LONG TERM SOIL ACIDIFICATION MONITORING IN THE LICA STUDY AREA

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EXECUTIVE SUMMARY

In 2007 LICA commissioned a preliminary study of potential soil and water acidification within the LICA Area which included recommendations for monitoring soil chemistry. The report herein describes the selection of long term soil acidification monitoring sites as well as the establishment of one site in the LICA area.

The protocol of a long term monitoring program by Alberta Environment was adopted by LICA, and a study to examine and select potential sites for monitoring was initiated in fall 2009. This study began with a review of existing information about the distribution and properties of soils in the LICA study area. The 2007 LICA study provided a means for targeting areas for potential monitoring sites because it provided information about locations of sensitive soils as well as current levels of exposure to acidic deposition.

Major considerations and criteria for selecting long term monitoring sites included the following:

- Soils should be sensitive to acidic deposition, as indicated by low acid buffering capacity;
- Sites should be on similar soils and under similar native vegetation; generally, sandy soils under jack pine stands are used in other monitoring programs;
- Landscape should be well drained and have gentle slopes; and,
- Since soil chemistry changes are slow, monitoring needs to be long-term; therefore, sites should have a high likelihood of protection from development over a long term.

Site Selection

Eleven sites were examined in the field in a region delineated approximately by Whitney Lakes Provincial Park in the southeast, Cold Lake Indian Reserve to the northeast, Wolf Lake to the northwest, and the hamlet of Mallaig to the west. Potential soil monitoring sites were accessed by vehicle on local roads and trails and then by foot in the forest. The jack pine vegetation type was first confirmed, and then the soil was examined by digging a small pit to a depth of approximately 50 cm, followed by hand augering to a one metre depth. The soil was described, and samples for laboratory analysis were taken of the LFH layer (forest floor, or duff layer), the Ae horizon (topsoil), and the top of the B horizon (upper subsoil). Samples were taken to 30 cm.

The chemistry data for all Brunisolic soils indicated suitability for monitoring based on the selection criteria. Two of the eleven sites were Luvisolic soils. Although Luvisolic soils generally have higher acid buffering capacity than Brunisolic soils, these were also evaluated in terms of possible inclusion in the monitoring program.

Indicators of Soil Acidification

The main indicators of soil acidification that will be monitored over time are as follows:

<u>Soil pH</u> – acidity is measured as pH; all soils have a certain level of acid buffering capacity, but as acid is added, the pH will begin to decrease.

<u>Base Saturation Percentage</u> – the term ‘base cations’ refers to a group of soluble elements that

consist of calcium, magnesium, potassium and sodium. These elements are also plant nutrients. The percent base saturation refers to the amount of base cations in soil as a proportion of all cations, including aluminum. As acid is added to the soil, the acidity removes base cations from the surfaces of particles in the soil. They are then washed deeper into the soil, where they are less available for use by plants.

Calcium to Aluminum (Ca:Al) and Base Cation to Aluminum (BC:Al) Ratio – as the pH decreases in a soil, the amount of soluble aluminum can increase. Aluminum can be toxic to plants at elevated levels, but toxicity is counteracted by base cations. The ratio of these ions to aluminum is an indicator of the toxic level of aluminum in the soil.

Model Results

A model applied at the Alberta Research Council (referred to as the ARC soil acidification model) has been applied to a number of studies in Alberta and Saskatchewan. The ARC model is a mathematical representation of soil acid chemistry. In the model, as acid is added to a soil over time, changes in pH, base saturation percentage, and base cation: aluminum ratio are calculated. The model was applied to Brunisolic soils from the Moose Lake and Whitney Lakes provincial parks sites, and to a Luvisolic soil from the Wolf Lake area. The model verified that little buffering is available in the mineral part of Brunisolic soils, and that much of the acid buffering is in the duff layer. The Wolf Lake soil had a somewhat higher buffering capacity, suggesting that this soil would not likely be a good candidate for monitoring in terms of potentially showing changes in the short term.

Overall, the modelling suggests that the Brunisolic soils would show only minor decreases in pH at the low acid input levels (0.1 to 0.2 $kmol^{-1}$ ha^{-1} y^{-1}), but changes can occur within a 50 year period in base saturation and base cation:aluminum ratio. Relatively large changes could occur at higher acid input levels.

The results of modelling should be interpreted with caution because the model is not calibrated to actual acidification of soils. It is useful mainly for comparing different types of soils, and for obtaining a general idea of the time frame in which a soil could become more acidic.

Monitoring Site Establishment and First Year Sampling

Upon LICA's decision to establish a monitoring site within Moose Lake Provincial Park, approval was sought from Alberta Tourism, Parks and Recreation, and a Research and Collection Permit was granted in October, 2010. Components of monitoring plot establishment were as follows:

- the landscape and forest characteristics were examined and two sub-site locations were selected; these were at least 100 m distant from neighbouring aspen, muskeg, or other non- jack pine ecosystems, and from roads or trails;
- sub-sites 24 m on each side were subdivided into 12 plots, and plots were subdivided into 12 subplots;
- corners of plots were staked with cedar pegs; about 5-10 cm of the stake was left exposed above ground level;
- ~10 cm diameter (1 m tall) treated posts were installed at the corners of each sub-site;

- GPS coordinates, legal location, and distance of the two sub-sites from each other were recorded; and,
- permanent metal labels were appended to the southwest corner post of each plot.

The two sub-sites at the Moose Lake site are referred to as the West and East Moose Lake sub-sites.

One subplot within each of the 12 plots indicated above is to be sampled every four years, thus providing 12 replicates for statistical analysis. The layers sampled in each subplot are: LFH, 0-2, 2-5, 5-10, 10-15, 15-30, 30-45, and 45-60 cm. At each of the two Moose Lake plots, soil profile descriptions were also completed according to protocols of the Canadian soil classification system. Soil samples were obtained by digging a square pit (about 60 cm x 60 cm) near the centre of each subplot. About one litre of sample was obtained from each of the above soil layers.

Laboratory analyses were completed according to methods applied in the Alberta Environment long term monitoring program. After completion of analyses, all remaining sample materials were archived. Data are presented in table format in the report. These data represent the baseline conditions for the soil monitoring at the Moose Lake Provincial Park site. As sampling of this site is carried out in the future, statistical analyses will be carried out to detect any changes over time.

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Glossary of Terms Abbreviations and Symbols

A horizon — A mineral soil horizon formed at or near the surface in the zone of removal of materials in solution and suspension, or maximum accumulation of organic carbon, or both.

AENV — Alberta Environment.

AITF — Alberta Innovates Technology Futures.

Al^{3+} — Aluminum ion.

B horizon — A mineral soil horizon characterized by one or more of the following: an enrichment in silicate clay, iron, aluminum or humus; a prismatic or columnar structure that exhibits pronounced coatings or staining associated with substantial amounts of exchangeable sodium, and/or an alteration of hydrolysis, reduction, or oxidation to give a change in colour or structure from the horizons above or below, or both.

BC:Al ratio — Ratio of base cations to aluminum in water in pores in the soil. BC refers to the sum of the cations calcium, magnesium, sodium and potassium.

Brunisolic soil, Brunisol — Brunisols in northeast Alberta are Boreal forest soils that occur mainly in sandy glacial sediments under jack pine forests. The main characteristics of these soils are the presence of a gray coloured topsoil (Ae) horizon) underlain by a brown to reddish brown coloured upper subsoil (Bm horizon).

C horizon — A mineral soil horizon comparatively unaffected by the pedogenic processes operative in A and B, except gleying, and the accumulation of carbonates and soluble salts.

Ca^{+} — Calcium ion.

Ca:Al ratio — Ratio of calcium to aluminum in water in pores in the soil.

Cation — Ion with a positive charge.

Cation exchange — The interchange between a cation in solution and another on the surface of any surface-active material in the soil such as clay or organic matter.

Cation exchange capacity — The total amount of exchangeable cations that a soil can adsorb, expressed in centimoles (positive charge) per kg of soil ($cmol_c\ kg^{-1}$).

Clay — A soil particle <0.002 mm equivalent diameter.

$cmol_c\ kg^{-1}$ — See ‘cation exchange capacity’ above.

Coarse fragments — Soil particles larger than 2 mm diameter; general term for gravel, cobbles, stones and boulders.

Drainage — The removal of excess surface water or groundwater from land by natural runoff and percolation, or by surface or subsurface drains.

Eolian — Well sorted materials, predominantly sand and silt, deposited by wind (e.g., sand dunes).

Exceedance	An emission whose measured value is more than that allowed by government regulations.
Forest floor	All dead vegetable and organic matter including litter and unincorporated humus on the mineral soil surface under forest vegetation; also called the LFH soil horizon, litter layer, or duff layer.
Glaciofluvial	Material moved by glaciers and subsequently deposited by streams flowing from the melting ice. The deposits are commonly sorted, such that they consist mainly of sand or gravel.
Glacial	Generally refers to the landscape and materials in the landscape that were produced by or derived from glaciers and ice sheets; e.g., sandy, glaciofluvial plain.
Horizon, soil	A layer of soil or soil material nearly parallel to the land surface; it differs from adjacent soil layers in properties such as colour, structure, texture, consistence and chemical, biological and mineralogical composition.
in situ	In place; commonly refers to an approach to remove bitumen from oil sand while the oil sand deposit is still in place underground.
K^+	Potassium ion.
kmol	1,000 mole (see mol L^{-1} below).
kmol ha^{-1} yr^{-1}	Kilomoles hydrogen ion equivalents per hectare per year. In assessing the amounts and critical loads of acidifying compounds, the deposition of nitrogen oxide or sulphur dioxide on land or water is converted to equivalent units of acidity (hydrogen ion equivalents) on an area (hectare) basis. Sulphur deposition is commonly expressed as kilograms of sulphur per hectare. One mole of sulphur is 32 grams, and 1 kmol is 32,000 g, or 32 kg. If 32 kilograms of sulphur falls on 1 ha of soil or water, this is equal to 1 kmol/ha. Sulphur is converted to sulphur dioxide (SO_2), and then to sulphuric acid (H_2SO_4). Since there are two hydrogen ions (H) in H_2SO_4, the number of hydrogen ions equivalent to 1 kmol of sulphur is 2 kmol.
LICA	Lakeland Industry and Community Association.
LFH	A soil horizon consisting of an organic layer developed primarily from leaves, twigs, and woody materials, with a minor component of mosses; same as forest floor.
Litter	See forest floor, LFH.
Mg^+	Magnesium ion.
mol L^{-1}	Unit of concentration of a substance in water; a mole is the unit amount of a substance. One mole of a substance is the mass that contains the same number of particles (atoms, molecules, ions, or electrons) as there are atoms in 12 grams of the isotope carbon-12.
Na^+	Sodium ion.
NAD 83	North American Datum 1983, Geographic coordinate system. This datum must

be recorded with GPS coordinates.

NH_4^+ Ammonium ion.

NO_2 Nitrogen dioxide.

NO Nitric oxide.

NO_3^- Nitrate ion.

NO_x General expression for oxides of nitrogen (mainly NO +NO_2).

PAI Potential Acid Input; usually expressed as kmol ha^{-1} yr^{-1}.

Parent material The unconsolidated mineral (e.g., sand, clay, clay till) or organic material (e.g., peat) from which a soil has developed by soil forming processes.

pH, soil The negative logarithm of the hydrogen-ion activity of a soil solution. The degree of acidity or alkalinity of a soil, as determined by a suitable electrode or indicator at a specified moisture content or soil-water (or $CaCl_2$ solution) ratio and expressed in terms of the pH scale.

Precipitation The rain and snow that falls on the earth's surface.

Profile, soil A vertical section of the soil through all its horizon and extending into the parent material.

Reaction, soil The degree of acidity or alkalinity of a soil, usually expressed as a pH value. Descriptive terms used here with certain ranges in pH are: acid, less than 5.5; neutral, 5.5-7.4; alkaline, greater than 7.4.

Sand A soil particle between 0.05 and 2.0 mm equivalent diameter. Also, a textural class composed mainly of sand-sized particles.

Silt A soil particle between 0.002 and 0.05 mm equivalent diameter.

Soil The naturally occurring, unconsolidated mineral or organic material at least 0.1 m thick that occurs at the earth's surface and is capable of supporting plant growth. Soil extends from the earth's surface through the genetic horizons, if present, into the underlying material to the depth of the control section (normally 1 or 2 m; 1.6 m in the case of Organic (peat) soils). Soil development involves climatic factors and organisms, conditioned by relief and water regime, acting through time on geological materials, and thus modifying the properties of the parent material.

SO_2 Sulphur dioxide.

SO_4^{2-} Sulphate ion.

Solution, soil The aqueous liquid phase of the soil and its solutes consisting of ions from the surfaces of the soil particles and of other soluble materials.

SO_x General expression for oxides of sulphur (mainly SO +SO_2).

Subsoil The B horizons of soils with distinct profiles. In soil with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil) in which roots normally grow.

Subxeric Soil moisture condition whereby water moves very rapidly; soil is moist for a short

period following precipitation.

Texture, soil — The relative percentages of the soil separates in a soil (i.e., sand, silt and clay particles).

Topsoil — (i) The layer of soil moved in cultivation. (ii) The A horizon. (iii) The Ah horizon. (iv) Presumably fertile soil material used to topdress road banks, gardens and lawns.

UTM — Universal Transverse Mercator (cartography); map coordinate system.

Water holding capacity — The percentage of water remaining in the soil material after having been saturated and after drainage of free water has practically ceased.

WBEA — Wood Buffalo Environmental Association.

Weathering — The physical and chemical disintegration, alteration and decomposition of rocks and minerals at or near the earth's surface by biological, chemical, and physical agents or combinations of them.

Xeric — Soil moisture condition whereby water moves very rapidly; soil is moist for a negligible to brief period following precipitation.

1.0 BACKGROUND

The Lakeland Industry and Community Association has as one of its objectives the implementation of a program to measure, monitor, and collect regional environmental air and soil data in the LICA area (LICA 2009). In 2009, the Alberta Research Council (now Alberta Innovates – Technology Futures (AITF)) provided recommendations for establishing a long term soil acidification monitoring program and conducted a preliminary assessment of potential soil monitoring sites. This was followed by establishment of a monitoring site in 2010 and collection of the baseline soil chemistry data for the site. This report describes the site selection and assessment of soils for monitoring and provides the results of the initial monitoring event. Background information regarding monitoring in the LICA region is provided below.

In 2006 LICA commissioned a preliminary study of potential soil and water acidification titled *Exploratory Study of Potential Acidification Impacts on Soils and Surface Water within the LICA Area* (AMEC Earth & Environmental 2007). The study included recommendations for monitoring soil chemistry in the LICA region, including:

- Establishment of monitoring sites with preferred soil types being 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, and mixedwood stands would be appropriate for the Athabasca soils
- Establishing monitoring sites in the 'monitoring exceedance zone' for sensitive soils; that is, within areas of 0.17 kmol $ha^{-1}y^{-1}$ potential acid input (PAI), as well as in a lower PAI area to enable comparison of near-source with relatively pristine sites;
- Encouraging Alberta Environment (AENV) to continue periodic monitoring at a site located near the west side of Cold Lake which was established as part of a provincial monitoring network in 1988; and
- To the extent possible, co-locating soil monitoring sites with air quality monitoring sites.

The AMEC (2007) report also suggested establishing a monitoring system following either the protocols of AENV in their Long Term Soil Acidification Monitoring Program, or that of the Wood Buffalo Environmental Association (WBEA) in their Terrestrial Effects Monitoring Program (TEEM). The purpose of the AENV program is to track possible changes in soil acidification status in different parts of the province, with eight sites having been established. The establishment of sites began in the early 1980s. The monitoring methodology and the results of the first two monitoring events were reported by AENV (Roberts et al. 1989). The AENV program was recommended by AITF in part because of the presence of a monitoring site already located within the LICA study area.

2.0 SITE SELECTION METHODS

The AENV approach to monitoring was adopted by LICA, and a study to examine and select potential sites for monitoring was initiated in fall 2009.

2.1 REVIEW OF EXISTING INFORMATION

A review of existing information about the distribution and properties of soils in the LICA study area was conducted prior to field examination of potential sites. Information was available in the *Soil Survey of the Sand River Area* (Kocaoglu 1975) and from the AGRASID soil database (Alberta Soil Information Centre 2007). The AGRASID database provides soil survey coverage for the agricultural regions of Alberta, along with descriptions of soil types, including typical soil chemical attributes. The AMEC (2007) report presented soil information for the LICA study area in terms of sensitivity of soils to acidic deposition, along with PAI isopleth mapping. Thus, the LICA report provided a means for targeting areas for potential monitoring sites on the basis of soil sensitivity coupled with potential levels of exposure to acidic deposition.

One of the criteria for selecting long term monitoring sites is that sites must be under native forest vegetation and that they have high likelihood of protection from development over a long term. Accordingly, the site pre-selection process involved examination of the Municipal District of Bonnyville and Lakeland County land ownership maps to locate Crown land areas such as natural areas, wildlife conservation areas and provincial parks. Sites were selected for field examination where these land dispositions coincided with acid sensitive soils and PAI levels greater than 0.17 kmol ha^{-1} y^{-1} (the PAI 'monitoring' level for sensitive soils as defined by Clean Air Strategic Alliance and Alberta Environment (1999).

2.2 SITE SELECTION CRITERIA

Characteristics considered to be suitable for long term monitoring of potential soil acidification are listed below. These characteristics pertain to sensitive soils, which are considered to be the most suitable for monitoring.

Landform

- Landform (site and local) – level to undulating landscapes
- Moisture regime – xeric to subxeric
- Nutrient regime – poor
- Slope – <5%
- Topographic position – level, or mid to upper slope
- Aspect – variable; not a factor on level to undulating landscapes
- Parent material – very coarse textured glaciofluvial or eolian
- Soil drainage – very well to rapidly drained

Vegetation

The community type should be either jack pine/bearberry/lichen, jack pine/blueberry/lichen, or jack pine/blueberry/bearberry/lichen community types (a1.1, a1.2 or a1.3 communities, according to Beckingham and Archibald (1996)). Sites should not be infected with dwarf

mistletoe, have excessive dead tops, or be damaged by fire or blowdown. Other specific vegetation criteria were not applied, other than the stand should be older than the sapling stage and younger than old growth, and that stem density be typical for jack pine forest in the region.

Soils

Soils should have the potential to be highly responsive to acidic deposition based on criteria of Holowaychuk and Fessenden (1987). Cation exchange capacities (CEC) should be <6 cmol kg^{-1}. Because CEC is correlated with soil texture, it can be estimated during a site assessment by examining soil texture. However, there should be a sufficient level of exchangeable cations, such that a potential change can be detected over time.

Since two sub-sites are established at a monitoring site, soils should be very similar at both potential sub-sites in terms of moisture regime, landscape, slope, and morphological properties, especially types and depths of horizons.

Other Site Characteristics

Other factors in site selection were as follows:

- Sites should be a minimum of 500 m from maintained roads to minimize impacts of dust and vehicle emissions;
- Sites should be located outside the influence of local air emission sources; and
- Sites should be located within the interior of and at least 100 m from the edge of the stand.

In addition to selecting highly sensitive soil sites for monitoring, other potentially sensitive to moderately sensitive soil types were also considered. Luvisolic soils were mapped as moderately sensitive in the AMEC (2006) study. Landscape criteria for these sites were as indicated above for sensitive soils. There were no criteria for vegetation types other than they be well drained, upland types.

2.3 FIELD ASSESSMENT AND SAMPLING

Potential soil monitoring sites were accessed by vehicle on local roads and trails and then by foot in the forest. The vegetation stand was first examined in terms of meeting the criteria above.

The soil at each site was examined by digging a small pit to a depth of approximately 50 cm, following by use of a hand auger to obtain soil material for examination. The soil was described in terms of type and thickness of horizons, texture, colour, structure, gleying, coarse fragment content, and any unique features such as uniformity of soil horizons. Soil description followed the *Canadian System of Soil Classification* (Soil Classification Working Group 1998).

Samples were taken from three upper soil layers for laboratory analysis. These consisted of the LFH layer (forest floor, or duff layer), the Ae horizon, and the top of the B horizon. Samples were taken to 30 cm. Soil layers below 30 cm were examined for presence of lime, relatively fine textured material, gravelly material or very acidic material.

Samples were analyzed in the laboratory for pH, cation exchange capacity and exchangeable cations. The main purpose of the analyses was to determine conformance to the soil chemistry criteria indicated above. A secondary objective was to obtain the required chemistry data for applying a chemistry model to predict potential acidification over time (Section 2.4).

2.4 POTENTIAL ACIDIFICATION PREDICTION

A subset of sites examined in the field and for which laboratory data were obtained was examined in terms of possible rates of acidification by applying a soil acidification model. Modelling provides a method of predicting potential response of soils to different levels of acid deposition over time. A model developed at the Alberta Research Council (referred to as the ARC soil acidification model) has been applied to a number of studies in Alberta and Saskatchewan. The ARC model was adapted from Bloom and Grigal (1985), and simulates soil chemical processes directly related to acidity and acidification of soils, and predicts the associated soil properties of pH, exchangeable base saturation, solution Al^{3+} concentration and base cation to aluminum (BC:Al) ratio. The most recent descriptions and applications of the model are in Abboud and Turchenek (2009a, 2009b). Details of the model are provided in these reports and in Appendix E.

The model was applied to three sites from the site selection process, namely the Moose Lake Provincial Park site, the Whitney Lakes Provincial Park site, and a site near Wolf Lake. The provincial park sites are each characterized by Brunisolic soils, while Luvisolic soils characterize the Wolf Lake site.

3.0 RESULTS OF SITE SELECTION PROCESS

3.1 DESCRIPTION OF POTENTIAL MONITORING SITES

Eleven sites were examined in the field in a region delineated approximately by Whitney Lakes Provincial Park in the southeast, Cold Lake Indian Reserve 149C in the northeast, Wolf Lake in the northwest, and the hamlet of Mallaig to the west. Locations and descriptions of the soil profiles and of vegetation and landscape attributes are presented in Appendix A.

Chemistry data for soils at the eleven sites are presented in Table 1. The data for all Brunisolic soils indicate suitability for monitoring, based on criteria in Section 2.2. The Luvisolic soils (Sites L3 and L9) have relatively high CEC and exchange cation levels, which are indicative of high acid buffering capacity. This soil type is not considered to be suitable for monitoring in terms of early detection of any changes. However, it may be affected by relatively high PAI levels, and monitoring of a similar soil type could be considered in areas where such levels could occur.

3.2 PREDICTION OF ACIDIFICATION RATES IN SOILS

The ARC soil acidification model was applied to three of the soils from the site selection process in order to assess the levels of acidity that could affect these soils, and to predict the rates of acidification.

3.2.1 Indicators of Soil Acidification

3.2.1.1 Soil pH

Soil pH is defined as the pH of a solution in equilibrium with soil. It is determined by means of a glass or other suitable electrode, or an indicator, usually using distilled water or a salt solution at a specified soil-solution ratio. Various methods can be used to measure soil pH; those particularly relevant in acid deposition impact evaluations are as follows:

- pH(H_2O) - a soil sample is made into a paste with distilled water, and the pH is measured by insertion of a pH electrode into the paste;
- pH($CaCl_2$) - a soil sample is mixed in 0.01M $CaCl_2$ at a 1:2 soil:solution ratio (w:v), and the pH is measured with an electrode dipped into the solution;
- pH(paste) - a saturated paste of soil in water is filtered, and the pH of the filtrate is measured with a glass electrode; and,
- pH(solution) - soil solution is extracted in *situ*, and the pH of the solution is measured with a glass electrode.

Theoretically, the pH(solution) measure provides the most realistic indication of the pH environment of plant roots. However, pH(solution) is the most difficult to obtain due to the time and equipment required for *in situ* extraction of adequate sample for measurement of pH and other parameters.

Table 1. pH and Cation Exchange Properties of Soils at Potential Monitoring Sites.

Site ID	Horizon	pH [z] (CaCl2)	Exch Na	Exch K	Exch Ca	Exch Mg	Exch Al	Exch Fe	Exch Mn	Sum Exch Cations	CEC-$BaCl_2$	$BaCl_2$ BSat	CEC-NH_4OAc (cmol kg^{-1})	NH_4OAc BSat
			(cmol kg^{-1})											
L1-1	LFH	4.0	0.55	0.78	9.03	1.65	0.77	0.06	2.06	12.01	14.9	0.81	78.2	0.15
L1-2	Ae	4.6	0.20	0.04	0.70	0.10	0.23	0.02	0.38	1.05	1.7	0.63	4.4	0.24
L1-3	Bm	4.4	0.17	0.01	0.11	0.03	0.23	0.01	0.01	0.32	0.6	0.56	2.4	0.13
L2-1	LFH	4.5	0.58	1.69	25.39	5.02	0.19	0.02	2.97	32.67	35.9	0.91		
L2-2	Ae	4.8	0.21	0.19	4.33	0.48	0.24	<0.01	0.37	5.21	5.8	0.90		
L2-3	Bm	4.8	0.19	0.06	1.12	0.20	0.17	0.01	0.03	1.57	1.8	0.88		
L3-1	LFH	5.9	0.85	3.84	71.65	15.67	0.10	0.02	0.66	92.01	92.8	0.99	125.0	0.74
L3-2	Ae	4.3	0.19	0.12	1.40	0.52	0.32	<0.01	0.05	2.23	2.6	0.86	4.7	0.48
L3-3	Bt	4.4	0.22	0.24	5.92	3.11	0.45	0.01	0.01	9.49	10.0	0.95	13.6	0.70
L5-1	LFH	4.6	0.49	1.55	21.23	3.85	0.14	0.02	1.51	27.11	28.8	0.94		
L5-2	Ae	4.9	0.17	0.06	1.73	0.19	0.08	<0.01	0.14	2.14	2.4	0.91		
L5-3	Bm	4.5	0.19	0.04	0.66	0.12	0.25	0.02	<0.01	1.02	1.3	0.79		
L6-1	LFH	4.2	0.58	1.59	28.67	4.14	0.25	0.02	4.23	34.98	39.5	0.89		
L6-2	Ae	4.3	0.17	0.05	1.49	0.14	0.46	0.01	0.20	1.85	2.5	0.73		
L6-3	Bm	4.5	0.17	0.03	0.24	0.05	0.34	0.03	<0.01	0.49	0.9	0.57		
L9-1	LFH	4.2	0.61	2.72	28.25	6.75	0.33	0.03	4.17	38.33	42.9	0.89		
L9-2	Ae	4.5	0.20	0.10	1.77	0.53	0.29	0.01	0.17	2.60	3.1	0.85		
L9-3	Bt	4.5	0.23	0.20	7.63	2.94	0.46	0.01	0.02	11.00	11.5	0.96		
L10-1	LFH	4.2	0.71	1.48	20.90	3.89	0.30	0.01	2.86	26.98	30.2	0.89		
L10-2	Ae	4.8	0.20	0.12	1.02	0.11	0.13	<0.01	0.20	1.45	1.8	0.81		
L10-3	Bm	4.8	0.19	0.03	0.18	0.04	0.15	0.02	<0.01	0.44	0.6	0.73		
L11-1	LFH	4.5	0.72	2.30	28.40	6.08	0.16	0.02	2.90	37.51	40.6	0.92	90.0	0.42
L11-2	Ae	4.4	0.20	0.09	2.08	0.34	0.28	0.01	0.28	2.72	3.3	0.83	6.4	0.43
L11-3	Bm	4.5	0.21	0.06	0.98	0.19	0.26	0.03	<0.01	1.45	1.7	0.83	2.9	0.49

[z] Abbreviations:
pH ($CaCl_2$) – pH measured in a 0.01 M $CaCl_2$ solution
Exch – exchangeable
CEC-NH_4OAc - cation exchange capacity measured with ammonium acetate solution; CEC-$BaCl_2$ – cation exchange capacity measured with $BaCl_2$ solution
BSat – base saturation percentage, measured as sum of exchangeable bases divided by the cation exchange capacity
cmol kg^{-1} – centimoles of ion charge of each exchangeable cation or of cation exchange capacity per kg soil

pH(H_2O) is commonly used to estimate pH in the plant root environment. Another method involves the pH of soil sample suspended in 0.01 M $CaCl_2$ solution at a fixed soil:solution ratio. This method has several advantages over pH(H_2O), among them being reproducibility even with dried soil samples. The salt solution generally results in a pH value about 0.5 units lower than that determined in water. Thus, it underestimates the soil solution pH, although it has also been considered to more accurately estimate the pH at the surfaces of soil particles because the weak salt solution simulates the soil electrolyte concentration adjacent to these surfaces. pH($CaCl_2$) expresses a relationship between hydrogen and other cations in the soil solution (Bache 1980). Thus, it is responsive to changes in the concentrations of base cations relative to hydrogen, and as such can be useful in monitoring because it would decrease as base cations are lost from soils. Miewes et al. (1986) also noted that pH($CaCl_2$) is the more appropriate pH measure for characterizing the buffer range of a soil. Measurement of pH($CaCl_2$) is most commonly applied at a 1:2 soil:solution ratio (Kalra and Maynard 1991).

The pH($CaCl_2$) and pH(H_2O) measures are most commonly used in research and reported in the literature. Different soil acidification models use different pH measures. Consequently, it is important to indicate which measure is used.

Low soil pH is typical of forest soils. However, very low pH levels can have an effect on growth of forest vegetation. Ulrich et al. (1984) suggested that a soil pH(H_2O) less than 4.0 to 4.2 posed a high risk of damage to forest ecosystems.

3.2.1.2 Calcium to Aluminum (Ca:Al) and Base Cation to Aluminum (BC:Al) Ratios

The aluminum ion (Al^{3+}) can be toxic to plants at elevated levels, but clear relationships between Al levels and plant health have been difficult to establish (Cronan and Grigal 1995). There has been more success in recognizing toxicity relationships through examination of the Ca:Al molar ratio in soils.

Cronan and Grigal (1995) reviewed Ca:Al ratios and other properties as indicators of stress in forest ecosystems and suggested a multiple assessment approach for determining the probability of suffering Al stress. A suggested threshold Ca:Al molar ratio of 1 is commonly applied in setting critical loads for forest soils in European countries (Warfvinge et al. 1992; de Vries 1993). In some countries, the BC:Al ratio is applied instead of Ca:Al because of work showing that BC:Al correlates more strongly with plant root or shoot damage than Ca:Al. The term ‘BC’ in this expression refers to the sum of the molar concentrations of the cations Ca, Mg and K.

In the absence of research specific to forest species in western Canada, it is difficult to select an appropriate BC:Al ratio that would be protective of all species. The BC:Al ratio of 1, which is applied to forest soils in Europe, may not be protective of all forest ecosystem types. The Cumulative Environmental Management Association (CEMA 2004) has examined critical loads of soils in the Athabasca oil sands region, and has suggested limiting model-predicted change in either base saturation or the ratio of base cations to aluminum (BC:Al) in mineral horizons of acid sensitive mineral soils located outside the full footprint of the surface oil sands mines to less than 50% of the difference between pre-industrial values and fixed effects levels (fixed case

is 1 for BC:Al) (CEMA 2004). This approach is adopted within this document in further discussion of results for potential LICA monitoring sites.

3.2.1.3 Base Saturation Percentage

Soil percent base saturation was identified by Cronan and Grigal (1995) and by Miewes et al. (1986) as important in evaluating potential acidification stress on forest ecosystems. While there are various methods of measuring base saturation, the method relevant to threshold limits is based on percent of 'effective cation exchange capacity', which is defined as the CEC that occurs at field pH, as opposed to CEC measured at a specified pH (i.e., using a pH buffered extractant). Effective CEC is measured by extraction of exchangeable cations using a neutral, unbuffered saturating solution such as NaCl, KCl, $BaCl_2$ or NH_4Cl. The effective CEC quantifies the number of negatively charged sites with which cations are associated; the major cations in most soils are Ca, Mg, K, Na, Al, Fe, Mn and H. Thus;

CEC = Ca+Mg+K+Na+Al+Fe+Mn+H (expressed as cmoles charge per kg)

Base Sat % = (Ca+Mg+K+Na) x 100 / (Ca+Mg+K+Na+Al+Fe+Mn+H)

Ca, Mg, K and Na are categorized as basic cations because the reaction between an exchangeable cation and free H^+ derived from dissociation of water results in generation of hydroxyl (OH^-). Al, Fe and Mn, on the other hand are categorized as acidic cations, as they react and tie up OH^- from H_2O, resulting in release of an equivalent amount of H^+ (McBride 1994).

The $BaCl_2$ method was adopted for the AENV long term monitoring program. For purposes of modelling acid deposition effects on soils, the ARC model was originally developed using a buffered ammonium acetate method. This method results in higher measures of cation exchange capacity, but with similar levels of exchangeable cations. Thus, the base saturation percentage calculated from the two methods can differ widely. However, data obtained using the buffered approach correlate well with soil pH, which is necessary for modelling.

For forest ecosystems, a threshold base saturation reduction to a level of 5% was suggested by Ulrich et al. (1984), while a reduction to 15% was recommended as a threshold by Cronan and Grigal (1995). These threshold values refer to base saturation calculations based on ‘effective cation exchange capacity’, defined as the sum of cations measured in an extract from a soil sample equilibrated with a neutral salt solution rather than a buffered solution. CEMA proposed an approach similar to that for BC:Al for determining a threshold level for base saturation to protect forest ecosystems. A change in base saturation (BSat) was established as the halfway point between the initial BSat of a soil and the fixed-effect value of 10 (CEMA 2004).

3.2.2 Model Inputs

The ARC model is semi-empirical; that is, it relies not only on basic chemical principles but also on relationships among soil properties that have been determined in previous studies of soils in the boreal regions of northeastern Alberta. The relationships were developed for the three main soil attributes that can change with increasing input of acidity, namely pH, exchangeable base

cation saturation, and the base cation to aluminum ratio (BC:Al ratio) in the soil solution (i.e., in soil water) (see Section 3.2.1 above). The soil pH, content of base cations and the cation exchange capacity of soils to be modelled are the main model inputs. The starting BC:Al ratio is not a model input but is derived from theoretical soil chemical equations. Model inputs for application to three sites from the LICA area are presented in Table 2.

3.3 MODEL PREDICTIONS

Results of modelling, presented in Table 3, show changes in pH(H_2O), base saturation and BC:Al ratio at baseline and after addition of acidity for 50, 100, and 150 or 300 years. The simulation was conducted for 6 levels of PAI ranging from 0.1 $kmol^{-1}$ ha^{-1} y^{-1} to 1 $kmol^{-1}$ ha^{-1} y^{-1}. The simulation for the Moose Lake site was terminated at about 150 years because the model cannot predict changes when pH or other parameters are very low, as occurred in the soil at this site.

The time and PAI at which base saturation or BC:Al ratio reaches approximately half its original value is a useful indicator of the rapidity of change in a soil. For the Moose Lake LFH horizon, the base saturation reaches this value at a PAI of 0.7 $kmol^{-1}$ ha^{-1} y^{-1} after about 50 years of addition at this level. However, in the mineral 25 cm layer, a rapid decrease occurs at the lowest PAI of 0.1 $kmol^{-1}$ ha^{-1} y^{-1}. This indicates that most of the buffering capacity is in the LFH (litter, or duff) soil layer, and that little buffering is available in the mineral soil. The pH and BC:Al levels do not change to the same extent in this soil.

In the Whitney Lakes soil, the LFH horizon likewise shows strong buffering, and a PAI of 0.5 $kmol^{-1}$ ha^{-1} y^{-1} changes the base saturation to about half its original level within 50 years. Unlike the Moose Lake soil, there is somewhat greater acid buffering in the mineral portion of the soil, with base saturation approaching half its original level only at the highest PAI. The pH and BC:Al ratio did not change markedly.

The LFH layer of the Wolf Lake Luvisol behaves differently from the Brunisols in that a relatively strong decrease in pH is seen at mid PAI levels (0.5 to 0.7 $kmol^{-1}$ ha^{-1} y^{-1}). Mineral soil buffering is strong, with small changes occurring only at the highest PAI level. This suggests that this soil is not likely a good candidate for monitoring in terms of potentially showing changes in the short term. However, there were changes in the LFH layer, and this or a similar site can be considered for monitoring should PAI in some areas reach levels of about 0.3 $kmol^{-1}$ ha^{-1} y^{-1} or greater.

Table 2. ARC Model Input Variables.

Site	Site L1-1	Site L1-11	Site L1-3
Soil Subgroup	Eluviated Dystric Brunisol Moose Lake Site	Eluviated Dystric Brunisol Whitney Lakes Site	Orthic Gray Luvisol Wolf Lake Site
Soil Series	Nestow	Nestow	Athabasca
LFH Thickness (cm)	2	4	8
LFH pH ($CaCl_2$)	4.0	4.5	5.9
LFH Total Bases ($kmol_c\ ha^{-1}$)	2.4	15.0	73.6
LFH CEC ($kmol_c\ ha^{-1}$)	15.6	36.0	100.0
LFH Base Saturation (%)	0.15	0.42	0.74
Mineral Soil Thickness (cm)	25	25	25
Mineral Soil pH ($CaCl_2$)	4.5	4.4	4.3
Mineral Bases ($kmol_c\ ha^{-1}$)	23.3	72.1	259.9
Mineral CEC ($kmol_c\ ha^{-1}$)	123.6	156.1	394.1
Mineral Base Saturation	0.74	0.46	0.66
Precipitation ($cm\ yr^{-1}$)	46	46	46
Litter ET ($cm\ yr^{-1}$)	14	14	18
Percolation into Mineral ($cm\ yr^{-1}$)	32	32	28
ET from Mineral ($cm\ yr^{-1}$)	13	13	14
Percolation below 25 cm ($cm\ yr^{-1}$)	19	19	14
CO_2 Partial Pressure (atm)	0.005	0.005	0.005
Weathering ($kmol_c\ ha^{-1}\ yr^{-1}$)	0.07	0.07	0.15
Activity Coefficient of Al^{3+}	0.692	0.663	0.727
Activity Coefficient of Al^{2+}	0.782	0.761	0.808
a in pH = a(BS) + b	2.25	2.25	2.27
b in pH = a(BS) + b	3.52	3.52	3.52
Acid Input ($kmol_c\ H^+\ ha^{-1}\ yr^{-1}$)	0.1, 0.2, 0.3, 0.5, 0.7, 1.0	0.1, 0.2, 0.3, 0.5, 0.7, 1.0	0.1, 0.2, 0.3, 0.5, 0.7, 1.0
Years of Iteration	300	300	300
Increment of Years	1	1	1

Abbreviations/Explanations:

Total Bases – sum of exchangeable K, Na, Ca and Mg
CEC – cation exchange capacity
ET – evapotranspiration rate
BS – base saturation (expressed as a proportion)

Table 3. Changes in Soil Chemistry in Relation to Different Acid Inputs

Moose Lake Site - Brunisol												
	pH (H_2O)				Base Saturation				BC:Al Ratio			
Acid Input ($kmol^{-1}$ ha^{-1} yr^{-1})	0 yr	50 yr	100 yr	150 yr	0 yr	50 yr	100 yr	150 yr	0 yr	50 yr	100 yr	150 yr
LFH												
0.1	4.4	4.4	4.4	4.4	0.15	0.15	0.15	0.15	25	25	25	25
0.2	4.4	4.4	4.4	4.4	0.15	0.15	0.15	0.15	25	25	25	25
0.3	4.4	4.4	4.4	4.4	0.15	0.15	0.15	0.15	25	25	25	25
0.5	4.4	4.4	4.4	4.4	0.15	0.15	0.15	0.15	25	25	25	25
0.7	4.4	4.1	4.1	na	0.15	0.07	0.07	na	25	25	25	na
1.0	4.4	3.8	na	na	0.15	0.00	na	na	25	25	na	na
Mineral												
0.1	5.0	4.7	4.6	4.6	0.19	0.04	0.00	0.00	13	9	8	8
0.2	5.0	4.7	4.6	4.6	0.19	0.04	0.00	0.00	13	9	8	8
0.3	5.0	4.7	4.6	4.6	0.19	0.04	0.00	0.00	13	9	8	8
0.5	5.0	4.7	4.6	4.6	0.19	0.04	0.00	0.00	13	9	8	8
0.7	5.0	4.7	4.6	na	0.19	0.02	0.00	na	13	9	8	na
1.0	5.0	4.6	na	na	0.19	0.00	na	na	13	9	na	na
Whitney Lakes Site - Brunisol												
LFH												
0.1	4.9	4.9	4.9	4.9	0.42	0.42	0.42	0.42	53	53	53	53
0.2	4.9	4.9	4.9	4.9	0.42	0.42	0.42	0.42	53	53	53	53
0.3	4.9	4.5	4.3	4.3	0.42	0.31	0.25	0.24	53	53	53	53
0.5	4.9	4.0	3.9	3.9	0.42	0.17	0.16	0.16	53	53	53	53
0.7	4.9	3.7	3.7	3.7	0.42	0.11	0.11	0.11	53	53	53	53
1	4.9	3.6	3.6	3.6	0.42	0.06	0.06	0.06	53	53	53	53
Mineral												
0.1	4.9	4.9	4.8	4.8	0.46	0.44	0.43	0.42	12	11	11	11
0.2	4.9	4.9	4.8	4.8	0.46	0.44	0.43	0.42	12	11	11	11
0.3	4.9	4.9	4.8	4.8	0.46	0.45	0.43	0.40	12	11	11	10
0.5	4.9	4.8	4.7	4.7	0.46	0.42	0.37	0.34	12	11	9	9
0.7	4.9	4.7	4.6	4.6	0.46	0.38	0.32	0.31	12	10	8	8
1	4.9	4.6	4.5	4.5	0.46	0.32	0.28	0.27	12	8	8	7
Wolf Lake Site - Luvisol												
LFH												
0.1	6.1	6.0	6.0	6.0	0.74	0.71	0.71	0.70	315	315	315	315
0.2	6.1	5.9	5.8	5.7	0.74	0.68	0.66	0.63	315	315	315	315
0.3	6.1	5.8	5.6	5.3	0.74	0.65	0.60	0.52	315	315	315	315
0.5	6.1	5.5	5.1	4.3	0.74	0.57	0.46	0.26	315	315	315	315
0.7	6.1	5.2	4.5	3.9	0.74	0.49	0.31	0.15	315	315	315	315
1.0	6.1	4.7	3.8	3.7	0.74	0.36	0.13	0.09	315	315	315	315
Mineral												
0.1	4.8	4.8	4.8	4.8	0.66	0.66	0.66	0.66	10	10	10	10
0.2	4.8	4.8	4.8	4.8	0.66	0.66	0.66	0.66	10	10	10	10
0.3	4.8	4.8	4.8	4.8	0.66	0.66	0.66	0.66	10	10	10	10
0.5	4.8	4.8	4.8	4.8	0.66	0.66	0.66	0.66	10	10	10	10
0.7	4.8	4.8	4.8	4.7	0.66	0.66	0.66	0.63	10	10	10	10
1.0	4.8	4.8	4.8	4.6	0.66	0.66	0.65	0.57	10	10	10	8

4.0 MONITORING RESULTS

4.1 LAND DISPOSITION AND REQUIRED PERMITS

Establishment of a monitoring site within a Provincial Park was sought due to the protection status of parks and the resultant likelihood of long-term monitoring without disturbance of a site. Alberta Tourism, Parks and Recreation authorizes research activities in parks through issuance of permits. Application for a Research and Collection Permit was made in September 2010. This involved description of the types of research activity that will be conducted in the park, over what period of time, specific locations within a park, and other information. Alberta Tourism, Parks and Recreation issued Research and Collection Permit No. 10-150, for work in Moose Lake Provincial Park, on 6 October 2010.

4.2 SITE ESTABLISHMENT AND SAMPLING METHODS

4.2.1 Plot Establishment

The sampling design for monitoring was based on a stratified random sampling procedure as originally established by AENV in the Long Term Soil Acidification Monitoring program (Roberts et al., 1989). Two sub-sites (24 m X 24 m) were located within each site in order to alleviate concerns about loss of a site through fire or other agent, and each sub-site was subdivided into 12 plots (6 m X 8 m) which were assigned letters from A to L. The plots were further subdivided into 12 subplots (2 m X 2 m); of these, one randomly selected subplot is to be sampled in each sampling event. This sampling scheme provides a total of 12 replicates for each sampling event, and 12 sampling events over the course of the monitoring program.

Components of monitoring plot establishment are as follows:

- at a proposed site, the landscape is examined and two plot locations are selected based on uniformity of landscape and tree canopy, and on distance from potential human disturbances and from other types of ecosystems (100 m is suggested; i.e., at least 100 m from neighbouring aspen, muskeg, or other non- jack pine ecosystems);
- sub-sites, plots, and subplots are measured;
- corners of plots are staked with cedar pegs; about 5-10 cm of the stake is exposed above ground level;
- ~10 cm diameter treated posts are installed at the corners of each sub-site; posts are about 1 m high;
- GPS coordinates, legal location, and distance of the two sub-sites from each other are recorded; and,
- metal or other permanent labels are appended to one corner post of each plot.

A sub-site is subdivided into 12 plots, and the plots are divided into 12 subplots. The two sub-sites at the Moose Lake site are referred to as the West and East Moose Lake sub-sites. The layout for each of these is presented in Figures 1 and 2.

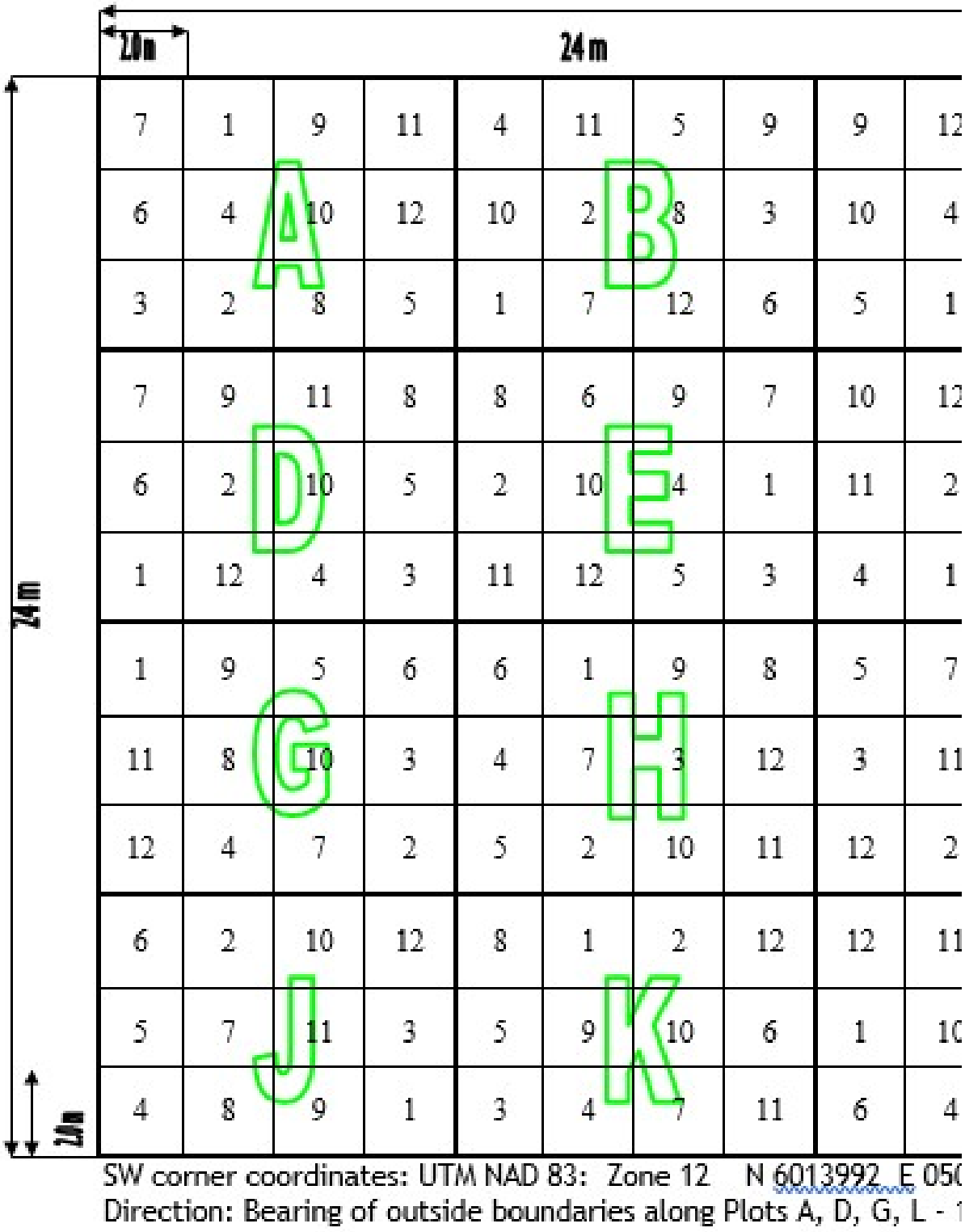

Figure 1. Plot Layout of the Moose Lake West Sub-Site

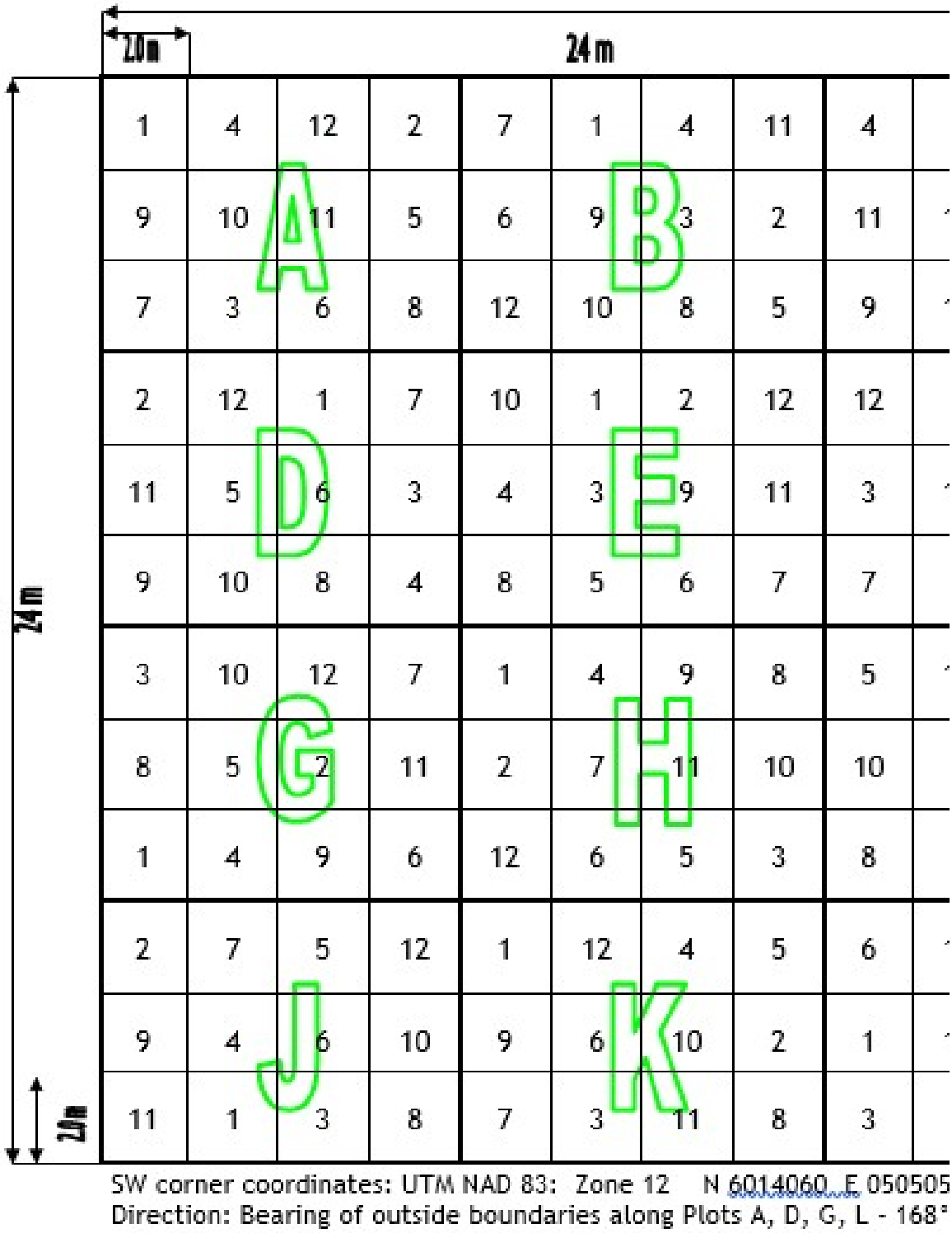

Figure 2. Plot Layout of the Moose Lake East Sub-Site

4.2.2 Protocol for Soil Sampling

The layers sampled in each subplot are shown in Figure 3. In obtaining soil samples, a square pit (about 60 cm x 60 cm) is dug near the centre of each subplot. Soil samples are obtained from 8 depths per pit. The sample size from each layer is about 1 litre. The upper soil layers are sampled with a flat scoop, and lower layer samples are obtained by scraping and probing the pit sides. A small area of vegetation is carefully removed, and the LFH (or duff) layer is sampled by scraping the material off the soil surface with a stainless-steel spoon or similar utensil. All sampling is completed using plastic gloves to avoid contamination.

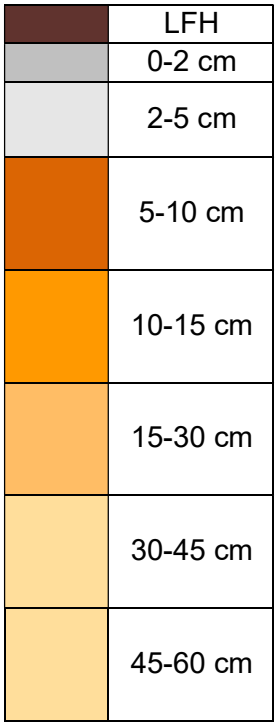

Figure 3. Layers Sampled at Soil Acidification Monitoring Plots

During excavation of soil pits, care is taken to prevent contamination of the soil surface and adjacent subplots. The soils are dug with a shovel, and excavated soil materials are placed on plastic sheets or tarps. After completion of sampling, soil layers are replaced in the original horizon sequence. Each layer is tamped so that all material is replaced with minimal increase in final volume. The topsoil and vegetation cap, originally cut to open the pit, are replaced. Litter and lichen are spread over the surface so as to leave it with a natural appearance, and to encourage rapid re-establishment of the lichen and any other plants (e.g., bearberry, lingonberry) that may have been disturbed in the sampled area.

Samples are collected in plastic bags and subsequently transported to the lab for analysis. Samples are kept cool, and if there is a delay in transporting samples the lab, the samples are kept in a freezer.

4.3 SOIL PROFILE DESCRIPTIONS

Long term soil monitoring is carried out by sampling of discrete layers, as described above. Full profile descriptions area also completed according to protocols of the *Canadian Soil Classification System* (Soil Classification Working Group 1998) and *CanSIS Manual for Describing Soils in the Field* (Expert Committee on Soil Survey 1983). A single soil pit was excavated to about 1-metre depth adjacent to each of the East and West sub-sites. Natural soil horizons were described and samples were collected for soil texture analysis and for nutrient analysis of the upper soil layers. The soil descriptions are presented in Appendix B.

4.4 LABORATORY ANALYSES

Laboratory analyses were completed according to methods applied in the AENV long term monitoring program. Sampled are initially dried at about 30°C, and then passed through a 2 mm sieve or through a rotary grinder with 2 mm openings. The grinder is used to break up any soil clumps and to separate roots from the soil fine earth fraction. The methods used for the various analyses are listed in Table 4.

Table 4. Analytical Methods Used for Soils Analysis

Parameter	Method	Notes
pH ($CaCl_2$)	Method 3.11 in McKeague (1978)	The soil-to-solution ratio for litter material is 1:4 and for mineral soil is 1:2. Solution is $CaCl_2$. Measurement is with a combination pH electrode.
pH (H_2O)	Method 4.12 in McKeague (1978)	As above, using de-ionized water.
Soil Texture (% Sand, Silt and Clay)	Method 2.12 in McKeague (1978)	Hydrometer method; does not include pre-treatment for removal of hydrous oxides and organic matter.
Electrical Conductivity	Method 4.13 in McKeague (1978)	Measurement occurs in the saturated paste extract of a soil sample.
Soluble Ions	Method 3.21 in McKeague (1978)	By the saturated paste method and ICP analysis of the extract.
Cation Exchange Capacity - Buffered	Method 15 (i) in Kalra & Maynard	By 1.0 M CH_3COONH_4 extractant buffered at pH 7, and measurement of NH_4^+ by distillation.
Cation Exchange Capacity - Unbuffered	Method 18.2 in Carter and Gregorich (2008)	By 0.1 M $BaCl_2$ extractant, and measurement of Ba by ICP-OES.
Exchangeable Cations	Method 18.2 in Carter and Gregorich (2008)	ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy) scan for Ca, Mg, Na, K, Fe, Mn, Al and Si on the unbuffered $BaCl_2$ extract.
Total Carbon, Nitrogen, and Sulphur	Method 3.611 in McKeague (1978)	LECO combustion method.
Available NH_4-N Available NO_3-N	Method 4.35 in McKeague (1978)	NH_4-N and NO_3-N extracted with 2N KCl and measured by steam distillation
Available Phosphorous (P)	Ashworth and Mrazek (1995)	Modified Kelowna extract using NH_4F, ammonium acetate and acetic acid, with measurement of P colorimetrically by autoanalyzer.

4.5 SOIL MONITORING DATA

Soil samples from the East and West Moose Lake sub-sites were analyzed for various soil parameters, as described above, at the Soil Laboratory of Alberta Innovates – Information Technologies in Edmonton. Analysis of all sampled layers was completed for the East sub-site. Analysis was carried out only for the top four layers from the West sub-site. This generally follows practice in the AENV long term monitoring program wherein analysis focuses on the top layers, which are expected to show any changes first. Deeper layer analyses have not been carried out in the AENV program, except for the first sampling event. All samples, whether analyzed or not, are archived to enable further analysis in the future if necessary.

The complete data are provided in Appendix D. Table 5 presents a summary of data for the main acidification indicators. The data consist of averages, standard deviations and coefficients of variation based on the 12 replicates from each sub-site. The data show that the highest cation exchange capacity levels and of exchangeable bases are in the LFH layer and in the 0-2 cm mineral layer.

The 2010 sampling event at the Moose Lake Provincial Park site is the first of several planned sampling events to be carried out at four-year intervals. As monitoring of this site is carried out in the future, statistical analyses will be carried out to detect any changes over time.

Table 5. Mean Values of Soil Acidity Parameters at the Moose Lake Monitoring Site

Layer	Statistic	pHc	Exch Bases	CEC	BSat	K	Ca	Mg	Al	BC:Al	TC	TN	TS
(cm)			(cmol kg^{-1})			(mol L^{-1})					(%)		
East Sub-Site													
LFH	Mean	4.3	na	na	na	na	na	na	na	na	41.48	1.18	0.13
	SD	0.2	na	na	na	na	na	na	na	na	3.70	0.19	0.02
	CV	0.1	na	na	na	na	na	na	na	na	0.09	0.16	0.17
0-2	Mean	4.6	4.58	5.43	0.83	0.24	0.87	0.26	0.18	8.93	2.63	0.08	0.01
	SD	0.2	2.17	2.27	0.08	0.12	0.5	0.12	0.06	5.92	1.05	0.04	0.002
	CV	0.04	0.47	0.42	0.10	0.5	0.58	0.45	0.33	0.66	0.40	0.51	0.34
2-5	Mean	4.8	2.24	2.71	0.81	0.1	0.50	0.16	0.19	5.02	1.07	0.02	0.004
	SD	0.1	1.14	1.27	0.06	0.04	0.23	0.07	0.10	2.81	0.70	0.02	0.001
	CV	0.03	0.51	0.47	0.08	0.37	0.45	0.42	0.54	0.56	0.65	1.04	0.29
5-10	Mean	4.7	0.93	1.23	0.74	0.07	0.25	0.1	0.18	2.77	0.44	0.01	0.002
	SD	0.2	0.28	0.28	0.08	0.05	0.08	0.04	0.09	1.24	0.15	0.000	0.001
	CV	0.03	0.30	0.23	0.11	0.75	0.32	0.38	0.49	0.45	0.34	0.000	0.25
10-15	Mean	4.7	0.69	0.95	0.72	0.04	0.15	0.07	0.13	2.08	0.26	0.01	0.002
	SD	0.2	0.16	0.15	0.08	0.03	0.04	0.03	0.04	0.77	0.03	0.00	0.000
	CV	0.03	0.24	0.16	0.11	0.68	0.28	0.4	0.32	0.37	0.11	0.00	0.26
15-30	Mean	4.8	0.62	0.84	0.74	0.03	0.10	0.05	0.11	2.07	na	na	na
	SD	0.1	0.12	0.13	0.07	0.02	0.03	0.02	0.04	1.57	na	na	na
	CV	0.02	0.20	0.15	0.1	0.52	0.29	0.36	0.40	0.76	na	na	na
30-45	Mean	4.8	0.53	0.70	0.75	0.03	0.06	0.03	0.14	1.78	na	na	na
	SD	0.1	0.19	0.18	0.10	0.01	0.03	0.02	0.15	1.82	na	na	na
	CV	0.03	0.35	0.25	0.13	0.41	0.57	0.68	1.09	1.02	na	na	na
45-60	Mean	4.9	0.52	0.62	0.84	0.03	0.04	0.02	0.18	1.27	na	na	na
	SD	0.3	0.23	0.27	0.11	0.01	0.02	0.02	0.19	1.24	na	na	na
	CV	0.1	0.44	0.44	0.13	0.41	0.55	0.67	1.05	0.97	na	na	na
West Sub-Site													
LFH	Mean	4.0	na	na	na	na	na	na	na	na	29.92	0.74	0.09
	SD	0.2	na	na	na	na	na	na	na	na	8.24	0.28	0.03
	CV	0.1	na	na	na	na	na	na	na	na	0.28	0.38	0.32
0-2	Mean	4.7	2.88	3.56	0.81	0.16	0.46	0.14	0.23	3.38	1.48	0.02	0.004
	SD	0.2	0.88	0.96	0.06	0.07	0.17	0.05	0.05	1.09	0.38	0.01	0.001
	CV	0.0	0.31	0.27	0.08	0.42	0.37	0.38	0.22	0.32	0.25	0.25	0.22
2-5	Mean	4.9	1.99	2.26	0.87	0.09	0.35	0.11	0.24	2.68	0.80	0.01	0.002
	SD	0.2	0.89	0.89	0.06	0.04	0.12	0.04	0.08	1.69	0.32	0.004	0.000
	CV	0.04	0.45	0.39	0.07	0.43	0.34	0.33	0.35	0.63	0.40	0.51	0.21
5-10	Mean	4.9	0.91	1.09	0.83	0.06	0.21	0.08	0.23	1.53	0.33	0.01	0.002
	SD	0.2	0.19	0.16	0.09	0.03	0.07	0.03	0.07	0.42	0.07	0.000	0.001
	CV	0.03	0.21	0.15	0.11	0.52	0.32	0.38	0.28	0.27	0.20	0.000	0.33
10-15	Mean	4.8	0.69	0.85	0.80	0.05	0.14	0.06	0.18	1.51	0.26	0.01	0.001
	SD	0.2	0.17	0.13	0.10	0.02	0.06	0.02	0.07	0.57	0.04	0.000	0.001
	CV	0.03	0.25	0.15	0.12	0.44	0.44	0.39	0.42	0.38	0.16	0.000	0.36

Abbreviations:
pHc – pH measured in 0.01M $CaCl_2$
CEC – cation exchange capacity
K, Ca, Mg, Al – water soluble cations
TC – total carbon
TS – total sulphur
SD –standard deviation
na – not analyzed
Exch Bases – sum of exchangeable K, Na, Ca and Mg
BSat – base saturation (sum of exchangeable base/CEC)
BC:Al – ratio of (K+Ca+Mg) concentration to Al concentration
TN – total nitrogen
Mean – average of 12 replicates in each sub-site
CV – coefficient of variation

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APPENDIX A

SOIL DESCRIPTIONS AT POTENTIAL MONITORING SITES

Site L1

Location:	E 504816 N 6013225 (UTM NAD83) Moose Lake Provincial Park
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Nestow
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Level to undulating; 0-5% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site mostly level; non to slightly stony - very few well rounded cobbles
Vegetation:	a1 ecosite phase; jack pine/bearberry/lichen
Samples:	LFH, 0-9 cm and 9-30 cm

<u>Profile Description</u>:

LF	2 to 0 cm	Dark brown and black; non to slightly decomposed needles and lichen.
Ae	0 to 9 cm	Light gray; sand; single grain; loose; no coarse fragments.
Bm	9 to 90 cm	light reddish brown; sand; single grain; loose; very few coarse fragments

Site L2

Location:	E 499587 N 6010901 (UTM NAD83) Southwest of Moose Lake Provincial Park
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Nestow
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Level to undulating; 0-3% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site mostly level; non stony
Vegetation:	b1 ecosite phase; jack pine/blueberry/bearberry/feathermoss/ lichen
Samples:	LFH, 0-3 cm and 3-25 cm

<u>Profile Description</u>:

LF	7 to 0 cm	Dark brown, dark gray and black; non to slightly decomposed needles and lichen.
Ahe	0 to 3 cm	Light gray and dark gray (salt and pepper colours); sand (about half coarse sand); single grain; loose; no coarse fragments.
Ae	3 to 25 cm	Light gray; sand; single grain; loose; no coarse fragments.
Bm	25 to 70+ cm	light reddish brown; sand, with coarse sand and some gravel; single grain; loose; very few coarse fragments

Site L3

Location:	E 499222 N 6052054 (UTM NAD83) South of Wolf Lake
Classification:	
Subgroup:	Orthic Gray Luvisol
Family	Moderately fine, mixed, alkaline, cold, subarid family
Series:	La Corey
Landform:	
Genetic Material:	Glacial till (morainal)
Surface Expression:	Undulating to hummocky; 2-9% slopes; regionally hummocky
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Site undulating; moderately stony
Vegetation:	d3 ecosite phase; dominantly aspen, minor white spruce, shrub understory
Samples:	LFH, 0-9 cm and 9-20 cm

Profile Description:

LF	8 to 0 cm	Mixed brown to black; mainly aspen leaf litter.
Ae	0 to 9 cm	Light gray; sandy loam; moderate, medium platy; very friable; 2-5% coarse fragments.
BA	9 to 23 cm	Gray and brown; clay loam; moderate, medium subangular blocky breaking to weak, medium platy; firm; 2-5% coarse fragments.
Bt	23 to 30+ cm	Brown; clay loam; moderate, medium subangular blocky; firm; 2-5% coarse fragments.

Site L4

Location: NE28-63-07-W4M

Fenced area – possibly leased crown land.
Photo taken from road.
Typical jack pine site on sandy Brunisol.
Potentially good site for monitoring but appears to be used for grazing.
No detailed site examination carried out

Site L5

Location: E 512414 N 6046508 (UTM NAD83)
South of Marguerite Lake

Classification:
- ***Subgroup***: Eluviated Dystric Brunisol
- ***Family*** Sandy, siliceous, neutral, cold, subarid family
- ***Series***: Liza

Landform:
- ***Genetic Material***: Glaciofluvial
- ***Surface Expression***: Gently undulating; 0-3% slopes

Drainage/ Perviousness: Very rapidly drained; high perviousness

Site Features: Site mostly level; non stony

Vegetation: a1 ecosite; Jack pine/bearberry/lichen

Samples: LFH, 0-12 cm and 12-25 cm

Profile Description:

LF	5 to 0 cm	Mixed browns to black; non to slightly decomposed needles and lichen.
Ae1	0 to 5 cm	Gray and dark gray; sand; single grain; loose; <1% coarse fragments.
Ae2	5 to 12 cm	Light gray; sand; single grain; loose; <1% coarse fragments.
Bm1	12 to 25 cm	Light reddish brown; sand; single grain; loose; 1-2% coarse fragments.
Bm2	25 to 50 cm	Light brown; sand; single grain; loose; 1-2% coarse fragments.
Bm3	50 to 70+ cm	Light yellowish brown; sand; single grain; loose; 1-2% coarse fragments.

Site L6

Location:	E 523410 N 6042408 (UTM NAD83) Near Tucker Lake, in recreation area
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Level to undulating; 0-5% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site mostly level; non to slightly stony
Vegetation:	a1 ecosite phase; jack pine/bearberry/feathermoss/lichen
Samples:	LFH, 0-15 cm and 15-30 cm

<u>Profile Description</u>:

LF	5 to 0 cm	Dark brown and black; non to slightly decomposed needles, lichen and moss.
Ae	0 to 9 cm	Light gray; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm1&2	15 to 65 cm	Light reddish brown; sand; single grain; loose; <1% coarse fragments (pebbles); gradual change to lighter colour with depth (Bm2).
Bm3	65 to 100 cm	Pale brown; sand; single grain; loose; <1% coarse fragments (pebbles).

Site L7

Location:	E 523695 N 6041120 (UTM NAD83) South of Tucker Lake
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Undulating to hummocky; 6-15% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Level site within generally roughly undulating to hummocky area
Vegetation:	a1 ecosite phase; jack pine/bearberry/blueberry/lichen

Samples: LFH, 0-16 cm and 16-30 cm

Profile Description:

LF	3 to 0 cm	Dark brown and black; non to slightly decomposed needles, lichen and moss.
Ae	0 to 16 cm	Light gray; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm1	16 to 55 cm	Light reddish brown; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm2	55 to 100 cm	Pale brown; sand; single grain; loose; <1% coarse fragments (pebbles).

Site L8

Location:	E 533203 N 6036853 (UTM NAD83) (SE25-63-04-W4)
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Disturbance within kilometre; within agricultural area
Vegetation:	a1 ecosite phase; jack pine/bearberry/lichen (some green alder)

Samples: LFH, 0-12 cm and 12-30 cm

Profile Description:

LF	3 to 0 cm	Dark brown and black; non to slightly decomposed needles, lichen and moss.
Ae	0 to 12 cm	Light gray; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm1&2	12 to 55 cm	Light reddish brown; sand; single grain; loose; <1% coarse fragments (pebbles); gradual change to lighter colour with depth (Bm2).
Bm3	55 to 100 cm	Pale brown; sand; single grain; loose; <1% coarse fragments (pebbles).

Site L9

Location:	E 5589853 N 6062787 (UTM NAD83) Near Cold Lake Indian Reserve 149C
Classification:	
Subgroup:	Orthic Gray Luvisol
Family	Moderately fine, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glacial till (morainal)
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Moderately well drained; medium perviousness
Site Features:	Top of flat, low hill; access from highway through muskeg;
Vegetation:	c1 ecosite phase; jack pine/aspen/Labrador tea/bunchberry/ feathermosses
Samples:	LFH, 0-16 cm and 16-30 cm

<u>Profile Description</u>:

LF	12 to 0 cm	Dark brown and black; feathermoss litter with leaves and twigs; non to slightly decomposed.
Ae	0 to 16 cm	Light gray; sandy loam; moderate, medium platy; very friable; 2-5% coarse fragments.
Bt1	16 to 40 cm	Reddish brown; sandy clay loam; moderate, medium subangular blocky; friable; 2-5% coarse fragments.
Bt2	40 to 60 cm	Brown; clay loam; moderate, medium subangular blocky; firm; 2-5% coarse fragments.
BC	60 to 100 cm;	Gray brown; clay loam; massive, medium subangular blocky; soft to firm; 2-5% coarse fragments.
Ck	100+ cm	Olive brown; clay loam; massive; soft to firm; 2-5% coarse fragments.

Site L10

Location:	E 484969 N 6044521 (UTM NAD83) West side of LICA area (SE24-64-9-W4)
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Some recreational use and hunting in area
Vegetation:	a1 ecosite phase; jack pine/bearberry/lichen (some feathermoss and pine grass)

Samples: LFH, 0-7 cm and 7-25 cm

Profile Description:

LF	3 to 0 cm	Dark brown and black; non to slightly decomposed needles, lichen and moss.
Ae	0 to 7 cm	Light gray; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm1	7 to 24 cm	Very Light brown; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm2	24 to 60 cm	Pale brown; sand; single grain; loose; <1% coarse fragments (pebbles).
Bm3	60 to 100 cm	Light yellowish brown; sand; single grain; loose; <1% coarse fragments (pebbles).

Site L11

Location:	E 530702 N 5964847 (UTM NAD83) In Whitney Lakes Provincial Park
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Liza
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Undulating to hummocky; 6-15% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site in level area on top of wide knoll
Vegetation:	a1 ecosite phase; jack pine/bearberry/blueberry/lichen (some feathermoss and grasses)

Samples: LFH, 0-15 cm and 15-28 cm

Profile Description:

LF	4 to 0 cm	Dark brown and black; non to slightly decomposed needles, lichen and moss.
Ahe/Ae	0 to 7 cm	Gray over light gray; sand; single grain; loose; no coarse fragments.
AB	7 to 15 cm	Light brownish gray; sand; single grain; loose; no coarse fragments.
Bm1	15 to 28 cm	Pale brown; sand; single grain; loose; <1% coarse fragments.
Bm2	28 to 100 cm	Light yellowish brown; sand; single grain; loose; <1% coarse fragments.

APPENDIX B

PROFILE DESCRIPTIONS - MOOSE LAKE PROVINCIAL PARK SOIL MONITORING SITE

Moose Lake Provincial Park – West Plot

Location:	Zone 12 E504740 N6013995 (UTM NAD83) (Near Southeast corner of West Plot)
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Nestow
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Level to undulating; 0-3% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site level to very gently undulating; non stony
Vegetation:	a1 ecosite phase; jack pine/bearberry/lichen

<u>Profile Description</u>:

LF	2 to 0 cm	Dark brown, dark gray and black; non to slightly decomposed needles, bearberry leaves and lichen.
Ahe	0 to 2 cm	Light gray and dark gray (salt and pepper colours); sand; single grain; loose; abundant, fine to coarse roots; no coarse fragments.
Ae1	2 to 4 cm	Light grayish brown (moist); sand; single grain; loose; plentiful, fine to coarse roots; no coarse fragments.
Ae2	4 to 8 cm	Light gray (moist); sand; single grain; loose; plentiful, fine to coarse roots; no coarse fragments.
AB	8 to 15 cm	Grayish brown (moist); sand; single grain; loose; plentiful, fine to coarse roots; no coarse fragments.
Bm1	15 to 30 cm	Reddish brown (moist); sand; single grain; loose; very few coarse fragments; few, fine to coarse roots; gradual, smooth boundary.
Bm2	30 to 80 cm	Dull reddish brown (moist); sand; single grain; loose; very few coarse fragments; very few roots; gradual, smooth boundary.
Bm3	80 to 100 cm	Yellowish brown (moist); sand; single grain; loose; very few coarse fragments; very few roots.

Moose Lake Provincial Park – East Plot

Location:	Zone 12 E505044 N6014060 (UTM NAD83) (Near Southwest corner of East Plot)
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Family	Sandy, siliceous, neutral, cold, subarid family
Series:	Nestow
Landform:	
Genetic Material:	Glaciofluvial
Surface Expression:	Level to undulating; 0-3% slopes
Drainage/ Perviousness:	Very rapidly drained; high perviousness
Site Features:	Site level to very gently undulating; non stony
Vegetation:	a1 ecosite phase; jack pine/ /bearberry/lichen

Profile Description:

LF	2 to 0 cm	Dark brown, dark gray and black; non to slightly decomposed needles, bearberry leaves and lichen.
Ahe	0 to 4 cm	Light gray and dark gray (salt and pepper colours); sand; single grain; loose; abundant, fine to coarse roots; no coarse fragments.
Ae	4 to 9 cm	Light gray (moist); sand; single grain; loose; plentiful, fine to coarse roots; no coarse fragments.
AB	9 to 17 cm	Grayish brown (moist); sand; single grain; loose; plentiful, fine to coarse roots; no coarse fragments.
Bm1	17 to 52 cm	Reddish brown (moist); sand; single grain; loose; very few coarse fragments; few, fine to coarse roots; gradual, smooth boundary.
Bm2	52 to 85 cm	Dull reddish brown (moist); sand; single grain; loose; very few coarse fragments; very few roots; gradual, smooth boundary.
Bm3	85 to 100 cm	Yellowish brown (moist); sand; single grain; loose; very few coarse fragments; very few roots.

APPENDIX C

LABORATORY DATA – MOOSE LAKE PROVINCIAL PARK SOIL MONITORING SITE

Table C1. Soil pH, Electrical Conductivity and Soluble Ions at the Moose Lake East Sub-Site

Subplot	Layer (cm)	Sat'n (%)	pH (ext)	EC (dS m^{-1})	Na	K	Ca	Mg (mg L^{-1})	Al	Fe	Mn	S
A1	**0-2**	51.2	5.3	0.20	5.7	11.1	29.1	4.8	4.1	2.4	4.2	6.4
	2-5	38.8	5.3	0.09	4.3	3.3	12.0	2.1	10.1	5.5	1.8	2.5
	5-10	39.2	5.4	0.07	5.0	2.3	7.7	1.3	5.7	3.1	0.5	1.9
	10-15	37.8	5.6	0.06	5.3	1.0	4.9	1.0	5.0	2.9	0.1	1.6
	15-30	38.0	5.9	0.05	5.0	0.7	4.1	1.0	3.0	1.8	<0.1	1.5
	30-45	37.2	6.4	0.05	6.7	0.8	1.6	0.5	4.2	2.1	<0.1	1.5
	45-60	36.4	5.9	0.04	4.9	1.5	2.0	1.1	15.3	7.5	<0.1	1.2
B1	**0-2**	46.8	5.5	0.15	4.7	9.5	17.2	4.1	5.1	2.8	2.0	4.8
	2-5	44.8	5.5	0.10	5.0	5.6	10.4	2.7	4.2	2.2	1.2	2.9
	5-10	40.4	5.5	0.08	6.2	3.6	6.3	2.0	5.3	2.7	1.2	2.2
	10-15	36.8	5.6	0.07	6.8	1.5	4.4	1.5	4.0	2.1	0.5	2.2
	15-30	36.8	5.7	0.06	6.2	1.7	4.4	1.2	4.6	2.6	0.1	1.8
	30-45	36.4	5.7	0.05	4.8	1.5	3.5	1.5	14.2	7.3	0.2	1.5
	45-60	36.4	5.6	0.05	7.4	1.2	1.1	0.6	6.5	3.2	<0.1	2.2
C1	**0-2**	53.2	5.2	0.23	6.8	8.2	39.0	7.1	5.3	2.9	5.5	7.0
	2-5	39.2	5.8	0.17	7.8	3.5	24.3	5.3	5.6	3.0	3.6	6.8
	5-10	37.2	5.8	0.13	6.6	2.6	12.7	3.9	4.5	2.3	2.4	6.3
	10-15	36.4	5.8	0.12	9.8	2.3	9.5	3.3	3.1	1.6	1.0	6.1
	15-30	36.4	6.3	0.09	8.3	1.3	6.5	2.3	1.2	0.7	0.3	5.1
	30-45	35.6	6.2	0.08	7.6	1.3	4.3	1.8	0.9	0.5	<0.1	4.2
	45-60	35.6	6.4	0.06	7.0	0.8	2.8	1.1	2.0	1.2	<0.1	2.6
D1	**0-2**	56.8	6.0	0.49	5.0	8.5	92.2	13.8	3.5	1.2	23.5	6.1
	2-5	43.2	6.5	0.19	9.5	2.2	29.1	6.2	3.4	1.3	6.3	3.1
	5-10	38.8	6.4	0.11	5.8	1.8	15.0	3.7	7.4	3.7	4.8	1.9
	10-15	36.0	6.2	0.08	7.0	0.8	7.8	2.0	4.9	2.7	0.7	1.7
	15-30	36.0	6.1	0.06	6.7	0.8	4.4	1.3	5.0	2.7	0.2	1.6
	30-45	35.2	5.8	0.05	7.0	1.2	1.0	0.4	4.3	2.1	<0.1	1.9
	45-60	36.4	5.9	0.04	5.8	1.0	1.6	0.9	10.6	5.0	<0.1	1.6
E1	**0-2**	59.2	5.1	0.25	4.6	11.6	35.3	5.8	4.7	1.8	20.5	6.4
	2-5	44.8	5.7	0.18	6.4	6.1	22.6	3.6	5.2	2.2	13.8	4.7
	5-10	37.2	5.9	0.09	7.2	2.7	7.5	1.8	2.5	1.2	3.1	3.8
	10-15	36.8	6.2	0.06	7.4	1.0	5.0	1.0	2.5	1.3	0.4	2.5
	15-30	36.4	6.0	0.05	5.5	0.8	3.6	0.9	3.1	1.6	0.2	1.9
	30-45	35.6	5.9	0.05	6.2	1.4	1.6	0.5	4.7	2.4	<0.1	1.6
	45-60	35.0	6.4	0.04	5.8	0.8	1.1	0.3	2.8	1.5	<0.1	1.3
F1	**0-2**	60.8	6.0	0.30	5.7	6.8	42.7	8.1	2.6	0.7	16.3	6.2
	2-5	57.2	5.6	0.24	5.5	4.1	38.3	6.7	3.2	1.0	13.4	5.1
	5-10	38.0	5.8	0.11	6.3	1.8	13.8	2.9	7.0	3.5	4.1	3.8
	10-15	36.8	5.8	0.08	7.4	1.5	7.0	1.7	4.4	2.3	1.5	3.3
	15-30	35.6	6.1	0.07	9.1	1.2	5.0	1.3	4.3	2.5	0.3	3.0
	30-45	35.6	5.9	0.06	8.2	1.1	1.7	0.4	0.6	0.4	0.1	2.9
	45-60	35.2	6.2	0.05	7.5	1.3	0.5	0.1	0.4	0.2	<0.1	2.4
G1	**0-2**	46.8	5.5	0.14	5.6	4.2	22.1	4.2	6.0	2.7	3.9	3.1
	2-5	47.2	5.7	0.12	5.2	3.7	23.0	3.9	4.4	2.2	2.6	2.6
	5-10	44.4	5.6	0.10	5.1	2.7	13.7	3.0	4.1	1.9	1.6	2.3
	10-15	36.8	6.0	0.07	7.4	0.9	5.5	1.5	4.8	2.6	0.2	1.6
	15-30	36.8	6.0	0.05	6.7	0.5	3.3	1.0	2.8	1.6	<0.1	1.3
	30-45	36.0	5.7	0.05	5.6	0.9	2.9	1.1	9.4	4.9	<0.1	1.2
	45-60	35.6	5.8	0.04	5.6	1.1	2.0	0.9	12.4	5.8	<0.1	1.1

Table C1. Soil pH, electrical conductivity and soluble ions at the Moose Lake East Site (concluded)

Subplot	Layer (cm)	Sat'n (%)	pH (ext)	EC (dS m^{-1})	Na	K	Ca	Mg (mg L^{-1})	Al	Fe	Mn	S
H1	**0-2**	68.8	5.0	0.30	4.4	21.6	41.2	9.1	7.4	5.1	14.8	9.6
	2-5	44.8	5.5	0.14	4.9	6.6	16.4	4.5	10.7	5.8	6.2	4.1
	5-10	37.6	5.2	0.13	7.0	9.0	10.4	3.3	8.8	3.2	4.6	4.3
	10-15	36.4	5.2	0.09	7.0	4.6	5.1	1.8	4.3	2.3	1.0	3.2
	15-30	36.4	5.8	0.07	7.4	2.6	5.4	1.5	2.1	1.1	0.1	2.6
	30-45	36.6	5.8	0.07	7.6	1.8	4.7	1.5	2.6	1.5	0.1	3.2
	45-60	34.8	6.2	0.06	6.4	1.8	3.2	1.1	5.8	3.4	0.2	2.1
I1	**0-2**	55.2	5.7	0.19	7.1	5.6	32.1	5.7	2.8	1.3	3.4	4.7
	2-5	46.4	5.6	0.17	5.8	3.7	27.8	5.3	4.0	1.9	4.2	4.2
	5-10	37.2	5.6	0.09	6.7	2.6	9.9	2.6	7.2	3.4	1.9	3.5
	10-15	39.2	5.4	0.08	6.2	2.4	6.0	1.9	2.6	1.3	0.9	4.1
	15-30	35.6	5.6	0.07	7.0	1.4	3.5	1.1	2.2	1.3	<0.1	3.3
	30-45	36.4	5.8	0.06	6.5	1.1	2.6	0.6	1.5	0.9	<0.1	2.5
	45-60	35.2	6.4	0.05	6.2	0.7	1.8	0.3	0.6	0.4	<0.1	1.7
J1	**0-2**	54.4	5.5	0.17	3.6	10.7	23.0	5.3	4.2	2.6	4.7	4.1
	2-5	44.0	5.7	0.10	4.8	3.8	11.0	2.3	2.4	1.3	1.6	2.5
	5-10	41.2	5.6	0.07	5.1	2.6	7.8	1.6	1.8	1.1	0.9	2.0
	10-15	41.2	5.7	0.07	5.1	2.9	6.6	1.5	3.2	1.7	0.8	1.8
	15-30	38.0	5.6	0.06	5.1	1.2	3.8	1.0	1.9	1.1	0.5	1.4
	30-45	36.4	6.1	0.04	5.3	0.3	1.4	0.5	1.0	0.7	<0.1	1.1
	45-60	36.8	6.1	0.04	5.9	0.4	0.8	0.2	1.0	0.6	<0.1	1.2
K1	**0-2**	49.6	5.4	0.17	5.0	4.8	27.1	4.5	3.9	2.3	3.3	4.7
	2-5	48.4	5.7	0.12	4.5	2.7	17.4	2.8	2.7	1.3	2.5	3.1
	5-10	44.0	5.9	0.08	4.9	1.0	9.6	1.8	1.9	0.9	0.9	2.4
	10-15	42.4	5.7	0.06	4.5	0.9	4.9	1.2	2.7	1.6	0.3	1.9
	15-30	38.0	6.2	0.05	5.0	2.2	2.4	0.8	2.5	1.5	<0.1	1.2
	30-45	37.6	6.0	0.04	4.5	0.6	1.3	0.5	1.4	0.9	<0.1	1.1
	45-60	35.2	6.3	0.04	5.2	0.8	1.0	0.3	0.8	0.6	<0.1	1.1
L1	**0-2**	44.4	5.5	0.16	6.7	7.8	17.0	3.8	7.3	4.4	7.2	4.4
	2-5	44.0	5.8	0.08	5.7	1.9	8.4	1.9	4.0	2.0	1.5	2.0
	5-10	40.8	5.8	0.06	6.0	1.0	5.2	1.3	2.3	1.4	0.5	1.7
	10-15	37.6	5.8	0.06	6.6	0.8	3.5	0.9	1.5	0.9	0.1	1.5
	15-30	37.6	5.7	0.05	5.7	0.7	2.4	0.7	2.1	1.3	0.1	1.4
	30-45	36.2	5.9	0.04	5.9	0.5	0.8	0.2	0.8	0.5	<0.1	1.3
	45-60	36.0	6.3	0.05	6.9	0.5	0.6	0.2	1.3	0.9	<0.1	1.3

Abbreviations:
Sat'n – saturation; the percentage by weight of water in a saturated soil sample
Ext – extract; the pH measured in water extracted from a saturated soil sample

Table C2. Soil pH, electrical conductivity and soluble ions at the Moose Lake West Sub-Site

Subplot	Layer (cm)	Sat'n (%)	pH (ext)	EC (dS m^{-1})	Na	K	Ca	Mg	Al	Fe	Mn	S
					(mg L^{-1})							
A1	**0-2**	44.0	5.5	0.22	5.0	10.6	28.9	6.0	7.4	10.4	9.7	5.0
	2-5	41.6	5.9	0.13	5.0	4.4	17.6	4.0	9.2	5.7	3.2	3.2
	5-10	36.4	6.2	0.10	6.5	3.2	11.6	3.1	8.1	4.4	0.6	2.5
	10-15	37.2	5.8	0.08	5.9	2.4	6.6	2.0	3.2	2.0	0.4	2.0
B1	**0-2**	49.6	5.5	0.13	3.8	6.3	15.1	2.8	6.6	3.6	4.7	3.6
	2-5	42.0	5.4	0.08	4.6	2.9	9.9	2.1	8.0	4.1	3.5	2.2
	5-10	38.4	6.0	0.06	5.5	1.0	4.4	1.1	3.9	2.1	0.8	1.5
	10-15	36.4	6.3	0.06	5.5	0.5	2.3	0.6	2.0	1.4	0.1	1.2
C1	**0-2**	49.2	6.0	0.11	4.5	4.4	13.0	2.5	4.1	2.4	5.3	3.1
	2-5	42.8	5.7	0.11	5.2	3.8	13.2	2.6	7.4	4.7	5.1	2.9
	5-10	38.4	5.9	0.07	5.4	1.7	6.0	1.6	8.8	4.8	1.0	1.9
	10-15	36.8	6.2	0.06	5.3	2.0	3.9	1.3	8.5	4.9	0.1	1.7
D1	**0-2**	44.0	6.0	0.10	6.4	3.6	9.6	2.2	6.3	3.3	4.0	3.4
	2-5	43.2	5.9	0.08	4.4	1.9	10.1	2.2	7.8	3.9	1.3	2.2
	5-10	36.8	5.9	0.08	6.0	1.5	7.3	1.7	4.5	2.9	1.1	2.0
	10-15	36.4	5.9	0.06	5.8	1.7	5.2	1.5	6.6	4.3	0.3	1.8
E1	**0-2**	50.0	5.5	0.16	6.0	6.5	22.1	4.5	8.3	4.4	6.7	4.8
	2-5	44.0	5.8	0.12	5.1	2.9	16.2	2.5	5.1	3.2	3.7	2.8
	5-10	38.8	5.8	0.09	5.1	2.6	10.8	2.0	6.8	3.5	0.2	2.1
	10-15	38.8	6.0	0.08	5.2	2.3	8.3	1.7	5.1	2.8	1.2	1.8
F1	**0-2**	47.2	6.0	0.12	4.2	5.4	14.4	2.4	5.8	3.2	3.7	3.3
	2-5	41.6	6.2	0.10	5.4	5.8	11.1	1.9	6.1	3.2	2.7	3.2
	5-10	37.6	5.7	0.07	6.0	3.7	6.4	1.4	6.1	3.4	0.7	2.3
	10-15	36.4	5.7	0.07	6.8	2.9	4.4	1.1	4.0	2.4	0.1	1.9
G1	**0-2**	49.6	5.8	0.11	4.0	5.1	14.0	2.3	3.6	2.0	2.1	3.0
	2-5	43.6	5.9	0.10	6.0	3.4	11.8	2.0	3.1	1.6	1.3	2.6
	5-10	38.0	6.1	0.07	6.7	1.8	6.2	1.1	3.5	1.8	0.6	1.8
	10-15	36.4	6.3	0.06	7.9	1.0	2.4	0.5	1.5	0.9	<0.1	1.3
H1	**0-2**	46.0	5.4	0.16	5.7	11.0	22.4	4.3	5.1	2.8	3.3	4.7
	2-5	42.8	5.9	0.11	7.1	4.3	14.2	3.1	5.8	3.3	0.9	3.0
	5-10	39.6	5.8	0.10	7.8	4.0	10.7	2.9	6.2	3.5	0.9	3.0
	10-15	37.2	5.9	0.07	7.4	2.5	6.3	1.8	3.7	2.1	0.4	2.4
I1	**0-2**	48.4	5.8	0.12	5.7	7.7	14.4	3.2	7.1	4.1	2.4	3.2
	2-5	44.0	6.0	0.08	4.4	5.6	9.9	2.5	10.6	5.9	1.1	2.1
	5-10	39.2	5.6	0.08	4.7	5.0	7.8	2.1	5.3	2.9	0.6	1.6
	10-15	36.2	5.7	0.06	5.7	2.7	3.9	1.2	4.7	2.8	0.1	1.4
J1	**0-2**	47.6	5.4	0.12	5.5	3.2	15.9	1.9	6.0	3.2	4.0	3.6
	2-5	42.8	5.8	0.07	5.0	1.2	8.7	1.2	5.8	3.0	1.1	1.6
	5-10	36.4	5.9	0.06	6.0	0.9	5.9	1.0	6.1	3.3	0.4	1.4
	10-15	36.0	6.1	0.05	6.0	0.7	4.3	1.0	5.9	3.5	<0.1	1.2
K1	**0-2**	52.0	5.6	0.19	6.2	6.4	32.1	4.9	6.6	4.7	5.4	6.0
	2-5	47.6	6.5	0.15	5.1	2.5	24.7	4.2	3.2	1.4	<0.1	2.7
	5-10	38.0	6.5	0.10	6.4	2.6	11.8	2.9	8.4	4.3	0.9	3.2
	10-15	38.4	6.1	0.08	5.8	2.2	10.0	2.3	6.5	3.4	0.5	2.7
L1	**0-2**	47.2	5.7	0.12	3.9	3.5	18.3	3.2	6.4	3.5	2.9	3.1
	2-5	40.8	6.0	0.12	5.1	1.9	18.8	3.1	5.3	2.5	2.4	2.3
	5-10	38.4	5.9	0.08	6.0	1.5	10.7	2.1	7.9	4.0	0.8	1.8
	10-15	37.6	6.1	0.07	5.9	1.1	7.9	1.5	5.0	2.7	0.1	1.6

Table C3. pH($CaCl_2$), and Total Carbon, Nitrogen and Sulphur at the Moose Lake East Sub-Site

Subplot	Layer (cm)	pH ($CaCl_2$)	Total Carbon (%)	Total Nitrogen (%)	Total Sulphur (%)
A1	LFH	4.0	40.2	1.40	0.147
	0-2	4.6	2.88	0.09	0.008
	2-5	4.6	0.53	<0.01	0.003
	5-10	4.6	0.32	<0.01	0.002
	10-15	4.7	0.24	<0.01	0.001
	15-30	4.9			
	30-45	5.0			
	45-60	4.8			
B1	LFH	4.5	38.0	1.33	0.136
	0-2	4.7	1.40	0.05	0.005
	2-5	4.7	1.15	0.03	0.004
	5-10	4.5	0.44	<0.01	0.002
	10-15	4.4	0.28	<0.01	0.001
	15-30	4.7			
	30-45	4.8			
	45-60	4.4			
C1	LFH	4.3	45.6	1.36	0.151
	0-2	4.6	3.50	0.11	0.010
	2-5	4.9	0.78	0.01	0.004
	5-10	5.0	0.32	<0.01	0.002
	10-15	4.8	0.28	<0.01	0.002
	15-30	4.9			
	30-45	4.9			
	45-60	5.2			
D1	LFH	4.7	41.8	1.03	0.114
	0-2	5.0	3.68	0.09	0.010
	2-5	4.9	1.46	0.03	0.004
	5-10	4.9	0.43	<0.01	0.003
	10-15	4.9	0.27	<0.01	0.002
	15-30	4.8			
	30-45	4.5			
	45-60	4.7			
E1	LFH	4.1	45.1	1.42	0.156
	0-2	4.3	3.08	0.08	0.007
	2-5	4.7	0.88	0.01	0.003
	5-10	4.7	0.47	<0.01	0.002
	10-15	4.7	0.23	<0.01	0.002
	15-30	4.8			
	30-45	4.7			
	45-60	5.0			
F1	LFH	4.3	43.1	1.05	0.107
	0-2	4.7	4.63	0.16	0.009
	2-5	4.6	3.10	0.08	0.006
	5-10	4.6	0.70	<0.01	0.002
	10-15	4.6	0.29	<0.01	0.002
	15-30	4.7			
	30-45	4.7			
	45-60	4.8			

Table C3. pH($CaCl_2$), and Total Carbon, Nitrogen and Sulphur at the Moose Lake East Sub-Site (concluded)

Subplot	Layer (cm)	pH ($CaCl_2$)	Total Carbon (%)	Total Nitrogen (%)	Total Sulphur (%)
G1	LFH	4.5	39.8	0.95	0.098
	0-2	4.7	1.34	0.02	0.004
	2-5	5.0	0.92	0.01	0.004
	5-10	4.9	0.77	<0.01	0.002
	10-15	4.9	0.26	<0.01	0.002
	15-30	4.9			
	30-45	4.8			
	45-60	4.8			
H1	LFH	3.9	44.7	1.16	0.127
	0-2	4.4	3.11	0.09	0.011
	2-5	4.8	0.62	<0.01	0.003
	5-10	4.6	0.33	<0.01	0.002
	10-15	4.6	0.21	<0.01	0.002
	15-30	4.6			
	30-45	4.8			
	45-60	5.4			
I1	LFH	4.5	45.7	1.29	0.144
	0-2	4.9	2.63	0.07	0.005
	2-5	4.9	1.29	0.02	0.003
	5-10	4.8	0.45	<0.01	0.002
	10-15	4.7	0.27	<0.01	0.002
	15-30	4.7			
	30-45	4.9			
	45-60	5.4			
J1	LFH	4.3	42.7	0.89	0.092
	0-2	4.7	2.03	0.04	0.005
	2-5	4.9	0.81	0.02	0.003
	5-10	4.8	0.43	<0.01	0.002
	10-15	4.9	0.32	<0.01	0.002
	15-30	4.7			
	30-45	4.8			
	45-60	4.9			
K1	LFH	4.5	35.7	1.02	0.108
	0-2	4.8	1.96	0.06	0.007
	2-5	4.9	0.79	0.01	0.003
	5-10	4.9	0.38	<0.01	0.003
	10-15	4.9	0.28	<0.01	0.001
	15-30	4.8			
	30-45	4.8			
	45-60	5.3			
L1	LFH	4.4	35.3	1.25	0.130
	0-2	4.7	1.29	0.04	0.005
	2-5	4.8	0.52	0.01	0.002
	5-10	4.8	0.27	<0.01	0.001
	10-15	4.7	0.25	<0.01	0.002
	15-30	4.8			
	30-45	4.7			
	45-60	5.3			

Table C4. pH($CaCl_2$), and Total Carbon, Nitrogen and Sulphur at the Moose Lake West Sub-Site

Subplot	Layer (cm)	pH ($CaCl_2$)	Total Carbon (%)	Total Nitrogen (%)	Total Sulphur (%)
A1	LFH	4.3	28.0	1.02	0.121
	0-2	5.1	1.52	0.03	0.004
	2-5	5.0	0.80	<0.01	0.002
	5-10	4.9	0.29	<0.01	0.002
	10-15	4.6	0.25	<0.01	0.002
B1	LFH	3.8	22.4	0.29	0.054
	0-2	4.6	1.68	0.03	0.004
	2-5	4.6	0.52	<0.01	0.002
	5-10	4.5	0.38	<0.01	0.002
	10-15	4.6	0.23	<0.01	0.001
C1	LFH	4.0	18.6	0.42	0.077
	0-2	4.8	1.27	0.02	0.004
	2-5	4.8	0.87	0.01	0.002
	5-10	4.8	0.29	<0.01	0.002
	10-15	4.8	0.22	<0.01	0.001
D1	LFH	3.9	31.7	0.46	0.061
	0-2	4.4	1.56	0.02	0.004
	2-5	4.8	0.79	<0.01	0.002
	5-10	4.9	0.29	<0.01	0.002
	10-15	4.9	0.25	<0.01	0.001
E1	LFH	4.6	43.1	0.91	0.099
	0-2	4.5	2.07	0.03	0.005
	2-5	4.9	1.19	0.01	0.003
	5-10	4.8	0.45	<0.01	0.001
	10-15	4.9	0.34	<0.01	0.001
F1	LFH	3.9	25.7	0.73	0.074
	0-2	4.6	1.07	0.01	0.003
	2-5	5.0	0.58	<0.01	0.002
	5-10	4.9	0.29	<0.01	0.002
	10-15	4.7	0.24	<0.01	0.002
G1	LFH	4.2	24.1	0.60	0.067
	0-2	4.7	1.29	0.02	0.004
	2-5	4.9	1.12	0.01	0.003
	5-10	5.0	0.32	<0.01	0.001
	10-15	4.7	0.26	<0.01	0.001
H1	LFH	4.2	37.8	0.95	0.128
	0-2	4.7	1.30	0.02	0.004
	2-5	4.8	0.86	0.01	0.002
	5-10	4.9	0.45	<0.01	0.002
	10-15	4.9	0.30	<0.01	0.002

Table C4. pH($CaCl_2$), and Total Carbon, Nitrogen and Sulphur at the Moose Lake West Sub-Site (concluded)

Subplot	Layer (cm)	pH ($CaCl_2$)	Total Carbon (%)	Total Nitrogen (%)	Total Sulphur (%)
I1	LFH	4.0	38.8	1.08	0.129
	0-2	4.7	1.05	0.02	0.003
	2-5	5.1	0.42	<0.01	0.002
	5-10	4.8	0.29	<0.01	0.002
	10-15	4.8	0.23	<0.01	0.002
J1	LFH	4.0	19.8	0.52	0.086
	0-2	4.6	1.46	0.02	0.003
	2-5	4.9	0.42	<0.01	0.002
	5-10	4.9	0.27	<0.01	0.001
	10-15	4.9	0.19	<0.01	0.001
K1	LFH	4.0	39.4	1.08	0.123
	0-2	4.8	2.26	0.03	0.006
	2-5	5.4	1.44	0.02	0.003
	5-10	5.1	0.38	<0.01	0.001
	10-15	5.1	0.31	<0.01	0.001
L1	LFH	4.0	29.8	0.86	0.063
	0-2	4.8	1.21	0.02	0.004
	2-5	5.1	0.64	0.01	0.003
	5-10	5.0	0.30	<0.01	0.001
	10-15	4.9	0.26	<0.01	0.002

Table C5. Exchangeable Cations, Cation Exchange Capacity and Base Saturation at the Moose Lake East Sub-Site

Subplot	Layer (cm)	pH ($CaCl_2$)	Na	K	Ca	Mg	Al	Fe	Mn	Bases	CEC[1]	Base Saturation
			(cmol kg^{-1})									
A1	LFH	4.0										
	0-2	4.6	0.24	0.10	3.80	0.35	0.34	<0.01	0.47	4.49	5.30	0.85
	2-5	4.6	0.23	0.04	0.88	0.10	0.27	0.01	0.09	1.25	1.61	0.78
	5-10	4.6	0.21	0.03	0.56	0.07	0.28	0.01	0.02	0.87	1.19	0.73
	10-15	4.7	0.24	0.02	0.41	0.07	0.23	0.02	<0.01	0.75	0.99	0.75
	15-30	4.9	0.20	0.02	0.40	0.09	0.12	0.01	<0.01	0.71	0.85	0.84
	30-45	5.0	0.22	0.02	0.44	0.10	0.08	<0.01	<0.01	0.78	0.86	0.90
	45-60	4.8	0.21	0.02	0.58	0.13	0.11	<0.01	<0.01	0.94	1.06	0.89
B1	LFH	4.5										
	0-2	4.7	0.21	0.11	1.92	0.32	0.25	<0.01	0.14	2.56	2.95	0.87
	2-5	4.7	0.20	0.07	1.59	0.25	0.37	<0.01	0.13	2.11	2.61	0.81
	5-10	4.5	0.20	0.04	0.45	0.11	0.35	<0.01	0.06	0.80	1.21	0.66
	10-15	4.4	0.23	0.02	0.23	0.07	0.40	0.01	0.02	0.56	0.99	0.56
	15-30	4.7	0.25	0.03	0.47	0.12	0.21	0.01	<0.01	0.86	1.09	0.79
	30-45	4.8	0.23	0.03	0.48	0.13	0.14	<0.01	0.01	0.86	1.01	0.85
	45-60	4.4	0.24	0.02	0.26	0.07	0.34	0.01	<0.01	0.60	0.96	0.63
C1	LFH	4.3										
	0-2	4.6	0.25	0.08	5.04	0.49	0.35	0.01	0.61	5.86	6.82	0.86
	2-5	4.9	0.24	0.05	1.94	0.25	0.18	<0.01	0.33	2.48	2.99	0.83
	5-10	5.0	0.23	0.04	0.62	0.15	0.12	0.01	0.12	1.04	1.27	0.81
	10-15	4.8	0.24	0.03	0.40	0.14	0.19	0.01	0.04	0.81	1.06	0.77
	15-30	4.9	0.23	0.03	0.33	0.13	0.18	0.02	0.01	0.72	0.93	0.78
	30-45	4.9	0.23	0.02	0.26	0.12	0.15	0.01	<0.01	0.65	0.81	0.80
	45-60	5.2	0.23	0.02	0.24	0.11	0.05	<0.01	<0.01	0.59	0.64	0.92
D1	LFH	4.7										
	0-2	5.0	0.22	0.08	7.68	0.60	0.14	<0.01	0.37	8.59	9.10	0.94
	2-5	4.9	0.22	0.03	3.17	0.35	0.22	<0.01	0.13	3.77	4.13	0.91
	5-10	4.9	0.23	0.03	0.89	0.16	0.17	<0.01	0.04	1.31	1.52	0.86
	10-15	4.9	0.22	0.02	0.61	0.14	0.20	0.01	0.01	0.99	1.21	0.82
	15-30	4.8	0.18	0.01	0.38	0.11	0.17	0.01	<0.01	0.69	0.86	0.80
	30-45	4.5	0.22	0.02	0.19	0.06	0.30	<0.01	<0.01	0.49	0.79	0.62
	45-60	4.7	0.20	0.02	0.35	0.11	0.21	<0.01	<0.01	0.68	0.89	0.77
E1	LFH	4.1										
	0-2	4.3	0.21	0.11	3.15	0.27	0.78	0.01	0.99	3.74	5.52	0.68
	2-5	4.7	0.21	0.04	1.18	0.12	0.37	<0.01	0.25	1.54	2.16	0.71
	5-10	4.7	0.18	0.03	0.34	0.08	0.25	<0.01	0.06	0.62	0.94	0.66
	10-15	4.7	0.20	0.02	0.36	0.09	0.27	0.01	0.02	0.66	0.96	0.69
	15-30	4.8	0.18	0.02	0.31	0.09	0.22	0.01	<0.01	0.60	0.83	0.72
	30-45	4.7	0.16	0.01	0.26	0.06	0.17	<0.01	<0.01	0.49	0.66	0.75
	45-60	5.0	0.19	0.01	0.27	0.06	0.05	<0.01	<0.01	0.53	0.58	0.92
F1	LFH	4.3										
	0-2	4.7	0.22	0.09	6.57	0.59	0.40	<0.01	0.69	7.46	8.55	0.87
	2-5	4.6	0.21	0.05	3.92	0.36	0.61	0.01	0.40	4.54	5.55	0.82
	5-10	4.6	0.18	0.03	0.94	0.14	0.34	<0.01	0.09	1.29	1.71	0.75
	10-15	4.6	0.20	0.03	0.46	0.11	0.25	<0.01	0.03	0.80	1.09	0.74
	15-30	4.7	0.17	0.02	0.37	0.10	0.24	0.01	0.02	0.67	0.94	0.71
	30-45	4.7	0.18	0.02	0.11	0.04	0.19	0.01	<0.01	0.33	0.53	0.63
	45-60	4.8	0.18	0.01	0.06	0.02	0.10	<0.01	<0.01	0.27	0.37	0.72

[1] **CEC – cation exchange capacity; measured by the barium chloride method**

Table C5. Exchangeable Cations, Cation Exchange Capacity and Base Saturation at the Moose Lake East Sub-Site (concluded)

Subplot	Layer (cm)	pH ($CaCl_2$)	Na	K	Ca	Mg	Al	Fe	Mn	Bases	C.E.C.	Base Saturation
			(cmol kg^{-1})									
G1	LFH	4.5										
	0-2	4.7	0.17	0.05	2.03	0.24	0.34	<0.01	0.31	2.50	3.15	0.79
	2-5	5.0	0.18	0.05	1.54	0.21	0.16	<0.01	0.13	1.98	2.26	0.87
	5-10	4.9	0.20	0.04	0.99	0.17	0.17	<0.01	0.09	1.39	1.65	0.85
	10-15	4.9	0.18	0.03	0.51	0.14	0.18	0.01	0.02	0.85	1.06	0.81
	15-30	4.9	0.17	0.02	0.37	0.12	0.14	0.01	<0.01	0.68	0.82	0.83
	30-45	4.8	0.23	0.02	0.38	0.11	0.14	<0.01	<0.01	0.74	0.88	0.84
	45-60	4.8	0.24	0.02	0.38	0.11	0.11	<0.01	<0.01	0.75	0.85	0.88
H1	LFH	3.9										
	0-2	4.4	0.24	0.19	4.77	0.63	0.44	0.02	1.04	5.83	7.32	0.80
	2-5	4.8	0.21	0.06	0.94	0.17	0.24	0.01	0.26	1.38	1.88	0.73
	5-10	4.6	0.21	0.06	0.33	0.09	0.34	0.02	0.11	0.70	1.17	0.60
	10-15	4.6	0.24	0.04	0.21	0.07	0.31	0.02	0.02	0.56	0.91	0.62
	15-30	4.6	0.23	0.04	0.24	0.09	0.33	0.01	0.01	0.59	0.95	0.62
	30-45	4.8	0.21	0.02	0.24	0.10	0.17	0.01	<0.01	0.57	0.75	0.76
	45-60	5.4	0.22	0.02	0.29	0.11	0.02	<0.01	<0.01	0.64	0.66	0.97
I1	LFH	4.5										
	0-2	4.9	0.23	0.07	5.18	0.46	0.15	<0.01	0.50	5.93	6.59	0.90
	2-5	4.9	0.24	0.05	2.99	0.32	0.16	<0.01	0.32	3.59	4.08	0.88
	5-10	4.8	0.21	0.03	0.61	0.11	0.20	<0.01	0.07	0.96	1.24	0.78
	10-15	4.7	0.23	0.03	0.29	0.09	0.24	0.01	0.03	0.63	0.91	0.70
	15-30	4.7	0.21	0.02	0.24	0.08	0.22	0.01	<0.01	0.55	0.78	0.70
	30-45	4.9	0.19	0.02	0.23	0.05	0.11	0.01	<0.01	0.48	0.60	0.80
	45-60	5.4	0.18	0.01	0.17	0.03	0.02	<0.01	<0.01	0.39	0.41	0.94
J1	LFH	4.3										
	0-2	4.7	0.15	0.09	2.24	0.29	0.30	0.01	0.33	2.77	3.42	0.81
	2-5	4.9	0.14	0.05	1.14	0.15	0.25	<0.01	0.14	1.48	1.87	0.79
	5-10	4.8	0.17	0.02	0.38	0.08	0.23	<0.01	0.03	0.65	0.91	0.71
	10-15	4.9	0.17	0.03	0.43	0.08	0.15	<0.01	0.04	0.71	0.90	0.79
	15-30	4.7	0.19	0.02	0.21	0.05	0.26	0.01	0.01	0.46	0.74	0.62
	30-45	4.8	0.19	0.01	0.12	0.05	0.19	0.01	<0.01	0.36	0.56	0.65
	45-60	4.9	0.18	<0.01	0.08	0.02	0.11	<0.01	<0.01	0.27	0.39	0.71
K1	LFH	4.5										
	0-2	4.8	0.15	0.05	3.17	0.29	0.21	<0.01	0.31	3.67	4.19	0.87
	2-5	4.9	0.21	0.03	1.49	0.15	0.19	<0.01	0.15	1.88	2.22	0.85
	5-10	4.9	0.20	0.02	0.61	0.09	0.20	<0.01	0.04	0.92	1.16	0.79
	10-15	4.9	0.17	0.01	0.27	0.06	0.18	0.01	0.01	0.50	0.69	0.73
	15-30	4.8	0.17	0.01	0.25	0.08	0.18	0.01	<0.01	0.52	0.71	0.73
	30-45	4.8	0.19	0.01	0.14	0.05	0.13	<0.01	<0.01	0.39	0.51	0.75
	45-60	5.3	0.14	<0.01	0.07	0.02	0.04	<0.01	<0.01	0.23	0.27	0.85
L1	LFH	4.4										
	0-2	4.7	0.20	0.06	1.13	0.16	0.34	0.01	0.40	1.56	2.30	0.68
	2-5	4.8	0.19	0.02	0.57	0.09	0.21	<0.01	0.08	0.87	1.16	0.75
	5-10	4.8	0.20	0.01	0.29	0.06	0.21	0.01	0.01	0.56	0.79	0.71
	10-15	4.7	0.18	0.01	0.19	0.05	0.24	0.01	<0.01	0.43	0.68	0.63
	15-30	4.8	0.18	0.01	0.19	0.05	0.18	0.01	<0.01	0.43	0.62	0.69
	30-45	4.7	0.18	<0.01	0.07	0.02	0.16	0.01	<0.01	0.27	0.44	0.62
	45-60	5.3	0.17	<0.01	0.09	0.02	0.04	<0.01	<0.01	0.28	0.33	0.85

Table C6. Exchangeable Cations, Cation Exchange Capacity and Base Saturation at the Moose Lake West Sub-Site

Subplot	Layer (cm)	pH ($CaCl_2$)	Na	K	Ca	Mg	Al	Fe	Mn	Bases	C.E.C.	Base Saturation
			(cmol kg^{-1})									
A1	LFH	4.3										
	0-2	5.1	0.22	0.10	2.99	0.34	0.12	<0.01	0.24	3.65	4.01	0.91
	2-5	5.0	0.18	0.05	1.54	0.21	0.11	<0.01	0.11	1.98	2.20	0.90
	5-10	4.9	0.24	0.04	0.55	0.13	0.12	<0.01	0.03	0.95	1.11	0.86
	10-15	4.6	0.22	0.03	0.24	0.08	0.25	0.02	0.01	0.56	0.84	0.67
B1	LFH	3.8										
	0-2	4.6	0.20	0.08	2.60	0.23	0.33	<0.01	0.32	3.10	3.76	0.83
	2-5	4.6	0.22	0.04	0.74	0.10	0.29	<0.01	0.12	1.10	1.50	0.73
	5-10	4.5	0.20	0.02	0.26	0.05	0.33	<0.01	0.04	0.52	0.89	0.59
	10-15	4.6	0.18	0.01	0.13	0.03	0.24	0.01	<0.01	0.35	0.60	0.58
C1	LFH	4.0										
	0-2	4.8	0.18	0.07	2.19	0.21	0.29	<0.01	0.22	2.65	3.16	0.84
	2-5	4.8	0.20	0.04	1.31	0.14	0.23	<0.01	0.13	1.69	2.05	0.82
	5-10	4.8	0.20	0.02	0.43	0.09	0.20	0.01	0.03	0.75	0.98	0.76
	10-15	4.8	0.22	0.03	0.38	0.09	0.16	0.01	0.01	0.72	0.91	0.79
D1	LFH	3.9										
	0-2	4.4	0.21	0.06	1.98	0.19	0.63	<0.01	0.46	2.44	3.52	0.69
	2-5	4.8	0.20	0.03	1.55	0.16	0.25	<0.01	0.14	1.94	2.33	0.83
	5-10	4.9	0.18	0.02	0.46	0.08	0.16	<0.01	0.03	0.74	0.93	0.80
	10-15	4.9	0.22	0.02	0.37	0.09	0.15	<0.01	0.01	0.70	0.86	0.81
E1	LFH	4.6										
	0-2	4.5	0.21	0.06	2.95	0.27	0.45	<0.01	0.53	3.50	4.47	0.78
	2-5	4.9	0.23	0.04	2.67	0.21	0.17	<0.01	0.21	3.14	3.52	0.89
	5-10	4.8	0.24	0.03	0.69	0.09	0.16	<0.01	0.07	1.05	1.28	0.82
	10-15	4.9	0.22	0.03	0.43	0.07	0.12	<0.01	0.03	0.75	0.90	0.83
F1	LFH	3.9										
	0-2	4.6	0.21	0.06	1.33	0.13	0.35	<0.01	0.34	1.73	2.42	0.71
	2-5	5.0	0.20	0.05	0.91	0.10	0.10	<0.01	0.10	1.26	1.46	0.86
	5-10	4.9	0.22	0.04	0.41	0.07	0.08	<0.01	0.02	0.74	0.85	0.88
	10-15	4.7	0.22	0.03	0.26	0.06	0.14	0.01	<0.01	0.58	0.73	0.79
G1	LFH	4.2										
	0-2	4.7	0.21	0.07	2.11	0.19	0.31	<0.01	0.27	2.57	3.15	0.82
	2-5	4.9	0.25	0.04	1.94	0.16	0.15	<0.01	0.17	2.39	2.71	0.88
	5-10	5.0	0.21	0.03	0.64	0.08	0.09	<0.01	0.05	0.96	1.10	0.87
	10-15	4.7	0.22	0.03	0.30	0.06	0.18	0.01	0.01	0.60	0.80	0.75
H1	LFH	4.2										
	0-2	4.7	0.21	0.10	2.46	0.26	0.30	<0.01	0.28	3.03	3.61	0.84
	2-5	4.8	0.25	0.05	1.42	0.18	0.25	<0.01	0.09	1.89	2.23	0.85
	5-10	4.9	0.25	0.04	0.71	0.13	0.17	<0.01	0.04	1.13	1.34	0.85
	10-15	4.9	0.21	0.03	0.39	0.09	0.14	0.01	0.01	0.72	0.89	0.81
I1	LFH	4.0										
	0-2	4.7	0.22	0.07	1.42	0.18	0.22	<0.01	0.20	1.89	2.31	0.82
	2-5	5.1	0.21	0.06	0.94	0.15	0.08	<0.01	0.06	1.36	1.49	0.91
	5-10	4.8	0.23	0.05	0.50	0.12	0.15	0.01	0.02	0.90	1.08	0.84
	10-15	4.8	0.23	0.03	0.28	0.08	0.15	0.01	<0.01	0.61	0.77	0.79

Table C6. Exchangeable Cations, Cation Exchange Capacity and Base Saturation at the Moose Lake West Sub-Site (concluded)

Subplot	Layer (cm)	pH ($CaCl_2$)	Na	K	Ca	Mg	Al	Fe	Mn	Bases	C.E.C.	Base Saturation
			(cmol kg^{-1})									
J1	LFH	4.0										
	0-2	4.6	0.22	0.04	2.32	0.12	0.50	<0.01	0.45	2.69	3.64	0.74
	2-5	4.9	0.22	0.02	0.83	0.07	0.13	<0.01	0.07	1.13	1.34	0.85
	5-10	4.9	0.24	0.02	0.56	0.06	0.10	<0.01	0.02	0.89	1.01	0.88
	10-15	4.9	0.20	0.02	0.44	0.06	0.10	0.01	<0.01	0.72	0.82	0.87
K1	LFH	4.0										
	0-2	4.8	0.23	0.07	4.37	0.34	0.32	0.01	0.51	5.01	5.85	0.86
	2-5	5.4	0.21	0.04	3.59	0.29	0.02	<0.01	0.14	4.13	4.29	0.96
	5-10	5.1	0.22	0.03	0.75	0.12	0.05	<0.01	0.05	1.13	1.23	0.92
	10-15	5.1	0.24	0.03	0.65	0.11	0.06	<0.01	0.02	1.04	1.12	0.93
L1	LFH	4.0										
	0-2	4.8	0.20	0.04	1.95	0.17	0.20	<0.01	0.23	2.35	2.78	0.84
	2-5	5.1	0.21	0.03	1.48	0.14	0.08	<0.01	0.10	1.85	2.04	0.91
	5-10	5.0	0.23	0.02	0.78	0.12	0.09	<0.01	0.03	1.15	1.27	0.91
	10-15	4.9	0.23	0.02	0.57	0.09	0.08	0.01	<0.01	0.91	1.00	0.91

Table C7. Nutrients and Texture in Pedogenic Horizons of the Moose Lake East and West Monitoring Sub-Sites

Sub-Site	Horizon	Depth (cm)	Plant Avail. (NO_3+NO_2)-N (mg kg^{-1})	Plant Avail. NH_4-N (mg kg^{-1})	Plant Avail. N (mg kg^{-1})	Plant Avail. P (mg kg^{-1})	Sand (%)	Silt (%)	Clay (%)
West	LFH	2-0	2.5	11.5	14.0	42.8			
	Ahe	0-2	0.4	2.4	2.9	15.1	94	4	2
	Ae1	2-4	0.3	1.0	1.3	10.1	93	4	3
	Ae2	4-8	0.4	0.3	0.7	15.1	93	4	3
	AB	8-15	0.3	0.4	0.6	36.2	94	2	3
	Bm1	15-30					94	3	3
	Bm2	30-80					95	2	2
	Bm3	80-100					98	0	2
East	LFH	2-0	2.9	19.1	22.0	33.7			
	Ahe	0-4	0.2	1.3	1.5	3.4	91	5	3
	Ae	4-9	0.2	0.5	0.7	10.3	92	5	3
	AB	9-17	0.4	0.3	0.7	22.2	91	5	4
	Bm1	17-52	0.4	0.1	0.5	66.6	92	4	3
	Bm2	52-85					96	2	2
	Bm3	85-100					98	0	2

APPENDIX D

MOOSE LAKE LONG TERM ACID DEPOSITION MONITORING SITE PHOTOGRAPHS

Photo D1. Soil Profile at Moose Lake East Sub-Site

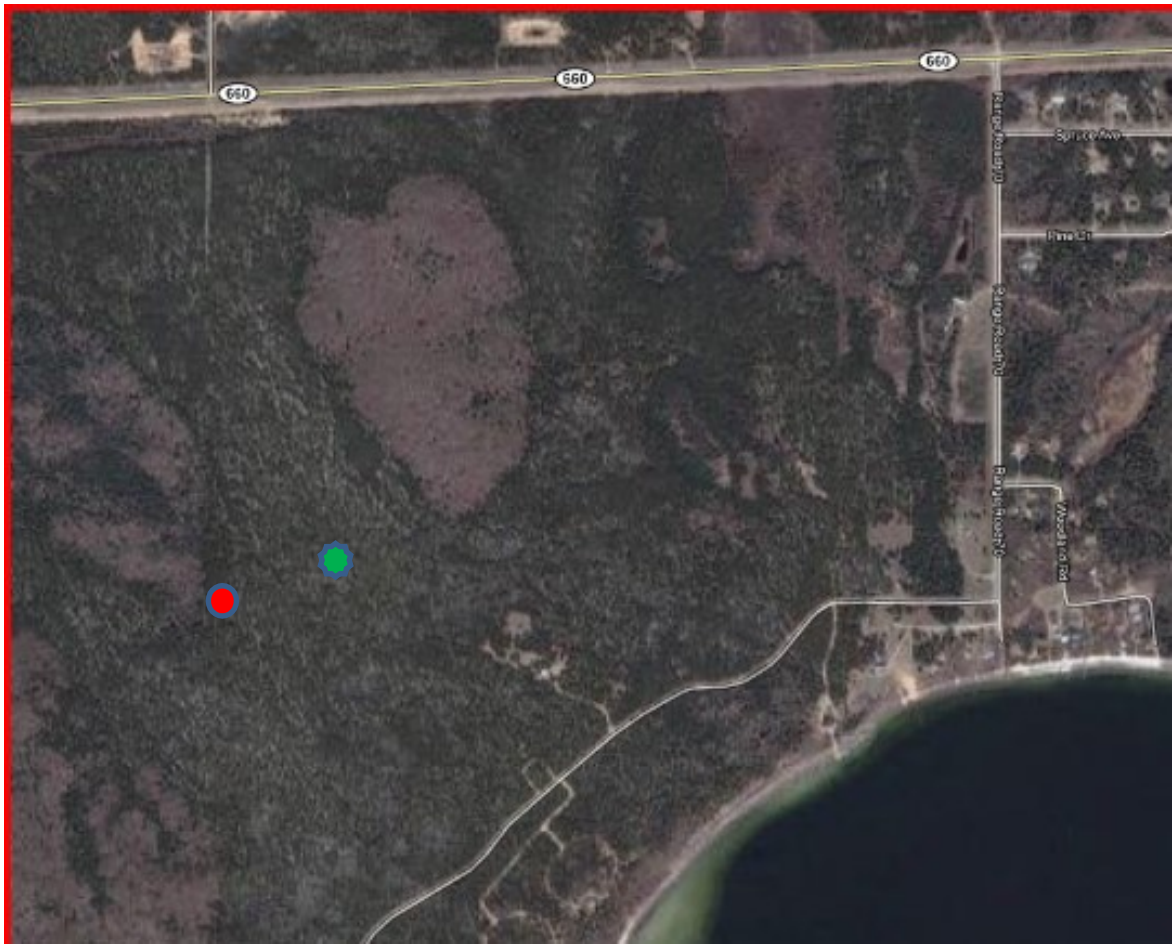
Photo D2. Surface Soil at Moose Lake East Sub-Site

Photo D3. Jack Pine Forest Stand at Moose Lake Monitoring Site

Photo D4. Soil Profile at Moose Lake West Sub-Site

APPENDIX E

LOCATION OF SOIL MONITORING SUB-SITES IN MOOSE LAKE PROVINCIAL PARK



Map 1. Location of soil monitoring sites within Moose Lake Provincial Park

Green – East Sub-Site

Red – West Sub-site

APPENDIX F

DESCRIPTION OF THE ARC SOIL ACIDIFICATION MODEL

INTRODUCTION

The ARC model simulates mineral soil chemical processes directly related to acidity and acidification of soils, and predicts the associated soil properties of pH, base saturation, solution Al^{3+} concentration and base cation to aluminum (BC:Al) ratio. The ARC model is described in detail in Turchenek et al. (1993), Abboud and Turchenek (1990) and Abboud et al. (2002). This model is adapted from the Bloom and Grigal (1985) model, with modifications for calculations of acid inputs and acidification processes, method of output of model results, and inclusion of calculations for base cation to aluminum (BC:Al) ratio. These are described in greater detail in the following sections.

DATA FOR CRITICAL LOAD DETERMINATIONS

The model requires climatic, soil and acid input data with a provision for varying time period for exposure and a varying time increment for reporting simulation results.

SOIL DATA INPUTS

Soil data inputs for the ARC model are as follows:

pH - by the water paste method; if the pH data were reported in a $CaCl_2$ solution (1:2), then the following equations (developed for mineral soils from a correlation of pH values using data from Pauls et al. (1996) were used to transform into a water paste pH:

for LFH horizons: $pH(H_2O) = 0.96\ pH(CaCl_2) + 0.55$ $R^2 = 0.989$, n= 65 samples (1)
for mineral horizons: $pH(H_2O) = 0.94\ pH(CaCl_2) + 0.72$ $R^2 = 0.984$, n= 130 samples (2)

Cation exchange capacity and exchangeable bases - by the ammonium acetate extraction method.

Partial pressure of CO_2 - assumed to be 0.005 atmosphere.

Activity coefficients of monovalent, divalent and trivalent ions - activity coefficients for each modelled soil horizon were calculated from the mean values for individual members of that series.
The activity coefficients (γ_i) were calculated using the Davies equation (Lindsay 1979).

$$\text{Log}\ \gamma_i = -AZ_i^2\ [\{I/(1+I^{0.5})\} - 0.3\ I] \quad (3)$$

Where A = 0.509 for water, Z is ion valence and I is ionic strength in moles L^{-1}.

The ionic strengths (I) were calculated from the electrical conductivities of the saturated paste extracts (Lindsay 1979).

$$I = 0.013\ EC \qquad (4)$$

where I is in moles L^{-1} and electrical conductivity (EC) of the saturated paste extracts in dS m^{-1}.

Initial weathering rates (kmol ha^{-1} yr^{-1}) for mineral soils - these varied with soil texture as discussed in Abboud et al. (2002) and shown in Table 11 below.

Table 1. **Weathering Rates Suggested for Modelling Soils of Different Textures[z]**

Soil Texture	Weathering Rate in 25 cm Surface Soil Layer (kmol ha^{-1} yr^{-1})
Sand	0.07
Loamy Sand	0.10
Sandy Loam	0.15
Loam, Silt Loam	0.25
Clay Loam, Silty Clay Loam, Sandy Clay Loam	0.50
Clay, Silty Clay	1.00

[z] From Abboud et al. (2002)

The input data for soil pH, CEC, and sum of bases were weighted mean values for the whole LFH layer (usually less than 25 cm) and the top 25 cm of air-dried mineral soil. The thickness of the soil horizons and the bulk density were applied in computing the means. The calculations were made as previously documented by Turchenek et al. (1993) and Abboud and Turchenek (1990).

ACID DEPOSITION DATA

The ARC model was applied using a range of PAI values to enable determination of critical loads. The loads used in this modelling exercise were 0.1, 0.2, 0.3, 0.5, 0.7 and 1.0 kmol H^+ ha^{-1} yr^{-1}. These values were recommended for model application by the Alberta Environment staff and cover existing PAI values and potential extreme future values encountered in the study area. The PAI values account for both wet and dry forms of acid deposition.

CLIMATE DATA

Data for precipitation and precipitation surplus as described in Abboud et al. (2002) were applied in the model. Previous applications of the model used a ‘precipitation minus potential evapotranspiration’ term to determine the amount of precipitation water that percolates beyond the 0.25 cm layer. This calculation results in a negative value for climates characteristic of central and southern Alberta. The precipitation surplus concept (Abboud et al., 2002) provides a more realistic approximation of the amount of water that is actually evaporated or transpired by accounting for episodes of high precipitation and deep moisture percolation.

TIME

The model can be executed for any specified length of time, and simulation results can be reported for any specified increment of time within the total simulation period. Predictive soil effects data are of greatest interest in terms of the immediate and near future; i.e., the period during which pollutant emissions can be forecast. It is also of interest, from a soil development point of view, to determine soil responses to acid deposition over very long periods of time since changes in soils occur slowly. Three hundred years was selected for the simulation period. This time frame would not obscure the data for interpretation of short-term effects, yet would provide a longer term view of soil changes.

A one-year increment of time between reported values in the simulations was selected. This increment assured that sufficient data points were obtained for determining the trends of pH, base saturation, Al^{3+} levels and BC:Al over time.

EFFECT OF WEATHERING

The weathering (r) of soil minerals is estimated in the model by the function,

$$r = r_o 10^{-0.5(pH-pHo)} \quad (13)$$

where r_o and pH_o are the initial conditions (Abboud et al., 2002). The r_o value is based on soil texture as shown in Table 11, and a pH_o of 5.0 was applied in the equation.

COMPUTATIONS

The loss of bases is calculated on an annual basis from,

$$S = I - A - C - W \quad (14)$$

where S is the sum of bases lost, I is the effective acidity in the precipitation plus dryfall (the PAI), A is the acid leached out of the top 25 cm of soil, C is the decrease in bicarbonate weathering due to the decrease in soil solution pH, and W is the base contribution due to weathering. At the end of each year of simulation, a new sum of bases is calculated from the sum for the previous year. New values for pH, Al^{3+} concentration and BC:Al ratio are also calculated from equations relating pH with base saturation, pH with solution Al^{3+} concentration and pH with BC:Al ratio. A linear function describes the relationship between pH and base saturation percentage of the soil. The functions have been determined previously for mineral soil orders and reported by Abboud and Turchenek (1990) and for LFH layers by Abboud et al. (2002).

ADJUSTMENTS TO THE ARC MODEL

Several changes were made to the earlier ARC model when applied in the Oil Sands area (Abboud et al, 2002) and to the Edmonton West grid cell (Abboud and Turchenek, 2007).

These included the addition of a new equation describing Al solubility in mineral soils and a new module to calculate the changes in mineral soil BC:Al ratios with changes in soil pH.

Al Solubility

The solubility of Al in the ARC model was assumed to follow the empirical model of Bloom and Grigal (1985), derived from Minnesota soils data. Recent changes to the ARC model, based on data from southeastern Alberta soils, resulted in the use of a more soluble form of gibbsite as an Al controlling mineral (Turchenek and Abboud, 2001). During our modeling of soil chemistry in the Oil Sands area, the solubility of Al in mineral horizons was further evaluated using archived data from a joint Syncrude-ARC project (Pauls et al 1996). The relationship between soluble Al and pH(H_2O) derived from data in these projects was applied in the model to determine critical loads of soils.

Figure 1 shows the solubility relationship for mineral soils in the upper 25 cm in the Oil Sands region. These covered several soil orders in the area. A linear relationship is evident with a significant R^2 term. This equation is similar in form to the Bloom and Grigal (1985) and Turchenek and Abboud (2001) equations and seem to imply a strong role for a mineral form controlling Al solubility. The pH coefficient in the equation (2.66) is close to the theoretical 3 required for gibbsite to be a controlling mineral, and the constant term (8.10) is close to the theoretical 8 assumed for the solubility product of gibbsite. Thus, the possibility of gibbsite controlling Al solubility in these soils is strong with the likelihood of some influence from the organic matter present in the Ah horizons and/or leaching from the LFH layer.

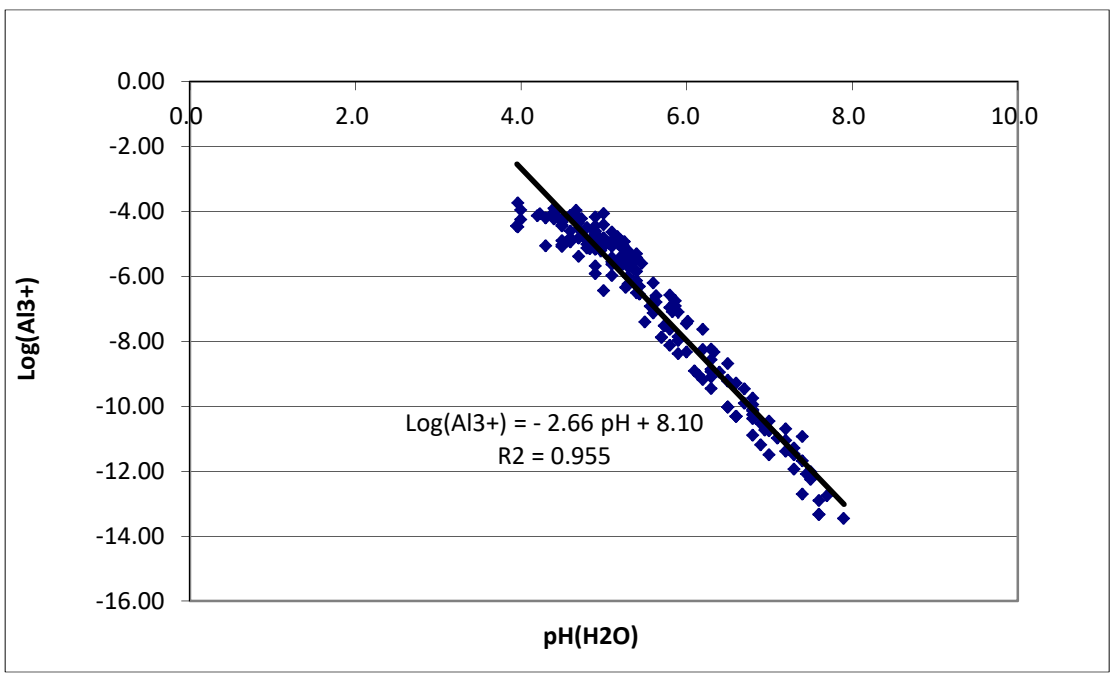


Figure 1. **Al Solubility in Mineral Horizons**

The pH-Al solubility relationship was similarly derived for the LFH layers of soils. In summary, the equations applied in modelling the soils of the Edmonton East grid cell were:

for LFH horizons: $pH(H_2O) = -2.72\ pH(H_2O) + 8.03$ $R^2 = 0.923$, n= 65 samples (14)
for 0-25 cm layer: $pH(H_2O) = 2.66\ pH(H_2O) + 8.10$ $R^2 = 0.955$, n= 130 samples (15)

BC:Al Ratios

The relationship between BC:Al ratios and pH for mineral soil layers was also derived from examination of soils in the oil sands region, as described in Abboud et al. (2002). An exponential relationship between BC:Al ratios and pH was observed as shown in Figure 2. This equation shows scatter that is likely due to the diverse nature of the soil orders and their mineralogy and texture, and to the influence of weathering and exchange/adsorption processes to both organic and mineral surfaces.

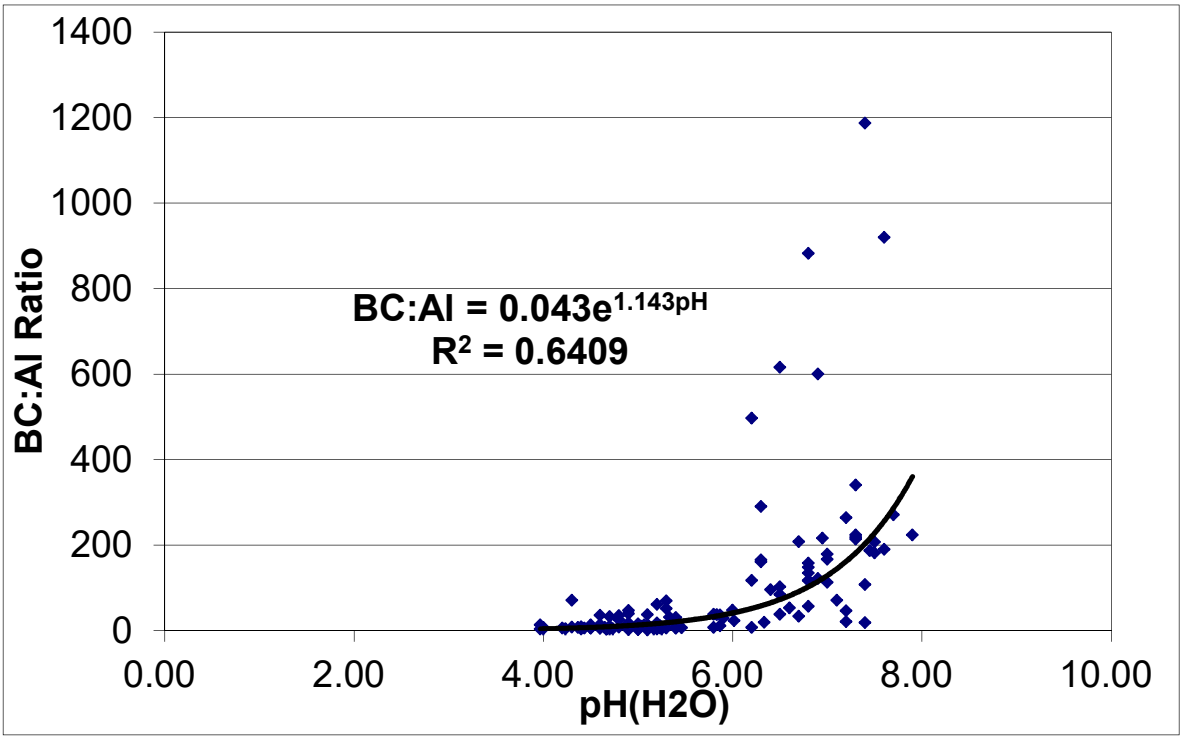


Figure 2. **BC:Al Ratio in Mineral Horizons**

The pH-Al solubility relationship was derived for both the mineral and the LFH layers of soils. The equations applied in modelling the soils of the Edmonton East grid cell were:

for LFH horizons: $BC:Al\ Ratio = 0.12e^{1.40pH(H2O)}$ $R^2 = 0.576$, n= 65 samples (16)
for 0-25 cm layer: $BC:Al\ Ratio = 0.043e^{1.14pH(H2O)}$ $R^2 = 0.641$, n= 65 samples (17)

MODEL EXECUTION AND DATA OUTPUTS

Computations were made for changes in soil properties on an annual basis. Output data for each time interval included: (1) year; (2) pH of soil; (3) acid input; (4) acid output; (5) protonation; (6) change in pH; (7) base saturation; (8) sum of base cations; (9) base cations lost; (10) Al^{3+} concentration in soil solution, and (11) BC:Al ratio.

MODEL OUTPUT

The outputs of major interest are the changing values of soil pH, base saturation, and BC:Al during the time period selected. Model data were transferred to EXCEL spreadsheets to facilitate data analysis in terms of critical loads. Simulations were conducted with a desktop computer using the program RS1. Table 13 shows the model output information generated in a table.

Table 2. **Example of Output from the ARC Model Simulating Processes.**

Mineral Soil Layer											
Time (Years)	pH (H2O)	Sol. Al (M)	Base Saturation	BC:Al Ratio	Acid In	Acid Out	Weathering	Protonat.	Bases Lost	Exch. Bases	Soil
					(kmol ha^{-1} yr^{-1})						
0	5.5	5.38E-07	0.73	60	*1.0*	0.0	0.00E+00	0.00E+00	0.0	370.4	Site 1
1	5.5	5.38E-07	0.73	60	*1.0*	0.0	0.00E+00	0.00E+00	1.0	369.4	Site 1
2	5.5	5.27E-07	0.72	58	1.0	0.0	1.30E-04	4.98E-04	1.0	368.4	Site 1
3	5.4	5.16E-07	0.71	55	1.0	0.0	2.60E-04	9.91E-04	1.0	367.4	Site 1