6.0 REGIONAL-LEVEL ASSESSMENT OF 2005 RESULTS

This part of the RAMP 2005 Technical Report presents regional assessments of the status of aquatic environmental resources considered by RAMP and the possible influence of oil sands developments at the level of the RAMP FSA. This regional assessments consists of three parts:

- For each RAMP component except for the Benthic Invertebrate Community component (not sampled in the Athabasca River in 2005) and Acid-Sensitive Lakes (ASL) component, a summary assessment of the 2005 results for the Athabasca River, representing the ultimate receiving environment for potential aquatic effects of Athabasca oil sands developments;

- Again, for each RAMP component except for the ASL component, a RAMP RSA-level assessment of the 2005 results, presented using FSA-level summary indices calculated from watershed-level measurement endpoints for each RAMP component; and

- A presentation of the 2005 results for the ASL component.

6.1 CLIMATE AND HYDROLOGY

6.1.1 Summary of Hydrologic Conditions in the Athabasca River

The assessed hydrologic effects of oil sands development activities in the RAMP FSA up to and including 2005 are summarized below (Table 6.1-1). All hydrologic measurement endpoints are calculated to be lower in the operational hydrograph than in the baseline hydrograph, indicating these measurement endpoints are less than what they would have been in the absence of oil sands development activities. This is largely because of water withdrawals and assumed decreased natural runoff from oil sands development areas. The percent change varies from -0.2% to -1.1% depending on the specific measurement endpoint and are similar to 2004 estimates (RAMP 2005a). The impact on low flows is greater in percentage terms than on high flows, because the more or less constant withdrawals are proportionately larger during low-flow than during high-flow periods. The reported changes in hydrologic measurement endpoints for 2005 would have been assessed as Negligible or Low in many oil sands EIAs (RAMP 2005b). Therefore, based on the available hydrologic and oils sands development information, it appears that changes in hydrologic measurement endpoints in the Athabasca River up to and including 2005 have been negligible to low.

Table 6.1-1 Summary of hydrologic conditions of the Athabasca River in 2005 with respect to oil sands developments.

Measurement Endpoint[1]	Percent Change	Assessment
Mean open-water (1 May to 31 October) season discharge	-0.4%	Negligible
Mean winter (1 November to 31 March) discharge	-1.1%	Low
Annual maximum daily discharge	-0.2%	Negligible
Open-water season minimum daily discharge	-0.7%	Low

[1] All as measured at RAMP Station S24, Athabasca River below Eymundson Creek.

6.1.2 Regional Assessment of Hydrologic Conditions at the RAMP FSA Level

Changes in hydrologic conditions for each watershed in 2005 designated as *potentially influenced-oil sands* that may be related to oil sands development activities were assessed using four hydrologic measurement endpoints:

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

The magnitude of change in each watershed for each of these measurement endpoints was classified using the following impact criteria: Negligible (<± 5%); Low (± 5 to 10%); Moderate (± 10 to 30%); or High (> 30%). The hydrologic change in each watershed designated either as *reference* or *potentially influenced-other* was assessed as None. These qualitative assessments were aggregated to the regional level by calculating the total area of watersheds in the RAMP FSA in each of the assessment classes for each of the four hydrologic measurement endpoints.

In 2005, the surface water hydrology of the RAMP FSA was relatively unchanged from what it would have been in the absence of oil sands developments (Figure 6.2-1); approximately 85% of the area of the RAMP FSA experienced no hydrologic effect in 2005, and approximately 14% was assessed to have experienced a negligible effect. A small part of the RAMP FSA (Tar River watershed) is assessed to have experienced a Low hydrologic effect of oil sands development activities for some hydrologic measurement endpoints. Differences between 2004 (RAMP 2005a) and 2005 (Figure 6.2-1) are due to an overall decrease in calculated, rather than actual, hydrologic effect. The use of remote sensing technologies in 2005 to estimate land changes from oil sands development activities (Section 2.4.1) enabled a more accurate estimation of different types of land changes, in contrast to assumptions made in 2004 that entire leases were changed by oil sands development activities.

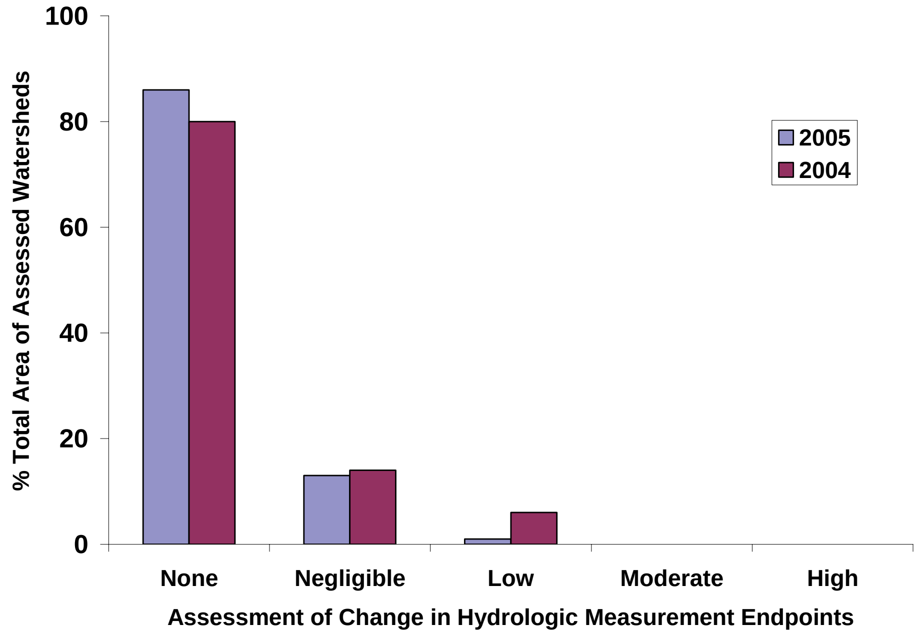
The assessment, therefore, is that there has been little change in hydrologic measurement endpoints throughout the RAMP FSA in relation to Athabasca oil sands developments.

6.2 WATER QUALITY

6.2.1 Summary of Water Quality Conditions in the Athabasca River

While water quality in the Athabasca River in fall 2004 was influenced strongly by higher than average flows and associated increased sediment loads (RAMP 2005a), flows in fall 2005 were more similar to historical average conditions, and water quality in the Athabasca River in fall 2005 reflected the more normal flow regime. Total suspended solids were lower in fall 2005 than in fall 2004 at all stations sampled. Concentrations of water quality analytes typically associated with TSS, including total aluminum, total iron, and total phosphorus, were also generally lower in 2005. Fall 2005 results for most selected water quality measurement endpoints were within the range of regional baseline concentrations. Ion balance characteristics varied within a narrow range for all stations regardless of sampling year or longitudinal location along the river.

Figure 6.2-1 Regional assessment of changes in all hydrologic measurement endpoints in the RAMP FSA with respect to oil sands developments, 2005, compared to 2004.



In summary, no discernible or detectable effects of oil sands development activities on water quality in the Athabasca River were apparent in 2005, based on available water quality and oil sands development information.

6.2.2 Regional Assessment of Water Quality Conditions at the RAMP FSA Level

The regional assessment of the status of water quality conditions in the RAMP FSA was conducted using the watershed-level results of water quality conditions compared against the appropriate regional baselines. Two indicators were used: frequency of guideline exceedance; and frequency of concentrations below the 5th or above the 95th percentile of regional baseline ranges. A count was made of the number of times a set of eleven water quality measurement endpoints in 2005 exceeded water quality guidelines. These eleven water quality measurement endpoints are those endpoints selected for this report (Section 3.2.7.1), which are included in the water quality summary tables provided in each of the watershed reports in Section 5 and which have a water quality guideline (Table 6.2-1). In addition, a count was made of the number of times a set of eight water quality measurement endpoints in 2005 were either below the 5th or above the 95th percentile of the appropriate regional baseline range. These eight water quality measurement endpoints are those endpoints selected for this report (Section 3.2.7.1), which are included in regional baseline graphs provided in each of the watershed reports in Section 5 (Table 6.2-1).

Table 6.2-1 Measurement endpoints used in regional assessment of water quality conditions.

Measurement Endpoints used for Determining Regional Frequency of Guideline Exceedance	Measurement Endpoints used for Determining Regional Frequency of Concentrations below 5th or above 95th Percentile of Reference Baseline Ranges
pH	Total suspended solids
Total phosphorus	Total dissolved solids
Total dissolved phosphorus	Dissolved phosphorus
Total nitrogen	Total nitrogen
Chloride	Total aluminum
Sulphate	Total boron
Total aluminum	Naphthenic acids
Dissolved aluminum	Total mercury (ultra-trace)
Total boron	
Total molybdenum	
Total mercury (ultra-trace)	

Counts were made in both cases for all water quality stations sampled in 2005 in the Athabasca River tributary watersheds; separate counts were made for stations designated as *potentially influenced-oil sands* and for stations designated as *reference* or *potentially influenced-other*. The distribution (i.e., proportion) of counts in the stations designated as *potentially influenced-oil sands* was then compared to the distribution of counts in the stations designated as *reference* or *potentially influenced-other*. With respect to frequency of guideline exceedance in 2005, there was a slightly higher frequency of guideline exceedance at stations designated as *potentially influenced-oil sands* (16.5%) than at stations designated as *reference* or *potentially influenced-other* (14.1%) (Table 6.2-2). This difference is not statistically significant (X^2 $p = 1$).

With respect to frequency with which concentrations of water measurement endpoints are below the 5th or above the 95th percentile of regional baseline ranges in 2005, there was a slightly higher frequency of such concentrations at stations designated as *potentially influenced-oil sands* (26.1%) than at stations designated as *reference* or *potentially influenced-other* (24.4%) (Table 6.2-3). This difference is also not statistically significant (X^2 $p = 1$).

On the basis of these results, it is concluded that there was no difference in 2005 in water quality measurement endpoints between areas of the RAMP FSA designated as *potentially influenced-oil sands* and areas designated as *reference* or *potentially influenced-other*.

Table 6.2-2 Distribution of water quality measurement endpoints in the RAMP FSA according to frequency of guideline exceedance.

Variable	Designation of Water Quality Station	
	Potentially Influenced-Oil Sands	Reference or Potentially Influenced-Other
No. of Stations	11	20
Total No. of Endpoint-Station Combinations	121	220
No. and % of Endpoint-Station Combinations Exceeding Guidelines	20 (16.5%)	31 (14.1%)
No. and % of Endpoint-Station Combinations Not Exceeding Guidelines	101 (83.5%)	189 (85.9%)

Table 6.2-3 Distribution of water quality measurement endpoints in the RAMP FSA according to frequency of concentrations less than 5th or greater than 95th percentile of regional baseline ranges.

Variable	Designation of Water Quality Station	
	Potentially Influenced-Oil Sands	Reference or Potentially Influenced-Other
No. of Stations	11	20
Total No. of Endpoint-Station Combinations	88	160
No. and % of Endpoint-Station Combinations with Concentrations <5th or >95th Percentile	23 (26.1%)	39 (24.4%)
No. and % of Endpoint-Station Combinations with Concentrations >=5th and <=95th Percentile	65 (73.9%)	121 (75.6%)

6.3 SEDIMENT QUALITY

6.3.1 Summary of Sediment Quality Conditions in the Athabasca River

Measured sediment quality in the Athabasca River has been highly variable under RAMP since 1997, both among stations in a given year and at specific stations across years. Sediment sampling in the Athabasca River has been confounded by variable river levels, which can result in sediment sampling in different locations from year to year, as the locations of the wetted banks of the river change within the river channel under different flow conditions. In addition, the Athabasca River is not a truly depositional environment, making temporal studies of accumulated sediment quality inappropriate.

Although highly variable, sediment quality in the Athabasca River in 2005 was generally within the range of previous years' observations. Overall, concentrations of all sediment quality measurement endpoints at the single Athabasca River station sampled in 2005 were below applicable CCME/ISQG guidelines in fall 2005. In addition, concentrations of selected sediment quality measurement endpoints measured in fall 2005 were between the 5th and 95th percentile of reference baseline ranges, with the exception of carbon-normalized total hydrocarbon concentrations, which were greater than the 95th percentile.

6.3.2 Regional Assessment of Sediment Quality Conditions at the RAMP FSA Level

The regional assessment of sediment quality conditions in the RAMP FSA was conducted using the same approach as the regional assessment of water quality (Section 6.2.2). Two indicators were again used: frequency of guideline exceedance; and frequency of concentrations below the 5th or above the 95th percentile of regional baseline ranges. A count was made of the number of times a set of five sediment quality measurement endpoints in 2005 exceeded sediment quality guidelines. These five sediment quality measurement endpoints are those endpoints selected for this report (Section 3.3.7.1), which are included in the sediment quality summary tables provided in each of the watershed reports in Section 5 and which have a sediment quality guideline (Table 6.3-1). In addition, a count was made of the number of times a set of three sediment quality measurement endpoints in 2005 were either below the 5th or above the 95th percentile of the appropriate regional baseline range. These three sediment quality measurement endpoints are those endpoints selected for this report (Section 3.3.7.1), which are included in sediment quality summary regional baseline comparison graphs provided in each of the watershed reports in Section 5 (Table 6.3-1).

Table 6.3-1 Measurement endpoints used in regional assessment of sediment quality conditions.

Measurement Endpoints used for Determining Regional Frequency of Guideline Exceedance	Measurement Endpoints used for Determining Regional Frequency of Concentrations below 5th or above 95th Percentile of Reference Baseline Ranges
CCME Fraction 1 (C6-C10)	Total Organic Carbon (TOC)
CCME Fraction 2 (C10-C16)	Total PAHs (normalized to TOC)
CCME Fraction 3 (C16-C34)	Naphthalene
CCME Fraction 4 (C34-C50)	
Naphthalene	

Counts were made in both cases for all sediment quality stations sampled in 2005 in the Athabasca River tributary watersheds; separate counts were made for stations designated as *potentially influenced-oil sands* and for stations designated as *reference* or *potentially influenced-other*. The distribution (i.e., proportion) of counts in stations designated as *potentially influenced-oil sands* was then compared to the distribution of counts in the stations designated as *reference* or *potentially influenced-other*.

With respect to frequency of guideline exceedance in 2005, there was a slightly higher frequency of guideline exceedance at stations designated as *potentially influenced-oil sands* (25.7%) than at stations designated as *reference* or *potentially influenced-other* (22.5%) (Table 6.3-2). This difference is not statistically significant (X^2 $p = 1$).

With respect to frequency with which concentrations of sediment measurement endpoints are below the 5th or above the 95th percentile of regional baseline ranges in 2005, there was a lower frequency of such concentrations at stations designated as *potentially influenced-oil sands* (23.8%) than at stations designated as *reference* or *potentially influenced-other* (37.5%) (Table 6.3-3). This difference is also not statistically significant (X^2 $p = 1$).

On the basis of these results, it is concluded that there was no difference in 2005 in sediment quality measurement endpoints between areas of the RAMP FSA designated as *potentially influenced-oil sands* and areas designated as *reference* or *potentially influenced-other*.

Table 6.3-2 Distribution of sediment quality measurement endpoints in the RAMP FSA according to frequency of guideline exceedance.

Variable	Designation of Sediment Quality Station	
	Potentially Influenced-Oil Sands	Reference or Potentially Influenced-Other
No. of Stations	7	8
Total No. of Endpoint-Station Combinations	35	40
No. and % of Endpoint-Station Combinations Exceeding Guidelines	9 (25.7%)	9 (22.5%)
No. and % of Endpoint-Station Combinations Not Exceeding Guidelines	26 (74.3%)	31 (77.5%)

Table 6.3-3 Distribution of sediment quality measurement endpoints in the RAMP FSA according to frequency of concentrations less than 5th or greater than 95th percentile of regional baseline ranges.

Variable	Designation of Sediment Quality Station	
	Potentially Influenced-Oil Sands	Reference or Potentially Influenced-Other
No. of Stations	7	8
Total No. of Endpoint-Station Combinations	21	24
No. and % of Endpoint-Station Combinations with Concentrations <5th or >95th Percentile	5 (23.8%)	9 (37.5%)
No. and % of Endpoint-Station Combinations with Concentrations >=5th and <=95th Percentile	16 (76.2%)	15 (62.5%)

6.4 BENTHIC INVERTEBRATE COMMUNITIES

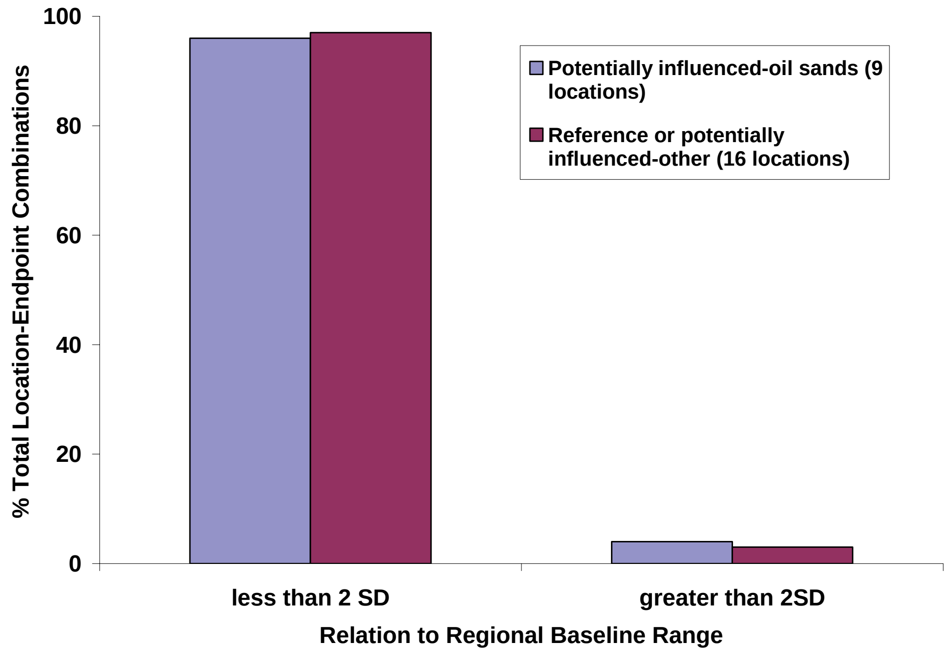
6.4.1 Regional Assessment of Benthic Invertebrate Community Conditions at the RAMP FSA Level

The regional assessment of the status of benthic invertebrate community conditions in the RAMP FSA was conducted in a similar fashion to the regional water and sediment quality assessments (above). Watershed-level results of benthic invertebrate community indices were compared against the regional baselines applied to each watershed, and the five benthic invertebrate community measurement endpoints (abundance, taxon richness, Simpson's Diversity Index, evenness; and %EPT) were summarized.

A count was made of the number of times these five benthic invertebrate community measurement endpoints in 2005 fell within two regional baseline ranges: within two standard deviations of regional baseline values; or greater than two standard deviations of regional baseline values. Counts were made for all benthic invertebrate community locations sampled in 2005 in the RAMP FSA; separate counts were made for locations designated as *potentially influenced-oil sands* and for locations designated as *reference* or *potentially influenced-other*.

In 2005, the percentage of benthic invertebrate community indices greater than two standard deviations from their regional baseline average in locations designated as *potentially influenced-oil sands* was low and basically the same as for reaches designated as *reference* or *potentially influenced-other* (Figure 6.4-1). The distributions are qualitatively almost identical, and they are statistically identical as well ($p = 1.0$, Kolmogorov-Smirnoff two-sample test with unequal sample sizes). It is concluded that in 2005, there was no difference in benthic invertebrate community measurement endpoints between areas of the RAMP FSA designated as *potentially influenced-oil sands* and areas designated as *reference* or *potentially influenced-other*.

Figure 6.4-1 Distribution of benthic invertebrate community measurement endpoints in the RAMP FSA in relation to regional baseline range for similar sites (depositional, erosional) in 2005.



6.5 FISH POPULATIONS

As in previous years, assessing the status of fish populations at a regional level in the RAMP FSA and possible relationships to oil sands development activities at a regional level is challenging due to the limited spatial coverage of the programs within the Fish Population component, limited number of years of information gathered and alterations to the sampling design between years for some elements. These factors make it difficult to establish the level of natural variability at the regional level associated with measurement endpoints defined for the Fish Population component.

6.5.1 Regional Assessment of Fish Inventory Results at the RAMP FSA Level

2005 fish inventory results from the Athabasca and Clearwater rivers indicate:

- While there is some species-specific variability in fish population measurement endpoints (i.e., relative abundance and condition factor), there are no significant trends in this regard, and there is little evidence to suggest that characteristics of key indicator fish populations have changed during increasing oil sands development;

- Overall, additional inventory data obtained using a standardized approach is required to permit appropriate trend analysis, and determination of the natural variability associated with designated measurement endpoints. Once the range of natural variability has been estimated, appropriate criteria can be developed for determining the presence of a significant change. Ongoing assessment and evaluation of the data gathering and analysis procedures used in the Athabasca River fish inventory should result in substantial enhancements to the component, particularly with respect to its monitoring function; and

- The fish inventory planned for the Clearwater River in 2006 will provide the third year of inventory data for this system. This will allow for a more in-depth assessment of the natural variability in fish populations in the Clearwater River.

With only a single year of actual inventory data and one season of reconnaissance effort on the Ells River, additional standardized inventory data are required for this watershed to establish the level of natural variability in measurement endpoints, which will eventually allow for the testing of associated impact criteria.

6.5.2 Regional Assessment of Fish Tissue Results at the RAMP FSA Level

Fish tissue results from the Athabasca River in 2005 indicate that:

- Concentrations of mercury in fish tissues are naturally high in this region, occurring at levels that pose a high risk to subsistence fishers, a variable risk for recreational fishers and general consumers; and

- Concentrations of metals (other than mercury) and tainting compounds in tissues of sampled fish generally pose a low risk to human health; concentrations of metals generally pose a low risk to fish.

However, mercury concentrations present in water and sediment in the Athabasca oil sands development area are generally at or below detection limits. Furthermore, fish tissue mercury concentrations observed in 2005 were similar to those observed historically. These findings indicate that mercury concentrations in fish tissue are naturally high in the Athabasca oil sands areas and these high levels are not related to oil sands developments.

6.5.3 Regional Assessment of Sentinel Species Results at the RAMP FSA Level

The sentinel species monitoring program was conducted for the first time in the Ells River watershed in 2005. Results indicate that:

- Longnose dace have some limitations for use as a sentinel species in the Ells River watershed, particularly as they are a comparatively slow growing small-bodied fish species, which has some implications for determining growth rates and changes in population distribution between sampling efforts;

- Despite these limitations, it was possible to track growth shifts in young-of-year fish between sampling periods and detect significant differences in population distribution between and with sampling sites; and

- Condition factor, the primary endpoint used in the sentinel species monitoring program, was greater for fish sampled at the lower site in the Ells River.

Because of the limited regional scope of the sentinel species monitoring program, and very preliminary nature of results from the Ells River, it is not possible at this time to extrapolate these results to the level of the RAMP FSA. The Ells River is currently designated as a RAMP reference watershed, and this early sentinel monitoring work will provide the foundation for future assessment work.

6.6 ACID-SENSITIVE LAKES

Analysis of the 2005 monitoring data for the Acid-Sensitive Lakes (ASL) component stressed the detection of changes in lake chemistry that might be attributable to regional acidic deposition. The analysis consisted of the following tasks:

- Review of the chemical characteristics of the RAMP lakes with the addition of the 2005 data. Summary statistics were calculated on the updated dataset that now includes four years of data on all 50 RAMP lakes. The chemical variables in the 2005 data were compared to values in previous years and unusual changes in lake chemistry were noted. Trace metal concentrations in the RAMP lakes were summarized and unusual or extreme metal concentrations in individual lakes were noted;

- Critical Loads of acidity were calculated and compared to recent estimates of modeled PAI and Critical Loads from other regions;

- Determination of both natural and analytical variability in water quality variables in the RAMP lakes were determined; and

- Trend analysis of measurement endpoints that might indicate acidification. Natural variability in concentrations water quality variables as well as analytical error in the estimation of those concentrations were incorporated into the trend analysis to distinguish real trends from these other sources of variability.

6.6.1 Summary Statistics

The chemical variables for the 50 RAMP lakes, augmented with data from the 2005 field season, are tabulated in Appendix H for each lake; summaries are provided in Table 6.6-1 and Figure 6.6-1. Table 6.6-1 presents summary statistics for all 2002 to 2005 combined as well as for 2005 individually. An ANOVA performed on the 2002 to 2005 data in order to determine whether there have been any discernable changes in the lake chemistry of the 50 RAMP lakes over this period found that only potassium concentrations in 2005 were significantly lower ($p < 0.005$) than in previous years (Table 6.6-1). As differences in other major cations and anions and conductivity were not significant, the decrease in potassium is regarded as anomalous. These analyses suggest that there has been no significant change in the overall chemistry of the 50 RAMP lakes in 2005 compared to previous years.

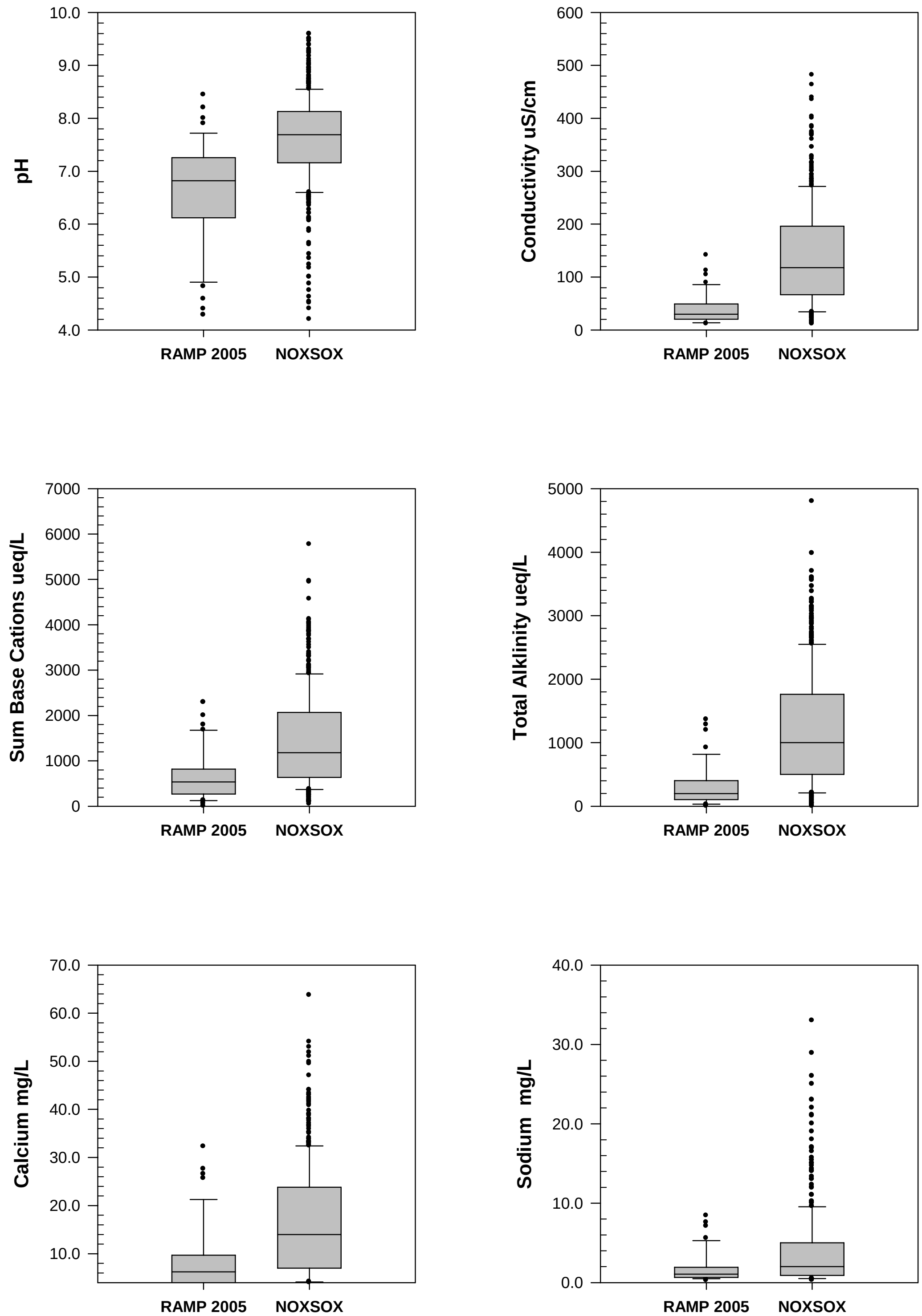
RAMP lakes with measured pH, Gran alkalinity, and DOC in 2005 either below or above the 5th and 95th percentile are presented in Table 6.6-2. Four lakes (lakes 168, 170, 287, and 447) with very low (negative) levels of Gran alkalinity (Appendix H describes how negative values of Gran alkalinity can occur with the analytical methodology used in the ASL component) are located in the Stony Mountains upland region (Figure 3.6-1). The highest values of Gran alkalinity were found in lakes 270, 271 and Kearl Lake, located in

Table 6.6-1 Summary statistics for lakes sampled for the RAMP ASL program, 2002-2005.

Parameter	Minimum		Maximum		Mean		Median		5^{th} Percentile 2005	95^{th} Percentile 2005
	2002-2005	2005	2002-2005	2005	2002-2005	2005	2002-2005	2005		
Lab pH	3.97	4.28	9.46	8.44	6.56	6.60	6.79	6.82	4.83	7.89
Total Alkalinity (mg/L)	0.00	0.00	1691	1363	301	315	210	198	23.9	915
Gran Alkalinity (mg/L	-57.20	-57.20	1687	1362	287.7	293.8	234	160	0.00	921
Specific Cond. (µS/cm)	11.20	11.20	172	141	42.8	39.3	32.2	29.5	13.73	109.8
Turbidity (NTU)	0.38	0.38	53	20	3.95	3.1	1.80	1.5	0.57	15.0
Total Suspended Solids(mg/L)	0.10	N/A	175	N/A	10.1	N/A	3.60	N/A	0.57	37.0
Colour (TCU)	8.00	8.50	486	408	148	142.	123	135	19.5	328
Sodium (mg/L)	0.25	0.25	10.3	8.41	1.84	1.79	1.21	1.05	0.44	5.84
Potassium (mg/L)	0.003	0.003	2.40	1.81	0.50	0.18	0.44	0.003	0.003	1.21
Calcium (mg/L)	0.20	0.20	32.2	32.2	5.79	8.28	4.76	6.22	1.17	15.7
Magnesium (mg/L)	0.14	0.16	13.6	13.6	1.81	2.30	1.42	1.53	0.35	5.40
Bicarbonate (mg/L)	0.00	0.00	103.1	83.1	18.2	19.2	12.9	12.04	1.68	52.1
Chloride (mg/L)	0.02	0.02	2.64	2.4	0.36	0.33	0.18	0.21	0.08	1.48
Sulphate (mg/L)	0.18	0.22	19.0	10.1	2.44	2.10	1.19	1.08	0.28	10.1
Total Dissolved N. (µg/L)	105.4	258	2891	2150	876	898	694	793	340	2076
Ammonia N (µg/L)	0.00	0.50	1509	146	49.1	20.9	16.7	13.4	1.18	192
Nitrate + Nitrite N (µg/L)	0.02	0.50	733	151	23.8	11.5	2.87	2.96	0.44	123
Total Phosphate (µg/L)	3.60	5.70	341	208.5	56.4	47.2	39.3	41.4	12.3	173.7
Dissolved Phosphate (µg/L)	1.20	1.20	156	66.1	20.4	16.3	11.7	10.6	4.03	61.5
Dissolved Inorganic C (mg/L)	0.14	0.17	20.3	14.5	3.1	3.1	2.34	1.62	0.28	10.0
Dissolved Organic C (mg/L)	6.8	7.7	81.2	51.0	22.9	23.1	21.6	21.7	9.74	44.6
Chlorophyll a (µg/L)	0.60	0.60	371	180	20.4	16.5	9.1	8.03	2.16	75.4
Silica (mg/L)	0.00	0.00	4.65	3.71	1.0	0.94	0.59	0.62	0.04	2.98
Total Nitrogen (µg/L)	0.00	319.93	6558	6558	1272	1190	970	831	373	3302
Total Kjeldahl Nitrogen (µg/L)	282	318	6552	6552	1275	1177	955	829	429	3296
Sum base cations (eq/L)	0.00	0.00	2291	2291	526	671	417	533	119	1485
Dissolved Aluminum (g/L)	0.25	0.57	681	338	387	87.6	24.7	27.8	1.08	335.8

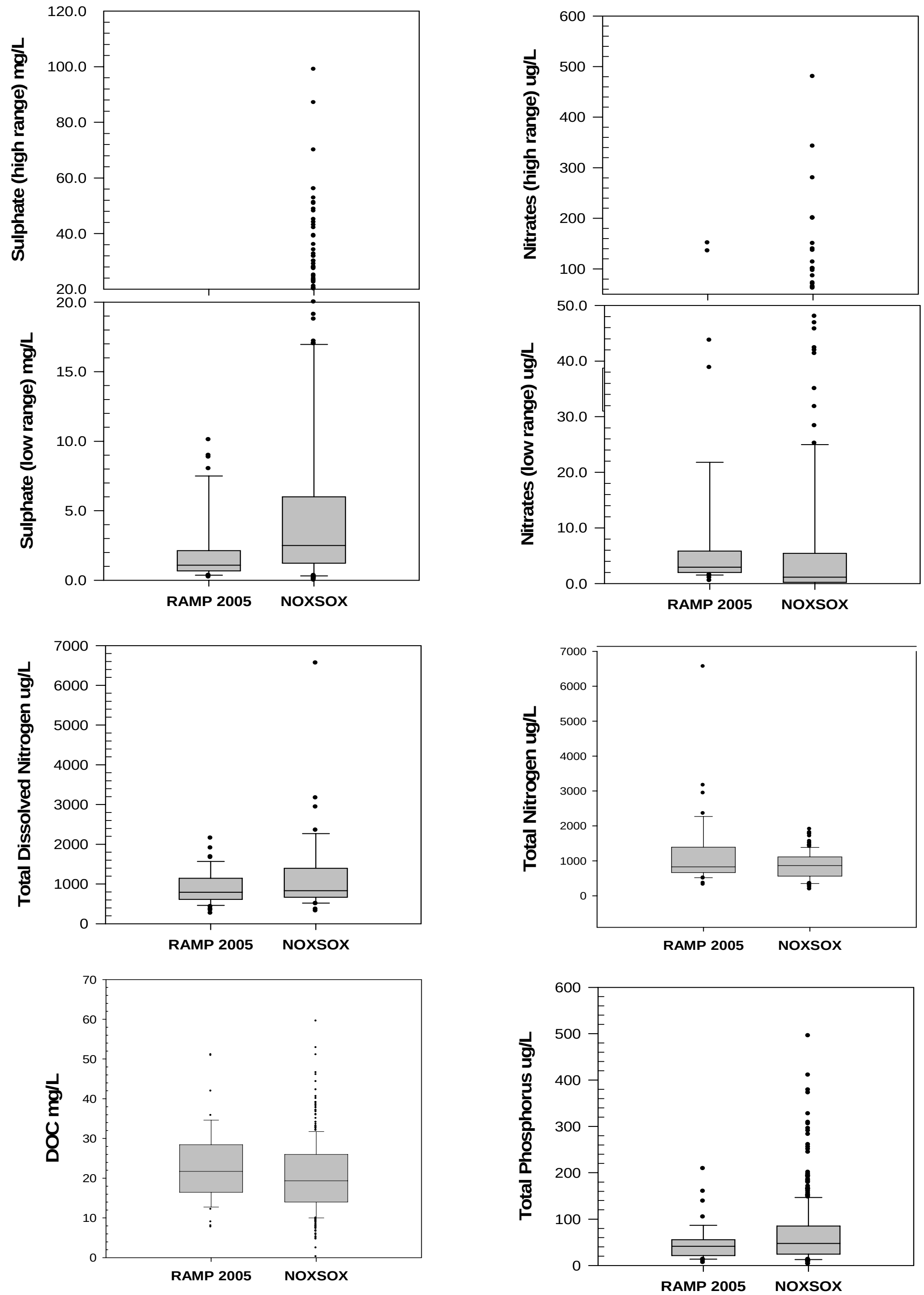
Note: Shaded value represents significant differences in the 2005 data determined from an analysis of variance. N/A: not available

Figure 6.6-1 Box plots of selected chemical variables for the RAMP acid-sensitive lakes in 2005 versus 450 regional lakes reported by the NSMWG.



Note: The boundaries of the shaded boxes indicate the 25th and 75th percentiles; the whiskers indicate the 10th and 90th Percentiles; the line within the box is the Median Value (50th percentile); and individual points represent observations either below the 10th or above the 90th percentile values.

Figure 6.6-1 (Cont'd.)



Note: The boundaries of the shaded boxes indicate the 25th and 75th percentiles; the whiskers indicate the 10^{th} and 90th Percentiles; the line within the box is the Median Value (50th percentile); and individual points represent observations either below the 10^{th} or above the 90^{th} percentile values.

Table 6.6-2 RAMP acid-sensitive lakes having chemical characteristics either below 5th or above 9th percentile of 2005 values, 2005 data.

Lake	Region	pH	Gran Alkalinity (µeq/L)	DOC (mg/L)
	5th percentile, 2005	4.83	0.0	9.7
	95th percentile, 2005	7.89	915	44.6
168 (A21)	Stony Mountains	**4.58**	**-54.8**	21.7
169 (A24)	Stony Mountains	**4.40**	0.0	22.0
170 A26	Stony Mountains	5.09	**-37.2**	16.7
287 (25)	Stony Mountains	4.82	**-57.2**	16.6
448 (L29) Clayton L.	Birch Mountains	**4.28**	0.0	17.0
447 (L28)	Birch Mountains	4.96	**-7.4**	28.4
436 (L18) Namur	Birch Mountains	7.43	389	**7.7**
270	northeast of Fort McMurray	*8.44*	*1296*	32.0
271	northeast of Fort McMurray	*8.20*	*1186*	21.6
418 Kearl	northeast of Fort McMurray	*8.00*	*1362*	16.2
268 (E15)	northeast of Fort McMurray	7.14	278	*50.8*
165 (A42)	West of Fort McMurray	7.14	328	*51.0*

Bold entries indicate levels or concentrations that are below the 5th percentile; *italicized* entries indicate levels or concentrations that are above the 95th percentile.

the Northeast of Fort McMurray subregion (Figure 3.6-1). These represent the lakes having the highest degree of buffering in the 50 RAMP lakes. Lake 168 and lake 169 in the Stony Mountains, and lake 448 in the Birch Mountains had the lowest pH values, while lakes 270, 271 and Kearl Lake had the highest pH levels.

The lowest levels of DOC were found in lake 436 (Namur Lake) in the Birch Mountains while the highest concentrations were found in lake 165 (West of Fort Mc Murray subregion) and lake 268 (northeast of Fort McMurray subregion). Lakes with the lowest Gran alkalinity (buffering capacity) are generally the same lakes having low pH, high DOC and low conductivity, and are often small, shallow lakes found in upland regions.

6.6.1.1 Comparison to Regional Lakes

In general, the 50 RAMP lakes in 2005 displayed similar characteristics to the set of lakes contained in the database on regional lakes created by the NO_xSO_x Management Working Group (NSMWG) (Table 6.6-3, Figure 6.6-1) although there were distinct differences:

- RAMP lakes covered a slightly narrower pH range (4.28 to 8.44) with a lower median value (6.82 vs. 7.69). The mean pH in the RAMP lakes is significantly less than that of the regional database ($p < 0.005$);

- Median total alkalinity was 198 µeq/L, again much lower than the regional median (1000 µeq/L). Mean total alkalinity in the RAMP lakes in 2005 was significantly less than that of the regional lakes ($p < 0.05$);

Table 6.6-3 Comparison between RAMP acid-sensitive lakes and 450 regional NSMWG lakes.

Variable	Units	RAMP Lakes (2005)				Regional Lakes				
		Min	Max	Median	Mean	No.	Min	Max	Median	Mean
Lake Area	Km^2	0.031	431	1.45	18.8	449	0.011	431	1.61	7.81
Net Catchment Area	Km^2	0.62	2137	14.6	92.5	450	0.083	2245	16.8	95.6
Drainage Ratio		0.223	88.6	10.1	15.7	449	1.22	1177	12.6	25.5
Runoff	m^3/s	0.001	8.57	0.041	0.298	450	0.0003	8.57	0.041	0.274
Lab pH		4.28	8.44	6.82	6.6	450	4.2	9.59	7.69	7.6
Total Alkalinity	µeq/L	0.00	68.13	9.88	15.75[a]	450	0.0	4797	1000	1201
Specific Conductivity	µS/cm	11.20	141.00	29.5	39.33[a]	417	11	481	118	140
Dissolved Organic Carbon	mg/L	0.17	14.54	1.62	3.05	398	0.2	59.5	19.4	20.4
Sodium	mg/L	0.25	8.41	1.05	1.79[a]	450	0.277	49.1	2	3.98
Potassium	mg/L	0.00	1.81	0.00	0.17[a]	450	0.05	13.6	0.6	0.925
Calcium	mg/L	0.20	32.24	6.22	8.28[a]	450	0.25	63.7	14	16.4
Magnesium	mg/L	0.16	13.64	1.53	2.30[a]	450	0.05	27.7	4.09	5.18
Sum of Base Cations	µeq/L	0.00	2290.85	533.46	671.02[a]	450	46	5770	1177	1442
Chloride	mg/L	0.02	2.42	0.21	0.33[a]	447	0.01	18	0.47	1.058
Sulphate	mg/L	0.22	10.09	1.08	2.10[a]	449	0.025	99	2.5	6.528
Nitrate + Nitrite	µg/L	0.50	151.0	2.96	11.50[a]	348	0.02	1860	2	21
Total Dissolved N	µg/L	258.02	2150.00	793.00	898.28	152	183	19.4	863	871
Total Phosphate	µg/L	5.70	208.50	41.40	47.15[a]	444	3	495	47.3	66.3

Shaded variables represent those with significantly different means between the two sets of lakes, as determined with a Student's t-test or non-parametric test when variances were non-homogenous ($p < 0.05$).

[a] Indicates a non-parametric test used.

- Conductivity was relatively low in the RAMP lakes and ranged from 11.2 μS/cm to 141 μS/cm (median: 29.5 μS/cm). The regional median for conductivity was 118 μS/cm. The mean conductivity of the RAMP lakes in 2005 was significantly less than that of the regional lakes;

- Consistent with the lower conductivity in the RAMP lakes, the mean and median concentrations of the principal cations (calcium, magnesium, sodium and potassium) and the sum of base cations (SBC) were all less than the values in the NSMWG database. SBC in the RAMP lakes in 2005 was 533 μeq/L compared with 1,177 μeq/L in the regional lakes. The mean values of these variables were all significantly less in the RAMP lakes ($p < 0.05$);

- The mean and median concentrations of major anions (chloride, sulphate and titration bicarbonate) were all less than those in the regional lakes dataset; and

- Colour, DOC, and nitrate concentrations were significantly greater in the RAMP lakes.

The chemical differences between the RAMP lakes and the population of regional lakes reflect the effects of the lake selection process for RAMP (RAMP 2005b).

6.6.1.2 Characterization of the RAMP Lakes by Ion Chemistry

Most of the RAMP lakes are of the Ca-Mg-bicarbonate type (Figure 6.6-2). Eight lakes have greater than 40% of the anion charge attributable to sulphate and chloride rather than bicarbonates and carbonates. Furthermore, two of these eight lakes, lying along the 100% sulphate/Cl axis (Lakes A24 and L29), represent lakes that have virtually no titration bicarbonate and whose anion chemistry is controlled entirely by sulphate and chloride.

These eight lakes identified are all found in the Birch Mountains and Stony Mountains upland sub-regions and represent lakes that are poorly buffered, low in pH, conductivity and relatively high in DOC (Table 6.6-4).

6.6.1.3 Analysis of Metals in the RAMP Lakes

Detailed results of trace metal analyses are presented in detail in Appendix H and summarized in Table 6.6-5. In general, the concentration of most trace metals has been low and often below detection limits. In particular, mercury and selenium concentrations have been almost always non-detectable. However, there are lakes and sub-regions with high concentrations of some metals. In particular, the Birch Mountains have the highest number of metal concentrations above 95th percentile (Figure 6.6-3). Within this sub-region, lakes 454, 455, and 457 had 13, 16, and 16, metals with concentrations above the 95th percentile for the RAMP lakes, respectively. Unusually high concentrations in these lakes were observed for aluminium, arsenic, cobalt chromium, copper, iron, lithium nickel, lead antimony, thorium, titanium, vanadium and zinc. These lakes are also identified as having unusual ion chemistry with more than 40% of the anionic charge attributable to sulphate rather than bicarbonates (Figure 6.6-2, Table 6.6-4). The lakes are soft-water lakes with relatively low pH of metals, low conductivity and low acid neutralizing capacity. The high concentrations in these lakes are most likely natural in origin rather that the result of anthropogenic emissions.

Figure 6.6-2 Piper plot showing the proportion of major cations and anions in lakes sampled for the RAMP ASL program, 2005.

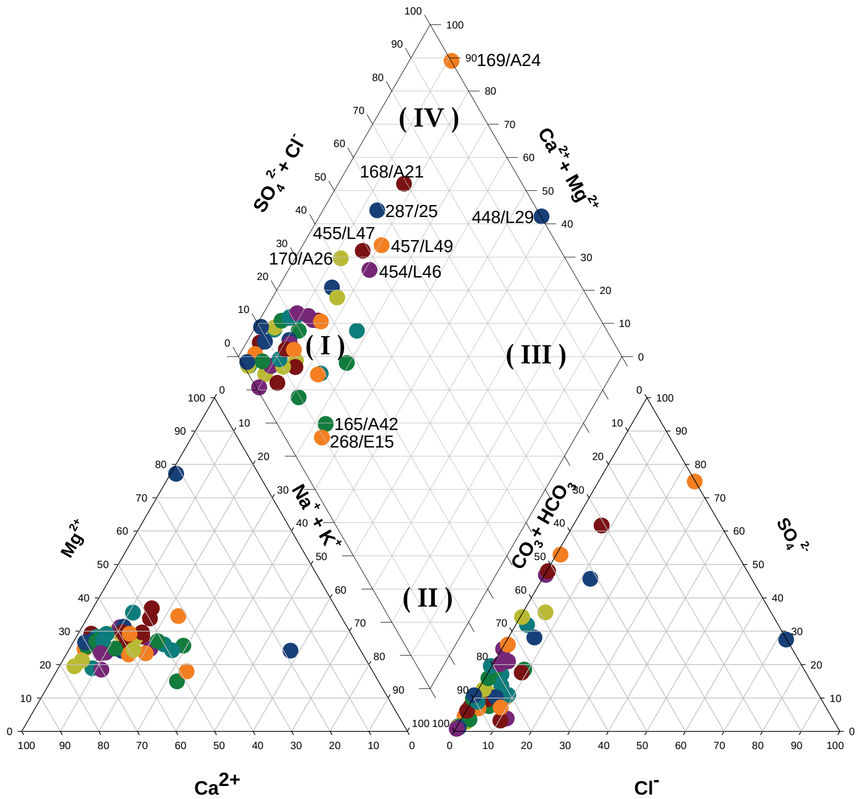


Table 6.6-4 Key chemical characteristics of lakes sampled for the RAMP ASL program having high proportions of sulphate and chloride anionic charge, 2005.

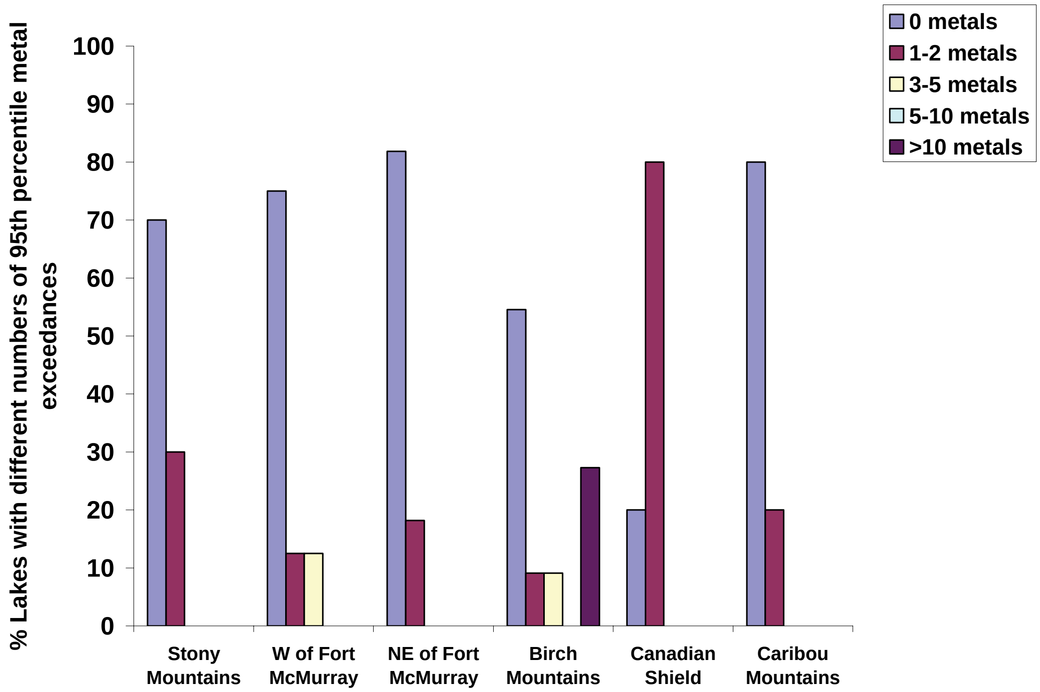
Lake	Original Name	pH	Gran Alkalinity (µeq/L)	Conductivity (µS/cm)	DOC (mg/L)	Lake Area (km^2)
Stoney Mountains Sub-Region						
168	A21	4.88	-5.53	15.41	20.85	1.38
169	A24	4.66	-1.9	14.91	21.79	1.45
170	A26	5.45	-7.07	13.56	15.10	2.78
287	25	5.07	-12.8	13.20	17.73	2.18
Birch Mountains Sub-Region						
448	L29 Clayton	4.24	-7.6	17.32	16.39	0.650
454	L46	6.61	8.56	45.70	28.89	1.2
455	L47	6.82	8.02	47.70	21.35	4.31
457	L49	6.56	6.74	45.00	26.41	2.61

Table 6.6-5 Statistical summary of trace metals in the RAMP acid-sensitive lakes over all lakes and years (2001, 2003, 2004, 2005).

Metal	Dissolved Fraction (µg/L)					Total Metals Fraction (µg/L)				
	Min.	Max.	Mean	Median	95th Percentile	Min.	Max.	Mean	Median	95th Percentile
Ag	L0.005	0.0120	0.0019	0.0010	0.0070	L0.005	0.0420	0.0054	0.0025	0.0209
Al	0.3	681.0	78.6	25.7	335.8	0.3	8694	288.5	70.0	1044.4
As	0.080	1.800	0.442	0.349	0.970	0.130	2.900	0.526	0.416	1.229
Ba	3.1	31.8	11.3	9.4	24.1	3.6	83.2	15.4	12.0	33.3
B	1.80	62.30	10.83	7.38	25.54	0.00	62.00	8.78	6.60	26.17
Be	L0.003	0.300	0.025	0.014	0.098	L0.003	55.70	3.325	0.020	18.600
Bi	L0.003	0.0280	0.0047	0.0025	0.0138	L0.003	0.066	0.0081	0.0040	0.0265
Cd	L0.002	0.215	0.015	0.007	0.050	L0.002	0.241	0.024	0.010	0.079
Co	0.002	0.679	0.124	0.049	0.427	0.001	2.200	0.185	0.100	0.547
Cr	0.020	1.880	0.263	0.190	0.784	0.020	7.300	0.530	0.300	1.772
Cu	L0.05	2.130	0.529	0.370	1.608	L0.05	4.700	0.799	0.476	2.593
Fe	L0.75	2909	375	153	1526	3.400	6528	670	395	2209
Li	0.010	15.20	2.368	1.510	6.780	0.110	15.30	2.642	1.900	8.170
Mn	0.094	137.0	17.81	3.440	59.780	5.800	231.0	42.520	29.60	132.500
Mo	0.001	1.430	0.123	0.085	0.378	0.003	1.440	0.138	0.090	0.468
Ni	L0.005	3.400	0.538	0.220	2.622	L0.005	8.400	0.751	0.363	3.305
Pb	L0.010	0.798	0.117	0.050	0.412	0.014	2.340	0.265	0.149	0.805
Sb	L0.004	0.122	0.026	0.019	0.079	L0.004	0.200	0.030	0.020	0.091
Se	L0.10	0.900	0.154	0.130	0.250	L0.10	0.900	0.190	0.180	0.594
Sn	L0.030	0.065	0.032	0.033	0.050	L0.030	3.020	0.225	0.049	1.640
Sr	2.400	70.00	21.23	15.900	53.660	2.610	75.10	22.80	17.40	55.100
Th	L0.003	0.167	0.023	0.009	0.091	L0.003	0.720	0.033	0.009	0.138
Ti	L0.04	13.800	1.296	0.450	6.100	0.100	79.00	4.039	1.100	15.350
Tl	L0.003	0.043	0.004	0.002	0.011	L0.003	0.077	0.004	0.002	0.016
U	L0.003	0.230	0.027	0.009	0.107	L0.003	0.390	0.046	0.019	0.199
V	0.011	3.030	0.416	0.219	1.618	L0.005	15.50	0.931	0.390	3.292
Zn	0.480	10.50	3.641	3.160	8.776	0.520	30.100	4.485	3.720	9.487
Hg						L0.005	0.074	0.016	L0.005	0.060

Metal concentrations below the detection limit were assumed to be one-half of the detection limit reported by the laboratory; these are indicated by "L".

Figure 6.6-3 Distribution of exceedance of 95th percentile metal concentrations in lakes sampled for the RAMP ASL program.



Exceedances of Alberta and CCME Surface Water Quality Guidelines for Protection of Aquatic Life (AENV 1999b, CCME 2003) were observed for aluminium, cadmium, iron and mercury (Table 6.6-6). The guideline exceedances are scattered throughout the sub-regions, with a large representation from lakes in the Birch Mountains and the Stony Mountains sub-regions, consistent with the high metal concentrations found in lakes from these two regions (Figure 6.6-3).

Table 6.6-6 List of exceedances of CCME surface water quality guidelines in lakes sampled for the RAMP ASL program.

Metal	No. of Exceedances	Lakes Having Guideline Exceedances
Aluminum	17	A21, A24, A26, A29, 25, 27, 28, A42, L7, L39, L28, L29, L46,L47, L49,E68, O-1
Cadmium	22	A21, A24, A26, A29, 25, 27, 28, A42, A59, P98, L4, L18, L25, L28, L29, L47, L49, P49, E52, E59, E68, O-1
Iron	31	A21, A24, A26, A29, A86, 25, 28, A42, A47, A59, L4, L7, L39, P27, P7, L23, L28, L29, L46 L47, L49, L60, P13, P49, L109, O-10, R1, E52, E68, O-1, O-2
Mercury	7	L4, L7, L39, E52, E59, E68, O-1

6.6.2 Critical Loads of Acidity and Critical Load Exceedance

6.6.2.1 Calculation of Critical Loads

Critical Loads of acidity (CL) were calculated for each lake for the years 1999 to 2005 using the Henriksen steady state water chemistry model as defined in RAMP (2005a). The CL values for each lake, the PAI and selected chemical variables are presented in Table 6.6-7.

CL values in 2005 ranged from -0.132 keq H^+/ha/y to 2.008 keq H^+/ha/y with an average value of 0.419 keq H^+/ha/y (Table 6.6-7). Mean CL has increased between 2002 and 2005, likely the result of increasing levels of base cations in the lakes over the four years of sampling. Mean SBC values over this four-year period have also increased, from 525 μeq/L to 685 μeq/L (Table 6.6-7). The generally low 2005 CL values of RAMP lakes in the upland regions (the Birch Mountains, the Caribou Mountains and the Stony Mountains) and in the Canadian Shield are consistent with findings of previous RAMP reports (RAMP 2004, 2005a). Mean CL values in 2005 for the six sub-regions are as follows:

- Stony Mountains – 0.007 keq H^+/ha/y
- West of Fort McMurray – 1.00 keq H^+/ha/y
- North-East of Fort McMurray – 0.796 keq H^+/ha/y
- Birch Mountains – 0.312 keq H^+/ha/y
- Canadian Shield – 0.357 keq H^+/ha/y
- Caribou Mountains – 0.218 keq H^+/ha/y

Negative CL values were observed in many of the lakes, especially in the Stony Mountains sub-region. These lakes are considered the most acid-sensitive of the 50 RAMP lakes. In general, the ponds in the RAMP lakes had relatively high CL values in 2005.

6.6.2.2 Critical Load Exceedances

RAMP lakes with calculated CL exceedances in 2005 are listed in Table 6.6-8 and presented in Figure 6.6-4; Table 6.6-9 presents a comparison of the 2005 results with results from previous years. As expected, most of the lakes with calculated CL exceedances in 2005 are of low pH, low conductivity, low ANC, and high in DOC (Table 6.6-8). A large proportion of these exceeded lakes are found in the Stony and Birch Mountain regions and many of are quite small (1-2 km^2) in area.

Of ASL sampled lakes in 2005, 17 out of 48 lakes (35.4%) had a calculated CL exceedance; this is in contrast to a calculated CL exceedance frequency of 45.8% (22 of 49 lakes) in 2004 (Table 6.6-9). These rates of CL exceedance are considerably higher than the rate of 8% reported for 399 oil sands lakes in a 2006 NSMWG lake sensitivity report using the same models (WRS 2006). The higher rates of exceedance in the RAMP lakes reflect a bias in selecting the study lakes where the most poorly buffered lakes were preferentially selected for sampling. It is also important to note that a high proportion of the 17 lakes calculated as having CL exceedance in 2005 would also have had CL exceedance background PAI levels as determined by the AENV RELAD modeling conducted in 2002 (WRS 2004; WRS 2006). Lakes with CL exceedance under background PAI levels are indicated in Table 6.6-8 for 2005.

Table 6.6-7 Critical Loads of acidity in lakes sampled for the RAMP ASL program, 1999-2005.

See key at end of table, following page.

ID No.	Original RAMP Designation	Catchment Area (km2)	Runoff (m3/s)	Mean pH	Mean Gran Alk. (µg/L)	Mean DOC (mg/L)	Mean SBC (µeq/L)	Critical Load of Acidity (keq/H^+/ha/y)							
								1999	2000	2001	2002	2003	2004	2005	PAI[1]
Stony Mountains Sub-Region															
168	A21	10.4	0.040	4.83	-5.5	20.9	150	-0.054	-0.046	-0.057	-0.089	-0.079	-0.087	-0.118[2]	0.148
169	A24	7.8	0.026	4.64	-1.9	21.8	114	-0.081	-0.085	-0.086	-0.124	-0.071	-0.205	-0.132[2]	0.143
170	A26	3.4	0.001	5.43	-7.1	15.1	163	0.017	-0.003	-0.003	-0.004	-0.003	-0.004	-0.006[2]	0.144
167	A29	4.5	0.013	5.72	11.0	15.2	160	-0.024	-0.001	-0.004	-0.028	-0.019	-0.002	0.004[2]	0.143
166	A86	197	0.264	6.56	114.3	17.6	275	0.030	0.039		0.049	0.053	0.057	0.057[2]	0.117
287	25	7.8	0.022	5.06	-12.8	17.7	120				-0.056	-0.055	-0.075	-0.077[2]	0.142
289	27	7.1	0.022	6.45	57.2	12.4	177				0.019	0.029	0.035	0.035[2]	0.144
290	28	3.2	0.012	5.71	30.4	22.1	211				0.004	0.033	-0.008	-0.007[2]	0.139
342	82	6.1	0.014	6.73	169	26.3	357				0.150	0.130	0.119	0.090	0.120
354	94	8.5	0.016	7.19	361	24.9	561				0.322	0.225	0.213	0.226	0.141
West of Fort McMurray Sub-Region															
165	A42	588	1.114	6.91	312	46.7	663	0.294	0.161	0.121	0.235	0.226	0.336	0.429	0.121
171	A47	1254	1.871	6.30	128	20.0	321	-0.003	0.075	-0.001	0.110	0.085	0.077	0.128	0.120
172	A59	2245	8.567	5.37	45.8	33.5	280	-0.024	-0.025	0.095	0.038	0.001	0.002	-0.023[2]	0.120
223	P94	0.7	0.002	7.37	786	46.8	1515				1.120	1.031	1.054	1.399	0.164
225	P96	1.3	0.003	7.34	633	32.6	977				0.745	0.595	0.666	0.825	0.142
226	P97	1.8	0.006	6.95	377	30.1	760				0.328	0.346	0.266	1.377	0.180
227	P98	1.9	0.007	7.18	578	32.2	879				0.969	0.956	0.917	0.462	0.156
267	1	34.5	0.118	7.81	792	24.5	1042				1.055	1.024	0.994	1.091	0.134
North-East of Fort McMurray Sub-Region															
452	L4	20.6	0.092	5.84	76.1	24.7	285	0.140	0.093	0.093	0.070	0.070	0.078	0.143	0.164
470	L7	21.5	0.101	6.38	147	29.1	380	0.269	0.311	0.316	0.170	0.190	0.141	0.307	0.148
471	L8	10.6	0.045	7.07	387	21.5	597	0.632	0.604	0.636	0.528	0.622	0.527	0.659	0.152
400	L39	19.2	0.050	6.77	167	15.8	357	0.313	0.192	0.175	0.157	0.157	0.144	0.073	0.104
268	E15	25.0	0.081	7.18	418	42.5	691		0.661	0.513	0.520	0.465	0.400	0.505	
182	P23	7.3	0.030	7.87	738	17.4	1051				0.294	1.084	2.017	2.008	0.259
185	P27	4.0	0.017	5.48	69.3	29.1	282				0.035	0.017	-0.095	0.233	0.168
209	P7	1.9	0.007	5.97	126	25.7	320				0.141	0.163	0.112	0.089	0.161
270	4	18.1	0.041	8.39	1450	36.8	1907				1.382	1.318	1.408	1.705	0.171
271	6	22.0	0.049	8.79	1380	31.4	1731				1.293	1.449	1.931	1.369	0.145
418	Kearl L.	71.1	0.169	7.98	1490	21.6	1456				NA	1.280	1.290	1.664	0.367

Table 6.6-7 (Cont'd).

ID No.	Original RAMP Designation	Catchment Area (km^2)	Runoff (m^3/s)	Mean pH	Mean Gran Alk. (µg/L)	Mean DOC (mg/L)	Mean SBC (µeq/L)	Critical Load of Acidity (keq/H^+/ha/y)							
								1999	2000	2001	2002	2003	2004	2005	PAI[1]
Birch Mountains Sub-Region															
436	L18	224	0.325	7.16	386	8.7	647	0.225	0.230	0.236	0.235	0.239	0.226	0.313	0.127
442	L23	23.4	0.043	6.77	140	14.0	276	0.078	0.085	0.080	0.087	0.074	0.065	0.074	0.117
444	L25	93.1	0.177	6.81	156	9.2	305	0.105	0.113	0.115	0.088	0.097	0.099	0.134	0.112
447	L28	19.0	0.045	5.18	20.7	28.3	229	-0.002	-0.024	-0.012	-0.016	-0.025	0.002	-0.025[2]	0.105
448	L29	13.1	0.033	4.20	-7.6	16.4	77	-0.094		-0.048	-0.127	-0.090	-0.073	-0.111[2]	0.113
454	L46	57.2	0.169	6.77	211	24.0	649	0.671	0.502	0.409	0.394	0.375	0.365	0.374	0.114
455	L47	49.2	0.102	6.78	223	22.9	783	0.380	0.304	0.291	0.282	0.241	0.958	0.324	0.120
457	L49	31.1	0.067	6.56	151	22.6	602	0.316	0.327	0.272	0.301	0.260	0.283	0.234	0.109
464	L60	60.2	0.163	7.10	279	19.9	624	0.337	0.424	0.428	0.408	0.420	0.501	0.422	0.115
175	P13	4.3	0.012	8.24	908	47.0	1466				1.198	1.235	2.149	1.449	0.133
199	P49	0.8	0.004	6.67	165	19.4	308				0.245	0.215	0.237	0.247	0.135
Canadian Shield Sub-Region															
473	A301	NA	NA	7.26	404	15.6	600	NA	NA	NA	NA	NA	NA	NA	
118	L107	12.2	0.009	7.28	434	10.9	651		0.121	0.128	0.118	0.116	0.114	0.168	0.007[3]
84	L109	115.8	0.354	7.03	362	19.5	587	0.403	0.465	0.453	0.409	0.394	0.341	0.496	0.014[3]
88	O-10	5.1	0.012	6.83	213	23.6	445	0.264	0.227	0.205	0.178	0.189	0.138	NA	0.014[3]
90	R1	24.3	0.079	7.03	278	18.9	458	0.287	0.331	0.316	0.318	0.311	0.279	0.408	0.014[3]
Caribou Mountains Sub-Region															
146	E52	17.6	0.044	7.05	364	23.3	638	0.309	0.353	0.374	0.377	0.365	0.350	0.531	0.027[3]
152	E59	30.1	0.012	6.81	168	13.0	331	0.023	0.022	0.025	0.023	0.025	0.026	0.031	0.027[3]
89	E68	54.1	0.158	6.86	234	22.0	500		0.361	0.337	0.258	0.274	0.223	0.395	0.027[3]
91	O-1/E55	3.3	0.001	6.26	79.4	21.4	417	0.004	0.005	0.005	0.004	0.007	0.009	0.122	0.027[3]
97	O-2 E67	9.3	0.003	6.63	172	23.3	382	0.021	0.025	0.023	0.022	0.021	0.017	0.009[2]	0.027[3]

Shaded values represent Critical Loads exceeded by the Potential Acid Input derived from the 2005 Kearl Lake EIA (Planned Development Case), Imperial Oil (2005).

[1] Estimate of PAI was based on SO_2 deposition alone except for lakes receiving Nitrogen deposition above a threshold value of 9 kg/ha/y.

[2] Critical Loads exceeded under background conditions (AENV RELAD modeling).

[3] PAI obtained from OPTI 2002 EIA (OPTI/Nexen 2002).

Figure 6.6-4 RAMP acid-sensitive lakes with calculated Potential Acid Input exceeding calculated Critical Load, 2005.

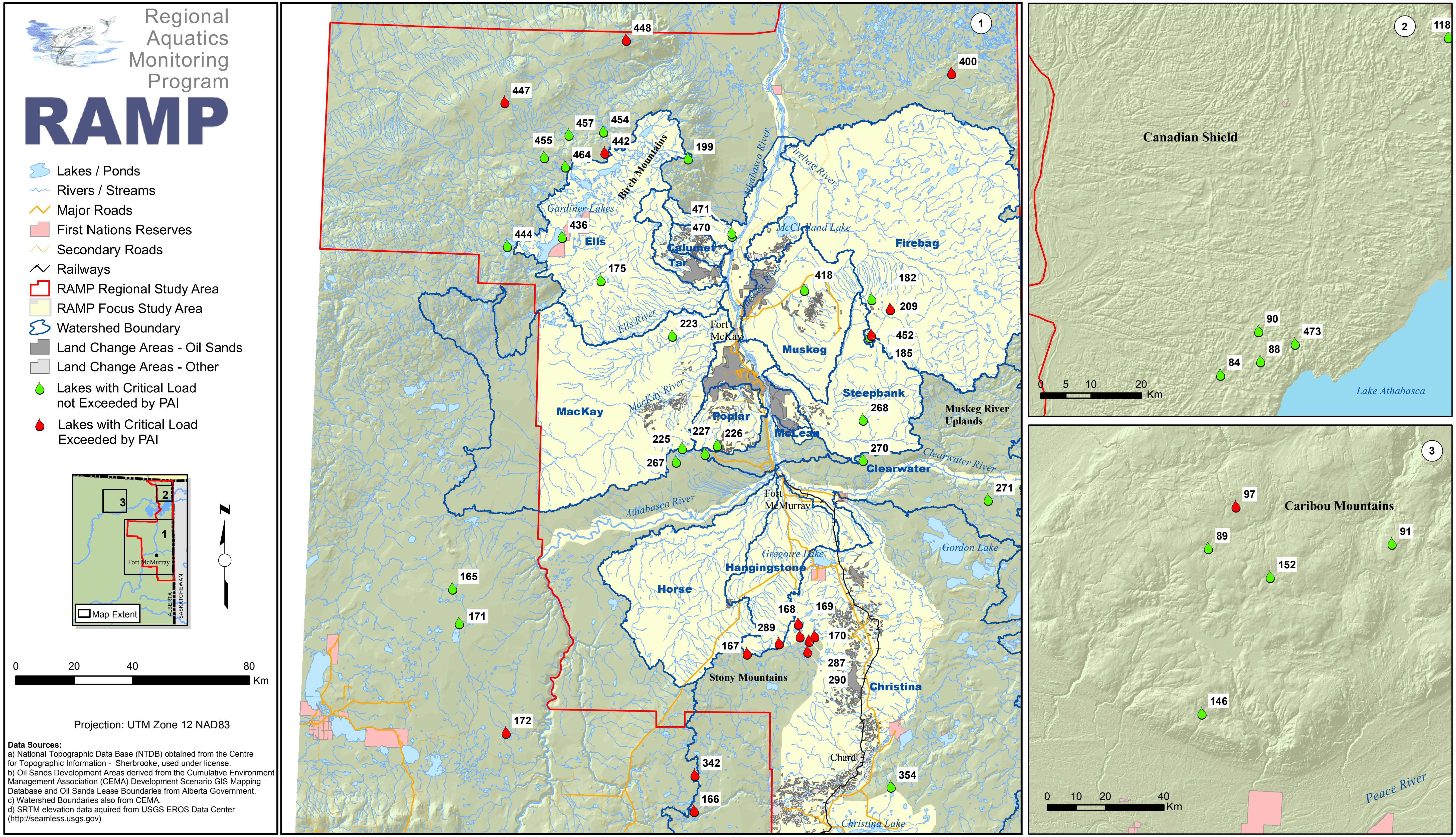


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Table 6.6-8 Key chemical variables in the 22 lakes having Critical Load exceedances, 2005.

Lake	Original Name	pH	Gran Alkalinity (µeq/L)	Conductivity (µS/cm)	DOC (mg/L)	Lake Area (km^2)
168	A21	4.88	-5.53	15.41	20.85	1.38
169	A24	4.66	-1.9	14.91	21.79	1.45
170	A26	5.45	-7.07	13.56	15.10	2.78
167	A29	5.76	10.97	12.70	15.24	1.05
166	A86	6.55	114.32	25.35	17.64	2.17
287	25	5.07	-12.8	13.20	17.73	2.18
289	27	6.42	57.15	15.10	12.44	1.83
290	28	5.72	30.35	17.70	22.08	0.54
342	82	6.71	168.90	30.70	26.32	
171	A47	6.31	127.80	30.60	19.99	
172	A59	5.39	45.77	24.31	33.52	108
452	L4	5.84	76.07	22.31	24.70	0.61
470	L7	6.36	146.88	28.67	29.12	0.33
185	P27	5.51	69.25	21.73	29.06	3.94
209	P7	6.00	125.50	23.93	25.71	
442	L23	6.76	140.30	24.67	14.01	3.44
444	L25	6.81	156.03	28.83	9.17	
447	L28	5.19	20.67	19.69	28.32	1.30
448	L29 Clayton	4.24	-7.6	17.32	16.39	0.65
152	E59	6.81	168.07	28.00	12.98	9.53
91	O-1	6.20	79.40	20.96	21.41	0.80
97	O-2	6.70	172.10	29.00	23.31	3.10

Table 6.6-9 Summary of Critical Loads and exceedance rates, 2002-2005.

Variables	2002	2003	2004	2005
No.of Lakes	48	49	49	48
Minimum CL	-0.127	-0.090	-0.205	-0.132
Maximum CL	1.382	1.449	2.149	2.008
Average CL	0.297	0.328	0.380	0.419
Median CL	0.174	0.190	0.144	0.233
No. of Exceedances	20	19	22	17
Exceedance Rate (%)	41.7	39.6	45.8	35.4
Average SBC (µeq/L)	525	544	560	685
Average DOC (mg/L)	23.2	23.7	27.0	23.1

All Critical Loads in keq H^+/H.

In summary, using the CL criterion, a large number of the RAMP lakes are sensitive to acidification and high rates of CL exceedance by PAI levels are calculated. Both the high sensitivity and high rates of CL exceedance are partially the result of a biased lake selection process which favored the most poorly buffered lakes. The high rates of CL exceedance do not indicate imminent acidification for these lakes.

6.6.3 Seasonal Variability in Measurement Endpoints

Table 6.6-10 summarizes the seasonal changes in six measurement endpoints on the ten lakes that AENV monitored on a seasonal basis from March 2004 to September 2005 (Appendix H contains graphical presentations of the temporal changes in the measurement endpoints, and Figure 6.6-5 and Figure 6.6-6 trends for pH and Gran alkalinity). Distinct chemical changes occurred during the year in most of the lakes over the sampling period:

- There were large changes in pH over the seasons. These included seasonal ranges of 2.39 pH units in lake 175 (P13), 1.96 units in lake 271 and 1.18 units in lake 448. An increase in pH was evident in most lakes during the summer months (July and August) while minima occurred in winter. An opposite trend seemed to occur in several lakes including lake 448. Changes representing 2-4 standard deviations form the mean value were not uncommon;

- Changes in Gran alkalinity over the seasons were very significant especially in some of the ponds. A seasonal range of 5346 µeq/L was observed in lake 175 (P13), 1647 µeq/L in lake 223 (P94) and 1544 µeq/L in lake 271. Kearl Lake changed by 874 µeq/L over the seasons. In most lakes, the highest values of Gran Alkalinity were observed in April under ice representing winter conditions (e.g., lake 271). Changes equivalent to 4-5 standard deviations from the mean values were observed in some lakes;

- Parallel to the changes in Gran alkalinity, very large changes were observed in base cations over the seasons. Changes of 5827 µeq/L, 1906 µeq/L and 1781 µeq/L were observed in lake 175 (P13), lake 223 (P94) and lake 271, respectively. Kearl Lake registered a change of 1164 µeq/L. As with Gran alkalinity, the highest concentrations occurred in April under ice representing winter conditions;

- Seasonal changes in sulphate were significant but not as pronounced as those for Gran alkalinity and base cations. The largest seasonal changes in sulphate occurred in lake 175 (3.16 mg/L), lake 223 (7.36 mg/L) and lake 448 (2.56 mg/L). Peak values were observed in both summer and winter;

- Seasonal changes in DOC were also highly significant, especially in the ponds. The largest seasonal changes occurred in lake 175 (P13) (149 mg/L), in lake 223 (P 94) (45.3 mg/L) and lake 271 (34.62 mg/L). Peaks in DOC occurred both in winter and in summer. Some of the highest values of DOC ever observed in the RAMP lakes were recorded in these data, especially in the shallow ponds in April under ice; and

- Seasonal changes in nitrates were also extremely large. Nitrates increased by as much as three orders of magnitude during a season, peaking in winter. The largest changes occurred in lake 175 (P13) (292 µg/L), lake 448 (206 µg/L) and lake 271 (111 µg/L).

Table 6.6-10 Seasonal variability in measurement endpoints in ten lakes (AENV data).

Lake		166/A86	169/A24	287/25	175/P13	199/P49	448/Clayton	223/P94	271/6	185/P27	418/Kearl
Region[1]		SM	SM	SM	BM	BM	BM	W. FtMc	N-E FtMc	N-E FtMc	N-E FtMc
pH	Minimum	6.24	4.58	4.06	6.74	6.41	4.15	6.97	7.48	4.94	7.49
	Maximum	7.08	5.14	5.16	9.12	6.76	5.33	7.42	9.44	5.43	8.04
	Mean	6.59	4.77	4.93	7.95	6.55	4.44	7.23	8.43	5.15	7.86
	SD[2]	0.25	0.17	0.36	0.83	0.12	0.42	0.18	0.69	0.15	0.19
	CV[3]	3.78	3.67	7.38	10.49	1.76	9.43	2.48	8.23	2.87	2.38
Gran Alkalinity (µeq/L)	Minimum	104	-50.00	-45.20	198	70	0.00	549	1274	16.0	1201
	Maximum	202	43.60	2.00	5544	440	52.00	2196	2818	94.4	2075
	Mean	137.5	-6.08	-11.10	1304	178	5.78	984	1603	35.7	1525
	SD	37.0	28.6	19.8	1605	126	17.3	607	560	24.9	250
	CV	26.94	-471	-179	123	70.5	300	61.7	35.0	69.8	16.4
Base Cations (µeq/L)	Minimum	277	86	93	349	227	52	986	1164	197	1348
	Maximum	373	287	123	6177	511	219	2891	2944	373	2512
	Mean	311	138	109	1762	333	97	1597	1772	259	1855
	SD	35.87	66.9	9.49	1697	94.0	52.11	646	597	73.30	367
	CV	11.5	48.4	8.75	96.3	28.2	53.7	40.5	33.7	28.3	19.8
Sulphate (mg/L)	Minimum	1.61	0.64	0.72	1.54	0.58	0.00	3.51	0.03	0.39	3.02
	Maximum	2.42	1.87	1.52	4.70	1.43	2.56	10.87	0.64	1.43	4.33
	Mean	2.03	1.04	1.23	3.47	0.94	0.71	8.16	0.30	0.65	3.71
	SD	0.29	0.43	0.28	1.04	0.25	0.91	2.24	0.19	0.33	0.52
	CV	14.2	41.8	22.7	29.8	26.2	127.6	27.4	64.2	50.9	13.9
Dissolved Organic Carbon (mg/L)	Minimum	16.4	16.2	13.4	14.2	15.5	12.3	44.0	19.0	24.8	22.0
	Maximum	29.0	48.6	44.1	163.6	28.5	34.9	89.2	53.6	44.4	41.5
	Mean	20.0	27.5	22.1	61.1	20.2	20.5	58.5	28.9	32.7	27.3
	SD	3.7	11.6	11.6	41.5	3.7	7.3	13.5	12.2	6.9	6.0
	CV	18.7	42.4	52.4	67.9	18.1	35.5	23.2	42.2	21.2	22.0
Nitrates + Nitrites (µg/L)	Minimum	0.5	0.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.4
	Maximum	170.4	37.9	48.9	291.7	3.6	206.3	28.5	111.1	38.3	58.6
	Mean	31.2	6.9	13.2	34.7	0.7	37.5	5.1	13.6	5.9	11.5
	SD	61.4	12.3	16.1	96.4	1.1	75.1	9.0	36.6	13.2	19.6
	CV	197	177	122	278	148	200	177	269	224	171

[1] Regions included Stony Mountains (SM), Birch Mountains (BM), West of Fort McMurray (W. FtMc), and North East of Fort McMurray (N-E FtMc).

[2] Standard deviation.

[3] Coefficient of Variation.

Figure 6.6-5 Seasonal changes in pH in 10 RAMP lakes – AENV data.

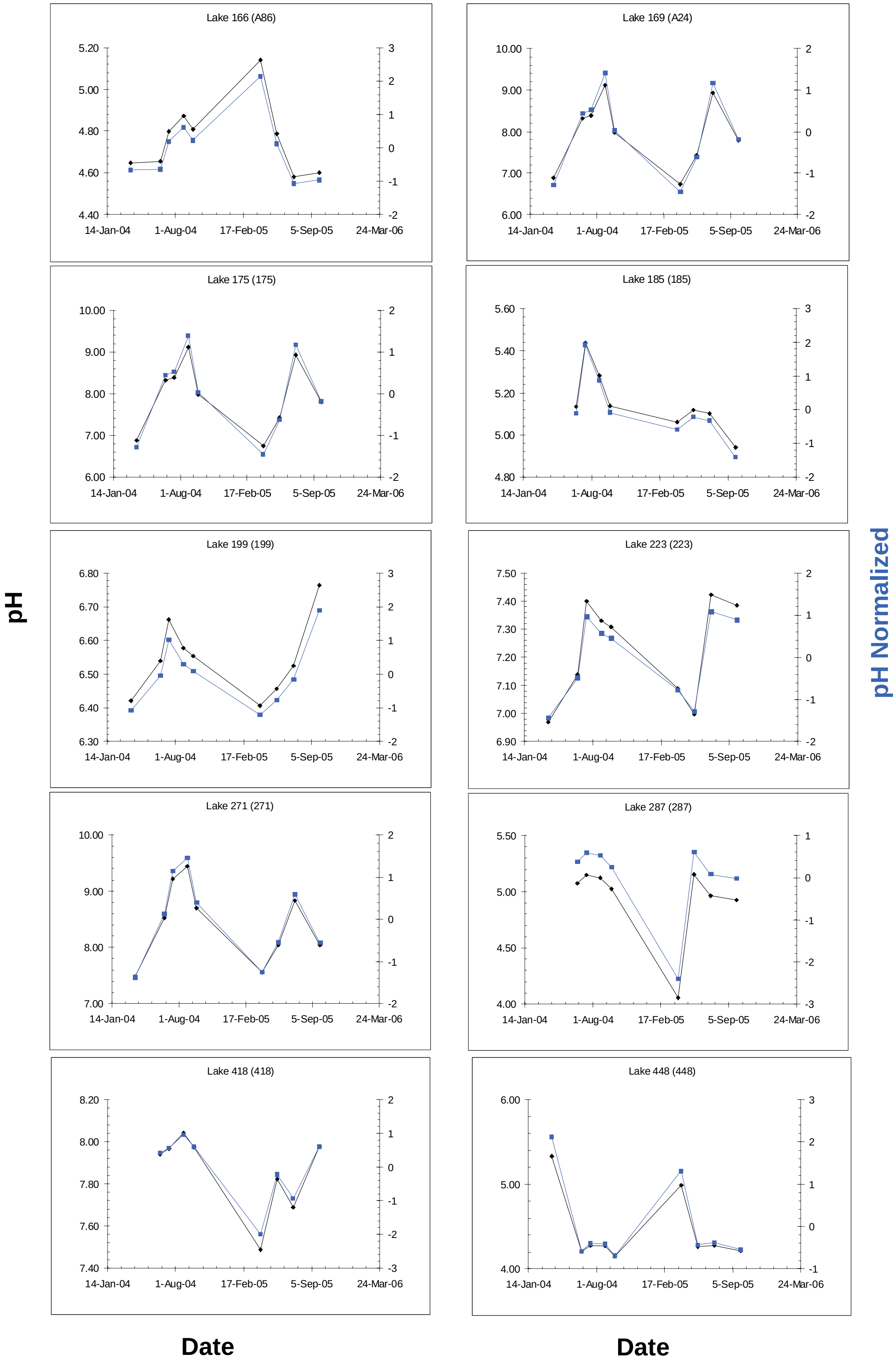
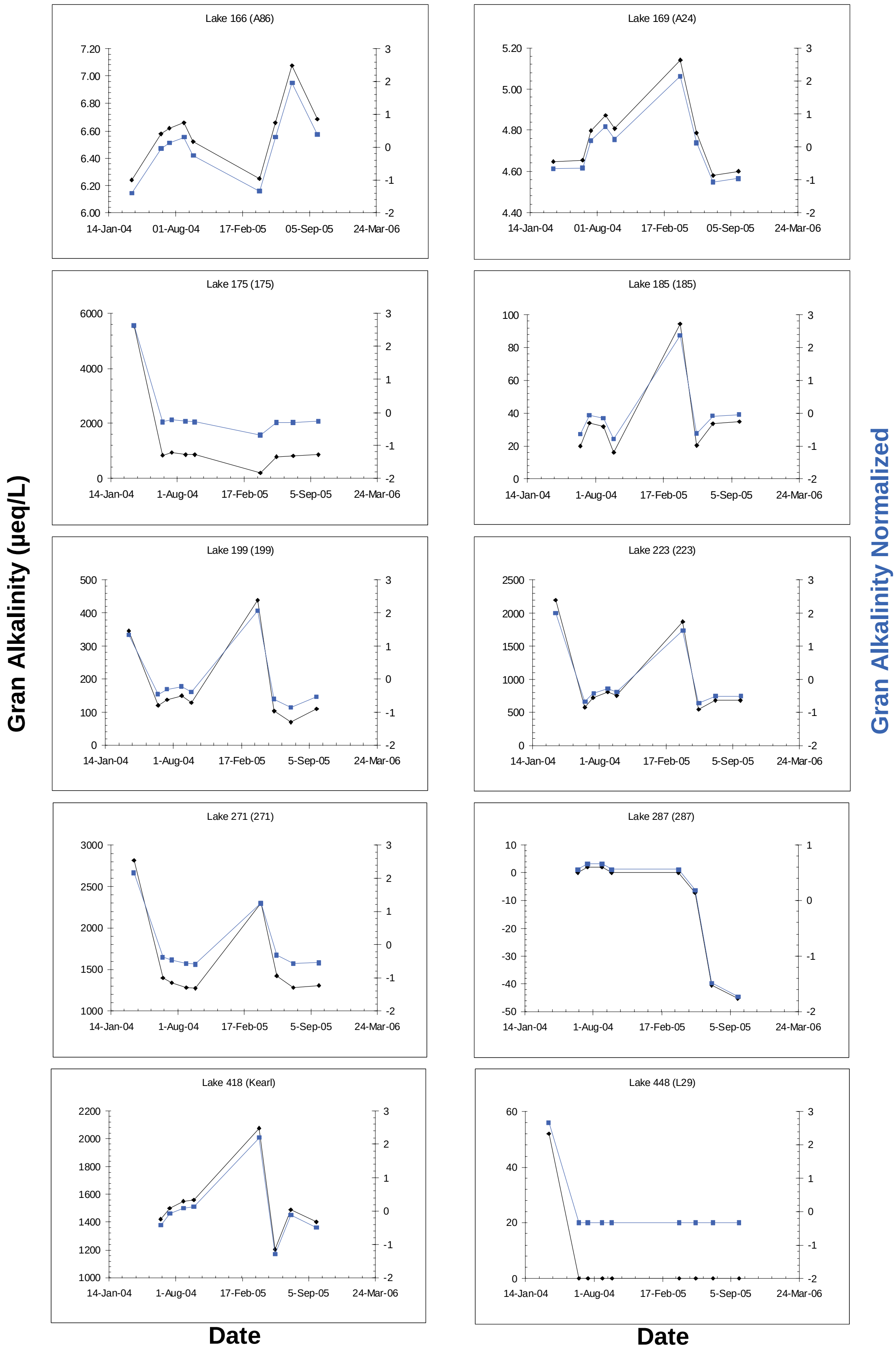


Figure 6.6-6 Seasonal changes in Gran alkalinity in ten RAMP lakes – AENV data.



In summary, the results from the seasonal sampling program show that there are very significant changes in the chemistry of the RAMP lakes over a year. The shallow ponds, in particular, show extremely large decreases in pH and increases in base cations, Gran alkalinity, DOC and nitrates in the winter season. These changes may be the result of a large proportion of the water volume in these small water bodies freezing during the winter.

6.6.4 Trend Analysis on Measurement Endpoints

While the results of the Mann Kendall trend analysis (Table 6.6-11) show a number of significant trends, these trends were often inconsistent with any conceivable acidification scenario:

- All significant changes in pH were positive (six lakes) rather than negative;
- Gran alkalinity decreased in five lakes; however, in four of these five lakes there was a significant decrease (rather than the expected increase) in sulphate, the primary acidifying agent. All significant changes in sulphate were actual decreases;
- Total alkalinity decreased in two lakes and increased in five lakes;
- Base cations decreased significantly in six lakes and increased in 4 lakes;
- A decrease in base cations in lake 442 was associated with an increase in pH, rather than a decrease; and
- Dissolved organic carbon increased significantly in four lakes, the opposite of the trend expected in acidified lakes (Schindler *et al*. 1992).

When analytical error was incorporated in the trend analysis (Section 3.6.7, Appendix H), one of the five significant decreases in Gran alkalinity (lake A168) and three of the six significant decreases in base cations (lakes 168, 442, 457) were rendered statistically insignificant.

Based on the inconsistent results of the trend analysis, there is no evidence to conclude that there have been any significant changes in lake chemistry over the length of the ASL component in RAMP.

Table 6.6-11 Results of Mann Kendall trend analyses on chemical variables to detect changes in lake chemistry.

Lake ID	Original RAMP Designation	pH (units)	Total Alkalinity (µeq/L)	Gran Alkalinity (µeq/L)	Calcium (mg/L)	Sulphate (mg/L)	Total Dissolved Nitrogen	Nitrates and Nitrites	Dissolved Organic Carbon	Sum Base Cations	Potential Acid Input (meq/L)
168	A21	-1	-10	-11	-15	-15	-7	-9	-7	-17	0.148
169	A24	6	6	-1	11	-11	-5	-7	13	1	0.143
170	A26	-9	-9	1	1	-15	-7	7	2	-7	0.144
167	A29	5	-1	3	12	-3	1	-5	5	11	0.143
166	A86	5	11	0	15	1	5	-1	11	15	0.117
165	A42	13	11	7	19	-7	-1	-2	9	9	0.121
171	A47	13	11	1	13	1	5	7	7	13	0.120
172	A59	-1	-3	-13	9	-1	-1	-5	-7	-3	0.120
452	L4	-1	-3	-5	-1	-13	-1	5	-1	-7	0.164
470	L7	-5	-13	-5	1	-13	-5	-8	3	-5	0.148
471	L8	9	-9	-7	5	-5	-11	3	3	-5	0.152
400	L39	1	-11	-9	-15	-11	-9	3	11	-21	0.104
268	E15 (L15b)	4	-5	-11	-9	5	-4	-5	0	-7	NA
436	L18	15	19	11	11	-1	-5	-7	5	15	0.127
442	L23	19	11	-1	-5	-15	5	1	-1	-17	0.117
444	L25	11	11	1	3	-11	-1	-1	11	5	0.112
447	L28	7	11	-1	-7	-9	-5	-11	15	-3	0.105
448	L29	3	0	0	-7	-9	1	-1	-1	-3	0.113
454	L46	-7	-17	-11	-9	-13	5	-1	7	-15	0.114
455	L47	4	-5	-3	-1	-11	-3	9	11	-3	0.120
457	L49	3	7	-3	-1	-13	7	1	15	-13	0.109
464	L60	11	11	5	11	-15	3	-4	15	-3	0.115
118	L107	11	1	3	-3	3	-1	-3	5	-1	0.007
84	L109	5	-9	-15	-5	-11	3	-5	9	-5	0.014
88	O-10	7	3	0	5	-8	-5	-5	3	-15	0.014
90	R1	9	-1	-7	3	-3	-1	-5	3	5	0.014
146	E52	7	15	5	9	-9	-3	-7	11	11	0.027
152	E59	11	15	7	11	-3	7	-5	9	11	0.027
89	E68	-5	3	-9	-3	-5	1	-3	-1	-3	0.027
91	O-1/E55	4	5	-5	-7	-11	-1	-3	-1	-11	0.027
97	O-2 E67	15	13	7	7	-1	3	-9	9	11	0.027

Numbers represent the S statistic used in the analysis; negative values represent overall decreases in a variable and positive values represent increases.

Grey shaded values are statistically significant; red shaded values represent significant trends rendered insignificant by incorporation of analytical error in the calculations.