collected in winter, but PAHs and several other parameters only measured once
[b] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the Delta)
[c] Samples were collected downstream of tributary in 1998
[d] Monthly sampling for nutrients and conventional parameters; quarterly sampling for total and dissolved metals
[e] In 1999, one composite samples was prepared with water from Big Point, Goose Island, Embarras and an unnamed side channel
[f] 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

potentially influenced - oil sands (blue)
potentially influenced - other (yellow)
reference (green)

√ = allowance made for potential TIE

Table 3.2-8 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997 W	1997 S	1997 S	1997 F	1998 W	1998 S	1998 S	1998 F	1999 W	1999 S	1999 S	1999 F	2000 W	2000 S	2000 S	2000 F	2001 W	2001 S	2001 S	2001 F	2002 W	2002 S	2002 S	2002 F	2003 W	2003 S	2003 S	2003 F	2004 W	2004 S	2004 S	2004 F	2005 W	2005 S	2005 S	2005 F
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
Shelley Creek (mouth)	SHC-1								11				11,1																								
Muskeg Creek (mouth)	MUC-1								11,2				11,1				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
Wapasu Creek (Canterra Road Crossing)	WAC-1					2			11	2			11,1																				1				1
Athabasca River tributaries (Western)																																					
Poplar Creek (mouth)	POC-1																1				1	1			1				1				1				1
Beaver River (mouth)	BER-1																																1			1	1
MacKay River (mouth)	MAR-1								1								1				1	1			1				1				1				1
(upstream of P.C. MacKay)	MAR-2																					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
(upstream of CNRL Lease 7)	ELR-2														11	11	11	14												1	1	1	2		1	1	2
Tar River (mouth)	TAR-1						1	1	1													1	1	1	2	1	1	1	2	1	1	1	1		1	1	1
(upstream of CNRL Horizon)	TAR-2																													1	1	1	1		1	1	1
Calumet River (mouth)	CAR-1																					1	1	1	2	1	1	1	2	1	1	1	2		1	1	2
Calumet River (upstrream of CNRL Horizon)	CAR-2																																		1	1	2
Fort Creek (mouth)	FOC-1														7	7	9		6	6	7	1	6	6	7		6	6	7								
Firebag River (mouth)	FIR-1																					1	1	1	1	1	1	1	1	1	1	1	1	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
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
(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
Christina River (upstream of Fort McMurray)	CHR-1																					1	1	1	3	1	1	1	3	1	1	1	3	1	1	1	3
(upstream of Janvier)	CHR-2																					1	1	1	3	1	1	1	3	1	1	1	1	1	1	1	3
Hangingstone River (upstream of Ft. McMurray)	HAR-1																														1	1	1		1	1	3
Wetlands (Lakes)																																					
Kearl Lake (composite)	KEL-1							1									1			1	1				1	1			1			1	1			1	1
Isadore's Lake (composite)	ISL-1							1									1			1	1												1			1	1
Shipyard Lake (composite)	SHL-1							1			1	1	1			1	1			1	1			1	1			1	1			1	1			1	1
McClelland Lake (composite)	MCL-1																1			1	1				1												
Additional Sampling (Non-Core Programs)																																					
Unnammed Creek north of Ft. Creek (mouth)	UNC-1															1	1																				
OPTI Lakes	-																		5		5		5		5												
Potential TIE	-																								√				√				√				
QA/QC																																					
Field and trip blanks, plus one split sample	-														1	1	1			1	1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1	1	1	1	1,1

Legend

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

Footnotes

[a] Two samples collected in winter, but PAHs and several other parameters only measured once
[b] Sample sites were previously labeled ATR-1, 2 and 3 (moving upstream from the Delta)
[c] Samples were collected downstream of tributary in 1998
[d] Monthly sampling for nutrients and conventional parameters; quarterly sampling for total and dissolved metals
[e] In 1999, one composite samples was prepared with water from Big Point, Goose Island, Embarras and an unnamed side channel
[f] 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

potentially influenced - oil sands
potentially influenced - other
reference

√ = allowance made for potential TIE

Table 3.2-9 Analytical approaches taken by the RAMP Water Quality component, 1997 to 2005.

Method	1997	1998	1999	2000	2001	2002	5-yr Report	2003	2004	2005
Descriptive										
Tabular	✓	✓	✓	✓	✓	-	-	✓	✓	✓
Graphical	-	✓	-	✓	✓	✓	✓	✓	✓	✓
Statistical										
Trend Analysis	-	-	-	-	-	-	✓	✓	✓	✓
Correlation	-	-	-	-	-	-	-	✓	✓	✓
Principal Component Analysis	-	-	-	-	-	-	-	✓	✓	✓
Regional Baseline Development	-	-	-	-	-	-	-	-	✓	✓

- Designation of stations to be used as baselines for water quality conditions through the establishment of regional baseline values for each water quality measurement endpoint;
- Tabular and graphical presentation of 2005 results comparing 2005 concentrations of the water quality measurement endpoints, water quality baseline conditions, and selected criteria for determination of change in water quality; and
- Specification of additional analyses to be conducted including trend analysis.

These components are described in detail below.

3.2.7.1 Selection of Water Quality Measurement Endpoints

RAMP collects data for over 100 water quality variables at some stations in a given sampling event. A number of these variables were selected as water quality measurement endpoints for the purpose of this 2005 technical report; the selection of the measurement endpoints was guided by information obtained from the following sources:

- Water quality measurement endpoints used in the EIAs of oil sands projects (see RAMP [2005b] for a review of these EIAs and specific predictions of relevance to the RAMP Water Quality component);
- A draft list of water quality variables of concern in the lower Athabasca region developed by CEMA (2004);
- Water quality variables of interest listed in the RAMP 5-year report (Golder 2003a);
- Results of correlation analysis of the RAMP 1997-2004 water quality dataset indicating significantly inter-correlation of various water quality variables (particularly metals) (Appendix D);

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

- Discussions with RAMP Technical Program Committee members, during and in relation to a meeting held in Calgary on February 2, 2006 to discuss analytical strategies for this report.

Table 3.2-10 presents variables listed in these various sources. The final list of water quality measurement endpoints used in this report, and reasons for their inclusion, are:

- *pH:* an indicator of acidity;

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

- *Dissolved phosphorus, total nitrogen and nitrate-nitrite:* indicators of nutrient status (note that 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 total suspended solids [Appendix E]);

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

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

- *Total dissolved solids and dissolved organic carbon:* indicators of total ion concentrations and dissolved organic matter (particularly humic acids), respectively;

- *Total and dissolved aluminum:* aluminum is mentioned as a variable of interest in some oil sands EIAs, by CEMA, and in the RAMP 5-year report (Table 3.2-10); given total aluminum, for which water quality guidelines exist, has been demonstrated to be strongly associated with suspended solids (Golder 2003a), dissolved aluminum also was assessed, as it more accurately represents biologically available forms of aluminum that may cause toxicity to aquatic organisms (Butcher 2001);

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

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

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

Table 3.2-10 Potential key water quality measurement endpoints.

Analyte Group	RAMP (2005b) Variables Listed in EIAs (No. of projects)	CEMA Variables of Concern (CEMA 2004)[1]	RAMP 5-year report (Golder 2003a)	Variables to Support other RAMP Components[2]	Additional Suggested Variables[3]
Physical Variables	Temperature (3) Total suspended solids (9) Dissolved oxygen (3) Conductivity (1) pH (1)	(None)	pH Total suspended solids	Temperature Dissolved oxygen pH Total suspended solids Conductivity	
Nutrients	Ammonia-N (1) Total nitrogen (2) Total phosphorus (2)	Ammonia-N Total nitrogen Total phosphorus	Dissolved organic carbon Total Kjeldahl nitrogen Total phosphorus	Dissolved phospohorus Nitrate+nitrite	
Ions and Ion Balance	Chloride (2) Sulphide (2) Total dissolved solids (2)	Sodium Chloride Potassium **Fluoride** Sulphate	Total dissolved solids Sulphate Total alkalinity	Total alkalinity Hardness	Carbonate Bicorbonate Magnesium Calcium
Dissolved and Total Metals	Aluminum (3) Arsenic (2) Barium (2) Boron (1) Cadmium (3) Chromium (3) Copper (3) Iron (2) Manganese (2) Mercury (2) Molybdenum (1) Selenium (1) Silver (1) Zinc (1)	Aluminum Antimony Boron Cadmium Chromium Lithium Molybdenum Nickel Strontium Vanadium	Total chromium Total boron Total aluminum	Total & dissolved copper Total & dissolved lead Total & dissolved nickel Total & dissolved zinc Ultra trace mercury	
Organics/ Hydrocarbons	Oil & grease (1) Napthenic acids (1) Total phenolics (2)	Oil & grease Total hydrocarbons Naphthenic acids **Toluene** **Xylene**	(None)	(None)	(None)
PAHs	Benzo(a)anthracene (3) Benzo(a)pyrene (2) Misc. PAHs (3)	Napthelene Biphenyl Acenapthene Acenaphtylene Fluorine Fluoranthene Alkyl-napthelenes Alkyl-biphenyls Alkyl-acenapthene Alkyl-benzo(a)anthracene Alkyl-fluorenes Alkyl-phenanthrenes Dibenzothiophene Alkyl-dibenzothiophenes	(None)	(None)	(None)
Effects-based Endpoints	Acute toxicity (1) Chronic toxicity (2)	Acute toxicity Chronic toxicity **Fish-tainting**			

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

1 Includes variables not necessarily related to oil sands operations.

2 Primarily fish and benthos (inferred).

3 Suggested by members of the RAMP Technical Program Committee, February 2005.

3.2.7.2 Criteria for Determining Effects

Two criteria for determining water quality effects were used:

- **Comparison to Water Quality Guidelines**: All water quality data collected by RAMP in 2005 were screened against Alberta acute and sublethal water quality guidelines for the protection of aquatic life (AENV 1999b) and Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) (CCME 2003). Analytes for which no AENV or CCME guidelines exist were screened against applicable guidelines from other jurisdictions where appropriate. All values that exceeded these guidelines are reported explicitly in the body of the RAMP report.

- **Comparison to Natural Variation in Baseline Conditions**: RAMP 2005 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 analytes. Procedures used to determine the range of natural variability are explained immediately below.

3.2.7.3 Development of Regional Water Quality Baselines

Discussions of the ability of the RAMP program to detect effects often have been framed by considerations of statistical power, a testable statistical concept used to assess the likelihood that the result of a statistical test is neither a false positive nor a false negative. Issues of low statistical power for ANOVA-based before-after and upstream-downstream comparisons were raised in previous RAMP reports (e.g., Golder 2003a) and in the RAMP Peer Review (Ayles *et al.* 2004) as potential reasons to increase temporal or spatial replication. However, true replication is problematic, if not impossible, in a water quality program such as RAMP. Additionally, the power in potential statistical comparisons in the RAMP water quality program would vary considerably for each measurement endpoint and comparison made. Given the large number of water quality endpoints measured and comparisons made by RAMP, assessment of the statistical power of each comparison would be onerous. Further, results of such an assessment would likely be confusing, as the number of samples required to achieve sufficient power would vary for each endpoint and each station comparison, rather than a uniform and consistent sampling strategy for the overall RAMP program. Therefore, in lieu of a power-based analytical approach, RAMP has adopted a regional baseline approach, in which individual observations may be compared against regional baseline data.

In this approach, water quality data from all RAMP reference water quality stations (i.e., those upstream of any oil sands development) for all years of sampling (i.e., 1997 to 2005) 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), and were first applied to the RAMP water quality dataset in the 2004 Technical Report, where more details may be found.

Detailed methods and results of the Objective Classification Analysis of the RAMP water quality data are provided in Appendix D. Results of this analysis of the RAMP 1997 to 2005 data set indicated three major groups of stations with similar water quality types (Table 3.2-11):

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

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

These groupings are generally consistent with results of similar cluster-based analyses 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 2005 was generally consistent with the clusters defined in the 2004 analysis, with the exception of Fort Creek, McLean Creek, and the Hangingstone River, which were grouped with northeastern and southern tributaries in 2004. These results indicate that water quality data collected in 2005 were consistent with the water quality characteristics of each group.

Within each cluster, data from stations designated as either *reference* or *potentially influenced-other* (i.e., those stations located in areas of watersheds in which significant oil sands development has not yet occurred) were pooled to develop descriptions of baseline regional water quality, against which RAMP data from stations designated as *potentially influenced-oil sands* and either *reference* or *potentially influenced-other* were assessed. Table 3.2-12 lists the station-year combinations from which 1997 to 2005 RAMP data were pooled to develop these baseline descriptions, and data from which stations were compared against these baselines. Numbers of observations in regional baseline data sets varied by cluster and by analyte.

3.2.7.4 Tabular and Graphical Presentation of Results

Comparison to Water Quality Guidelines

Water quality data from fall 2005 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 2004. Concentrations of any water quality measurement endpoint that exceeded relevant guidelines were noted and, as indicated above, all values that exceeded these guidelines were also reported.

Table 3.2-11 Classification of groups of RAMP water quality monitoring stations with similar water quality, from 1997 to 2005 data.

Waterbody	Total No. of Station/Year Combinations	Cluster		
		1	2	3
Athabasca River	**74**	**1**	**1**	**72**
Athabasca River Delta	**4**	**0**	**0**	**4**
Eastern tributaries	**20**	**10**	**9**	**1**
Firebag River	8	8	0	0
Fort Creek	4	1	3	0
McLean Creek	7	0	6	1
Unnamed Creek	1	1	0	0
Muskeg River	**47**	**33**	**13**	**1**
Muskeg River	20	14	5	1
Alsands Drain	1	0	1	0
Jackpine Creek	7	6	1	0
Muskeg Creek	8	5	3	0
Shelley Creek	1	0	1	0
Stanley Creek	6	5	1	0
Wapasu Creek	4	3	1	0
Steepbank River	**18**	**14**	**3**	**1**
Steepbank River	14	10	3	1
N. Steepbank River	4	4	0	0
Western tributaries	**39**	**3**	**34**	**2**
Beaver River	3	0	3	0
Calumet River	5	0	5	0
Ells River	7	2	3	2
MacKay River	11	1	10	0
Poplar Creek	6	0	6	0
Tar River	7	0	7	0
Southern tributaries	**20**	**13**	**5**	**2**
Christina River	8	5	3	0
Clearwater River	10	8	0	2
Hangingstone River	2	0	2	0
Regional lakes	**22**	**20**	**2**	**0**
Isadore's Lake	4	3	1	0
Kearl Lake	7	7	0	0
McClelland Lake	4	4	0	0
Shipyard Lake	7	6	1	0
Total	**244**	**94**	**67**	**83**

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

Shaded entries denote the cluster into which each waterbody was put

Table 3.2-12 Regional baseline water quality data groups and station comparisons.

Regional Baseline Grouping (Cluster)	Baseline Stations Used for Regional Comparison[1]	Stations (2005) Compared with this Regional Baseline
1. Eastern and southern tributaries to the Athabasca River; regional lakes	CHR-1, CHR-2, CLR-1, CLR-2, NSR-1, STR-2, STR-3, MUR-5, MUR-6, MUC-1, JAC-1, SHC-1, STC-1, WAC-1, FIR-1, FIR-2, FIR-2X, UNC-1, KEL-1, MCL-1	CHR-1, CHR-2, CLR-1, CLR-2, NSR-1, STR-1, STR-2, STR-3, MUR-1, MUR-6, JAC-1, MUC-1, WAC-1, STC-1, FIR-1, FIR-2, ISL-1, SHL-1, KEL-1
2. Western tributaries to the Athabasca River; Fort Creek; McLean Creek; Hangingstone River	CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, TAR-1, TAR-2, FOC-1, HAR-1	CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, TAR-1, TAR-2, BER-1, POC-1, MCC-1
3. Athabasca River and Athabasca River Delta	ATR-DC-CC, ATR-DC-CC-D, ATR-DC-E, ATR-DC-W, ATR-DC-M, ATR-UFM[2]	ATR-DC-CC, ATR-DC-E, ATR-DC-W, ATR-DD, ATR-DD-E, ATR-DD-W, ATR-FR, ATR-MR-E, ATR-MR-W, ATR-SR-E, ATR-SR-W

See Table 3.2-8 for classification of station status by year. Where station status changed from baseline to operational during 1997-2005, only baseline data were used to determine regional water quality characteristics.

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

Comparison to Natural Variation in Baseline Conditions

To allow a regional comparison, untransformed data from all baseline stations sampled by RAMP from 1997 to 2005 (fall only), for all water quality measurement endpoints, were pooled from each cluster of similar stations (Table 3.2-11). Descriptive statistics describing natural water quality characteristics for each group were calculated; for each water quality cluster (Table 3.2-11), the 5th, 25th, 50th (median), 75th, and 95th percentiles were determined for comparison against 2005 data. The number of observations for each water quality measurement endpoint varied by cluster (Table 3.2-13). The median rather than the mean was used as an indicator of typical conditions, given water quality data are characteristically positively skewed.

Table 3.2-13 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)	83	30	63
Total Dissolved Solids (TDS)	83	30	27
Dissolved phosphorus	81	30	31
Total nitrogen	80	30	38
Total aluminum	83	30	27
Total boron	80	30	26
Total mercury (ultra-trace)	41	17	11
Naphthenic acids	84	30	20

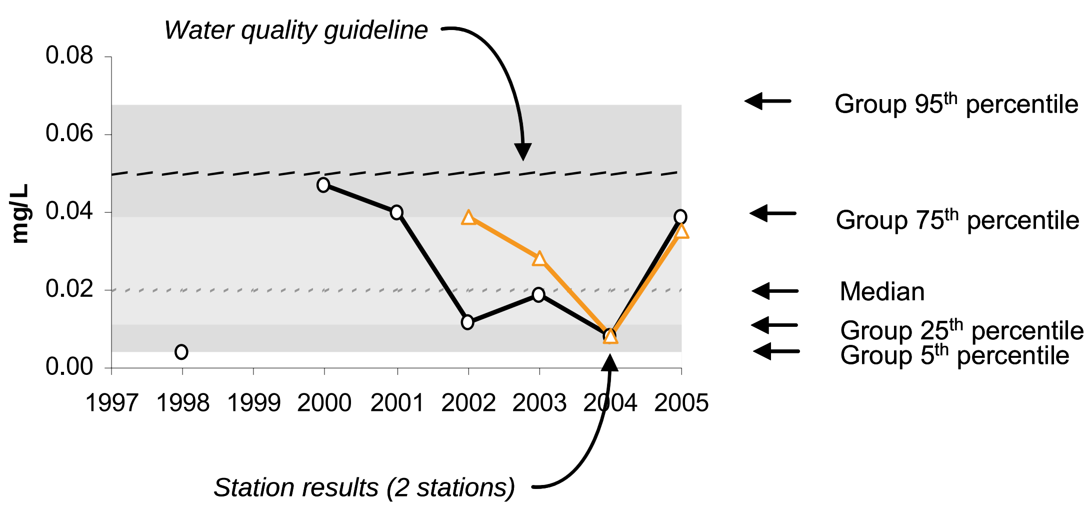
Data for a subset of the water quality measurement endpoints were presented graphically in the context of relevant regional variability, as shown in the example graph below (Figure 3.2-2). Data for each station were presented for all years of sampling by RAMP, to allow assessment of any temporal trends.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

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

Trend Analysis

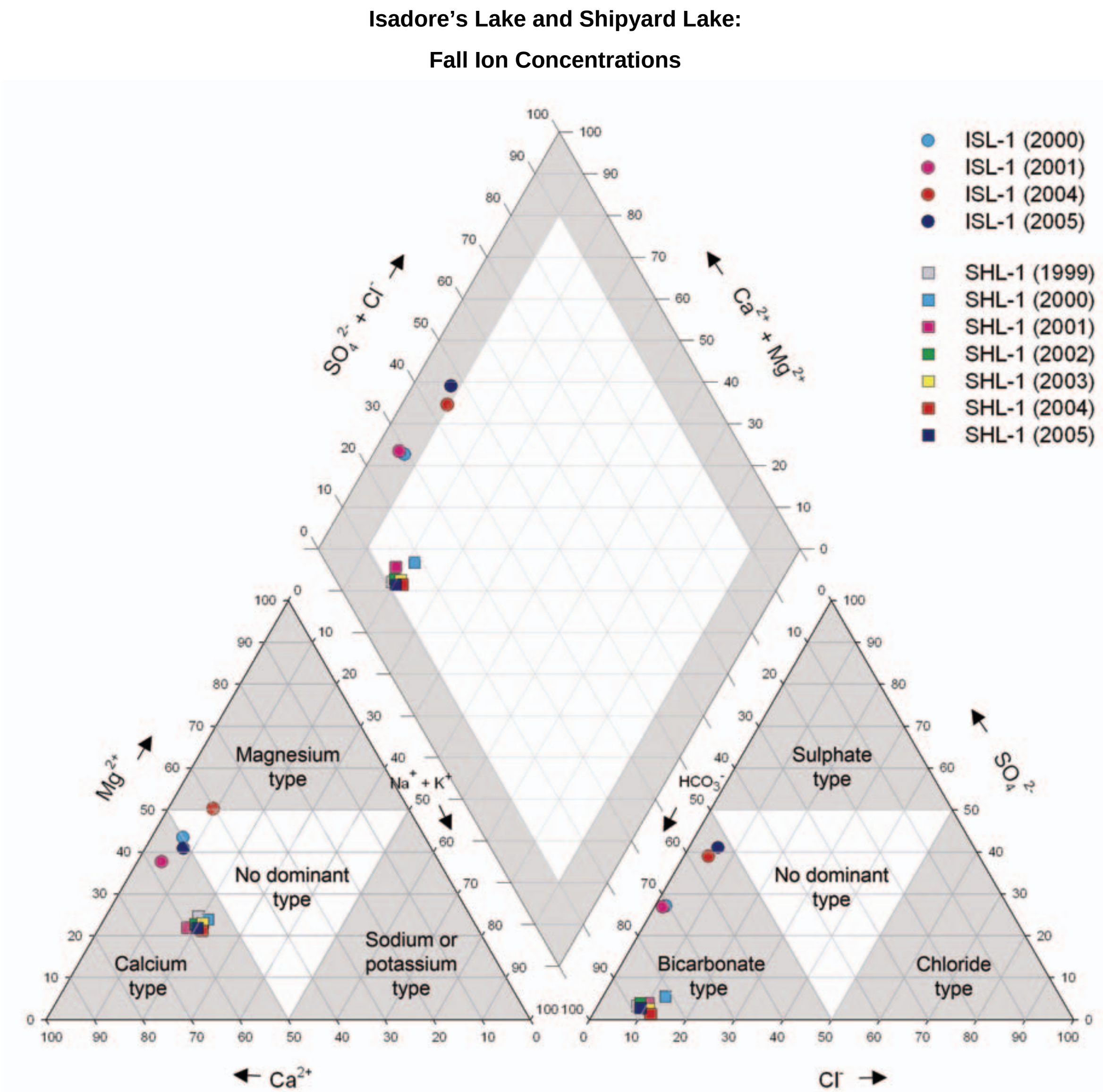
In addition to qualitative trend analysis using graphical means, statistical trend analysis was undertaken on water quality data for the Athabasca River, which has been monitored continuously by Alberta Environment since 1976. Trend analysis was undertaken on data from three stations: Athabasca River at the town of Athabasca (ATR-ATH); Athabasca River upstream of Fort McMurray (ATR-UFM, approximately 100 m upstream of the Horse River); and Athabasca River at Old Fort (ATR-OF), located near the head of the Athabasca River Delta (ARD), downstream of the Embarras River distributary. Trend analysis was conducted on data for the water quality measurement endpoints from the period of RAMP sampling (1997 to 2005) in order to assess trends potentially related to oil sands development during this time.

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



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

Figure 3.2-3 Example Piper diagram, illustrating ion concentrations in waters from Isadore's Lake and Shipyard Lake, collected by RAMP, 1997 to 2005.



Statistical trend analysis was not undertaken on RAMP data from tributaries to the Athabasca River sampled by RAMP, partly due to typically insufficient sample sizes (numbers of years of data), and partly because changes in water quality in these smaller tributaries due to oil sands and other anthropogenic activities are not expected to necessarily occur incrementally, but rather step-wise, which would not necessarily be captured by statistical assessment of incremental trends in water quality. By contrast, incremental changes in water quality may be postulated in the Athabasca River, given its large volume relative to its tributaries (Figure 1.3-2), from which changes in water quality in the Athabasca River may be most likely expected. Therefore, for all other stations besides the three AENV long-term monitoring stations on the Athabasca mainstem, any trends in water quality in key variables of interest were assessed qualitatively by graphical means.

3.2.7.5 Additional Analyses

Chlorophyll a

RAMP has collected and analyzed water samples from all stations for concentrations of chlorophyll *a* since 1997. Chlorophyll concentrations in surface water samples are used to estimate algal biomass in the aquatic environment; in this case, suspended algae in RAMP area streams and lakes. Algae levels in surface waters may be indicative of the nutrient status of the water, and some algae (cyanobacteria) can produce toxins harmful to humans and animals.

However, an analysis of chlorophyll *a* data collected by RAMP from 1997 to 2004 for the RAMP 2004 Technical Report found that most chlorophyll *a* values measured by RAMP since 1997 were below analytical detection limits, and showed no correlation with other, more direct measures of nutrient status, such as nitrogen and phosphorus concentrations. These observations, as well as the fact that the RAMP Benthic Invertebrate Community component already measures attached periphyton at all its sampling stations, lead to a recommendation in the 2004 report that consideration be given by the RAMP Technical Program Committee to eliminating chlorophyll *a* as a RAMP Water Quality component analyte.

This recommendation was discussed at the RAMP 2006 program design workshop in March 2005. Discussions focused partly on how the RAMP-contracted laboratory had handled chlorophyll *a* samples (since 1997), which resulted in holding times being routinely exceeded for these samples, leading to questions about the validity of results. Prior to 2005, samples for chlorophyll *a* analysis were collected in glass amber bottles, wrapped in aluminum foil and delivered to ETL. Upon receipt of samples at the ETL Fort McMurray laboratory, samples were placed into coolers with ice packs and shipped to the ETL Winnipeg lab for analysis, which required two days. Samples were filtered in Winnipeg prior to analysis (using a spectrophotometric pheophytin method).

Concerns about the validity of these previous results led to guidance from the RAMP Technical Program Committee, which recommended that RAMP ensure that chlorophyll *a* samples were promptly filtered (with filter papers subsequently frozen), to arrest chlorophyll synthesis and/or degradation in samples in advance of analysis. This approach was adopted and followed in 2005 (see Section 3.2.2.1).

Effects of this change in sample handling methodology in 2005 were assessed through comparison of 2005 results against previous RAMP results. Comparative endpoints included incidence of non-detectable values, and correlation with concentrations of various waterborne nutrients in water samples collected concurrently at each station. Detailed analytical methods and results of these analyses are reported in Appendix D of this report.

Seasonal Differences in Water Quality

RAMP began collecting seasonal water quality data (i.e., those in other seasons besides fall) in 2002, and has a strategy of sampling water quality seasonally at stations in newly sampled waterbodies for at least 3 years before reverting to sampling in fall only.

Given fall is the key monitoring period for RAMP, when most water quality observations are made, most of RAMP's analysis and assessment of water quality, historically and currently, focuses on fall data. However, a more rigorous assessment of seasonal differences in water quality was conducted for this year's report, to provide a better understanding of seasonal changes and variability in water quality in the RAMP FSA, as well as provide a qualitative assessment of the value of continued seasonal water quality sampling in RAMP.

Analyses included screening of all historical RAMP water quality data, collected in any season, to assess the frequency and nature of water quality guideline exceedances in each season, and multivariate summary and clustering of water quality data by season in a manner similar to the Objective Classification Analysis undertaken by RAMP each year on the complete RAMP water quality data set from fall only. Detailed analytical methods and results of these analyses are reported in Appendix D of this report.

3.3 SEDIMENT QUALITY

3.3.1 Overview of 2005 Program

Objectives of the 2005 RAMP sediment quality monitoring program included assessment of baseline sediment quality and identification of any potential effects related to oil sands development or other factors in rivers and lakes in the RAMP study area.

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

Sediment samples were collected by RAMP from 28 stations located along the Athabasca River and its major tributaries in the oil sands region, and from regionally important lakes and wetlands. Stations sampled and variables analyzed in 2005 are presented in Table 3.3-1; locations of the 2005 sampling stations are found in Figure 3.3-1.

3.3.1.1 Athabasca River and Delta Stations

In the Athabasca River, sediment samples were collected only from station ATR-ER, located upstream of the Embarras River distributary, at the head of the ARD. Up to 2004, RAMP collected sediments from several stations located along the Athabasca River,

Table 3.3-1 Summary of sampling for the RAMP Sediment Quality component, September 2005.

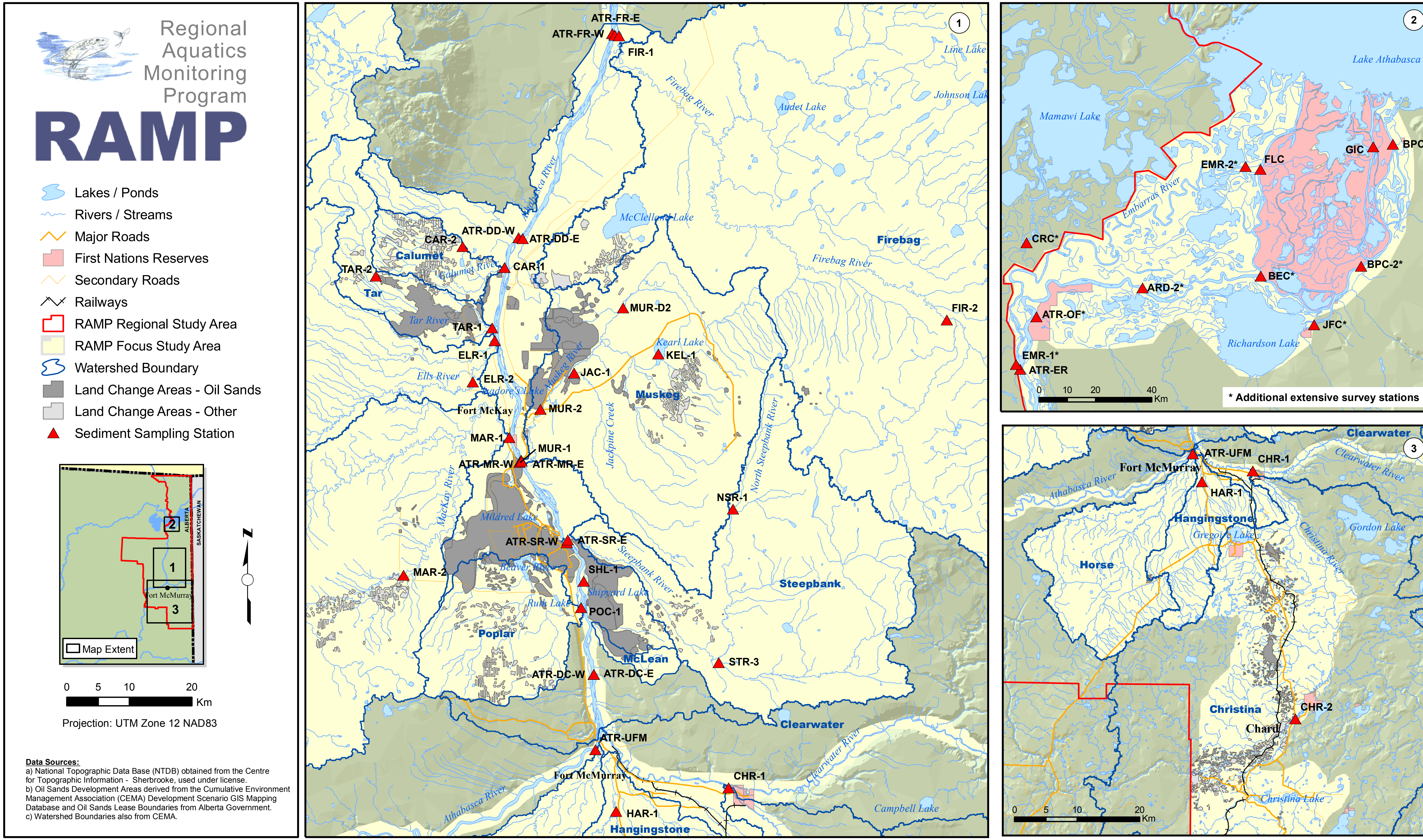
Station Identifier and Location		UTM Coordinates		Analytical Package
		Easting	Northing	
Athabasca River				
ATR-ER	Athabasca River u/s of Embarras River	468280	6468177	1
Athabasca River Delta				
ATR-OF*	Athabasca River at Old Fort	470205	6474330	1
ARD-2*	Athabasca River Delta	483721	6476680	1
BEC*	Big Eddy Channel	496401	6479092	1
JFC*	Jackfish Creek (mouth)	501455	6472923	1
EMR-1*	Embarras River (upper)	467807	6468730	1
EMR-2*	Embarras River	494635	6491898	1
CRC*	Cree Creek	469032	6482965	1
BPC	Big Point Channel	511963	6496407	1
BPC-2*	Big Point Channel (upper)	508137	6480208	1
FLC	Fletcher Channel	496382	6491567	1
GIC	Goose Channel	509601	6494060	1
Tributaries to the Athabasca River (Eastern)				
MCC-1	McLean Creek (mouth)			3
STR-1	Steepbank River (mouth)	471273	6320092	3
STR-2	Steepbank River (upstream of Project Millennium)	485863	6309311	3
STR-3	Steepbank River (upstream of N Steepbank River)	495022	6300250	3
NSR-1	North Steepbank River (upstream of PC-Lewis)	497380	6324549	1
Muskeg River				
MUR-1	Muskeg River (mouth)	463473	6332409	3
MUR-2	Muskeg River upstream of Canterra Rd. crossing	466569	6340506	3
MUR-D2	Upstream of Stanley Creek	479759	6356751	3
Tributaries to the Athabasca River (Southern)				
Hangingstone River				
HAR-1	Hangingstone River (upstream of Ft. McMurray)	478653	6276265	3
Tributaries to the Athabasca River (Western)				
Ells River				
ELR-1	Ells River (mouth)	459241	6351495	3
ELR-2	Ells River (upstream of CNRL Lease 7)	455753	6344915	1
Tar River				
TAR-1	Tar River (mouth)	458852	6353527	1
TAR-2	Tar River (upstream of CNRL Horizon)	440261	6361800	1
Calumet River				
CAR-1	Calumet River (mouth)	460816	6363196	3
CAR-2*	Calumet River (upstream of CNRL Horizon)	454108	6366533	3
QA/QC				
-	2x split samples, duplicate samples, rinseate blanks			1

* New station in 2005.

Legend to Analytical Packages:

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

Figure 3.3-1 RAMP sediment quality sampling locations, 2005.



generally corresponding to water quality monitoring station locations (Section 3.2.2.1). Data from these mainstem stations generally were predominantly sand and/or eroded bank materials, and did not accurately represent suitable depositional environments for monitoring potential accumulation of sediment constituents of concern. Assessment of these data in the 2003 and 2004 Technical Reports, and subsequent discussions by the RAMP Technical Program Committee in March 2005, lead to a decision to eliminate sediment quality monitoring in the Athabasca River in fall 2005, with resources reallocated to an expanded sediment sampling program in the ARD, a truly depositional environment downstream of oil sands development.

3.3.1.2 Other Waterbodies

Sediment samples were collected from center channel locations of stations located along Athabasca River tributaries, where water depth and velocity allowed for safe sample collection.

3.3.2 Field Methods

3.3.2.1 Discrete Field Sampling

The 2005 sediment quality field program was implemented from September 7 to September 24, concurrent with the fall water quality program. Sediment samples were collected from depositional zones at each station. At several sampling locations in tributaries to the Athabasca, substrates were predominantly erosional rather than depositional. At these locations, sampling was conducted where depositional sediments were found. Historical sampling locations were identified from 2004 GPS coordinates or written descriptions from previous reports, and followed a general rule-of-thumb followed by the previous RAMP implementation team of sampling approximately 100 m upstream of river confluences. Stations were accessed by helicopter, jet boat, canoe, or four-wheel drive vehicle.

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

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

3.3.2.2 Sample Shipping and Analysis

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

Table 3.3-2 summarizes physical, chemical and toxicological variables assessed for the RAMP 2005 Sediment Quality component.

3.3.3 Changes in Monitoring Network from 2004 Field Program

Relative to 2004, key changes to the sampling program included:

- Elimination of all Athabasca River sampling locations located upstream of the ARD;
- Implementation of a one-time extensive sediment sampling program in channels of the ARD (n=12 stations, including ATR-ER, on the Athabasca River immediately upstream of the Embarras River and the ARD);
- Station TAR-2 (Tar River, upstream) was relocated to an undisturbed location several kilometers further upstream, given the area surrounding the river at the 2004 location had recently been logged and therefore no longer was a suitable reference location; and
- A new *potentially influenced-other* monitoring station was established in the upper Calumet River (CAR-2).

3.3.4 Challenges Encountered and Solutions Applied

Selection of sediment sampling locations in the ARD was based partly on historical locations sampled by Environment Canada during extensive collection of surficial sediments and sediment cores throughout the ARD and Lake Athabasca areas from 1997 to 2000. These historical sampling locations and unpublished data were kindly provided to RAMP by Dr. Marlene Evans of the National Water Research Institute (Saskatoon, SK).

High organic carbon content at stations CAR-2 and MUR-2 precluded particle size analysis at these stations, particularly at station CAR-2, where very little river flow was evident and the bulk of bottom samples consisted purely of organic matter.

3.3.5 Other Information Obtained

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

3.3.6 Summary of Component Data Now Available

As a supporting activity to the 2005 field program, all sediment quality data collected by RAMP since 1997 were input into a relational database with consistent structure and formats. This data set, which includes over 15,000 sediment quality observations from 1997 to 2005, facilitated comprehensive and comparative analysis of sediment quality in the RAMP area since 1997, as described in Section 3.3.7.

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

3.3.7 Analytical Approach

Analysis of the RAMP sediment quality data set built upon results of previous studies by RAMP and others, and followed a similar conceptual approach to that used by the 2005

Table 3.3-2 RAMP sediment quality variables analyzed in 2005.

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 *Hyallela azteca* Survival and growth of *Chironomus tentans* midge larvae	

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

Table 3.3-3 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			
		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				1
Upstream of Donald Creek (west bank)[a]	ATR-DC-W				3				3								1				3				1				3				1				1
(east bank)[a]	ATR-DC-E				3				3								1				3				1				3				1				1
Upstream of Steepbank River (west bank)	ATR-SR-W																1				3				1				3				1				1
(east bank)	ATR-SR-E																1				3				1				3				1				1
Upstream of the Muskeg River (west bank)[a b]	ATR-MR-W								3								1				3				1				3				1				1
(east bank)[a b]	ATR-MR-E								3								1				3				1				3				1				1
Upstream of Fort Creek (west bank)[a b]	ATR-FC-W				3				3								1				3				1				3								
(east bank)[a b]	ATR-FC-E				3				3								1				3				1				3								
Testing inter-site variability (3 comp. samples)	-																1								1												
Downstream of all development (west bank)	ATR-DD-W																								1				3				1				1
(east bank)	ATR-DD-E																								1				3				1				1
Upstream of mouth of Firebag River (west bank)	ATR-FR-W																								1				3				1				1
(east bank)	ATR-FR-E																								1				3				1				1
Upstream of the Embarras River	ATR-ER																3				1				1				3				1				1
Athabasca Delta / Lake Athabasca																																					
Delta composite[c]	ARD-1											3					3																				
Big Point Channel	BPC																				3				3				3								1
Goose Island Channel	GIC																				3				3				3								1
Fletcher Channel	FLC																				3				3				3								1
Flour Bay	FLB-1																3																				
Athabasca River Tributaries (South of Fort McMurray)																																					
Clearwater River (upstream of Fort McMurray)	CLR-1																				1				3				3								
(upstream of Christina River)	CLR-2																				1				3				3								
Christina River (upstream of Fort McMurray)	CHR-1																								1				3				3				
(upstream of Janvier)	CHR-2																								1				3				3				
Hangingstone River (upstream of Ft. McMurray)	HAR-1																																3				3
Athabasca River Tributaries (North of Fort McMurray)																																					
McLean Creek (mouth)	MCC-1												3				3				1				3												3
Poplar Creek (mouth)	POC-1				1																				3								3				
Steepbank River (mouth)	STR-1				1				1																3												3
(upstream of Project Millennium)	STR-2				1																				3												3
(upstream of Nt. Steepbank)	STR-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, Lumbricului variegatus,* Hyalella azteca)
3 = standard s.q. + toxicity testing
√ = allowance made for potential TIE

potentially influenced - oil sands
potentially influenced - other
reference

Footnotes

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

Table 3.3-3 (Cont'd.)

See symbol key below.

Waterbody and Location	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005			
		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)																																					
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 P.C. MacKay)	MAR-2																				1				3								3				
Ells River (mouth)	ELR-1								1																3				3				3				1
(upstream of CNRL Lease 7)	ELR-2																																3				1
Tar River (mouth)	TAR-1								1																3				3				1				1
(upstream of CNRL Horizon)	TAR-2																																1				1
Calumet River (mouth)	CAR-1																								3								3				
Calumet River (upstream of CNRL)	CAR-2																																				3
Fort Creek (mouth)	FOC-1																1				1				3												
Firebag River (mouth)	FIR-1																								3				3				1				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-D2																								3				3				3				
Upstream of Wapasu Creek	MUR-6																1												1								
Muskeg River Tributaries																																					
Jackpine Creek (mouth)	JAC-1				1																												3				
Stanley Creek (mouth)	STC-1																												1								
Wetlands																																					
Kearl Lake (composite)	KEL-1																				1												1				
Isadore's Lake (composite)	ISL-1																				1																
Shipyard Lake (composite)	SHL-1																				1				3				1				3				
McClelland Lake (composite)	MCL-1																								1												
Additional Sampling (Non-Core Programs)																																					
Un-nammed Creek - north of Ft. Creek (mouth)	UNC-1																																				
Potential TIE	-																				√																
QA/QC																																					
One split and one duplicate sample	-																1				1				1				1				1				1

Legend

1 = standard sediment quality parameters (carbon content, particle size, recoverable hydrocarbons, TEH and TVH, total metals, PAHs and alkylated PAHs)
2 = sediment toxicity testing (*Chironomus tentans, Lumbriculus variegatus,* Hyalella azteca)
3 = standard s.q. + toxicity testing
√ = allowance made for potential TIE

Footnotes

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

potentially influenced - oil sands
potentially influenced - other
reference

Water Quality component (see Section 3.2.7, above). The RAMP 2005 sediment quality analysis included the following major components:

- Selection of particular sediment quality variables as sediment quality measurement endpoints, including predicted toxicity of sediments due to PAHs, calculated using an equilibrium-partitioning model;
- Development of criteria to be used in detecting changes in sediment quality measurement endpoints;
- Designation of stations to be used as baselines for sediment quality conditions through the establishment of regional baseline values for each sediment quality measurement endpoint;
- Tabular and graphical presentation of 2005 results comparing 2005 concentrations of the sediment quality measurement endpoints, sediment quality baseline conditions, and selected criteria for determination of change in sediment quality; and
- Specification of additional analyses to be conducted including trend analysis.

These components are described in detail below.

3.3.7.1 Selection of Sediment Quality Measurement Endpoints

A subset of sediment quality variables measured by RAMP each year were selected as sediment quality measurement endpoints for presentation and discussion in the body of this report, drawn from the following sources:

- Sediment quality measurement endpoints listed in the environmental impact assessments of oil sands projects as being potentially affected (RAMP 2005b);
- 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 variables (Appendix F);
- Discussions among RAMP Component Managers about the importance of various sediment quality variables to interpretation of other RAMP components, particularly fish and benthos; and
- Discussions with RAMP Technical Program Committee members, during and in relation to a meeting held in Edmonton in early February 2006 to discuss analytical strategies for this report.

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

- *Particle size distribution (clay, silt and sand)*: sediment particle size is an indicator of depositional regime at a given station, and an important factor affecting organic chemical sorption.

Table 3.3-4 Potential key sediment quality measurement endpoints.

Analyte Group	EIA Review: Variables Listed in EIAs (No. of projects)	RAMP 5-year Report (Golder 2003a)	Variables to Support other RAMP Components[1]	Additional Suggested Variables
Physical variables	(None)	(None)	Particle size distribution	
Carbon content	(None)	(None)	Total organic carbon	Total inorganic carbon Total organic carbon
Total Hydrocarbons	(None)	TRH	CCME F1, F2 Tier 1 TEH	CCME F1-F4+BTEX
Metals	(None)	Total metals	Total metals	(Metals that are high relative to SQGs)
PAHs	General PAHs (4)	Naphthelene C1 Naphthelene	Total PAHs LMW PAHs (parent+alkylated)	LMW PAHs HMW PAHs Naphthelene Dibenzothiophenes Retene
Effects-based endpoints	Sublethal toxicity (1)		Sublethal toxicity	

[1] Primarily benthos (inferred).

- *Total organic carbon*: an indicator of organic matter in sediment, including hydrocarbons.
- *Total hydrocarbons (CCME fractions)*: Indicators of the total hydrocarbon content of sediments, with each measurement endpoint capturing hydrocarbon compounds of different molecular weights (more specifically, numbers of carbon atoms).
- *Various PAH measurement endpoints, including:*
    - Total PAHs: a sum of concentrations of all PAHs measured in a given sample, including parent and alkylated forms;
    - Total Low-Molecular Weight PAHs: a sum of concentrations of all PAHs with 1 to 3 benzene rings (including parent and alkylated forms) measured in a given sample;
    - Total High-Molecular Weight PAHs: a sum of concentrations of all PAHs with 4 to 6 benzene rings (including parent and alkylated forms) measured in a given sample;
    - Naphthalene: a volatile, low-molecular-weight PAH that may cause toxicity when dissolved in water;
    - Retene: an alkylated phenanthrene generated through decomposition of plant materials (i.e., not associated with petroleum sources);
    - Total dibenzothiophenes: a sulphonated PAH (parent and alkylated forms) that is associated with bitumen (i.e., petrogenic); and

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

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

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

Predicting Potential Toxicity of PAH Mixtures in Sediments

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

Bioavailability and toxicity to aquatic organisms is assumed to increase with aqueous PAH concentration. Thus, overall toxicity of the sediment PAH assemblage is related to the solubility and toxicity of individual PAH species within the assemblage, and is assumed to result from the additive effects of individual PAH molecules (Neff *et al.* 2005). Methods used to estimate cumulative PAH toxicity in sediment were adapted from Neff *et al.* (2005); various necessary constants used in this analysis (i.e., K_{ow}, freshwater solubility and toxicity for various PAH species) were assembled from Neff *et al.* (2005) and other sources.

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

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

The toxicity contributed by each PAH species in a given sample was estimated from its predicted concentration in porewater and its known toxicity in aqueous phase, to generate a hazard quotient (HQ). These HQs then were summed for all compounds in the sample to generate a hazard index (HI), which described predicted toxicity of sediments to aquatic organisms. HIs were determined for the entire RAMP historical dataset (1997-2005). Hazard indices greater than 1 indicate PAH concentrations in excess of toxicity values—i.e., a potential toxic effect of sediments on aquatic organisms.

3.3.7.2 Criteria for Determining Effects

Two criteria for determining sediment quality effects were used:

- **Comparison to Sediment Quality Guidelines:** All sediment quality data collected by RAMP in 2005 were screened against CCME Interim Sediment Quality Guidelines (ISQG) (CCME 2003). All values that exceeded these guidelines were reported explicitly in the body of the RAMP report; and

- **Comparison to Natural Variation in Baseline Conditions:** The concentration in 2005 of each of the selected sediment quality measurement endpoints was assessed against a rigorously defined natural condition of concentration of the measurement endpoint. The definition of the natural condition is explained immediately below.

3.3.7.3 Establishment of Regional Baseline Values for Comparison

Given similar concerns regarding the analytical power of RAMP Water and Sediment Quality components, the analytical approach for the 2005 Sediment Quality component followed that of the 2005 Water Quality component, namely assessment of 2005 data against the range of natural variability defined by representative regional baseline data collected by RAMP from 1997 to 2005. The background and rationale for this regional baseline approach are presented in Section 3.2.7, above.

Groups of RAMP baseline stations with similar sediment quality characteristics were determined using multivariate data reduction and iterative clustering techniques, described in detail in Appendix F. This Objective Classification Analysis (OCA) involved multivariate data reduction of sediment metals and PAH datasets using Principal Component Analysis (PCA), followed by application of hierarchical and k-means clustering algorithms using derived metals and PAH Principal Components as well as other sediment characteristics (i.e., particle size distribution, inorganic and total organic carbon, and total recoverable hydrocarbons,), to define meaningful, internally consistent clusters from the RAMP 1997-2005 dataset that exhibit consistently similar sediment quality(Appendix E).

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

- Tributaries to the Athabasca River, with some exceptions;

- Athabasca River and ARD stations;

- Regional lakes; and

- Other tributaries, including the lower Muskeg River stations MUR-1 (mouth) and MUR-1B (1 km upstream of the mouth).

Given lower Muskeg River stations MUR-1 and MUR-1B are not considered baseline stations, this fourth cluster was not used in any regional baseline characterization.

As discussed further in RAMP (2005a), clustering of RAMP station-year data using sediment quality data from 1997 to 2004 was much less clear than was the case for water

Table 3.3-5 Classification of groups of RAMP sediment monitoring stations with similar sediment quality, from 1997 to 2005 data.

Waterbody	Total No. of Station/ Year Combinations	Cluster			
		1	2	3	4
Athabasca River	**67**	**17**	**30**	**0**	**20**
Athabasca River Delta	**23**	**2**	**21**	**0**	**0**
Eastern tributaries	**13**	**8**	**2**	**0**	**3**
Fort Creek	2	0	1	0	1
McLean Creek	5	2	1	0	2
Firebag River	6	6	0	0	0
Regional lakes	**9**	**0**	**3**	**6**	**0**
Isadore's Lake	1	0	1	0	0
Kearl Lake	2	0	0	2	0
Shipyard Lake	4	0	2	2	0
McLelland Lake	2	0	0	2	0
Muskeg River	**28**	**14**	**2**	**6**	**6**
Muskeg River	25	13	2	5	5
Jackpine Creek	2	1	0	0	1
Stanley Creek	1	0	0	1	0
Southern tributaries	**14**	**13**	**1**	**0**	**0**
Clearwater River	6	5	1	0	0
Christina River	6	6	0	0	0
Hangingstone River	2	2	0	0	0
Steepbank River	**11**	**9**	**0**	**0**	**2**
North Steepbank River	4	4	0	0	0
Steepbank River	7	5	0	0	2
Western tributaries	**29**	**13**	**10**	**1**	**5**
MacKay River	7	2	3	0	2
Calumet River	4	2	1	1	0
Ells River	8	4	3	0	1
Poplar Creek	3	1	1	0	1
Tar River	7	4	2	0	1
Total	**195**	**76**	**70**	**13**	**36**

Bold entries refer to sum of station-year combinations in each group of waterbodies.
Shaded entries denote the cluster into which each waterbody was put.

quality. Reanalysis of these data using 1997 to 2005 data yielded similar results. For many stations included in the cluster analysis, particularly those on the Athabasca River, samples from the same stations for different years did not cluster closely together, indicating that many stations did not exhibit consistent and characteristic sediment quality across years (i.e., in many cases, variation among years within the historical dataset was larger than spatial variation among stations). However, all ARD stations sampled in 2005 and previously except Athabasca River at Old Fort (near the head of the delta) in 2005 and Fletcher Channel in 2001 clustered together (Table 3.3-5), suggesting similar and consistent year-to-year sediment quality characteristics throughout the ARD.

From these clusters, data from baseline stations (i.e., those located in watersheds where oil sands development has not yet occurred) were pooled to develop descriptions of regional baseline sediment quality against which 2005 RAMP data were assessed.

Athabasca River stations showed high variability in membership among clusters, but, given the physical linkage between the river mainstem and the delta, were grouped with ARD stations (Cluster 2).

Baseline stations within the Athabasca River include stations at Donald Creek (ATR-DC) and upstream of Fort McMurray (ATR-UFM). Because of the different hydrologic and sediment regime of the Athabasca River relative to the ARD, 2005 sediment quality data for the ARD were not compared to mainstem baseline data. Instead, 2005 ARD data were compared against all available data from the ARD, pooled to give a range of sediment quality characteristics for this environment.

Table 3.3-6 lists the station-year combinations from which from 1997 to 2005 RAMP data were pooled to develop baseline descriptions for all clusters and which stations were compared against these baselines. Numbers of observations in regional baseline data sets ranged from n=1 (Cluster 3: Regional lakes) to n=55 (Cluster 1: Athabasca River tributaries) (Table 3.3-6).

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

Regional Baseline Group	Baseline Stations Used for Regional Comparison[1]	Stations (2005) Compared with Regional Baseline Data	Number of Observations (Station-Year Combinations) for Baseline Regional Water Quality		
			Total Hydrocarbons (C6-C50)	Total PAHs	Naphthalene
1. Tributaries to the Athabasca River	CHR-1, CHR-2, CLR-1, CLR-2, HAR-1, NSR-1, STR-2, STR-3, MUR-5, MUR-6, JAC-1, FOC-1, FIR-1, FIR-2, FIR-2X, CAR-1, CAR-2, ELR-1, ELR-2, MAR-1, MAR-2, TAR-1, TAR-2	HAR-1, MCC-1, NSR-1, STR-1, STR-2, STR-3, MUR-1, MUR-2, MUR-D2, CAR-1, CAR-2, ELR-1, ELR-2, TAR-1, TAR-2	19	55	55
2. Athabasca River, Athabasca River Delta	ATR-DC-CC, ATR-DC-E, ATR-DC-W, ATR-UFM	ATR-ER, ARD-2, ATR-OF, BEC, BPC, BPC-2, CC-1, E-A, EMR-1, FLC, GIC, JC-1	3	16	16
3. Regional lakes	KEL-1, MCL-1	No. of lakes sampled in 2005	1	4	3

[1] See Table 3.3-3 for designation of station status by year.

3.3.7.4 Tabular and Graphical Presentation of 2005 Sediment Quality Results

Comparison to Sediment Quality Guidelines

2005 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 2004 at that station. Concentrations of any sediment quality measurement endpoint that exceeded relevant guidelines were noted and, as indicated above, all values that exceeded these guidelines were also reported.

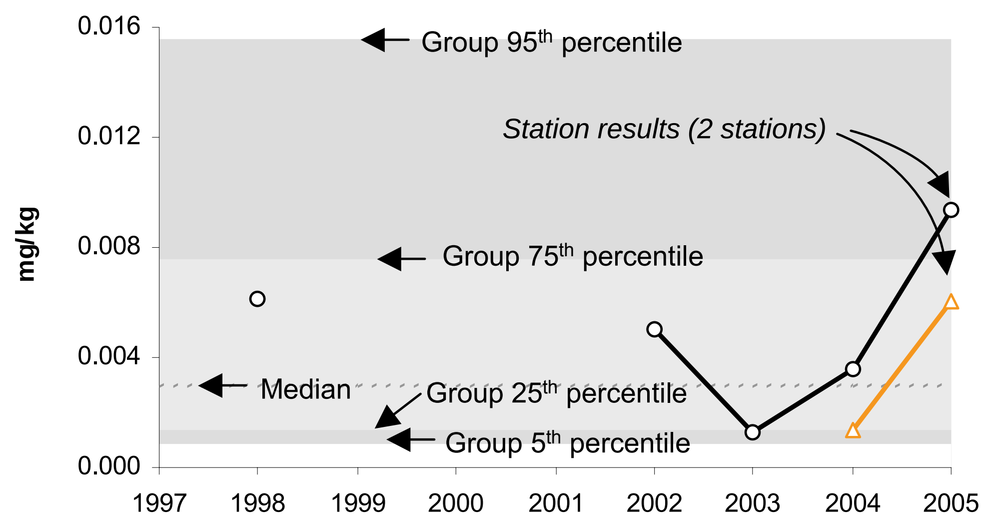
Comparison to Natural Variation in Baseline Conditions

To allow a regional comparison, untransformed data from all baseline stations sampled by RAMP from 1997 to 2005, for all sediment quality measurement endpoints, were pooled from each cluster of similar stations (with the exception of delta stations, for which operational data from the ARD were pooled as described above); descriptive statistics describing natural sediment quality characteristics for each group were calculated. For each cluster, the 5th, 25th, 50th (≡median), 75th, and 95th percentiles were determined, for comparison against 2005 data. Data for a subset of the sediment quality measurement endpoints (namely, total PAHs, total hydrocarbons, and naphthalene) were presented graphically in the context of relevant regional variability, as shown in the example graph below (Figure 3.3-2). Data for each station were presented for all years of sampling by RAMP, to allow assessment of any temporal trends. To allow more sensitive assessment of any temporal trends, hydrocarbon concentrations were normalized to organic carbon content and expressed as mg/kg of organic carbon. Where possible, stations located upstream and downstream on specific watersheds were presented together, to allow assessment of any differences in values or trends between upstream/downstream locations.

Trend Analysis

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

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



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

3.3.7.5 Additional Analyses

Comparison of Sediment Toxicity Against Other Sediment Quality Variables

In order to better assess the utility and value of sediment toxicity testing undertaken by RAMP, results of RAMP sediment toxicity tests (using the amphipod *Hyalella azteca* and larvae of the midge *Chironomus tentans*) from 2003 to 2005 were compared against various sediment quality variables, including aggregate measures of PAH concentration and toxicity, metals concentrations, and physical variables. Detailed analytical methods and results of these analyses are reported in Appendix E.

3.4 BENTHIC INVERTEBRATE COMMUNITIES

3.4.1 Overview of 2005 Program

A total of 29 locations were sampled in 2005 for the Benthic Invertebrate Community component, comprising 23 river reaches, three stations in the ARD, and three lakes (Table 3.4-1, Figure 3.4-1). As in previous years, samples were collected in the dominant habitat type found in each reach (Table 3.4-1). Habitats were defined as being either depositional (dominated by fine sediment deposits and low to no current) or erosional (dominated by rocky substrates and frequent riffle areas). Most tributaries in the study area are predominately depositional, with some variation within watercourses.

3.4.2 Field Methods

Field Sampling

The benthic invertebrate community field program was conducted from September 7 to 24, 2005. Benthic invertebrates were collected according to standard methods used in previous years (Golder 2003a, RAMP 2005b). A Neill-Hess cylinder (0.093-m^2 opening and 210-µm mesh) was used for collection of invertebrates in erosional areas. In depositional habitats, a pole-mounted Ekman grab (0.023 m^2, 6″ x 6″) was used for invertebrate collection. In lakes greater than 1 m deep, the 6″ x 6″ Ekman grab was used, but the device was deployed using a rope and messenger from the surface.

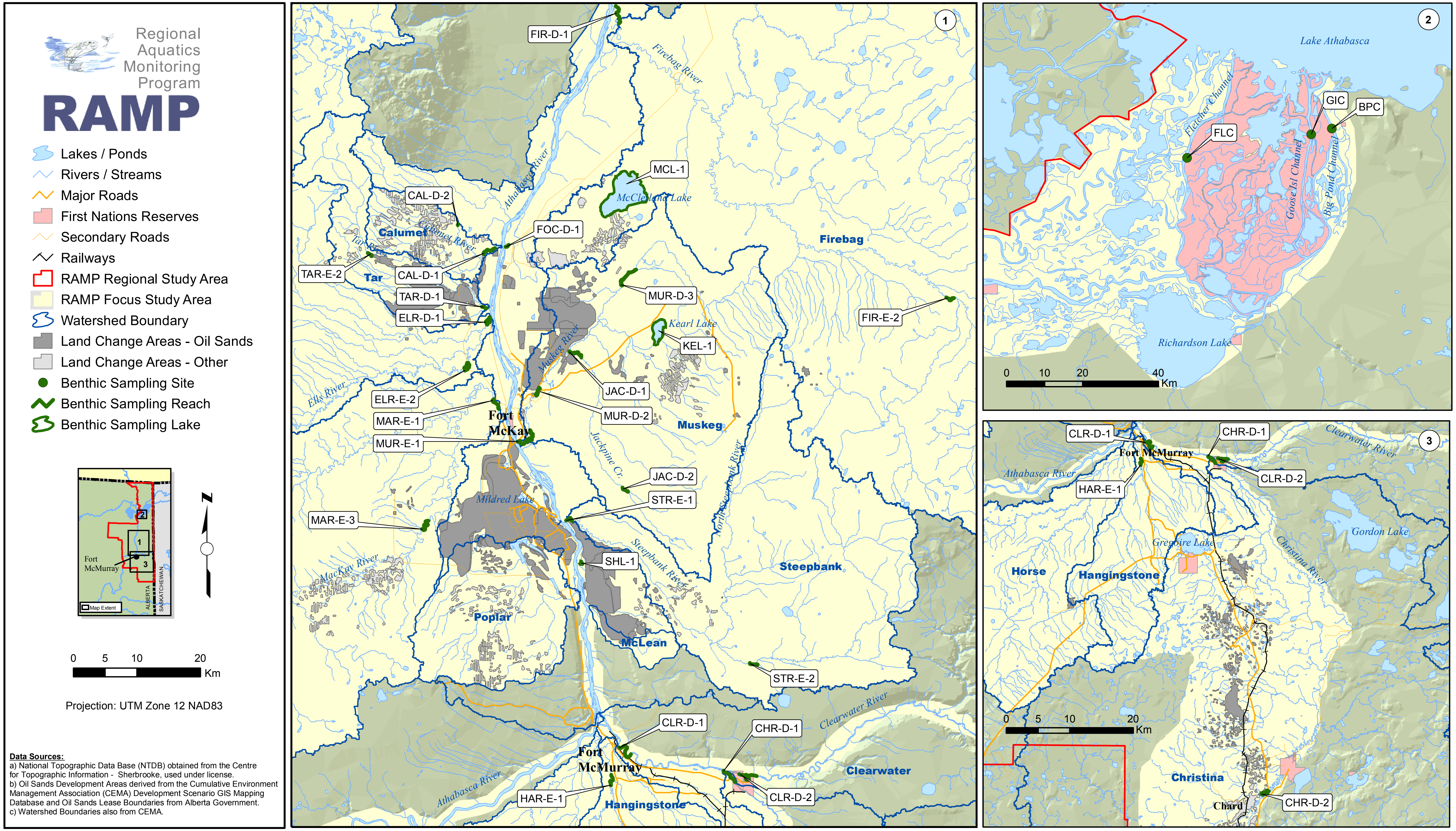
In rivers, a total of 10 replicate samples (using the Ekman or Neill-Hess depending on habitat type) were collected from within pre-established reaches. Reaches were typically 2 to 4 km long. Samples were selected randomly from within the reach, based on habitat availability and approximately equal spacing.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

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

Table 3.4-1 Summary of sampling for the RAMP 2005 Benthic Invertebrate Community component.

Waterbody and Location	Habitat	Reach or Station	UTM Coordinates			
			Downstream Limit of Reach		Upstream Limit of Reach	
			Easting	Northing	Easting	Northing
Athabasca River Delta						
Goose Island Channel	depositional	GIC	509601	649060	509601	649060
Big Point Channel	depositional	BPC	511964	6494405	511964	6494405
Fletcher Channel	depositional	FLC	496382	6491567	496382	6491567
Calumet River						
Lower reach near mouth	depositional	CAL-D-1	460698	6363156	459679	6362808
Upper reach	depositional	CAL-D-2	454001	6366521	454001	6366521
Clearwater River						
Lower Reach (downstream of Christina River)	depositional	CLR-D-1	479432	6284190	481249	6283264
Upper Reach (upstream of Christina River)	depositional	CLR-D-2	498358	6279898	500866	6279639
Christina River						
Lower Reach (near mouth)	depositional	CHR-D-1	496458	6280212	497723	6278682
Upper Reach (at Janvier)	depositional	CHR-D-2	511621	6192395	510923	6191929
Ells River						
Lower Reach (near mouth)	depositional	ELR-D-1	459166	6351577	459178	6351525
Upper Reach	erosional	ELR-E-2	455479	6344965	455097	6343636
Firebag River						
Lower Reach (near mouth)	depositional	FIR-D-1	531171	6355154	532137	6355085
Upper Reach	erosional	FIR-E-2	479380	6400735	479641	6397373
Fort Creek						
Lower Reach	depositional	FOC-1	461595	6363073	462071	636391
Hangingstone River						
Lower Reach (near mouth)	erosional	HAR-E-1	478405	6278941	478127	6277674
Jackpine Creek						
Lower Reach (near mouth)	depositional	JAC-D-1	471705	6346518	472846	6346582
Upper Reach	depositional	JAC-D-2	480059	6324905	480796	6324615
MacKay River						
Lower Reach (near mouth)	erosional	MAR-E-2	461251	6336292	460349	6337141
Upper Reach	erosional	MAR-E-3	449162	6319949	448864	6318830
Muskeg River						
Lower Reach (near mouth)	erosional	MUR-E-1	464135	6332065	464388	6332064
Middle Reach	depositional	MUR-D-2	466295	6339482	466576	6340400
Upper Reach (upstream of Stanley Creek)	depositional	MUR-D-3	479771	6357033	482137	6359826
Steepbank River						
Lower Reach (near mouth)	erosional	STR-E-1	471398	6320173	472629	6320281
Upper Reach	erosional	STR-E-2	500091	6297630	501118	6297776
Tar River						
Lower Reach (near mouth)	depositional	TAR-D-1	458566	6353556	457912	6353687
Upper Reach	erosional	TAR-E-2	440461	6361570	439866	6362104
Kearl Lake						
Kearl Lake	lake	KEL-1	n/a	n/a	n/a	n/a
McClelland Lake						
McClelland Lake	lake	MCL-1	481107	6374076	481022	6373941
Shipyard Lake						
Shipyard Lake	lake	SHL-1	473466	6313126	473534	6313220

Figure 3.4-1 RAMP benthic invertebrate community sampling locations, 2005.



G:\DATA\PROJECTS\RAMP1166\GIS\RAMP1166_G_Benthos_2006APR20.mxd

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

- Wetted and bankfull channel widths – visual estimate (for rivers/streams only); field water quality measurements – dissolved oxygen, conductivity, temperature (YSI85 multi-meter) and pH (WTW Set 2 pH meter). All instruments calibrated according to manufacturers instructions;
- Current velocity – Marsh-McBirney current velocity meter or a Swoffer Model 2100 current velocity measurement;
- Water depth – measured from the graduated wading rod associated with each current velocity meter;
- Amount of benthic algae at erosional stations (for chlorophyll *a* measurement) – obtained through scraping of a 2 cm x 2 cm square from three randomly selected cobbles and combined into one composite sample per station;
- Substrate particle size distribution (erosional stations only) – visual estimates of areal coverage by particles in standard size categories using the modified Wentworth classification system (Cummins 1962) and expressed as percentages;
- Geographical position – using a hand-held Magellan Global Positioning System (GPS) unit; and
- General station appearance.

Laboratory Methods

Benthic samples were sieved in the laboratory using a 250-µm mesh sieve to remove the preservative and any remaining fine sediments. The material retained by the sieve was elutriated using a flotation technique to separate organic material from sand and gravel, and invertebrates from organic material. Samples containing bitumen were treated with paint thinner to remove hydrocarbons prior to sorting. Inorganic material was scanned under a magnifying lens and any remaining invertebrates were removed before discarding. The remaining organic material was separated into coarse and fine size fractions using a 1-mm sieve. The fine size fraction of large samples was sub-sampled using a method based on that described by Wrona *et al*. (1982). Invertebrates were removed from the detritus under a dissecting microscope. All sorted material was preserved for random checks of removal efficiency.

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

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

3.4.3 Changes in Monitoring Program from 2004

The biggest change from the 2004 program was a reduction in the number of replicates per reach from 15 (2004 and previous) to 10 (2005). This decision was made on the basis that the program had very high statistical power for detecting effects with multiple years of data before and after development. The naming convention for sampling sites within a reach was affected by that decision. Whereas in previous years samples were numbered in the field as 1 to 15 (downstream to upstream) for a lower reach and 16 to 30 for an upstream reach in the same tributary, those same samples would have been numbered in 2005 as 1 to 10 in the lower reach and 11 to 20 in the upper reach. Recognizing the potential for confusion when comparing across years, the RAMP benthic database was revised to include a single numerical identifier for relative upstream-downstream position in the watershed.

An addition to the 2005 program was the sampling of McClelland Lake. McClelland Lake now has three years of baseline data with the previous data being collected in 2002 and 2003.

3.4.4 Challenges Encountered and Solutions Applied

Only two samples were collected from the lower erosional reach of the Muskeg River because of unusually high flows. Water levels in riffles in that reach were higher than the sampling apparatus making sampling infeasible.

3.4.5 Other Information Obtained

No additional or supplementary information was obtained as part of the 2005 Benthic Invertebrate Community component.

3.4.6 Summary of Component Data Now Available

As of 2005, 1,373 benthic community samples have been collected under RAMP. The distribution of stations and reaches, and the time-series of data available for individual water bodies are presented in Table 3.4-2. At least three years of data have been collected for each watercourse with the exception of the Steepbank River for which there are two years of data. The MacKay River and Tar River each have benthic data collected before and after development pressures from both lower and upper reaches; so there are opportunities to test for differences in time trends between upstream reference and downstream control reaches. There are six years of operational data from the lower reaches of the Steepbank and Muskeg Rivers, and from Shipyard Lake, as well as multiple years of data (typically four) from site-specific reference reaches or lakes. There are also five years of data for the ARD, which is designated as *potentially influenced-oil sands* for the purposes of analysis here.

3.4.7 Analytical Approach and Methods

The RAMP 2005 benthic invertebrate community analysis included the following major components:

- Selection of benthic invertebrate community measurement endpoints;
- Development of criteria to be used in detecting changes in benthic invertebrate community measurement endpoints; and

Table 3.4-2 Summary of RAMP data available for the Benthic Invertebrate Community component.

See symbol key below.

Waterbody and Location	Type	Habitat	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005			
				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																																							
Near Donald Creek (west bank)	1	depositional	ATR-B-B4 to B6				1																																
Near Donald Creek (east bank)	1	depositional	ATR-B-B1 to B3				1																																
Near Fort Creek (west bank)	1	depositional	ATR-B-A4 to A6				1																																
Near Fort Creek (east bank)	1	depositional	ATR-B-A1 to A3				1																																
Suncor near-field monitoring	2	depositional	-																				2																
Athabasca Delta	1	depositional	FLC,GIC,BPC																								1				1				1				1
Calumet River																																							
Lower reach near mouth	1,2[a]	depositional	CAL-D-1																				2				1				1				1				1
Upper reach	1	depositional	CAL-D-2																												1				1				1
Clearwater River																																							
Downstream of Christina River	1	depositional	CLR-D-1																				1				1				1				1				1
Upstream of Christina River	1	depositional	CLR-D-2																				1				1				1				1				1
Christina River																																							
Lower reach near mouth	1	depositional	CHR-D-1																								1				1				1				1
Upper reach at Janvier	1	depositional	CHR-D-2																								1				1				1				1
Ells River																																							
Lower reach near mouth	1	depositional	ELR-D-1																								1				1				1				1
Upper Reach	1	erosional	ELR-E-2																												1				1				1
Firebag River																																							
Lower reach near mouth	1	erosional	FIR-E-1																												1				1				1
Upper reach	1	depositional	FIR-D-2																												1				1				1
Fort Creek																																							
Lower reach near mouth	1[b]	depositional	FOC-D-1												2								1				1				1								
Hangingstone River																																							
Lower reach near mouth	1	erosional	HAR-E-1																																1				1
Jackpine Creek																																							
Lower reach near mouth	1	depositional	JAC-D-1																								1				1				1				1
Upper reach	1	depositional	JAC-D-2																												1				1				1
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																												
Lower reach near mouth	1	erosional	MAR-E-1																1				1				1				1				1				1
Upper reach	1	erosional	MAR-E-2																								1				1				1				
Upper MacKay River	1	erosional	MAR-E-3																																				
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																												
Lower reach near mouth	1	erosional	MUR-E-1																1				1				1				1				1				1
Lower to middle reach	1	depositional	MUR-D-2																1				1				1				1				1				1
Upstream of Stanley Creek	1	depositional	MUR-D-3																								1				1				1				1

Legend

1 = RAMP site

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

Footnotes

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

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

potentially influenced - oil sands

potentially influenced - other

reference

Table 3.4-2 (Cont'd.)

See symbol key below.

Waterbody and Location	Type	Habitat	Station	1997				1998				1999				2000				2001				2002				2003				2004				2005			
				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
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																												
Lower reach near mouth	1	erosional	STR-E-1																1				1				1				1				1				1
Upper reach	1	erosional	STR-E-2																												1				1				1
Tar River																																							
Lower reach near mouth	1[a]	depositional	TAR-D-1																				2				1				1				1				1
Upper reach	1	erosional	TAR-E-2																												1				1				1
Kearl Lake																																							
Kearl Lake	1	lake	KEL-1																				1				1				1				1				1
Isadore's Lake																																							
Isadore's Lake	1	lake	ISL-1																																				
McClelland Lake																																							
McClelland Lake	1	lake	MCL-1																								1				1								
Shipyard Lake																																							
Shipyard Lake	1	lake	SHL-1																1				1				1				1				1				1
Historical Data																																							
Historical Data Review																1	1	1	1					1	1	1	1												
5-Year Summary Report																																							
Summary Report																								1	1														

Legend

1 = RAMP site

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

Footnotes

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

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

potentially influenced - oil sands (blue)

potentially influenced - other (yellow)

reference (green)

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

These components are described in detail below.

3.4.7.1 Selection of Benthic Invertebrate Community Measurement Endpoints

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

- Abundance (total number of individuals/m2);
- Taxon richness (number of distinct taxa);
- Simpson's Diversity Index (D), where

$$D = 1 - \sum (p^{i})^{2} \qquad [1]$$

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

- Evenness, where

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

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

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

- Percent EPT (Ephemeroptera, Plecoptera, Trichoptera).

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

3.4.7.2 Criteria for Determining Effects

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

Based on similarities in fauna across years groupings of similar reaches were used to calculate regional ranges of variability for the select indices of composition based on the mean and standard deviation (i.e., regional range was estimated as $\overline{X} \pm 2SD$). That approach to estimating the normal range of variability is consistent with the recommended approach in the Five-Year report (Golder, 2003a), but differs in that separate ranges were produced for erosional and depositional reaches. This approach does not take into account trends in the baseline condition over time. The Muskeg River (middle through to lower reaches), the MacKay River (lower reach since 2002), Steepbank River (lower reach since 1998), Tar River (lower reach, 2004), ARD, and Shipyard Lake are designated as *potentially influenced-oil sands*. Data from all other reaches (and lakes) for 2005 are designated as either *reference* or *potentially influenced-other*. Variations in benthic invertebrate community measurement endpoints in reaches designated as *potentially influenced-oil sands* were evaluated relative to variations in reaches designated as *reference* or *potentially influenced-other*.

3.4.7.3 Detailed Data Analysis

Taxonomic and water/sediment quality summaries were generated for all river and lake samples collected in 2005, averaged across sample locations for each reach/lake. The mean percent abundance of major taxonomic groups, as well as the percent of the total samples represented by the EPT taxa (Ephemeroptera – mayflies, Plecoptera – stoneflies, and Trichoptera – caddisflies) was also determined for each sampling location.

Determination of Regional Baseline Conditions

As part of the analysis of the 2005 data an ordination (Correspondence Analysis [CA]) of the data was conducted to identify natural groupings of study reaches that were designated as in a baseline condition. The natural groupings were then used to identify regional baseline conditions for different habitat types. Depositional and erosional habitats grouped well in that analysis (RAMP 2005b) and justified the calculation of "normal ranges" for each of the benthic community indices for erosional and depositional reaches. This same approach was used in this 2005 analysis of the benthic invertebrate community (Appendix F). An ordination of the family-level data was used to demonstrate unique assemblages of benthos in erosional and depositional baseline reaches. Normal ranges for each of the indices of community composition were calculated as the mean ± 2 standard deviations of observations, and those ranges have been compared to the observed mean index values for reaches designated as *potentially influenced-oil sands*. We have also shown how the communities from reaches classified as operational fall relative to the normal ranges depicted in the multivariate ordination diagrams. The technical aspects of the multivariate analysis are documented in Appendix F.

Effects of Oil Sands Development on Benthic Invertebrate Communities

Possible effects of oil sands development were evaluated by comparing benthic measurement endpoints in reaches designated as *potentially influenced-oil sands* to upstream reference reaches and/or to pre-development conditions with analysis of variance (ANOVA). When necessary, dependent variables (measurement endpoints) were $\log_{10}$-transformed to meet assumptions of normality and homogeneity of variances. One-way ANOVAs were conducted for each benthic community index with each reach-year combination as the factorial variable. Planned linear orthogonal contrasts (Hoke *et al*., 1990) were then used to identify differences between baseline and operational reaches, between baseline and operational periods, and differences in time trends between Lower operation and Upper baseline reaches. We also evaluated differences between reference and reaches designated as *potentially influenced-oil sands* for data collected in 2005 only. In all cases, the comparisons were tested against the residual error of the overall one-way ANOVA.

Reaches designated as *potentially influenced-oil sands* and reaches designated as *potentially influenced-other* or *reference* within a watercourse were not always the same habitat type (e.g., Muskeg River, MUR-E-1 and MUR-D-3). In these cases we expected that trends over time should be the same in both reaches unless oil sands development was influencing the downstream reach differently from the upstream reach.

The three channels of the ARD were designated as *potentially influenced-oil sand,* but due to the unique nature of the deltaic environment there were no other similar reaches against which to compare them. ANOVA was therefore not used, but multivariate ordination procedures were used to illustrate the similarity of the samples from the ARD to samples from depositional baseline reaches.

3.4.7.4 Environmental Variables

A number of routine variables are measured at each site including measures of both physical substrate condition, as well as measures of temperature, water chemistry and water flow velocities. Those attributes are measured because they fundamentally influence the kinds of benthic fauna found at a site. Where benthic communities are shown to vary over time in a fashion consistent with oil sands development, the impact may be demonstrated to be due to changes in some of these fundamental attributes. No attempt was made in this report to relate variations in benthic community composition to variations in these measured attributes. It makes sense, however, to look at those associations when and/if there are significant impacts in the benthic community.

Some general conclusions about the condition of a reach can be made based on the one-time measurements. Dissolved oxygen, for example, is typically above concentrations considered critical for the protection of aquatic life (5.5 mg/L for warm-water biota; CCME, 1999a), and concentrations below that can be indicative of potential risks to aquatic life, especially if those concentrations are observed during the day (typical time of measurement in the RAMP design). Chlorophyll *a* is one of the measurements made in erosional reaches, and was identified early in the AOSERP studies as a potential indicator of oil sands activity (Barton and Lock, 1979). Chlorophyll *a* can also be used to classify the nutrient status of a stream, and Dodds *et al*. (1998) suggest that the boundary between oligotrophic and mesotrophic conditions in streams is between 20 and 70 mg/m^2; while the boundary between mesotrophic and eutrophic is between 60 and 200 mg/m^2. Those rough categories are used here to discuss the chlorophyll *a* measurements made in erosional reaches. Conductivity measurements provide a measure of the dissolved constituents. Individual conductivity values (µS/cm) for a site cannot be easily interpreted, but differences in conductivity between two sites can be used to infer much about the quality of the water.

3.5 FISH POPULATIONS

3.5.1 Overview of 2005 Program

In 2005, RAMP conducted the following monitoring of fish populations in the Athabasca oil sands area:

- Fish inventory on the Athabasca River (spring and fall sampling), the Clearwater River (spring and fall sampling), and the Ells River (summer sampling);

- Tissue collection and chemical analysis for target fish species in the Athabasca River; and

- Sentinel fish species program (using non-lethal method) on the Ells River (summer and fall field trips).

A fish fence program in the lower Muskeg River was planned in 2005; however, this program could not be implemented due to prohibitively high water levels that coincided with the program timing (May). This program is scheduled to be implemented in spring 2006, pending assessment of seasonal water levels at that time.

Table 3.5-1 lists the watercourses sampled and the target fish species for the 2005 RAMP Fish Population component. Locations of sampling sites for the 2005 Fish Population component elements are shown in Figure 3.5-1. Common and scientific names for each fish species noted in this report are listed in Appendix G.

Table 3.5-1 Tasks, sampling sites, timing and target species for the 2005 RAMP Fish Population component.

Waterbody	2005 RAMP Fish Population Component Activity		
	Fish Inventory	Fish Tissue	Sentinel Species
Athabasca River	SPRING & FALL fish community	FALL lake whitefish walleye	
Clearwater River	SPRING & FALL fish community		
Ells River	SUMMER fish community		SUMMER & FALL non-lethal program

3.5.2 Field Methods

3.5.2.1 Fish Inventory

Athabasca River and Clearwater River

Overview The RAMP Athabasca River and tributary fish inventory is conducted to provide data on geographic and temporal variations in fish species composition, relative abundance, size and condition factor. In 2005, spring and fall inventories were carried out to augment existing fish presence and abundance data for key indicator fish species (i.e., Key Indicator Resources) in the oil sands region of the Athabasca River. Key indicator fish species include (CEMA 2001):

- Walleye (*Sander vitreus*);

- Northern pike (*Esox lucius*);

- Lake whitefish (*Coregonus clupeaformis*);

- Longnose sucker (*Catostomus catostomus*);

- Goldeye (*Hiodon alosoides*); and
- Trout-perch (*Percopis omyscomaycus*).

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

Fish Sampling and Handling Spring sampling was conducted between May 9 and May 31, 2005. The survey focused primarily on the Athabasca River (6 days of effort), with a secondary effort on the Clearwater River (2 days of effort).

The fall program was implemented from September 16 to September 29, 2005. This survey included six days of effort on the Athabasca River and two days on the Clearwater River. Fish captured during the Athabasca River component of the inventory were also used to support fish tissue monitoring studies outlined in Section 3.5.2.2.

In 2005, Athabasca River sampling focused on ten reaches specifically established by RAMP for the inventory program (Table 3.5-2, Figure 3.5-1). The ten reaches have been re-sampled each year (1997-2004) and are located in four sections of the Athabasca River near major tributary confluences: the Poplar Area (Reaches 0 and 1); Steepbank Area (Reaches 4 to 6); Muskeg Area (Reaches 10, 11 and 12); and Tar-Ells Area (Reaches 16 and 17). Sampling in the Clearwater River was conducted at three locations (Figure 3.5-1) during the spring and fall sampling efforts. Low water conditions encountered in 2004, which prevented jetboat access to the upper Clearwater River, were not encountered in 2005. In all cases, sampling was conducted in areas conducive to boat electrofishing, primarily shallow river margins.

Table 3.5-2 Athabasca River and tributary fish inventory sampling locations, 2005.

Site Name	Reach Numbers	UTM Coordinates (NAD 83, zone 12V)	
		Upstream Boundary	Downstream Boundary
Poplar Area	0 and 1	474627 E / 6305817 N	473052 E / 6311432 N
Steepbank Area	4, 5 and 6	472838 E / 6317197 N	469314 E / 6322688 N
Muskeg Area	10, 11 and 12	463967 E / 6331391 N	463253 E / 6341314 N
Tar-Ells Area	16 and 17	459859 E / 6350353 N	459913 E / 6356845 N
Clearwater River	CR1	527711 E / 6290586 N	489943 E / 6281368 N
	CR2	514251 E / 6283905 N	510636 E / 6281851 N
	CR3	496363 E / 6280331 N	489812 E / 6281153 N

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

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

Ells River Fish Inventory

A fish inventory was conducted in the Ells River from August 22 to 29, 2005. Sampling methods were suitable for collection of all sizes of fish. Sampling was conducted using a Smith-Root 12B backpack electrofishing unit and a pole-seine net (a approximately 1 m wide 1/8″ mesh panel strung between two poles). Current was applied to the water in 5 to 10 second bursts and sampling was conducted throughout the river width and in all habitat types. An area of river approximately 2 to 4 m^2 was sampled for each burst.

All captured fish were identified and measured for fork length (± 1 mm), and the majority of fish were measured for wet weight (± 0.01 g) using a calibrated electronic balance. Fish were examined externally for signs of injury, abnormalities, parasitism or disease. Fish were revived in a bucket of fresh water and released at or near the point of capture. All fish were monitored during the holding period to ensure full recovery before release.

3.5.2.2 Fish Tissue

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

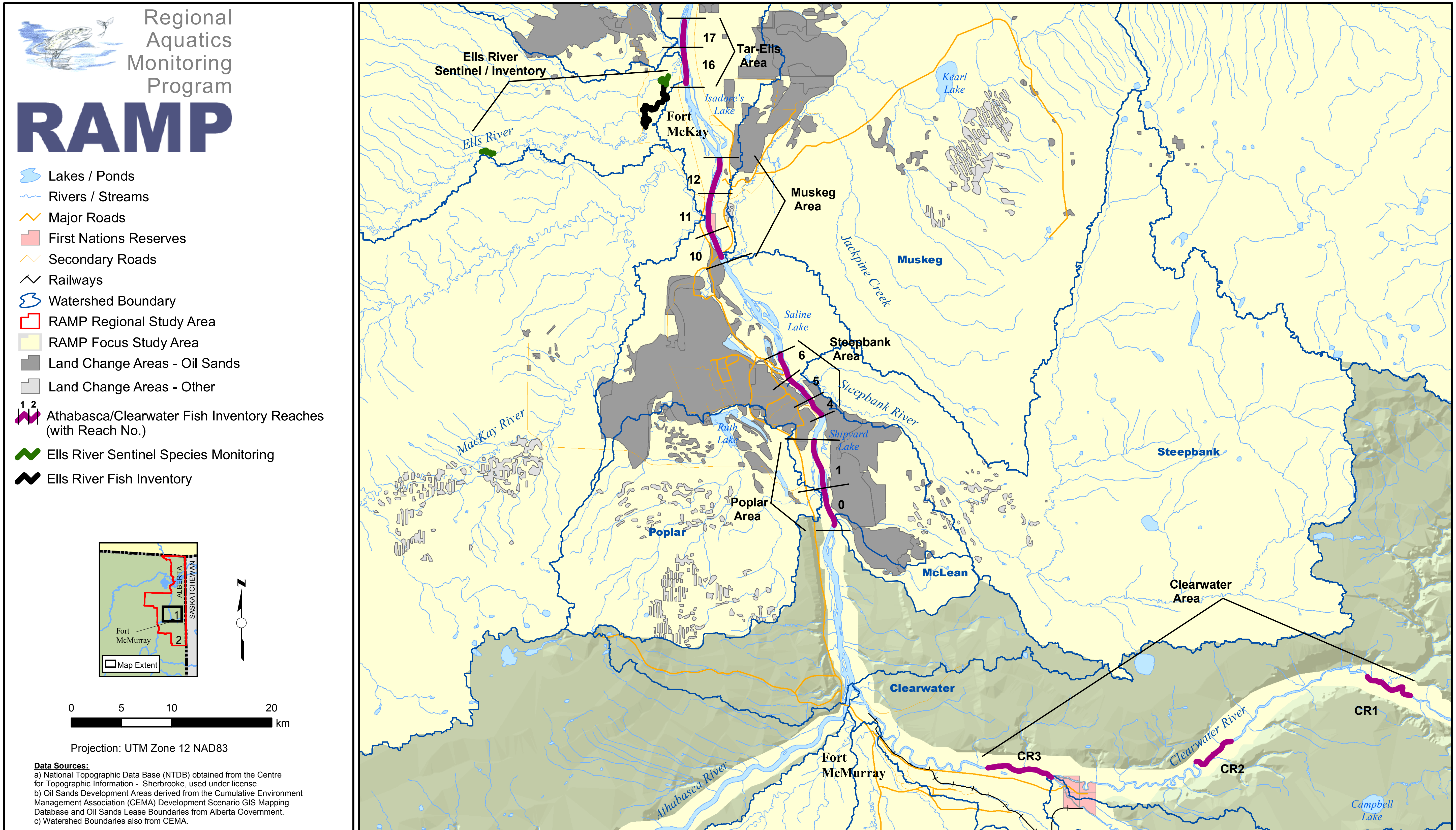
Fish sampling for tissues was conducted in the Athabasca River in fall 2005.

Fish Collection and Sampling

Fish species targeted for the Athabasca River included lake whitefish and walleye. Fish sacrificed for tissue analysis were acquired from a sub-sample of fish captured during the fall Athabasca River inventory program (see Section 3.5.2.1). Fish were selected for tissue analysis based on several length classes (Table 3.5-3) and transferred to an onshore portable sampling station. All fish were held in coolers prior to dissection.

For each selected fish species, up to 25 individuals were targeted for mercury tissue analyses on the basis of size. The objective was to collect tissues for mercury analysis from five fish of each sex from each of five predetermined size classes for each species (Table 3.5-3). Size classes were used to ensure an equal distribution of tissue samples were collected from a wide range of fish sizes and ages; this approach helped obtain a better understanding of tissue concentrations within the populations being assessed, and allowed direct comparison with data from previous sampling efforts. Size classes were selected based on typical size ranges of fish available in the fall, as observed during past fish inventory surveys (RAMP 2005a). In addition to the size ranges of fish selected for

Figure 3.5-1 Location of sampling areas used for inventory, fish tissue, and sentinel species monitoring as part of the RAMP Fish Population Component, 2005.



G:\DATA\PROJECTS\RAMP1166\GIS\RAMP1166_H_Fish_2006APR20.mxd

Table 3.5-3 Target fork length classes for the selection of fish for the RAMP fish tissue program, Athabasca River, 2005.

Species	Target Size Classes for Mercury Analysis (mm) (5 fish per class)					Target Size Classes for Composite Samples	
	1	2	3	4	5	Female	Male
Lake whitefish	350-400	401-450	451-500	501-550	551-600	400-450	400-450
Walleye	201-300	301-400	401-500	501-600	601-700	500-550	450-500

fish inventory surveys (RAMP 2005a). In addition to the size ranges of fish selected for mercury analysis, sub-samples of male and female fish within a narrow size class from each species were targeted for a more comprehensive suite of organics and metals analyses (Table 3.5-3). This range was selected to remove potential variability associated with size and age, and to allow for direct comparison to previous surveys (RAMP 2005a). Mercury concentration was measured in all fish selected for tissues analysis, while a more comprehensive suite of metals and tainting compounds analyses was completed on composite samples prepared for each species and sex. Composite sample sizes of five walleye and five northern pike from each sex were targeted during field operations.

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

Each fish was measured for fork length (± 1.0 mm), total weight (± 1.0 g) and underwent an external health assessment prior to dissection. For each fish, muscle tissue was removed for mercury analyses. Additional muscle tissues were targeted from five males and females per species for composite samples. Muscle tissues were removed from the left side of the fish following procedures outlined in the RAMP protocol for fish health assessment for organic chemicals (RAMP 2005b), and from the right side of the fish according to the RAMP fish health assessment protocol for metals (RAMP 2005b). Minimum muscle tissue requirements per fish were set at a minimum of 20 g (50 to 100 g is preferred) for organics analyses and a minimum of 2 g (5 g is preferred) for metals analyses; typically, tissue samples submitted exceeded these weights. Muscle samples collected for organics analyses were individually wrapped in solvent-rinsed aluminum foil and samples collected for metals analyses were individually wrapped in plastic wrap. All samples were labeled, stored on dry ice, and shipped to Enviro-Test Laboratories (ETL) in Edmonton for analysis. Composite samples were prepared by the analytical lab.

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

Non-Lethal Biopsy Pilot Study In 2004, RAMP initiated a non-lethal fish tissue biopsy pilot study in response to RAMP Technical Program Committee concerns regarding potential effects of lethal monitoring activities on fish populations. This study was continued in 2005 due inconclusive results associated with small samples sizes in 2004.

The continued goal of this investigation was to evaluate whether mercury levels in target fish species can be reliably measured using non-lethal methods (e.g., Baker *et al*. [2004]). Mercury concentrations of non-lethal samples relative to lethal (fillet) samples have been documented to be dependent on a number of factors: non-lethal collection method, analytical method, tissue sample weight, and possible loss of mercury during freeze-drying.

In 2005, an alternative non-lethal sampling was tested that involved a 4 mm AcuPunch biopsy punch (Acuderm Inc.) instead of a biopsy needle. The modification in sampling technique was based on increased sample weight (60 mg versus 25 mg), no observed effects on northern pike survival in the wild subject to single dermal punch sampling (Baker *et al*. 2004), and inconclusive results observed from the biopsy needle technique tested in 2004.

A few scales were removed and the dermal punch positioned on the surface of the skin. The punch was then pushed straight in with moderate pressure and a twisting motion to penetrate the muscle. The twisting action and slight angular pressure was used upon extraction to assist in obtaining the muscle plug sample. The tissue plug was then placed into a 4 ml externally threaded, sterile cryovial with a clean dissecting probe and pair of tweezers. A minimum of two biopsy plugs were collected for a composite sample per fish, to ensure the minimum 50 mg sample weight was met, although one plug in many cases would have been sufficient.

Similar to methods in 2004, quality assurance samples for collection method and inter-laboratory comparisons were collected from eleven individual fish and submitted frozen to Flett Research in Winnipeg and ETL for mercury analysis. Two samples, one for each lab, consisted of a minimum of 10 g of tissue collected using standard RAMP dissection methods outlined above, while the third consisted of at least 50 mg of tissue collected using the dermal punch procedure for analysis by Flett Research.

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

Chemical Analysis of Tissue Samples

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

Individual muscle samples of fish from the Athabasca River were analyzed for mercury. Composite samples from the Athabasca River fish were analyzed for mercury as well as the following variables:

- 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, o-xylene, 1,3,5-tribmethylbenzene, and naphthalene. There are fourteen compounds that are known to have the potential to taint fish muscle (described in Golder 2002a), but only these six analytes can be measured effectively.

Analyses were conducted on a wet weight basis. Methods and detection limits used for chemical analyses are presented in Table 3.5-4.

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

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

3.5.2.3 Ells River Sentinel Species

Background

Sentinel species monitoring measures morphological changes occurring in a designated species of fish deemed a good indicator of, and/or particularly susceptible to, changes in environmental quality. Based on reconnaissance sampling conducted in 2004 (RAMP 2005a), longnose dace were selected as the most suitable sentinel species in the Ells River. Slimy sculpin, the chosen sentinel species in other oil sands area tributaries, are not present in sufficient numbers in the Ells River.

The overall design of the RAMP sentinel species monitoring programs is based on the federal environmental effects monitoring (EEM) requirements currently in place for the metal mining and pulp and paper sectors in Canada (Environment Canada 2002, 2005). In particular, this involves fish sampling at sites designated as *potentially influenced-oil sands* and either *potentially influenced-other* or *reference*. (RAMP 2005b).

Monitoring Sites In 2005, sentinel species monitoring was carried out at two sites in the Ells River (Table 3.5-5). Since all parts of the Ells River watershed are designated as *reference* watershed, there were no sites designated as *potentially influenced-oil sands* included in the 2006 sentinel monitoring program on the Ells River. Until this designation changes the two sentinel sampling sites on the Ells River will be referred to as the upper and lower sites.

Table 3.5-4 Methods of analyses and detection limits for metals and tainting compounds.

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

Table 3.5-5 Sampling locations for the Ells River sentinel fish species monitoring program, 2005.

Watershed	Site Code	Location Description	UTM Coordinates (NAD83)
Ells River	UPPER	Upstream of the CNRL road bridge (~10km)	Start: 440611 6342439 Finish: 440286 6342418
	LOWER	In the area of the CNRL access road bridge	Start: 457363 6349969 Finish: 457556 6349891

In previous years, sentinel species studies conducted under RAMP have used a non-lethal approach, whereby a species health is monitored without sacrificing individual fish to acquire the necessary data. This non-lethal approach was adopted according to methods in Gray *et al*. (2002) and was first used for RAMP sentinel studies in 2004.

The non-lethal sentinel approach involves the collection of growth data from populations of sentinel species at the RAMP sites designated as *potentially influenced-oil sands* and either *potentially influenced-other* or *reference* (lower and upper sites in the case of the Ells) by non-lethally sampling a minimum of 100 fish at each location twice during the annual growth period. Rather than conduct internal health assessments and calculate organ-somatic indices, the two-sampling period approach was used to assess external growth characteristics (length, weight, and condition factor) of young-of-year fish between emergence and winter ice-cover.

Fish Sampling and Handling The two sampling periods for the 2005 non-lethal sentinel species monitoring program were August 22 to 29, 2005 and October 4 to 7, 2005. All fish sampling was carried out by a two-person crew using a Smith-Root 12B-POW battery-powered electrofishing unit and a portable pole seine, which was deployed downstream of the anode prior to and during the application of electrical current. The pole seine was fitted with a fine mesh net (0.125 in) to ensure that young-of-year dace were captured. The lower edge of the pole seine was weighted with lead weights to keep it on the substrate. Fish sampling was concentrated in areas that were considered optimum dace habitat, based on results of inventory studies conducted concurrently with the Ells River sentinel program. All dace captured were enumerated by life history stage, measured for fork length (± 1.0 mm) and weight (± 0.01 g) using an electronic balance that was calibrated prior to each measurement. An external pathology examination was also performed. The fish were then revived in a bucket of fresh water for eventual release back into the river. All fish were monitored at regular intervals to ensure full recovery prior to being released.

In addition to the basic fish sampling outlined above, the August sampling effort included habitat assessments of the upper and lower reaches to evaluate inter-site comparability. The habitat assessment involved measuring and recording a range of variables relating to channel morphology, substrate, water quality, and fish cover as outlined in Golder (2002a) and RIC (1999). Water quality variables were measured with a YSI Model 85 multi-meter, and included temperature, dissolved oxygen, and specific conductance/conductivity. Water velocity was measured using a Swoffer current flow meter.

Fish abundance/density studies, as were done in previous tributary sentinel programs (RAMP 2005a), could not be conducted in 2005 due to high water conditions. Under these conditions, full-width blocking nets, that are necessary to determine the abundance of fish in particular stream reach, could not be installed.

3.5.2.4 Fish Tag Return Assessment

Since the inception of RAMP in 1999, tagging of key indicator fish species has been regularly undertaken as part of various fish program activities, including inventories and the operation of fish fences. Records have been kept by RAMP and the Alberta Ministry of Sustainable Resource Development (ASRD); these records provide information on movements of tagged fish in the event a tag is returned by an angler. Data may include the tagging date and geographical location, as well as basic morphometric parameters, such as fish length and weight.

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

3.5.3 Changes in Monitoring Network from 2004 Field Program

There were no changes in the monitoring network for fish program elements that were common to 2004 and 2005 (i.e., Athabasca fish inventory and tissue sampling).

The Regional Lakes Program, where fish tissue from stakeholder or government partners is analyzed for mercury levels, was not conducted in 2005. No fish were submitted to RAMP for opportunistic analysis and a Fall Walleye Index Netting (FWIN) program was not conducted by Alberta Sustainable Resources Development (ASRD). Planning is currently underway by ASRD for FWIN programs in 2006, under which fish tissues are expected to be submitted to RAMP.

3.5.4 Challenges Encountered and Solutions Applied

In general, field activities implemented under the 2005 RAMP fish program were completed successfully. However, two of the component elements, the spring Muskeg River fish counting fence and the Regional Lakes Program for fish tissue, were not implemented in 2005. The Muskeg River experienced sustained unusually high discharge levels that coincided with the desired study period (May); conditions consistently exceeded the safe installation discharge criterion of 9 m^3/s (peak flow in May exceeded 35 m^3/s).

The Regional Lakes Program was not implemented in 2005; there were no fish submitted opportunistically for analysis and ASRD did not conduct a FWIN program in this year.

In response to difficulties encountered in 2004 in regards to identification of two co-occurring species of sculpin in the oil sands region (slimy sculpin and spoonhead sculpin), a one-day workshop was staged with Mr. Wayne Roberts of the University of Alberta, Museum of Zoology in Edmonton. Two Hatfield field biologists (both common field crew leaders) attended this workshop. A diagnostic field identification card was produced as an outcome of the workshop. This card has been circulated to RAMP fish sub-group members as well as posted to the RAMP website (www.ramp-alberta.org) for broader circulation.

3.5.5 Other Information Obtained

No additional information was obtained by the Fish Population component in 2005.

3.5.6 Summary of Component Data Now Available

The Fish Population component data collected to date for the RAMP monitoring program is summarized in Table 3.5-6.

3.5.7 Analytical Approach

The RAMP 2005 Fish Population component analysis included the following major elements:

- Selection of fish population measurement endpoints;
- Development of criteria to be used in detecting changes in fish population measurement endpoints; and
- Detailed data analysis, consisting of statistical analyses and tabular and graphical presentations of 2005 results for the Fish Population component.

These elements are described in detail below.

3.5.7.1 Selection of Fish Population Measurement Endpoints

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

Fish Inventory Studies

With respect to the fish inventory studies, the possible measurement endpoints considered for each key indicator fish species included:

- Relative abundance (catch per unit effort);
- Length-frequency;
- Age-frequency;
- Percent composition; and
- Condition factor.

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

Fish Tissue Studies

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

Table 3.5-6 Summary of RAMP data available for the Fish Population Component.

See symbol key below.

Waterbody and Location	Reach	1997				1998				1999				2000				2001				2002				2003				2004				2005			
		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
Steepbank Area	4/5/6		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		1		1,6
Muskeg Area	10/11/2012		1	1,5	1,5		1,6	1,5	1,3,6									7			6		1		10,6				6		1		1		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
CNRL/TrueNorth Area (Fort/Asphalt reaches)																							1														
Reference Area - about 200 km upstream[b]	5/6							1,5	1,3,6																												
Reference Area - upstream of Fort McMurray[c]			1																																		
Radiotelemetry study region[d]					2		2		2						2	2	2	2	2																		
Downstream of Suncor's Discharge	AR-SD												1,3												10,3				10								
Below Muskeg River	AR-MR												1,3												10,3				10								
Reference site upstream of Ft. McMurray STP																									3				10								
Reference site between STP and Suncor	AR-R												1,3												3				10								
Downstream of Developments (near Firebag R.)																													10,6								
Athabasca River Delta																																					
Athabasca River Tributaries																																					
Fort Creek (mouth)															1,8,5,9	1																					
Historical Review of Tributary Fish Data																																					
Clearwater River	CR1																														1		1		1		1
Clearwater River	CR2																														1				1		
Clearwater River	CR3																											10			1				1		
Christina River[e]																																	1				1
Muskeg River																																					
Lower 35 km below Jackpine Creek confluence				1			4						1,3		2,8	2	2	2	2	1	6			1	6							1	6				
Mouth (within 1 km of confl. with Athabasca R.)	MR-MT												1,3						4		3		4		4		4						3				
Reference sites (Steepbank, Horse and Dunkirk R.)																	3				3												3				
Upper Muskeg River (near Wapasu Ck. Confluence)																							1,4		1,4												
Muskeg River Tributaries																																					
Alands Drain																																					
Jackpine Creek (accessable areas of lower creek)															8					1				1								1					
Shelley Creek																																					
Muskeg Creek (Canterra road crossing)[f]																							1,4		1,4												
Stanley Creek																																					
Wapasu Creek (mouth or Canterra road)[f]																							1,4		1,4												
Regionally Important Lakes																																					
Various lakes in water/air emissions pathway																													6				6				
Kearl Lake																																					
Isadore's Lake																																					

Legend

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

N/A = site unnamed

potentially influenced - oil sands (blue)
potentially influenced - other (yellow)
reference (green)

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 reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing
f 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
g located from 3 to 11 km upstream of the confluence with the Athabasca River
h reference site located approximately 21 km upstream of confluence with Athabasca River; sampling done by Environment Canada, NWRI, Burlington, Ontario
i in 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers
j 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

Table 3.5-6 (Cont'd.)

See symbol key below.

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

Legend

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

N/A = site unnamed

potentially influenced - oil sands (blue)
potentially influenced - other (yellow)
reference (green)

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] reconaissance inventory carried out in the Christina River upstream and downstream of the Hwy 881 bridge crossing
[f] 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
[g] located from 3 to 11 km upstream of the confluence with the Athabasca River
[h] reference site located approximately 21 km upstream of confluence with Athabasca River; sampling done by Environment Canada, NWRI, Burlington, Ontario
[i] in 2004 a fish fence reconnaissance was carried out on the Ells and Mackay Rivers
[j] 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

Sentinel Species Monitoring

Measurement endpoints selected for RAMP sentinel species monitoring on the Athabasca River and select tributaries are dependent on whether a lethal or non-lethal sampling approach is used. In both cases, the selected endpoints are based on Environment Canada's Environmental Effects Monitoring (EEM) guidelines developed for the metal mining and pulp and paper sectors (Environment Canada 2002, 2005). Table 3.5-7 provides a summary of measurement endpoints for each sentinel monitoring approach as they related to growth, reproduction, condition and survival.

Table 3.5-7 Summary of measurement endpoints for lethal and non-lethal sentinel species monitoring.

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

***** Measurement endpoints used for determining effects. Other endpoints used for supporting analyses.
Adapted from Environment Canada (2005).

3.5.7.2 Criteria for Determining Effects

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

Fish Inventory Studies

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

Fish Tissue Studies

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

- Health Canada Guidelines for chemical contaminants in fish (CFIA 2003) and for exposure of Indian and Inuit residents to methylmercury in the Canadian environment (Health Canada 1978, as cited in Lockhart *et al*. 1995);
- Region III USEPA risk-based criteria for consumption of fish tissue for recreational and subsistence fishers (USEPA 2003, updated April 2006); and
- National USEPA risk-based screening values for consumption of fish tissue (USEPA 2000).

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

Effects on Fish To assess potential effects on fish health, fish tissue data were compared to the lowest tissue residue concentrations linked to effects (or a lack of effects). Effects thresholds were derived from laboratory-based studies summarized in Jarvinen and Ankley (1999); these effects thresholds relate tissue residues to sublethal and lethal effects for aquatic organisms exposed to a number of inorganic and organic chemicals. The full range of effects (or no effects) thresholds are presented in Table 3.5-8, along with information regarding the studies that these thresholds were derived from, including the endpoints evaluated, tissue type, species, life stage and/or fish size, exposure route and duration of exposure. Only the most relevant studies are used for effects threshold assessment by RAMP. Studies for small-bodied fish or tropical fish species, and those that simultaneously evaluated effects of conventional variables on toxicity or maternal transfer studies, are excluded. Data derived from acute exposures are only included for contaminants where few data exist.

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

Table 3.5-8 Concentrations of metals that have lethal, sublethal or no effect on freshwater fish.

Variable	Endpoint		Effects Concentrations (mg/kg)	Tissue	Species	Life Stage or Size	Route	(days)
Metals								
Aluminum	Survival	no effects	1.0 - 1.15	muscle	rainbow trout, Atlantic salmon	171 g, alevin	oral, water	30 - 42
		effects	20 - 36.8	whole body	Atlantic salmon	alevin	water	30
Antimony	Survival	no effects	5	whole body	rainbow trout	fingerling (1.2 g)	water	30
		effects	9	whole body	rainbow trout	fingerling (1.2 g)	water	30
Arsenic	Survival	no effects	2.6 - 11.4	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	11.2 - 17.9	carcass	rainbow trout	juvenile	oral	56
	Growth	no effects	0.9 - 6.5	carcass, whole body	rainbow trout	juvenile	oral, water	21 - 56
		effects	3.1	carcass	rainbow trout	juvenile	oral	56
Barium	-	-	-	-	-	-	-	-
Cadmium	Survival	no effects	0.02 - 2.8	muscle	rainbow trout, brook trout	150 -200 g, adult	water, ip injection	210 - 455
		effects	0.14 - 0.7	whole body	rainbow trout, brook trout	5 - 15 g	water	29 - 30
	Growth	no effects	0.09 - 2.8	muscle, whole body	rainbow trout, brook trout	3.1 g, 5 g, adult	water	30 - 455
		effects	0.12 - 0.96	muscle, whole body	rainbow trout, Atlantic salmon	3.1 g, alevin	water	92 - 210
	Reproduction	no effects	0.4	muscle	rainbow trout	adult	water	455
		effects	0.6	muscle	rainbow trout	adult	water	455
Chromium	-	-	-	-	-	-	-	-
Copper	Survival	no effects	0.5 - 3.4	muscle	rainbow trout, brook trout	embryo-adult-juvenile	water	0.33 - 720
		effects	0.5	muscle	rainbow trout	138 g	water	0.33
	Growth	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
	Reproduction	no effects	3.4	muscle	brook trout	embryo-adult-juvenile	water	720
Iron	-	-	-	-	-	-	-	-
Lead	Survival	no effects	4.0	carcass	rainbow trout	under-yearlings (6.5 g)	water	224
Manganese	-	-	-	-	-	-	-	-
Mercury[1]	Survival	no effects	1.91 - 35.0	whole body, muscle	rainbow trout, brook trout	10 - 20 mm, juvenile, fingerling, yearling-adult, adult	ip injection, oral, water	15 -273
		effects	3.7 - 31	whole body, muscle	rainbow trout, brook trout northern pike	10 - 20 mm, subadult (100 - 150 g), yearling-adult, adult	ip injection, oral, water	186 - 273
	Growth	no effects	2.28 - 29.0	whole body, muscle	rainbow trout	fingerling, juvenile	oral, water	24 - 105
		effects	8.6 - 35.0	whole body, muscle	rainbow trout	fingerling	oral	84 - 105
	Reproduction	no effects	9.2	muscle	brook trout	yearling-adult	water	273
		effects	23.5	muscle	brook trout	yearling-adult	water	273
Nickel	Survival	no effects	0.82 - 58.0	muscle	rainbow trout, carp	15 g, 150 - 200 g	water	5 - 180
		effects	118.1	muscle	carp	15 g	water	4
Selenium	Survival	no effects	0.28 - 3.1	whole body, carcass	rainbow trout, chinook salmon, largemouth bass	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	water, oral	28 - 308
		effects	0.92 - 2.5	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, .fingerling-juvenile	water, oral	28 - 168
	Growth	no effects	0.08 - 1.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, egg-juvenile, fingerling-juvenile, juvenile	oral	60 - 308
		effects	0.32 - 2.08	whole body, carcass	rainbow trout, chinook salmon	larvae-swim-up, fingerling-juvenile, juvenile	oral	60 -168
Silver	Survival	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
	Growth	no effects	0.003	carcass	largemouth bass	young-of-year	water	180
Strontium		-	-	-	-	-	-	-
Tin		-	-	-	-	-	-	-
Titanium		-	-	-	-	-	-	-
Vanadium	Survival	no effects	5.33	carcass	rainbow trout	juvenile	oral	84
	Growth	no effects	0.02	carcass	rainbow trout	juvenile	oral	84
		effects	0.41	carcass	rainbow trout	juvenile	oral	84
Zinc	Survival	no effects	60	whole body	Atlantic salmon	juvenile	water	80
	Growth	no effects	60	whole body	Atlantic salmon	juvenile	water	80

Data obtained from Jarvinen and Ankley 1999.

- = No data.

[1] Methylated forms of mercury.

Sentinel Species Monitoring

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

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

3.5.7.3 Detailed Data Analysis

Fish Inventory

Athabasca River and Clearwater River All fish captured during the inventory were summarized by species composition (i.e., percent of total catch) and relative abundance (i.e., catch-per-unit-effort [CPUE]).

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

- Length-frequency distribution;
- Mean condition factor; and
- Mean external pathology index.

Walleye and northern pike are have been designated as key indicator species under RAMP and are also the two sport fish targeted most often by anglers in the oil sands area. Given the ecological and socioeconomic importance of these two fish species, it was decided that it would be useful to conduct a temporal comparison of the ratio of captured fish abundance above and below the corresponding legal size limits. This determination would provide an index of recruitment to the sport fishery and a means to gain insight into overall survival of these two species. Fork length is the standard metric for most fish captured during RAMP activities (exceptions include the two sculpin species, as well as burbot), while the ASRD size regulations for the Athabasca River in the Northern Boreal Zone 3 are given in total length (legal walleye ≥ 430 mm; legal northern pike ≥ 630 mm). Using regression equations for each species, approximations of the appropriate fork length size were calculated (walleye 370 mm and pike 600 mm). These corresponded extremely well to length size-classes already used in the length frequency distributions and did not required reassignment.

With the exception of lake whitefish, analysis of condition was restricted to data for fish collected in the spring. Fall data were used for lake whitefish. To be consistent with past years, analyses were restricted to fish of a minimum length: walleye >400 mm; lake whitefish >350 mm; northern pike >400 mm; goldeye >300 mm; and longnose sucker >350 mm. For each species, fish condition was estimated by the relationship of total body weight versus fork length (log_{10} data). Potential differences in condition among years (1997-2004) were initially tested using Analysis of Covariance (ANCOVA). However, for some species when the full ANCOVA model (i.e., test of slopes) was conducted, there was a high number of fish that exhibited studentized residual values > 4.0. Given these results, the residual values for each fish derived from the ANCOVA model were saved and these data were used to test for differences in condition among years using the non-parametric Kruskall-Wallis test (similar to ANOVA). This approach avoided the potential problems associated with arbitrarily omitting high numbers of fish from the analyses based on residual values, and potentially biasing the results of the test. For graphical purposes, Fulton's Condition Factor was also calculated using the following equation: $K=(\text{body weight}/\text{fork length}^3 x10^5)$.

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

Fish Tissue Studies

Statistical Analysis Scatterplots were used to initially assess the relationships between mercury concentrations in fish and whole-organism indices. Rank correlations were then used to evaluate relationships between these variables for each species and sex combination. The significance of a correlation was determined using critical values of Spearman's correlation coefficient (r_s). A correlation was described as moderate if $|0.50| > r_s < |0.75|$ and strong if $r_s > |0.75|$. If significant rank correlations were observed, linear regression was used to further evaluate the relationship. Assumptions of regression models were tested and if necessary were performed using log_{10}-transformed or ranked data. All statistical analyses were conducted using SYSTAT 10 (SPSS 2000).

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

Screening of Potential Effects Tissue chemistry data for the Athabasca River were compared to several criteria to assess potential effects on humans and fish.

Sentinel Species Monitoring

Ells River Monitoring

Data Analysis As indicated above, the intent of the non-lethal sentinel species initiative was to generate interpretable data on population/age distribution, energy use and energy storage for fish sampled at the upper and lower sites sites in order to achieve the monitoring objectives established for the lethal sampling approach. The intent is to assess and compare these three parameters for populations with similar age class structure at the upper and lower sites.

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

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

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

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

Growth Longnose dace lengths and weights were $\log_{10}$-transformed and compared between sites using ANOVA (α = 0.05).

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

3.5.7.4 Fish Tag Return Assessment

A preliminary assessment and spatial presentation of tagging data was prepared based on tag returns received in 2004 (RAMP 2005a). A similar approach was used in 2005 for tag numbers returned in 2005.

3.6 ACID-SENSITIVE LAKES

3.6.1 Overview of 2005 Program

As in previous years, the 2005 Acid-Sensitive Lakes (ASL) component consisted of monitoring 50 lakes and ponds in the oil sands region for water quality variables during late August and early September (Table 3.6-1). Interpretation of the water quality data included:

- Comparisons of the chemical characteristics of the RAMP lakes to the general characteristics of lakes within the oil sands region;
- Calculations of critical loads of acidity for each lake and comparison with modeled PAI and critical loads from other regions;
- Determination of both natural and analytical variability in water quality variables;
- Analysis of emerging trends in water quality variables that might indicate incipient acidification; and
- Analysis of trace metal concentrations in the RAMP lakes, especially those that might indicate incipient acidification.

The previous year's calculations of organic buffering and effects of strong organic acids on acid-base dynamics in these highly coloured lakes were not repeated. The equations derived in 2003 and 2004 were applied to this year's data to calculate these effects.

3.6.2 Methods

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

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

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

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

Table 3.6-1 Name, location and date of sampling of lakes in 2005 for the Acid-Sensitive Lakes component.

Lake Identification			UTM Coordinates		Sampling Date
Unique ID[1]	Name	Tertiary Watershed	E	N	m/d 00:00
Stony Mountains Sub-Region					
168	A21	7CE	483819	6235130	08/25 18:30
169	A24	7CE	484387	6230872	08/25 18:16
170	A26	7CE	489502	6230877	08/25 17:32
167	A29	7CE	466180	6224950	08/25 13:48
166	A86	7CE	448014	6170896	08/25 12:05
287	25		487594	6229281	08/25 16:45
289	27		477248	6228400	08/25 11:31
290	28		487068	6225576	08/25 13:48
342	82		448271	6183205	08/25 11:25
354	94		515689	6179207	08/25 10:20
Birch Mountains Sub-Region					
436	L18/Namur		402704	6368016	08/26 09:55
442	L23/Otasan		417321	6396959	08/26 13:45
444	L25/Legend		383849	6364923	08/26 11:13
447	L28		382996	6414339	08/26 16:45
448	L29/Clayton	7KE/7KF	424694	6435790	08/26 17:30
454	L46/Bayard		416941	6404239	08/26 15:00
455	L47		396500	6395456	08/26 12:10
457	L49		404995	6403111	08/26 12:45
464	L60		403796	6392247	08/26 15:50
175	P13	7DA	416003	6353212	09/01 14:05
199	P49	7DA	446002	6394961	09/01 13:40
Northeast of Fort McMurray Sub-Region					
452	L4 (A-170)		508990	6334305	08/31 14:15
470	L7		461006	6368512	08/31 15:15
471	L8		460931	6369481	08/30 16:58
400	L39/E9/A-150		536495	6424234	08/30 14:34
268	E15		506092	6305335	08/31 16:00
182	P23	7DA	509000	6346712	09/01 10:45
185	P27	7DA	508300	6333712	09/01 10:00
209	P7	7DC	515399	6343212	09/01 11:45
270	4		506113	6291421	08/31 17:18
271	6		549064	6277789	08/27 15:38
418	Kearl		485939	6349881	08/31 14:40
West of Fort McMurray Sub-Region					
165	A42	7CC	365015	6247322	08/27 12:40
171	A47	7CC	367321	6235430	08/27 13:30
172	A59	7PA	383467	6197733	08/27 11:45
223	P94	7BD	440557	6334112	09/01 14:45
225	P96	7BD	444002	6295513	09/01 15:20
226	P97	7DA	456002	6296463	09/01 16:00
227	P98	7CC	451762	6293513	09/01 16:15
267	1		441917	6290884	08/27 10:00
Caribou Mountains Sub-Region					
146	E52/ Fleming	7JF	243692	6522556	08/28 11:05
91	O-1/E55	7PC	298955	6571856	08/28 14:40
97	O-2/E67	7PA	253582	6582654	08/28 13:40
152	E59/Rocky Island	7JF	263546	6562225	08/28 12:20
89	E68 Whitesand	7PA	245596	6570610	08/28 13:00
Canadian Shield Sub-Region					
473	A301		525150	6559733	08/29 14:45
118	L107/Weekes	7MD	555469	6620456	08/29 09:45
84	L109/Fletcher	7NA	510321	6553552	08/29 15:50
88	O-10	7NA	518279	6556260	08/29 16:35
90	R1	7NA	517889	6562197	08/29 13:46

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

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

The water quality samples were analyzed for the following variables listed in Table 3.6-2.

As part of the QA/QC program, one blind field blank was collected using deionized water from the Limnology Laboratory, University of Alberta. Split samples were additionally assessed by the University of Alberta laboratory. Quality control samples were analyzed for all variables listed above (Appendix B).

3.6.3 Changes in Monitoring Program Network from 2004

There were no changes in the field program in 2005 from 2004.

3.6.4 Challenges and Solutions Applied

There were no exceptional challenges encountered in implementing the field program in 2005.

3.6.5 Other Information Obtained

AENV provided analysis of a suite of 29 metals and trace elements on the RAMP lakes. These samples were collected at the same time as the RAMP samples during the 2005 field season and sent to ARC Vegreville for analysis. The inclusion and analysis of these data in the RAMP program follow recommendations of the Peer Review Committee (Ayles *et al*. 2004).

3.6.6 Summary of Component Data Now Available

The ASL component within RAMP has evolved over the seven years since its initiation. In general, the number of lakes monitored has increased to the current total of 50. For a variety of reasons, largely logistical, a number of lakes that were monitored in the initial stages of the component have been dropped. The selection of lakes sampled during the seven years of the component is summarized in Table 3.6-3.

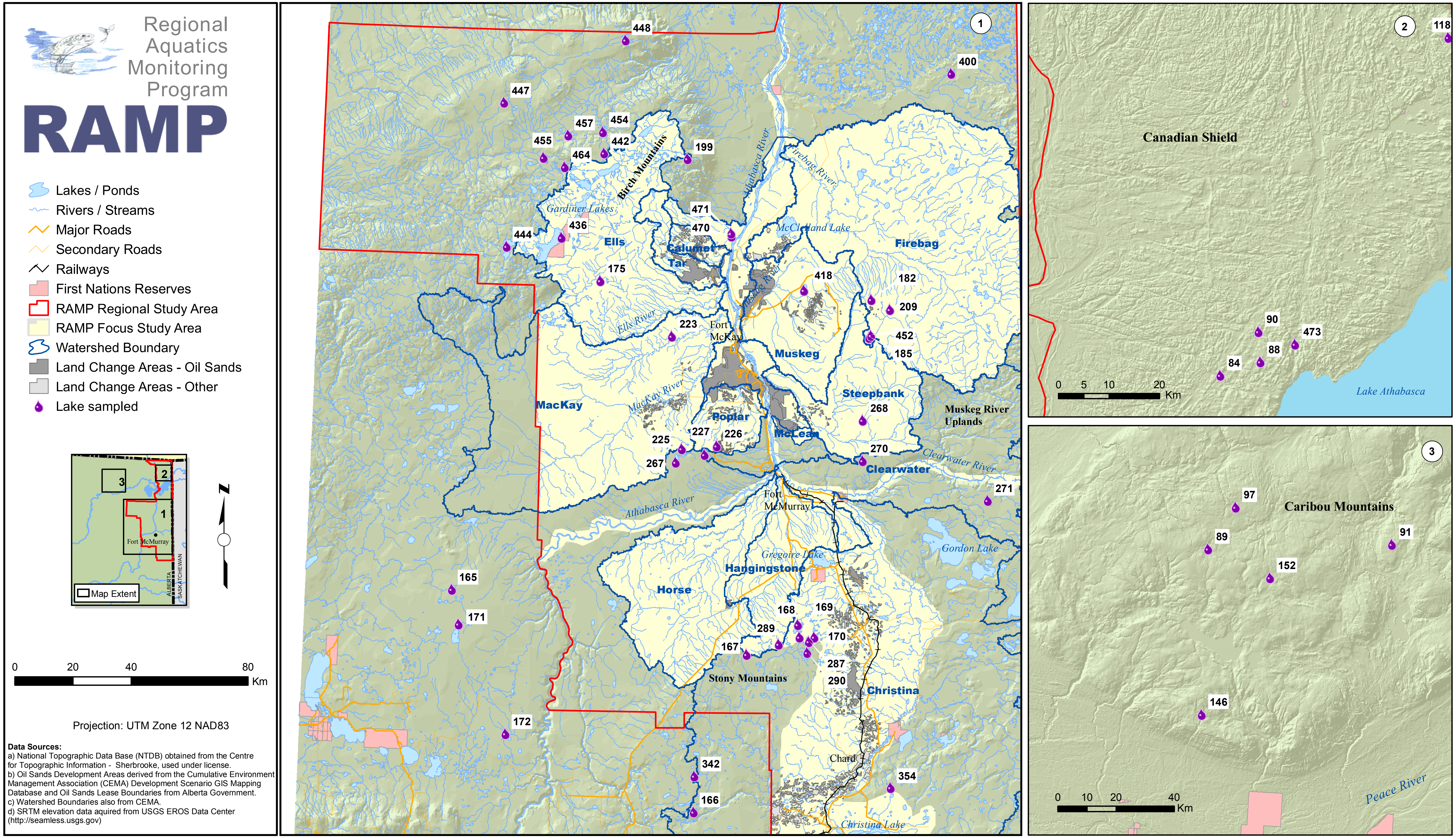
3.6.7 Analytical Approach

3.6.7.1 Measurement Endpoints

In accordance with the overall analytical approach used for the preparation of this report (Section 1.6) and the RAMP Technical Design and Rationale Study (RAMP 2005b), analyses of the 2005 ASL monitoring data involved the determination of measurement endpoints and application of specific criteria for determining potential effects on regional lakes from oil sands developments. The measurement endpoints for the ASL component included:

- Critical load of acidity;
- pH;

Figure 3.6-1 Location of RAMP acid-sensitive lakes surveyed in 2005.



G:\DATA\PROJECTS\RAMP1166\GIS\RAMP1166_1_ASL_2006APR20.mxd

Table 3.6-2 Water quality variables analyzed for the RAMP lakes.

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

- Gran alkalinity;
- Base cation concentrations;
- Nitrate plus nitrite;
- Sulphate;
- Dissolved organic carbon; and
- Dissolved aluminum.

The critical load of acidity is considered the principal measurement endpoint for the ASL component. The other measurement endpoints listed above are known to be affected during acidification. Sulphate was included in the list of 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 deposition (AEP 1990; Lau 1982; Legge 1988). In fact, sulphate correlates better with calcium than with H^+. The poor correlation between sulphate and H^+ in the RAMP lakes was demonstrated in RAMP (2004).

3.6.7.2 Criteria for Determining Effects

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

A significant impact on a lake from acid deposition is concluded if a significant change is noted in one or more measurement endpoints beyond natural variability. These endpoints include a reduction of lake pH, Gran alkalinity, critical load or base cation concentrations or an increase in nitrates or aluminum concentrations. A significant change is defined as a statistically significant change at $P<0.05$ that is directly attributable to increased deposition of acidifying substances. Natural variability is measured as the variance of the measurement endpoint.

3.6.7.3 Details of Data Analysis

In 2005, the emphasis in the data analysis was placed on the detection and evaluation of potential trends in key chemical variables in the RAMP lakes that would indicate incipient changes in buffering and acid sensitivity.

Table 3.6-3 Summary of lakes sampled during RAMP, 1999 to 2005.

NO_x-SO_x GIS No.	Original RAMP Designation	Available ASL Data						
		1999	2000	2001	2002	2003	2004	2005
168	A21	+	+	+	+	+	+	+
169	A24	+	+	+	+	+	+	+
170	A26	+	+	+	+	+	+	+
167	A29	+	+	+	+	+	+	+
166	A86	+	+		+	+	+	+
287	25 (287)				+	+	+	+
289	27 (289)				+	+	+	+
290	28 (290)				+	+	+	+
342	82 (342)				+	+	+	+
354	94 (354)				+	+	+	+
165	A42	+	+	+	+	+	+	+
171	A47	+	+	+	+	+	+	+
172	A59	+	+	+	+	+	+	+
223	P94 (223)				+	+	+	+
225	P96 (225)				+	+	+	+
226	P97 (226)				+	+	+	+
227	P98 (227)				+	+	+	+
267	1 (267)				+	+	+	+
452	L4	+	+	+	+	+	+	+
470	L7	+	+	+	+	+	+	+
471	L8	+	+	+	+	+	+	+
400	L39	+	+	+	+	+	+	+
268	E15 (268)		+	+	+	+	+	+
182	P23 (182)				+	+	+	+
185	P27 (185)				+	+	+	+
209	P7 (209)				+	+	+	+
270	4 (270)				+	+	+	+
271	6 (271)				+	+	+	+
418	Kearl L.					+	+	+
436	L18 Namur	+	+	+	+	+	+	+
442	L23 Otasan	+	+	+	+	+	+	+
444	L25 Legend	+	+	+	+	+	+	+
447	L28	+	+	+	+	+	+	+
448	L29 Clayton	+		+	+	+	+	+
454	L46 Bayard	+	+	+	+	+	+	+
455	L47	+	+	+	+	+	+	+
457	L49	+	+	+	+	+	+	+
464	L60	+	+	+	+	+	+	+
175	P13 (175)				+	+	+	+
199	P49 (199)				+	+	+	+
473	A301			+	+	+	+	+
118	L107 Weekes		+	+	+	+	+	+
84	L109 Fletcher	+	+	+	+	+	+	+
88	O-10	+	+	+	+	+	+	+
90	R1	+	+	+	+	+	+	+
146	E52 Fleming	+	+	+	+	+	+	+
152	E59 Rocky Is.	+	+	+	+	+	+	+
89	E68 Whitesand		+	+	+	+	+	+
91	O-1	+	+	+	+	+	+	+
97	O-2	+	+	+	+	+	+	+
428	L1	+						
83	O3/E64	+						
85	R2	+						
86	R3	+						
310	A300			+				

Note: Lakes sampled during the 2005 field component have been shaded.

Data analyses included the following:

- 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 2005 to the range of chemical characteristics of lakes within the 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 were identified in individual lakes;

- Calculation of the critical loads of acidity (CL) for each lake for comparison with the modeled potential acid input (PAI); and

- Trend analysis on measurement endpoints. Potential trends were evaluated in the context of the estimates of natural variability and analytical error.

Update of the ASL Database, Summary Statistics and Comparisons of RAMP Lake Chemistry to Regional Lake Chemistry

The chemical data from all years of the ASL program were tabulated and summarized statistically. Box plots were drawn of selected parameters in the 2005 data to show the range of each variable and existence of outliers. An analysis of variance was conducted on most parameters to determine whether there have been any detectable changes in the chemistry of the RAMP lake population over the four years of data available on the 50 lakes. Lakes having unusual chemistry were identified as those falling below or above the 5^{th} and 95^{th} percentile for pH, Gran alkalinity and DOC. A piper diagram was prepared for the 2005 data to characterize the RAMP lakes by their major ion chemistry. As in 2004, the chemical characteristics of the lakes were compared to those of 450 regional lakes reported in the NSMWG lake sensitivity mapping study (WRS 2004). Comparisons involved:

- Examination of the ranges, medians and mean values of key chemical parameters for 2005 in the RAMP lakes relative to the regional data set;

- Graphical presentation of both data sets in box plots; and

- Statistical comparison of chemical parameters between the two populations.

Analysis of Metal Concentrations in the RAMP Lakes

Examination of metals in the RAMP lakes was included in the 2005 ASL component for the first time in RAMP. The total and dissolved metal fractions from four years of monitoring by AENV (2001, 2003, 2004 and 2005) were tabulated and summarized statistically to establish baseline concentrations for each metal. Lakes having extreme metal concentrations were identified as those exceeding the 95^{th} percentile concentration for individual metals. Exceedances of the Alberta and CCME surface water quality guidelines were identified.

Calculation of Critical Loads of Acidity to the RAMP Lakes

The critical load (CL), in units of keq H+/ha/y, is defined as the highest load of acid deposition that will not cause long-term changes in lake chemistry and biology. The critical load of a lake represents a measure of its sensitivity to acidification. The lower the critical load, the greater the lake's acid sensitivity. CL for 2005 for the RAMP lakes was calculated using the modified Henriksen steady state water chemistry model described in applied in RAMP (2005a) (Henriksen and Posch 2001; Henriksen *et al*. 1992; Forsius *et al*. 1992; Rhim 1994).

The critical loads were compared with levels of PAI for each lake basin. Calculated lake-specific CL values were compared to modeled rates of acid deposition (planned development case) for each lake published in the Kearl Lake EIA (Imperial Oil 2005), representing the most recent and up-to-date estimation of the deposition of acidifying emissions. As listed values of PAI for this EIA were unavailable for lakes in the Caribou Mountains and the Shield region in the Kearl Lake EIA, they were estimated from the air modeling study reported for the Long Lake EIA (OPTI/Nexen 2002). In both regions the values of the PAI corresponded to background values (no industrial input) determined from RELAD modeling conducted by Alberta Environment in 2002.

Analysis of Trends in the ASL Measurement Endpoints

Potential trends in the measurement endpoints (critical load of acidity, pH, Gran alkalinity, base cation concentrations, nitrates, DOC and aluminum concentrations were examined over the seven-year ASL monitoring period. The analysis involved graphic presentation of the data as a function of time and trend analysis using the Mann-Kendall non-parameteric test (Gilbert 1987). Estimates of analytical error and natural variability in the measurement endpoints were used to evaluate the validity of all trends observed in measurement endpoints. Analytical error was determined from the laboratory as the standard deviation of each variable at the observed concentration. Natural variability in each variable was determined from the between-year variability observed in the seven years of the RAMP program itself and the within-year variability obtained from the seasonal water quality study conducted by AENV on ten of the RAMP lakes. These sources of error/variability were combined to obtain estimates of error and confidence limits for each measurement endpoint. These error estimates were used to evaluate the results of the trend analyses to determine potential changes in measurement endpoints as described above.