

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

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**LAKELAND INDUSTRY AND
COMMUNITY ASSOCIATION**
Bonnyville, Alberta

Submitted by:

AMEC EARTH & ENVIRONMENTAL
Edmonton, Alberta

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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 NO_x 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

$\mu\text{g}/\text{m}^3$	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
<i>in situ</i>	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 ($\text{NO} + \text{NO}_2$)
PAI	Potential Acid Input
$\text{PM}_{2.5}$	Particulate Matter emissions with particle diameter less than $2.5 \mu\text{m}$
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

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Water Within the LICA Area; Bonnyville, Alberta
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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 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 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 fluvio-glacial 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. It includes 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, fluvio-glacial 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 (SO₂) 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 SO₄²⁻, NO₃⁻, NH₄⁺, K⁺, Na⁺, Ca²⁺ and Mg²⁺.

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

$$\text{PAI}_{\text{dry}} (\text{keq/ha/yr}) = 2 \frac{[\text{SO}_4^{2-}]}{96} + \frac{[\text{NO}_3^-]}{62} - \left(\frac{[\text{K}^+]}{39} + \frac{[\text{Na}^+]}{11} + 2 \frac{[\text{Ca}^{2+}]}{40} + 2 \frac{[\text{Mg}^{2+}]}{24} \right) \quad (2)$$

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

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

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

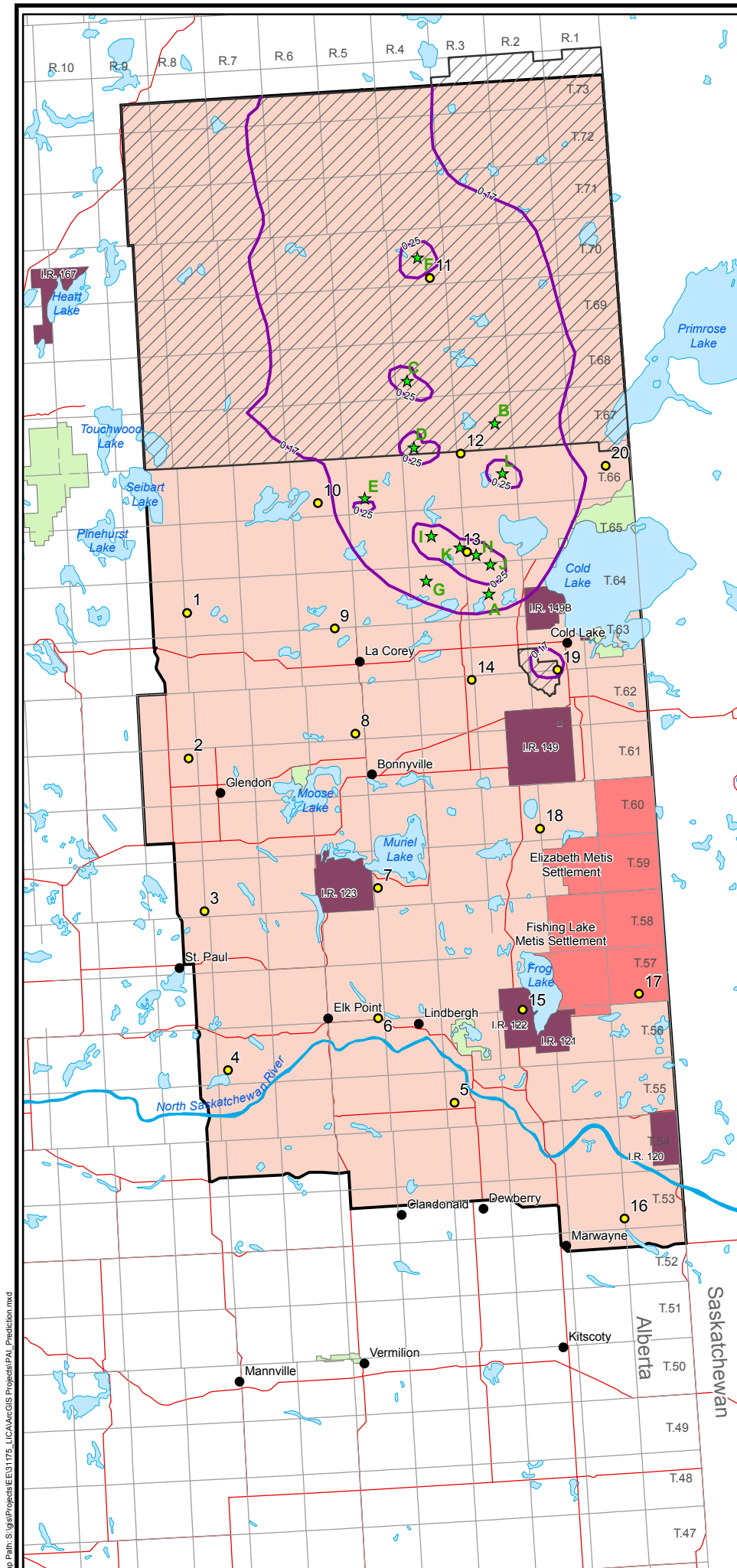
2.3.1 LICA Passive Network

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



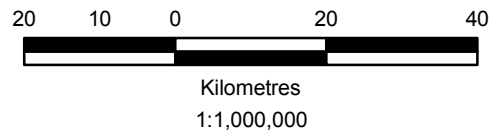
Legend

- 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

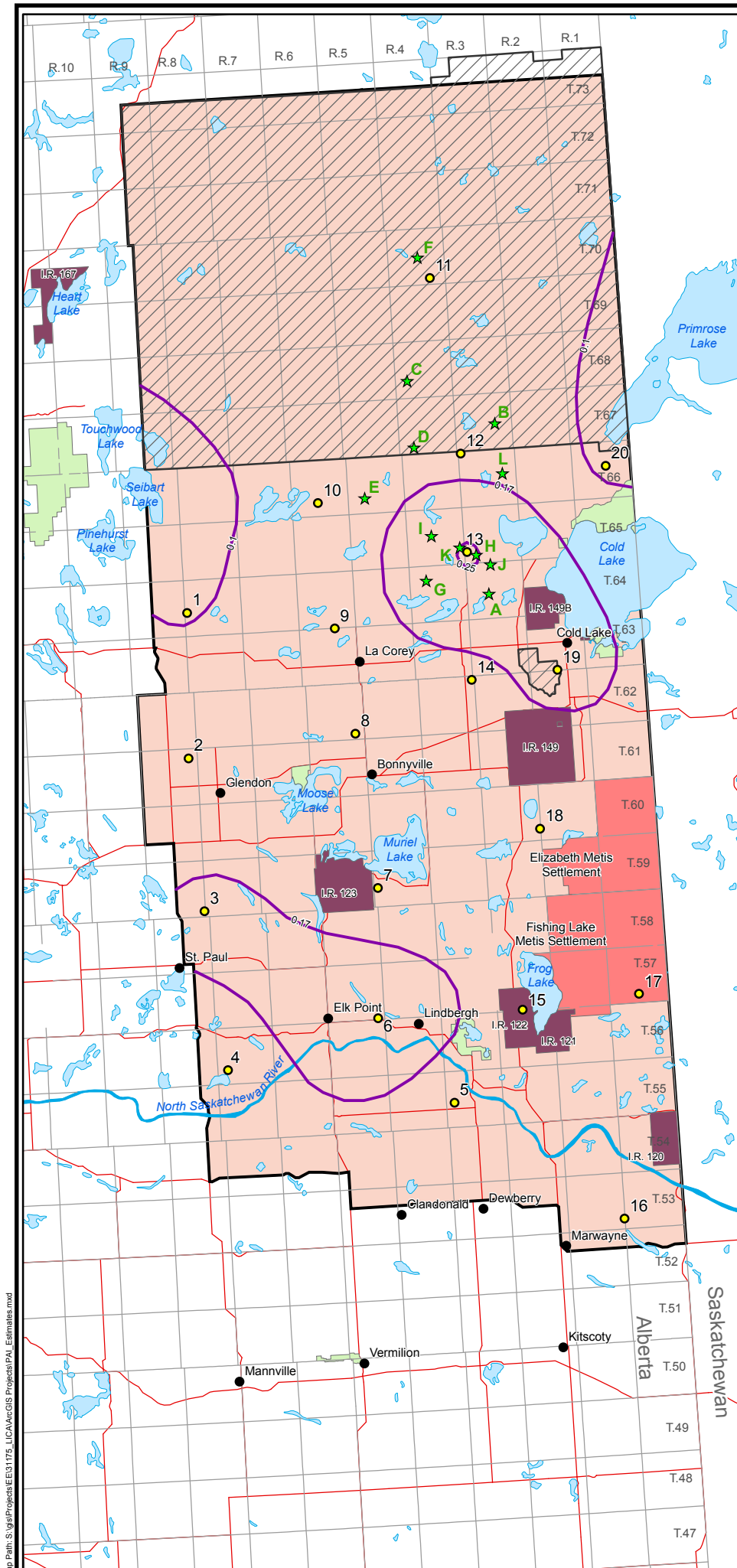
- Road
- Prediction from Primrose EIA
- ▨ Cold Lake Air Weapons Range
- ▨ Provincial Park
- ▨ Metis Settlement
- ▨ First Nations Settlement
- ▨ Lake
- ▨ LICA Airshed



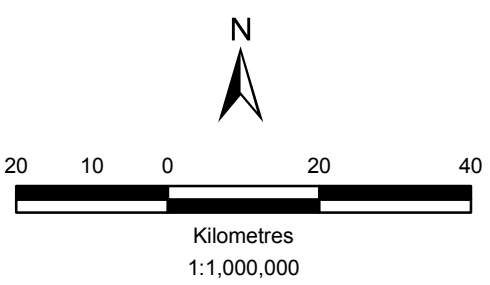
Lakeland Industry and Community Association (LICA)

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		



- Legend**
- Passive Monitoring Station
 - Town
 - 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
 - Estimates from LICA Measurements
 - ▨ Cold Lake Air Weapons Range
 - Provincial Park
 - Metis Settlement
 - First Nations Settlement
 - Lake
 - LICA Airshed



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	Figure 2	
GIS File: PAI_Estimates		
PDF File: PAI_Estimates_07-06-21		

2.3.2 Dry Deposition of Nitrate and Sulphate

Average NO₂ and SO₂ 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 SO₂ and NO₂, respectively and are referenced from average values in EPCM (2002).

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

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

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

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

Table 3: NO₂ and SO₂ Measurements, Nitrate and Sulphate Dry Deposition Estimates, July 2003 to August 2006

Station No.	Meas. Type	NO ₂	NO ₂	Nitrate	SO ₂	SO ₂	Sulphate
		Concentration (µg/m ³)	Dry Deposition (kg/ha/yr)	Equiv. Dry Deposition (keq/ha/yr)	Concentration (µg/m ³)	Dry Deposition (kg/ha/yr)	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 SO₄²⁻	Nitrate NO₃⁻	Ammonium NH₄⁺	Sodium Na⁺	Potassium K⁺	Calcium Ca²⁺	Magnesium Mg²⁺
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 SO₄²⁻	Nitrate NO₃⁻	Ammonium NH₄⁺	Sodium Na⁺	Potassium K⁺	Calcium Ca²⁺	Magnesium Mg²⁺	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⁺, Ca²⁺, Mg²⁺, 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/m³) of Na⁺, Ca²⁺, Mg²⁺, 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)	Ca²⁺ (mg/L)	Mg²⁺ (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 Ca²⁺	Magnesium Mg²⁺	Potassium K⁺	Total Dry Cation
Concentration (µg/m³)					
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 Ca²⁺, Mg²⁺ and K⁺ concentrations in the oilsands area were based on WBEA observations and are 0.048, 0.057 and 0.346 µg/m³, 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 SO₂ and NO₂ 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 SO₂ and 0.13 to 0.25 cm/s for NO₂. The values used in the current evaluation are at the high end of this range for SO₂ and average for NO₂.

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 SO₂ 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 (SO₂). 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 ($\mu\text{eq/L}$) where $20 \mu\text{eq/L} = 1 \text{ mg/L}$ 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 [$\mu\text{eq/L}$]
$[ANC]_{lim}$	Critical value for the acid neutralizing capacity in the water [$\mu\text{eq/L}$]
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 ($[BC]^*_o$) were assumed to represent pre-industrial base cation levels. The original non-marine base cation concentrations in $\mu\text{eq/L}$ 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 $\mu\text{eq/L}$ for Northern European lakes was applied. This value of 20 $\mu\text{eq/L}$ 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 $\mu\text{eq/L}$ 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/y¹ 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:

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

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.

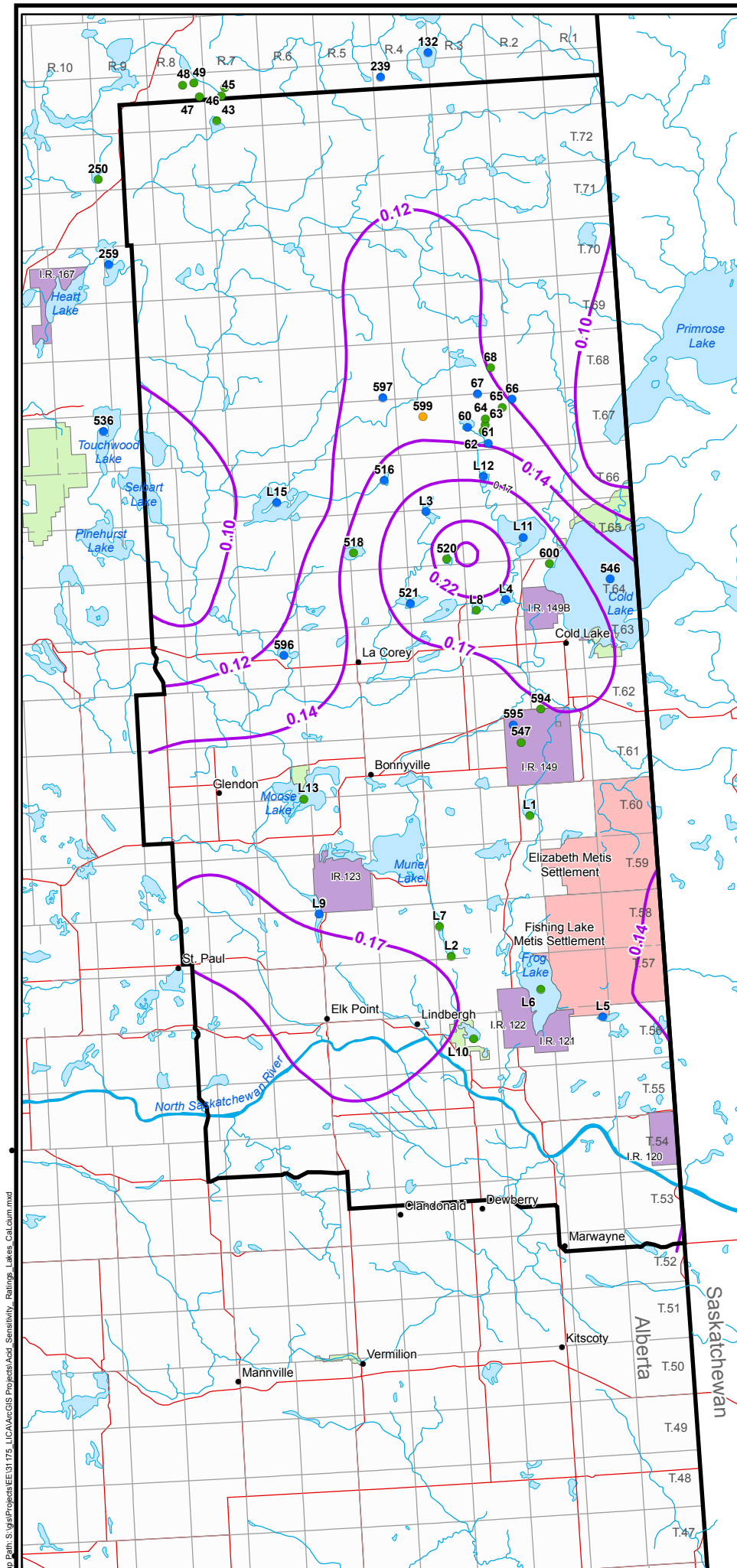
Table 13: Acid Sensitivity Ratings for Lakes in the Study Area

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	Iptiak 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	Manatohan 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)

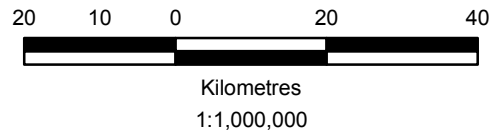
Parameter	High	Moderate	Low	Least
Alkalinity	0 - 10	11 - 20	21 - 40	> 40
pH	0 - 6.5	6.6 - 7.0	7.1 - 7.5	> 7.5
Calcium	0 - 4	5 - 8	9 - 25	> 25

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	Figure 3	
GIS File: Acid_Sensitivity_Ratings_Lakes_Calcium		
PDF File: Acid_Sen_Ratings_Lakes_Calc_07-03-22		

Map Path: S:\GIS\Projects\EE31175_LICA\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 ⁺] _a (µeq/L)	Gross Critical Load (keqH ⁺ /ha/yr)	Potential Acid Inputs (keqH ⁺ /ha/yr)	Net Critical Load (keqH ⁺ /ha/yr)
LICA Study Area												
43	Ipiatak 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

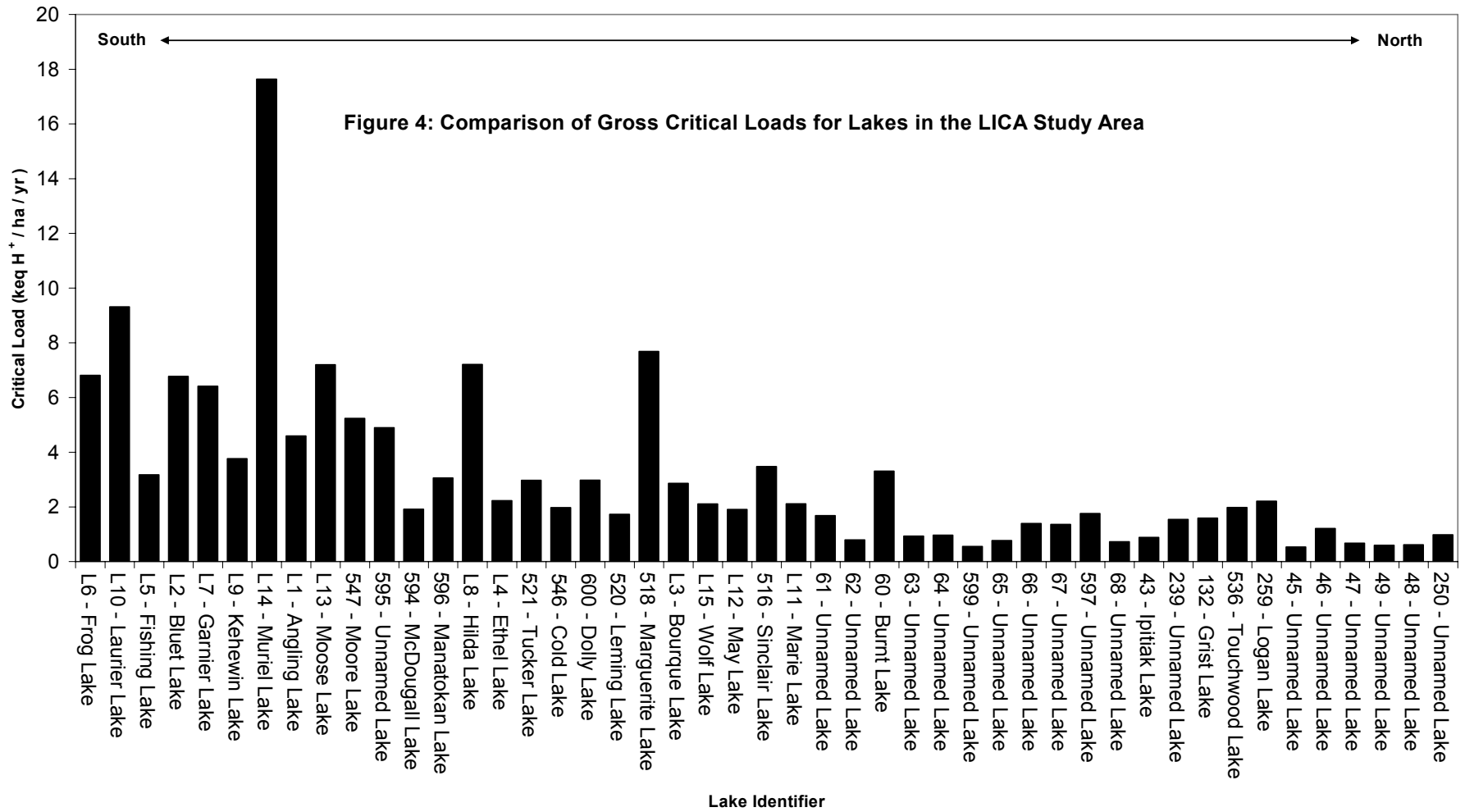
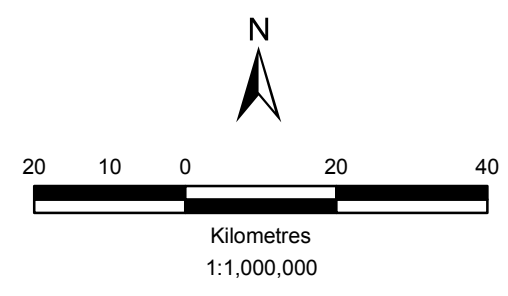
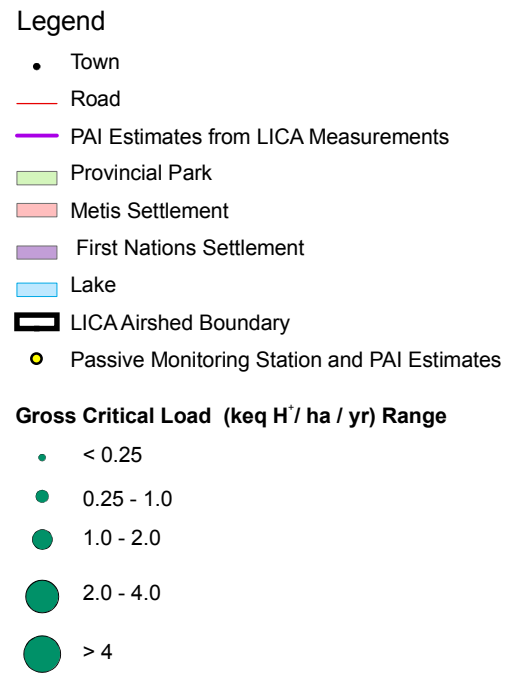
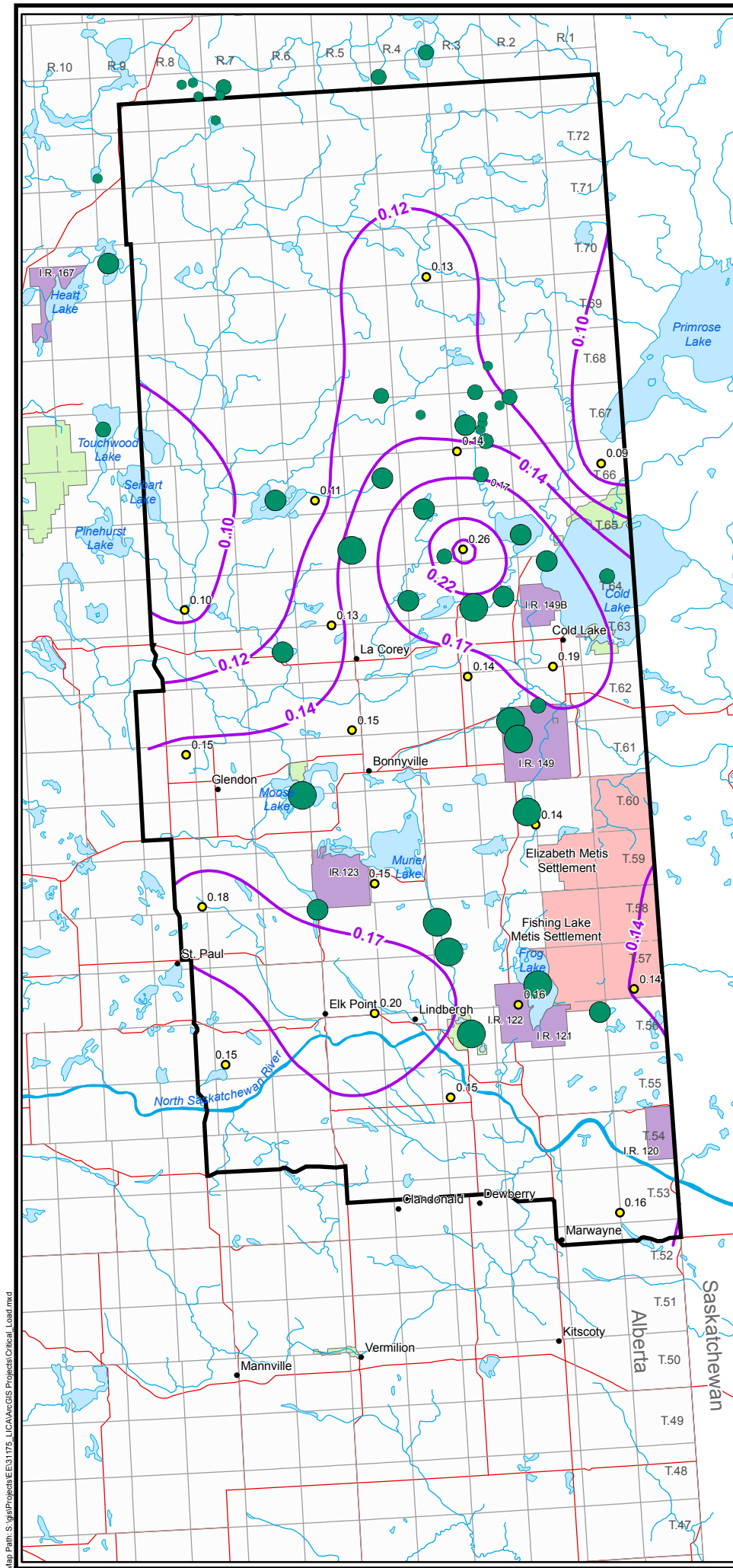


Figure 4: Comparison of Gross Critical Loads for Lakes in the LICA Study Area



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		

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

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.

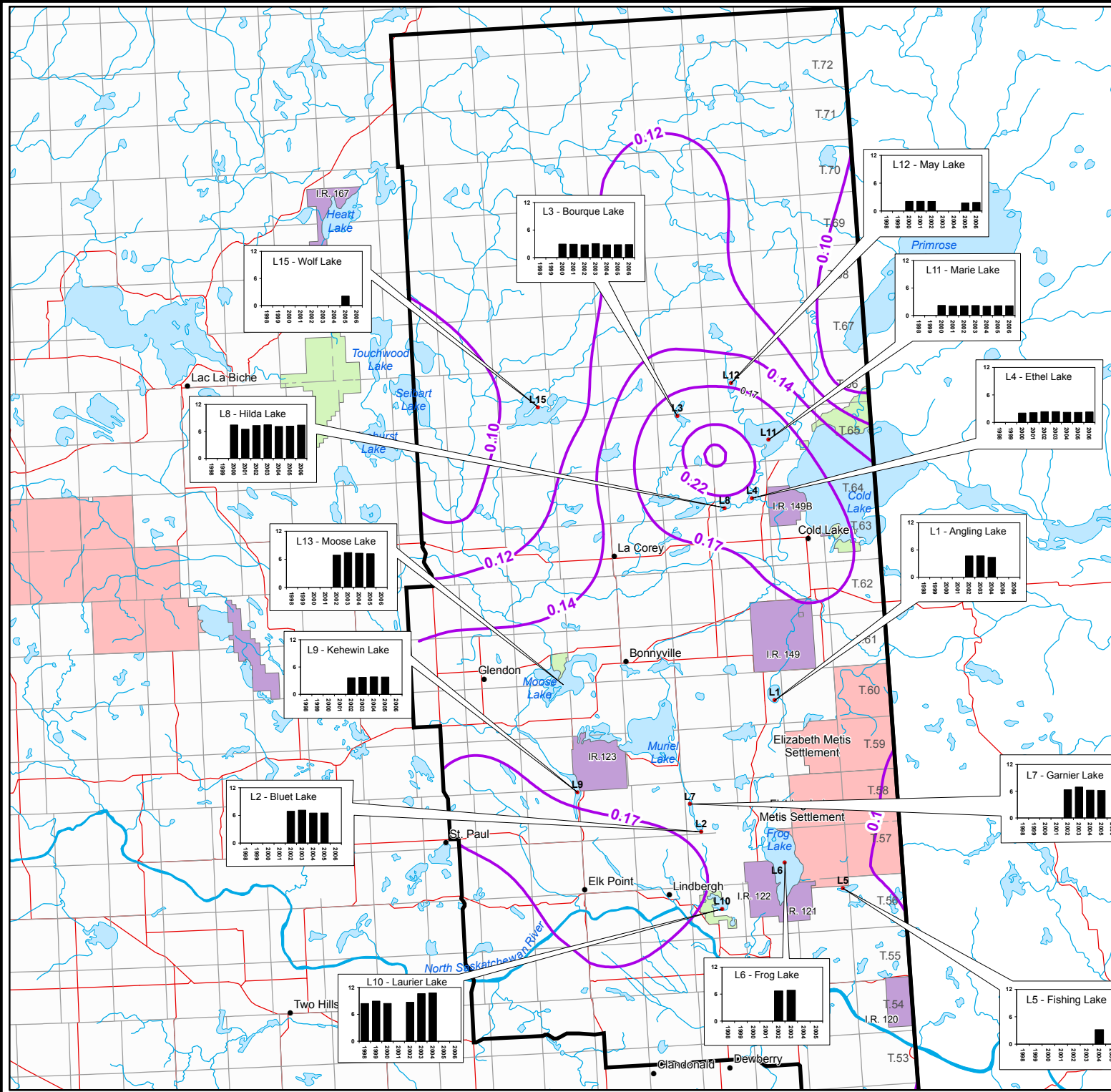
3.5.3 Comparison with Potential Acid Deposition

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.

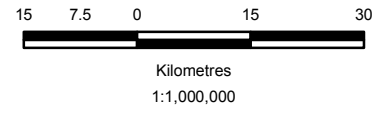
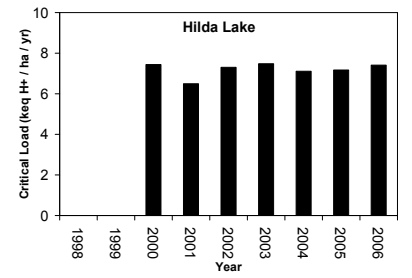
All lakes in the LICA study area have gross critical loads above the monitoring load for sensitive receptors of 0.17 keq H⁺/ha/yr and even above the upper limit of critical deposition for sensitive receptors of 0.25 keq H⁺/ha/yr (CASA and AENV 1999). An airborne depositional rate exceeding 0.17 keq H⁺/ha/yr 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



Lakeland Industry and Community Association (LICA)

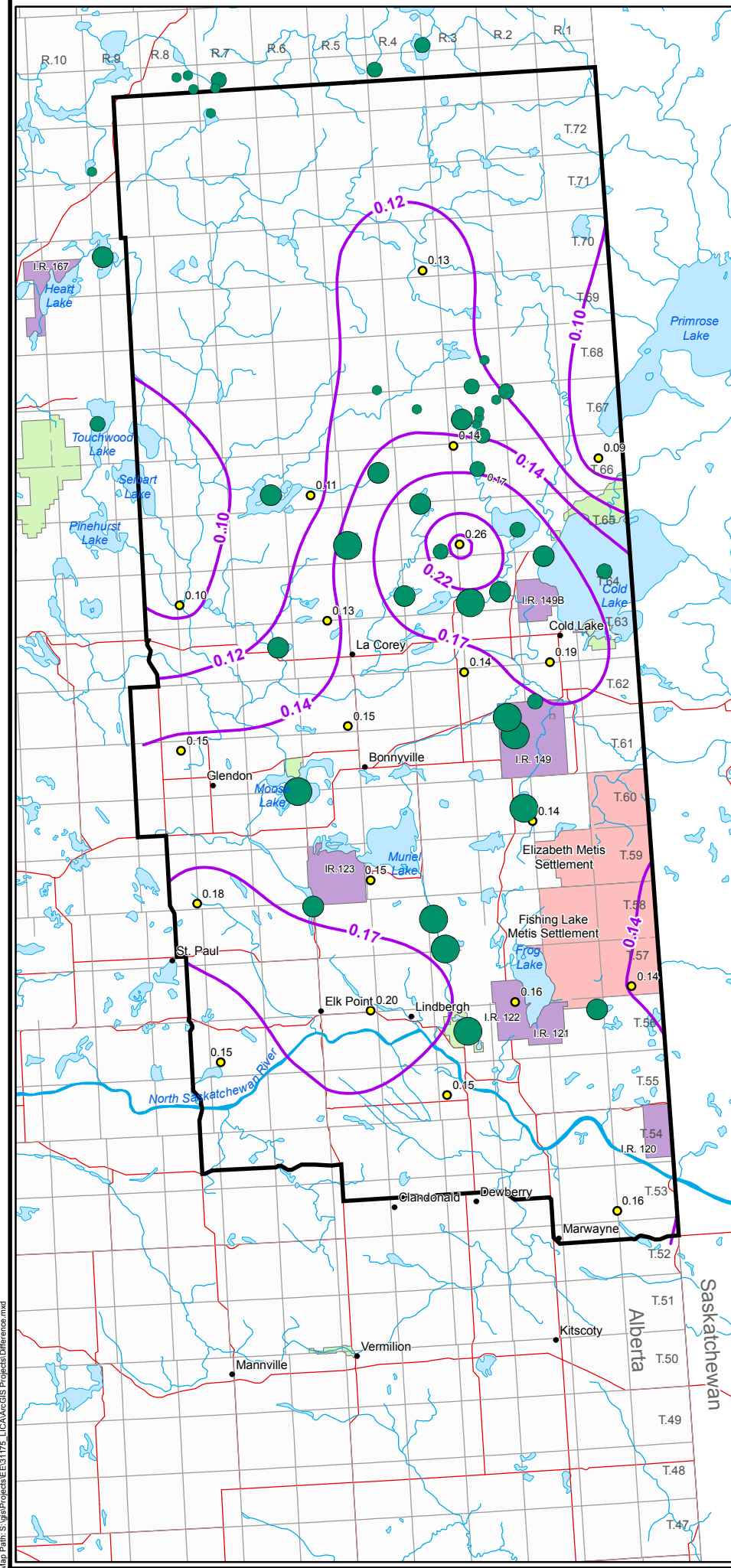
Annual Gross Critical Load (keq H⁺ / ha / yr) for Selected Lakes in the LICA Study Area

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	L4	L8	L10	L11	L12
		Bourque Lake	Ethel Lake	Hilda Lake	Laurier Lake	Marie Lake	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 \geq 80% Confidence Level		No Trend	INCREASING	No Trend	INCREASING	No Trend	DECREASING
Trend \geq 90% Confidence Level		No Trend	No Trend	No Trend	INCREASING	No Trend	No Trend

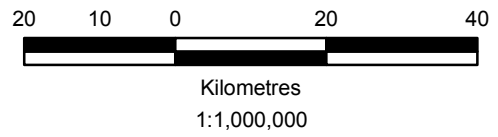


Legend

- 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



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		

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

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).

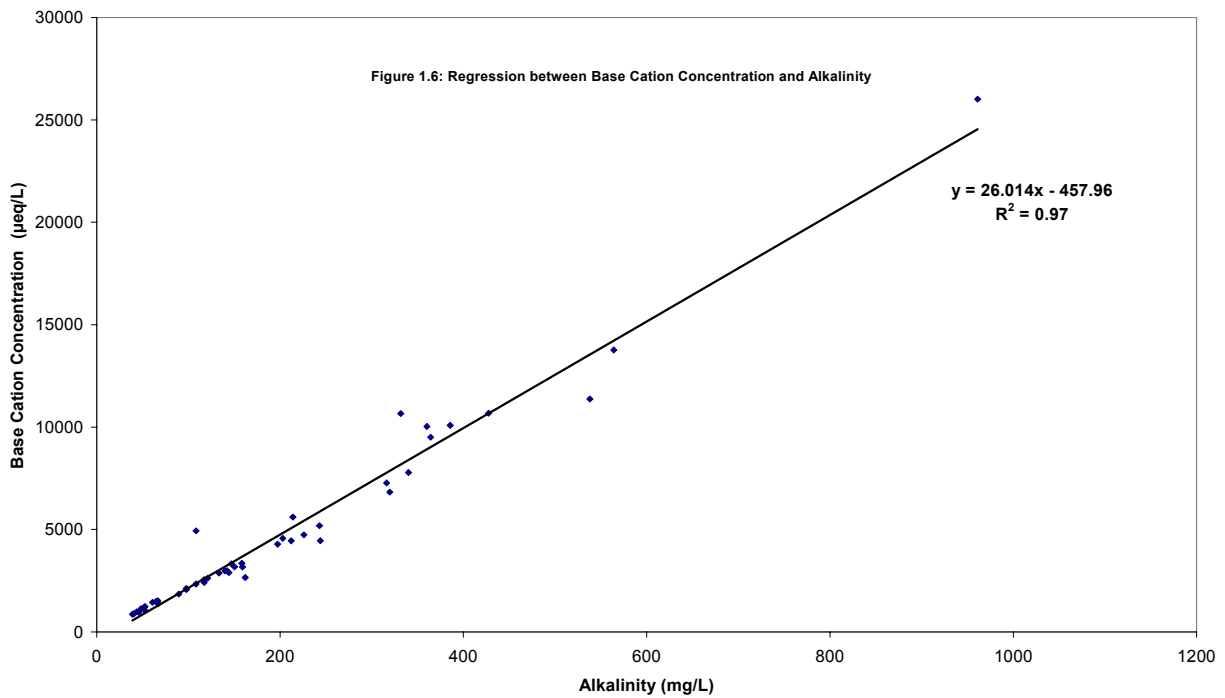


Figure 8: Regression between Base Cation Concentration and Alkalinity

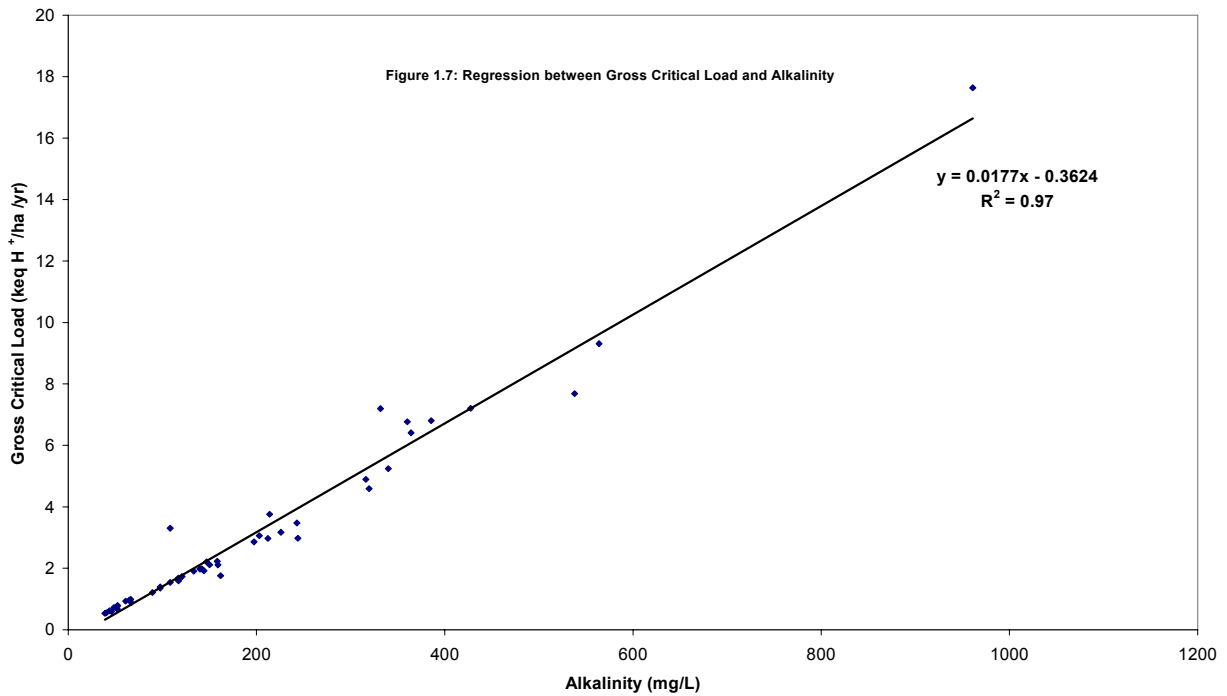


Figure 9: Regression between Gross Critical Load and Alkalinity

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.

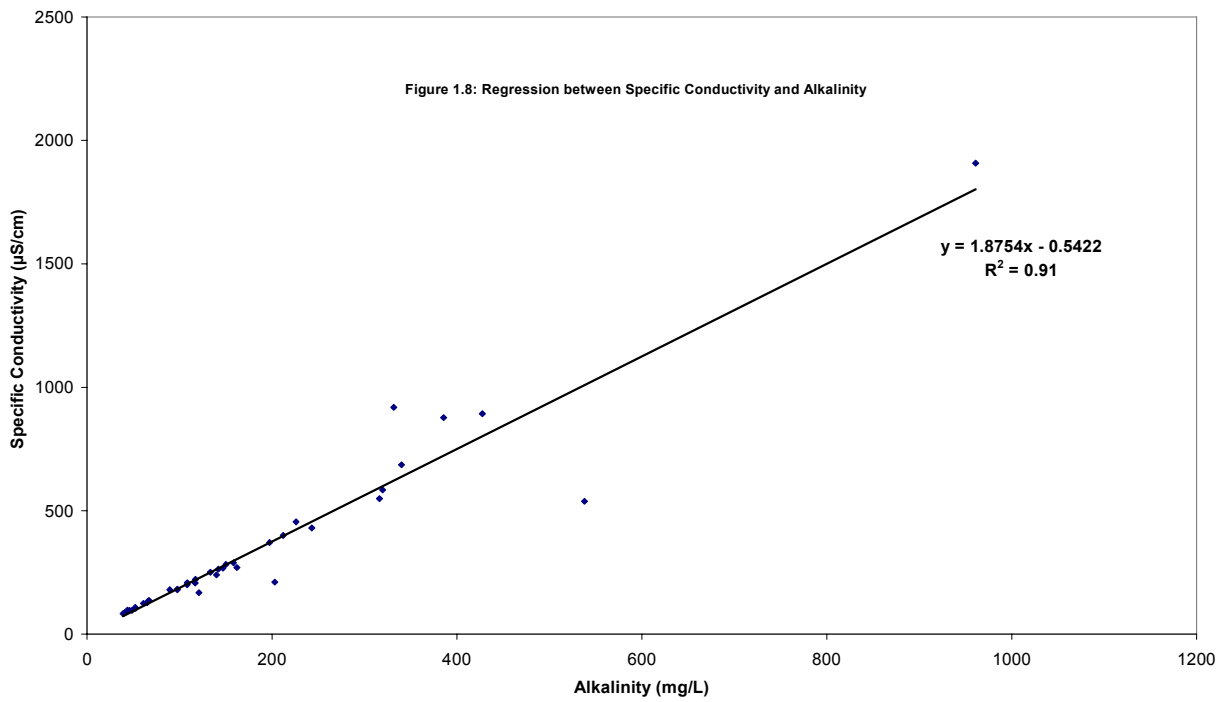


Figure 10: Regression between Specific Conductivity and Alkalinity

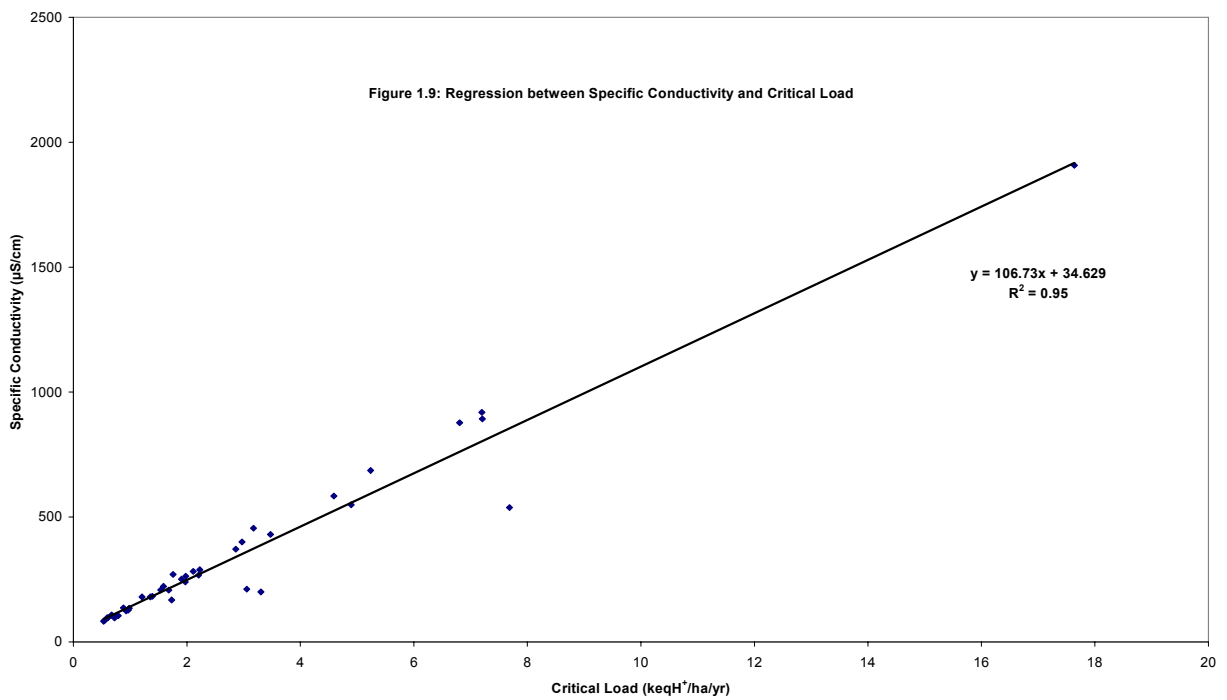


Figure 11: Regression between Specific Conductivity and Critical Load

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 et 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](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](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](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	Horborg	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.	<u>Eutric Brunisol</u> - Ah<10 cm, pH>5.5 <u>Dystric Brunisol</u> - Ah<10 cm, pH<5.5	E.EB - Eluviated Eutric Brunisol 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 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.	<u>Black Chernozem</u> - Black Ah, semiarid climate <u>Dark Gray Chernozem</u> - Dark Gray Ah, semiarid climate	O.BL – Orthic Black E.BL – Eluviated Black O.DG – Orthic Dark Gray
Gleysolic - Features indicative of periodic or prolonged water saturation, and reducing conditions - mottling and gleying.	<u>Humic Gleysol</u> - Ah≥10 cm, no Bt <u>Gleysol</u> - Ah≤10 cm, no Bt <u>Luvic Gleysol</u> - Has a Btg, usually has an Ahe or an Aeg	O.LG - Orthic Luvic Gleysol HU.LG - Humic Luvic Gleysol O.G - Orthic Gleysol
Luvisolic - Light coloured eluvial horizons - Ae; illuvial B horizons of silicate clay accumulation - Bt; developed under forest vegetation.	<u>Gray Luvisol</u> - May or may not have Ah, has Ae and Bt, usually MAST ≤8 degrees Celsius ^Y	O.GL - Orthic Gray Luvisol D.GL - Dark Gray Luvisol GL.GL - Gleyed Gray Luvisol GLD.GL - Gleyed Dark Gray Luvisol BR.GL - Brunisolic Gray Luvisol
Organic (Composed dominantly of organic materials; most are water saturated for prolonged periods)	<u>Mesisol</u> - Dominantly mesic <u>Fibrisol</u> - Dominantly fibric	T.F. - Terric Fibrisol T.M. - Terric Mesisol TF.M - Terric Fibric Mesisol TM.F - Terric Mesic Fibrisol TY.F - Typic Fibrisol M.F - Mesic Fibrisol TY.M - Typic Mesisol 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 Mundare Peace Hills	Gleysols
Pasatchaw Plain	Black-Dark Gray	Beaverhills	
Dewberry Plain	Black-Dark Gray	Beaverhills Mundare	Ukalta
Irish Creek Plain	Black-Dark Gray	Angus Ridge Gabriel	Helliwell
Gadois Upland	Black-Dark Gray	Angus Ridge Uncas	Redwater; with Eroded & misc. Black Chernozems
Clandonald Upland	Black-Dark Gray	Slawa	Angus ridge
Queenie Plain	Black-Dark Gray	Angus Ridge 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 Angus Ridge	Gleysols, Eroded
Kawatt Plain	Black-Dark Gray	Angus Ridge	Uncas, Gleysols
Kerensky Plain	Black-Dark Gray	Angus Ridge Uncas	Gleysols
Val Soucy Plain	Black-Dark Gray	Angus Ridge	Uncas, Mooswa
Laurier Upland	Black-Dark Gray	Angus Ridge	Primula, Uncas
Makao 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 Spedden	Fergy, La Corey
Lessard Plain	Dark Gray-Gray	Spedden 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 Ardmore	Spedden Nestow
Ardmore Plain	Dark Gray-Gray	Fergy Kehiwin	Spedden
Danuta Plain	Dark Gray-Gray	Spedden	La Corey Kehiwin
Glendon Plain	Dark Gray-Gray	Spedden	La Corey Vilna
Denning Lake Upland	Dark Gray-Gray	Spedden La Corey	Gleysols
Goodridge Plain	Dark Gray-Gray	Spedden Goodridge	Nicot
Moose Lake Plain	Dark Gray-Gray	Nicot	Nestow Manatokan
Manatokan Plain	Dark Gray-Gray	Spedden La Corey	Gleysols
Stebbing Lake Plain	Dark Gray-Gray	Nicot	Edward Nestow
Punk Creek Plain	Dark Gray-Gray	La Corey 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 Uncas	Angus Ridge Gleysols
Beauvallon Upland	Black-Dark Gray	Cooking Lake Uncas	Rolly View Gleysols
Eliza Upland	Black-Dar Gray	Cooking Lake Peace Hills	Uncas Two Hills
Canard Upland	Black-Dark Gray	Uncas Angus Ridge	Cooking Lake Gleysols
Beauvallon Plain	Black-Dark Gray	Rolly View Uncas	Gleysols Mundare
Landon Upland	Black-Dark Gray	Redwater Cooking Lake	Rolly View Gleysols
Kopernik Upland	Gray	Athabasca	St. Lina
Fredro Plain	Gray	Athabasca	Grosmont Birkland
Reita Lake Plain	Gray	Athabasca	Grosmont Gleysols
Murial Lake Plain	Gray	Athabasca	Grosmont
Redspring Upland	Gray	Athabasca	St. Lina
Asnyk Upland	Dark Gray-Gray	Spedden La Corey	Gleysols Eroded & misc. Dark Gray Chernozems
Hilda Lake Plain	Gray	Athabasca Liza	Spedden 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 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 Nicot	St. Lina Tucker
Standish Plain	Gray	Athabasca St. Lina	Nicot Tucker
Heart Upland	Gray	Athabasca	St. Lina
Seibert Plain	Gray	Athabasca Goodridge	St. Lina Tucker
Mostoos Upland	Gray	Kinosis McLelland 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.

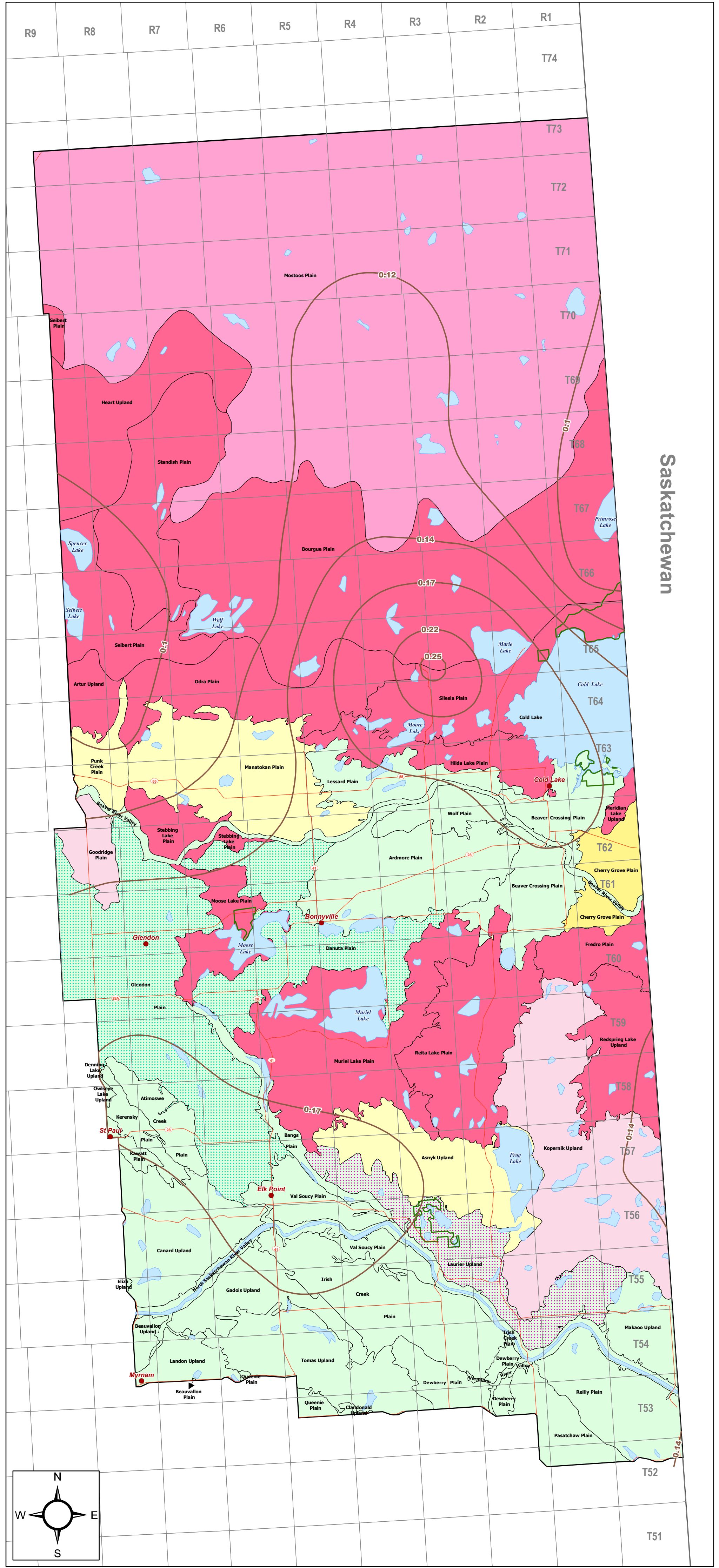
Table 21: Categories of Soil Acidification Sensitivity and their Extent in the LICA Area

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

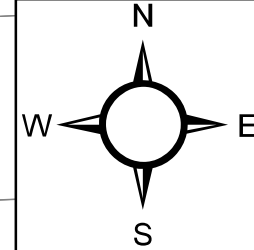
^z Except for Cold Lake, lake areas and other miscellaneous land types such as roads and urban areas have not been subtracted from the sensitivity category areas.

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).



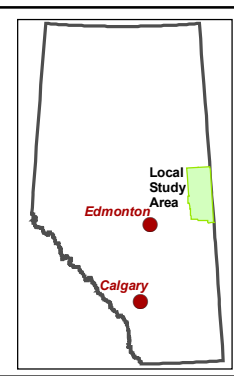
Saskatchewan



- Legend**
- Town
 - Major Road
 - Potential Acid Input ($\text{kmol H}^+ \text{ha}^{-1} \text{y}^{-1}$)
 - ▭ 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

DATE: MARCH 2007
 MAP PROJECT: EE31175
 SOURCE: PAI_INTERPOLATION_LICA.MXD
 PROFILE: PAI_INTERPOLATION_LICA.PDF
 PROJECTOR: UTM
 DATUM: NAD83

0 2.5 5 10
 KILOMETRES 1:400,000

amec

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 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 cell 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 assess 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	<i>Pinus banksiana</i>	high
Paper birch	<i>Betula papyrifera</i>	high
Trembling aspen	<i>Populus tremuloides</i>	high
White spruce	<i>Picea glauca</i>	medium
Balsam fir	<i>Abies balsamea</i>	medium
Balsam poplar	<i>Populus balsamifera</i>	low
Black spruce	<i>Picea mariana</i>	unknown
Tamarack	<i>Larix laricina</i>	unknown
Mosses		
Brown moss	<i>Drepanocladus spp.</i>	high
Schreber's moss	<i>Pleurozium schreberi</i>	high
Knight's plume moss	<i>Ptilium crista-castrensis</i>	high
Stair-step moss	<i>Hylocomium splendens</i>	high
Peat moss	<i>Sphagnum spp.</i>	variable
Golden moss	<i>Tomenthypnum nitens</i>	variable
Lichens		
Lichen	<i>Cladina spp.</i>	high
Lichen	<i>Stereocaulon lividum</i>	high
Reindeer lichen	<i>Cladina spp.</i>	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 (SO₂) 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 SO₂ 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 SO₂ 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 SO₂. 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 SO₂ 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 on 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 SO₂.

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-SO₂ Management Program of CEEMA 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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Aherne, J. and S.A. Watmough. 2006. Calculating Critical Loads of Acid Deposition for Forest Soils in Manitoba and Saskatchewan. PN1372. Canadian Council of Ministers of the Environment. Ottawa.

Presents a description and application of a model for deriving critical loads of acidity for soils in Manitoba and Saskatchewan at a broad, regional level.

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GIS coverage of the major characteristics of soils and landscape for Canada. It is based on existing soils survey maps and each area is described by a standard set of attributes including a distinct type of soil and its soils composition.

Agriculture Canada and Alberta Research Council. 1989. Soil Survey of the Fishing Lake Metis Settlement, Alberta. Open File Report No. 1989-12. Edmonton, AB.

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'Provides soils information in digital files, published maps and reports. It also includes the Alberta Soil information finder which allows to view and query soils information with landscape images, ortho photographs and cadastrals. AGRASID has an extensive soil information for 26 million hectares that make up the agricultural land of Alberta.

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Describes the soil and vegetation monitoring program in the oil sands area. Ten sites were established for the program, consisting of near source or High deposition sites and relatively distant, or Low, deposition sites. No differences were found in between High and Low sites, with the exception that total sulphur content was higher in the litter layer of soils of High sites. The program was initially intended to consist of four year sampling intervals; this was subsequently changes to six year intervals.

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'This report is a study of vegetation stress in the Cold Lake Operations Area for 2002, to find potential effects of sulphur dioxide (SO₂) emissions. The vegetation conditions were interpreted from false color infrared (FCIR) air photos and a field inspection. No direct evidence of damage from SO₂ emissions was evident. This study also used leaf tissue chemistry, to find the total amount of sulphur content found in aspen trees. It was shown that the total sulphur content with similar to the content of the control site, therefore it was found that there was no direct impact to vegetation from sulphur emissions.'

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'This report is a study of vegetation stress in the Cold Lake Operations Area for 2005, to find potential effects of sulphur dioxide (SO₂) emissions. The vegetation conditions were interpreted from false color infrared (FCIR) air photos and a field inspection. No direct evidence of damage from SO₂ emissions was evident. This study also used leaf tissue chemistry, to find the total amount of sulphur content found in aspen trees. It was shown that the total sulphur content was similar to the content of the control site; therefore, it was found that there was no direct impact to vegetation from sulphur emissions.'

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Primrose In-situ Sands Project is an expansion project for Canadian Natural Resources Limited situated in the Cold Lake region of Alberta. This detailed project description and Environmental Impact Assessment encompasses assessments of air, noise and health, terrestrial resources, aquatic resources, and social aspects. It also includes mitigation and monitoring measures for all of the different assessments that occur.

Volume 8: 'Air Emission Effects' provided regulators with supplemental information, specifically on the potential effects of acidifying emissions on local and regional lakes. Several lakes in the LICA study area had relevant water quality data that were used in the LICA report. Lake identifiers, coordinates and analytical water quality data were used.

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An inference technique is developed that allows estimation of the annual and monthly dry deposition of Ca^{2+} , Mg^{2+} , Na^+ , and K^+ . Conceptually, this technique is based on the premise that precipitation efficiently scavenges aerosols, resulting in a strong correlation between concentrations within precipitation and the surface-level air. Empirically, it is based on the linear relationship exhibited between the measured surface-level air and precipitation concentrations at 23 stations in Ontario, Canada, for the period 1983–1985. Correlations ranged from 0.513 for K^+ to 0.946 for Mg^{2+} . Because of the stochastic nature of such an approach, the assumptions inherent to the concept of scavenging ratios, and therefore this inference technique, must be carefully considered. Under such considerations, annual and monthly dry deposition of alkaline aerosols can be estimated at many locations across North America where precipitation concentrations are routinely measured.

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Surmont In-situ Oil Sands Project in the Fort McMurray region of Alberta includes a project description and commercial application. This project also encompasses a biophysical and resource (air, water and soil) use and socioeconomic assessments. There is also an environmental baseline study, wildlife habitat suitability modelling, traditional land use study cumulative effects assessment and hydrogeology modelling.

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Appendix B-Soil Survey of the Proposed Mahkeses Plant site gave detailed information on soil series and soils chemistry for the Cold Lake region, used for the LICA study.

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Roberts, T.L., G.E. Nason, and H. Regier. 1989. Long Term Soil Acidification Monitoring in Alberta from 1981 – 1988. Prepared for Alberta Environment. 175 pp.

This report describes the long term monitoring of soil acidification at eight different sites within the province of Alberta, including Cold Lake and Fort McMurray. Samples were collected every four years beginning in 1981 at each site at differing depths in the soil to determine if any changes had occurred over the four year period.

Saffran, K.A., and D.O. Trew. 1996. Sensitivity of Alberta Lakes to Acidifying Deposition: An Update of Sensitivity Maps with Emphasis on 109 Northern Lakes. Water Sciences Branch, Water Management Division. Alberta Environmental Protection. Edmonton, Alberta.

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 SO₂ 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 SO₂ and NO_x emissions in the LICA area are 31 and 26 t/d, respectively.

Table A1: Maximum Approved SO₂ and NO_x 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 SO₂ emission limit of 13.15 t/d, so the 18.56 t/d figure significantly overstates SO₂ emissions from Imperial Cold Lake facilities. Actual SO₂ emissions in 2005 were 6.615 t/d and actual NO_x emissions were 5.48 t/d.

The current SO₂ 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	Husky Energy. 2003
				Ae		5.6	3		
				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			
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		Moderate	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 coarse glaciofluvial, moderately fine till and very coarse 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 coarse 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 coarse 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 coarse 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 coarse 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)	Edward (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)	Edward (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 coarse 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.