# EXPLORATORY STUDY OF POTENTIAL ACIDIFICATION IMPACTS ON SOILS AND SURFACE WATER WITHIN THE LICA AREA

Submitted to:

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November 2007

EE31175

## EXECUTIVE SUMMARY

An exploratory study was conducted in the Lakeland Industry and Community Association (LICA) area to assess the current levels of deposition of acidic and acidifying substances, and to assess their potential impacts on surface waters, soils and vegetation. This study has three main components. The effects of potential emissions of oxides of nitrogen ($NO_X$) and sulphur dioxide ($SO_2$) on acid deposition in the LICA region were examined. The objective of this component was to compile and analyze existing data from the LICA regional air monitoring network to provide an indication of the extent of deposition in the area, and the extent of any resulting impacts. An outcome of this study is the prediction of Potential Acid Input (PAI) levels in the LICA area. The second component involves an assessment of surface water sensitivity to acidification and analysis in relation to the PAI levels. A soils component assesses soil sensitivity in relation to PAI estimates, and accompanies an overview of potential vegetation impacts.

The LICA study area, referred to as the original LICA Geographical Area, extends from the Fourth Meridian (the Saskatchewan border) to Range 8, inclusive, with varying portions of Range 9. North to south, the study area extends from the middle of Township 73 to portions of Townships 52 to 54. The study area spans three ecoregions, namely the Aspen Parkland in the south, the Boreal Transition Ecoregion in the middle, and the Mid-Boreal Uplands Ecoregion in the north.

The objective of the air quality study was to compile and analyze the current data from the LICA regional air monitoring network in order to provide an indication of the extent of deposition in the area, and the extent of any resulting impacts. This evaluation was principally carried out by determining the PAI, which takes into account the acidification effect of sulphur and nitrogen species as well as the neutralizing effect of available base cations. The PAI, in units of keq/ha/yr, was calculated from wet and dry forms of deposition of NOx and $SO^2$. PAI deposition rates at 20 passive monitoring stations as well as one continuous monitoring station were estimated from measurements from 2003 to 2006.

PAI estimates from observations in the LICA area showed spatial variability. The estimates at some locations between Leming and Marie Lakes exceeded the CASA 0.25 keq/ha/yr critical load for the most sensitive ecosystems. The value appears to be isolated and is likely related to local sources such as the Imperial Oil Limited Maskwa and Lemming plants. Values above the monitoring threshold for the most sensitive ecosystems were also measured in the Lindbergh to St. Paul area.

The study recommended that further examination be made of the locations of passive monitoring stations, particularly in relation to industrial and other known sources in the area, in order to help explain relatively high estimates of PAI in parts of the area. Also, the uncertainties in PAI calculations were discussed, with cation concentration and deposition identified as being poorly understood and quantified. It was therefore recommended that further work be conducted to quantify cation emission and deposition and its contribution to reducing acidification potential.

The surface water component of this study estimated and analyzed the critical loads for different waterbodies in the LICA study area. Potential effects of acidification on water bodies were evaluated by review of water quality information for the LICA area, by classification using an acidification ranking system, and by estimating the critical loads of acidity for different waterbodies. The critical loads for individual lakes were calculated using the Henriksen's steady state water chemistry ratio.

Acid sensitivity ratings were identified for lakes within and bordering the LICA study area, based on average alkalinity, pH and calcium values observed between 1998 and 2006. Alkalinity levels were relatively high, such that all lakes fell into the 'least' sensitive ranking. However, two small lakes in the Burnt Lake area (Tp. 67 - R. 3) were ranked as being moderately sensitive to acidic deposition, based on pH and calcium criteria.

Net critical loads of lakes were calculated by determination of the gross critical load from the Henriksen model, and subtracting the PAI determined in the air quality component of this study. In the southern portion of the study area, the net critical load ranged between 1.49 keq $H^+$/ha/yr and 9.15 keq $H^+$/ha/yr. The average net critical load observed in these lakes was 4.47 keq $H^+$/ha/yr. In the northern portion, the net critical load ranged between 0.42 keq $H^+$/ha/yr and 3.32 keq $H^+$/ha/yr. The average net critical load observed in these lakes was 1.28 keq $H^+$/ha/yr.

Regression analyses between several indicator parameters were computed between major water quality parameters reflecting buffering capacity and critical load for lakes. Strong relationships were found between major cations, alkalinity and conductivity, all of which reflect the buffering capacity in a water body. The use of regression equations developed between gross critical load, alkalinity and specific conductivity is suggested as a useful method to monitor acid deposition and lake sensitivity throughout the study area.

Monitoring is recommended for lakes with critical loads <0.50 keq $H^+$/ha/yr. Lakes with relatively low critical loads that occur in the Burnt Lake area are particularly recommended for monitoring because future acid deposition could approach critical load levels, based on acid deposition predictions in environmental impact assessments in the region. Monitoring of other lakes within the PAI isopleth >0.17 keq $H^+$/ha/yr should also be considered. Although these lakes have relatively high critical loads, they may be considered for monitoring as they are located in areas most likely to receive higher PAI in the future.

The information presented, particularly the data from monitoring programs, is suggested as being sufficient to assist design of a monitoring program. An important consideration is that the monitoring locations should be based on habitat sensitivity and acid depositional factors. In this regard, consideration should be given to co-location of water quality and air monitoring stations.

The potential effects of acid deposition on soils and vegetation in the LICA area were examined by assessing and mapping the sensitivity of soils to acidic and acidifying substances, determining the potential exceedances of acidity for soils based on proposed critical load levels, and reviewing information about soil and vegetation monitoring in the study area.

The mapping of soil sensitivity suggests that more than half of the LICA area is characterized by soils that are Sensitive to acidic soil inputs, or are mixtures of Sensitive with Moderate or Low Sensitivity soils. Soils that are recognized as being most sensitive are Brunisols characterized by very sandy textures. These soils have low acid buffering capacity and low nutrient content. However, the largest area of Sensitive soils is represented by the Athabasca and related series, which are Gray Luvisols developed on morainal deposits. While the subsoils of these Luvisols are generally well buffered, the surface textures are mainly very sandy and weakly buffered. These soils occur mainly in the northern part of the LICA area.

Critical load exceedances may occur presently in some areas. A small area located immediately northeast of Leming Lake with PAI >0.25 keqmol $H^+$/ha/yr represents an area in which the critical load of Sensitive soils is potentially exceeded. A relatively small area encircling the latter represents the area of target load exceedance, and a somewhat larger extending southeast beyond the City of Cold Lake represents an area of monitoring load exceedance. A second area exceeding the monitoring load for sensitive systems is located between Lindberg and St. Paul. This area has a small proportion of sensitive soils for which the monitoring load is potentially exceeded.

Current monitoring in the LICA area consists solely of long term assessment of a site within the Alberta Environment monitoring program. In existence since the late 1980s, initial results did not show changes in soils chemistry. Examination of recent results is currently being carried out by Alberta Environment.

Vegetation sensitivity to acidification has been reviewed in environmental impact assessments in the LICA region. Monitoring by remote sensing has not revealed any effects of acidic emissions. Also, field observation and laboratory analysis of plant tissue has indicated generally healthy appearance and low sulphur levels of aspen leaves, indicating that there was no direct impact to vegetation on the study area from $SO_2$ emissions.

A number of recommendations related to monitoring soil impacts are presented. The main recommendations are: establishment of soil chemistry monitoring sites additional to the single Alberta Environment site; co-location of soil and vegetation monitoring sites with air quality monitoring sites; conducting further in-depth analysis of soil types, their acidification sensitivity, and their critical loads similar to the grid-cell approach applied in the Provost-Esther area; and, maintaining awareness and participating to the extent possible in monitoring and research programs conducted by the $NO_X$-$SO_2$ Management Program of CEMA and the Terrestrial Environmental Effects Monitoring programs in the oil sands region.

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## Glossary of Terms Abbreviations and Symbols

| | |
|---|---|
| $\mu g/m^3$ | micrograms per cubic metre |
| AENV | Alberta Environment |
| anion | Ion with a negative charge |
| bpd | Barrel(s) per day |
| $Ca^+$ | Calcium ion |
| CASA | Clean Air Strategic Alliance |
| cation | Ion with a positive charge |
| $Cl^-$ | Chloride ion |
| cm/s | centimetre per second |
| CNRL | Canadian Natural Resources Limited |
| CSS | Cyclic Steam Stimulation |
| EIA | Environmental Impact Assessment |
| EPA | Environmental Protection Agency |
| EUB | Alberta Energy and Utilities Board |
| Exceedance | An emission whose measured values is more than that allowed by government regulations |
| $HNO_2$ | Nitrous acid |
| $HNO_3$ | Nitric acid |
| *in situ* | A approach to remove the bitumen from the sand while the oil sands deposits is still in place underground |
| $K^+$ | Potassium ion |
| keq | kmol $H^+$, kilomole hydrogen ion equivalents |
| keq/ha/yr | Kilomole hydrogen ion equivalents per hectare per year |
| kg/ha/yr | kilogram per hectare per year |
| LICA | Lakeland Industry and Community Association |
| m/s | Wind speed unit, meters per second |
| mg/L | milligrams per litre |
| $Mg^+$ | Magnesium ion |
| $Na^+$ | Sodium Ion |
| NAD 83 | North American Datum 1983, Geographic coordinate system |
| NAtChem | National Atmospheric Chemistry database |
| $NH_4^+$ | Ammonium ion |
| $NO_2$ | Nitrogen dioxide |
| $NO_3^-$ | Nitrate ion |
| $NO_x$ | Oxides of nitrogen (NO +$NO_2$) |
| PAI | Potential Acid Input |
| $PM_{2.5}$ | Particulate Matter emissions with particle diameter less than 2.5 $\mu m$ |
| precipitation | The rain and snow that falls on the earth's surface |
| RELAD | Regional Lagrangian Acid Deposition model |
| SAGD | Steam Assisted Gravity Drainage |
| $SO_2$ | Sulphur dioxide |
| $SO_4^{2-}$ | Sulphate ion |

| | |
|---|---|
| T/d | tonnes per day |
| UTM | Universal Transverse Mercator (cartography), map coordinate system |
| WBEA | Wood Buffalo Environmental Association |
| WHO | World Health Organization |

# 1.0 INTRODUCTION

The Lakeland Industry and Community Association (LICA) has as one of its goals the collection, analysis, and communication of data regarding water and air monitoring. Through the LICA Airshed Zone and the Regional Environmental Water Monitoring Committee, its goals include understanding of air quality issues and related impacts on soil chemistry and productivity, and on water quality. LICA has to date determined that neither regional nor site-specific monitoring conducted in the LICA area appear to indicate that acidic deposition is an issue locally, but it is a concern in other parts of the province and is included in LICA's terms of reference. In response to growing concerns over the potential effects of projected industrial growth in the Cold Lake region, LICA has commissioned an exploratory study of the potential acidification impacts on soils as well as surface waters within the LICA area.

This study has three main components. The effects of potential emissions of oxides of nitrogen ($NO_X$) and sulphur dioxide ($SO_2$) on acid deposition in the LICA region are examined. The intent of this component is to compile and analyze existing data from the LICA regional air monitoring network that can give an indication of the extent of deposition in the area, and the extent of any resulting impacts. An outcome of this study is the prediction of Potential Acid Input (PAI) levels in the LICA area. The second component provides an assessment of surface water sensitivity to acidification and analyzes this in relation to the PAI levels. Likewise, the soils component assesses soil sensitivity in relation to PAI estimates. The latter component also includes an overview of potential vegetation impacts.

## 1.1 STUDY AREA

The study area is referred to as the original LICA Geographical Area (LICA 2005). It extends from the Fourth Meridian (the Saskatchewan borer) to Range 8, inclusive, with varying portions of Range 9. North to south, the study area extends from the middle of Township 73 to Township 55, inclusive, and includes most of Township 54 within Ranges 7 and 8; about a third of Township 53 within Ranges 3, 4 and 5; Township 53, Ranges 1 and 2; and, and the upper part of Township 52 within Ranges 1 and 2.

The LICA study area lies within three ecoregions as described in the National Ecological Framework for Canada (Marshall and Schut 1999). The descriptions below are taken directly from the National Ecological Framework website (http://www.ec.gc.ca/soer-ree/English/Framework/Nardesc/praire_e.cfm).

The southern part, from Township 52 at the Saskatchewan border to about Townships 57 and 58 in Ranges 8 and 9, occurs within the Aspen Parkland Ecoregion. This ecoregion "extends in a broad arc from southwestern Manitoba, northwestward through Saskatchewan to its northern apex in central Alberta. The parkland is considered transitional between the boreal forest to the north and the grasslands to the south. The climate is marked by short, warm summers and long, cold winters with continuous snow cover. The mean annual temperature is approximately 1.5°C. The mean summer temperature is 15°C and the mean winter temperature is -12.5°C. The mean annual precipitation ranges 400-500 mm. The ecoregion is classified as having a transitional grassland ecoclimate. Most of the ecoregion is now farmland but in its native state, the landscape was characterized by trembling aspen, oak groves, mixed tall shrubs, and intermittent fescue grasslands. Open stands of trembling aspen and shrubs occur on most sites, and bur oak (in Manitoba) and grassland communities occupy increasingly drier sites on loamy Black Chernozemic soils. Poorly drained, Gleysolic soils support willow and sedge species. This broad plains region, underlain by Cretaceous shale, is covered by undulating to kettled, calcareous, glacial till with significant areas of level lacustrine and hummocky to ridged fluvioglacial deposits. Associated with the rougher hummocky, glacial till landscapes are numerous tree-ringed, small lakes, ponds, and sloughs that provide a major habitat for waterfowl. ….. Owing to its favourable climate and fertile, warm black soils, this ecoregion represents some of the most productive agricultural land in the Prairies. It produces a wide diversity of crops, including spring wheat and other cereals, oilseeds, as well as forages and several specialty crops. Dryland continuous cropping methods for spring wheat and other cereal grains are prevalent.” This ecoregion generally corresponds with the Black Soil Zone in Alberta.

The middle part of the ecoregion, to the north of the Aspen Parkland and extending to Townships 63 and part of 64 in the northeast, is within the Boreal Transition Ecoregion. “This ecoregion extends from southern Manitoba to central Alberta. The ecoregion is characterized by warm summers and cold winters. The mean annual temperature is approximately 1°C. The mean summer temperature is 14°C and the mean winter temperature is -13.5°C. The mean annual precipitation ranges from 450 mm in the west to 550 mm in the east. The ecoregion is classified as having a subhumid low boreal ecoclimate. As part of the dominantly deciduous boreal forest, it is characterized by a mix of forest and farmland. It marks the southern limit of closed boreal forest and northern advance of arable agriculture. A closed cover of tall, trembling aspen with secondary quantities of balsam poplar, a thick understory of mixed herbs, and tall shrubs is the predominant vegetation. White spruce and balsam fir are the climax species, but are not well represented because of fires. Poorly drained sites are usually covered with sedges, willow, some black spruce, and tamarack. Underlain by Cretaceous shale, this hummocky to kettled plain is covered by calcareous, glacial till and significant inclusions of relatively level lacustrine deposits. Associated with the rougher morainal deposits are a large number of small lakes, ponds, and sloughs occupying shallow depressions. The region drains northeastward via the Saskatchewan River system. Well- to imperfectly drained Gray Luvisols and Dark Gray Chernozemic soils are predominant. Local areas of Black Chernozemic, peaty Gleysolic, and Mesisolic soils also occur. The region also provides habitat for white-tailed deer, black bear, moose, beaver, coyote, snowshoe hare, and cottontail. It also provides critical habitat for large numbers of neotropical migrant bird species, as well as ruffed grouse and waterfowl. Over 70% of the ecoregion is farmland, spring wheat and other cereals, oilseeds, and hay are the dominant crops. Other land uses include forestry, hunting, fishing, and recreation.”

The northern part of the LICA area, northward from the southern to middle part of Township 63 in Ranges 1-5, and from the middle of Township 64 within Ranges 6-9, is within the Mid-Boreal Uplands Ecoregion. “This mid-boreal ecoregion occurs as 10 separate, mostly upland areas, south of the Canadian Shield, stretching from north-central Alberta to southwestern Manitoba. Itincludes remnants of the Alberta Plateau in Alberta …... The climate has predominantly short,cool summers and cold winters. The mean annual temperature ranges from -1°C to 1°C. The mean summer temperature ranges from 13°C to 15.5°C and the mean winter temperature ranges from -13.5°C to -16°C. Some areas of the ecoregion can be very cold with winter mean temperatures exceeding -17°C in northern Alberta. The mean annual precipitation ranges 400-550 mm. The ecoregion is classified as having a predominantly subhumid mid-boreal ecoclimate. These uplands form part of the continuous mid-boreal mixed coniferous and deciduous forest extending from northwestern Ontario to the foothills of the Rocky Mountains. Medium to tall, closed stands of trembling aspen and balsam poplar with white and black spruce, and balsam fir occurring in late successional stages, are most abundant. Deciduous stands have a diverse understory of shrubs and herbs; coniferous stands tend to promote feathermoss. Cold and poorly drained fens and bogs are covered with tamarack and black spruce. Consisting for the most part of Cretaceous shales, these uplands are covered entirely by kettled to dissected, deep, loamy to clayey-textured glacial till, lacustrine deposits, and inclusions of coarse, fluvioglacial deposits. Elevations range from about 400 to over 800 m asl. Associated with rougher morainal deposits are a large number of small lakes, ponds, and sloughs occupying shallow depressions. Permafrost is very rare and found only in peatlands. Well-drained Gray Luvisolic soils are dominant in the region. Significant inclusions are peaty-phase Gleysols and Mesisols that occupy poorly drained depressions. Dystric Brunisols occur on droughty, sandy sites. In Alberta, the ecoregion slopes gently and drains northward via the Athabasca and Clearwater rivers and their tributaries. ....... Pulpwood and local sawlog forestry, water-oriented recreation, hunting, and trapping are the main land use activities. Agricultural activities are significant in southern parts of the ecoregion…” main land use activities. Agricultural activities are significant in southern parts of the ecoregion…” Oil and gas extraction and processing, including heavy oil production, has also become a significant land use in the last two decades.

# 2.0 AIR QUALITY

## 2.1 INTRODUCTION

Deposition of sulphur and nitrogen compounds includes both wet and dry processes and can result in the long-term accumulation of atmospheric pollutants in aquatic and terrestrial ecosystems. Wet processes involve the removal of these atmospheric pollutants by precipitation. Dry processes involve the removal by direct contact with surface features (e.g., vegetation, soils and surface water). The deposition of sulphur and nitrogen compounds to these systems has been associated with changes in water and soil chemistry and with the acidification of water and soil.

The mandate of the exploratory study is to obtain an understanding of the impacts associated with air emissions of oxides of nitrogen ($NO_X$) and sulphur dioxide ($SO_2$) on acid deposition in the LICA area. The study comprises compilation and analysis of current data from the LICA regional air monitoring network that can give an indication of the extent of deposition in the area, and the extent of any resulting impacts. No additional measurements or monitoring were undertaken as part of this study.

## 2.2 ACID DEPOSITION DEFINITION AND CRITERIA

### 2.2.1 Potential Acid Input Definition

The preferred method for evaluating acid deposition is to determine the Potential Acid Input (PAI), which takes into account the acidification effect of sulphur and nitrogen species as well as the neutralizing effect of available base cations.

Both wet and dry depositions are expressed as a flux in units of kg/ha/yr. Where more than one acidifying chemical species is considered, the flux is often expressed in keq/ha/yr where a kiloequivalent (keq) is defined as a kilomole (kmol) of hydrogen ions produced from compounds containing sulphur and nitrogen that are deposited to the soil surface.

The potential acid input (PAI) in units of keq/ha/yr can be calculated from wet and dry deposition. In the following equations, the deposition of acid-causing ions (- superscript) and base ions (+ superscript) are in square brackets. Wet deposition values are those measured in precipitation. Dry values are often inferred from concentration measurements. The calculation of PAI is from both the wet deposition and the particulate dry deposition of $SO_4^{2-}$, $NO_3^-$, $NH_4^+$, $K^+$, $Na^+$, $Ca^{2+}$ and $Mg^+$.

$$\mathbf{PAI_{wet}}\text{ (keq/ha/yr)} = 2\frac{[SO_4^{2-}]}{96} + \frac{[NO_3^-]}{62} + \frac{[NH_4^+]}{18} - \left(\frac{[K^+]}{39} + \frac{[Na^+]}{11} + 2\frac{[Ca^{2+}]}{40} + 2\frac{[Mg^{2+}]}{24}\right) \quad (1)$$

$$\mathbf{PAI_{dry}}\ \text{(keq/ha/yr)} = 2\frac{[SO_4^{2-}]}{96} + \frac{[NO_3^-]}{62} - \left(\frac{[K^+]}{39} + \frac{[Na^+]}{11} + 2\frac{[Ca^{2+}]}{40} + 2\frac{[Mg^{2+}]}{24}\right) \qquad (2)$$

The numerical values in the denominator are the molecular weights of the compounds and ions represented in the numerator in the above equations.

$$\textbf{Total PAI} = \text{PAI}_{wet} + \text{PAI}_{dry} \qquad (3)$$

Although $NH_4^+$ is a cation, once in the soil it oxidizes into nitrate that can acidify the soil (this is the so-called “nitrification process”). Chloride ($Cl^-$) is not included in the Alberta PAI definition (Cheng 2007) as it is not a major contributor to the anion count.

### 2.2.2 Potential Acid Input Criteria

Critical, target and monitoring loads for management of acid deposition in Alberta were established on the basis of the work of the CASA Target Loading Subgroup (CASA and AENV 1999). The loads defined by this committee and accepted by AENV were specifically tied to management of deposition based upon predictions of the RELAD model over 1° latitude by 1° longitude grid cells, and based upon the specific definitions of receptor sensitivity. The management levels for the most sensitive ecosystems (Table 1) proposed by CASA and AENV (1999) are:

- A **monitoring load** of 0.17 keq/ha/yr for the most sensitive ecosystem that will trigger monitoring or research action;
- A **target load** of 0.22 keq/ha/yr that is the maximum acceptable deposition that provides long-term protection from adverse ecological consequences to the most sensitive ecosystem components, and is practically achievable; and
- A **critical load** of 0.25 keq/ha/yr that will not result in chemical changes and long-term harmful effects to the most sensitive ecosystem components.

**Table 1: Deposition Loads by Receptor Sensitivity**

| Deposition Load | Receptor Sensitivity | Potential Acid Input (keq/ha/yr) |
|---|---|---|
| Critical | Sensitive | 0.25 |
| | Moderate | 0.50 |
| | Low | 1.00 |
| Target | Sensitive | 0.22 |
| | Moderate | 0.45 |
| | Low | 0.90 |
| Monitoring | Sensitive | 0.17 |
| | Moderate | 0.35 |
| | Low | 0.70 |

Source: CASA and AENV (1999)

The CASA approach is based on the European approach outlined in WHO (1994).

### 2.2.3 Approach to Potential Acid Input Estimation

As indicated above, PAI criteria are based on RELAD model predictions. These predictions are made over 1˚ by 1˚ degree areas and therefore have limited utility for decision making over an area the size of the LICA airshed zone.

Current AENV criteria are designed for provincial-scale management of PAI and to identify areas that are potentially at risk of becoming acidified. Upon identifying such areas, actions towards confirming the acidification sensitivity of these areas are to be taken. The provincial acid deposition management framework considers only predictions over 1˚ by 1˚ degree. AENV has recently remodelled PAI on the provincial scale and is currently reviewing its management plan. A report is expected at any time.

Given that RELAD modelling is at a scale too coarse for LICA decision making, this investigation considered monitoring data in the region. The PAI estimates that are used for the spatial assessment of potential impacts on soil, vegetation and surface water are those calculated from the LICA passive monitors.

The approach herein was to include modelled deposition results from the most recent Application in the area (CNRL Primrose East), to provide context and to serve as a cross check for the values calculated based on LICA measurements. The comparison is valid in the northern part of the region where modelling results and monitoring overlap.

## 2.3 OBSERVATIONS AND ESTIMATES OF POTENTIAL ACID INPUT

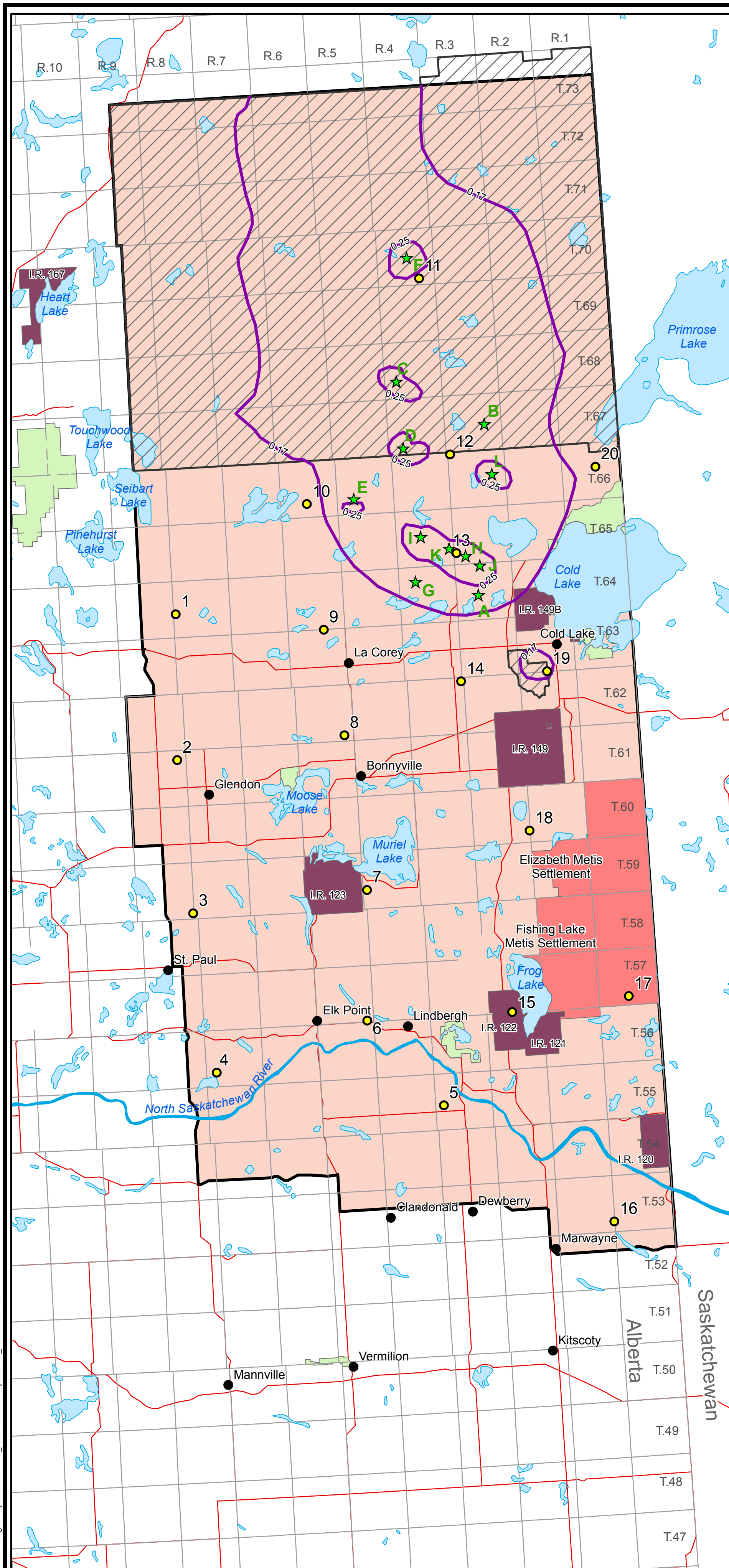
### 2.3.1 LICA Passive Network

Since July 2003, LICA has operated a 20-station passive network consisting of a strategic distribution of nitrogen dioxide, ozone, sulphur dioxide, and hydrogen sulphide monitors. In late October 2005, LICA commissioned a continuous air monitoring trailer, owned by Alberta Environment (AENV) and operated by LICA, in the City of Cold Lake. The trailer is equipped to continuously measure sulphur dioxide, nitrogen dioxide, oxides of nitrogen, ozone, total hydrocarbons, total reduced sulphur, particulate matter ($PM_{2.5}$), wind speed, and wind direction. A twenty-first station was added in April 2005 but data from this station was not used in this study. Additional stations were added in late 2006 and are also not included in this assessment.

Table 2 lists the locations of the 20 passive monitoring stations in the LICA area. The continuous monitoring is co-located with passive station #19 (Cold Lake South). Figure 1 shows the all stations.

**Table 2: Monitoring Stations in the LICA Area**

| Station No | Station Name | Location | | | | |
|---|---|---|---|---|---|---|
| | | Legal | Lat/Long (WGS 84) | | UTM (NAD 83, Zone 12) | |
| | | | Latitude N | Longitude W | m E | m N |
| 1 | Sand River | 6-18-64-8-W4M | 54.53658 | 111.20898 | 486478.0 | 6043244.9 |
| 2 | Therien | 13-25-61-9-W4M | 54.31085 | 111.22607 | 485292.0 | 6018131.4 |
| 3 | Flat Lake | 9-1-59-9-W4M | 54.07262 | 111.20510 | 486579.2 | 5991620.6 |
| 4 | Lake Eliza | 12-8-56-8-W4M | 53.82417 | 111.16605 | 489069.7 | 5963971.5 |
| 5 | Telegraph Creek | 9-18-55-4-W4M | 53.75308 | 110.57797 | 527827.4 | 5956132.8 |
| 6 | Elk Point Airport | 3-1-57-6-W4M | 53.89118 | 110.76460 | 515470.6 | 5971440.4 |
| 7 | Muriel-Kehewin | 13-7-59-6-W4M | 54.09340 | 110.74437 | 516719.1 | 5993943.7 |
| 8 | Bonnyville | 12-1-62-6-W4M | 54.33462 | 110.77965 | 514327.7 | 6020774.7 |
| 9 | La Corey | 8-34-63-6-W4M | 54.49967 | 110.81792 | 511792.1 | 6039132.4 |
| 10 | Wolf Lake | 8-9-66-6-W4M | 54.69542 | 110.84253 | 510149.1 | 6060910.0 |
| 11 | Foster Creek | 11-02-70-4-W4M | 55.03343 | 110.50453 | 531667.8 | 6098624.0 |
| 12 | Burnt Lake | 9-36-66-4-W4M | 54.75848 | 110.45217 | 535254.1 | 6068053.8 |
| 13 | Maskwa | 3-7-65-6-3-W4M | 54.60518 | 110.45263 | 535357.1 | 6050995.7 |
| 14 | Ardmore | 10-36-62-4-W4M | 54.40670 | 110.46202 | 534919.7 | 6028906.2 |
| 15 | Frog Lake | 4-21-57-3-W4M | 53.89065 | 110.38418 | 540472.0 | 5971531.2 |
| 16 | Clear Range | 1-12-53-2-W4M | 53.55648 | 110.15423 | 556026.6 | 5934510.3 |
| 17 | Fishing Lake | 13-3-57-1-W4M | 53.90295 | 110.07623 | 560692.5 | 5973119.3 |
| 18 | Beaverdam | 1-12-60-3-W4M | 54.16925 | 110.30690 | 545247.6 | 6002574.7 |
| 19 | Cold Lake South | 4-3-63-2-W4M | 54.41370 | 110.23285 | 549785.9 | 6029822.8 |
| 20 | Medley-Martineau | 7-22-66-1-W4M | 54.72430 | 110.06618 | 560142.9 | 6064512.6 |




Legend

- Town
- Passive Monitoring Station

**Plant Sites**

- A Black Rock Venture
- B CNRL Burnt Lake
- C CNRL Primrose North
- D CNRL Primrose South
- E CNRL Wolf Lake
- F EnCana Foster Creek
- G Husky Tucker Lake
- H Imperial Oil Leming
- I Imperial Oil Mahihkan
- J Imperial Oil Makheses
- K Imperial Oil Maskwa
- L Imperial Oil Nabiye
- Road
- Prediction from Primrose EIA
- Cold Lake Air Weapons Range
- Provincial Park
- Metis Settlement
- First Nations Settlement
- Lake
- LICA Airshed

N

20 10 0 20 40

Kilometres

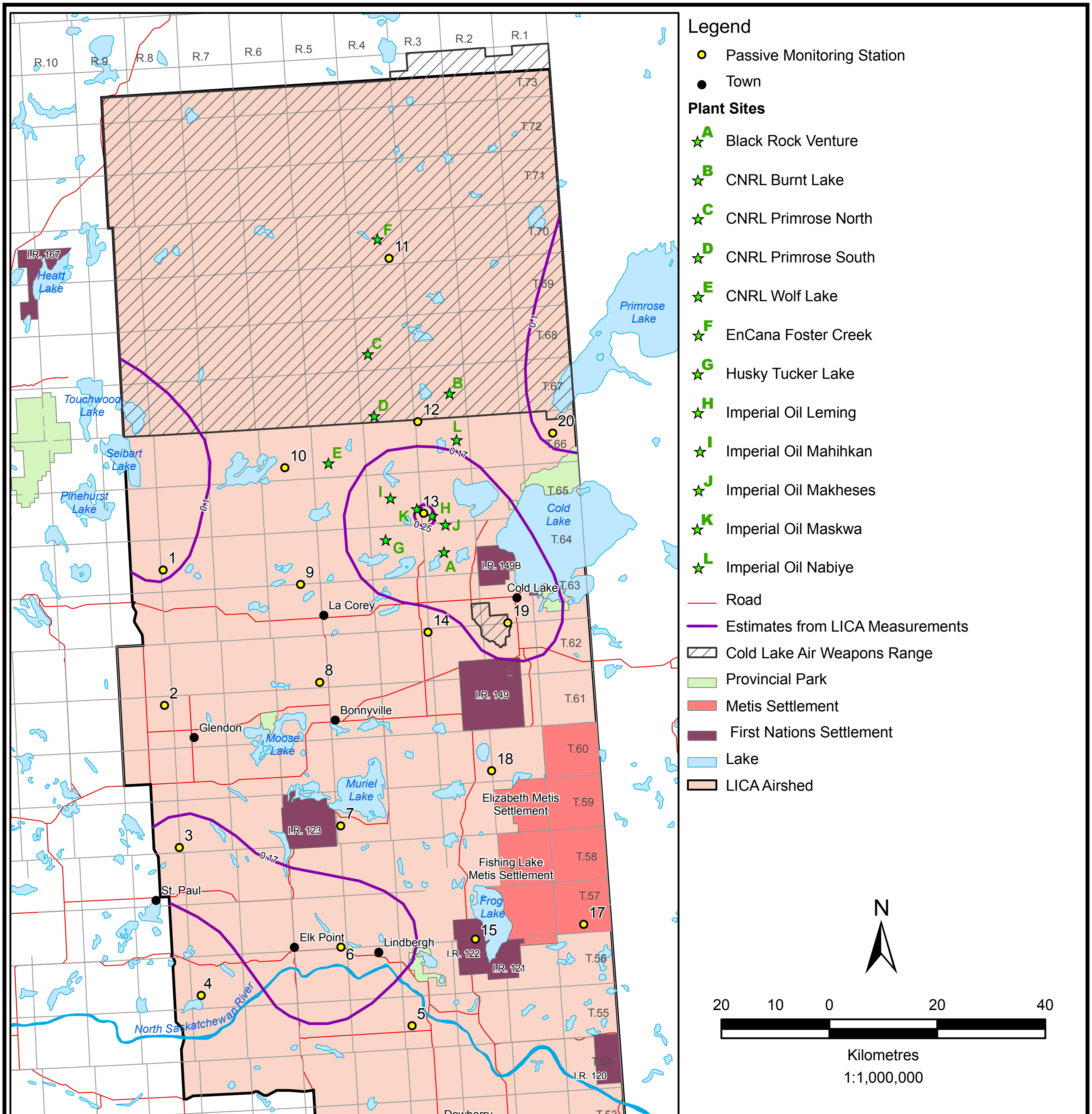
1:1,000,000

# Lakeland Industry and Community Association (LICA)

# PAI Prediction (keq/ha/yr) from Primrose EIA

| Date: June 2007 | Projection: 10TM AEP Forest | Datum: NAD83 |
|---|---|---|
| Job No: EE31175 | **Figure 1** | |
| GIS File: PAI_Prediction | | |
| PDF File: PAI_Prediction_07-06-21 | | |

Map Path: S:\gis\Projects\EE31175_LICA\ArcGIS Projects\PAI_Prediction.mxd




Lakeland Industry and Community Association (LICA)

# PAI Estimates (keq/ha/yr) from LICA Measurement, July 2003 - August 2006

| Date: June 2007 | Projection: 10TM AEP Forest | Datum: NAD83 |
|---|---|---|
| Job No: EE31175 | | |
| GIS File: PAI_Estimates | **Figure 2** | |
| PDF File: PAI_Estimates_07-06-21 | | |

Map Path: S:\gis\Projects\EE31175_LICA\ArcGIS Projects\PAI_Estimates.mxd

### 2.3.2 Dry Deposition of Nitrate and Sulphate

Average $NO_2$ and $SO_2$ concentrations measured from July 2003 to August 2006, as well as calculated sulphate and nitrate deposition, are listed in Table 3. Sulphate and nitrate deposition were calculated as the product of a dry deposition velocity and average ground-level air concentrations. Deposition velocities of 0.58 and 0.19 cm/s were used for $SO_2$ and $NO_2$, respectively and are referenced from average values in EPCM (2002).

Equation 4: Dry Deposition (nitrate keq/ha/yr) =

$$[NO_2]\frac{\mu g}{m^3} * 0.19\ \frac{cm}{s} * \frac{1kg}{10^9\ \mu g} * \frac{0.01m}{1cm} * \frac{1m^2}{0.0001\,ha} * \frac{31536000\ s}{1year} * \frac{1}{MW\ \ NO_2\ (46)} * \frac{1keq}{mol}$$

Equation 5: Dry Deposition (sulphate keq/ha/yr) =

$$[SO_2]\frac{\mu g}{m^3} * 0.58\ \frac{cm}{s} * \frac{1kg}{10^9\ \mu g} * \frac{0.01m}{1cm} * \frac{1m^2}{0.0001\,ha} * \frac{31536000\ s}{1year} * \frac{1}{MW\ \ SO_2\ (64)} * \frac{2\ keq}{mol}$$

**Table 3: $NO_2$ and $SO_2$ Measurements, Nitrate and Sulphate Dry Deposition Estimates, July 2003 to August 2006**

| Station No. | Meas. Type | $NO_2$ Concentration (µg/m$^3$) | $NO_2$ Dry Deposition (kg/ha/yr) | Nitrate Equiv. Dry Deposition (keq/ha/yr) | $SO_2$ Concentration (µg/m$^3$) | $SO_2$ Dry Deposition (kg/ha/yr) | Sulphate Equiv. Dry Deposition (keq/ha/yr) |
|---|---|---|---|---|---|---|---|
| 1 | Passive | 2.14 | 1.3 | 0.03 | 0.63 | 1.1 | 0.04 |
| 2 | Passive | 3.75 | 2.3 | 0.05 | 1.12 | 2.1 | 0.06 |
| 3 | Passive | 3.41 | 2.1 | 0.05 | 1.77 | 3.2 | 0.10 |
| 4 | Passive | 3.14 | 2.0 | 0.04 | 1.40 | 2.6 | 0.08 |
| 5 | Passive | 4.19 | 2.6 | 0.06 | 1.12 | 2.0 | 0.06 |
| 6 | Passive | 7.38 | 4.6 | 0.10 | 1.19 | 2.2 | 0.07 |
| 7 | Passive | 3.04 | 1.9 | 0.04 | 1.34 | 2.4 | 0.08 |
| 8 | Passive | 3.75 | 2.3 | 0.05 | 1.14 | 2.1 | 0.07 |
| 9 | Passive | 3.38 | 2.1 | 0.05 | 0.99 | 1.8 | 0.06 |
| 10 | Passive | 1.95 | 1.2 | 0.03 | 0.94 | 1.7 | 0.05 |
| 11 | Passive | 2.41 | 1.5 | 0.03 | 1.15 | 2.1 | 0.07 |
| 12 | Passive | 2.45 | 1.5 | 0.03 | 1.37 | 2.5 | 0.08 |
| 13 | Passive | 3.85 | 2.4 | 0.05 | 3.17 | 5.8 | 0.18 |
| 14 | Passive | 3.68 | 2.3 | 0.05 | 1.10 | 2.0 | 0.06 |
| 15 | Passive | 3.98 | 2.5 | 0.05 | 1.34 | 2.4 | 0.08 |
| 16 | Passive | 4.31 | 2.7 | 0.06 | 1.26 | 2.3 | 0.07 |
| 17 | Passive | 3.43 | 2.1 | 0.05 | 1.03 | 1.9 | 0.06 |
| 18 | Passive | 2.91 | 1.8 | 0.04 | 1.22 | 2.2 | 0.07 |
| 19 | Passive | 5.42 | 3.4 | 0.07 | 1.00 | 1.8 | 0.06 |
| 20 | Passive | 1.12 | 0.7 | 0.02 | 0.70 | 1.3 | 0.04 |
| 21[z] | Continuous | 6.23 | 3.9 | 0.08 | 1.32 | 2.4 | 0.08 |

[z] Period of record for continuous station is November 2005 through August 2006.

Nitrate dry deposition values ranged from 0.02 to 0.10 keq/ha/yr and sulphate dry deposition values ranged from 0.04 to 0.18 keq/ha/yr in all LICA monitoring stations during the mid-2003 to mid-2006 period. Co-located concentration measurements and deposition estimates using passive and continuous samples show good agreement overall (within about 20%) given the differences in monitoring period.

### 2.3.3 Wet Deposition

Precipitation chemistry measurements are made periodically throughout the year at the Environment Canada Cold Lake station. Monthly precipitation rates were used to calculate wet deposition. Table 4 summarizes precipitation chemical composition from 2003 to 2005 at Cold Lake, taken from the CASA data warehouse.

**Table 4: Wet Deposition Rates (kg/ha/yr) in Precipitation at Cold Lake, 2003-2005**

| | **Sulphate $SO_4^{2-}$** | **Nitrate $NO_3^-$** | **Ammonium $NH_4^+$** | **Sodium $Na^+$** | **Potassium $K^+$** | **Calcium $Ca^{2+}$** | **Magnesium $Mg^{2+}$** |
|---|---|---|---|---|---|---|---|
| 2003 | 2.10 | 2.61 | 1.22 | 0.03 | 0.11 | 0.96 | 0.14 |
| 2004 | 2.06 | 2.35 | 0.86 | 0.04 | 0.12 | 0.56 | 0.10 |
| 2005 | 2.01 | 1.29 | 1.29 | 0.07 | 0.31 | 0.58 | 0.40 |
| **Average** | **2.06** | **2.08** | **1.12** | **0.04** | **0.18** | **0.70** | **0.21** |

Table 5 summarizes equivalent rates of wet deposition calculated from the precipitation chemistry measurements (equation 1). PAI wet deposition is calculated by the equation listed in Section 2.1. The average PAI wet deposition during 2003 to 2005 at the Environment Canada Cold Lake station, which is taken to be representative of the LICA area because it is the nearest station to the area, was 0.08 keq/ha/yr.

It should be noted that PAI wet deposition appears to be trending lower over the three years considered in this assessment, due largely to a reduction in nitrate deposition. However, reductions in nitrate deposition at this station are unknown; possible reasons for lower nitrate values may be related to year to year variations in atmospheric concentration of the pollutant, and/or varying weather conditions.

**Table 5: Wet Deposition Rates (keq/ha/yr) at the Cold Lake Station, 2003-2005**

| | Sulphate $SO_4^{2-}$ | Nitrate $NO_3^-$ | Ammonium $NH_4^+$ | Sodium $Na^+$ | Potassium $K^+$ | Calcium $Ca^{2+}$ | Magnesium $Mg^{2+}$ | PAI Wet Deposition |
|---|---|---|---|---|---|---|---|---|
| 2003 | 0.044 | 0.042 | 0.068 | 0.001 | 0.003 | 0.048 | 0.0118 | 0.090 |
| 2004 | 0.043 | 0.038 | 0.048 | 0.002 | 0.003 | 0.028 | 0.0084 | 0.087 |
| 2005 | 0.042 | 0.021 | 0.072 | 0.003 | 0.008 | 0.029 | 0.0326 | 0.062 |
| **Average** | **0.043** | **0.034** | **0.062** | **0.002** | **0.005** | **0.035** | **0.018** | **0.080** |

### 2.3.4 Dry Deposition of Cations

Eder and Dennis (1990) developed a general linear regression method to estimate surface-level air concentrations of $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $K^+$ from precipitation concentrations. Monthly measured air concentrations at Beaverlodge and Esther from 1991 to 1999 were then used to develop a regression to be used in western Canada by Chaikowsky (2001). Table 6 lists the equations and their regression correlation values for the relationship between air concentrations (in µg/m$^3$) of $Na^+$, $Ca^{2+}$, $Mg^{2+}$, and $K^+$ and precipitation concentrations (in mg/L).

**Table 6: Alberta (Beaverlodge and Esther) Linear Regression Equations**

| Cation | Linear Regression Equations[Z] | Correlation |
|---|---|---|
| $Na^+$ | Air conc. = 0.5414(Prec. conc.) + 0.0279 | 0.84 |
| $Ca^{2+}$ | Air conc. = 0.1906(Prec. conc.) + 0.1166 | 0.32 |
| $Mg^{2+}$ | Air conc. = 0.3459(Prec. conc.) + 0.0147 | 0.86 |
| $K^+$ | Air conc. = 0.2958(Prec. conc.) + 0.0285 | 0.35 |

[Z] From Chaikowsky (2001).

Table 7 lists the mean precipitation chemistry data for 2003 and 2004 at the Environment Canada Cold Lake station obtained from Canadian National Atmospheric Chemistry (NAtChem) database. Table 8 lists the air concentration of cations estimated by the Alberta regression equation shown in Table 6 and their dry deposition rates. The dry deposition rates are estimated by multiplying the air concentration of cations with the dry deposition velocity, and the resulting deposition rate is expressed in units of keq/ha/yr. Because of the large variation in deposition velocities, a typical deposition velocity of 0.01 m/s, as suggested by Eder and Dennis (1990), was used for all cations.

**Table 7: Precipitation Cation Composition at Cold Lake, 2003-2004**

| | $Na^+$ (mg/L) | $Ca^{2+}$ (mg/L) | $Mg^{2+}$ (mg/L) | $K^+$ (mg/L) |
|---|---|---|---|---|
| 2003 | 0.108 | 0.366 | 0.054 | 0.06 |
| 2004 | 0.103 | 0.156 | 0.029 | 0.037 |
| **Average** | **0.103** | **0.300** | **0.052** | **0.049** |

**Table 8: Dry Cation Deposition Rates at Cold Lake, 2003-2004**

| | Sodium $Na^+$ | Calcium $Ca^{2+}$ | Magnesium $Mg^{2+}$ | Potassium $K^+$ | Total Dry Cation |
|---|---|---|---|---|---|
| **Concentration (μg/m$^3$)** | | | | | |
| 2003 | 0.086 | 0.186 | 0.033 | 0.046 | 0.352 |
| 2004 | 0.084 | 0.146 | 0.025 | 0.039 | 0.294 |
| **Dry deposition (keq/ha/yr)** | | | | | |
| 2003 | 0.0118 | 0.0294 | 0.0087 | 0.0037 | 0.054 |
| 2004 | 0.0115 | 0.0231 | 0.0064 | 0.0032 | 0.044 |
| **Average** | **0.0117** | **0.0262** | **0.0075** | **0.0035** | **0.049** |

The average dry deposition rate of cations is 0.049 keq/ha/yr as illustrated in Table 8. The cation concentration values can be compared to values from the Surmont EIA (Gulf Canada 2001) which indicated that regional background $Ca^{2+}$, $Mg^{2+}$ and $K^+$ concentrations in the oilsands area were based on WBEA observations and are 0.048, 0.057 and 0.346 μg/m$^3$, respectively, which are slightly larger but comparable to the values in Table 8.

### 2.3.5 Potential Acid Input

Potential acid input (PAI) deposition rates at 20 passive monitoring stations as well as one continuous monitoring station are estimated from measurements from 2003 to 2006 and listed in Table 9. This table is based on information provided in Tables 3 to 8. Total PAI is calculated using equation (3).

The PAI estimates in Table 9 show substantial spatial variability with the smallest values (0.086 keq/ha/yr) based on passive measurements at Medley – Martineau (#20) and the largest values (0.264 keq/ha/yr) at Maskwa (#13).

PAI estimates at three passive stations (Flat Lake, Elk Point Airport and Maskwa) are higher than the CASA monitoring load of 0.17 keq/ha/yr for the most sensitive ecosystems. Subsequent sections of this report present information to determine the sensitivity of ecosystems and water bodies near these locations.

## 2.4 UNCERTAINTY IN PAI DEPOSITION ESTIMATES

Passive measurements are widely used in Alberta to provide monthly estimates of the concentrations of $SO_2$ and $NO_2$ which contribute to acid deposition. The passive monitoring approach is considered to provide reasonable long-term average concentration measurements.

The LICA regional PAI estimates were based on deposition velocity measurements made in the oilsands region. These deposition velocities are applied uniformly throughout the region and are most applicable for northern, non-agricultural parts of the oilsands area. Use of the oilsands deposition velocity measurements lends itself to uncertainty in the PAI estimation for the LICA region, as this region's land use is more diverse than that of the oilsands region.

The level of uncertainty in deposition velocities is governed by key variables such as surface wetness, seasonal leaf area index (LAI), turbulence, temperature, solar radiation and surface characteristics, which add to the level of uncertainty in the estimate of dry acidic deposition. The range in deposition velocity from oil sands measurements at passive monitoring sites in a variety of cover types in 1999 (EPCM 2002) was 0.44 to 0.59 cm/s for $SO_2$ and 0.13 to 0.25 cm/s for $NO_2$. The values used in the current evaluation are at the high end of this range for $SO_2$ and average for $NO_2$.

**Table 9: PAI Estimates from Measurements, July 2003- August 2006**

| Station No. | Meas. Type | Nitrate | Sulphate | PAI | Cations | Total PAI |
|---|---|---|---|---|---|---|
| | | Dry Deposition (keq/ha/yr) | Dry Deposition (keq/ha/yr) | Wet Deposition (keq/ha/yr) | Dry Deposition (keq/ha/yr) | Deposition (keq/ha/yr) |
| 1 | Passive | 0.03 | 0.04 | 0.08 | 0.049 | 0.096 |
| 2 | Passive | 0.05 | 0.06 | 0.08 | 0.049 | 0.146 |
| 3 | Passive | 0.05 | 0.10 | 0.08 | 0.049 | **0.178** |
| 4 | Passive | 0.04 | 0.08 | 0.08 | 0.049 | 0.154 |
| 5 | Passive | 0.06 | 0.06 | 0.08 | 0.049 | 0.151 |
| 6 | Passive | 0.10 | 0.07 | 0.08 | 0.049 | **0.199** |
| 7 | Passive | 0.04 | 0.08 | 0.08 | 0.049 | 0.148 |
| 8 | Passive | 0.05 | 0.07 | 0.08 | 0.049 | 0.147 |
| 9 | Passive | 0.05 | 0.06 | 0.08 | 0.049 | 0.133 |
| 10 | Passive | 0.03 | 0.05 | 0.08 | 0.049 | 0.111 |
| 11 | Passive | 0.03 | 0.07 | 0.08 | 0.049 | 0.129 |
| 12 | Passive | 0.03 | 0.08 | 0.08 | 0.049 | 0.143 |
| 13 | Passive | 0.05 | 0.18 | 0.08 | 0.049 | **0.264** |
| 14 | Passive | 0.05 | 0.06 | 0.08 | 0.049 | 0.144 |
| 15 | Passive | 0.05 | 0.08 | 0.08 | 0.049 | 0.161 |
| 16 | Passive | 0.06 | 0.07 | 0.08 | 0.049 | 0.161 |
| 17 | Passive | 0.05 | 0.06 | 0.08 | 0.049 | 0.136 |
| 18 | Passive | 0.04 | 0.07 | 0.08 | 0.049 | 0.140 |
| 19 | Passive | 0.07 | 0.06 | 0.08 | 0.049 | 0.161 |
| 20 | Passive | 0.02 | 0.04 | 0.08 | 0.049 | 0.086 |
| 21 [Z] | Continuous | 0.08 | 0.08 | 0.08 | 0.049 | **0.191** |

[Z] Period of record for continuous station is November 2005 through August 2006.

Cation concentrations and deposition rates as considered in equations 1 and 2 influence PAI estimates. Cation emissions, ambient concentrations and deposition are not well known and they further contribute to uncertainty in the estimates. There are almost no measurements of dry deposition and only limited data on air concentrations that could be used in connection with inferential models (dry deposition velocities for different land covers) to estimate dry deposition amounts. Bulk deposition, for which there are limited data available in Alberta, capture wet deposition and an unknown part of the dry deposition.

The reliability of wet base cation deposition is relatively high (although few stations in Alberta measure it), while there are greater uncertainties for dry deposition. The estimates of Chaikowsky (2001) are useful but have large uncertainties, as evidenced by the need to infer dry deposition from rainfall chemistry.

## 2.5 OBSERVATIONS COMPARED TO PREDICTIONS

The acid deposition estimations were compared to modelling results from Primrose East In-Situ Oil Sands Project EIA (CNRL 2006). This step is important as it provides an indication of the relationship between predicted and observed data, and therefore guidance on the use of model results as a performance measure. It also provides guidance on expected increases in acid deposition with projected emissions of acid forming compounds (primarily $SO_2$ and $NO_x$) in the region.

Figure 1 shows Existing and Approved case PAI predictions taken from the Primrose East In-Situ Oil Sands Project EIA (CNRL 2006). The model results cover only the area north of Township 60, about two-thirds of the LICA area. Figure 2 shows contours of PAI calculated from observations and Table 10 lists the comparison between observations and predictions based on contour levels.

Model predictions are consistent with measurements where they overlap (8 measurement locations are without corresponding predictions). PAI predictions at Foster Creek and Burnt Lake exceed 0.17 keq/ha/yr, while both estimated PAI are lower than 0.15 keq/ha/yr. PAI estimates from continuous monitoring data are consistent with model predictions and both exceed 0.17 keq/ha/yr, while the PAI estimated from co-located passive samples is 0.16 keq/ha/yr.

Emissions used in modelling may be higher than those contributing to measured values for two reasons:

- Emissions for some facilities used in the Primrose East model are higher than actual (Appendix A)
- Approved projects that are currently not operating are included in the modelling (examples: CNRL Primrose East CSS Project, Orion )

At the same time, smaller emission sources are not accounted for. The net result is that model emissions are expected to be somewhat higher than actual emissions but this does not invalidate the overall consistency of model predictions with observed values. This implies that model results generated to date in the LICA area can be used with reasonable confidence to predict future changes in acid deposition.

**Table 10: Comparison between PAI Estimates from Measurements with Prediction from the Primrose EIA**

| Station No | Station Name | Meas. Type | PAI Estimates from Measurements | PAI Prediction from Primrose EIA |
|---|---|---|---|---|
| 1 | Sand River | Passive | 0.096 | <0.17 |
| 2 | Therien | Passive | 0.146 | <0.17 |
| 3 | Flat Lake | Passive | 0.178 | n/a |
| 4 | Lake Eliza | Passive | 0.154 | n/a |
| 5 | Telegraph Creek | Passive | 0.151 | n/a |
| 6 | Elk Point Airport | Passive | 0.199 | n/a |
| 7 | Muriel-Kehewin | Passive | 0.148 | n/a |
| 8 | Bonnyville | Passive | 0.147 | <0.17 |
| 9 | La Corey | Passive | 0.133 | <0.17 |
| 10 | Wolf Lake | Passive | 0.111 | <0.17 |
| 11 | Foster Creek | Passive | 0.129 | 0.17~0.25 |
| 12 | Burnt Lake | Passive | 0.143 | 0.17~0.25 |
| 13 | Maskwa | Passive | 0.264 | >0.25 |
| 14 | Ardmore | Passive | 0.144 | <0.17 |
| 15 | Frog Lake | Passive | 0.161 | n/a |
| 16 | Clear Range | Passive | 0.161 | n/a |
| 17 | Fishing Lake | Passive | 0.136 | n/a |
| 18 | Beaverdam | Passive | 0.140 | <0.17 |
| 19 | Cold Lake South | Passive | 0.161 | 0.17~0.25 |
| 20 | Medley-Martineau | Passive | 0.086 | <0.17 |
| 19c[z] | | Continuous | 0.191 | 0.17~0.25 |

[z] Period of record for continuous station (19C) is November 2005 through August 2006. For stations 1-20 period of record used is July 2003 through August 2006. Primrose EIA results were based on meteorological data from January through December 1995.

## 2.6 SUMMARY

PAI estimates from observations in the LICA area show spatial variability:

- PAI estimates at Maskwa exceed the CASA 0.25 keq/ha/yr critical load for the most sensitive ecosystems. The value appears to be isolated and is expected to be due to local sources. The nearest facilities are the Maskwa and Lemming plants.
- Values above the monitoring threshold for the most sensitive ecosystems are measured near Cold Lake and in the Lindbergh to St. Paul areas (Flat Lake and Elk Point Airport).
- Estimated PAI deposition at most stations south of Cold Lake's latitude approaches the monitoring threshold for the most sensitive ecosystems. Knowledge of the sensitivity of soils and water bodies in the area to acid input is key to understanding the form of management framework required for the LICA region.

Measurements at the co-located passive and continuous station are reasonably consistent, to within about 20% of each other. Model predictions and observations are also consistent.

The CASA and AENV (1999) framework provides a tool for provincial scale management of acid deposition. The scale of the provincial approach (RELAD predictions averaged over a 1x1 degree area compared to load thresholds) is too coarse for the framework to be used by an airshed such as LICA. While the load thresholds are likely to be useful, LICA will need to rely on finer scale measurements such as those provided by the passive network and on modelling results.

## 2.7 RECOMMENDATIONS

A number of specific recommendations would help to reduce uncertainty in PAI estimates.

Primrose East model results could be re-plotted to provide greater detail in the results (i.e., more than just the CASA thresholds for the most sensitive ecosystems). This would help in the comparison of observed and predicted PAI but it would likely not change the conclusions of this report.

The locations of passive stations should be plotted relative to industrial and other known sources in the area. This would provide guidance on the spatial extent (or isolated nature) of specific observations such as those at Maskwa and would provide guidance on a management approach.

PAI observations (and model predictions) are influenced by cation concentration and deposition, which are not well known. Further work is needed to quantify cation emission and deposition and its contribution to reducing acidification potential.

## 3.0 SURFACE WATER

Water bodies can be affected as a result of acid deposition originated by emissions of nitrogen oxides ($NO_X$) and sulphur dioxide ($SO_2$). The resistance of waterbodies to acidification effects is represented by the buffering capacity and commonly is assessed by application of critical load values. In this study, the critical loads for different waterbodies are estimated and analyzed. The applicable database for the estimates was computed and the appropriate regression analyses between major acidification potentials and indicative buffering capacity water quality parameters were completed.

The sources of information include LICA area data archives, provincial database sources, as well as industry water quality monitoring programs. The water quality information review includes data analysis of waterbody chemistry, specifically major cations and anions, alkalinity, pH, and total dissolved solids (TDS) and/or electrical conductivity.

Lakes within and bordering the LICA study area were classified based on an acid sensitivity ranking system developed by Saffran and Trew (1996). This approach ranks the sensitivity of a waterbody to acidification based on alkalinity and calcium concentrations, as well as the pH level. Spatial results of the acid sensitivity rankings are presented in this report.

The potential for acidification of standing water is evaluated by comparison of critical loads with spatially correspondent acid input rates (potential acidification input – PAI). The assessment focuses on the potential effects from air emissions and uses monitoring data rather than modelling to estimate the existing level of potential acid deposition in the LICA airshed. The analysis is based on the Henriksen model, which is widely used for analysis of surface water acidification. This approach provides results comparable to other studies in the area and in Alberta.

Regression analyses between several indicator parameters were computed using the available water quality data. The results of this analysis illustrate the relationships between several water quality indicators, establishing relationships between base cation concentrations, critical load, alkalinity and specific conductivity. These results will aid in the future monitoring of lakes in the LICA study area.

In an effort to clearly present the key water quality indicators in a spatial and/or temporal manner, maps were created displaying baseline water quality data, critical loads and acid sensitivity rankings. These maps were created using Geographic Information System (GIS) software, and they provide a useful tool to highlight areas in the study area that can be more sensitive to acid inputs.

Based on the findings of this report, recommendations are presented including further monitoring approaches. The aim is to provide LICA with the most cost effective and useful methods to continue monitoring acid deposition and lake sensitivity throughout the study area.

## 3.1 DEFINITIONS

The potential effect of acidified emissions on waterbodies can be evaluated using a comparison between predicted acid deposition and critical loads. The assessment method involves calculations of critical loads of acidity for lakes. Critical loads (CL) are then compared to potential acid inputs (PAI). The PAI values for the derived scenarios are obtained from air quality calculation results and determined for the coordinates of each lake. If the PAI value is greater than the calculated critical load, there is potential for acidification of the lake at the current rates of deposition. If the critical load is not exceeded, it implies that the buffering capacity of the lake is adequate to protect the lake from acidification impacts.

### 3.1.1 Acidification

Acidification is the process by which acids are added to a waterbody, causing a decrease in its buffering capacity (also referred to as alkalinity or acid neutralizing capacity), and ultimately resulting in a significant decrease in pH that may lead to the waterbody becoming acid.

Acid neutralizing or buffering capacity of water is a measure of the ability of water to resist changes in pH caused by the addition of acids or bases and it is, therefore, the main indicator of susceptibility to acid rain. In natural waters it is due primarily to the presence of bicarbonates, carbonates and to a much lesser extent borates, silicates and phosphates. It is expressed in units of milligrams per litre (mg/L) of $CaCO_3$ (calcium carbonate) or as micro-equivalents per litre (µeq/L) where 20 µeq/L = 1 mg/L of $CaCO_3$. A solution having a pH below 5.0 contains no alkalinity.

A scale used to determine the alkaline or acidic nature of a substance is represented by the pH value. The scale ranges from 0-14 with 0 being the most acidic and 14 the most basic. Pure water is neutral with a pH of 7.0.

### 3.1.2 Critical Load

The term “Critical Load” can be defined using the following definitions:

- The maximum load of deposition required to protect against further acidification or to allow resource recovery.

- The highest deposition of acidifying compounds or other pollutants that will not cause chemical changes leading to long-term harmful effects on the overall structure or function of an ecosystem.

- The maximum amount of acid deposition permissible to protect 95% of lakes in a particular region from acidification (pH < 6), or the threshold above which the pollutant load harms the environment. (http://www.qc.ec.gc.ca/csl/glo/glo002_e.html)

- A measure of how much pollution an ecosystem can tolerate (i.e., the threshold above which the pollution load harms the environment). Different regions have different critical loads. Ecosystems that can tolerate acidic pollution have high critical loads, while sensitive ecosystems have low critical loads. The critical load for aquatic ecosystems is the amount of wet sulphate that must not be exceeded in order to protect 95% of the lakes in a region from acidifying to a pH level of less than 6.0 (http://www.ec.gc.ca/soer-ree/English/Indicator_series/techs.cfm?tech_id=14&issue_id=3&supp=5).

## 3.2 METHODS

### 3.2.1 Lake Sensitivity Classification

Acid sensitivity of 37 waterbodies in the LICA study area and 10 waterbodies bordering the northern edge of the study area was assessed using the classification system presented in Saffran and Trew (1996).

Alkalinity and calcium cations were rated on a scale where “high” indicates an increased acidification potential due to relatively low concentrations, and “least” refers to the potentially higher buffering capacity of a given waterbody due to the presence of a high concentration of these parameters (Table 11). pH was also rated in a similar manner, where a “high” acid sensitivity rank was attributed when the pH value was relatively low; conversely a high pH value was attributed a “least” acid sensitivity rank.

**Table 11: Acid Sensitivity Ratings Based on Saffran and Trew (1996)**

| Parameter | Units | High | Moderate | Low | Least |
|---|---|---|---|---|---|
| **Alkalinity (as $CaCO_3$)** | mg/L | 0 - 10 | 11 - 20 | 21 - 40 | > 40 |
| **Calcium** | mg/L | 0 - 4 | 5 - 8 | 9 - 25 | > 25 |
| **pH** | pH Units | 0 - 6.5 | 6 .6 - 7.0 | 7.1 - 7.5 | > 7.5 |

The variables in Table 11 were used to map the sensitivity of lakes in the study area to acidifying deposition.

### 3.2.2 Critical Load Calculations

A critical load for each lake was calculated using the Henriksen’s steady state water chemistry ratio (Henriksen et al., 1992). This method has also been used in a number of Environmental Impact Assessment (EIA) applications in the Cold Lake area.

In the Henriksen model, the critical load for a lake is calculated as:

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

Where:

| | |
|---|---|
| CL | Critical load level of acidity [keq/ha/yr] |
| $[BC]^*_o$ | Base cation concentration in the lake [µeq/L] |
| $[ANC_{lim}]$ | Critical value for the acid neutralizing capacity in the water [µeq/L] |
| Q | Mean annual runoff [L/ha/yr] |

In applying the Henriksen steady state model to lakes in the study area, which are not affected by acid deposition to the same extent as European lakes, the current base cation concentrations ($[BC]^*_0$) were assumed to represent pre-industrial base cation levels. The original non-marine base cation concentrations in µeq/L for each lake were calculated based on observed concentrations of calcium, magnesium, sodium and potassium from the various data sources.

The critical load concept in the model assumed a dose-response relationship between a water quality variable and an aquatic indicator organism. The water quality variable is presented as the acid neutralizing capacity ($ANC_{lim}$) required for maintaining a healthy fish population in each water body. In Henriksen's study, an $ANC_{lim}$ of 20 µeq/L for Northern European lakes was applied. This value of 20 µeq/L was adopted in the Northwest Territories where the natural conditions were considered to be similar to the Northern Europe conditions. However, in the Oil Sands area and the heavy oil region of the LICA study area, 75 µeq/L has been widely used and was thus applied in this study.

This report graphically presents data on the gross critical loads and net critical loads of lakes. The gross critical load is derived using Henriksen's model and is based on the reported concentration of base cations for selected lakes. The net critical load represents the difference between gross critical load and the estimated potential acid input.

### 3.2.3 Mean Annual Runoff

The runoff to a lake was calculated from a regional hydrological analysis, based on long-term data from gauged catchments in the study area. The mean annual runoff was presented in unit discharge values (L/ha/yr) and calculated from regional water yield, depending on the watershed each lake belonged to.

Runoff data were obtained from different sources and calculations were provided for the study area. Previous reports provided estimates for annual water yield, such as 80 mm (Golder 2000) and 75 mm (BlackRock 2001). The estimated annual water yield was more recently assessed at 68 mm (CNRL 2006). The latter water yield was based on 36 years of observation and was accepted for use in this study. Some estimated annual water yields were calculated for several basins and represented in the Table 12.

**Table 12: Estimated Annual Water Yield (CNRL 2006)**

| Stream | Area $km^2$ | Annual water yield | |
|---|---|---|---|
| | | mm | $m^3/s$ |
| Jackfish Creek Headwaters (to Bourque Lake inlet) | 81.5 | 81 | 0.18 |
| Marie Creek at Burnt Lake outlet | 141.4 | 60 | 0.27 |
| Marie Creek at May Lake outlet | 270.2 | 61 | 0.52 |
| Medley River Headwaters | 39.6 | 68 | 0.09 |
| Sinclair Creek at Wolf Lake Inlet | 131 | 68 | 0.28 |

The mean annual yield of 68 mm/y[1] was most representative of the long-term runoff characteristics of the typical basins in the area. The average precipitation during this period was 427 mm and during 1998 – 2006 water quality observations at some lakes reported variations within +/- 25%.

In the critical load calculations, the runoff was determined from the mean annual water yield of 68 mm/yr. Because this value was used in a number of local EIAs, the results from the current analysis allow comparisons with the other studies.

### 3.2.4 Critical, Target and Monitoring Loads

The effects of acidifying emissions on lakes were assessed by reference to critical, target and monitoring loads as described in CASA and AENV (1999). Definitions for these are provided in Section 2.2.2 of this report. It is important to note that the provincial framework is explicit in indicating that the target load may be applied as a benchmark but not as a regulatory objective in the context of assessing effects from single or multiple projects.

### 3.2.5 Trend Detection

The Mann-Kendall test was used to detect trends in the annual critical load values which are monotonic but not necessarily linear. These tests only indicate the direction, and not the magnitude, of significant trends. The Mann-Kendall test is particularly useful because missing values are allowed and the data need not conform to any particular probability distribution.

The computation of Mann-Kendall statistic consists of calculating possible differences between observations in the data population (put in the order in which they are collected over time) followed by computation of the number of positive differences minus the number of negative differences. The Mann-Kendall formula is as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

Thus, no absolute values are involved, but the count of signs is compared. The algorithm to calculate the Mann-Kendall Test is used in this study to analyze the temporal trend (Gilbert 1987).

The Mann-Kendall Test can be used to show whether concentrations at a monitoring site are increasing, stable, or decreasing. However, it cannot determine the rate at which concentrations are changing over time. The Mann-Kendall Test can be used with a minimum of five sampling results/data points, but the test is not valid for data that exhibit periodicity. Thus, it is not applicable for seasonal data within annual time series; however, it can be used for trend analysis of average annual values.

## 3.3 DATA SOURCES

Water quality data used in this report were collected from the following sources:

- Alberta Lake Management Society reports (ALMS 2007);
- Imperial Oil Resources Surface Water Quality Monitoring Program (IOR 2007); and,
- Canadian National Resources Limited, Primrose In-Situ Oil Sands Project, East Primrose Expansion (CNRL 2006).

The passive monitoring station data provided by LICA were used to spatially compute the potential acid inputs (PAIs) from air emissions throughout the study area (see Section 2). Isopleths were created from the 20 passive monitoring stations throughout the study area and used to estimate the PAIs of the different lakes with water quality data.

The Alberta Lake Management Society (ALMS) conducts annual water quality testing of several lakes throughout Alberta, including 12 lakes in the LICA study area. Available data between 1998 and 2006 are presented in this report.

Imperial Oil Resources (IOR), Cold Lake Operations collects water quality data on an annual basis for several lakes and streams in the Jackfish and Marie Creek sub-watersheds. Data have been collected since 2000 and are presented in this report. In 2005 and 2006, data were collected in both spring and fall, the results of which were averaged for presentation in this report.

Canadian National Resources Limited (CNRL) completed an environmental impact assessment in the vicinity of Burnt Lake. Data from previous water quality monitoring programs were included in this report. The data for these waterbodies were collected once and no temporal comparisons were available.

## 3.4 ACID SENSITIVITY RATINGS

Acid sensitivity ratings were identified within and bordering the LICA study area based on average alkalinity, pH and calcium values observed between 1998 and 2006. These results provide a qualitative approach of classifying the sensitivity of lakes to acidic inputs, based on the classification system presented in Saffran and Trew (1996) and presented in Table 13.

All lakes in the study area displayed sensitivity ratings of “least” for alkalinity, indicating that these lakes have a high buffering capacity to acid inputs. Alkalinity ranged between 28 mg/L and 961 mg/L. Concentrations under 100 mg/L were observed in small lakes in the northwestern corner of the study area and in the vicinity of Burnt Lake. The highest concentrations of alkalinity were generally observed in the lakes of the southern portion of the study area.

Sensitivity ratings for pH were considered “least” in 42 (89%) of the surveyed lakes, with pH ranging between 7.5 and 9.2. Four lakes (9%) were rated as “low” sensitivity with a range in pH of 7.1 to 7.4. A small-unnamed lake (Lake ID = 599) west of Burnt Lake was considered to be moderately sensitive to acidification based on pH (pH = 6.8).

The concentration of calcium cations was variable throughout the study area, ranging between 5 mg/L and 37 mg/L. “Least” sensitive ratings were attributed to 21 lakes (45%), which varied in size and location throughout the study area (Figure 3). Most lakes of the least sensitive category ranged in concentration between 26 mg/L and 37 mg/L. “Low” sensitivity ratings were attributed to 24 lakes (49%), found throughout the study area. Most lakes of the low sensitivity category ranged in concentration between 10 mg/L and 25 mg/L. Two lakes (4%) were rated as moderately sensitive to acidification. These are small lakes located in the Wolf River sub-watershed, just west of Burnt Lake.

Lakes of the LICA study area are generally resistant to acidification based on sensitivity ratings. Alkalinity and pH demonstrate that most lakes are well buffered, while only two lakes are moderately sensitive to acidification based on the concentration of calcium ions. The most sensitive lakes are characteristically small headwater waterbodies found in the Wolf River sub-watershed, west of Burnt Lake.

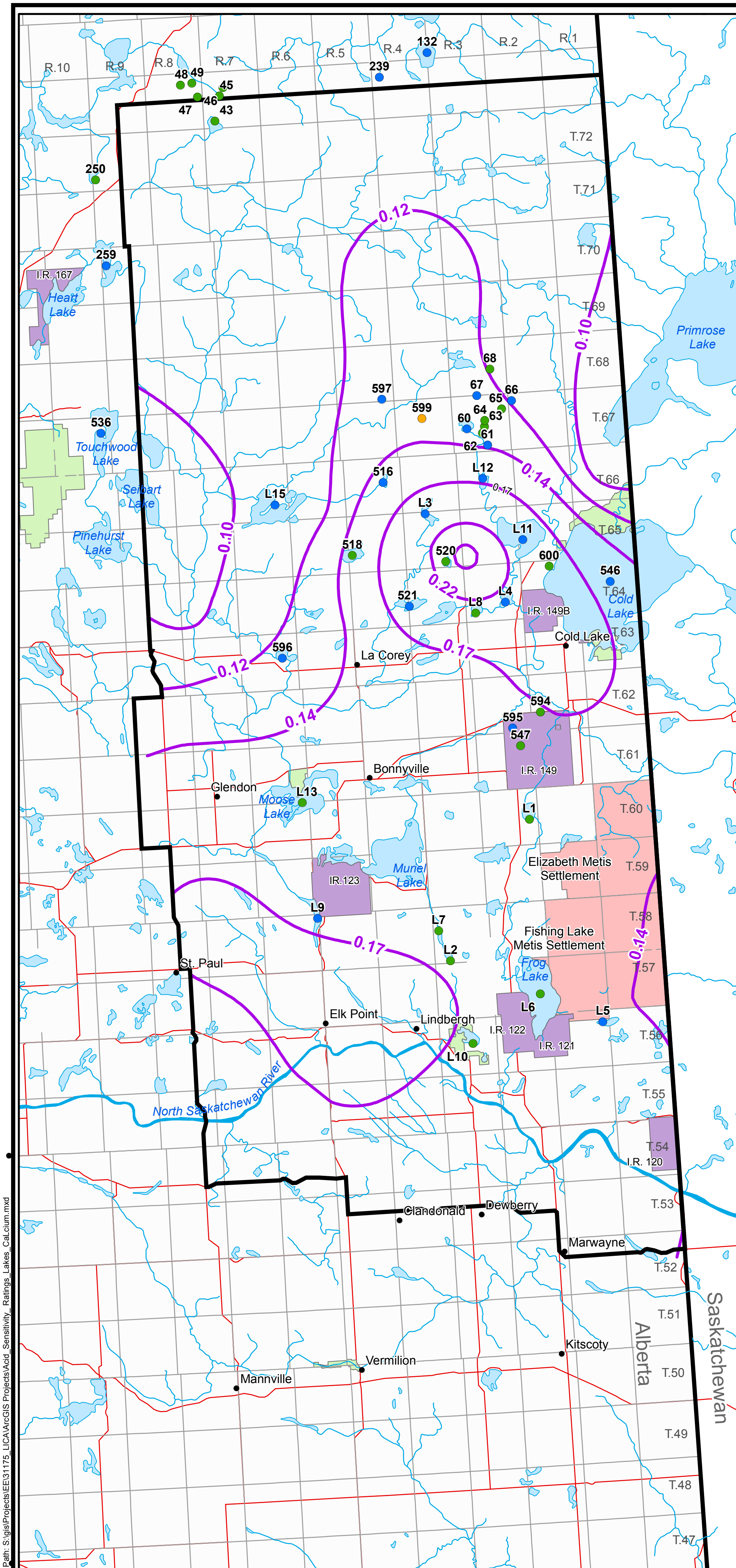
## Table 13: Acid Sensitivity Ratings for Lakes in the Study Area

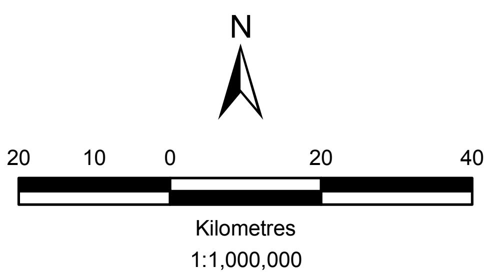
| Lake Identifier | Lake Name | Zone | Easting | Northing | Lake Surface Area (ha) | Alkalinity (mg/L) | pH | Calcium (mg/L) | Specific Conductivity (µS/cm) | Total Dissolved Solids (mg/L) | Hardness (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **LICA Study Area** | | | | | | | | | | | |
| 43 | Ipitiak Lake | 12 | 496692 | 6127900 | - | 67 | 7.5 | 17 | 136 | 67 | - |
| 60 | Burnt Lake | 12 | 536930 | 6072588 | - | 108 | 8.1 | 28 | 200 | 142 | - |
| 61 | Unnamed Lake | 12 | 540333 | 6069577 | - | 117 | 8.2 | 30 | 207 | 153 | - |
| 62 | Unnamed Lake | 12 | 539546 | 6071719 | - | 53 | 7.8 | 13 | 105 | 110 | - |
| 63 | Unnamed Lake | 12 | 539930 | 6072774 | - | 61 | 7.9 | 16 | 124 | 113 | - |
| 64 | Unnamed Lake | 12 | 540067 | 6073823 | - | 65 | 7.9 | 18 | 127 | 120 | - |
| 65 | Unnamed Lake | 12 | 543092 | 6075676 | - | 52 | 7.8 | 14 | 105 | 100 | - |
| 66 | Unnamed Lake | 12 | 544835 | 6076985 | - | 98 | 8.1 | 26 | 182 | 140 | - |
| 67 | Unnamed Lake | 12 | 538930 | 6078203 | - | 98 | 8.1 | 26 | 180 | 137 | - |
| 68 | Unnamed Lake | 12 | 541457 | 6082627 | - | 49 | 7.8 | 13 | 96 | 125 | - |
| 516 | Sinclair Lake | 12 | 522000 | 6064200 | - | 243 | 8.0 | 36 | 430 | 248 | - |
| 518 | Marguerite Lake | 12 | 516000 | 6052000 | - | 538 | 9.0 | 22 | 538 | 516 | - |
| 520 | Leming Lake | 12 | 532000 | 6050000 | - | 121 | 9.0 | 18 | 168 | 35 | - |
| 521 | Tucker Lake | 12 | 525300 | 6042700 | - | 212 | 8.1 | 28 | 400 | 234 | - |
| 546 | Cold Lake | 12 | 560000 | 6045000 | - | 140 | 8.3 | 31 | 240 | 155 | - |
| 547 | Moore Lake | 12 | 543043 | 6017650 | - | 340 | 8.7 | 15 | 686 | 408 | - |
| 594 | McDougall Lake | 12 | 546792 | 6023259 | - | 144 | - | 22 | - | - | - |
| 595 | Unnamed Lake | 12 | 541860 | 6020776 | - | 316 | 8.1 | 33 | 549 | 597 | - |
| 596 | Manatokan Lake | 12 | 503000 | 6035000 | - | 203 | 8.7 | 35 | 211 | 16 | - |
| 597 | Unnamed Lake | 12 | 522600 | 6078500 | - | 162 | 7.9 | 29 | 270 | 146 | - |
| 599 | Unnamed Lake | 12 | 529300 | 6074800 | - | 41 | 6.8 | 8 | 86 | 46 | - |
| 600 | Dolly Lake | 12 | 549700 | 6048200 | - | 244 | 8.5 | 14 | - | 239 | - |
| L1 | Angling Lake | 12 | 542500 | 6005000 | 585 | 320 | 8.8 | 25 | 584 | - | - |
| L2 | Bluet Lake | 12 | 528500 | 5979500 | 120 | 360 | 9.0 | 21 | - | 511 | - |
| L3 | Bourque Lake | 12 | 528900 | 6058400 | Unknown | 197 | 8.2 | 37 | 371 | 221 | 182 |
| L4 | Ethel Lake | 12 | 541800 | 6042450 | 490 | 158 | 8.2 | 33 | 289 | 179 | 148 |
| L5 | Fishing Lake | 12 | 550000 | 5971000 | Unknown | 226 | 8.8 | 26 | 455 | 243 | - |
| L6 | Frog Lake | 12 | 543000 | 597500 | 5800 | 386 | 8.8 | 18 | 877 | 500 | - |
| L7 | Garnier Lake | 12 | 527500 | 5985000 | 520 | 364 | 9.0 | 18 | - | 475 | - |
| L8 | Hilda Lake | 12 | 536600 | 6040900 | 362 | 428 | 8.8 | 19 | 893 | 563 | 280 |
| L9 | Kehewin Lake | 12 | 506500 | 5990000 | 620 | 214 | 8.6 | 26 | - | - | - |
| L10 | Laurier Lake | 12 | 532000 | 5967000 | 642 | 564 | 8.9 | 14 | - | 655 | - |
| L11 | Marie Lake | 12 | 547000 | 6064900 | 3600 | 150 | 8.3 | 35 | 282 | 161 | 146 |
| L12 | May Lake | 12 | 539150 | 6063900 | Unknown | 133 | 8.1 | 35 | 251 | 161 | 135 |
| L13 | Moose Lake | 12 | 505000 | 6010000 | 4000 | 332 | 8.9 | 25 | 919 | 581 | - |
| L14 | Muriel Lake | 12 | 520000 | 6000000 | 6410 | 961 | 9.3 | 5 | 1908 | - | - |
| L15 | Wolf Lake | 12 | 503222 | 6061410 | 3150 | 159 | 8.5 | 27 | - | 156 | - |
| **Lakes Bordering the LICA Study Area** | | | | | | | | | | | |
| 45 | Unnamed Lake | 12 | 497711 | 6132160 | - | 39 | 7.4 | 10 | 83 | 41 | - |
| 46 | Unnamed Lake | 12 | 498367 | 6133579 | - | 90 | 8.1 | 21 | 180 | 119 | - |
| 47 | Unnamed Lake | 12 | 493933 | 6132222 | - | 52 | 7.6 | 13 | 108 | 76 | - |
| 48 | Unnamed Lake | 12 | 491151 | 6134421 | - | 44 | 7.3 | 11 | 97 | 45 | - |
| 49 | Unnamed Lake | 12 | 493107 | 6134651 | - | 46 | 7.4 | 11 | 96 | 45 | - |
| 132 | Grist Lake | 12 | 533788 | 6137575 | - | 117 | 8.5 | 30 | 222 | 119 | - |
| 239 | Unnamed Lake | 12 | 525364 | 6133813 | - | 108 | 8.3 | 30 | 208 | - | - |
| 250 | Unnamed Lake | 12 | 475613 | 6118973 | - | 67 | 8.7 | 17 | 135 | - | - |
| 259 | Logan Lake | 12 | 476591 | 6104122 | - | 147 | 9.2 | 33 | 267 | - | - |
| 536 | Touchwood Lake | 12 | 474032 | 6075393 | - | 142 | 8.0 | 31 | 263 | 148 | - |

**Legend for Acid Sensitivity Ratings (Saffran and Trew, 1996)**

| Parameter | High | Moderate | Low | Least |
|---|---|---|---|---|
| **Alkalinity** | 0 - 10 | 11 - 20 | 21 - 40 | > 40 |
| **pH** | 0 - 6.5 | 6 .6 - 7.0 | 7.1 - 7.5 | > 7.5 |
| **Calcium** | 0 - 4 | 5 - 8 | 9 - 25 | > 25 |

Saffran, K., and D. Trew. 1996. Sensitivity of alberta Lakes to Acidifying Deposition: An Update on Sensitivity Maps with Emphasis on 109 Northern Lakes. Special report prepared by Water Sciences Branch, Water Management Division, Alberta Environment Protection.




Legend

- Town
- Road
- PAI Estimates from LICA Measurements
- Provincial Park
- Metis Settlement
- First Nations Settlement
- Lake
- LICA Airshed Boundary

**Acid Sensitivity Ratings (Based on Saffran and Trew, 1996)**

- High
- Moderate
- Low
- Least

Lakeland Industry and Community Association (LICA)

Acid Sensitivity Ratings of Lakes for Calcium (mg/L)

| Date: March 2007 | Projection: 10TM AEP Forest | Datum: NAD83 |
|---|---|---|
| Job No: EE31175 | | |
| GIS File: Acid_Sensitivity_ Ratings_Lakes_Calcium | **Figure 3** | |
| PDF File: Acid_Sen_ Ratings_Lakes_Calc_07-03-22 | | |

Map Path: S:\gis\Projects\EE31175_LICA\ArcGIS Projects\Acid_Sensitivity_ Ratings_Lakes_Calcium.mxd

## 3.5 CRITICAL LOADS FOR LAKES IN THE LICA AIRSHED

### 3.5.1 Spatial Variability

The gross critical loads for the lakes in the LICA study area were calculated using the average concentrations of base cations (calcium, magnesium, potassium and sodium) for all data available between 1998 and 2006. Gross critical loads varied between 0.53 keq $H^+$/ha/yr and 9.31 keq $H^+$/ha/yr (Table 14), with higher values generally observed in the southern portion of the study area (Figure 4).

Muriel Lake (L14) had a gross critical load of 17.64 keq $H^+$/ha/yr due to high concentrations of sodium (238 mg/L) and magnesium (173 mg/L). Since the gross critical load for this lake is much higher than all other lakes in the study area, it was excluded from further analysis and considered as an anomalous case.

The highest gross critical load values were observed in lakes located in the southern portion of the study area, where the aspen parkland ecosystem is dominant (Figure 5). The southern portion of the study area includes all areas to the south of IOR Cold Lake Operations, Husky Tucker Lake SAGD and Highway 55. Farmland with small patches of a mixed coniferous and deciduous forest is found in this region. The gross critical load for the 16 lakes in this area ranged between 1.73 keq $H^+$/ha/yr and 9.31 keq $H^+$/ha/yr, and the average gross critical load was 4.64 keq $H^+$/ha/yr.

Lakes to the north of IOR and Husky facilities were more sensitive to acid inputs due to their lower overall gross critical load values. This portion of the LICA airshed is located in an area of transition between the aspen parkland and boreal forest ecosystems. Most of the 30 surveyed lakes are found in forests or muskeg and tend to have smaller surface areas than the lakes to the south. The gross critical load in this area ranged between 0.53 keq $H^+$/ha/yr and 3.47 keq $H^+$/ha/yr. The average gross critical load was 1.41 keq $H^+$/ha/yr. The lowest gross critical loads were observed in small waterbodies in the vicinity of Burnt Lake and in the northwestern portion of the study area.

## Table 14: Critical Load Results based on Henriksen's Model for Lakes in the LICA Study Area

| Lake Identifier | Lake Name | Zone | Easting | Northing | Calcium (mg/L) | Magnesium (mg/L) | Potassium (mg/L) | Sodium (mg/L) | Base Cations [$BC^*_o$] (µeq/L) | Gross Critical Load ($keqH^+$/ha/yr) | Potential Acid Inputs ($keqH^+$/ha/yr) | Net Critical Load ($keqH^+$/ha/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LICA Study Area** | | | | | | | | | | | | |
| 43 | Ipitiak Lake | 12 | 496692 | 6127900 | 17 | 5 | 0.4 | 2 | 1373 | 0.88 | 0.11 | 0.77 |
| 60 | Burnt Lake | 12 | 536930 | 6072588 | 28 | 40 | 0.7 | 3 | 4935 | 3.30 | 0.13 | 3.17 |
| 61 | Unnamed Lake | 12 | 540333 | 6069577 | 30 | 10 | 1.3 | 4 | 2548 | 1.68 | 0.14 | 1.54 |
| 62 | Unnamed Lake | 12 | 539546 | 6071719 | 13 | 6 | 0.7 | 2 | 1239 | 0.79 | 0.13 | 0.66 |
| 63 | Unnamed Lake | 12 | 539930 | 6072774 | 16 | 6 | 0.7 | 2 | 1443 | 0.93 | 0.13 | 0.80 |
| 64 | Unnamed Lake | 12 | 540067 | 6073823 | 18 | 6 | 0.5 | 2 | 1499 | 0.97 | 0.13 | 0.84 |
| 65 | Unnamed Lake | 12 | 543092 | 6075676 | 14 | 5 | 0.6 | 2 | 1199 | 0.76 | 0.13 | 0.63 |
| 66 | Unnamed Lake | 12 | 544835 | 6076985 | 26 | 8 | 0.5 | 3 | 2122 | 1.39 | 0.12 | 1.27 |
| 67 | Unnamed Lake | 12 | 538930 | 6078203 | 26 | 8 | 0.6 | 2 | 2068 | 1.36 | 0.13 | 1.23 |
| 68 | Unnamed Lake | 12 | 541457 | 6082627 | 13 | 5 | 0.4 | 2 | 1141 | 0.73 | 0.12 | 0.61 |
| 516 | Sinclair Lake | 12 | 522000 | 6064200 | 36 | 24 | 3 | 30 | 5184 | 3.47 | 0.15 | 3.32 |
| 518 | Marguerite Lake | 12 | 516000 | 6052000 | 22 | 95 | 30 | 38 | 11376 | 7.68 | 0.15 | 7.53 |
| 520 | Leming Lake | 12 | 532000 | 6050000 | 18 | 14 | 6 | 8 | 2620 | 1.73 | 0.24 | 1.49 |
| 521 | Tucker Lake | 12 | 525300 | 6042700 | 28 | 24 | 3 | 21 | 4447 | 2.97 | 0.20 | 2.77 |
| 546 | Cold Lake | 12 | 560000 | 6045000 | 31 | 12 | 2 | 9 | 2977 | 1.97 | 0.15 | 1.82 |
| 547 | Moore Lake | 12 | 543043 | 6017650 | 15 | 39 | 6 | 83 | 7779 | 5.24 | 0.16 | 5.08 |
| 594 | McDougall Lake | 12 | 546792 | 6023259 | 22 | 18 | 8 | 3 | 2896 | 1.92 | 0.16 | 1.76 |
| 595 | Unnamed Lake | 12 | 541860 | 6020776 | 33 | 53 | 15 | 19 | 7273 | 4.89 | 0.16 | 4.73 |
| 596 | Manatokan Lake | 12 | 503000 | 6035000 | 35 | 27 | 7 | 9 | 4570 | 3.06 | 0.13 | 2.93 |
| 597 | Unnamed Lake | 12 | 522600 | 6078500 | 29 | 9 | 1 | 10 | 2660 | 1.76 | 0.13 | 1.63 |
| 599 | Unnamed Lake | 12 | 529300 | 6074800 | - | 3 | 8 | 0.7 | 888 | 0.55 | 0.13 | 0.42 |
| 600 | Dolly Lake | 12 | 549700 | 6048200 | 14 | 32 | 5 | 22 | 4451 | 2.98 | 0.18 | 2.80 |
| L1 | Angling Lake | 12 | 542500 | 6005000 | 25 | 44 | 11 | 38 | 6828 | 4.59 | 0.15 | 4.44 |
| L2 | Bluet Lake | 12 | 528500 | 5979500 | 21 | 71 | 20 | 60 | 10030 | 6.77 | 0.16 | 6.61 |
| L3 | Bourque Lake | 12 | 528900 | 6058400 | 37 | 21 | 3 | 14 | 4282 | 2.86 | 0.20 | 2.66 |
| L4 | Ethel Lake | 12 | 541800 | 6042450 | 33 | 15 | 2 | 8 | 3350 | 2.23 | 0.21 | 2.02 |
| L5 | Fishing Lake | 12 | 550000 | 5971000 | 26 | 28 | 11 | 19 | 4741 | 3.17 | 0.15 | 3.02 |
| L6 | Frog Lake | 12 | 543000 | 5975000 | 18 | 63 | 17 | 80 | 10083 | 6.81 | 0.15 | 6.66 |
| L7 | Garnier Lake | 12 | 527500 | 5985000 | 18 | 75 | 18 | 45 | 9505 | 6.41 | 0.15 | 6.26 |
| L8 | Hilda Lake | 12 | 536600 | 6040900 | 19 | 55 | 10 | 112 | 10673 | 7.21 | 0.21 | 7.00 |
| L9 | Kehewin Lake | 12 | 506500 | 5990000 | 26 | 29 | 13 | 35 | 5605 | 3.76 | 0.16 | 3.60 |
| L10 | Laurier Lake | 12 | 532000 | 5967000 | 14 | 94 | 28 | 105 | 13769 | 9.31 | 0.16 | 9.15 |
| L11 | Marie Lake | 12 | 547000 | 6064900 | 35 | 13 | 2 | 6 | 3182 | 2.11 | 0.20 | 1.91 |
| L12 | May Lake | 12 | 539150 | 6063900 | 35 | 10 | 0.9 | 6 | 2877 | 1.91 | 0.17 | 1.74 |
| L13 | Moose Lake | 12 | 505000 | 6010000 | 25 | 51 | 18 | 109 | 10659 | 7.20 | 0.15 | 7.05 |
| L14 | Muriel Lake | 12 | 520000 | 6000000 | - | 173 | 39 | 238 | 26012 | 17.64 | 0.15 | 17.49 |
| L15 | Wolf Lake | 12 | 503222 | 6061410 | 27 | 15 | 2 | 12 | 3175 | 2.11 | 0.11 | 2.00 |
| **Lakes Bordering the LICA Study Area** | | | | | | | | | | | | |
| 45 | Unnamed Lake | 12 | 497711 | 6132160 | 10 | 4 | 0.3 | 1 | 860 | 0.53 | 0.11 | 0.42 |
| 46 | Unnamed Lake | 12 | 498367 | 6133579 | 21 | 8 | 0.3 | 2 | 1854 | 1.21 | 0.11 | 1.10 |
| 47 | Unnamed Lake | 12 | 493933 | 6132222 | 13 | 5 | 0.5 | 0.5 | 1068 | 0.68 | 0.11 | 0.57 |
| 48 | Unnamed Lake | 12 | 491151 | 6134421 | 11 | 4 | 0.5 | 1 | 976 | 0.61 | 0.11 | 0.50 |
| 49 | Unnamed Lake | 12 | 493107 | 6134651 | 11 | 4 | 0.4 | 0.5 | 949 | 0.59 | 0.11 | 0.48 |
| 132 | Grist Lake | 12 | 533788 | 6137575 | 30 | 8 | 0.9 | 4 | 2411 | 1.59 | 0.11 | 1.48 |
| 239 | Unnamed Lake | 12 | 525364 | 6133813 | 30 | 9 | 2 | 2 | 2341 | 1.54 | 0.11 | 1.43 |
| 250 | Unnamed Lake | 12 | 475613 | 6118973 | 17 | 7 | 0.5 | 2 | 1521 | 0.98 | 0.11 | 0.87 |
| 259 | Logan Lake | 12 | 476591 | 6104122 | 33 | 12 | 2 | 14 | 3322 | 2.21 | 0.11 | 2.10 |
| 536 | Touchwood Lake | 12 | 474032 | 6075393 | 31 | 12 | 3 | 8 | 2988 | 1.98 | 0.10 | 1.88 |

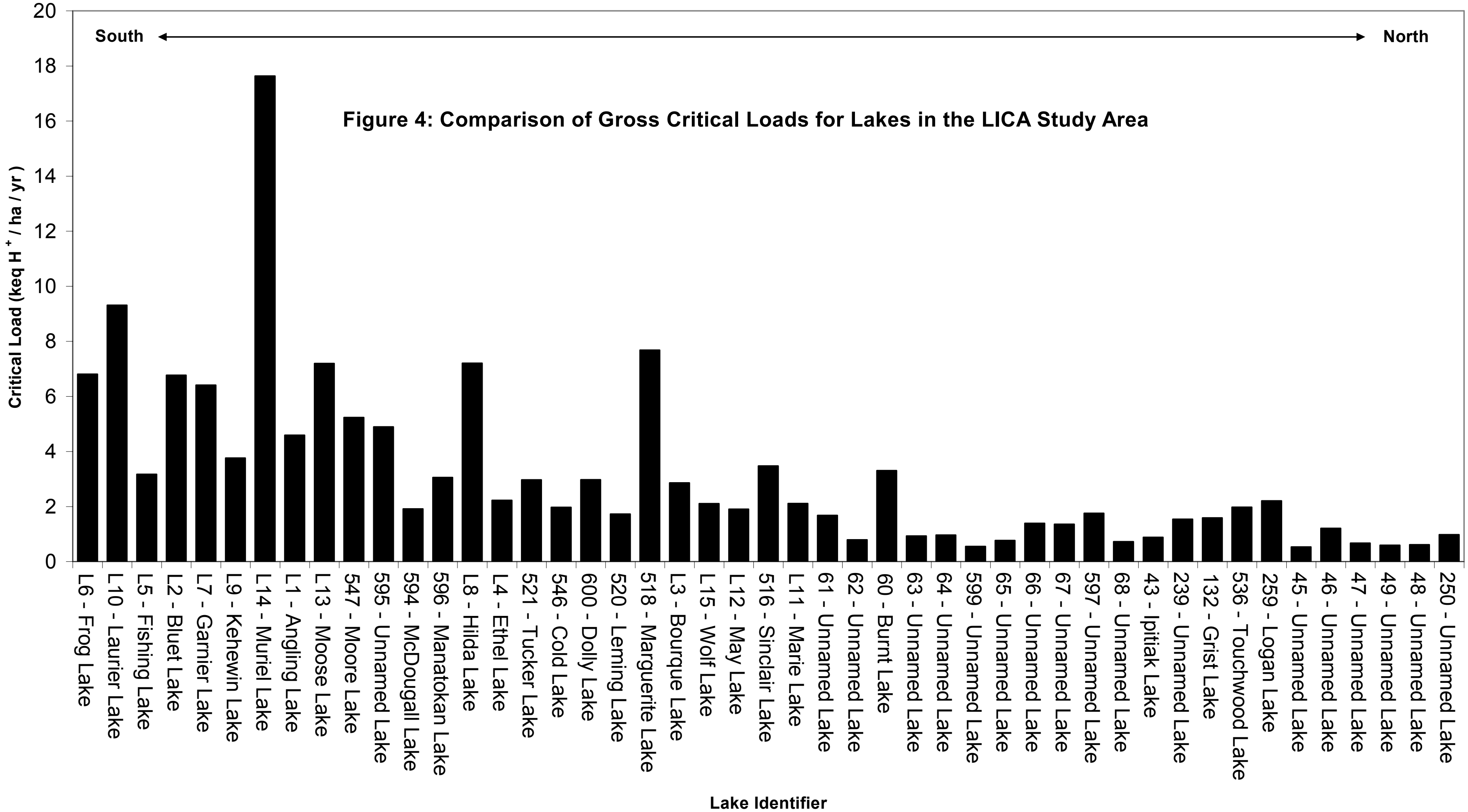
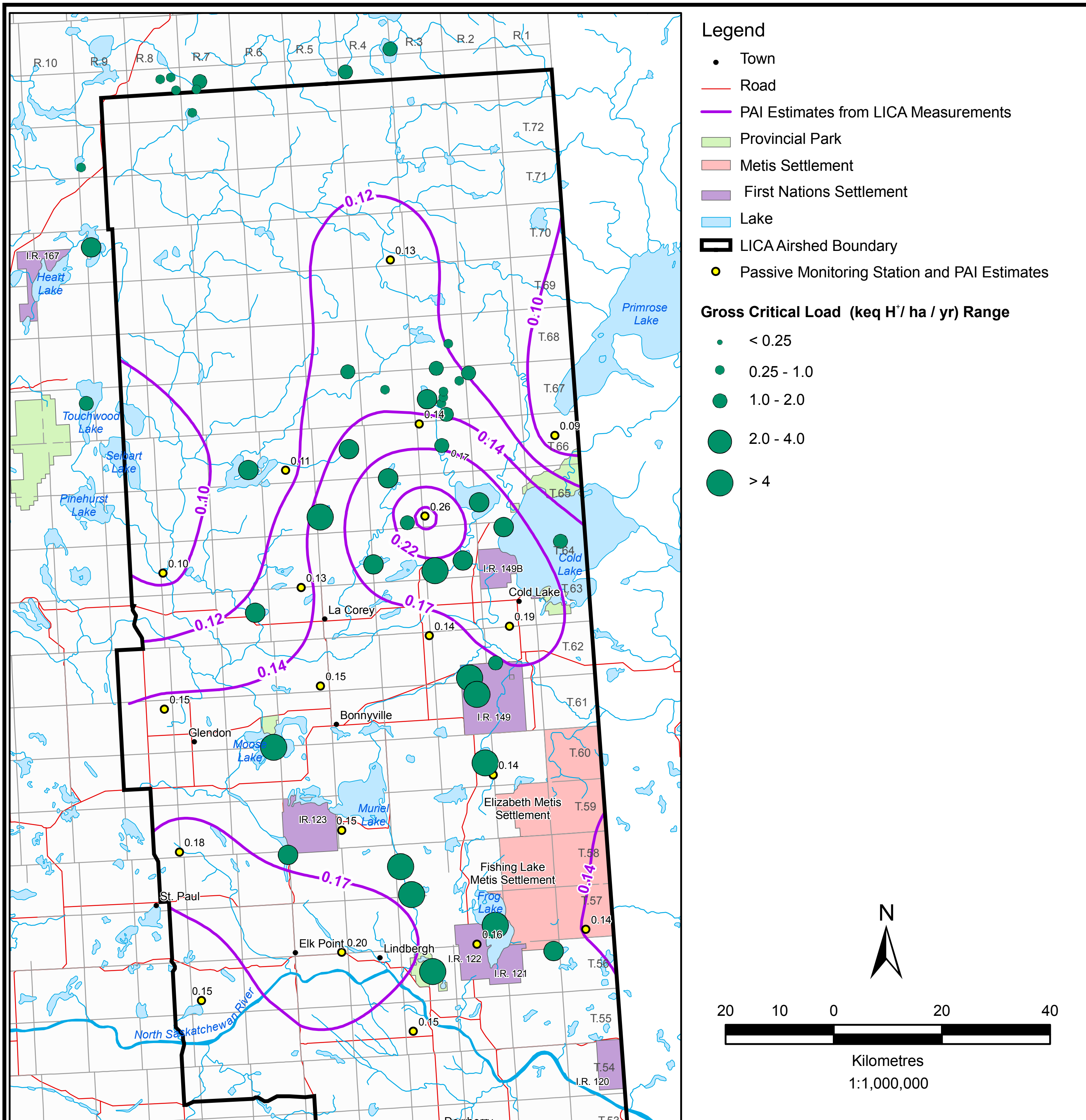



**Figure 4: Comparison of Gross Critical Loads for Lakes in the LICA Study Area**



Map Path: S:\gis\Projects\EE31175_LICA\ArcGIS Projects\Critical_Load.mxd

Lakeland Industry and Community Association (LICA)

Gross Critical Load (keq H+/ ha / yr) for Lakes in the LICA Study Area

| Date: June 2007 | Projection: 10TM AEP Forest | Datum: NAD83 |
|---|---|---|
| Job No: EE31175 | **Figure 5** | |
| GIS File: Critical_Load | | |
| PDF File: Critical_Load_07-06-21 | | |

### 3.5.2 Temporal Changes and Trend Analysis

Temporal water quality data between 1998 and 2006 were available for 12 lakes within the LICA study area. The annual gross critical load was calculated and is presented for these lakes in Figure 6. The surveyed waterbodies displayed little fluctuation in gross critical loads between years. No definitive trend was observed within the period of monitoring. The highest gross critical loads compared to other years were generally observed in 2003, while values for other years remained relatively constant. The largest fluctuations were observed in Laurier Lake, varying between 8.4 keq $H^+$/ha/yr (1998 and 2000) and 10.8 keq $H^+$/ha/yr (2004).

The Mann-Kendall Test was applied to the gross critical loads of six lakes in the study area that had data available for at least five years. The results of the test indicate that gross critical loads are increasing at the 80% confidence interval in Ethel (L4) and Laurier (L10) Lakes (Table 15). No trend could be confirmed at the 90% level of confidence for Ethel Lake; however, an increasing trend was confirmed in Laurier Lake. May Lake (L12) exhibited a decreasing trend in gross critical load which was not supported at the 90% level of confidence. No trends in annual gross critical loads were observed in Bourque (L3), Hilda (L8) or Marie (L11) Lakes at either level of confidence.

### 3.5.3 Comparison with Potential Acid Deposition

The net critical loads for the lakes of the LICA study area were calculated by comparing the gross critical loads of the surveyed lakes (see Section 2.5.1) to airborne deposition levels (i.e., PAI levels), which were computed in Section 2. The difference between these two values (gross critical load minus PAI) represents the net critical load for the lakes.

All lakes in the LICA study area have gross critical loads above the monitoring load for sensitive receptors of 0.17 keq $H^+$/ha/yr and even above the upper limit of critical deposition for sensitive receptors of 0.25 keq $H^+$/ha/yr (CASA and AENV 1999). An airborne depositional rate exceeding 0.17 keq $H^+$/ha/yr was observed in the vicinity of Cold Lake and Elk Point, affecting six lakes within the study area. However, the lakes' gross critical loads were consistently greater than the PAI values for sensitive, moderate or low sensitivity systems.

In the southern portion of the study area (Figure 7), the net critical load ranged between 1.49 keq $H^+$/ha/yr and 9.15 keq $H^+$/ha/yr. The average net critical load observed in these lakes was 4.47 keq $H^+$/ha/yr.

In the northern portion, the net critical load ranged between 0.42 keq $H^+$/ha/yr and 3.32 keq $H^+$/ha/yr. The average net critical load observed in these lakes was 1.28 keq $H^+$/ha/yr.

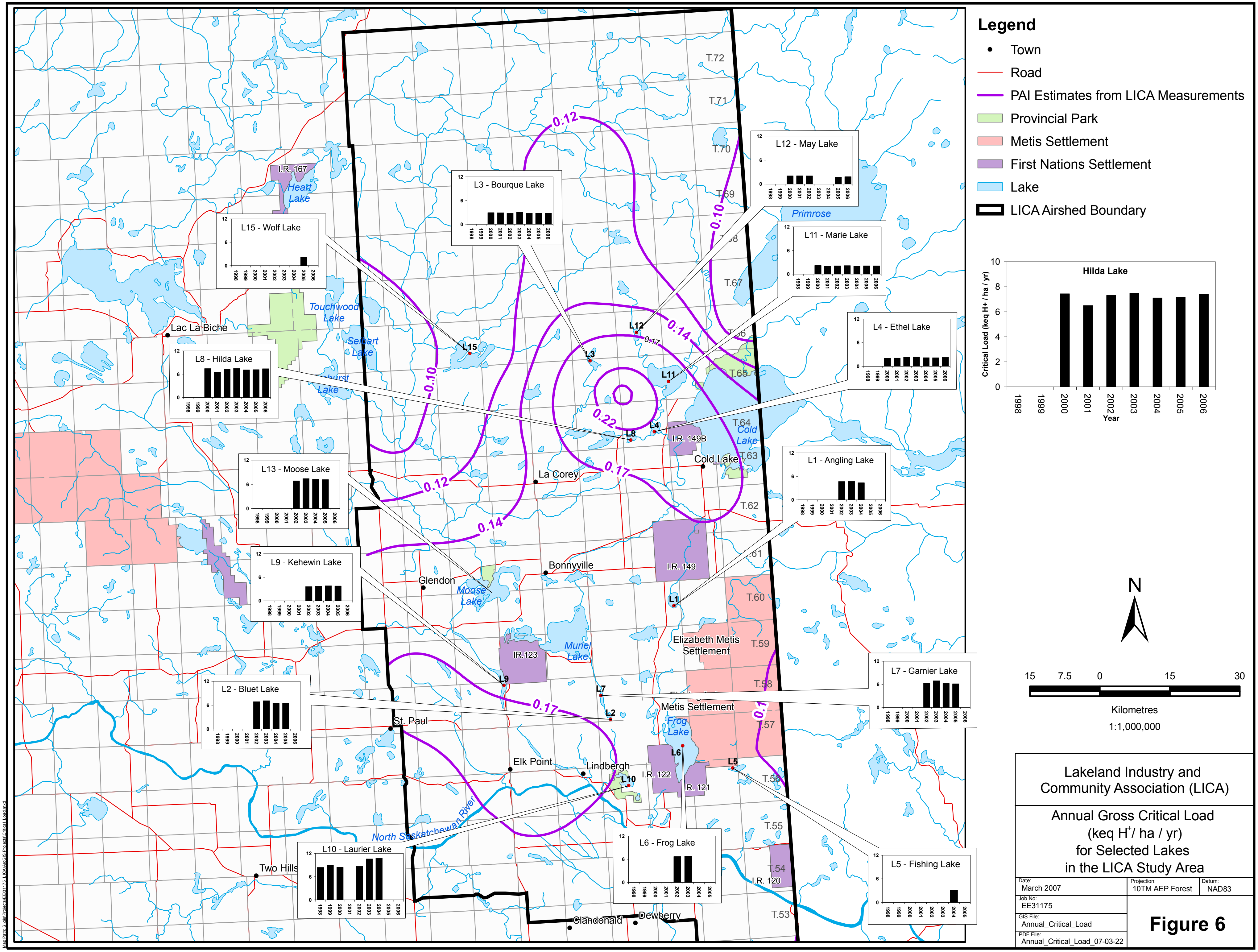
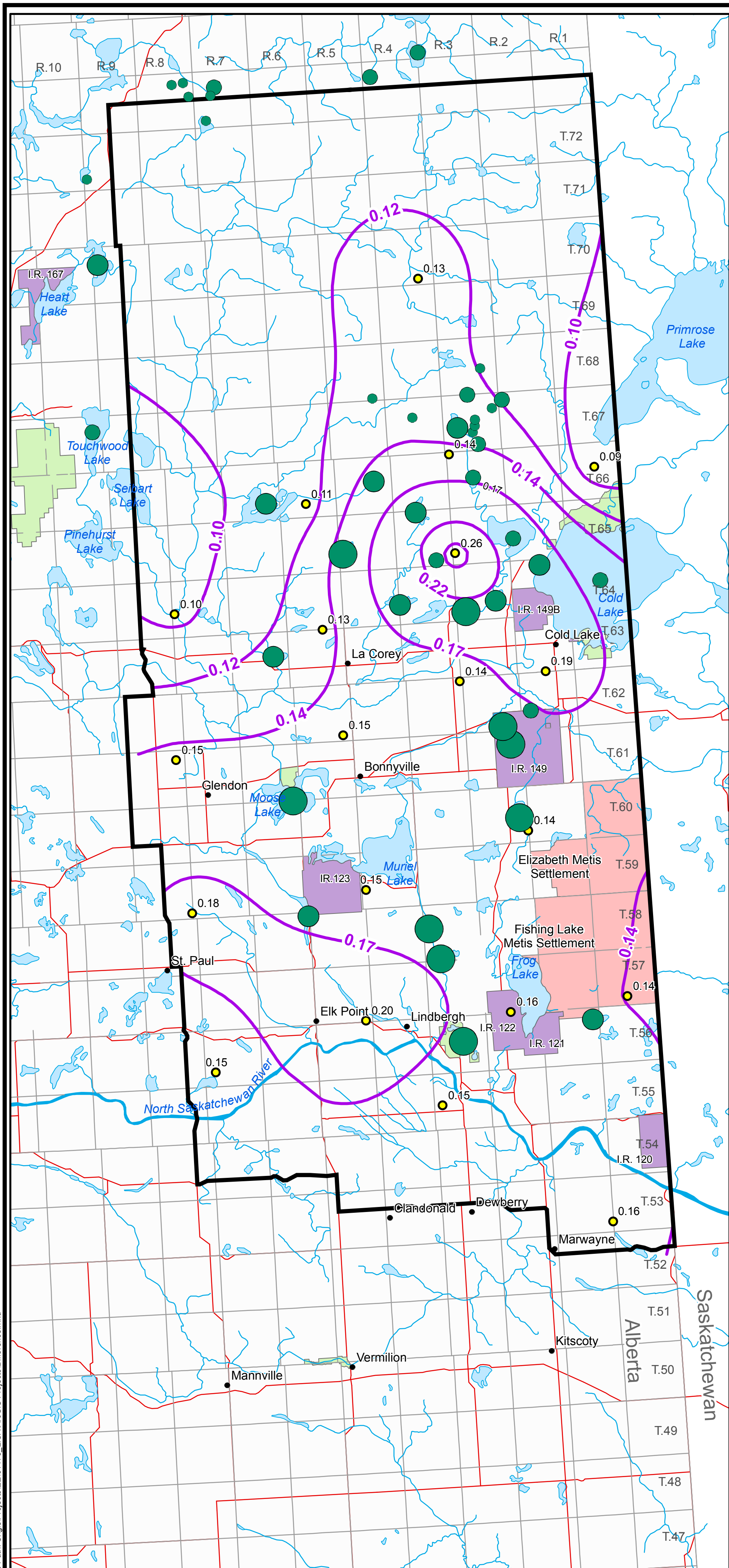

Legend
Town
Road
PAI Estimates from LICA Measurements
Provincial Park
Metis Settlement
First Nations Settlement
Lake
LICA Airshed Boundary
Hilda Lake
Critical Load (keq H+ / ha / yr)
Year
1998
1999
2000
2001
2002
2003
2004
2005
2006
L1 - Angling Lake
L2 - Bluet Lake
L3 - Bourque Lake
L4 - Ethel Lake
L5 - Fishing Lake
L6 - Frog Lake
L7 - Garnier Lake
L8 - Hilda Lake
L9 - Kehewin Lake
L10 - Laurier Lake
L11 - Marie Lake
L12 - May Lake
L13 - Moose Lake
L15 - Wolf Lake
0.10
0.12
0.14
0.17
0.22
Lac La Biche
Heart Lake
I.R. 167
Touchwood Lake
Seibert Lake
Primrose
Cold Lake
I.R. 149B
I.R. 149
La Corey
Bonnyville
Glendon
Moose Lake
Muriel Lake
IR.123
Elizabeth Metis Settlement
Metis Settlement
Frog Lake
I.R. 122
R. 121
St. Paul
Elk Point
Lindbergh
North Saskatchewan River
Two Hills
Clandonald
Dewberry
I.R. 120
T.72
T.71
T.70
T.69
T.67
T.65
T.64
T.63
T.62
T.60
T.59
T.58
T.57
T.56
T.55
T.54
T.53
N
15
7.5
0
15
30
Kilometres
1:1,000,000
Lakeland Industry and Community Association (LICA)
Annual Gross Critical Load (keq H+/ ha / yr) for Selected Lakes in the LICA Study Area
Date: March 2007
Projection: 10TM AEP Forest
Datum: NAD83
Job No: EE31175
GIS File: Annual_Critical_Load
PDF File: Annual_Critical_Load_07-03-22
Figure 6

**Table 15: Results of the Mann-Kendall Test for Gross Critical Loads from Selected Lakes in the LICA Study Area**

| Event | Year | L3 Bourque Lake | L4 Ethel Lake | L8 Hilda Lake | L10 Laurier Lake | L11 Marie Lake | L12 May Lake |
|---|---|---|---|---|---|---|---|
| 1 | 1998 | - | - | - | 8.41 | - | - |
| 2 | 1999 | - | - | - | 8.95 | - | - |
| 3 | 2000 | 2.95 | 2.04 | 7.44 | 8.43 | 2.20 | 2.06 |
| 4 | 2001 | 2.91 | 2.12 | 6.49 | - | 2.04 | 2.07 |
| 5 | 2002 | 2.79 | 2.35 | 7.30 | 8.70 | 2.12 | 2.06 |
| 6 | 2003 | 3.05 | 2.36 | 7.48 | 10.62 | 2.17 | - |
| 7 | 2004 | 2.79 | 2.21 | 7.11 | 10.77 | 2.01 | - |
| 8 | 2005 | 2.81 | 2.19 | 7.17 | - | 2.13 | 1.72 |
| 9 | 2006 | 2.84 | 2.29 | 7.41 | - | 2.12 | 1.85 |
| **Mann Kendall Statistic (S)** | | -5.0 | 7.0 | 1.0 | 11.0 | -5.0 | -6.0 |
| **Number of Rounds (n)** | | 7 | 7 | 7 | 6 | 7 | 5 |
| **Average** | | 2.88 | 2.22 | 7.20 | 9.31 | 2.11 | 1.95 |
| **Standard Deviation** | | 0.100 | 0.118 | 0.342 | 1.092 | 0.067 | 0.159 |
| **Coefficient of Variation (CV)** | | 0.035 | 0.053 | 0.048 | 0.117 | 0.032 | 0.081 |
| **Trend ≥ 80% Confidence Level** | | No Trend | **INCREASING** | No Trend | **INCREASING** | No Trend | **DECREASING** |
| **Trend ≥ 90% Confidence Level** | | No Trend | No Trend | No Trend | **INCREASING** | No Trend | No Trend |




Map Path: S:\gis\Projects\EE31175_LICA\ArcGIS Projects\Difference.mxd

## Legend

- • Town
- Road
- PAI Estimates from LICA Measurements
- Provincial Park
- Metis Settlement
- First Nations Settlement
- Lake
- LICA Airshed Boundary
- Passive Monitoring Station and PAI Estimates

**Net Critical Load (keq H / ha / yr) Range**

- < 0.25
- 0.25 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- > 4

N

20 10 0 20 40

Kilometres

1:1,000,000

# Lakeland Industry and Community Association (LICA)

Net Critical Load [keq $H^+$/ ha / yr]
(Gross Critical Load - Potential Acid Inputs)
for Lakes in the LICA Study Area

| Date: June 2007 | Projection: 10TM AEP Forest | Datum: NAD83 |
|---|---|---|
| Job No: EE31175 | **Figure 7** | |
| GIS File: Difference | | |
| PDF File: Difference_07-06-21 | | |

### 3.5.4 Critical Loads and Water Quality

A regression analysis was conducted in order to develop relationships between major water quality parameters reflecting buffering capacity and critical load for lakes. The statistical relationship between base cation concentrations and alkalinity displayed an adequate regression ($R^2$= 0.97) between these two values (Figure 8). The same $R^2$ value existed between the gross critical loads and alkalinity (Figure 9).

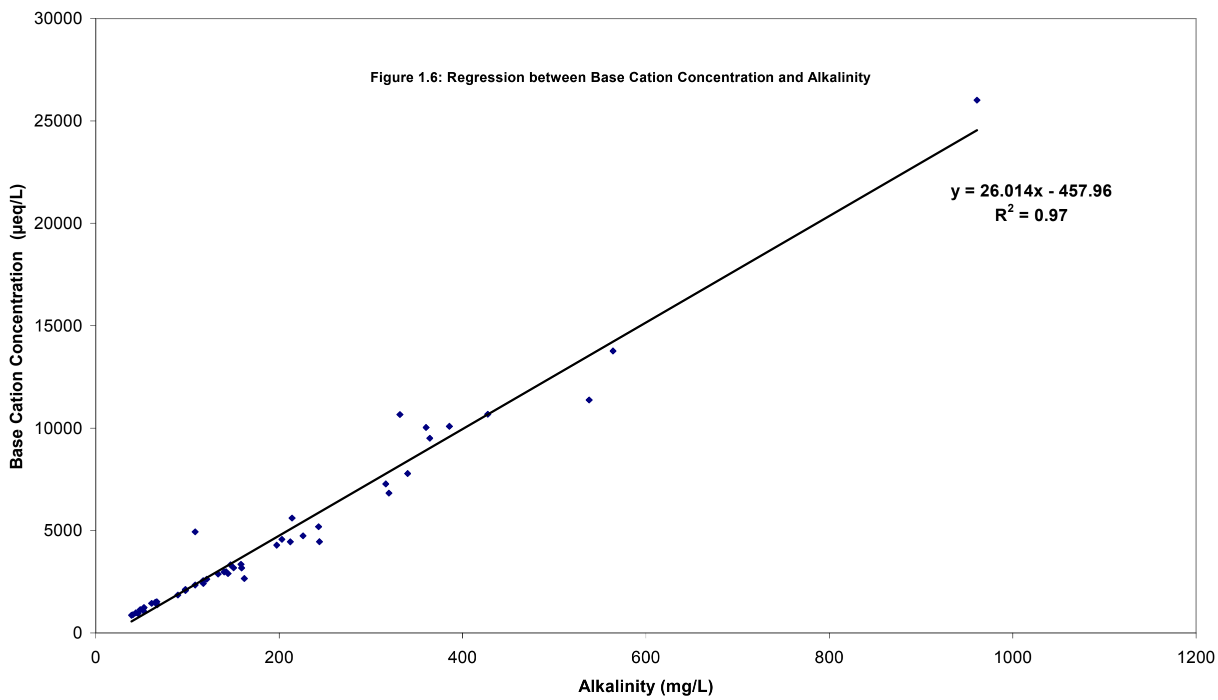



**Figure 8: Regression between Base Cation Concentration and Alkalinity**

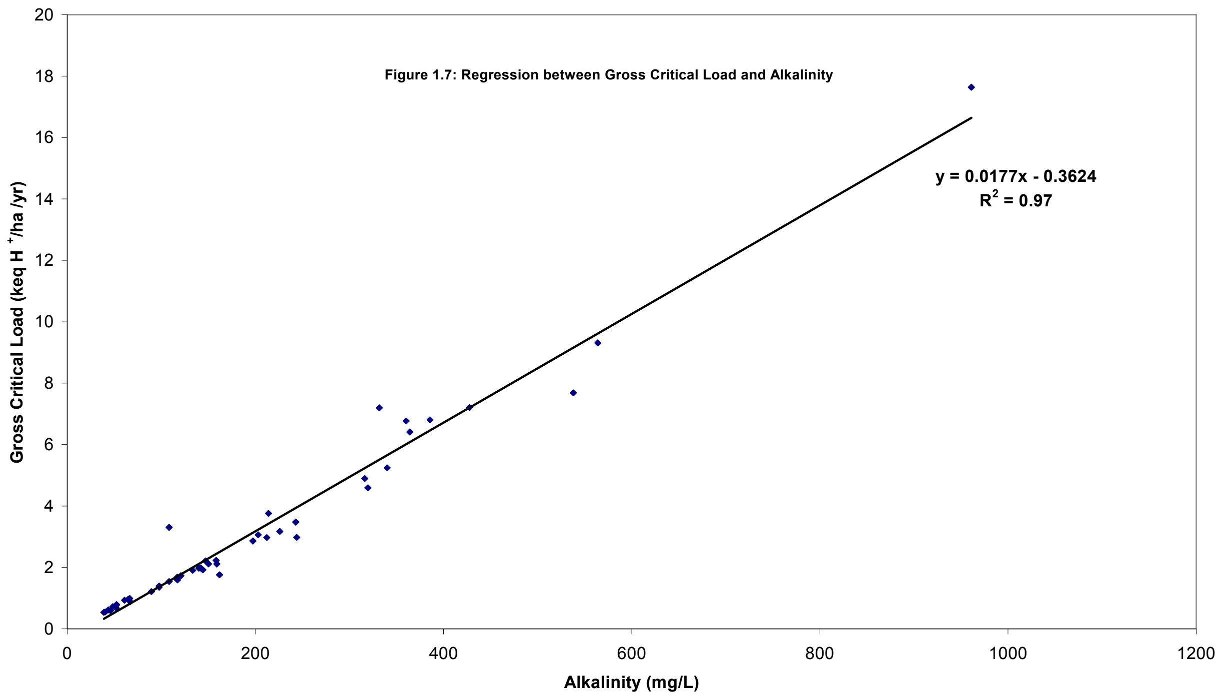



**Figure 9: Regression between Gross Critical Load and Alkalinity**

The regression of specific conductivity and alkalinity ($R^2$= 0.91) was developed and can be applied when base cation data are not available (Figure 10).

Under current climate conditions and annual runoff regimes, specific conductivity can be field measured and directly related to gross critical load, as the regression of these two parameters yielded an $R^2$ value of 0.95 (Figure 11). This regression can also be used in conjunction with the estimated PAI to infer the lowest possible specific conductivity needed to prevent acidification (Table 16). This is useful especially during peak runoffs observed at freshet, where the dilution of base cations can temporarily occur.

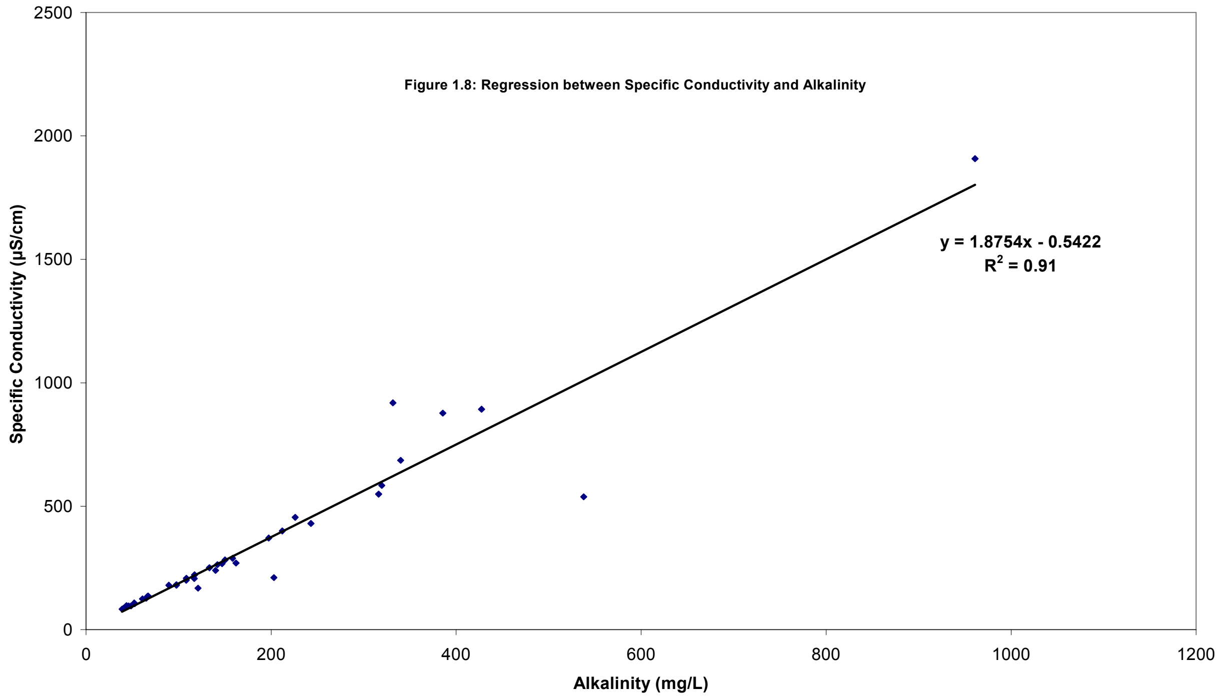



**Figure 10: Regression between Specific Conductivity and Alkalinity**

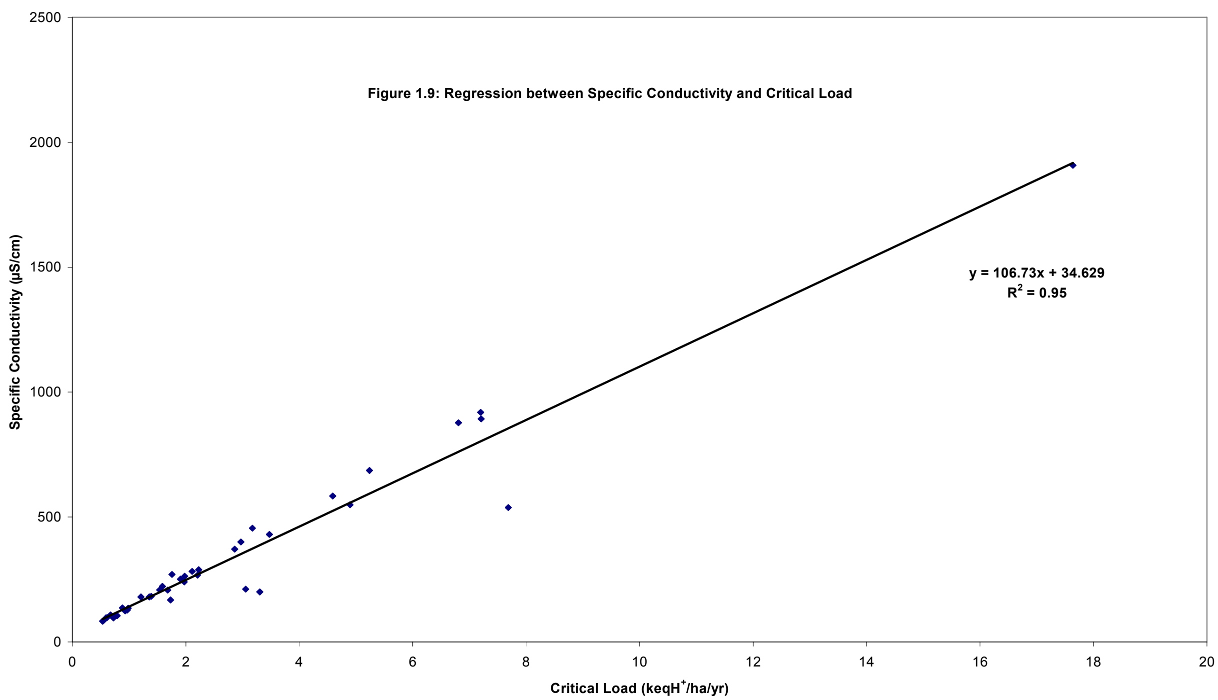



**Figure 11: Regression between Specific Conductivity and Critical Load**

### 3.6 MONITORING AND RECOMMENDATIONS

Lakes within and bordering the LICA study area generally have elevated concentrations of base cations, resulting in relatively high critical load. Lakes in the southern portion of the study area have higher critical loads than those found in the northern section. The acid sensitivity ratings based on Saffran and Trew (1996) support the results from the Henriksen steady state model.

Most of the study area has a depositional rate (PAI) below the CASA monitoring load of 0.17 keq $H^+$/ha/yr. The net critical loads of the lakes remained above 0.25 keq $H^+$/ha/yr, with most lakes registering no appreciable effect from PAIs.

Some lakes in the study area did have resulting critical loads that were under 0.50 keq $H^+$/ha/yr,(Table 14) which increases the risks of acidification if acidifying emissions were to increase in the study area. Bourque (L3), Marie (L11), Ethel (L4), Hilda (L8), Leming (520), Tucker (521), and Dolly (600) Lakes are located within the 0.17 keq $H^+$/ha/yr PAI monitoring load isopleth generated from LICA passive monitors in the region (Section 2). Although these lakes have relatively high critical loads, they could be considered for monitoring by virtue of being located within this PAI isopleth, and being within potentially higher PAI areas in the future as indicated in CNRL (2006). Unnamed Lake 599 has a critical load of 0.42 keq $H^+$/ha/yr. It is located near Burnt Lake in Tp. 67 - R. 3 - W4M, along with some other small lakes that have relatively low critical loads in the range of 0.50 – 1.00 keq $H^+$/ha/yr. These lakes occur close to the 0.25 keq $H^+$/ha/yr isopleth for the 'Existing and Approved Conditions' scenario of the Primrose East Expansion EIA of CNRL (2006). Because of the proximity between critical loads and predicted PAI values, monitoring is recommended for some of these lakes

Relationships exist between major cations, alkalinity and conductivity, all of which reflect the buffering capacity in a water body. The regression equations developed between gross critical load, alkalinity and specific conductivity makes it possible for future monitoring to be conducted in an inexpensive fashion.

Specific conductivity can be measured in-situ, using a conductivity probe. The field results can then be computed into sum of base cations or, in some cases, into gross critical loads through the regression between specific conductivity and alkalinity, and then between alkalinity and gross critical load, or through direct regression between specific conductivity and gross critical loads. Constant runoff is an important condition in application of the regression equation for gross critical loads because it is one of the major components governing the gross critical load calculations.

As noted previously, monitoring is recommended particularly for lakes with critical loads <0.50 keq $H^+$/ha/yr, and for lakes within the PAI isopleth >0.17 keq $H^+$/ha/yr. The data presented herein are sufficient to support a monitoring framework; however, the design of a monitoring program would require some time to develop. The locations for monitoring should be identified based on habitat sensitivity and acid depositional factors. In this regard, consideration should be given to co-location of water quality and air monitoring stations. The frequency and timing of

## Table 16: Minimum Specific Conductivity Required to Prevent Acidification in Lakes in the LICA Study Area

| Lake Identifier | Lake Name | Zone | Easting | Northing | Observed Specific Conductivity (µS/cm) | Current Gross Critical Load ($keqH^+/ha/yr$) | Potential Acid Inputs ($keqH^+/ha/yr$) | Minimum Specific Conductivity (µS/cm) |
|---|---|---|---|---|---|---|---|---|
| **LICA Study Area** | | | | | | | | |
| 43 | Ipitiak Lake | 12 | 496692 | 6127900 | 136 | 0.88 | 0.11 | 46 |
| 60 | Burnt Lake | 12 | 536930 | 6072588 | 200 | 3.30 | 0.13 | 49 |
| 61 | Unnamed Lake | 12 | 540333 | 6069577 | 207 | 1.68 | 0.14 | 50 |
| 62 | Unnamed Lake | 12 | 539546 | 6071719 | 105 | 0.79 | 0.13 | 49 |
| 63 | Unnamed Lake | 12 | 539930 | 6072774 | 124 | 0.93 | 0.13 | 49 |
| 64 | Unnamed Lake | 12 | 540067 | 6073823 | 127 | 0.97 | 0.13 | 49 |
| 65 | Unnamed Lake | 12 | 543092 | 6075676 | 105 | 0.76 | 0.13 | 49 |
| 66 | Unnamed Lake | 12 | 544835 | 6076985 | 182 | 1.39 | 0.12 | 47 |
| 67 | Unnamed Lake | 12 | 538930 | 6078203 | 180 | 1.36 | 0.13 | 49 |
| 68 | Unnamed Lake | 12 | 541457 | 6082627 | 96 | 0.73 | 0.12 | 47 |
| 516 | Sinclair Lake | 12 | 522000 | 6064200 | 430 | 3.47 | 0.15 | 51 |
| 518 | Marguerite Lake | 12 | 516000 | 6052000 | 538 | 7.68 | 0.15 | 51 |
| 520 | Leming Lake | 12 | 532000 | 6050000 | 168 | 1.73 | 0.24 | 60 |
| 521 | Tucker Lake | 12 | 525300 | 6042700 | 400 | 2.97 | 0.20 | 56 |
| 546 | Cold Lake | 12 | 560000 | 6045000 | 240 | 1.97 | 0.15 | 51 |
| 547 | Moore Lake | 12 | 543043 | 6017650 | 686 | 5.24 | 0.16 | 52 |
| 594 | McDougall Lake | 12 | 546792 | 6023259 | - | 1.92 | 0.16 | 52 |
| 595 | Unnamed Lake | 12 | 541860 | 6020776 | 549 | 4.89 | 0.16 | 52 |
| 596 | Manatokan Lake | 12 | 503000 | 6035000 | 211 | 3.06 | 0.13 | 49 |
| 597 | Unnamed Lake | 12 | 522600 | 6078500 | 270 | 1.76 | 0.13 | 49 |
| 599 | Unnamed Lake | 12 | 529300 | 6074800 | 86 | 0.55 | 0.13 | 49 |
| 600 | Dolly Lake | 12 | 549700 | 6048200 | - | 2.98 | 0.18 | 54 |
| L1 | Angling Lake | 12 | 542500 | 6005000 | 584 | 4.59 | 0.15 | 51 |
| L2 | Bluet Lake | 12 | 528500 | 5979500 | - | 6.77 | 0.16 | 52 |
| L3 | Bourque Lake | 12 | 528900 | 6058400 | 371 | 2.86 | 0.20 | 56 |
| L4 | Ethel Lake | 12 | 541800 | 6042450 | 289 | 2.23 | 0.21 | 57 |
| L5 | Fishing Lake | 12 | 550000 | 5971000 | 455 | 3.17 | 0.15 | 51 |
| L6 | Frog Lake | 12 | 543000 | 5975000 | 877 | 6.81 | 0.15 | 51 |
| L7 | Garnier Lake | 12 | 527500 | 5985000 | - | 6.41 | 0.15 | 51 |
| L8 | Hilda Lake | 12 | 536600 | 6040900 | 893 | 7.21 | 0.21 | 57 |
| L9 | Kehewin Lake | 12 | 506500 | 5990000 | - | 3.76 | 0.16 | 52 |
| L10 | Laurier Lake | 12 | 532000 | 5967000 | - | 9.31 | 0.16 | 52 |
| L11 | Marie Lake | 12 | 547000 | 6064900 | 282 | 2.11 | 0.20 | 56 |
| L12 | May Lake | 12 | 539150 | 6063900 | 251 | 1.91 | 0.17 | 53 |
| L13 | Moose Lake | 12 | 505000 | 6010000 | 919 | 7.20 | 0.15 | 51 |
| L14 | Muriel Lake | 12 | 520000 | 6000000 | 1908 | 17.64 | 0.15 | 51 |
| L15 | Wolf Lake | 12 | 503222 | 6061410 | - | 2.11 | 0.11 | 46 |
| **Lakes Bordering the LICA Study Area** | | | | | | | | |
| 45 | Unnamed Lake | 12 | 497711 | 6132160 | 83 | 0.53 | 0.11 | 46 |
| 46 | Unnamed Lake | 12 | 498367 | 6133579 | 180 | 1.21 | 0.11 | 46 |
| 47 | Unnamed Lake | 12 | 493933 | 6132222 | 108 | 0.68 | 0.11 | 46 |
| 48 | Unnamed Lake | 12 | 491151 | 6134421 | 97 | 0.61 | 0.11 | 46 |
| 49 | Unnamed Lake | 12 | 493107 | 6134651 | 96 | 0.59 | 0.11 | 46 |
| 132 | Grist Lake | 12 | 533788 | 6137575 | 222 | 1.59 | 0.11 | 46 |
| 239 | Unnamed Lake | 12 | 525364 | 6133813 | 208 | 1.54 | 0.11 | 46 |
| 250 | Unnamed Lake | 12 | 475613 | 6118973 | 135 | 0.98 | 0.11 | 46 |
| 259 | Logan Lake | 12 | 476591 | 6104122 | 267 | 2.21 | 0.11 | 46 |
| 536 | Touchwood Lake | 12 | 474032 | 6075393 | 263 | 1.98 | 0.10 | 45 |

monitoring would need to be identified through further research into the hydrologic regimes, climatic variations and limnological characteristics, in order to provide LICA with representative data of the study area. Monitoring protocols would need to be established to ensure continuity and compatibility between the data.

# 4.0 SOILS AND VEGETATION

Possible impacts of acidic and acidifying substances on soils include changes in chemical properties such as pH, exchangeable base saturation, and levels of soluble aluminum in soils. The lowering of pH and increase in soluble aluminum beyond threshold levels are associated with plant growth impacts due to toxicity or to inability to take up plant nutrients. Further-reaching effects include changes in the nature of organic matter and changes to overall nutrient dynamics. An in depth review of potential impacts of acidity on soils in Alberta can be found in Turchenek et al. (1987).

## 4.1 STUDY APPROACHES AND METHODS

The potential effects of acid deposition on soils and vegetation in the LICA area were examined using the following approaches:

- Assessment and mapping the sensitivity of soils to acidic and acidifying substances in the LICA study area;
- Determination of potential exceedances of acidity for soils based on proposed critical load levels;
- Review of information about soil monitoring in the study area; and
- Review of information about vegetation monitoring in the study area.

### 4.1.1 Soil Sensitivity Mapping

Soil sensitivity to acidification refers to the ease by which soils can be affected or influenced by acidic and acid forming substances. Soil sensitivity rating schemes have been developed for the purposes of grouping soil types and their associated geographic areas into sensitivity classes and for predicting the impact of acid inputs to soil chemical properties such as pH and base saturation. Effects on other soil properties such as organic matter and nutrient dynamics are not considered in these soil sensitivity rating systems because insufficient information exists to support criteria development. Initially, soil acidification may lead to a decrease in soil pH, leaching of base cations, and increased solubility of toxic acid cations such as aluminum (Al) (Turchenek et al., 1987). In sensitivity ratings systems, soils are categorized as having high, medium or low sensitivity ratings based on select criteria; these criteria vary with the sensitivity classification approach. A discussion of sensitivity ratings can be found in Turchenek at al. (1987) and Holowaychuk and Fessenden (1987). A system developed for Western Canada by Wiens et al. (1987) was applied in Alberta by Holowaychuk and Fessenden (1987). The sensitivity mapping was applied to broad areas of land at a small mapping scale. More recently, the system was applied at a higher scale in a study of soil sensitivity in the Provost-Esther area, Alberta (Turchenek and Abboud 2001).

The sensitivity of mineral soils to acid deposition was evaluated using the criteria in Holowaychuk and Fessenden (1987). In applying these criteria, sensitive, moderate sensitivity and low sensitivity ratings, with respect to losses of base cations, to acidification (pH decrease) and to aluminum solubilization, are applied to the pH-CEC categories, and an overall sensitivity category is then assigned (Table 17). In general, decreasing pH and/or CEC of a soil is proportional to increasing overall sensitivity of the soil. [Holowaychuk and Fessenden (1987) used the term 'high sensitivity'; this is changed herein to the term 'Sensitive' based on usage recommended by CASA and AENV (1996, 1999).]

**Table 17: Criteria for Rating the Sensitivity of Mineral Soils to Acidic Inputs[Z]**

| Soil Property | | Sensitivity to: | | | |
|---|---|---|---|---|---|
| **Cation Exchange Capacity (cmol (+)/kg)[Y]** | **pH** | **Base Loss** | **Acidification** | **Aluminum Solubilization** | **Overall Sensitivity** |
| <6 | <4.6 | S[X] | S | S | S |
| | 4.6–5.0 | S | S | S | S |
| | 5.1–5.5 | S | M | S | S |
| | 5.6–6.0 | S | S | M | S |
| | 6.1–6.5 | S | S | L | S |
| | >6.5 | L | L | L | L |
| 6-15 | <4.6 | S | L | S | S |
| | 4.6–6.0 | M | L | S | M |
| | 5.1–5.5 | M | L–M | M | M |
| | 5.6–6.0 | M | L–M | L–M | M |
| | >6.0 | L | L | L | L |
| >15 | <4.6 | S | L | S | H |
| | 4.6–5.0 | M | L | S | M |
| | 5.1–5.5 | M | L | M | M |
| | 5.6–6.0 | L | L–M | L–M | L |
| | >6.0 | L | L | L | L |

[Z] Source: Holowaychuk and Fessenden (1987)
[X] Centimoles of cation per kilogram of soil
[Y] Abbreviations: L - Low sensitivity; M - Moderate sensitivity; S - Sensitive

Holowaychuk and Fessenden (1987) provided sensitivity rating criteria for Organic soils as well as mineral (upland) soils. Turchenek et al. (1998) reviewed the sensitivity of peatlands to acidification and recommended modifications to the ratings of peatlands. The modified ratings, as indicated in Table 18, were applied in the LICA area.

**Table 18. Acidification Sensitivity Ratings for Peatlands.**

| Peatland Type | Sensitivity to: | | | Rating |
|---|---|---|---|---|
| | Base Loss | Acidification | Aluminum Solubilization | |
| Eutrophic - Extreme Rich Fen | Low | Low | n/a | Low |
| Mesotrophic - Moderate Rich Fen | Low - Medium | Low | n/a | Low |
| Oligotrophic - Bog & Poor Fen | Medium - High | Medium | n/a | Medium |

[z] Source: Turchenek et al. (1998)

Soil map information used for derivation of sensitivity ratings was obtained from the Agricultural Region of Alberta Soil Information Database (AGRASID) (Alberta Soil Information Centre: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903) for the southern part of the region. The AGRASID database provides soil survey coverage along with descriptions of Soil Series, including typical soil chemical attributes.

Soil distribution is presented in the AGRASID database within a hierarchical framework based on the National Ecological Framework for Canada (Marshall and Schul 1999). The LICA study area is within the Prairies Ecozone. An Ecozone is an area that is representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors. Canada is divided into 15 terrestrial ecozones.

An Ecoregion is a part of an Ecozone characterized by distinctive ecological responses to climate as expressed by the development of vegetation, soil, water, fauna, etc. (Marshall and Schul 1999). The study area is located within the Aspen Parkland, Boreal Transition and Mid-Boreal Uplands Ecoregions. Descriptions of each of these are presented in Section 1.

An Ecodistrict is a subdivision of an Ecoregion characterized by distinct assemblages of landform, relief, surficial geologic material, soil, water bodies, vegetation and land uses (Marshall and Schul 1999). The soil mapping system in AGRASID further subdivides Ecodistricts into Land Systems. A Land System is a subdivision of an Ecodistrict recognized and separated by differences in one or more of general pattern of land surface form, surficial geologic materials, amount of lakes or wetlands, or general soil pattern. All Land Systems within one Ecodistrict have the same general climate for agriculture, but differences in microclimatic pattern can be recognized. Land Systems are further divided into Soil Landscapes, which are land areas that display a consistent and recognizable pattern of distribution of soils and landscape elements (Alberta Soil Information Centre: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903). Soil Landscapes are the level at which most soil survey information is presented. The AGRASID database provides soil survey information at a scale equivalent to about 1:100,000. Somewhat larger scale information is available from the soil surveys carried out for environmental impact assessments in the LICA area. However, for purposes of assessing soil sensitivity to acidification on a regional basis, use of a smaller scale is spatially more appropriate (e.g., for presentation purposes) and also less wieldy as compared to the large amount of data that would be handled at a larger scale. Therefore, soil types as identified at the more generalized Land System level were applied in assessing sensitivity. This provides information at a lower level of detail, but at a somewhat greater level than that of the land units applied in soil sensitivity mapping by Holowaychuk and Fessenden (1987). Consequently, Land System information was considered to be a practical basis for refining the previous soil sensitivity mapping and for calculating critical loads.

Land Systems coverage in the AGRASID database is provided only for the agricultural regions of Alberta. For the northern part of the study area beyond the agricultural zone, a similar mapping concept was applied based on the CanSIS database for land systems (National Land and Water Information Service: http://res.agr.ca/cansis/nsdb/slc/intro.html). The level of detail in the national system lies between that of the Land System in the AGRASID database, and the Ecodistrict in the National Ecological Framework for Canada. Thus, the delineations in the northern part of the LICA area are more generalized and larger than those on the southern boreal and agricultural regions. The term 'Land System' was adopted for both of these mapping concepts in this report.

Each of these databases describes soil composition of Land Systems in terms of proportions of Soils Series. A Soil Series is a fundamental taxonomic level in the Canadian System of Soil Classification, defined as a particular Soil Subgroup on a specific parent material (Soil Classification Working Group 1998). For example, the Athabasca soil series is defined as an Orthic Gray Luvisol developed in moderately fine textured Morainal (glacial till) material. Naming of Soil Series is based on Alberta Soil Names, Generation 3 in the AGRASID soil names file (Alberta Soil Information Centre: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903). Within AGRASID, each Soil Series is described in terms of a typical soil profile within the associated database referred to as the Soil Layer File. This file was the source of information for soil pH and cation exchange capacity required to develop a sensitivity rating from the system of Holowaychuk and Fessenden (1987), as presented in Table 17 above.

Since the Soil Layer File provides only one soil profile description (with chemical analysis of horizons), other soil survey reports both within and neighbouring the LICA area were referenced to corroborate the data provided. Information from environmental impact assessments and development plans of oil production companies in the LICA area was also applied in this way. A list of publications referred to for soil information is included in the annotated bibliography in this report, and available soil chemistry information is summarized in Appendix B1.

The Sensitive, Moderate sensitivity, and Low sensitivity categories were developed for each of the Land Systems in the LICA area. In some cases, combinations of sensitivity classes were applicable. The spatial coverages of the Land Systems were superimposed on a base map of the study area using ARCGIS©. The colour scheme of the original Holowaychuk and Fessenden (1987) report, with modifications for complex map units, was applied in designating the sensitivity class or classes of the Land Systems.

### 4.1.2 Potential Critical Load Exceedance Mapping

The critical load represents the level of sustained deposition of a substance that will not cause long-term harmful change to an ecosystem. The critical load is thus dependent on the inherent characteristics of the ecosystem, and is a property of the ecosystem. Nilsson and Grennfelt (1988) specifically defined the critical load for acidic deposition to soils as "*the highest deposition of acidifying compounds that will not cause chemical changes in the soil which will lead to long-term harmful effects on the structure and function of the ecosystem*".

The critical load concept has been applied to the deposition of acidifying substances, heavy metals and other contaminants on soils, waters and other receptors. Essentially, the concept of critical loads was originally adopted in the European Union and later in North America as a method for development and implementation of control strategies for air pollutants. A recent description of approaches and methods for critical load derivation is provided by Task Force on Mapping and Modelling (2004). In Canada, the history of critical loads applications has been discussed by Jeffries and Ouimet (2004), and critical loads studies have been carried out on upland forest ecosystems throughout eastern Canada, and most recently for forest soils in Manitoba and Saskatchewan (Aherne and Watmough, 2006).).

In 1999, Alberta Environment implemented the Acid Deposition Management Framework for the long-term, provincial management of acid deposition (Clean Air Strategic Alliance and Alberta Environment, 1999). This framework is based upon the current understanding of the levels of acid deposition and the sensitivity of soil and water receptors in the province. Critical loads are the foundation of the framework. Potential effects on soils in the LICA area were assessed by reference to critical loads, as well as to target and monitoring loads. The framework within which these loads are applied is described in Section 2.2.2 of this report.

The possible exceedance of monitoring, target and critical loads for soils in the LICA study area was examined by superimposing the PAI isopleths (Section 2) on the Land System map using ArcGIS© (ESRI Canada). Areas of soils exceeding the monitoring, target and critical loads were then determined using GIS techniques.

### 4.1.3 Soil and Vegetation Monitoring

Soil and vegetation monitoring programs in the LICA study area and in other parts of the province were reviewed using currently available information.

## 4.2 ACIDIFICATION SENSITIVITY RATING OF SOILS

### 4.2.1 Sensitivity Ratings of Soil Series

A list of the main soil series occurring in the LICA study area was derived from the component listings of each Land System. Soil chemical attributes of the soil series were then tabulated from the AGRASID database and the sensitivity classes were derived by reference to the criteria presented in Tables 17 and 18. The soil series sensitivity ratings are presented in Table 19, which is based on the sensitivity class derivation presented in Appendix B2.

## Table 19: Acidification Sensitivity of Soil Series in the LICA Study Area

| Symbol | Series | Drainage | Calcar | Salinity | PM1 Texture | PM1 Type | PM2 Texture | PM2 Type | Soil Subgroup | Sensitivity Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| Soils of the Thick Black Soil Zone of Central and East Central Alberta | | | | | | | | | | |
| AGS | Angus Ridge | W | M | N | MF | TILL | - | - | E.BL | L |
| BVH | Beaverhills | W | M | N | MF | TILL | - | - | O.BL | L |
| COA | Cooking Lake | W | M | N | MF | TILL | - | - | O.GL | L |
| FTH | Ferintosh | W | W | N | GRVC | GLFL | - | - | O.BL | L |
| GBL | Gabriel | W | M | N | MC | GLFL | MF | TILL | D.GL | L |
| GRZ | Gratz | W | M | N | ME | FLUV | - | - | CU.HR | L |
| HBG | Horburg | R | M | N | GRVC | GLFL | - | - | BR.GL | M |
| HLW | Helliwell | W | W | N | VC | GLFL | - | - | O.DG | L |
| KVG | Kavanagh | MW | W | W | MF | SRFS | - | - | BL.SS | M |
| MDR | Mundare | W | W | N | VC | FLEO | - | - | O.BL | L |
| MSW | Mooswa | W | M | N | MC | GLFL | - | - | E.BL | L |
| PHS | Peace Hills | W | W | N | MC | GLFL | - | - | O.BL | L |
| PRM | Primula | R | N | N | VC | GLFL | - | - | E.EB | S |
| RDW | Redwater | W | W | N | MC | GLFL | - | - | O.DG | L |
| RLV | Rolly View | W | M | N | MF | TILL | - | - | O.DG | L |
| SLW | Slawa | W | W | N | FI | TILL | - | - | E.BL | L |
| TWH | Two hills | W | W | N | GRVC | GLFL | - | - | O.DG | L |
| UCS | Uncas | W | M | N | MF | TILL | - | - | D.GL | L |
| UKT | Ukalta | W | M | N | MC | GLFL | MF | TILL | O.BL | L |
| Soils of the Dark Gray – Gray Soil Zone of Northeast Central Alberta | | | | | | | | | | |
| ADM | Ardmore | W | M | N | ME | GLLC | - | - | E.BL | L |
| EDW | Edwand | R | W | N | VGVC | GLFL | - | - | E.EB | S |
| FNC | Franchere | W | M | N | MF | GLLC | - | - | O.GL | M |
| FRY | Fergy | W | M | N | MF | TILL | - | - | E.BL | L |
| KHW | Kehiwin | W | M | N | MF | TILL | - | - | O.DG | L |
| LCY | La Corey | W | M | N | MF | TILL | - | - | O.GL | M |
| MNT | Manatokan | VP | N | N | O | FNPT | MC | GLFL | T.M | L-M |
| MPV | Mapova | P | M | N | MF | TILL | - | - | HU.LG | L |
| NIT | Nicot | R | W | N | VC | GLFL | - | - | E.EB | S |
| NTW | Nestow | R | N | N | VC | GLFL | - | - | E.DYB | S |
| SDN | Spedden | W | M | N | MF | TILL | - | - | D.GL | L |
| TNW | Tawatinaw | W | W | N | GRMC | TILL | - | - | O.GL | S |
| VIL | Vilna | I | M | N | MF | TILL | - | - | GLE.BL | L |
| Soils of the Central Mixedwood Area of Northeastern Alberta | | | | | | | | | | |
| ABC | Athabasca | W | W | N | MF | TILL | - | - | O.GL | S |
| BLA | Birkland | VP | N | N | O | SPPT | MF | TILL | T.F | L-M |
| GMT | Grosmont | W | W | N | MF | TILL | - | - | D.GL | S |
| GOG | Goodridge | W | W | N | MC | TILL | - | - | O.GL | S |
| LIZ | Liza | R | N | N | VC | GLFL | - | - | E.DYB | S |
| LRD | Lessard | W | M | N | ME | GLLC | - | - | O.DG | L |
| PIN | Pinehurst | R | W | N | VGVC | GLFL | - | - | E.EB | S |
| SLN | St. Lina | VP | N | N | O | FNPT | MF | GLLC | THU.M | L-M |
| TCK | Tucker | VP | W | N | O | SPPT | VC | FLUV | TME.F | M |

## Table 19: Acidification Sensitivity of Soil Series in the LICA Study Area (concluded)

| Symbol | Series | Drainage | Calcar | Salinity | PM1 Texture | PM1 Type | PM2 Texture | PM2 Type | Soil Subgroup | Sensitivity Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| Soils of the Central Mixedwood of Central and Northern Alberta | | | | | | | | | | |
| MUS | Muskeg | VP | N | N | O | SPPT | - | - | TY.M | M |
| HLY | Hartley | VP | N | N | O | FOPT | MF | TILL | T.F | L-M |
| MIL | Mildred | R | N | N | VC | GLFL | - | - | E.DYB | S |
| MLD | McClelland | VP | N | N | O | FNPT | - | - | TY.M | L-M |
| Miscellaneous Soil and Land Types | | | | | | | | | | |
| ZCOzdg | Coarse textured with Dark Gray soils | | | | | | | | | L |
| ZERzbl | Eroded with Black soils | | | | | | | | | L |
| ZERzdg | Eroded, with Dark Gray soils | | | | | | | | | L |
| ZGW | Poorly drained % Shallow water | | | | | | | | | L |
| ZOR | Organic soils | | | | | | | | | L-M |
| ZUN | Undifferentiated | | | | | | | | | L |
| ZWA | Water bodies | | | | | | | | | na |

Abbreviations:

Drainage: VR - very rapid; R - rapid; W - well; MW – moderately well; I - imperfect; P - poor; VP - very poor.

Calc (calcareousness) and Salinity: N – non; W – weak; M – moderate

PM1 (upper parent material), PM2 (lower parent material):

PM Texture: VC – very coarse; C – coarse; GRVC – gravelly very coarse; MC – moderately coarse; GRMC – gravelly moderately coarse; ME – medium; MF – moderately fine; FI – fine;

PM Type: TILL – glacial till, or morainal; GLFL – glaciofluvial; FLUV – fluvial; FLEO – fluvioeolian; GLLC – glaciolacustrine; SRFS – soft rock; FNPT – fen peat; SPPT – sphagnum peat

Soil Subgroup: Defined below in context of the Canadian System of Soil classification

| Order | Great Group | Subgroups |
|---|---|---|
| Brunisolic - Sufficient development to exclude from the Regosolic order, but lack degrees or kinds of development specified for other orders. | Eutric Brunisol - Ah<10 cm, pH>5.5<br>Dystric Brunisol - Ah<10 cm, pH<5.5 | E.EB - Eluviated Eutric Brunisol<br>E.DYB - Eluviated Dystric Brunisol |
| Regosolic - Development too weak to meet requirements of any other Order. | Regosol – Ah<10 cm, Bm absent or <5 cm<br>Humic Regosol – Ah≤10 cm, Bm absent or <5 cm | (Non in above table) |
| Chernozemic - Surface horizons darkened by accumulation of organic matter from decomposition of grassland vegetation. | Black Chernozem - Black Ah, semiarid climate<br>Dark Gray Chernozem - Dark Gray Ah, semiarid climate | O.BL – Orthic Black<br>E.BL – Eluviated Black<br>O.DG – Orthic Dark Gray |
| Gleysolic - Features indicative of periodic or prolonged water saturation, and reducing conditions - mottling and gleying. | Humic Gleysol - Ah≥10 cm, no Bt<br>Gleysol - Ah≤10 cm, no Bt<br>Luvic Gleysol - Has a Btg, usually has an Ahe or an Aeg | O.LG - Orthic Luvic Gleysol<br>HU.LG - Humic Luvic Gleysol<br>O.G - Orthic Gleysol |
| Luvisolic - Light coloured eluvial horizons - Ae; illuvial B horizons of silicate clay accumulation - Bt; developed under forest vegetation. | Gray Luvisol - May or may not have Ah, has Ae and Bt, usually MAST ≤8 degrees Celsius[Y] | O.GL - Orthic Gray Luvisol<br>D.GL - Dark Gray Luvisol<br>GL.GL - Gleyed Gray Luvisol<br>GLD.GL - Gleyed Dark Gray Luvisol<br>BR.GL - Brunisolic Gray Luvisol |
| Organic<br>(Composed dominantly of organic materials; most are water saturated for prolonged periods) | Mesisol - Dominantly mesic<br>Fibrisol - Dominantly fibric | T.F. - Terric Fibrisol<br>T.M. - Terric Mesisol<br>TF.M - Terric Fibric Mesisol<br>TM.F - Terric Mesic Fibrisol<br>TY.F - Typic Fibrisol<br>M.F - Mesic Fibrisol<br>TY.M - Typic Mesisol<br>F.M - Fibric Mesisol |

Z Source: Soil Classification Working Group (1998). Y MAST = mean annual soil temperature.

### 4.2.2 Soil Series Composition of Land Systems

Land Systems are characterized by a number of soil types due to variations in parent materials and to factors such as drainage and topography. The predominant soil types in the Land Systems mapped in the LICA study area are indicated in Table 20. The same table with additional information is presented in Appendix B3.

**Table 20: Soil Composition of the Land Systems in the LICA Study Area.**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Types or Series |
|---|---|---|---|
| Vermilion River Valley | Thin Black | Eroded, with misc. Black Chernozems | |
| Reilly Plain | Black-Dark Gray | Beaverhills<br>Mundare<br>Peace Hills | Gleysols |
| Pasatchaw Plain | Black-Dark Gray | Beaverhills | |
| Dewberry Plain | Black-Dark Gray | Beaverhills<br>Mundare | Ukalta |
| Irish Creek Plain | Black-Dark Gray | Angus Ridge<br>Gabriel | Helliwell |
| Gadois Upland | Black-Dark Gray | Angus Ridge<br>Uncas | Redwater; with Eroded & misc. Black Chernozems |
| Clandonald Upland | Black-Dark Gray | Slawa | Angus ridge |
| Queenie Plain | Black-Dark Gray | Angus Ridge<br>Uncas | Slawa, Gleysols |
| Tomas Upland | Black-Dark Gray | Rolly View | Gleysols, Redwater |
| Beaver River Valley | Dark Gray-Gray | Eroded; with misc. Dark Gray Chernozems | Gleysols; with Coarse soils & misc. Dark Gray Chernozems |
| North Saskatchewan River Valley | Black-Dark Gray | Eroded; with misc. Black Chernozems | Water |
| Atimoswe Creek Plain | Black-Dark Gray | Uncas<br>Angus Ridge | Gleysols, Eroded |
| Kawatt Plain | Black-Dark Gray | Angus Ridge | Uncas, Gleysols |
| Kerensky Plain | Black-Dark Gray | Angus Ridge<br>Uncas | Gleysols |
| Val Soucy Plain | Black-Dark Gray | Angus Ridge | Uncas, Mooswa |
| Laurier Upland | Black-Dark Gray | Angus Ridge | Primula, Uncas |
| Makaoo Upland | Black-Dark Gray | Angus Ridge | Kavanagh, Mundare |
| Cherry Grove Plain | Dark Gray-Gray | La Corey | Spedden, Birkland |
| Beaver Crossing Plain | Dark Gray-Gray | Kehiwin<br>Spedden | Fergy, La Corey |
| Lessard Plain | Dark Gray-Gray | Spedden<br>Lessard | Franchere, Gleysols |

**Table 20. Soil Composition of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series |
|---|---|---|---|
| Wolf Plain | Dark Gray-Gray | Fergy<br>Ardmore | Spedden<br>Nestow |
| Ardmore Plain | Dark Gray-Gray | Fergy<br>Kehiwin | Spedden |
| Danuta Plain | Dark Gray-Gray | Spedden | La Corey<br>Kehiwin |
| Glendon Plain | Dark Gray-Gray | Spedden | La Corey<br>Vilna |
| Denning Lake Upland | Dark Gray-Gray | Spedden<br>La Corey | Gleysols |
| Goodridge Plain | Dark Gray-Gray | Spedden<br>Goodridge | Nicot |
| Moose Lake Plain | Dark Gray-Gray | Nicot | Nestow<br>Manatokan |
| Manatokan Plain | Dark Gray-Gray | Spedden<br>La Corey | Gleysols |
| Stebbing Lake Plain | Dark Gray-Gray | Nicot | Edwand<br>Nestow |
| Punk Creek Plain | Dark Gray-Gray | La Corey<br>Tawatinaw | Organic; with Eroded & misc. Dark Gray Chernozems |
| Bangs Plain | Dark Gray-Gray | Eroded, with misc. Dark Gray Chernozems | Gleysols |
| Owlseye Lake Upland | Black-Dark Gray | Cooking Lake<br>Uncas | Angus Ridge<br>Gleysols |
| Beauvallon Upland | Black-Dark Gray | Cooking Lake<br>Uncas | Rolly View<br>Gleysols |
| Eliza Upland | Black-Dar Gray | Cooking Lake<br>Peace Hills | Uncas<br>Two Hills |
| Canard Upland | Black-Dark Gray | Uncas<br>Angus Ridge | Cooking Lake<br>Gleysols |
| Beauvallon Plain | Black-Dark Gray | Rolly View<br>Uncas | Gleysols<br>Mundare |
| Landon Upland | Black-Dark Gray | Redwater<br>Cooking Lake | Rolly View<br>Gleysols |
| Kopernik Upland | Gray | Athabasca | St. Lina |
| Fredro Plain | Gray | Athabasca | Grosmont<br>Birkland |
| Reita Lake Plain | Gray | Athabasca | Grosmont<br>Gleysols |
| Murial Lake Plain | Gray | Athabasca | Grosmont |
| Redspring Upland | Gray | Athabasca | St. Lina |
| Asnyk Upland | Dark Gray-Gray | Spedden<br>La Corey | Gleysols<br>Eroded & misc. Dark Gray Chernozems |
| Hilda Lake Plain | Gray | Athabasca<br>Liza | Spedden<br>St. Lina |

**Table 20: Soil Composition of the Land Systems in the LICA Study Area (concluded).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series |
|---|---|---|---|
| Silesia Plain | Gray | Athabasca | Eroded & misc. Dark Gray Chernozems<br>Gleysols |
| Odra Plain | Gray | Athabasca | Organic; with Coarse textured soils and misc. Dark Gray Chernozems |
| Artur Upland | Gray | Athabasca | St. Lina |
| Meridian Lake Upland | Gray | Athabasca | |
| Cold Lake | Gray | Water | Eroded & misc. Dark Gray Chernozems |
| Bourque Plain | Gray | Athabasca<br>Nicot | St. Lina<br>Tucker |
| Standish Plain | Gray | Athabasca<br>St. Lina | Nicot<br>Tucker |
| Heart Upland | Gray | Athabasca | St. Lina |
| Seibert Plain | Gray | Athabasca<br>Goodridge | St. Lina<br>Tucker |
| Mostoos Upland | Gray | Kinosis<br>McLelland<br>Mildred | Hartley |

### 4.2.3 Mapping of Soil Sensitivity

The sensitivity categories are Sensitive, Moderate Sensitivity and Low Sensitivity. In Land Systems composed mainly of a individual Soil Series, or a combination of Soil Series with the same sensitivity rating, a single Sensitive, Moderate or Low rating was applied. Where co-dominant Soil Series had different sensitivity ratings, mixtures were mapped (e.g., Sensitive with Low). Land Systems were differentiated in cases where the dominant soil series sensitivity was Low, but there was a 5-10 percent component of Sensitive or Moderate soils. These types of Land Systems were identified in keeping with the CASA and AENV (1999) criteria that a grid cell with more than 5% Sensitive soils would have the lowest critical load.

The categories of soil sensitivity to acidic and acidifying substances, and the areas and proportions of Land Systems characterized by the different sensitivity categories are given in Table 21. A map of land systems and their soil sensitivities to acid input is presented in Figure 12.

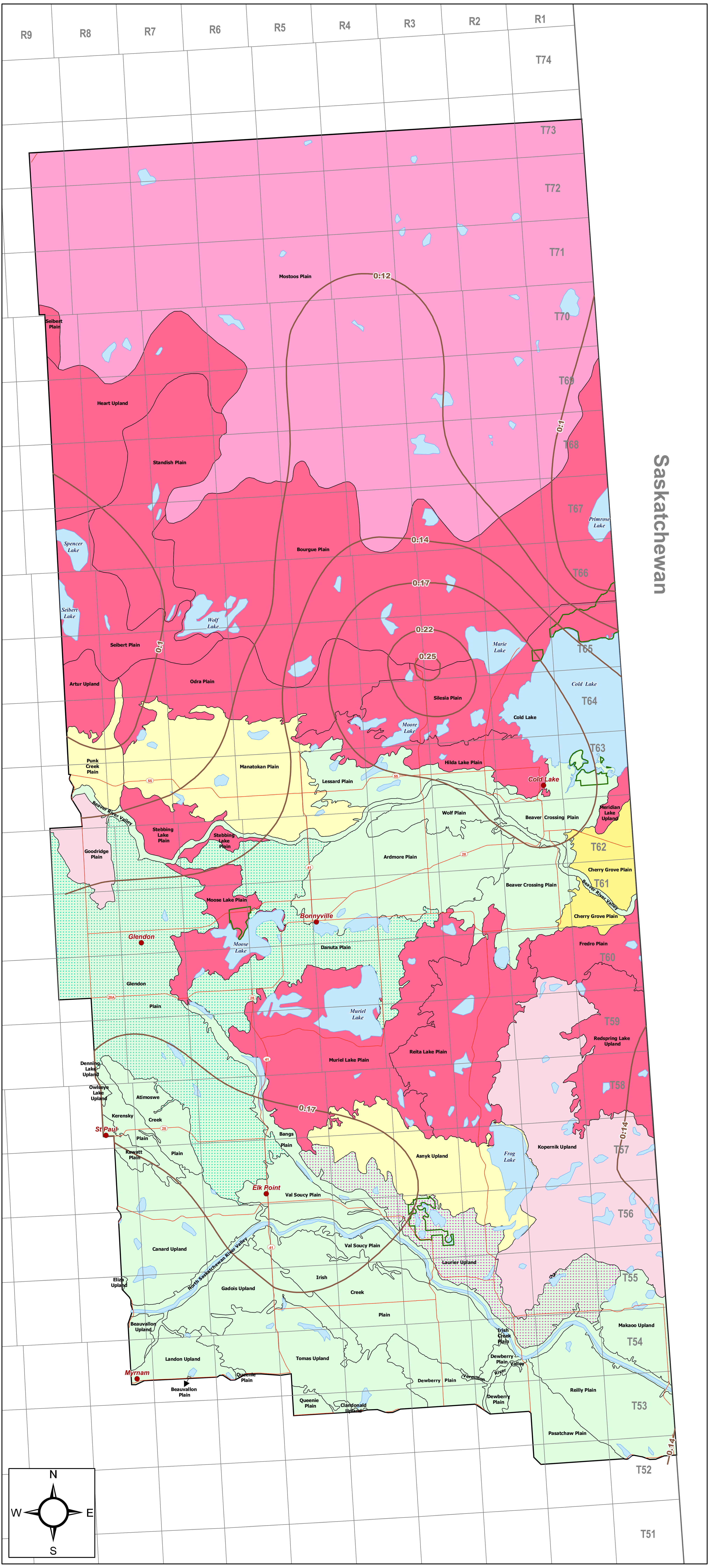
**Table 21: Categories of Soil Acidification Sensitivity and their Extent in the LICA Area**

| Acidification Category | Area (ha)[z] | Area (% of LICA Area) |
|---|---|---|
| Low | 343,520 | 21.2 |
| Low, with 5-10% Moderate | 122,848 | 7.6 |
| Low, with 5-10% Sensitive | 33,633 | 2.1 |
| Moderate | 13,840 | 0.9 |
| Moderate with Low | 88,851 | 5.5 |
| Sensitive | 512,151 | 31.6 |
| Sensitive/ Moderate Mixture | 396,454 | 5.1 |
| Sensitive/ Low Mixture | 82,165 | 24.4 |
| Cold Lake[Z] | 28,547 | 1.8 |
| Total | 1,622,009 | 100.0 |

[Z] Except for Cold Lake, lake areas and other miscellaneous land types such as roads and urban areas have not been subtracted from the sensitivity category areas.

The mapping of soil sensitivity suggests that more than half of the LICA area is characterized by soils that are Sensitive to acidic soil inputs, or are mixtures of Sensitive with Moderate or Low Sensitivity soils. Soils that are recognized as being most sensitive are those of very sandy texture, these mainly being the Nicot and Liza Soil Series (Table 19). These soils have low acid buffering capacity and low nutrient content. The Land Systems characterized by predominance of these soils are the Stebbing Lake Plain and Moose Lake Plain. The Hilda Lake Plain, Bourque Plain and Goodridge Plain Land Systems have a significant component of these soils.

Most of the Sensitive Land Systems in the LICA area are characterized by the Athabasca Soil Series. This is an Orthic Gray Luvisol soil developed on medium to moderately fine textured glacial till. The Goodridge soil series is a close associate of the Athabasca soil, the main difference being a sandier and stonier composition. These soil are rated in the Sensitive category because their surface mineral horizons (the A horizons) are generally very sandy and/or their A horizons are relatively acidic. The A horizon is underlain by a Bt horizon (a horizon of clay accumulation) with considerably higher buffering capacity. The closely related La Corey soil is rated as having Moderate Sensitivity to acidification because its A (i.e., topsoil) horizon is not as acidic as that of the Athabasca soil. Similarly, Cooking Lake soils, which occur to a much lesser extent in the southern part of the LICA area, are also characterized by higher buffering A horizons. In some locations, the Athabasca soil has a relatively thick sandy surface layer. Where these layers are greater than 30 cm thick, the soils are classified as a different Soil Series in more detailed soil surveys. Such soils have not been recognized within the Land System descriptions provided in the AGRASID and CanSIS databases. However, they do exist, as evidenced by the soil and terrain baseline report for the CNRL Primrose East Expansion project (CNRL 2006). The Moose Hills Soil Series, for example, is an Orthic Gray Luvisol developed on relatively thin, sandy glaciofluvial material overlying glacial till. The Moose Hills soils are Sensitive to acidification, based on their soil chemistry (see CNRL soils in Appendix B1).



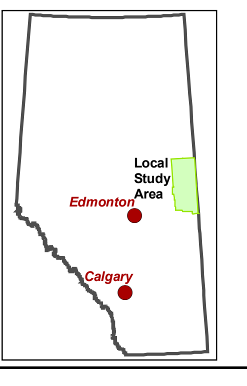

## Legend

- Town
- Major Road
- Potential Acid Input (kmol $H^+$ $ha^{-1}$ $y^{-1}$)
- Provincial Park
- Waterbody
- LICA Airshed Boundary
- Township
- Alberta Boundary

**Sensitivity to Acidic Inputs**

- Low
- Mixture Low / 5-10% Sensitive
- Mixture Low / 5-10% Moderate
- Moderate
- Mixture Moderate / Low
- Sensitive
- Mixture Sensitive / Moderate
- Mixture Sensitive / Low

**Land System Information from AGRASID 3.0 and CanSIS.**




**Lakeland Industry and Community Association (LICA)**

**Land Systems and Soil Sensitivity to Acid Input in the LICA Area**

March 2007

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FIGURE 12

The CNRL Primrose East Expansion soil survey report also indicates that the Mostoos Plain, in the northern part of the LICA area, has a significant proportion of Caslan soils, which are Brunisols on sandy glaciofluvial deposits overlying glacial till, and Amisk-Liza soils, which are Brunisols in deep sands. Both these soils are in the Sensitive category of acidification because of the their low acid buffering capacities. The Mostoos Plain is rated in this study as a Sensitive/Moderate mix because of the large proportion of Organic soils, most of which are fens The fens are likely a combination of moderate rich to rich fens (relatively low acidity and high nutrient content) and poor fens (relatively high acidity and poor nutrient content), which are rated as Low and Moderate Sensitivity, respectively. Thus, the Mostoos Plain does have a relatively small component of Low Sensitivity soils, which is not reflected in the overall rating. However, inclusions of soils with different ratings than those indicated likely characterize all of the Land Systems. Thus, an overall rating of Sensitive/Low mixture or even of Sensitive and Sensitive/Medium categories does not preclude occurrence of a small component of well buffered, Low Sensitivity soils in a Land system.

## 4.3 POTENTIAL CRITICAL LOAD EXCEEDANCE

Critical loads corresponding to the sensitivity classes discussed in the previous section have been suggested in Alberta as described in CASA and AENV (1999) and Foster and Eastlick (2001). Monitoring, target and critical loads expressed as potential acid input (PAI) for Sensitive, Moderate Sensitivity and Low Sensitivity soils were previously presented in Section 2.2.2. The PAI isopleths developed in the Air Quality section of this report (i.e., those determined using the LICA air monitoring network data – see Section 2) were superimposed on the Land System map to calculate the areas of potential exceedance of the critical, target and monitoring loads. These areas of the sensitivity ratings within >0.25, 0.22 – 0.25, and 0.17 – 0.22 keq $H^+$/ha/yr PAI isopleths are presented in Table 22.

**Table 22: Areas of Soil Acidification Sensitivity Categories within PAI Ranges**

| Acidification Category | Area with >0.25 keq $H^+$/ha/yr | | Area with 0.22–0.25 keq $H^+$/ha/yr | | Area with 0.17–0.22 keq $H^+$/ha/yr | |
|---|---|---|---|---|---|---|
| | (ha) | (%)$^Z$ | (ha) | (%)$^Z$ | (ha) | (%)$^Z$ |
| Low | 0 | 0 | 0 | 0 | 75,032 | 4.6 |
| Low, 5-10% Moderate | 0 | 0 | 0 | 0 | 25,831 | 1.6 |
| Low, 5-10% Sensitive | 0 | 0 | 0 | 0 | 7,567 | 0.5 |
| Moderate | 0 | 0 | 0 | 0 | 180 | 0.01 |
| Moderate with Low | 0 | 0 | 0 | 0 | 9,065 | 0.6 |
| Sensitive | 1,197 | 0.07 | 12,437 | 0.8 | 57,327 | 3.5 |
| Sensitive/Moderate | 0 | 0 | 0 | 0 | 0 | 10.8 |
| Sensitive/Low | 0 | 0 | 0 | 0 | 0 | 0 |
| Cold Lake | 0 | 0 | 0 | 0 | 3,271 | 0.2 |
| Total | 1,197 | 0.07 | 12,437 | 0.8 | 178,273 | 10.8 |

$^Z$ % of LICA area.

A small area (1,197 ha) with PAI >0.25 keq $H^+$/ha/yr occurs immediately northeast of Leming Lake. This represents an area in which the critical load of Sensitive soils is potentially exceeded. A relatively small area encircling the latter represents the area of target load exceedance. A somewhat larger area of 0.17 to 0.22 keq $H^+$/ha/yr, surrounding the latter two, is oblong in shape and extends southeast beyond the City of Cold Lake. A second area exceeding 0.17 keq $H^+$/ha/yr is located between Lindberg and St. Paul, more or less centring on Elk Point. These areas have a small proportion of sensitive soils within them, and the monitoring load is potentially exceeded for these soils.

Comments and implications of the PAI exceedances in the LICA area are as follows:

- When considered in the context of the acid deposition management strategy for Alberta as described by Clean Air Strategic Alliance and Alberta Environment (1999), about two-thirds of the LICA area falls within a grid cell corresponding to the 73L East Half National Topographic Sheet. The proportion of Sensitive soils in this grid cell is more than 5%, and the potential exceedance would trigger management principles as outlined in the above document. [The 73L E½ NTS sheet extends from the Saskatchewan border to the middle of Range 7, and from Townships 58 to 76 inclusive.]
- The CASA and AENV (1999) document should be referred to for details of management implications.
- Possible exceedance of the monitoring load for sensitive soils represents the largest exceedance area in the LICA area. In general, recommended actions include application of air quality (specifically PAI) modelling in neighbouring grid cells to determine contribution to the grid call of concern, accompanied by implementation of monitoring and receptor sensitivity studies.
- In order to adequately assess receptor sensitivity, verification of acid inputs is necessary.
- A portion of the 0.17 keq $H^+$/ha/yr, isopleth between Lindberg and St. Paul passes through an area of sensitive soils.
- In the grid cell context, most of the monitoring load exceedance surrounding Elk Point is located within the 73E East Half grid cell. This would not trigger action according to CASA and AENV (1999) because most of the soil receptors are of Low sensitivity to acidic inputs. However, this is an uncertain statement because this area is the northernmost part of the grid cell, and investigation of other parts of the grid cell would be required to asses it fully.

## 4.4 SOIL MONITORING IN THE LICA AREA

Monitoring refers to a process of checking, observing or keeping track of something for a specified period of time or at specified intervals (Gregorich et al. 2001). Soil monitoring for acidification effects involves measurement of specific soil properties that respond to acidity. Two major Alberta programs involve soil monitoring, namely the Long Term Soil Acidification Monitoring Program of Alberta Environment (Roberts et al. 1989) and the Terrestrial Environment Effects Monitoring (TEEM) program of the Wood Buffalo Environmental Association (AMEC 2000). The main soil parameters included in these monitoring programs are pH, cation exchange capacity, exchangeable cations, and soil solution ions (including aluminum).

The AENV monitoring program consists of eight sites distributed around the province. One of the sites is within the LICA area, located in NW20/SW29-64-2-W4. This location is close to Cold Lake, lies southeast of the heavy oil production areas, and lies within the 0.17 – 0.22 keq $H^+$/ha/yr PAI isopleth zone. As such, it is ideally situated for monitoring in the 0.17 keq $H^+$/ha/yr potential exceedance zone.

The Cold Lake monitoring site is located on Eluviated Dystric Brunisol soils developed in sandy, glaciofluvial deposits that thin out in places to a veneer (<1m sand) overlying loamy glacial till materials. It was established in 1981, and has had six sampling events since that time. Although the sampling interval was initially intended to be four years, various factors led to inconsistent intervals in the 1990s.

An initial report on the Long Term Monitoring Sites was completed on the initial two sampling events in 1981 and 1985 (Roberts et al. 1989). There were no detectable changes in pH, base saturation percentage or other acidification parameters at that time. A report on five sampling events is currently in preparation by Alberta Environment, with publication expected during 2007.

The Wood Buffalo Environmental Association sites are located mainly in the Fort McMurray area, with long distance sites located in each direction. After the initial site selection, as reported in AMEC (2001), additional near and long distance sites were selected in 2001 and 2004. The southernmost site is located in Township 84, Range 3, West of 4th Meridian. It is thus quite distant from the LICA area. While the TEEM program does not extend to the LICA region, the site establishment and procedures would have applicability to the LICA area, as would those of the Alberta Environment program.

## 4.5 VEGETATION SENSITIVITY AND MONITORING IN THE LICA AREA

### 4.5.1 Effects of Acidification on Vegetation

Emissions of substances such as the oxides of sulphur and nitrogen can have short-term and long-term effects on vegetation and the surrounding environment. Short-term effects can include the deterioration of the waxy outer layers, causing chlorosis of the plant tissues in localized areas, eventually resulting in mortality. Long-term effects involve direct effects of acidity on plant tissues, from either deposition onto the soil and uptake through the roots or from absorption from the surface of the plant. Acidification effects on plant tissues include interference with the plant's chemical processes, such as respiration, thereby decreasing the ability to repair tissues, resist disease and reproduce.

Indirect effects of acidification on vegetation involve development of imbalance in the chemistry and biology of the surrounding soil and water, thereby impacting soil nutrients. The amount and type of soil nutrients can be increased or decreased through acidification, in turn changing the availability to plants and increasing uptake of toxic elements. Availability of nutrients is also directly linked to the mass of fine root growth. With increased acidification there is a reduction in fine root growth, thereby reducing nutrient uptake. Change in soil pH is another imbalance created by acidification. As the soil pH becomes more acidic the current vegetation can give way to acid tolerant vegetation moving in and changing the species diversity. Stress placed on vegetation from acidification can also predispose plants to other stresses and injuries such as insect infestation, disease, drought and frost.

Vegetation acidification assessments in Alberta use critical loads for vegetation based on the CASA and AENV (1999) framework for soil critical loads. Acidification is considered in terms of indirect effects to vegetation; therefore, vegetation will be potentially affected in areas where the corresponding soils are affected (>0.25 keq $H^+$ /ha/yr level). Consequently, critical load exceedances areas for soils as determined in the previous section are also areas of potential acidification effects on vegetation. The species composition can be determined by overlaying the soil exceedance information on vegetation (i.e., ecosite) maps. Based on a review of literature, plant sensitivities to acidification as indicated in Table 23 were reported in the environmental impact assessment of the Primrose East Project area in CNRL (1999).

**Table 23: Plant Sensitivity to Acidifying Emissions**

| Common Name | Species Name | Ranking[z] |
|---|---|---|
| **Trees** | | |
| Jack pine | *Pinus banksiana* | high |
| Paper birch | *Betula papyrifera* | high |
| Trembling aspen | *Populus trembuloides* | high |
| White spruce | *Picea glauca* | medium |
| Balsam fir | *Abies balsamea* | medium |
| Balsam poplar | *Populus balsamifera* | low |
| Black spruce | *Picea mariana* | unknown |
| Tamarack | *Larix laricina* | unknown |
| **Mosses** | | |
| Brown moss | *Drepanocladue spp.* | high |
| Schreber's moss | *Pleurozium schreberi* | high |
| Knight's plume moss | *Ptilium crista-castrensis* | high |
| Stair-step moss | *Hyloconium splendens* | high |
| Peat moss | *Sphagnum spp.* | variable |
| Golden moss | *Tomenthypnum nitens* | variable |
| **Lichens** | | |
| Lichen | *Cladina spp.* | high |
| Lichen | *Stereocaulon lividum* | high |
| Reindeer lichen | *Cladina spp.* | high |

[z] From CNRL (2006)

In terms of vegetation cover classes, the CNRL (1999) report indicated sensitivity classes as follows:

Sensitive (High Sensitivity):
- deciduous-aspen/aspen-balsam poplar dominant
- mixedwood -aspen/white spruce dominant
- mixedwood - jack pine-aspen dominant
- coniferous- jack pine

Moderate Sensitivity:
- coniferous- white spruce dominant
- coniferous- black spruce-white spruce (jack pine) dominant
- poor wooded fen/wooded bog
- graminoid fen

Low Sensitivity:
- wooded fen
- shrubby fen
- marsh
- upland shrubland
- agriculture
- cutblocks
- burn

According to these sensitivity classes, most aspen, Mixedwood, or jack pine forests fall into the sensitive category, where they occur on Sensitive soils. Spruce forests are of Moderate sensitivity, presumably because they tend to occur in richer sites. Fens and marshes have Low sensitivity due to higher nutrient content, including relatively high calcium (and alkalinity) in the associated waters.

### 4.5.2 Vegetation Monitoring Programs in the Cold Lake Region

Vegetation monitoring has been carried out in the Cold Lake Operations area of Imperial Oil Resources as reported by AMEC (2001, 2003, 2006). In 2000, a study of vegetation stress with particular reference to sulphur dioxide ($SO_2$) emissions was conducted. Through the use of false colour infra-red (FCIR) air photos and field inspection, the type of stress on the plant was evaluated. With FCIR photography, uniform patterns of pink to brownish colours widespread and downwind of processing facilities with $SO_2$ emissions are indicative of stress. Direct observations focussed on vascular plants. Non-vascular plants are more sensitive to air emissions because they absorb all their nutrients through the rain and water, whereas vascular plants are less sensitive. Non-vascular plants were not used in the study, however, due to lack of readability on the air photos and visibility in the field. Vascular plants also have the advantage of demonstrating measurable symptoms including chlorosis and necrosis.

Stress symptoms in conifers include chlorosis of older needles and brown discolouration, desiccation and necrosis, leading to chlorosis, stunted growth and premature needle drop. In deciduous species, symptoms are wet appearance and chlorosis of underside of leaf, leading to stunted growth, chlorosis and foliar death.

Using both of the direct observation and photographic approaches, no stress directly caused by $SO_2$ emissions was apparent. Insect and disease stress were present throughout the area at low levels. The most common forms of stress were logging and excess moisture stress associated with flooding due to beaver activity and to obstruction to water flow by roads.

In 2002, the monitoring program was expanded to include the Cold Lake First Nations Reserve (I.R. 149A) (AMEC 2003). In 2006, the monitoring was again carried out in the Cold Lake Operations area (AMEC 2006). Results of these two studies were similar to the previous report. Vascular vegetation was re-assessed for stress from air emissions, particularly $SO_2$. False-Colour air photos were examined, and field inspections were carried out for visible symptoms. As in the 2000 study, it was found that there were no direct long-term effects or vegetation stress from air emissions on the vascular plants in the study area.

In these monitoring programs, additional testing was carried out through tissue sampling and analysis of aspen leaves. Sulphur is an essential element for plant metabolism. Through sampling and analyzing aspen leaves, it was found that the concentrations of sulphur in the aspen leaves in the study area were similar to that of a control site. The low sulphur levels and healthy appearance of aspen leaves indicated that there was no direct impact to vegetation on the study area from $SO_2$ emissions.

## 4.6 SUMMARY AND RECOMMENDATIONS

A soil map of the LICA area was developed at the Land System level of detail wherein Land Systems are defined as areas recognized and separated by differences in one or more of general pattern of land surface form, surficial geologic materials, amount of lakes or wetlands, or general soil pattern. The application of a western Canadian rating system for potential acidification of soils resulted in about 32% of the LICA area rated as Sensitive to deposition, and another 29% rated as a mix of Sensitive and Moderate or Low Sensitivity soils. The Moderate category was dominant in about 6% of the LICA area, and the remainder (31%) was rated as having Low sensitivity. Cold Lake occupies about 2% of the area. Most of the sensitive soils occur in the northern part of the area, although there is also a sizable area in the southeast part of the region.

Small areas of PAI isopleths in the 0.22 – 0.25 and the >0.25 keq/ha/yr zones are characterized by soils rated as Sensitive to acidification. Somewhat larger areas of Sensitive soils fall into the 0.17 – 0.22 keq/ha/yr zone. This range exceeds the monitoring load as defined by CASA and AENV (1999), and the area is sufficiently large that actions such as increased monitoring and receptor research are recommended.

Soil monitoring to date consists of the operation by Alberta Environment of a long term program of monitoring eight sites around the province, one of which is located ion the Cold Lake area.

The site is located within the PAI monitoring zone indicated above. One report in 1989 indicated no change between the first and second monitoring events. A second report on five monitoring events is to be published in 2007. With respect to vegetation, monitoring in recent years has not indicated any vegetation damage attributable to $SO_2$.

In considering enhanced soil chemistry monitoring, the programs of Alberta Environment and of the TEEM program of the Wood Buffalo Environmental Association serve as suitable models. THE AENV program involves establishment of two plots at a site, with each plot sampled at 12 sample points. Eight soil layers are sampled, and analyses are carried out for a number of parameters including pH, exchangeable base cations, and soluble ions. All samples are analysed, or only samples from the uppermost layers have been analysed, depending on available funding. The analyses are costly, and therefore the overall costs for samples from a number of sites could be high.

The TEEM program involves establishment of four soil sampling plots surrounding a vegetation monitoring plot (AMEC 2001). Four subplots are sampled from each plot, and the samples from each layer are composited into a single sample. The composite samples considerably reduce the analytical costs. The TEEM program has had two sampling events to date, in 1998 and 2004. Higher sulphur content in forest floor (litter) layers in near-source sites as compared to far-from-source sites has been the only trend detected to date. The vegetation component of the TEEM program has not revealed any trends to date.

Elements of a soil and vegetation monitoring program that should be considered are as follows:

- Continuation of periodic sampling at the AENV monitoring site, located in the monitoring exceedance zone, should be encouraged.
- Additional monitoring sites in the monitoring exceedance zone for sensitive soils should be established to determine regional trends. At least one of the sites should be located in the monitoring exceedance zone near Elk Point, provided suitable forest stands are available.
- Establishment of a site near the 0.25 keq/ha/yr PAI isopleth would provide the opportunity not only to monitor but to research soil response to higher PAI.
- At least one control site should be established in the region to enable comparison of near source with relatively pristine sites.
- Preferred soil and vegetation types for establishment of monitoring sites are highly sensitive, sandy Brunisolic soils, as well the extensively occurring Luvisols on glacial till capped by coarse textured materials (the Athabasca Soil Series). Vegetation types should be uniform across sites. The Brunisols are mostly associated with jack pine/lichen stands. Mixedwood stands would be appropriate for the Athabasca soils, although some effort may be required in locating forest stands with similar characteristics.

- Consideration should be given to establishing paired sites in a monitoring program. One of the main reasons for establishing paired sites in the AENV program was to increase the probability of retaining a site should fire or other mishap destroy a site.
- A recurring criticism of other monitoring sites entails lack of establishment of acid deposition monitoring at the same sites, thus precluding investigation of true dose-response relationships. To the extent possible, soil and vegetation monitoring sites should be co-located with air quality monitoring sites.
- Prior to establishment of monitoring sites, consideration should be given to more in-depth analysis of soil types and their acidification sensitivity. Within the CASA and AENV grid cell context, this has been conducted for soils of the Provost-Esther area by soil sampling, laboratory analysis and calculation of critical loads using a predictive acidification model developed at the Alberta Research Council. Similar work is being conducted in the Edmonton area, with results to be published in 2007. This type of investigation would assist in verifying sensitivity ratings in the current study, and would provide a framework for locating monitoring sites. The level of soil mapping is the same as that applied in the current study (i.e., the Land System level of detail). The main problem in thorough assessment of the complete LICA area is the lack of information in the Cold Lake Air Weapons range, and means of acquiring additional information would need to be considered.
- The LICA Airshed Zone should maintain awareness of research programs conducted by the $NO_X$-$SO_2$ Management Program of CEMA in the oil sands region. These include the refinement of critical load determinations for soils and waters, and the establishment of research watersheds in which detailed soil, surface water and groundwater investigations are being conducted.

## 5.0 ANNOTATED BIBLIOGRAPHY

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*This report provides acid sensitivity ratings based on alkalinity, pH and calcium for 109 lakes in northern Alberta. The findings are based on analytical results of water quality collected for the lakes and compares concentrations to the potential for acidification.*

Soil Classification Working Group. 1998. The Canadian System of Soil Classification. 3rd ed. Agriculture and Agri-Food Canada Publ. 1646. NRC Research Press, Ottawa. 187 pp.

Target Loading Subgroup. 1996. Final Report of the Target Loading Subgroup on Critical and Target Loading in Alberta. Clean Air Strategic Alliance. Edmonton, Alberta. 14 pp.

*‘This report about acid deposition is broken into three main parts. The first part presents information on framework and reviewing data which developed the framework and evaluation of the current state of acid deposition in Alberta. The second part applies the framework to the long-term management of emissions and deposition, as well as discussing effects of new projects. The third part provides information on monitoring for deposition, inter-jurisdictional issues and future development.’*

Task Force on Mapping and Modelling. 2004. Manual on methodologies and criteria for modelling and mapping critical loads & levels and air pollution effects, risks and trends. UNECE Convention on Long-range Transboundary Air Pollution.

*This manual describes concepts, approaches and methods to derive critical loads for soils and other receptors in Europe.*

Turchenek, L.W., S.A. Abboud, U. Dowey. 1998. Critical Loads for Organic (Peat) Soils in Alberta. Target Loading Subgroup, Alberta Clean Air Strategic Alliance. Edmonton, AB. 71 pp.

*'Review of the current status of critical loads for organic soils, objectives being to adopt a critical load for organic soils in Alberta based on published literature and regulatory criteria from Europe and North America. It is concluded that the recommended interim critical load for sensitive ecosystems in Alberta is 0.25 keq/ha/yr. It is considered that this critical load will likely protect all categories of peatlands, but verification is required.'*

Turchenek, L.W., S.A. Abboud. 2001. Site-Specific critical loads of Acid deposition on soils in the Provost-Esther Area, Alberta. Prepared for Air and Water Branch, Alberta Environment. 128 pp.

*This study first reviews available methods for deriving critical loads, and are then applied to an area in east central Alberta (Provost-Esther grid cell or study area). There are two main objectives in this study. The first was to develop a methodology by mapping soil types, land uses and aquatic systems within the study area and analyzing samples collected, then estimating the site-specific critical load for each sample using one or more mathematical receptor models. The second objective was to estimate the critical load using derived methods, providing an estimate of the critical load for the Provost-Esther area.*

Turchenek, L.W., S.A. Abboud, C.J. Tomas, R.J. Fessenden and N. Holowaychuk. 1987. Effects of Acid Deposition on Soils in Alberta. Alberta Research Council. Edmonton, Alberta. 202 pp.

*'The objectives of this report to describe and discuss present concepts of the nature of soils acidity, to describe and discuss influences of acidity from both natural and anthropogenic source on soil attributes, describe major soils in Alberta and evaluate the potential impact of the deposition of varying levels of acidic and acid-forming substances on agricultural and forest soils and potential changes in soils properties and chemical cycles.'*

Wiens, J. H. and others. 1987. Soils and Geology Sensitivity Mapping in Western Canada. Prepared by J.H. Wiens on behalf of the Coordinating Committee on Soil and Geology Sensitivity Mapping for Western Canada LRTAP Technical Committee. Ministry of Environment. Victoria, B.C.

*Presents western Canada soil sensitivity rating system and maps. Applied by Holowaychuk and Fessenden 1999), referenced above, for mapping in Alberta.*

# APPENDICES

# APPENDIX A

## Air Emissions In LICA Area – Context For Modelling

Table A1 provides a summary of the existing and approved $SO_2$ and $NO_x$ emissions of the major oil sands projects in the LICA area. Emission data were taken from Primrose In-Situ Oil Sands Project EIA (CNRL 2006). Total existing $SO_2$ and $NO_x$ emissions in the LICA area are 31 and 26 t/d, respectively.

**Table A1: Maximum Approved SO2 and NOx Emissions of the Major Oil Sands Projects in the LICA Area**

| | Existing Emissions (t/d) | | Existing & Approved Emissions (t/d) | |
|---|---|---|---|---|
| | $SO_2$ | $NO_x$ | $SO_2$ | $NO_x$ |
| Canadian Natural Primrose, Wolf Lake and Burnt Lake[1] | 4.30 | 7.14 | 6.20 | 10.02 |
| Imperial Cold Lake, Nabiye and Mahihkan[2] | 18.56 | 12.8 | 18.56 | 12.8 |
| EnCana Foster Creek | 4.95 | 5.93 | 4.95 | 7.49 |
| Husky Tucker | | | 1.16 | 1.41 |
| BlackRock Orion | | | 0.90 | 1.16 |
| **Total Emissions in LICA Area** | **28** | **26** | **32** | **33** |

[1] The emissions shown in the table were those used by Canadian Natural in their air modelling work for the Primrose East EIA. They represent CNRL's estimation of maximum approved emissions and do not represent actual emissions.

[2] The value shown for Imperial Cold Lake is the sum of the individual plant maximum approved emissions. The operations are subject to a maximum cumulative $SO_2$ emission limit of 13.15 t/d, so the 18.56 t/d figure significantly overstates SO2 emissions from Imperial Cold Lake facilities. Actual $SO_2$ emissions in 2005 were 6.615 t/d and actual $NO_x$ emissions were 5.48 t/d.

The current $SO_2$ EPEA approval limit for Primrose South and Wolf Lake is 6.7 t/d. However CNRL expects that when the approval is amended for the Primrose East Expansion (~ May 31 2007) the Primrose South Limit will be reduced to 2.0 t/d and this also reflects the approximate current emission rate. As a result, for Primrose East, for the Existing/Approved case it was decided to model Primrose South at the lower limit (2.0 t/d).

# APPENDIX B

**Table B1. Soil Data Relevant to Acidification Sensitivity Rating in the LICA Area**

| Soil Series | Subgroup | Location | Parent Material | Horizon | Depth (cm) | pHw | CEC (cmol $kg^{-1}$) | Sensitivity Rating | Source |
|---|---|---|---|---|---|---|---|---|---|
| Athabasca | O.GL | nd | Morainal | LFH | | nd | | Sensitive | Husky Energy. 2003 |
| | | | | Ae | | 5.2 | 7.6 | | |
| | | | | Bt | | 4.7 | | | |
| | | | | C | | 5.2 | | | |
| Lahaieville | O.GL | nd | Glaciofluvial | LH | | 6.7 | 72 | Low | Husky Energy. 2003 |
| | | | | Ae | | 6.5 | 9 | | |
| | | | | Bt1 | | 6 | 15 | | |
| | | | | Bt2 | | 5.9 | 18 | | |
| | | | | BC | | 5.8 | 14 | | |
| | | | | Ck | | 7.5 | 14 | | |
| Maloy | TY.M | nd | Fen Peat | Om | | 5.1 | 114 | Moderate | Husky Energy. 2003 |
| Moose Hills | O.GL;BR.GL | nd | Glaciofluvial/ Morainal | LFH | | nd | | | Husky Energy. 2003 |
| | | | | Ae1 | | 4.4 | 11 | | |
| | | | | Ae2 | | 5.2 | | | |
| | | | | AB | | 5.7 | | | |
| Pinehurst | E.EB; O.EB | nd | Glaciofluvial | LFH | | | | Sensitive | |
| | | | | Ae | | 5.6 | 3 | | Husky Energy. 2003 |
| | | | | AB | | 5.5 | | | |
| | | | | Bm | | 6 | | | |
| | | | | C | | 6.2 | | | |
| St.Lina | T.M. | nd | Fen Peat /Glaciofluvial or Morainal | Of | | 4.8 | 107 | Moderate | Husky Energy. 2003 |
| | | | | Om | | 6.3 | | | |
| | | | | Ah | | | | | |
| | | | | Bg | | | | | |
| | | | | Cg1 | | | | | |
| | | | | Cg2 | | | | | |

Table B1. Soil Data Relevant to Acidification Sensitivity Rating in the LICA Area

| Soil Series | Subgroup | Location | Parent Material | Horizon | Depth (cm) | pHw | CEC (cmol $kg^{-1}$) | Sensitivity Rating | Source |
|---|---|---|---|---|---|---|---|---|---|
| Angus Ridge | E.BLC | SW17-56-14-W4 | Glacial Till | Ah | 0-23 | 6.8 | 24.2 | Low | Macyk et. al. 1985 |
| | | | | Ahe | 23-30 | 6.3 | 17.2 | | County Two Hills |
| | | | | Btj | 30-55 | 6.4 | 15.5 | | Soil Survey |
| | | | | Cca | 55-88 | 8.1 | | | |
| | | | | Ck | 88+ | 8.2 | | | |
| Cooking Lake | O.GL | SE12-53-9-W4 | Glacial Till | L-H | May-00 | 6.5 | | Low | Macyk et. al. 1985 |
| | | | | Ae | 0-12 | 6.6 | 10 | | County Two Hills |
| | | | | AB | 26-Dec | 6.4 | 19.5 | | Soil Survey |
| | | | | Bt | 26-55 | 6.1 | 17.5 | | |
| | | | | BC | 55-80 | 7.2 | 15.5 | | |
| | | | | Ck | 80+ | 8.1 | | | |
| Ferintosh | O.BLC | SE14-56-15-W4 | Glaciofluvial gravel and sand | Ahe | 0-18 | 7.2 | 25.5 | Low | Macyk et. al. 1985 |
| | | | | Btj | 18-33 | 7 | 16.7 | | County Two Hills |
| | | | | BC | 33-51 | 7.2 | 9.2 | | Soil Survey |
| | | | | Ck | 51+ | 7.3 | | | |
| Kavanagh | BL.SS | NE34-52-7-W4 | Bedrock | Ahe | 0-15 | 6.3 | 39.4 | Low | Macyk et. al. 1985 |
| | | | | Ae | 15-23 | 6.3 | 36.7 | | County Two Hills |
| | | | | Bnt1 | 23-41 | 7.5 | 25 | | Soil Survey |
| | | | | Bnt2 | 41-61 | 7.9 | | | |
| | | | | Csk | 61+ | 7.9 | | | |
| Nicot | O.EB | NW20-55-12-W4 | Glaciofluvial | Ap | 0-13 | 7.1 | 4.3 | Low | Macyk et. al. 1985 |
| | | | | Bm1 | 13-30 | 6.8 | 1.5 | | County Two Hills |
| | | | | Bm2 | 30-86 | 6.9 | 1.5 | | Soil Survey |
| | | | | BC | 86+ | 7 | 2.3 | | |
| Mundare (called Peace Hills in report) | O.BLC | SW10-55-15-W4 | Glaciofluvial | Drift | 42-0 | 6.7 | 10 | Low | Macyk et. al. 1985 |
| | | | | Ah | 0-25 | 6.5 | 9.2 | | County Two Hills |
| | | | | AB1 | 25-35 | 6.6 | 5.8 | | Soil Survey |
| | | | | AB2 | 35-52 | 6.8 | 4.7 | | |
| | | | | Bm | 52-88 | 6.8 | 5.7 | | |
| | | | | C | 88+ | 6.7 | 5.7 | | |

## Table B1. Soil Data Relevant to Acidification Sensitivity Rating in the LICA Area

| Soil Series | Subgroup | Location | Parent Material | Horizon | Depth (cm) | pHw | CEC (cmol $kg^{-1}$) | Sensitivity Rating | Source |
|---|---|---|---|---|---|---|---|---|---|
| Redwater | O.DGC | NE14-55-8-W4 | Glaciolacustrine | Ah | 0-23 | 6.8 | 17.6 | Low | Macyk et. al. 1985 |
| | | | | Ahe | 23-38 | 6.9 | 10.7 | | County Two Hills |
| | | | | Bt | 38-58 | 7.2 | 9.5 | | Soil Survey |
| | | | | BC1 | 58-89 | 7.5 | 5.4 | | |
| | | | | BC2 | 89-109 | 7.1 | 3.5 | | |
| | | | | Ck | 109+ | 7.4 | | | |
| Two Hills | O.DGC | NW32-53-10-W4 | Glaciofluvial gravel | Ah | 0-13 | 5.9 | 40 | Low | Macyk et. al. 1985 |
| | | | | Ahe | 13-20 | 6.1 | 25.9 | | County Two Hills |
| | | | | Btj | 20-40 | 6.6 | 13.7 | | Soil Survey |
| | | | | BC | 40+ | 7.7 | | | |
| Uncas | D.GL | NW20-55-7-W4 | Glacial Till | Ah | 0-5 | 7.3 | 26.5 | Low | Macyk et. al. 1985 |
| | | | | Ahe | 18-May | 7 | 21.5 | | County Two Hills |
| | | | | Ae | 18-31 | 6.2 | 10.3 | | Soil Survey |
| | | | | Bt1 | 31-51 | 6.5 | 15 | | |
| | | | | Bt2 | 51-69 | 6.7 | 13.7 | | |
| | | | | BC | 69-87 | 6.9 | 12.6 | | |
| | | | | Ck | 87+ | 7.8 | | | |
| Athabasca (gleyed) | GL.GL | nd | Medium-fine Till | LFH | Oct-00 | 6.07 | | Sensitive | Imperial Oil Resources Ltd. 1998 (Site 58) |
| | | | | Ae | 0-8 | 5.4 | 4.3 | | |
| | | | | AB | Aug-33 | 5.4 | 11.2 | | |
| | | | | Bt | 33-63 | 5.83 | 28 | | |
| | | | | BCg | 63-83 | 6.89 | | | |
| | | | | CKg | 83-125 | 8.34 | | | |
| Athabasca (overwashed) | | nd | Medium-fine Till | LFH | Aug-00 | 6.4 | | Sensitive | Imperial Oil Resources Ltd. 1998 (Site 86) |
| | | | | Ae | 0-10 | 4.5 | 3.5 | | |
| | | | | AB | 19-Oct | 5.21 | 3.8 | | |

**Table B1. Soil Data Relevant to Acidification Sensitivity Rating in the LICA Area**

| Soil Series | Subgroup | Location | Parent Material | Horizon | Depth (cm) | pHw | CEC (cmol $kg^{-1}$) | Sensitivity Rating | Source |
|---|---|---|---|---|---|---|---|---|---|
| Athabasca | O.GL | nd | Medium-fine Till | LFH | Aug-00 | 6.09 | | Sensitive | Imperial Oil Resources Ltd. 1998 (Plant Site E) |
| | | | | Ae | 0-11 | 5 | 4.1 | | |
| | | | | AB | 27-Nov | 5.3 | 4.7 | | |
| | | | | Bt | 27-63 | 5.5 | 21.4 | | |
| | | | | BC | 63-85 | 5.43 | | | |
| Athabasca | O.GL | nd | Medium-fine Till | Ae | 0-23 | 5.3 | 4 | Sensitive | Imperial Oil Resources Ltd. 1998 (Site 89) |
| Athabasca (gleyed) | GL.GL | nd | Medium-fine Till | Ae | 0-8 | 5.7 | 5 | Sensitive | Imperial Oil Resources Ltd. 1998 |
| | | | | BCg | 18-60 | 6.26 | | | |
| Athabasca | E.EB | nd | Glaciolacustrine | Bm | | 4.9 | 4.1 | Sensitive | Canadian Natural Resources Limited. 2006. |
| | | | | Bt | | 4.1 | 6.6 | | |
| | | | | C | | 6.9 | | | |
| Amber Valley | O.G | nd | Glaciolacustrine | Bg | | 7.9 | 27.3 | Low | Canadian Natural Resources Limited. 2006. |
| | | | | Cg1 | | 8 | | | |
| | | | | Ckg | | 8 | 14 | | |
| Stebbing | TY.F | nd | Organic | Of | | 5.2 | | Moderate | Canadian Natural Resources Limited. 2006. |
| | | | | Cg | | 6.2 | 5.4 | | |
| Moose Hills (zb) | O.GL | nd | Moraine | Ae | | 5.8 | 3.6 | Sensitive | Canadian Natural Resources Limited. 2006. |
| | | | | Bt | | 5.3 | 9.4 | | |
| | | | | BC | | 5.4 | | | |
| | | | | C | | 6.1 | | | |

**Table B1. Soil Data Relevant to Acidification Sensitivity Rating in the LICA Area**

| Soil Series | Subgroup | Location | Parent Material | Horizon | Depth (cm) | pHw | CEC (cmol $kg^{-1}$) | Sensitivity Rating | Source |
|---|---|---|---|---|---|---|---|---|---|
| Moose Hills (gleyed) | GLE.DYB | nd | Glaciofluvial/ Moraine | Ae | | 3.8 | 3.5 | Sensitive | Canadian Natural Resources Limited. 2006. |
| | | | | Bm | | 4.9 | 3.7 | | |
| | | | | II C | | 5.4 | 14 | | |
| Moose Hills | O.GL | nd | Glaciofluvial/ Moraine | Ae | | 5.1 | 2.1 | Sensitive | Canadian Natural Resources Limited. 2006. |
| | | | | Bmgj | | 5.2 | 1.9 | | |
| | | | | Btgj | | 6.3 | 8.2 | | |
| | | | | II BC | | 6.3 | | | |
| | | | | C | | 5.6 | 13 | | |
| Grandin | O.GL | nd | Moraine | Ae | | 5.5 | 3.1 | Moderate | Canadian Natural Resources Limited. 2006. |
| | | | | Bt | | 5.7 | 9.8 | | |
| | | | | Bt2 | | 5.5 | | | |
| | | | | BCkj | | 5.6 | | | |
| | | | | Ckj | | 5.2 | 16 | | |
| Grandin (overwashed) | O.GL | nd | Moraine | Bt | | 5.5 | | nd | Canadian Natural Resources Limited. 2006. |
| | | | | BC | | 5.4 | | | |
| Maloy | TY.F | nd | Organic | Of | | 5.7 | | Moderaste | Canadian Natural Resources Limited. 2006. |
| Liza | E.DYB | SE16-63-3-W4 | Glaciofluvial | Bm1 | 18-34 | 4.3 | nd | Sensitive | AMEC. 2001a. for Imperial Oil Resources Ltd. |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Athabasca | ABC | LH | -5 | 0 | 0 | -9 | -9 | -9 | 40 | 5.8 | 6.4 | 70 | 83 | 0 | 0 | | S |
| | ABC | Ae | 0 | 13 | 5 | 50 | 39 | 11 | 0.3 | 5.3 | 5.9 | 5 | 74 | 0 | 0 | S | |
| | ABC | AB | 13 | 23 | 5 | 43 | 29 | 28 | 0.4 | 4.7 | 5.2 | 13 | 74 | 0 | 0 | M | |
| | ABC | Bt1 | 23 | 58 | 5 | 41 | 27 | 32 | 0.4 | 4.3 | 4.9 | 15 | 96 | 0 | 0 | | |
| | ABC | Bt2 | 58 | 91 | 5 | 42 | 28 | 30 | 0.4 | 4.9 | 5.4 | 18 | 83 | 0 | 0 | | |
| | ABC | BC | 91 | 120 | 5 | 43 | 29 | 28 | 0.5 | 5.5 | 6 | 17 | 92 | 0 | 0 | | |
| | ABC | Ck | 120 | 160 | 5 | 40 | 30 | 30 | 0 | 6.5 | 7 | 14 | 99 | 0 | 4 | | |
| Ardmore | ADM | Ah | 0 | 43 | 0 | 32 | 44 | 24 | 4.2 | 6.4 | 6.8 | 33 | 95 | 0 | 0 | L | L |
| | ADM | Ae | 45 | 53 | 0 | 36 | 42 | 22 | 0.7 | 6.3 | 6.7 | 17 | 91 | 0 | 0 | | |
| | ADM | Btj | 53 | 79 | 0 | 30 | 45 | 25 | 0.4 | 6 | 6.4 | 21 | 99 | 0 | 0 | | |
| | ADM | BC | 79 | 117 | 0 | 37 | 41 | 22 | 0.4 | 6.5 | 6.9 | 18 | 99 | 0 | 0 | | |
| | ADM | Ck | 117 | 152 | 0 | 25 | 55 | 20 | 0 | 7.4 | 7.6 | 17 | 99 | 0 | 9 | | |
| | ADM | Ck | 152 | 200 | 0 | 35 | 45 | 20 | 0 | 7.6 | 7.8 | 17 | 99 | 0 | 10 | | |
| Angus Ridge | AGS | Ah | 0 | 17 | 3 | 50 | 41 | 9 | 5.1 | 5.5 | 6 | 32 | 90 | 0 | 0 | L | L |
| | AGS | Ae | 17 | 23 | 5 | 45 | 33 | 22 | 0.6 | 6.6 | 7 | 16 | 99 | 0 | 0 | L | |
| | AGS | Bt | 23 | 70 | 5 | 42 | 26 | 32 | 0 | 6.1 | 6.5 | 23 | 90 | 0 | 0 | | |
| | AGS | BC | 70 | 100 | 5 | 41 | 29 | 30 | 0 | 6.5 | 6.9 | 18 | 99 | 0 | 0 | | |
| | AGS | Ck | 100 | 120 | 5 | 43 | 27 | 30 | 0 | 7.6 | 7.8 | 21 | 99 | 1 | 5 | | |
| | BLA | Of1 | 0 | 60 | 0 | -9 | -9 | -9 | 48.8 | 2.8 | 3.4 | 132 | 12 | 0 | 0 | | |
| Birkland | BLA | Of2 | 60 | 120 | 0 | -9 | -9 | -9 | 45 | 3.2 | 3.8 | 171 | 23 | 0 | 0 | M | M |
| | BLA | O | 120 | 127 | 0 | -9 | -9 | -9 | 40 | 3.9 | 4.5 | 120 | 30 | 0 | 0 | M | |
| | BLA | Cg | 127 | 160 | 5 | 25 | 47 | 28 | 0 | 4.9 | 5.5 | 20 | 60 | 0 | 0 | | |
| Beaverhill | BVH | Ah | 0 | 25 | 5 | 42 | 38 | 20 | 4.3 | 5.4 | 5.9 | 32 | 80 | 0 | 0 | L | L |
| | BVH | Btj | 25 | 56 | 5 | 48 | 31 | 21 | 0.8 | 5.5 | 6 | 20 | 80 | 0 | 0 | | |
| | BVH | Bm | 56 | 76 | 5 | 45 | 32 | 23 | 1 | 7 | 7.3 | 21 | 99 | 0 | 1 | | |
| | BVH | Ck | 76 | 102 | 10 | 40 | 30 | 30 | 0 | 7.7 | 7.9 | 21 | 99 | 0 | 6 | | |
| | BVH | Ck | 102 | 120 | 10 | 40 | 30 | 30 | 0 | 7.6 | 7.8 | 21 | 99 | 1 | 6 | | |

**Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.**

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cooking Lake | COA | LH | -2 | 0 | 0 | -9 | -9 | -9 | 40 | 5.4 | 6 | 70 | 90 | 0 | 0 | | L |
| | COA | Ah | 0 | 3 | 2 | 45 | 33 | 22 | 4 | 6.3 | 6.9 | 20 | 90 | 0 | 0 | L | |
| | COA | Ae | 3 | 18 | 3 | 44 | 37 | 19 | 1 | 6.3 | 6.9 | 15 | 85 | 0 | 0 | L | |
| | COA | Bt1 | 18 | 61 | 5 | 41 | 28 | 31 | 0.6 | 5.3 | 5.8 | 21 | 83 | 0 | 0 | L | |
| | COA | Bt2 | 61 | 86 | 5 | 41 | 31 | 28 | 0.5 | 6.5 | 6.9 | 19 | 91 | 0 | 0 | | |
| | COA | Ck | 86 | 100 | 5 | 41 | 31 | 28 | 0 | 7.4 | 7.6 | 16 | 99 | 1 | 6 | | |
| Edwand | EDW | LH | -2 | 0 | 0 | -9 | -9 | -9 | 40 | 5.6 | 6.2 | 70 | 80 | 0 | 0 | | S |
| | EDW | Ah | 0 | 3 | 10 | 60 | 35 | 5 | 8.2 | 5.6 | 6.2 | 10 | 81 | 0 | 0 | L | |
| | EDW | Ae | 3 | 10 | 20 | 90 | 2 | 8 | 0.3 | 5.2 | 5.8 | 5 | 57 | 0 | 0 | H | |
| | EDW | Bm | 10 | 30 | 40 | 85 | 10 | 5 | 0.3 | 5.6 | 6.2 | 3 | 68 | 0 | 0 | S | |
| | EDW | BC | 30 | 61 | 50 | 85 | 10 | 5 | 0.1 | 5.8 | 6.4 | 3 | 78 | 0 | 0 | | |
| | EDW | Ck | 61 | 120 | 70 | 98 | 2 | 0 | 0 | 6.7 | 7.2 | 1 | 99 | 0 | 3 | | |
| Franchere | FNC | LH | -5 | 0 | 0 | -9 | -9 | -9 | 40 | 5.9 | 6.5 | 72 | 89 | 0 | 0 | | M |
| | FNC | Ah | 0 | 3 | 0 | 26 | 55 | 19 | 10 | 5.6 | 6.2 | 35 | 85 | 0 | 0 | L | |
| | FNC | Ae | 3 | 25 | 0 | 27 | 62 | 11 | 1 | 5.2 | 5.8 | 10 | 79 | 0 | 0 | M | |
| | FNC | Bt | 25 | 71 | 0 | 15 | 56 | 29 | 0.6 | 4.9 | 5.5 | 18 | 81 | 0 | 0 | | |
| | FNC | BC | 71 | 104 | 0 | 20 | 55 | 25 | 0.5 | 5.4 | 6 | 18 | 89 | 0 | 0 | | |
| | FNC | Ck | 104 | 190 | 0 | 20 | 50 | 30 | 0 | 7 | 7.4 | 20 | 99 | 0 | 6 | | |
| Fergy | FRY | Ah | 0 | 18 | 3 | 43 | 39 | 18 | 4.5 | 6.2 | 6.8 | 27 | 95 | 0 | 0 | L | L |
| | FRY | Ae | 18 | 20 | 5 | 39 | 45 | 16 | 1.1 | 5.8 | 6.4 | 13 | 94 | 0 | 0 | L | |
| | FRY | Bt | 20 | 46 | 5 | 36 | 37 | 27 | 1.1 | 5.5 | 6.1 | 18 | 98 | 0 | 0 | | |
| | FRY | BC | 46 | 69 | 5 | 44 | 35 | 21 | 0.5 | 5.6 | 6.2 | 14 | 99 | 0 | 0 | | |
| | FRY | Ck1 | 69 | 89 | 5 | 53 | 29 | 18 | 0 | 7.2 | 7.5 | 10 | 99 | 0 | 7 | | |
| | FRY | Ck2 | 89 | 107 | 5 | 44 | 28 | 28 | 0 | 7.2 | 7.5 | 15 | 99 | 0 | 6 | | |
| Ferintosh | FTH | Ah | 0 | 18 | 2 | 59 | 28 | 13 | 5.1 | 6.7 | 7.2 | 26 | 99 | 0 | 0 | L | L |
| | FTH | Btj | 18 | 33 | 35 | 62 | 23 | 15 | 2.7 | 6.5 | 7 | 17 | 99 | 0 | 0 | L | |
| | FTH | BC | 33 | 51 | 50 | 83 | 12 | 5 | 0.5 | 6.7 | 7.2 | 9 | 99 | 0 | 0 | | |
| | FTH | Ck | 51 | 100 | 70 | 84 | 12 | 4 | 0 | 6.9 | 7.3 | 2 | 99 | 0 | 4 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol kg$^{-1}$) | Bases (cmol kg$^{-1}$) | EC (dS m$^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gabriel | GBL | LFH | -3 | 0 | 0 | -9 | -9 | -9 | 40 | 5.9 | 6.5 | 70 | 90 | 0 | 0 | | |
| | GBL | Ahe | 0 | 15 | 0 | 67 | 17 | 16 | 2.3 | 6.1 | 6.7 | 18 | 88 | 0 | 0 | L | L |
| | GBL | Ae | 15 | 28 | 0 | 83 | 11 | 6 | 0.5 | 6.3 | 6.9 | 7 | 92 | 0 | 0 | L | |
| | GBL | Bt | 28 | 48 | 0 | 75 | 12 | 13 | 0.3 | 5.6 | 6.2 | 13 | 90 | 0 | 0 | | |
| | GBL | Bt | 48 | 71 | 5 | 30 | 34 | 36 | 0.5 | 5.8 | 6.4 | 20 | 99 | 0 | 0 | | |
| | GBL | Ck | 71 | 100 | 5 | 29 | 34 | 37 | 0 | 7.1 | 7.5 | 20 | 99 | 0 | 6 | | |
| Grosmont | GMT | LH | -5 | 0 | 0 | -9 | -9 | -9 | 40 | 5.5 | 6.1 | 70 | 80 | 0 | 0 | | S |
| | GMT | Ahe | 0 | 13 | 5 | 45 | 40 | 15 | 4 | 5.2 | 5.8 | 12 | 74 | 0 | 0 | M | |
| | GMT | Ae | 13 | 23 | 5 | 50 | 40 | 10 | 0.9 | 4.8 | 5.4 | 5 | 74 | 0 | 0 | S | |
| | GMT | Bt1 | 23 | 51 | 5 | 40 | 25 | 35 | 1 | 4.4 | 5 | 18 | 80 | 0 | 0 | | |
| | GMT | Bt2 | 51 | 81 | 5 | 40 | 28 | 32 | 0.5 | 4.4 | 5 | 15 | 80 | 0 | 0 | | |
| | GMT | BC | 81 | 120 | 5 | 25 | 45 | 30 | 0.5 | 4.9 | 5.5 | 13 | 85 | 0 | 0 | | |
| | GMT | Ck | 120 | 160 | 5 | 25 | 45 | 30 | 0 | 6.9 | 7.3 | 13 | 99 | 0 | 3 | | |
| Goodridge | GOG | LFH | -5 | 0 | 0 | -9 | -9 | -9 | 40 | 5 | 5.6 | 70 | 70 | 0 | 0 | | S |
| | GOG | Ahe | 0 | 2 | 10 | 60 | 30 | 10 | 3 | 4.7 | 5.3 | 13 | 50 | 0 | 0 | M | |
| | GOG | Ae | 2 | 20 | 10 | 64 | 30 | 6 | 0.3 | 4.4 | 5 | 5 | 30 | 0 | 0 | S | |
| | GOG | Bt1 | 20 | 50 | 10 | 60 | 19 | 21 | 0.5 | 5.2 | 5.7 | 16 | 83 | 0 | 0 | | |
| | GOG | Bt2 | 50 | 70 | 10 | 67 | 18 | 15 | 0.3 | 5.4 | 5.9 | 12 | 86 | 0 | 0 | | |
| | GOG | BC | 70 | 120 | 10 | 75 | 15 | 10 | 0.1 | 5.5 | 6 | 6 | 91 | 0 | 0 | | |
| | GOG | Ck | 120 | 150 | 10 | 65 | 24 | 11 | 0 | 7.2 | 7.5 | 9 | 99 | 0 | 3 | | |
| Gratz | GRZ | Ah | 0 | 15 | 0 | 32 | 54 | 14 | 6.7 | 7.3 | 7.6 | 31 | 99 | 0 | 1 | L | L |
| | GRZ | Ck1 | 15 | 40 | 0 | 53 | 37 | 10 | 1 | 7.6 | 7.8 | 17 | 99 | 0 | 12 | L | |
| | GRZ | Ahkb | 40 | 41 | 0 | 30 | 55 | 15 | 3 | 7.4 | 7.7 | 23 | 99 | 0 | 10 | | |
| | GRZ | Ck | 41 | 58 | 0 | 37 | 51 | 12 | 0.5 | 7.7 | 7.9 | 16 | 99 | 0 | 13 | | |
| | GRZ | Ahkb | 58 | 61 | 0 | 30 | 55 | 15 | 2 | 7.4 | 7.7 | 21 | 99 | 0 | 11 | | |
| | GRZ | Ck | 61 | 87 | 0 | 57 | 33 | 10 | 0.5 | 7.7 | 7.9 | 15 | 99 | 0 | 11 | | |
| | GRZ | Ahkb | 87 | 90 | 0 | 30 | 55 | 15 | 1 | 7.5 | 7.7 | 18 | 99 | 0 | 12 | | |
| | GRZ | Ck | 90 | 100 | 0 | 35 | 53 | 12 | 0 | 7.6 | 7.8 | 15 | 99 | 0 | 12 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horberg | HBG | LH | -3 | 0 | 0 | -9 | -9 | -9 | 40 | 4.2 | 4.8 | 80 | 40 | 0 | 0 | | M |
| | HBG | Ae1 | 0 | 3 | 0 | 35 | 58 | 7 | 1.2 | 5.7 | 6.3 | 8 | 90 | 0 | 0 | L | |
| | HBG | Bm | 3 | 8 | 2 | 35 | 50 | 15 | 1 | 4.9 | 5.5 | 14 | 60 | 0 | 0 | M | |
| | HBG | Ae2 | 8 | 15 | 5 | 45 | 45 | 10 | 0.2 | 5.1 | 5.7 | 15 | 70 | 0 | 0 | M | |
| | HBG | Bt | 15 | 28 | 10 | 30 | 30 | 40 | 1.3 | 5.8 | 6.4 | 30 | 90 | 0 | 0 | L | |
| | HBG | Ck | 28 | 100 | 70 | 85 | 10 | 5 | 0 | 7.1 | 7.5 | 3 | 99 | 0 | 9 | | |
| Helliwell | HLW | LH | -3 | 0 | 0 | -9 | -9 | -9 | 40 | 5.9 | 6.5 | 70 | 85 | 0 | 0 | | L |
| | HLW | Ahe1 | 0 | 30 | 0 | 77 | 17 | 6 | 2 | 6.1 | 6.7 | 15 | 88 | 0 | 0 | L | |
| | HLW | Ahe2 | 30 | 48 | 0 | 79 | 15 | 6 | 1 | 6.2 | 6.8 | 10 | 93 | 0 | 0 | | |
| | HLW | Bm1 | 48 | 71 | 0 | 82 | 12 | 6 | 0.4 | 6.2 | 6.8 | 8 | 97 | 0 | 0 | | |
| | HLW | Bm2 | 71 | 112 | 0 | 83 | 10 | 7 | 0.2 | 5.9 | 6.5 | 8 | 91 | 0 | 0 | | |
| | HLW | Ck1 | 112 | 152 | 0 | 86 | 8 | 6 | 0 | 7.6 | 7.8 | 7 | 99 | 0 | 2 | | |
| | HLW | Ck2 | 152 | 200 | 0 | 89 | 8 | 3 | 0 | 8.1 | 8.1 | 5 | 99 | 0 | 2 | | |
| Hartley | HLY | Of1 | 0 | 25 | 0 | -9 | -9 | -9 | 45 | 5 | 5.5 | 106 | 70 | 0 | 0 | S | M |
| | HLY | Of2 | 25 | 80 | 0 | -9 | -9 | -9 | 45 | 6 | 6.5 | 172 | 90 | 0 | 0 | | |
| | HLY | Cg | 80 | 100 | 5 | 28 | 37 | 35 | 0.7 | 5.8 | 6.2 | 24 | 83 | 0 | 0 | | |
| Kehiwin | KHW | Ahe | 0 | 26 | 5 | 41 | 40 | 19 | 3.7 | 6.6 | 7.1 | 24 | 99 | 0 | 0 | L | L |
| | KHW | A | 26 | 30 | 5 | 38 | 39 | 23 | 0.8 | 6.2 | 6.8 | 14 | 99 | 0 | 0 | | |
| | KHW | Bt1 | 30 | 36 | 5 | 36 | 37 | 27 | 0.8 | 6.2 | 6.8 | 18 | 99 | 0 | 0 | | |
| | KHW | Bt2 | 36 | 61 | 5 | 36 | 38 | 26 | 0.8 | 6 | 6.6 | 17 | 99 | 0 | 0 | | |
| | KHW | BC | 61 | 66 | 5 | 38 | 37 | 25 | 0.5 | 6.7 | 7.2 | 15 | 99 | 0 | 1 | | |
| | KHW | Cca | 66 | 127 | 5 | 38 | 34 | 28 | 0 | 7.7 | 7.9 | 14 | 99 | 0 | 12 | | |
| Kavanaugh | KVG | Ah | 0 | 10 | 2 | 33 | 49 | 18 | 5 | 4.8 | 5.4 | 22 | 50 | 0 | 0 | M | M |
| | KVG | Ae | 10 | 15 | 2 | 35 | 51 | 14 | 1 | 4.7 | 5.3 | 12 | 56 | 0 | 0 | M | |
| | KVG | Bnt | 15 | 30 | 2 | 43 | 34 | 23 | 0.5 | 5.9 | 6.5 | 26 | 99 | 0 | 0 | | |
| | KVG | Bnt | 30 | 45 | 2 | 27 | 43 | 30 | 0.5 | 7.6 | 7.8 | 21 | 99 | 1 | 0 | | |
| | KVG | Csk | 45 | 100 | 2 | 28 | 38 | 34 | 0 | 7.7 | 7.9 | 19 | 99 | 5 | 3 | | |

**Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.**

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LaCorey | LCY | LH | -8 | 0 | 0 | -9 | -9 | -9 | 40 | 5.6 | 6.2 | 70 | 77 | 0 | 0 | | M |
| | LCY | Ae | 0 | 10 | 5 | 38 | 48 | 14 | 0.9 | 5.4 | 6 | 7 | 79 | 0 | 0 | M | |
| | LCY | BA | 10 | 15 | 5 | 35 | 39 | 26 | 0.5 | 5 | 5.6 | 11 | 82 | 0 | 0 | M | |
| | LCY | Bt1 | 15 | 45 | 5 | 36 | 34 | 30 | 0.4 | 4.5 | 5 | 17 | 78 | 0 | 0 | M | |
| | LCY | Bt2 | 45 | 81 | 5 | 34 | 37 | 29 | 0.4 | 4.5 | 5 | 17 | 89 | 0 | 0 | | |
| | LCY | BC | 81 | 96 | 5 | 28 | 39 | 33 | 0.5 | 6.5 | 6.9 | 21 | 99 | 0 | 0 | | |
| | LCY | Ck | 96 | 130 | 5 | 37 | 35 | 28 | 0 | 7.5 | 7.7 | 15 | 99 | 0 | 6 | | |
| Liza | LIZ | LH | -5 | 0 | 0 | -9 | -9 | -9 | 40 | 5.5 | 6 | 70 | 80 | 0 | 0 | | S |
| | LIZ | Aej | 0 | 8 | 0 | 90 | 9 | 1 | 0.2 | 5.3 | 5.8 | 2 | 80 | 0 | 0 | S | |
| | LIZ | Bm1 | 8 | 33 | 0 | 89 | 9 | 2 | 0.2 | 5.4 | 5.9 | 2 | 80 | 0 | 0 | S | |
| | LIZ | Bm2 | 33 | 51 | 1 | 92 | 6 | 2 | 0.1 | 5.3 | 5.8 | 1 | 80 | 0 | 0 | | |
| | LIZ | BC1 | 51 | 76 | 2 | 93 | 6 | 1 | 0.1 | 6.4 | 6.9 | 1 | 99 | 0 | 0 | | |
| | LIZ | BC2 | 76 | 102 | 0 | 89 | 8 | 3 | 0.1 | 5.7 | 6.2 | 2 | 90 | 0 | 0 | | |
| | LIZ | C | 102 | 120 | 0 | 83 | 13 | 4 | 0 | 6 | 6.5 | 2 | 90 | 0 | 0 | | |
| Lessard | LRD | Ah | 0 | 8 | 0 | 20 | 55 | 25 | 5.5 | 5.7 | 6.3 | 39 | 91 | 0 | 0 | L | L |
| | LRD | Ahe | 8 | 36 | 0 | 15 | 58 | 27 | 3 | 6.2 | 6.8 | 27 | 94 | 0 | 0 | L | |
| | LRD | AB | 36 | 48 | 0 | 14 | 58 | 28 | 1.5 | 6 | 6.6 | 20 | 96 | 0 | 0 | | |
| | LRD | Bm | 48 | 69 | 0 | 15 | 55 | 30 | 0.5 | 6 | 6.6 | 20 | 97 | 0 | 0 | | |
| | LRD | BC | 69 | 89 | 0 | 12 | 61 | 27 | 0.5 | 7 | 7.4 | 18 | 99 | 0 | 0 | | |
| | LRD | Cca | 89 | 117 | 0 | 20 | 55 | 25 | 0 | 7.7 | 7.9 | 15 | 99 | 0 | 13 | | |
| | LRD | Ck1 | 117 | 142 | 0 | 25 | 55 | 20 | 0 | 7.7 | 7.9 | 13 | 99 | 0 | 8 | | |
| | LRD | Ck2 | 142 | 160 | 0 | 24 | 56 | 20 | 0 | 7.6 | 7.8 | 13 | 99 | 0 | 7 | | |
| Mundare | MDR | Ah | 0 | 25 | 0 | 85 | 9 | 6 | 2.2 | 5.9 | 6.5 | 9 | 59 | 0 | 0 | L | L |
| | MDR | AB1 | 25 | 35 | 0 | 85 | 10 | 5 | 0.9 | 6 | 6.6 | 6 | 53 | 0 | 0 | | |
| | MDR | AB2 | 35 | 52 | 0 | 87 | 8 | 5 | 0.8 | 6.2 | 6.8 | 5 | 45 | 0 | 0 | | |
| | MDR | Bm | 52 | 88 | 0 | 90 | 5 | 5 | 0.4 | 6.2 | 6.8 | 6 | 56 | 0 | 0 | | |
| | MDR | BC | 88 | 120 | 0 | 88 | 6 | 6 | 0.5 | 6.1 | 6.7 | 6 | 70 | 0 | 0 | | |
| | MDR | Ck | 120 | 150 | 0 | 90 | 5 | 5 | 0 | 7.1 | 7.5 | 5 | 99 | 0 | 3 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mildred | MIL | LFH | -1 | 0 | 0 | -9 | -9 | -9 | 36.4 | 4.4 | 4.9 | 70 | 33 | 0 | 0 | | S |
| | MIL | Ahe | 0 | 3 | 3 | 92 | 6 | 2 | 1.4 | 5.2 | 6.2 | 2 | 71 | 0 | 0 | S | |
| | MIL | Ae | 3 | 9 | 3 | 89 | 10 | 1 | 0.4 | 4.8 | 5.6 | 3 | 65 | 0 | 0 | S | |
| | MIL | AB | 9 | 15 | 3 | 86 | 12 | 2 | 0.4 | 5 | 5.8 | 2 | 60 | 0 | 0 | S | |
| | MIL | Bm1 | 15 | 25 | 3 | 88 | 10 | 2 | 0.4 | 5.1 | 6.2 | 1 | 65 | 0 | 0 | L | |
| | MIL | Bm2 | 25 | 55 | 3 | 95 | 2 | 3 | 0.2 | 5 | 6.2 | 1 | 99 | 0 | 0 | | |
| | MIL | BC | 55 | 90 | 3 | 95 | 3 | 2 | 0.2 | 5.2 | 6.3 | 1 | 70 | 0 | 0 | | |
| | MIL | C | 90 | 100 | 3 | 95 | 3 | 2 | 0.1 | 5.1 | 6.2 | 1 | 70 | 0 | 0 | | |
| McClelland | MLD | Of | 0 | 25 | 0 | -9 | -9 | -9 | 45 | 5 | 5.5 | 106 | 70 | 0 | 0 | H | M-L |
| | MLD | Om1 | 25 | 86 | 0 | -9 | -9 | -9 | 40 | 6 | 6.5 | 172 | 90 | 0 | 0 | | |
| | MLD | Om2 | 86 | 160 | 0 | -9 | -9 | -9 | 40 | 6 | 6.5 | 170 | 90 | 0 | 0 | | |
| Manatokan | MNT | Of | 0 | 24 | -9 | -9 | -9 | -9 | 54.2 | 3.4 | 4 | 100 | 20 | 0 | 0 | | M |
| | MNT | Om1 | 24 | 66 | -9 | -9 | -9 | -9 | 53.4 | 5.5 | 6.1 | 200 | 80 | 0 | 0 | | |
| | MNT | Om2 | 66 | 102 | -9 | -9 | -9 | -9 | 53.9 | 5 | 5.6 | 180 | 70 | 0 | 0 | | |
| | MNT | Om3 | 102 | 135 | -9 | -9 | -9 | -9 | 50 | 5.4 | 6 | 160 | 80 | 0 | 0 | | |
| | MNT | Cg | 135 | 160 | 2 | 50 | 45 | 5 | 0 | 5.9 | 6.5 | 2 | 80 | 0 | 0 | | |
| Mapova | MPV | Om | -5 | 0 | -9 | -9 | -9 | -9 | 40 | 5.9 | 6.5 | 120 | 90 | 0 | 0 | | L |
| | MPV | Ahgj | 0 | 13 | 1 | 50 | 32 | 18 | 3.4 | 6 | 6.6 | 20 | 95 | 0 | 0 | L | |
| | MPV | Aeg | 13 | 20 | 3 | 55 | 37 | 8 | 0.2 | 6.5 | 7.1 | 4 | 99 | 0 | 0 | L | |
| | MPV | Btg | 20 | 33 | 5 | 41 | 22 | 37 | 0.4 | 5.9 | 6.5 | 21 | 94 | 0 | 0 | | |
| | MPV | BCg | 33 | 60 | 5 | 44 | 24 | 32 | 0.5 | 6 | 6.6 | 18 | 97 | 0 | 0 | | |
| | MPV | Ckg | 60 | 93 | 5 | 44 | 27 | 29 | 0 | 7 | 7.4 | 12 | 99 | 0 | 4 | | |
| | MPV | Ckg | 93 | 100 | 5 | 43 | 27 | 30 | 0 | 7.3 | 7.6 | 13 | 99 | 0 | 6 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mooswa | MSW | Ah | 0 | 15 | 2 | 37 | 58 | 5 | 4.4 | 6.1 | 6.5 | 24 | 90 | 0 | 0 | L | L |
| | MSW | Ahe | 15 | 23 | 2 | 52 | 34 | 14 | 1 | 5.9 | 6.4 | 13 | 90 | 0 | 0 | L | |
| | MSW | Ae | 23 | 31 | 2 | 51 | 34 | 15 | 0.6 | 6 | 6.5 | 12 | 90 | 0 | 0 | | |
| | MSW | Btj | 31 | 51 | 5 | 44 | 41 | 15 | 0.4 | 6.1 | 6.5 | 11 | 90 | 0 | 0 | | |
| | MSW | BC | 51 | 101 | 10 | 48 | 39 | 13 | 0.2 | 6.1 | 6.5 | 10 | 90 | 0 | 0 | | |
| | MSW | Cca | 101 | 120 | 10 | 55 | 31 | 14 | 0 | 7.8 | 8 | 16 | 99 | 0 | 8 | | |
| Muskeg | MUS | Of | 0 | 25 | 0 | -9 | -9 | -9 | 45 | 3 | 3.6 | 106 | 10 | 0 | 0 | L | M |
| | MUS | Om1 | 25 | 86 | 0 | -9 | -9 | -9 | 40 | 4 | 4.6 | 172 | 40 | 0 | 0 | | |
| | MUS | Om2 | 86 | 160 | 0 | -9 | -9 | -9 | 40 | 4 | 4.6 | 170 | 40 | 0 | 0 | | |
| Niton | NIT | LH | -5 | 0 | 0 | -9 | -9 | -9 | 30 | 5.7 | 6.3 | 70 | 73 | 0 | 0 | | S |
| | NIT | Ae | 0 | 5 | 1 | 90 | 8 | 2 | 0.4 | 5.6 | 6.2 | 2 | 90 | 0 | 0 | S | |
| | NIT | Bm1 | 5 | 18 | 0 | 85 | 13 | 2 | 0.3 | 5.7 | 6.3 | 2 | 87 | 0 | 0 | S | |
| | NIT | Bm2 | 18 | 38 | 0 | 86 | 12 | 2 | 0.2 | 5.8 | 6.3 | 2 | 90 | 0 | 0 | S | |
| | NIT | Bm3 | 38 | 66 | 3 | 96 | 2 | 2 | 0.1 | 5.9 | 6.4 | 1 | 95 | 0 | 0 | | |
| | NIT | BC | 66 | 130 | 2 | 96 | 2 | 2 | 0.5 | 6.2 | 6.6 | 1 | 99 | 0 | 0 | | |
| | NIT | Ck | 130 | 150 | 0 | 90 | 8 | 2 | 0 | 7.1 | 7.4 | 1 | 99 | 0 | 3 | | |
| Nestow | NTW | LH | -13 | 0 | 0 | -9 | -9 | -9 | 40 | 6 | 6.6 | 70 | 70 | 0 | 0 | | S |
| | NTW | Ah | 0 | 5 | 0 | 88 | 8 | 4 | 5.1 | 5.3 | 5.9 | 15 | 57 | 0 | 0 | M | |
| | NTW | Ae | 5 | 13 | 0 | 92 | 8 | 0 | 0.4 | 4.8 | 5.4 | 3 | 53 | 0 | 0 | S | |
| | NTW | Bm1 | 13 | 36 | 0 | 93 | 6 | 1 | 0.2 | 5.2 | 5.8 | 3 | 55 | 0 | 0 | S | |
| | NTW | Bm2 | 36 | 64 | 0 | 93 | 6 | 1 | 0.1 | 5.4 | 6 | 2 | 58 | 0 | 0 | | |
| | NTW | BC | 64 | 147 | 0 | 97 | 2 | 1 | 0.5 | 5.7 | 6.3 | 2 | 60 | 0 | 0 | | |
| | NTW | C | 147 | 168 | 0 | 92 | 3 | 5 | 0.1 | 6.3 | 6.9 | 4 | 90 | 0 | 0 | | |
| Pece Hills | PHS | Ah | 0 | 30 | 0 | 64 | 20 | 16 | 2.5 | 6.1 | 6.5 | 21 | 70 | 0 | 0 | L | L |
| | PHS | AB | 30 | 46 | 0 | 65 | 19 | 16 | 0.8 | 6.1 | 6.5 | 12 | 70 | 0 | 0 | | |
| | PHS | Btj | 46 | 76 | 0 | 59 | 22 | 19 | 0.4 | 5.8 | 6.2 | 13 | 65 | 0 | 0 | | |
| | PHS | BC | 76 | 122 | 0 | 66 | 17 | 17 | 0.5 | 6.4 | 6.8 | 12 | 99 | 0 | 0 | | |
| | PHS | Ck | 122 | 150 | 0 | 65 | 20 | 15 | 0 | 6.7 | 7.2 | 11 | 99 | 0 | 5 | | |

**Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.**

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol kg$^{-1}$) | Bases (cmol kg$^{-1}$) | EC (dS m$^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pinto | PIN | LH | -2 | 0 | 0 | -9 | -9 | -9 | 40 | 5.6 | 6.2 | 70 | 80 | 0 | 0 | | S |
| | PIN | Ah | 0 | 3 | 10 | 60 | 35 | 5 | 8.2 | 5.6 | 6.2 | 10 | 81 | 0 | 0 | L | |
| | PIN | Ae | 3 | 10 | 20 | 90 | 2 | 8 | 0.3 | 5.2 | 5.8 | 5 | 57 | 0 | 0 | S | |
| | PIN | Bm | 10 | 30 | 40 | 85 | 10 | 5 | 0.3 | 5.6 | 6.2 | 3 | 80 | 0 | 0 | S | |
| | PIN | BC | 30 | 61 | 50 | 85 | 10 | 5 | 0.1 | 5.8 | 6.4 | 3 | 90 | 0 | 0 | | |
| | PIN | Ck | 61 | 120 | 70 | 98 | 2 | 0 | 0 | 6.7 | 7.2 | 1 | 99 | 0 | 3 | | |
| Primula | PRM | LH | -5 | 0 | 0 | -9 | -9 | -9 | 30 | 5.7 | 6.3 | 70 | 73 | 0 | 0 | | S |
| | PRM | Ae | 0 | 5 | 1 | 90 | 8 | 2 | 0.4 | 5.6 | 6.2 | 2 | 90 | 0 | 0 | S | |
| | PRM | Bm1 | 5 | 18 | 0 | 85 | 13 | 2 | 0.3 | 5.7 | 6.3 | 2 | 87 | 0 | 0 | S | |
| | PRM | Bm2 | 18 | 38 | 0 | 86 | 12 | 2 | 0.2 | 5.8 | 6.3 | 2 | 90 | 0 | 0 | S | |
| | PRM | Bm3 | 38 | 66 | 3 | 96 | 2 | 2 | 0.1 | 5.9 | 6.4 | 1 | 95 | 0 | 0 | | |
| | PRM | BC | 66 | 130 | 2 | 96 | 2 | 2 | 0.5 | 6.2 | 6.6 | 1 | 90 | 0 | 1 | | |
| | PRM | Ck | 130 | 150 | 0 | 90 | 8 | 2 | 0 | 7.1 | 7.4 | 1 | 99 | 0 | 3 | | |
| Redwater | RDW | Ah | 0 | 10 | 0 | 70 | 18 | 12 | 3.5 | 5.9 | 6.5 | 20 | 90 | 0 | 0 | L | L |
| | RDW | Ahe | 10 | 35 | 0 | 65 | 20 | 15 | 1.2 | 5.5 | 6.1 | 13 | 80 | 0 | 0 | L | |
| | RDW | Bm | 35 | 60 | 0 | 64 | 25 | 11 | 0.5 | 6.1 | 6.7 | 8 | 90 | 0 | 0 | | |
| | RDW | BC1 | 60 | 80 | 0 | 60 | 30 | 10 | 0.5 | 6.3 | 6.9 | 6 | 90 | 0 | 0 | | |
| | RDW | BC2 | 80 | 100 | 0 | 80 | 10 | 10 | 0.5 | 6.6 | 7.1 | 6 | 99 | 0 | 1 | | |
| | RDW | Ck | 100 | 130 | 0 | 65 | 25 | 10 | 0 | 7 | 7.4 | 6 | 99 | 0 | 3 | | |
| Roly View | RLV | LFH | -3 | 0 | 0 | -9 | -9 | -9 | 40 | 5.8 | 6.4 | 70 | 90 | 0 | 0 | | L |
| | RLV | Ah | 0 | 8 | 2 | 45 | 35 | 20 | 6 | 6.2 | 6.8 | 38 | 67 | 0 | 0 | L | |
| | RLV | Ahe | 8 | 30 | 3 | 45 | 40 | 15 | 2.6 | 6.3 | 6.9 | 22 | 68 | 0 | 0 | L | |
| | RLV | AB | 30 | 35 | 3 | 45 | 35 | 20 | 0.8 | 6.2 | 6.8 | 19 | 69 | 0 | 0 | | |
| | RLV | Bt | 35 | 70 | 5 | 45 | 25 | 30 | 0.4 | 5.9 | 6.5 | 17 | 72 | 0 | 0 | | |
| | RLV | BC | 70 | 95 | 5 | 50 | 25 | 25 | 0.5 | 7.4 | 7.7 | 15 | 99 | 0 | 0 | | |
| | RLV | Ck | 95 | 100 | 10 | 50 | 25 | 25 | 0 | 8 | 8.1 | 15 | 99 | 1 | 6 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol kg$^{-1}$) | Bases (cmol kg$^{-1}$) | EC (dS m$^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spedden | SDN | LH | -8 | 0 | 0 | -9 | -9 | -9 | 40 | 5.9 | 6.5 | 75 | 90 | 0 | 0 | | M |
| | SDN | Ahe | 0 | 10 | 5 | 31 | 47 | 22 | 4 | 5.7 | 6.3 | 28 | 95 | 0 | 0 | L | |
| | SDN | Ae | 10 | 15 | 5 | 35 | 47 | 18 | 1.1 | 5.4 | 6 | 14 | 90 | 0 | 0 | L | |
| | SDN | AB | 15 | 25 | 5 | 30 | 45 | 25 | 0.7 | 5.3 | 5.9 | 17 | 90 | 0 | 0 | L | |
| | SDN | Bt1 | 25 | 40 | 5 | 30 | 35 | 35 | 0.6 | 5.2 | 5.8 | 24 | 85 | 0 | 0 | | |
| | SDN | Bt2 | 40 | 65 | 5 | 35 | 35 | 30 | 0.6 | 5.4 | 6 | 21 | 90 | 0 | 0 | | |
| | SDN | BC | 65 | 90 | 5 | 31 | 36 | 33 | 0.5 | 6.2 | 6.8 | 23 | 90 | 0 | 0 | | |
| | SDN | Ck | 90 | 110 | 5 | 34 | 33 | 33 | 0 | 7.1 | 7.5 | 21 | 99 | 0 | 10 | | |
| St. Lina | SLN | Of | 0 | 25 | -9 | -9 | -9 | -9 | 45 | 5.4 | 6 | 140 | 80 | 0 | 0 | L | L |
| | SLN | Om1 | 25 | 51 | -9 | -9 | -9 | -9 | 40 | 5.7 | 6.3 | 132 | 90 | 0 | 0 | | |
| | SLN | Om2 | 51 | 97 | -9 | -9 | -9 | -9 | 45.4 | 5.2 | 5.8 | 103 | 70 | 0 | 0 | | |
| | SLN | Oh | 97 | 137 | -9 | -9 | -9 | -9 | 42.7 | 5.1 | 5.7 | 75 | 70 | 0 | 0 | | |
| | SLN | Cg | 137 | 160 | 5 | 30 | 40 | 30 | 0 | 6.9 | 7.3 | 25 | 99 | 0 | 0 | | |
| Slawa | SLW | Ah | 0 | 10 | 5 | 40 | 30 | 30 | 8 | 6.3 | 6.7 | 39 | 90 | 0 | 0 | L | L |
| | SLW | Ae | 10 | 13 | 5 | 40 | 30 | 30 | 2 | 6.3 | 6.7 | 26 | 90 | 0 | 0 | L | |
| | SLW | Btj | 13 | 30 | 5 | 25 | 35 | 40 | 2.6 | 7.4 | 7.6 | 30 | 99 | 0 | 0 | L | |
| | SLW | BC | 30 | 60 | 10 | 30 | 35 | 35 | 0.5 | 6.2 | 6.6 | 24 | 90 | 0 | 0 | | |
| | SLW | Ck | 60 | 100 | 15 | 20 | 35 | 45 | 0 | 6.8 | 7.1 | 26 | 99 | 0 | 2 | | |
| Tucker | TCK | Of | 0 | 41 | -9 | -9 | -9 | -9 | 39.2 | 3.8 | 4.4 | 115 | 30 | 0 | 0 | L | M |
| | TCK | Om | 41 | 66 | -9 | -9 | -9 | -9 | 34.7 | 6.6 | 7.1 | 180 | 99 | 0 | 0 | | |
| | TCK | Ckg | 66 | 160 | 0 | 80 | 10 | 10 | 0 | 7.1 | 7.5 | 7 | 99 | 0 | 3 | | |
| Tawatinaw | TNW | LH | -5 | 0 | 0 | -9 | -9 | -9 | 30 | 6 | 6.4 | 65 | 90 | 0 | 0 | | S |
| | TNW | Ae1 | 0 | 10 | 5 | 46 | 51 | 3 | 0.6 | 5.9 | 6.3 | 6 | 90 | 0 | 0 | S | |
| | TNW | Ae2 | 10 | 25 | 5 | 71 | 27 | 2 | 0.2 | 6 | 6.6 | 5 | 90 | 0 | 0 | L | |
| | TNW | AB | 25 | 36 | 10 | 53 | 26 | 21 | 0.5 | 5.5 | 6 | 18 | 90 | 0 | 0 | | |
| | TNW | Bt | 36 | 76 | 20 | 55 | 25 | 20 | 0.4 | 5.8 | 6.2 | 13 | 90 | 0 | 0 | | |
| | TNW | BCk | 76 | 117 | 20 | 68 | 27 | 5 | 0.5 | 7 | 7.3 | 4 | 99 | 0 | 1 | | |
| | TNW | Ck | 117 | 136 | 25 | 52 | 35 | 13 | 0 | 7.2 | 7.4 | 15 | 99 | 0 | 5 | | |

## Table B2: Derivation of Acidification Sensitivity Ratings of Soil Series.

| Soil Series | Series Symbol | Horizon | Upper Depth (cm) | Lower Depth (cm) | Coarse Fragments (%) | Sand (%) | Silt (%) | Clay (%) | Org Carbon (%) | pHca | pHw | CEC (cmol $kg^{-1}$) | Bases (cmol $kg^{-1}$) | EC (dS $m^{-1}$) | $CACO_3$ (%) | Acid'n Rating by Horizon | Acid'n Rating to 20 cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two Hills | TWH | Ah | 0 | 13 | 10 | 44 | 37 | 19 | 8 | 5.4 | 5.9 | 40 | 58 | 0 | 0 | L | L |
| | TWH | Ahe | 13 | 20 | 20 | 49 | 32 | 19 | 4.6 | 5.7 | 6.1 | 26 | 53 | 0 | 0 | L | |
| | TWH | Bm | 20 | 41 | 40 | 60 | 26 | 14 | 1.4 | 6.2 | 6.6 | 14 | 61 | 0 | 0 | | |
| | TWH | BC | 41 | 100 | 40 | 82 | 9 | 9 | 0.5 | 7.5 | 7.7 | 15 | 99 | 0 | 2 | | |
| Uncas | UCS | Ah | 0 | 5 | 2 | 44 | 35 | 21 | 8.2 | 7 | 7.3 | 27 | 99 | 0 | 0 | L | L |
| | UCS | Ahe | 5 | 18 | 2 | 45 | 32 | 23 | 3.2 | 6.6 | 7 | 22 | 99 | 0 | 0 | L | |
| | UCS | Ae | 18 | 31 | 3 | 34 | 45 | 21 | 0.9 | 5.8 | 6.2 | 10 | 90 | 0 | 0 | L | |
| | UCS | Bt1 | 31 | 51 | 5 | 45 | 25 | 30 | 0.6 | 6.1 | 6.5 | 15 | 90 | 0 | 0 | | |
| | UCS | Bt2 | 51 | 69 | 5 | 49 | 23 | 28 | 0.5 | 6.3 | 6.7 | 14 | 90 | 0 | 0 | | |
| | UCS | BC | 69 | 89 | 5 | 50 | 23 | 27 | 0 | 6.5 | 6.9 | 13 | 99 | 0 | 0 | | |
| | UCS | Ck | 89 | 100 | 5 | 51 | 23 | 26 | 0 | 7.6 | 7.8 | 10 | 99 | 1 | 6 | | |
| Ukalta | UKT | Ah | 0 | 30 | 0 | 64 | 20 | 16 | 3 | 5.9 | 6.5 | 85 | 95 | 0 | 0 | L | L |
| | UKT | AB | 30 | 35 | 0 | 65 | 19 | 16 | 1 | 5.9 | 6.5 | 14 | 95 | 0 | 0 | | |
| | UKT | Btj | 35 | 70 | 0 | 59 | 22 | 19 | 0.5 | 5.6 | 6.2 | 13 | 90 | 0 | 0 | | |
| | UKT | BC | 70 | 100 | 5 | 43 | 27 | 30 | 0.5 | 6.5 | 7 | 17 | 99 | 0 | 0 | | |
| | UKT | Ck | 100 | 120 | 5 | 42 | 30 | 28 | 0 | 7.5 | 7.7 | 16 | 99 | 1 | 5 | | |
| Wilna | VIL | Ah | 0 | 20 | 2 | 48 | 33 | 19 | 3.6 | 5.7 | 6.3 | 23 | 85 | 0 | 0 | L | L |
| | VIL | Ahe | 20 | 25 | 2 | 48 | 34 | 18 | 1 | 5.8 | 6.4 | 15 | 83 | 0 | 0 | | |
| | VIL | AB | 25 | 36 | 5 | 55 | 24 | 21 | 0.4 | 5.8 | 6.4 | 14 | 94 | 0 | 0 | | |
| | VIL | Btgj | 36 | 71 | 5 | 47 | 26 | 27 | 0.4 | 6.2 | 6.8 | 15 | 99 | 0 | 0 | | |
| | VIL | Ckg | 71 | 90 | 5 | 47 | 27 | 26 | 0 | 7.6 | 7.8 | 14 | 99 | 0 | 8 | | |
| | VIL | Ckg | 90 | 100 | 5 | 44 | 28 | 28 | 0 | 7.4 | 7.6 | 16 | 99 | 0 | 6 | | |
| **Miscellaneous Land Types** | | | | | | | | | | | | | | | | | |
| Coarse textured, with Dark Gray soils | | | | | ZCOzdg | | | | | | | | | | | L | L |
| Eroded, with Black soils | | | | | ZERzbl | | | | | | | | | | | L | L |
| Eroded, with Dark Gray soils | | | | | ZERzdg | | | | | | | | | | | L | L |
| Poorly drained and shallow water | | | | | ZGW | | | | | | | | | | | NA | NA |
| Organic soils | | | | | ZOR | | | | | | | | | | | M-L | M-L |
| Undifferentiated soils | | | | | ZUN | | | | | | | | | | | L | L |
| Water bodies | | | | | ZWA | | | | | | | | | | | NA | NA |

**Table B3. Description of Land Systems in the LICA Study Area.**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 05.00.02a Vermilion River Valley | Thin Black | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | | | Wide valley landscape with one or more terraces with some confined floodplain. Dark Brown Chernozem. |
| 05.5c.07b Reilly Plain | Black-Dark Gray | Beaverhills (Orthic Black Chernozem) Mundare (Orthic Black Chernozem) Peace Hills (Orthic Black Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with some low relief hummocky. Black Chernozems developed on combination of moderately course glaciofluvial, moderately fine till and very course fluvioeolian. Minor Gleysols. |
| 05.5c.11 Pasatchaw Plain | Black-Dark Gray | Beaverhills (Orthic Black Chernozem) | | | High relief undulating landscape with low relief inclined plain. Black Chernozems developed on moderately fine till. |
| 05.5c.15a Dewberry Plain | Black-Dark Gray | Beaverhills (Orthic Black Chernozem) Mundare (Orthic Black Chernozem) | Ukalta (Orthic Black Chernozem) | | High relief undulating landscape with some low relief undulating. Black Chernozems developed on combination of moderately fine till and very course fluvioeolian. Minor Chernozems. |
| 05.5c.15b Dewberry Plain | Black-Dark Gray | Beaverhills (Orthic Black Chernozem) Mundare (Orthic Black Chernozem) | Ukalta (Orthic Black Chernozem) | | High relief undulating landscape with some low relief undulating. Black Chernozems developed on combination moderately fine till and very course fluvioeolian. Minor Chernozems. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 05.5c.15c Dewberry Plain | Black-Dark Gray | Beaverhills (Orthic Black Chernozem) Mundare (Orthic Black Chernozem) | Ukalta (Orthic Black Chernozem) | | High relief undulating landscape with some low relief undulating. Black Chernozems developed on combination moderately fine till and very course fluvioeolian. Minor Chernozems. |
| 05.5c.17 Irish Creek Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) Gabriel (Dark Gray Luvisol) | Helliwell (Orthic Dark Gray Chernozem) | | High relief undulating landscape with low relief undulating and inclined plain. Black Chernozems and Gray Luvisols developed on moderately fine till and moderately course glaciofluvial. Minor Chernozems. |
| 05.5d.06 Gadois Upland | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) Uncas (Dark Gray Luvisol) | Redwater (Orthic Dark Gray Chernozem) Miscellaneous Eroded-ZBL (Rego Black Chernozem) | | High relief hummocky landscape with low relief hummocky and inclined plain. Black Chernozems and Gray Luvisols developed on moderately fine till. Minor Chernozems. |
| 05.5d.23 Clandonald Upland | Black-Dark Gray | Slawa (Eluviated Black Chernozem) | Angus Ridge (Eluviated Black Chernozem) | | Moderate relief hummocky landscape with low relief hummocky and high relief undulating. Black Chernozems developed on fine till. Minor Black Chernozems. |
| 05.5d.24 Queenie Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) Uncas (Dark Gray Luvisol) | Slawa (Eluviated Black Chernozem) Miscellaneous Gleysol (Orthic Humic Gleysol) | | Low relief hummocky landscape with level plain and moderate relief hummocky. Black Chernozems and Gray Luvisols developed on moderately fine till. Minor Chernozems and Gleysols. |
| 05.5d.32 Tomas Upland | Black-Dark Gray | Rolly View (Orthic Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Redwater (Orthic Dark Gray Chernozem) | | Moderate relief hummocky landscape with high relief hummocky and low relief ridged. Dark Gray Chernozems developed on moderately fine till. Minor Gleysols and Chernozems. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.00.01a Beaver River Valley | Dark Gray-Gray | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Course-ZDG (Orthic Brown Chernozem) | | High relief valley with confined floodplain landscape with some v-shaped valley with no terraces or floodplain. Dark Gray Chernozems developed on undetermined parent material. Minor Gleysols and Chernozems. |
| 06.00.01b Beaver River Valley | Dark Gray-Gray | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Course-ZDG (Orthic Brown Chernozem) | | High relief valley with confined floodplain landscape with some v-shaped valley with no terraces or floodplain. Dark Gray Chernozems developed on undetermined parent material. Minor Gleysols and Chernozems. |
| 06.00.01c Beaver River Valley | Dark Gray-Gray | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Course-ZDG (Orthic Brown Chernozem) | | High relief valley with confined floodplain landscape with some v-shaped valley with no terraces or floodplain. Dark Gray Chernozems developed on undetermined parent material. Minor Gleysols and Chernozems. |
| 06.00.01d Beaver River Valley | Dark Gray-Gray | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Course-ZDG (Orthic Brown Chernozem) | | High relief valley with confined floodplain landscape with some v-shaped valley with no terraces or floodplain. Dark Gray Chernozems developed on undetermined parent material. Minor Gleysols and Chernozems. |
| 06.00.03a North Saskatchewan River Valley | Black-Dark Gray | Miscellaneous Eroded-ZBL (Rego Black Chernozem) | Miscellaneous Water | | High relief inclined slope landscape with some single water body basin which may be filled or partly filled with water (> 65 ha) and high relief undulating. Black Chernozems developed on undetermined parent material. |
| 06.00.03b North Saskatchewan River Valley | Black-Dark Gray | Miscellaneous Eroded-ZBL (Rego Black Chernozem) | Miscellaneous Water | | High relief inclined slope landscape with some single water body basin which may be filled or partly filled with water (greater than 65 ha) and high relief undulating. Black Chernozems developed on undetermined parent material. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2b.01 Atimoswe Creek Plain | Black-Dark Gray | Uncas (Dark Gray Luvisol) Angus Ridge (Eluviated Black Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Eroded (Rego Black Chernozem) | | High relief undulating landscape with some high relief inclined to steep landscape. Gray Luvisols and Black Chernozems developed on moderately fine till. Minor Gleysols and Chernozems. |
| 06.2b.02 Kawatt Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) | Uncas (Dark Gray Luvisol) Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with some low relief undulating. Black Chernozems developed on moderately fine till. Minor Luvisols and Gleysols. |
| 06.2b.10 Kerensky Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) Uncas (Dark Gray Luvisol) | Miscellaneous Gleysol (Orthic Humic Gleysol) | | Low relief hummocky landscape with some moderate relief hummocky. Black Chernozems and Gray Luvisols developed on moderately fine till. Minor Gleysols. |
| 06.2b.11a Val Soucy Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) | Uncas (Dark Gray Luvisol) Mooswa (Eluviated Black Chernozem) | | Low relief undulating landscape with some high relief undulating. Black Chernozems developed on moderately fine till. Minor Luvisols and Chernozems. |
| 06.2b.11b Val Soucy Plain | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) | Uncas (Dark Gray Luvisol) Mooswa (Eluviated Black Chernozem) | | Low relief undulating landscape with some high relief undulating. Black Chernozems developed on moderately fine till. Minor Luvisols and Chernozems. |
| 06.2b.13 Laurier Upland | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) | Primula (Eluviated Eutric Brunisol) Uncas (Dark Gray Luvisol) | | Moderate relief hummocky landscape with some low relief hummocky landscape. Black Chernozems developed on moderately fine till. Minor Brunisols and Luvisols. |
| 06.2b.14 Makaoo Upland | Black-Dark Gray | Angus Ridge (Eluviated Black Chernozem) | Kavanagh (Black Solodized Solonetz) Mundare (Orthic Black Chernozem) | | Low relief hummocky landscape with some moderate relief hummocky and ridged. Black Chernozems developed on moderately fine till. Minor Solonetz and Chernozems. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2d.01b Cherry Grove Plain | Dark Gray-Gray | La Corey (Orthic Gray Luvisol) | Spedden ( Dark Gray Luvisol) Birkland-AA (Terric Fibrisol) | | High relief undulating landscape with some level, flat, horizontal or plateau organic. Gray Luvisols developed on moderately fine till. Minor Luvisols and Organics. |
| 06.2d.02a Beaver Crossing Plain | Dark Gray-Gray | Kehiwin (Orthic Dark Gray Chernozem) Spedden (Dark Gray Luvisol) | Fergy (Eluviated Black Chernozem) La Corey (Orthic Gray Luvisol) | | High relief hummocky landscape with some low relief ridged landscape. Gray Chernozems and Gray Luvisols developed on moderately fine till. Minor Chernozems and Luvisols. |
| 06.2d.02a Beaver Crossing Plain | Dark Gray-Gray | Kehiwin (Orthic Dark Gray Chernozem) Spedden (Dark Gray Luvisol) | Fergy (Eluviated Black Chernozem) La Corey (Orthic Gray Luvisol) | | High relief hummocky landscape with some low relief ridged landscape. Gray Chernozems and Gray Luvisols developed on moderately fine till. Minor Chernozems and Luvisols. |
| 06.2d.05 Lessard Plain | Dark Gray-Gray | Spedden (Dark Gray Luvisol) Lessard (Orthic Dark Gray Chernozem) | Franchere (Orthic Gray Luvisol) Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with some low relief undulating and level landscapes. Gray Luvisols and Gray Chernozems developed on medium textured glaciolacustrine and moderately fine till. Minor Luvisols and Gleysols. |
| 06.2d.06 Wolf Plain | Dark Gray-Gray | Fergy (Eluviated Black Chernozem) Ardmore (Eluviated Black Chernozem) | Spedden ( Dark Gray Luvisol) Nestow (Eluviated Dystric Brunisol) | | High relief undulating landscape with some low relief undulating and low relief longitudinal dunes. Black Chernozems developed on moderately fine till and medium textured glaciolacustrine. Minor Luvisols and Brunisols. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2d.07 Ardmore Plain | Dark Gray-Gray | Fergy (Eluviated Black Chernozem) Kehiwin (Orthic Dark Gray Chernozem) | Spedden ( Dark Gray Luvisol) | | Low relief undulating landscape with high relief undulating and single water body basin which may be filled or partly filled with water (> 65 ha). Black Chernozems and Dark Gray Chernozems developed on moderately fine till. Minor Luvisols. |
| 06.2d.08 Danuta Plain | Dark Gray-Gray | Spedden (Dark Gray Luvisol) | La Corey (Orthic Gray Luvisol) Kehiwin (Orthic Dark Gray Chernozem) | | High relief undulating landscape with some low relief undulating landscape. Gray Luvisols developed on moderately fine till. Minor Luvisols and Chernozems. |
| 06.2d.11 Glendon Plain | Dark Gray-Gray | Spedden (Dark Gray Luvisol) | La Corey (Orthic Gray Luvisol) Vilna (Gleyed Eluviated Black Chernozem) | | Low relief undulating landscape with some high relief undulating landscape. Gray Luvisols developed on moderately fine till. Minor Luvisols and Chernozems. |
| 06.2d.17 Denning Lake Upland | Dark Gray-Gray | Spedden (Dark Gray Luvisol) La Corey (Orthic Gray Luvisol) | Miscellaneous Gleysol (Orthic Humic Gleysol) | | Moderate relief ridged landscape with moderate and high relief hummocky landscape. Gray Luvisols developed on moderately fine till. Minor Gleysols. |
| 06.2d.19 Goodridge Plain | Dark Gray-Gray | Spedden (Dark Gray Luvisol) Goodridge-AA (Orthic Gray Luvisol) | Goodridge-AA (Orthic Gray Luvisol) Nicot (Eluviated Eutric Brunisol) | | High relief undulating landscape with some low relief valley with confined floodplain. Gray Luvisols developed on moderately fine till. Minor Luvisols and Brunisols. |
| 06.2d.22 Moose Lake Plain | Dark Gray-Gray | Nicot (Eluviated Eutric Brunisol) | Nestow (Eluviated Dystric Brunisol) Manatokan (Terric Mesisol) | | High relief undulating landscape with some single water body basin which may be filled or partly filled with water (>65 ha) and organic with level, flat, horizontal or plateau terrain. Eutric Brunisols developed on very course glaciofluvial. Minor Brunisols and Organics. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2d.23 Manatokan Plain | Dark Gray-Gray | Spedden (Dark Gray Luvisol) La Corey (Orthic Gray Luvisol) | Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with some low relief hummocky and level organic with hummocky mineral soils. Gray Luvisols developed on moderately fine till. Minor Gleysols. |
| 06.2d.24a Stebbing Lake Plain | Dark Gray-Gray | Nicot (Eluviated Eutric Brunisol) | Edwand (Eluviated Eutric Brunisol) Nestow (Eluviated Dystric Brunisol) | | High relief undulating landscape with some low relief longitudinal dunes and moderate relief hummocky terrain. Eutric Brunisols developed on very course glaciofluvial. Minor Brunisols. |
| 06.2d.24b Stebbing Lake Plain | Dark Gray-Gray | Nicot (Eluviated Eutric Brunisol) | Edwand (Eluviated Eutric Brunisol) Nestow (Eluviated Dystric Brunisol) | | High relief undulating landscape with some low relief longitudinal dunes and moderate relief hummocky terrain. Eutric Brunisols developed on very course glaciofluvial. Minor Brunisols. |
| 06.2d.25 Punk Creek Plain | Dark Gray-Gray | Tawatinaw (Orthic Gray Luvisol) La Corey (Orthic Gray Luvisol) | Miscellaneous Organic (Typic Mesisol) Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | | High relief hummocky with some level organics with hummocky mineral soils and v-shaped valley with no terraces or floodplain. Gray Luvisols developed on gravelly moderately course till and moderately fine till. Minor Organics and Chernozems. |
| 06.2d.26 Bangs Plain | Dark Gray-Gray | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief inclined plain landscape with some steep landforms with extensive failure slumps and a single water body basin which may be filled or partly filled with water (> 65 ha). Gray Chernozems developed on undetermined parent material. Minor Gleysols. |
| 06.2d.30 Owlseye Lake Upland | Black-Dark Gray | Cooking Lake (Orthic Gray Luvisol) Uncas (Dark Gray Luvisol) | Angus Ridge (Eluviated Black Chernozem) Miscellaneous Gleysol (Orthic Humic Gleysol) | | Moderate relief hummocky landscape with some low relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Chernozems and Gleysols. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2e.02 Beauvallon Upland | Black-Dark Gray | Cooking Lake (Orthic Gray Luvisol) Uncas (Dark Gray Luvisol) | Rolly View (Orthic Dark Gray Chernozem) Miscellaneous Gleysol (Orthic Humic Gleysol) | | Moderate relief hummocky landscape with some high relief undulating and high relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Chernozems and Gleysols. |
| 06.2e.03 Eliza Upland | Black-Dark Gray | Cooking Lake (Orthic Gray Luvisol) Peace Hills (Orthic Black Chernozem) | Uncas (Dark Gray Luvisol) Two Hills (Orthic Dark Gray Chernozem) | | Moderate relief hummocky landscape with some low and high relief hummocky terrain. Gray Luvisols and Black Chernozems developed on moderately fine till and moderately course glaciofluvial. Minor Luvisols and Chernozems. |
| 06.2e.04 Canard Upland | Black-Dark Gray | Uncas (Dark Gray Luvisol) Angus Ridge (Eluviated Black Chernozem) | Cooking Lake (Orthic Gray Luvisol) Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief hummocky landscape with some with some low and high relief hummocky terrain. Gray Luvisols and Black Chernozems developed on moderately fine till. Minor Luvisols and Gleysols. |
| 06.2e.05 Beauvallon Plain | Black-Dark Gray | Rolly View (Orthic Dark Gray Chernozem) Uncas (Dark Gray Luvisol) | Miscellaneous Gleysol (Orthic Humic Gleysol) Mundare (Orthic Black Chernozem) | | High relief undulating landscape with some non-aligned aggregation of sloughs and ponds with little inter-slough area and low relief valley with confined floodplain. Dark Gray Chernozems and Gray Luvisols developed on moderately fine till. Minor Gleysols and Chernozems. |
| 06.2e.07 Landon Upland | Black-Dark Gray | Redwater (Orthic Dark Gray Chernozem) Cooking Lake (Orthic Gray Luvisol) | Rolly View (Orthic Dark Gray Chernozem) Miscellaneous Gleysol (Orthic Humic Gleysol) | | Moderate relief hummocky landscape with some moderate relief ridged terrain. Dark Gray Chernozems and Gray Luvisols developed on moderately course glaciofluvial and moderately fine till. Minor Chernozems and Gleysols. |
| 06.2g.01 Kopernik Upland | Gray | Athabasca (Orthic Gray Luvisol) | St. Lina (Terric Humic Mesisol) | | Moderate relief hummocky landscape with some low and high relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Organics. |

**Table B3.  Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 06.2g.02 Fredro Plain | Gray | Athabasca (Orthic Gray Luvisol) | Grosmont (Dark Gray Luvisol) Birkland (Terric Fibrisol) | | High relief undulating landscape with some organics with level, flat, horizontal or plateau terrain. Gray Luvisols developed on moderately fine till. Minor Organics. |
| 06.2g.03 Reita Lake Plain | Gray | Athabasca (Orthic Gray Luvisol) | Grosmont (Dark Gray Luvisol) Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with some single water body basin which may be filled or partly filled with water (> 65 ha) and low relief ridged terrain. Gray Luvisols developed on moderately fine till. Minor Luvisols and Gleysols. |
| 06.2g.04 Murial Lake Plain | Gray | Athabasca (Orthic Gray Luvisol) | Grosmont (Dark Gray Luvisol) | | Low relief undulating landscape with some moderate relief undulating terrain and single water body basin which may be filled or partly filled with water (> 65 ha). Gray Luvisols developed on moderately fine till. Minor Luvisols. |
| 06.2g.05 Redspring Upland | Gray | Athabasca (Orthic Gray Luvisol) | St. Lina (Terric Humic Mesisol) | | Moderate relief hummocky landscape with some low relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Organics. |
| 06.2g.13 Asnyk Upland | Dark Gray-Gray | Spedden (Dark Gray Luvisol) La Corey (Orthic Gray Luvisol) | Miscellaneous Gleysol (Orthic Humic Gleysol) Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) | | Low relief hummocky landscape with some moderate relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Gleysols and Chernozems. |
| 08.2a.01 Hilda Lake Plain | Gray | Athabasca (Orthic Gray Luvisol) Liza (Eluviated Dystric Brunisol) | Spedden (Dark Gray Luvisol) St. Lina (Terric Humic Mesisol) | | High relief undulating landscape with level, flat, horizontal or plateau organic. Gray Luvisols and Dystric Brunisols developed on moderately fine till and very course glaciofluvial. Minor Luvisols and Organics. |

**Table B3. Description of the Land Systems in the LICA Study Area (continued).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 08.2a.02 Silesia Plain | Gray | Athabasca (Orthic Gray Luvisol) | Miscellaneous Eroded-ZDG (Rego Dark Gray Chernozem) Miscellaneous Gleysol (Orthic Humic Gleysol) | | High relief undulating landscape with a single water body basin which may be filled or partly filled with water (> 65 ha) and a low relief valley with confined floodplain. Gray Luvisols developed on moderately fine till. Minor Chernozems and Gleysols. |
| 08.2a.03 Odra Plain | Gray | Athabasca (Orthic Gray Luvisol) | Miscellaneous Organic (Typic Mesisol) Miscellaneous Course-ZDG (Orthic Dark Gray Chernozem) | | High relief undulating landscape with some level organics with moderate relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Organics and Chernozems. |
| 08.2a.05 Artur Upland | Gray | Athabasca (Orthic Gray Luvisol) | St. Lina (Terric Humic Mesisol) | | Hummocky and Ridged landscape with some low and moderate relief hummocky terrain. Gray Luvisols developed on moderately fine till. Minor Organics. |
| 08.2a.08 Meridian Lake Upland | Gray | Athabasca (Orthic Gray Luvisol) | | | Low relief hummocky landscape with some high relief inclined terrain. Gray Luvisols developed on moderately fine till. |
| 08.2a.10 Cold Lake | Gray | Miscellaneous Water | | | A single water body basin which may be filled or partly filled with water (> 65 ha) |
| 650005 Bourque Plain | Gray | Athabasca (Orthic Gray Luvisol) Nicot (Eluviated Dystric Brunisol) | St. Lina (Terric Humic Mesisol) Tucker Terric Mesisol) | | Low relief undulating to hummocky landscape with peatlands. Gray Luvisols developed on medium to moderately fine textured till. Significant Organics. |
| 650003 Standish Plain | Gray | Athabasca (Orthic Gray Luvisol) St. Lina (Terric Humic Mesisol) | Nicot (Eluviated Dystric Brunisol) Tucker Terric Mesisol) | | Low relief undulating to hummocky landscape with peatlands. Gray Luvisols developed on moderately fine textured till. Minor Organics. |

**Table B3. Description of the Land Systems in the LICA Study Area (concluded).**

| Land System Symbol & Name | Soil Zone | Major Soil Series | Minor Soil Series | Wetland Area (%) | General Description |
|---|---|---|---|---|---|
| 650002 Heart Upland | Gray | Athabasca (Orthic Gray Luvisol) | St. Lina (Terric Humic Mesisol) | | Low relief hummocky landscape. Gray Luvisols developed on moderately fine textured till. Minor Organics. |
| 650001 Seibert Plain | Gray | Athabasca (Orthic Gray Luvisol) Goodridge (Orthic Gray Luvisol) | St. Lina (Terric Humic Mesisol) Tucker Terric Mesisol) | | Low relief undulating to hummocky landscape. Gray Luvisols developed on moderately coarse and to moderately fine textured tills. Minor Organics. |
| 644001 Mostoos Upland | Gray | Kinosis (Orthic Gray Luvisol) McClelland (Typic Mesisol) | Mildred (Eluviated Dystric Brunisol) Hartley (Terric Fibrisol) | | Low relief hummocky landscape with extensive peatlands. Gray Luvisols developed on moderately fine textured till. Co-dominant Organics. |