Site-Specific Critical Loads of Acid Deposition on Soils in the Edmonton 83H West Map Sheet, Alberta

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EXECUTIVE SUMMARY

The Alberta Acid Deposition Management Framework stipulates that Alberta Environment is responsible for conducting an evaluation of the acid deposition monitoring data in the province, as well as conducting an evaluation of receptor sensitivity. The present study addresses the latter of these two requirements with respect to potentially acid sensitive soils in the Edmonton NTS 83H West Half map sheet. This map sheet extends from 113°W longitude to 114°W longitude, and from 53°N latitude to 54°N latitude.

The objective of this receptor sensitivity study is to provide an estimate of the critical load for the soil types and water bodies in the Edmonton West study area. On the basis of these critical loads estimates, a recommendation regarding the sensitivity of the study area as a whole is provided. The categories Sensitive, Moderate Sensitivity, and Low Sensitivity are applied herein to soils, where the term Sensitive is equivalent to 'High Sensitivity' and Moderate Sensitivity is equivalent to 'Medium Sensitivity' used in some publications.

This area is herein referred to as the Edmonton West grid cell. The areal extent of the study area is approximately 7,376 square kilometres.

Three sensitivity assessment and modelling approaches were applied in examination of the soils of the Edmonton West grid cell. Critical load assessment by the empirical method referred to as the Skokloster approach resulted in a wide range of critical loads for soils ranging in texture from sands to clays. The method is not specifically applied to soil series, but to textural groupings of soils. This approach indicated critical loads as follows: very coarse textured soils - 0.2-0.5 kmol ha^{-1} yr^{-1}; moderately coarse textured soils - 0.5-1.0 kmol ha^{-1} yr^{-1}; medium to moderately fine textured soils - 1.0-2.0 kmol ha^{-1} yr^{-1}; fine textured soils >2.0 kmol ha^{-1} yr^{-1}.

The Steady State Mass Balance (SSMB) approach treats the soil as a single compartment to a 0.75 m depth. The SSMB assessment resulted in relatively high critical loads, as follows: very coarse textured soils - 0.6-0.7 kmol ha^{-1} yr^{-1}; moderately coarse to medium textured soils - 1.0-1.6 kmol ha^{-1} yr^{-1}; medium to moderately fine textured soils - 2.9 kmol ha^{-1} yr^{-1}; and fine textured soils - 5.6 kmol ha^{-1} yr^{-1}.

The ARC model utilizes the buffering capacity of soils due to cation exchange as well as to weathering, and assesses changes in soil chemistry over time. The modelling results were expressed as critical loads, which were subsequently applied in deriving sensitivity classes of soils. Two soil series (Primula and Nestow) were determined to be Moderately Sensitive to acid deposition. These same soil series were determined to be potentially Highly Sensitive in a similar study of the Edmonton East Grid Cell, and it is therefore considered that some areas of Highly Sensitive soils occur in the Edmonton West Grid Cell as well. Both these soils are Brunisols developed on very coarse (sandy) materials. Soils of coarse to moderately coarse texture (sand to loamy sand; Helliwell and Mundare soil series) showed Moderate Sensitivity in some soil samples, and Low Sensitivity in others. The differences in sensitivity within the same soil series are thought to be related to the amount of organic matter in the A horizon. The north part of the Edmonton West grid cell is located in a transition area between Chernozemic soils to the south and forested Brunisolic and Luvisolic soils to the north. It is likely that those soils with

relatively low amounts of organic matter are the most Highly Sensitive to acid deposition. All other soils in the grid cell, being of finer texture and having A horizons rich in organic matter, were rated based on the basis of previous studies as being of Low Sensitivity.

Acidification sensitivity categories of soils examined in this study were compared to sensitivity classes in mapping carried out by Holowaychuk and Fessenden (1987). In the Holowaychuk-Fessenden mapping, the Cooking Lake moraine (i.e., the Islet Upland Land System) was identified as having soils with potentially Moderate Sensitivity, and the Graminia Plain was categorized as being of High Sensitivity. All other soils were categorized as being of Low Sensitivity to acidification. The ARC modelling results suggest that the predominantly Luvisolic soils of the Islet Upland have Low Sensitivity to acidification. Other differences between the Holowaychuk-Fessenden mapping and the ARC model results pertain to the sandy Brunisolic soils of areas such as Redwater Plain, Eldorena Plain and Halfway Lake Dunefield, in the north part of the Edmonton West grid cell. These are mapped as being of Low Sensitivity in the Holowaychuk-Fessenden map. In the current study, some of the soils that characterize these Land Systems were indicated as being Sensitive or of Moderate Sensitivity according to the ARC model.

A map depicting the Land Systems, land cover and soil sensitivity to acid inputs in the Edmonton West map sheet was developed based on the soil sensitivity assessment and on land cover information. Proportions of soil series within Land Systems were estimated from information provided in AGRASID, and from this, the proportions of soils in Moderate to Sensitive (Nestow and Primula), Moderate to Low (Helliwell and Mundare), and Low (all other soils) acidification sensitivity categories were derived. The assignment of Sensitive, Moderate and Low Sensitivity categories was applied only to lands classified as having grassland, tree or shrub cover, on the basis of land use mapping by the Prairie Farm Rehabilitation Administration in 1993-1995. Wetlands, including peatlands, were considered to be of Low Sensitivity. Cultivated soils were not rated, nor were lands categorized as ‘Other Lands’. Two sensitivity map units were developed: Low Sensitivity and Low-Moderate-Sensitive Mix.

Portions of three land systems in the Edmonton 83H West Half grid cell were characterized as having a component of Sensitive and Moderately Sensitive soils. These are the Eldorena Plain, Redwater Plain, and Halfway Lake Dunefield. Other Land Systems likely have small components of Sensitive and Moderately Sensitive soils, but of too low extent to enable mapping at the scale applied in this assessment. Sensitive soils account for 0.65% and Moderately Sensitive soils account for 2.3% of the entire grid cell area. As defined in the Acid Deposition Management Framework (Clean Air Strategic Alliance and Alberta Environment 1999), this finding does not support the assignment of this grid cell to a Sensitive or Moderate Sensitivity rating.

1.0 INTRODUCTION

The Acid Deposition Management Framework for the long-term, provincial management of acid deposition was implemented in December, 1999 (Clean Air Strategic Alliance and Alberta Environment 1999). This framework is based upon the current understanding of the levels of acid deposition and the sensitivity of soil and water receptors in the province. Development of this framework included significant stakeholder consultation through Alberta's Clean Air Strategic Alliance.

Critical loads are the foundation of the framework. A critical load is a property of the receptor (soil, water), and is defined as the amount of acid input that can be received by the receptor that will not cause chemical changes leading to long-term harmful change to the receptor.

The province of Alberta is divided into grid cells measuring 1° latitude x 1° longitude, and each grid cell is categorized as being Sensitive, Moderately Sensitive or of Low Sensitivity to acid deposition based upon soil and water sensitivity databases. A Sensitive cell is defined as a cell within which 5% or more of the area is categorized as being Sensitive, and to such cells, a critical load of 0.25 kmol H^+ ha^{-1} yr^{-1} is applied. A Moderately Sensitive cell is defined as a cell within which less than 5% of the area is categorized as Sensitive, but where the total of Sensitive and Moderately Sensitive areas equals or exceeds 5% of the cell area. To these Moderately Sensitive cells, a critical load of 0.50 kmol H^+ ha^{-1} yr^{-1} is applied. The remainder of the grid cells are classified as being of Low Sensitivity to acid deposition and are assigned a critical load of 1.00 kmol H^+ ha^{-1} yr^{-1}.

In addition to critical loads, grid cells have also been assigned target and monitoring loads. Target loads are based upon the critical loads, with the added proviso that target loads be an expression of society's values – in the Alberta framework, target loads are set at 90% of the critical loads (0.22, 0.45 and 0.90 kmol H^+ ha^{-1} yr^{-1} for the three sensitivity classes). These target loads are also the environmental objectives as defined in provincial environmental legislation. By establishing target loads below the critical loads, provincial stakeholders and Alberta Environment have established a system of preventing an increase in deposition to the level believed harmful (the critical load). An exceedance of a target load will initiate processes to reduce emissions such that deposition in the exceedance cell is reduced to or below the target load for that cell.

Monitoring loads are also assigned to the sensitivity classes; these are set at 70% of the critical loads. Exceedance of this load initiates studies of receptor sensitivity and monitoring of deposition – the results of such studies are used to revise the initial assignments of cell sensitivity (and therefore the assigned numerical loads). If the studies confirm model prediction and sensitivity, the cell is watched more closely to ensure that deposition does not increase to the point of a target load exceedance.

The REgional Lagrangian Acid Deposition (RELAD) model (Cheng and Angle 1996; Cheng et al. 1995, 1997) has been used to estimate the amount of acid deposition in Alberta. There are no grid cells currently receiving acid deposition in excess of their assigned critical or target loads. However, soils in some parts of the province may be sensitive to levels of acid deposition less than the monitoring load (0.17 kmol H^+ ha^{-1} yr^{-1}) for sensitive ecosystems.

1.1 OBJECTIVES

As stipulated in the Alberta Acid Deposition Management Framework, Alberta Environment is responsible for conducting an evaluation of the acid deposition monitoring data in the province, as well as conducting an evaluation of receptor sensitivity. The present study addresses the latter of these two requirements for the Edmonton West map sheet (NTS 83H West Half).

The objective of this receptor sensitivity study is to provide an estimate of the critical load for the soil types and water bodies present in the Edmonton West study area. On the basis of these critical loads estimates, a recommendation regarding the sensitivity of the study area as a whole is provided.

1.2 THE EDMONTON WEST GRID CELL STUDY AREA

The study area in this project is the West Half of Map Sheet 83H, located in central Alberta. The boundaries are:

- 113°W longitude – east side
- 53°N latitude – south side
- 114°W longitude – west side, and
- 54°N latitude – north side

This area is herein referred to as the Edmonton West study area. All of the City of Edmonton is located within this area. Landmarks and/or towns located at or near the four corners of the grid cell are Pigeon Lake in the southwest, Busby in the northwest, Val Soucy/Redwater River in the northeast, and Bittern Lake in the southeast. Expected areas with Sensitive and Moderate Sensitive soils are the Brunisolic soils in the Devon and Redwater sandy areas, Chernozemic soils in the Peace Hills sandy area in the Millet/Wetaskiwin area, and Luvisolic soils developed on glacial till in the Cooking Lake, Pigeon Lake and Calahoo areas. The areal extent of the study area is approximately 7,376 square kilometres.

1.3 APPROACH TO CRITICAL LOAD DETERMINATION

In order to determine the appropriate critical load for the study area, it is necessary to determine the soil types and land uses, to chemically analyze samples collected from the various soil types and water bodies present within the study area, and to estimate the site-specific critical load for each sample using a mathematical receptor model. The approach follows the critical loads determination for the Provost-Esther area reported by Turchenek and Abboud (2001) and for the Edmonton West area (Abboud and Turchenek, 2009).

Critical loads are essentially a measure of the buffering capacity of the system. The buffering capacity can be altered by processes other than deposition of acidic substances from the atmosphere. Agricultural and range management practices may have a large impact on soil chemistry and, therefore, make it difficult to assess the relatively small impacts of acid deposition on soils used for agriculture (crop production) or for livestock grazing. For this reason, the emphasis of this project was on soil and water systems that are not, or are minimally, affected by intensive farming and/or range management practices.

The study included a number of components as follows:

- Compilation of available data on soil types, land uses and aquatic systems within the defined area, and generate a map showing this information.
- Collect samples of soil and water to determine the critical load for each soil type/land use/aquatic unit.
- Conduct laboratory analysis of the soil and water samples to obtain model input data.
- Using the ARC and Steady State Mass Balance models, and the laboratory data, estimate the critical load for each sample. Provide an estimate of the critical load for each soil type/land use/aquatic unit, and express in terms of acidification sensitivity categories.
- Generate a map showing the soil acidification sensitivity categories.

2.0 CRITICAL LOADS AND APPROACHES TO THEIR DERIVATION

2.1 CRITICAL LOAD DEFINITION

The term ‘critical load’ is defined in Alberta as ‘the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems’ (Clean Air Strategic Alliance and Alberta Environment 1999). The critical load represents the level of sustained deposition of a substance that will not cause long-term harmful change to an ecosystem. It is thus a property of the ecosystem. The concept of critical loads has been adopted in various countries, especially those of the European Union, as a method for development and implementation of control strategies for air pollutants. Critical load approaches and mapping programs are most extensively developed in Europe, and are described in publications by Downing et al. (1993), Task Force on Mapping (1996), and Posch et al. (1995 1997, 2003). The applicability of critical loads in Alberta has been discussed in Maynard (1996) and Schindler (1996). Based upon these two reports, critical loads have become the foundation of Alberta’s Acid Deposition Management Framework (Clean Air Strategic Alliance and Alberta Environment 1999).

2.2 CRITICAL CHEMICAL CRITERIA AND CRITICAL CHEMICAL VALUES

The process to establish critical loads depends upon the selection of critical chemical criteria. For soils, these criteria are chemical parameters such as pH, base saturation, aluminum (Al) concentration in soil solution, base cation (BC) concentration in soil solution, and the ratio of BC to Al concentrations. Any or all of these may be selected, and critical loads based upon the inputs chosen may be derived. For water the process is similar, with acid neutralizing capacity (ANC) being the most common critical chemical criterion used.

For each critical chemical criterion, critical chemical values must be established (Sverdrup et al. 1990). Critical chemical values are frequently referred to as thresholds. The criteria selected for this study and the rationale for each selection, and the critical chemical values (thresholds) assigned to each criterion, are discussed below.

2.2.1 Soil pH

Soil pH is defined as the pH of a solution in equilibrium with soil. It is determined by means of a glass, quinhydrone, or other suitable electrode or 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 measured by insertion of an 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 a glass 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 need for *in situ* extraction equipment and due to the time required to obtain sample for the pH measurement.

The closest estimates of the pH of solution *in situ*, particularly for soils having low soluble ion content, as reflected by low electrical conductivity are provided by pH(H_2O) and pH(solution) (Hendershot et al. 1993). However, accuracy and reproducibility by these methods are difficult to attain because of various factors that can affect the measurement, including soil:solution ratio, position of the measuring electrode, drying of soil, CO_2 concentration, and others. The value obtained may thus not reflect the actual pH of soil solution; however, close estimates of the pH in the root environment can be obtained by controlling some factors, particularly the soil:water ratio (e.g., 1:2 weight:volume).

The pH of soil sample suspended in 0.01 M $CaCl_2$ solution at a fixed soil:solution ratio is a commonly used method to characterize soil pH. 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.

Ulrich et al. (1984) suggested that a soil pH(H_2O) of 4.0 to 4.2 posed a high risk of damage to forest ecosystems, and that there was some risk at pH(H_2O) values greater than 4.2. Low soil pH is typical of forest soils, but is relatively uncommon in grassland soils. Chernozemic soil pH values are typically in the range of 5.6 to 7.7 (Turchenek et al. 1987). Soils in the range of pH(H_2O) 5.6 to 6.0 are sufficiently acidic to cause serious loss in yields of most crops in Alberta (Penney et al. 1977; Hoyt et al. 1981). Turchenek and Abboud (2001), in determining critical loads for the predominantly Chernozemic soils of the Esther area, suggested that the critical chemical value for pH (4.0 to 4.2) for forest soils is not appropriate for application to grassland soils. Furthermore, the typical range in Chernozemic soil pH values would also suggest that the forest soil criteria are not appropriate for Chernozemic soils under native grassland. Because pH values below 5.6 represent the lower limit of pH values associated with Chernozemic soils (and grassland soils in general), and a reduction in pH below 5.6 could trigger changes in microbiological and plant species composition, the critical chemical value for pH(H_2O) of pH 5.6 is applied. This is equivalent to a pH($CaCl_2$) of about 5.0.

2.2.2 Calcium to Aluminum and Base Cation to Aluminum Ratios

Different threshold levels of Al^{3+} related to plant health have been suggested (Bloom and Grigal 1985; Ulrich et al. 1984; Levine and Ciolkosz 1988); however, Cronan and Grigal (1995) indicated that although total concentration of Al in soil solution might appear to be the most straightforward index of potential Al toxicity to plants, this measure usually fails to be closely related to plant health. This may be due to the differential toxicity of the various Al species and to the ameliorative effects of other ions in solution. Reported Al toxicity thresholds for trees have a wide range, from <40 μmol L^{-1} to >3,000 μmol L^{-1}. However, toxicity has been shown within a much narrower range in terms of the Ca:Al molar ratio (range of 0.2 to 2.5), and risk thresholds are therefore indicated in terms of this latter measure.

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. The suggested threshold Ca:Al molar ratio of 1 is commonly applied in setting critical loads for forest soils in European countries (Warfvinge and Sverdrup 1992; de Vries 1993; Task Force on Modelling and Mapping 2004). Little information is available with respect to the significance of Ca:Al ratios in grassland soils, although the same critical chemical value (Ca:Al of 1) has been applied to various types of ecosystems in critical load determinations in Europe (Posch et al. 1997). 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.

Sverdrup and Warfvinge (1993) presented a data compilation from the literature showing response curves of growth of seedlings of various tree and ground vegetation species in relation to the BC:Al ratio. The BC:Al ratios at which growth of various grass species was negatively affected ranged widely from 0.3 to 300. Of the species listed, only Kentucky bluegrass (*Poa pratensis*), an introduced species, is found in Alberta grasslands. This species is listed as having a critical BC:Al ratio of 250. Some grasses of the same genus as those found in Alberta (*Festuca, Bromus, Agrostis*), and some *Carices*, have ratios ranging from 1 to 45. Only species of the *Poa* genus have BC:Al ratios of 250 or greater, while the maximum ratio for all other species is 45. Sensitivity of species of the *Festuca*, *Poa* and *Bromus* genus to pH and Al has also been found by Edmeades et al. (1991).

In the absence of research specific to grasslands in western Canada, it is difficult to select an appropriate BC:Al ratio that would be protective of all species. The ratio applied to forest soils of 1.0 appears to be low for grass species. The median value for the range of grasses reported by Sverdrup and Warfvinge (1993) is about 10. A critical value of 45 had previously been selected in a study of sensitivity of soils in the Provost-Esther grid cell (Turchenek and Abboud 2001). Most of the soils examined in the Edmonton West grid cell occur in the northern part of the study area where Chernozems are transitional to Brunisolic and Luvisolic, forested soils. A transitional BC:Al ratio might, therefore, be more appropriate for these soils. The grass species median range of 10 (Sverdrup and Warfvinge 1993) is thus suggested as the critical chemical value for Chernozemic soils in the Edmonton West grid cell. However, for purposes of comparison with this suggested critical chemical value for BC:Al, the examination of critical loads in this study includes derivations of critical loads using ratios of 1, 10, 45 and 250.

2.2.3 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'. Effective cation exchange capacity (CEC) 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;

$$\text{CEC} = \text{Ca+Mg+K+Na+Al+Fe+Mn+H (expressed as cmoles charge per kg)} \qquad (1)$$

$$\text{Base Sat \%} = \text{(Ca+Mg+K+Na)} \times 100 / \text{(Ca+Mg+K+Na+Al+Fe+Mn+H)} \qquad (2)$$

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 H^+ (McBride 1994).

The measurement of CEC and base saturation according to equations (1) and (2) rely on measurement of each of the individual cations. An independent measure of CEC can also be obtained. When unbuffered NH_4Cl, or other neutral salt solution, is passed through a soil sample, NH_4^+ displaces the exchangeable cations. The NH_4^+ on the exchange complex is then replaced by Na by passing a NaCl solution through the sample, and the amount of NH_4^+ is measured, the quantity of NH_4^+ being equal to the CEC. Base saturation is then calculated as:

$$\text{Base Sat \%} = \text{(Ca+Mg+K+Na)} \times 100 / \text{(CEC)} \qquad (3)$$

Base saturation can also be calculated from an independent estimate of the portion of the exchange attributable to acid cations (Al, Fe, Mn and H). This measure is referred to as the Exchangeable Titrateable Acidity (ETA). Base saturation is then calculated as:

$$\text{Base Sat \%} = \text{(Ca+Mg+K+Na)} \times 100 / \text{(Ca+Mg+K+Na)} + \text{ETA} \qquad (4)$$

All of the above approaches theoretically provide the same base saturation value, although they seldom do so in practice. Different methods are applied in different institutions and countries. The protocol of the UNECE International Cooperative Programme on Integrated Monitoring (UNECE Convention on Long-Range Transboundary Air Pollution 2006) applies methodology according to equation (4) above, although the other approaches are used in other programs (e.g., Miewes et al. 1986). Cation exchange capacity values applied in dynamic modelling of critical loads in Europe are based on measurement in a solution buffered at pH 6.5 (Task Force on Modelling and Mapping 2004). Thus, methodologies differ between monitoring and modelling applications, and it is important that the specific methods be specified.

For forest ecosystems, a threshold base saturation reduction to a level of 5% (a critical chemical value of 5% base saturation) was suggested by Ulrich et al. (1984), while a reduction to 15% was recommended as a threshold by Cronan and Grigal (1995) on the basis of work by Cronan and Schofield (1990). These threshold values refer to base saturation calculations based on 'effective cation exchange capacity'; that is, cations measured in an extract from a soil sample equilibrated with a neutral salt solution rather than a buffered solution (i.e., Equation 1). A base saturation value of 10%, based on neutral salt exchangeable cation determination, is commonly applied as a critical value in modelling of soil chemistry effects.

Low base saturation is a characteristic of forest soils, and forest soils typically have relatively low pH values. Grassland soils, however, are characterized by relatively high base saturation and pH values. Chernozemic soils are the most common grassland soils, with Solonetzic and Vertisolic soils being common associates. A Chernozemic 'A' horizon is diagnostic for the Chernozemic Order of soils in Canada (Soil Classification Working Group 1998). Among the criteria associated with a Chernozemic A horizon is a base saturation greater than 80% and dominance of exchangeable Ca^{2+} on the exchange complex (other criteria apply to Chernozemic soils, but they are not associated with acidification). This 80% base saturation level is based on measurement by the 'neutral salt' method.

On the Canadian Prairies there is a gradual change in the nature of surface soil horizons from grassland soils in the south to forested soils in the north, where leached (Ae) horizons become more prevalent. A leached Ae horizon is indicative of loss of base cations and decreased pH in this horizon. There is thus a relationship between vegetation and the type of surface soil, the implication being that vegetation changes as pH and base saturation decrease. Climate, however, is another major factor that prevents grasslands on the dry prairie from converting to forest vegetation if they become acidified. It might be hypothesized, however, that prairie vegetation assemblages would change in response to acidification, such that more acid tolerant species may become more prevalent. On this basis, therefore, a base saturation of 80% appears to be an applicable threshold limit for acidification of grassland soils.

As noted above, the 80% base saturation criterion for Chernozemic soils is based on measurement by the 'neutral salt' method, and an equivalent value based on a 'buffered' CEC measurement is not provided in the Canadian System of Soil Taxonomy (Soil Classification Working Group 1998). In 'Soil Taxonomy' (United States Natural Resources Conservation Service, 1999), the system of soil classification applied in the United States, a base saturation of at least 50%, determined by the ammonium acetate buffered method, is a criterion for definition of a mollic epipedon. The mollic epipedon is similar in definition to the Chernozemic A horizon, which is diagnostic of Chernozemic soils in the Canadian system of soil classification. Consequently, since the ARC model utilizes the base saturation based on a pH 7.0 buffered extraction procedure, a base saturation of 50% based on an ammonium acetate measurement of CEC could be adopted as a critical chemical value for Chernozemic soils. This is applied together with the pH(H_2O) criterion (Section 2.2.1) as an indicator of acidification effects in this report. Further discussion about application of base saturation to critical load determination is provided in Section 5.3.6.

2.2.4 Acid Neutralizing Capacity (ANC) of Aquatic Systems

Acid neutralizing capacity (ANC) is the ability of a solution to neutralize inputs of strong acid to a pre-selected equivalence. It is calculated as:

$$[ANC] = [BC] – [AN] = [HCO_3^-] = [A^-] – [H^+] – [Al^{n+}] \tag{5}$$

where, [BC] is the base cation concentration, [AN] is the strong acid anion concentration, $[HCO^{3-}]$ is the bicarbonate concentration, $[A^-]$ is the organic anion concentration and $[Al^{n+}]$ is the sum of all inorganic Al ions. A threshold (critical chemical value) for ANC of 20 μeq L^{-1} has been applied in Scandinavia as a critical chemical value for fish in surface waters (Henriksen et al. 1990), although different ANC values specific to different receptors have also been suggested (Henriksen et al. 1995). The threshold is applied in models used to determine critical loads for surface water bodies; e.g., the Steady State Water Chemistry model and the First-Order Acidity Balance model (Task Force on Mapping 1996).

2.2.5 Summary

The threshold or critical chemical value refers to the value of a critical chemical criterion or combination of criteria (e.g. ratios) above or below which no harmful response in a biological indicator is expected to occur. The critical chemical values pertinent to grassland soils and to surface waters that are used in this study are given in Table 1.

Table 1. Proposed Indicators and Thresholds of Stress in Forest and Grassland Ecosystems

Critical Chemical Criteria (Indicators)	Critical Chemical Values (Thresholds)
Soils	
$pH(CaCl_2)$ – Forest Soils [Z]	3.5
$pH(H_2O)$ – Forest Soils [Z]	4.2
$pH(CaCl_2)$ – Grassland Soils [Y]	5.0
$pH(H_2O)$ – Grassland Soils [Y]	5.6
Base saturation percentage – Forest Soils [X]	<15% of effective CEC
Base saturation percentage – Grassland Soils [Y]	<80% of effective CEC
BC:Al ratio – Forest Soils [X]	1.0 (50% risk) 0.5 (75% risk) 0.2 (95-100% risk)
BC:Al ratio – Grassland Soils [Y]	10
Surface Water	
ANC[W]	20 μeq L^{-1}

[Z] After Ulrich et al. (1984)
[Y] After Turchenek and Abboud (2001)
[X] After Cronan and Grigal (1995)
[W] After Task Force on Mapping (1996)

2.3 EMPIRICAL METHOD FOR DERIVATION OF CRITICAL LOADS

Empirical methods of critical load derivation are based mainly on observation of responses of ecosystem components to acid deposition. In the case of soils, it has been suggested that a basic principle underlying a critical load is that the total input of hydrogen ions to the soil must not exceed the alkalinity produced by the weathering of soil minerals (Nilsson 1986). At a workshop in Skokloster, Sweden, it was concluded that the rate of chemical weathering is the single most important factor governing the soils ability to buffer incoming acidity, and therefore critical loads, for forest soils (Nilsson and Grennfelt 1988).

This mineralogical approach (the Skokloster approach) was adopted with some modifications for critical load determination of soils in the U.K. (Hornung et al. 1995). Texture, drainage, soil thickness and other factors were considered in deriving critical loads in the U.K. Details of the application of this mineralogical approach to the Edmonton West study area are presented in Section 5.1.

2.4 USE OF MODELS TO DERIVE CRITICAL LOADS

Numerous models have been developed to examine soil acidification and to derive critical loads. Modelling approaches comprise two main categories referred to as ‘steady-state methods’ and ‘dynamic modelling’. Within each category, there are varying degrees of sophistication ranging from simple calculations to complex mathematical constructs. The most complex are integrated forest soil models that link soil processes to other processes such as vegetation growth, hydrology and nutrient cycling.

Steady-state models calculate deposition levels that avoid harmful effects to ecosystems that are in steady-state (Task Force on Mapping 1996). Processes such as cation exchange and sulphate adsorption have a finite time scale and therefore cannot be included in steady-state models. Therefore, steady-state models are mainly used for calculation of critical loads over very long periods of time. Two types of steady-state models have been developed for soils. One-layer models, such as the Steady State Mass Balance (SSMB) model consider the soil as a single layer, whereas the multi-layer models consider chemical conditions in different soil layers or horizons. The one-layer SSMB model has been the most commonly applied tool for derivation of critical loads of soils in Europe (Task Force on Mapping 1996).

Dynamic models are a family of more complex models that use various calculations to simulate changes in soil solution or water chemistry due to acid deposition over time. Examples are the MAGIC, SAFE, VSD and SMART models, which have been developed in Europe (UNECE Convention on Long-Range Transboundary Air Pollution 2006), and the ARC model, applied in this report. Calculations of critical loads using these models is not as straightforward as with steady-state models because of the temporal aspect; i.e., it is necessary to determine the acceptability or non-acceptability of chemical changes in soils or waters in relation to a predetermined period of time. Another reason for non-usage is the need for much data required to run some of the dynamic models. Consequently, dynamic models have not been used to a great extent in determining critical loads. However, these models are useful in scenario analysis; i.e., for assessing effects of given deposition levels over a selected period of time, and for determining the effects of different emission abatement strategies.

Dynamic models are used to calculate the acidification process for an ecosystem through time. Dynamic models, as compared to steady-state models, require more input data of which several parameters are more difficult to obtain. Since an assessment of the time periods involved in acidification responses and recovery from acidification can be made with these models, they are the best tools available for addressing time-dependent scenarios and the impact of episodic events on ecosystems. Several of these models are research tools, and are not available for evaluation and application in Alberta at the present time.

The gradual change with time in the acidification state of the system in response to some change in deposition is calculated with dynamic models. Critical loads can be calculated from different deposition scenarios, and the results can be compared to the critical chemical values (thresholds) for several different critical chemical criteria (e.g., ion exchange, weathering of soil minerals, uptake and cycling of base cations and nitrogen by plants, and soil solution equilibrium chemistry) in the system simultaneously. They use integrated mass balances for substances and differential equations for the rates of different processes. The time-dependent scenarios are obtained by numerical integration of the model subroutines advancing in small time-steps.

Various assumptions are made in the equations within the dynamic models. It is generally assumed that the CEC is constant over time and that a certain ion exchange equilibrium applies (Gapon or Gaines-Thomas exchange equation), and aluminum is assumed to be in continuous equilibrium with a mineral of the same composition as gibbsite (de Vries 1991). Some models assume sulphate adsorption to be negligible or at steady-state, while others have sulphate adsorption as a major process.

Some soil models are subroutines of more complex models used for impact studies and critical load determinations for aquatic systems. Sverdrup et al. (1990) suggested that several models be examined before choosing a model for soil evaluations and critical load calculations. The models differ somewhat in their basic principles, and have different limitations connected to their use and to the interpretation of their results. Such factors must be carefully studied before a model is chosen for a specific type of system.

The availability of data is a major consideration in determining the method to be used for critical load determination. This factor generally limits the methods to empirical methods or to steady-state and the simpler dynamic modelling approaches.

2.4.1 Steady State Mass Balance (SSMB) Model

The Steady State Mass Balance model is calculated manually and can be used for quick evaluation of scenarios involving relatively higher and lower levels of acid deposition and neutralizing capacities to arrive at critical loads. This is a one-layer model wherein only a specified thickness of the soil profile can be considered. Details are presented in Section 5.2.1.

Critical load determination by the SSMB model is directly dependent on the weathering rate, which is the major long-term source of alkalinity that neutralizes acidity in the soil system and the major source of base cations for replacing those removed by leaching. Thus, confidence in the critical load determined by this method depends on the level of confidence in the model input value for the weathering rate. Most estimations of weathering rate are based on correlations of experimentally determined weathering rates with soil type, mineralogy, base cation content or texture. Others are based on computations using soil mineralogy, wherein quantitative data for the complete suite of minerals present in a soil are required. The approach has been widely used in Europe to provide a weathering term for input into the SSMB equation (Task Force on Mapping 1996).

Another approach to estimating weathering is based on an estimation of mineralogy from total chemical analysis of soil by use of the UPPSALA model which performs a stepwise allocation of elements (Ca, Mg etc.) to different soil minerals. Minimal data needed by the UPPSALA model for converting elemental contents to mineralogy are levels of total Na, K, Ca, Mg, P, Al, Si and Fe (Sverdrup 1990).

The SSMB approach is applicable in Alberta in terms of the three criteria of simplicity, availability and applicability in critical load derivation. Critical loads can easily be calculated for an individual soil, or a large number of computations can be made within a spreadsheet. The SSMB model was applied to the Edmonton West study area using a weathering rate estimated from information in the literature as described in Section 5.2.2.

2.4.2 Alberta Research Council (ARC) Model

The ARC model is derived from Bloom and Grigal (1985) and incorporates empirical relationships for cation exchange and pH based on Alberta soil properties. The model has been described by Abboud and Turchenek (1990) and Turchenek and Abboud (1988), and is described in part in Section 6 of this report.

2.5 SURFACE WATER ACIDIFICATION MODELS

The determination of critical loads of acidity to surface waters was an initial objective in determining critical loads in the Edmonton West study area. However, the high salinity of lakes in the region results in very low acidification sensitivity. Thus, there was no concerted effort made in determining the critical loads to surface waters in this area.

2.6 MODELS USED TO DERIVE CRITICAL LOADS FOR SOILS IN THE EDMONTON WEST STUDY AREA

The SSMB and ARC models were previously applied to determination of critical loads in the Provost-Esther area (Turchenek and Abboud 2001) and the Edmonton East study area (Abboud and Turchenek 2008). An empirical method was also applied, in which critical loads were based on the Skokloster method.

3.0 DATA ACQUISITION AND COMPILATION METHODS

3.1 BASELINE SOIL INFORMATION

Information about the distribution and properties of soils in the Edmonton West study area is available from soil survey reports and from the AGRASID database (Alberta Soil Information Centre 2007). The AGRASID database provides soil survey coverage for the agricultural regions of Alberta, along with descriptions of soil series, including typical soil chemical attributes. Soil distribution is presented in the database within a hierarchical framework based on the national ecological framework for Canada (Ecological Stratification Working Group 1995).

The Edmonton West study area is within the Prairies Ecozone. An Ecozone is an area that is representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors.

An Ecoregion is a part of an Ecozone characterized by distinctive ecological responses to climate as expressed by the development of vegetation, soil, water, fauna, etc. (Ecological Stratification Working Group 1995). The study area occurs within the Aspen Parkland ecoregion, with the northern edges bordering the Boreal Transition Ecoregion. The Aspen Parkland is characterized by predominance of Black Chernozemic soils, with inclusions of Gleysolic and Solonetzic soils. These soils transition to the predominantly Luvisolic soils of the Boreal Plains ecoregion, which are associated with Brunisolic soils where materials are coarse textured. Gleysols occupy poorly drained depressions, and Organic (peat) soils occur increasingly toward the northern part of the area.

An Ecodistrict is a subdivision of an Ecoregion in the ecological land classification hierarchy. It is characterized by distinct assemblages of landform, relief, surficial geologic material, soil, water bodies, vegetation and land uses (Ecological Stratification Working Group 1995). The soil mapping system in Alberta further subdivides Ecodistricts into Land Systems. A Land System is defined as a subdivision of an Ecodistrict that is recognized and separated by differences in one or more of general pattern of land surface form, surficial geologic materials, amount of lakes or wetlands, or general soil pattern. All Land Systems within one Ecodistrict have the same general climate for agriculture, but differences in microclimatic pattern can be recognized. Soil Landscapes are subdivisions of Land Systems that display a consistent and recognizable pattern of distribution of soils and landscape elements (Alberta Soil Information Centre, 2007).

Soil types as identified at the Land System level were applied in developing a sampling protocol and critical loads map of the study area. Analysis of soil types at the Soil Landscape level of mapping would prove to be unwieldy due to the large number of delineations within one grid cell. Land Systems provide information at a lower level of detail, but at a somewhat greater level than that of the land units that form the basis of soil sensitivity mapping by Holowaychuk and Fessenden (1987). Consequently, Land System information was considered to be a practical basis for refining the previous soil sensitivity mapping and for calculating critical loads.

3.2 INITIAL ACID SENSITIVITY RATING

Each Land System is characterized by an assemblage of dominant and subdominant soil series. The extent of each series was estimated from the attribute information provided in AGRASID. These were then allocated an acid sensitivity rating based on base loss, acidification, aluminum solubilization and overall sensitivity ratings using soil pH and cation exchange capacity as the major criteria (Holowaychuk and Fessenden 1987). The ratings were developed for the top 20 cm of soil. However, soil chemical data reported in soil survey reports are based on one or very few sampled profiles, and it is difficult to fully rely on these data for sensitivity classification. Of the soil attributes described in soil survey reports, texture would be considered as one that is frequently and reliably estimated in the field. Cation exchange capacity is strongly related to texture because of its dependence on the clay content of the soil. Thus, instead of applying the Holowaychuk and Fessenden (1987) sensitivity classification using chemistry data only, soils in the Edmonton West study area were assigned preliminary sensitivity ratings on the basis of texture as well. Soils of sand or loamy sand texture were characterized as being Sensitive to acid deposition. Soils of sandy loam texture were assigned a Moderate Sensitivity rating. Luvisols were mainly assigned a Moderate rating because the topsoils (A horizons) commonly have sandy loam textures, even though the underlying material is fine textured. All Chernozemic soils of texture finer than sandy loam (including fine and very fine sandy loam) were assigned a Low Sensitivity rating.

The sensitivity rating allocation to Land Systems provided information about coverage of all potentially acid sensitive soils. This provided a framework for representative sampling of soils for the critical loads evaluation. Agricultural soils and native/range soils of Low Sensitivity were excluded from the evaluation because (1) acid deposition management is to be based on the extent of sensitive soils affected (Clean Air Strategic Alliance and Alberta Environment 1999), and (2) these soils are generally under cultivation and subject to various management practices, particularly fertilization, which confound any evaluations of acidification due to atmospheric deposition. In the Edmonton West study area, native rangelands were included, although these consist mainly of soils under native forest. Open forage and range areas have generally had tree cover removed and consist of non-native species. Although these lands have been cultivated and possibly fertilized, soil samples were taken from some sites in order to examine their potential sensitivity to acid deposition.

The sensitivity ratings were re-evaluated upon completion of the critical load determinations, with allocations to sensitivity classes based on pH, base saturation percentage and base cation to aluminum ratio. These were compared with the criteria of Holowaychuk and Fessenden (1987), and a revised soil distribution and acid sensitivity map was produced for the study area.

3.3 LAND USE INFORMATION

As indicated previously, forage and crop lands are subjected to various practices such as fertilization and manure application, and these would complicate evaluations in relation to atmospheric acid deposition. Additionally, soils under cultivation are generally soils that have higher nutrient content and buffering capacity (base cations), and are therefore the least sensitive soils within any given area. In addition to land use information, soil and landscape information was therefore required to enable planning of a sampling program, and more importantly, to enable calculation of the areal extents of soils of different acid sensitivity.

Land use information was obtained from the Prairie Farm Rehabilitation Administration (PFRA 2001) which had undertaken mapping for the purpose of verifying applications under the Western Grain Transition Payments Program (WGTPP). The WGTPP map was based on analysis of satellite images acquired from 1993 to 1995, and land cover was allocated to one of eleven classes:

1. Cultivated crop land – land that is annually seeded or under summer fallow;
2. Forage (hay) – land that is in perennial forage for hay or silage production (dominantly alfalfa);
3. Grasslands – land that is in perennial grasses and herbaceous species for grazing use including native range, seeded tame pasture, abandoned farm areas and other non-cultivated uses (ditches, riparian areas, etc.);
4. Shrubs – land that has perennial woody shrub coverage;
5. Trees – hardwoods, mixed woods, recent burns and cutovers;
6. Wetlands – intermittent water bodies, area that have semi-permanent or permanent wetland vegetation, including fens, bogs, swamps, sloughs, marshes, etc.;
7. Water – permanent water bodies including lakes, rivers, irrigation canals;
8. Non-agricultural lands – land that is dominantly in a non-vegetative or non-agricultural land use, including farmsteads, roads, cities, towns, open pit mines, industrial sites, etc.;
9. Clouds and shadow;
10. Mud, sand and/or saline areas; and,
11. Unclassified area – areas outside of the study area.

Areas classed as Shrubs or Trees (categories 4 and 5 above) were selected from the WGTPP digital database and superimposed on the initial soil and soil sensitivity map, the development of which is described in Section 3.2 above. All other land was regarded as tilled land, although minor areas of disturbed lands (in addition to urban areas) occurred as well. Spatial information about water bodies was then taken from a separate digital layer in the database to produce a combined soil/land use/surface water map.

There can be uncertainty in the classification of certain types of land in the PFRA land classification. Moreover; the imagery that the classification was based on is now dated. This is nevertheless the most readily available land cover database. An inherent assumption in the sensitivity analysis herein is that this land cover information is more or less accurate, and that it is adequate for deriving statistics for areas of soils with different sensitivity ratings.

3.4 BASELINE SURFACE WATER INFORMATION

Information about the distribution and extent of surface water bodies in the Edmonton West study area was derived from the WGTPP information as indicated in Section 3.3. Detailed information about the areas of wetlands within the ecosystems of Alberta is available in ‘Ecodistricts of Alberta: Summary of Biophysical Attributes’ (Strong and Thompson 1995) and in ‘Characterization of Wetlands in the Settled Area of Alberta’ (Strong et al. 1993). Information about shallow water bodies is included in the latter compilation, but lakes are not included.

Water quality information is available in the form of a digital database maintained by Alberta Environment. The database presents values for pH, alkalinity, total dissolved solids and calcium for more than 1,000 Alberta Lakes, with information about additional lakes added on an ongoing basis (Saffran and Trew 1996).

3.5 SOIL SAMPLING

The goals established for soil sampling to meet the needs of critical load determination were to obtain soil samples of the LFH and the top 25 cm of mineral topsoil at a minimum of 25 sites from the Sensitive and Moderate acidification sensitivity areas in the study region.

The initial soil and soil sensitivity rating (Section 3.2) resulted in identification of 12 Land Systems that have a component of potentially Sensitive or 'Sensitive plus Moderate' soils, and one additional Land System in which soils of potential Moderate Sensitivity to acidic deposition occur. These areas varied in size. Sampling within the Edmonton region was logistically challenging in terms of obtaining permission to enter lands, and finding suitable areas for sampling within relatively densely populated areas such as acreage developments. Consequently, locations categorized as natural areas, parks and other crown lands were targeted for collection of samples. Some sites outside the boundaries of the study area were selected, provided they were located within land systems that extended into the Edmonton West study area.

Soil samples were taken by excavating a small pit to at least 50 cm depth and taking about a volume of about 2 L of both LFH (forest floor) and 0-25 cm horizons. In most instances, the 0-25 sampling layer occurred entirely within the A horizon. In some case where the A horizon was thinner than 25 cm, a portion of the B horizon to the 25 cm depth was included in the sample. The samples were collected in October and early November, 2005.

3.6 WATER SAMPLING

Water samples were collected from two water bodies that were of significant size but not included in the provincial water quality database. It was found, however, that most lakes in the study area appeared to be very shallow, or had dried out, and all were generally characterized by saline margins. The samples were taken from Longhurst Lake, located in NE36-51-1-W5 (just outside grid cell, on the 5th Meridian), and an unnamed lake located in NW33-51-27-W4. One 500 mL sample was collected, and pH was determined within two hours with a portable pH meter. Samples were collected from the lake shore using a pole of about 4 metres length, with the sample bottle attached to the end of the pole.

3.7 SOIL ANALYSES

Soil samples were analyzed for various properties as follows:

pH($CaCl_2$): By potentiometric measurement using 0.01 M $CaCl_2$ in a 1:2 (w:v) solid-to-liquid mixture (Method 7 (ii) in Kalra and Maynard (1991). The soil-to-solution ratio for litter (LFH) material was 1:4.

Cation Exchange Capacity (Buffered): By 1.0 M ammonium acetate extractant buffered at pH 7, and measurement of NH_4^+ by distillation. The method was applied as described in Procedure

3.3.2 in McKeague (1978), except that NH_4^+ was not displaced with Na, and the whole sample was distilled to determine the content of adsorbed NH_4^+.

Exchangeable Ions: By Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy of the unbuffered CEC extract. Ions included in the ICP scan were Ca, Mg, Na, K, Fe, Mn and Al.

Electrical Conductivity and Soluble Salts: By measurement of electrical conductivity and ions in the aqueous extract from a saturated paste of a soil sample (Method 8(i), Kalra and Maynard (1991). EC and pH were measured in the extract. A portion of the extract was filtered using a 0.45-μm micropore filter, and a full ICP elemental scan, including S and Al, was conducted on the extract.

3.8 METEOROLOGICAL DATA

Precipitation data were obtained from the website of the Atmospheric Environment Service (Environment Canada 2006), for the years 1990 - 2000. This was supplemented by data from Canadian Climate Normals 1961 - 1990 (Environment Canada 1993). Data were obtained for the meteorological station at the Edmonton International Airport.

3.9 PRECIPITATION SURPLUS

Some models use the term ‘precipitation minus potential evapotranspiration’ to obtain an approximation of the amount of deep percolation of soil moisture, or to approximate total precipitation surplus including runoff. Potential evapotranspiration exceeds precipitation in the study area, however, the depth of soil profile development suggests that water penetrates to about 0.8 metres in sandy soils in the study area. A soil depth of 25 cm was applied in determining acidification with models, this being the depth within which the majority of plant roots occur. Therefore, the amount of water percolating beyond the surface 25 cm zone was calculated.

Daily precipitation data for the months of April to October, inclusive, were obtained for the years 1990 to 1995. The amounts of precipitation retained by the soil on a daily basis was estimated by assuming a field capacity of 16.7 mm per 25 cm, this being based on an available water content of 80 mm per 1.2 metres for sandy soils (Tajek et al. 1989). The daily evapotranspiration rates were subtracted from this amount. Actual monthly evapotranspiration rates were obtained from Bothe and Abraham (1993). These rates were as follows: April, 2 mm d^{-1}; May, 4 mm d^{-1}; June, 6 mm d^{-1}; July, 7 mm d^{-1}; August, 6 mm d^{-1}; September, 4 mm d^{-1}; and, October, 2 mm d^{-1}. All winter snowfall was assumed to percolate into the soil, and evapotranspiration was assumed to be zero for this period.

The difference between the precipitation and the precipitation surplus represents the proportion of the precipitation that reacts with the upper 25 cm soil layer. Another implication of the precipitation surplus concept is that the products of any reactions within the top 25 cm of the soil are carried down the profile; that is, base cations may be lost from the upper layer.

While most roots are assumed to occur in the top 25 cm, a proportion occurs at some depth in the profile and takes up nutrients as well as water. Thus, it is possible that upward movement of nutrients through deep roots would add nutrients to the upper soil layers, which would serve to counteract the effects of acidification on plants. However, it is difficult to estimate the amount of upward nutrient transport by deep roots. It was considered that this is a minor process within the ecosystem, and therefore, this amount was not estimated and it was assumed for modelling purposes that no nutrient return occurs by this mechanism.

3.10 ACID DEPOSITION DATA

Acid deposition data were obtained from province-wide estimates of deposition by Cheng et al. (1997). For the ARC model, the Potential Acid Input (PAI) was applied. The PAI reported by Cheng et al. (1997) for the Edmonton West map sheet was 0.15 to 0.20 kmol H^+ ha^{-1} yr^{-1}, and more recently the estimate was 0.17 to 0.22 kmol H^+ ha^{-1} yr^{-1} (WBK & Associates Inc., 2006). The upper number in this range (0.20 kmol H^+ ha^{-1} yr^{-1}) was applied in models. This rate is equivalent to 0.3 kmol H^+ ha^{-1} yr^{-1} of SO_x, NO_x and NH_x deposition, partially neutralized by 0.1 kmol H^+ ha^{-1} yr^{-1} of base cation deposition.

3.11 OTHER DATA REQUIREMENTS

Other model data inputs consisting of constants, coefficients, soil analytical data or soil parameters obtained from the literature, or they have been derived for Alberta soils (see Section 5).

3.12 MAP COMPILATION

A soil map of the Edmonton West study area was developed from the AGRASID soils database and PFRA land cover databases as described in Sections 3.1 to 3.3. Only information at the Land System level was used, as this was considered to be an appropriate level of detail for generalized depiction of the distribution of soil types and their sensitivity to acid deposition. Additionally, it provided a suitable level of stratification for planning a soil sampling program.

Digital files for base map information as well as land use data were obtained from the PFRA-WGTPP data base (PFRA 2001). The base map files were registered to UTM Zone 12, NAD ‘83 coordinates. This coordinate system was maintained throughout all digital processing and formed the basis for geographic referencing of the final map products.

Delineations of Land Systems from the AGRASID database were linked to the base information using ARC/VIEW©. The data were exported to ARC/INFO© for topological construction, attribute linkage and map product output, the latter including incorporation of a soil sensitivity legend.

4.0 OVERVIEW OF SOILS AND SURFACE WATERS IN THE STUDY AREA

4.1 ECOLOGICAL STRATIFICATION

The most detailed level of mapping in the AGRASID database is the Soil Landscape unit. A Soil Landscape is a subdivision of a Land System that displays a consistent and recognizable pattern of distribution of soils and landscape elements (Alberta Soil Information Centre 2007). As indicated in Section 3.12, the Soil Landscape mapping unit was considered to be too detailed for application in this project, and the Land System was applied instead.

A map of Land Systems in the study area is presented in the back pocket of this report. A legend describes characteristics of the Land Systems in terms of parent geologic materials, landscapes and soil types. The Land Systems are also described in Table 2.

4.2 SOIL CLASSIFICATION

The study area occurs within the Aspen Parkland ecoregion, with the northern edges bordering the Boreal Transition Ecoregion. The Aspen Parkland is characterized by predominance of Black Chernozemic soils, with inclusions of Gleysolic and Solonetzic soils. These soils transition to the predominantly Luvisolic soils of the Boreal Plains ecoregion, which are associated with Brunisolic soils where materials are coarse textured. Gleysols occupy poorly drained depressions, and Organic (peat) soils occur increasingly toward the northern part of the area.

Individual soil types within Soil Landscapes are identified at the Soil Series level of the Canadian System of Soil Classification (Soil Classification Working Group 1998). A soil series is a category (or level) in the Canadian system of soil classification. It is the basic unit of soil classification, and consists of soils that are essentially alike in all major profile characteristics except the surface texture. Naming of Soil Series is based on the Alberta Soils Names File (Generation 3) User's Handbook and Soil Correlation Area (SCA) Map of Alberta (2006) (Alberta Soil Information Centre 2007). Soil series within the study area are listed in Table 3.

Table 2. Description of the Land Systems in the Edmonton West Study Area

LAND SYSTEM SYMBOL[Z]	LAND SYSTEM NAME	LAND SYSTEM DESCRIPTION	SOIL ZONE	MAJOR SOILS	MINOR SOILS
05.00.09	Battle River Valley	Landscape is valley bottom with some confined floodplain. Regosols developed on undifferentiated material. Minor soils include coarse textured soils. Significant eroded soils present.	Thin Black	ZER	MKR-AA
05.3d.01	Morinville Plain	Landscape is undulating. Black Solonetz developed on medium textured till and fine textured water-laid sediments. Minor soils include Chernozems and Gleysols.	Black-Dark Gray	CMO DUG	AGS ZGW
05.3d.07	Namao Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments and medium textured water-laid sediments.	Black-Dark Gray	MMO POK	AGS MCO
05.3d.09	Partridge Plain	Landscape is undulating. Black Chernozems developed on medium textured till. Minor soils include Gleysols.	Black-Dark Gray	AGS	RLV ZGL
05.3d.10	Cawes Plain	Landscape is undulating. Black Chernozems developed on medium textured till.	Black-Dark Gray	AGS	HBM RLV
05.3d.11	Pointe-aux-Pins Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments.	Black-Dark Gray	MMO	AGS LOM
05.3d.14	City of Edmonton	City of Edmonton.	Black-Dark Gray	ZDL	
05.3d.18	Spruce Grove Plain	Landscape is undulating with some peatlands. Dark Gray Chernozems developed on medium textured water-laid sediments. Minor soils include Organic and fine textured soils.	Black-Dark Gray	WTB	ZOR MMO
05.3d.19	Longhurst Plain	Landscape is undulating with some peatlands. Dark Gray Chernozems developed on medium textured water-laid sediments. Minor soils include Organic and coarse textured soils.	Black-Dark Gray	WTB	RDW ZOR
05.3d.20	Graminia Plain	Landscape is undulating with some duned. Dark Gray Luvisols developed on coarse textured sediments. Minor soils include Organic.	Black-Dark Gray	ELP TGL	ZOR
05.3d.21	Calmar Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments.	Black-Dark Gray	MMO	POK LOM
05.3d.22	Watelet Plain	Landscape is undulating. Black Chernozems and Black Solonetz developed on medium textured till and medium textured softrock.	Black-Dark Gray	AGS KVG	HBM RLV
05.3d.26	Big Hay Plain	Landscape is undulating with some level, closed basin. Black Chernozems and Black Solonetz developed on medium textured till and fine textured water-laid sediments. Minor soils include Gleysols.	Black-Dark Gray	AGS WKN	MMO ZGW
05.3d.27	Ferlow Plain	Landscape is hummocky. Black Chernozems developed on medium textured till. Minor soils include Gleysols.	Black-Dark Gray	AGS	RLV ZGW
05.3d.28	Pipestone Upland	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments and medium textured water-laid sediments. Minor soils include Gleysols.	Black-Dark Gray	PHS POK	ZGW
05.3d.30	Bigstone Plain	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments and medium textured material over medium textured till. Minor soils include Gleysols.	Black-Dark Gray	PHS HBM	POK ZGW

Table 2. Description of the Land Systems in the Edmonton West Study Area

LAND SYSTEM SYMBOL[Z]	LAND SYSTEM NAME	LAND SYSTEM DESCRIPTION	SOIL ZONE	MAJOR SOILS	MINOR SOILS
05.3d.31	Samson Lake Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments. Minor soils include Solonetz and Gleysols.	Black-Dark Gray	MMO	WKN ZGW
05.3d.50	Looma Upland	Landscape is hummocky. Dark Gray Chernozems and Dark Gray Luvisols developed on medium textured till. Minor soils include Gleysols and fine textured soils.	Black-Dark Gray	RLV UCS	MCO ZGW
05.4a.15	Ryley Plain	Landscape is undulating. Black Solonetz developed on medium textured till. Minor soils include Chernozems and Gleysols.	Black-Dark Gray	CMO	NRM ZGW
05.6.01	Islet Upland	Landscape is hummocky. Dark Gray and Dark Gray Luvisols developed on medium textured till. Minor soils include Gleysols, Chernozems and fine textured soils.	COA UCS	ZGW MCO	H1m H1l
06.00.03	North Saskatchewan River Valley	Landscape is inclined <10% exposed bedrock with some numerous water bodies and undulating.	Black-Dark Gray	ZER	
06.1b.02	Yeoford Plain	Landscape is undulating with some rolling and hummocky. Dark Gray and Gray Luvisols developed on medium textured till. Minor soils include Chernozems.	Black-Dark Gray	BEN BTN	FLU KHS
06.1b.03	Pigeon Lake	Large water body.	Black-Dark Gray	N/A	N/A
06.1c.12	Falun Plain	Landscape is undulating. Dark Gray Luvisols and Dark Gray Chernozems developed on medium textured till. Minor soils include Organic.	Black-Dark Gray	BEN FLU	BTN ZOR
06.1d.02	George Lake Plain	Landscape is hummocky with some numerous water bodies. Gray Luvisols and Gray Solonetz developed on medium textured till. Minor soils include Gleysols.	Black-Dark Gray	COA DNT	NKU ZGW
06.1d.08	Onoway Upland	Landscape is hummocky. Gray and Dark Gray Luvisols developed on medium textured till. Minor soils include Organic and Chernozems.	Black-Dark Gray	COA UCS	ZOR ZCO
06.1d.20	Mink Lake Plain	Landscape is hummocky. Gray Luvisols developed on medium textured water-laid sediments.	Black-Dark Gray	GOY HGV	CVL KHS
06.1d.21	Pemburton Hill Plain	Landscape is undulating. Dark Gray Luvisols developed on very fine textured water-laid sediments and areas of moderately fine textured till. Minor soils include Gleysols.		MLA	BOB ZGW
06.2a.05	Redwater Plain	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments. Minor soils include Brunisols.	Black-Dark Gray	MDR	PRM PHS
06.2a.09	Halfway Lake Dunefield	Landscape is undulating and duned. Brunisols and Dark Gray Chernozems developed on coarse textured sediments. Minor soils include Organic and Gleysols.	Black-Dark Gray	PRM HLW	ZOR ZGW
06.2a.11	Eldorena Plain	Landscape is undulating with some duned. Black Chernozems and Brunisols developed on coarse textured sediments.	Black-Dark Gray	PHS PRM	MNT-AA MDR
06.2b.17	Pakan Plain	Landscape is undulating. Black Chernozems developed on medium textured water-laid sediments. Minor soils include Solonetz.	Black-Dark Gray	POK	HBM KVG
06.2c.25	Thorhild Plain	Landscape is undulating. Dark Gray Luvisols and Dark Gray Chernozems developed on medium textured till. Minor soils include Gleysols.	Dark Gray-Gray	SDN KHW	LCY ZGW

[Z] Land System identifier in AGRASID.

Table 3. Soil Series in the Edmonton West Map Sheet

Symbol	Series	Drainage	Calcar	Salinity	PM1 Texture	PM1 Type	PM2 Texture	PM2 Type	Soil Subgroup
AGS	Angus Ridge	W	M	N	MF	TILL	-	-	E.BL
BEN	Benalto	W	W	N	MF	TILL	-	-	D.GL
BOB	Boscombe	I	M	N	MF	TILL	-	-	GLD.GL
BTN	Breton	W	W	N	MF	TILL	-	-	O.GL
CMO	Camrose	W	M	M	MF	TILL	-	-	BL.SS
CVL	Carvel	W	N	N	ME	GLFL	-	-	D.GL
COA	Cooking Lake	W	M	N	MF	TILL	-	-	O.GL
DUG	Duagh	MW	W	M	FI	GLLC	-	-	BL.SZ
DNT	Dnister	W	M	M	MF	TILL	-	-	G.SS
ELP	Elk Point	W	W	N	MC	GLFL	-	-	D.GL
FLU	Falun	W	W	N	MF	TILL	-	-	O.DG
GOY	Glory	W	N	N	ME	GLFL	-	-	O.GL
HLW	Helliwell	W	W	N	VC	GLFL	-	-	O.DG
HGV	Highvale	W	W	N	MF	GLLC	-	-	O.GL
HBM	Hobbema	W	M	N	ME	GLLC	MF	TILL	E.BL
KVG	Kavanagh	MW	W	W	MF	SRFS	-	-	BL.SS
KHS	Keephills	W	W	N	MF	GLLC	-	-	D.GL
KHW	Kehiwin	W	M	N	MF	TILL	-	-	D.GL
LCY	La Corey	W	M	N	MF	TILL	-	-	O.GL
LOM	Looma	W	W	N	VF	GLLC	MF	TILL	O.DG
MLA	Macola	MW	M	N	VF	GLLC	-	-	D.GL
MMO	Malmo	W	W	N	FI	GLLC	-	-	E.BL
MCO	Mico	MW	M	N	VF	GLLC	-	-	O.DG
MKR	Milk River-aa	W	M	N	MC	FLUV	-	-	CU.R
NTW	Nestow	R	W	N	VC	GLFL	-	-	E.DYB
ZDL	Disturbed Lands	-	-	-	-	-	-	-	-
ZER	Misc. Eroded	W	-	-	-	UNDM	-	-	-
ZGW	Misc. Gleysol	P	-	-	-	UNDM	-	-	O.HG
ZOR	Misc. Organic	VP	-	-	-	UNDO	-	-	TY.M
ZCO	Misc. Coarse Textured	W	-	-	-	UNDM	-	-	O.BL
ZWA	Misc. Water	VP	-	-	-	-	-	-	- .-
MDR	Mundare	W	W	N	VC	GLFL	-	-	O.BL
NKU	Nakamun	W	M	W	MF	TILL	-	-	SZ.GL
NRM	Norma	W	M	N	MF	TILL	-	-	SZ.BL
PHS	Peace Hills	W	W	N	MC	GLFL	-	-	O.BL
POK	Ponoka	W	M	N	ME	GLLC	-	-	E.BL
PRM	Primula	R	N	N	VC	GLFL	-	-	E.EB
RDW	Redwater	W	W	N	MC	GLFL	-	-	O.DG
RLV	Rolly View	W	M	N	MF	TILL	-	-	O.DG
SDN	Spedden	W	M	N	MF	TILL	-	-	O.DG
TGL	Tigerlily	W	M	N	MC	GLFL	-	-	O.GL
UCS	Uncas	W	M	N	MF	TILL	-	-	D.GL
WKN	Wetaskiwin	MW	W	M	FI	GLLC	-	-	BL.SS
WTB	Winterburn	W	W	N	ME	GLFL	-	-	O.DG

<u>Source</u>: AGRASID 3.0. Alberta Soil Information Centre (2007): http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903)

Abbreviations:
Drainage: VR - very rapid; R - rapid; W - well; MW - moderately well; I - imperfect; P - poor; VP - very poor.
Calc (calcareousness) and Salinity: N - non; W - weak; M - moderate
PM1 (upper parent material), PM2 (lower parent material):
  PM Texture: VC - very coarse; C - coarse; GRVC - gravelly very coarse; MC - moderately coarse; GRMC - gravelly moderately coarse; ME - medium; MF - moderately fine; FI - fine;
  PM Type: TILL - glacial till, or morainal; GLFL - glaciofluvial; FLUV - fluvial; FLEO - fluvioeolian; GLLC - glaciolacustrine; SRFS - soft rock; FNPT - fen peat; SPPT - sphagnum peat; UNDM - undetermined
Soil Subgroup: Defined below (Table 4, based on the Canadian System of Soil classification)
Subgroup modifier: CRSA – carbonated and saline

Table 4. Soil Orders and Great Groups in the Edmonton East Map Sheet

Order	Great Group	Subgroups
Brunisolic - Sufficient development to exclude from the Regosolic order, but lack degrees or kinds of development specified for other orders.	Eutric Brunisol - Ah<10 cm, pH>5.5 Dystric Brunisol - Ah<10 cm, pH<5.5	E.EB - Eluviated Eutric Brunisol E.DYB - Eluviated Dystric Brunisol
Regosolic - Development too weak to meet requirements of any other Order.	Regosol - Ah<10 cm, Bm absent or <5 cm Humic Regosol - Ah≤10 cm, Bm absent or <5 cm	(Not in above table)
Chernozemic - Surface horizons darkened by accumulation of organic matter from decomposition of grassland vegetation.	Black Chernozem - Black Ah, semiarid climate Dark Gray Chernozem - Dark Gray Ah, semiarid climate	O.BL - Orthic Black E.BL - Eluviated Black SZ.BL - Solonetzic Black O.DG - Orthic Dark Gray
Gleysolic - Features indicative of periodic or prolonged water saturation, and reducing conditions - mottling and gleying.	Humic Gleysol - Ah≥10 cm, no Bt Gleysol - Ah≤10 cm, no Bt Luvic Gleysol - Has a Btg, usually has an Ahe or an Aeg	R.HG – Rego Humic Gleysol SZ.HG - Solonetzic Humic Gleysol Various Gleysol subgroups occur in ZGW units (Table 3), including: O.LG - Orthic Luvic Gleysol HU.LG - Humic Luvic Gleysol O.G - Orthic Gleysol
Luvisolic - Light coloured eluvial horizons - Ae; illuvial B horizons of silicate clay accumulation - Bt; developed under forest vegetation.	Gray Luvisol - May or may not have Ah, has Ae and Bt, usually MAST ≤8 degrees Celsius[Y]	O.GL - Orthic Gray Luvisol D.GL - Dark Gray Luvisol GL.GL - Gleyed Gray Luvisol GLD.GL - Gleyed Dark Gray Luvisol BR.GL - Brunisolic Gray Luvisol
Solonetzic - Has Solonetzic B horizon - Bn or Bnt - columnar or prismatic structure, hard to extremely hard when dry, exchangeable Ca/Na≤10.	Solonetz - Lack a continuous Ae≥2 cm Solodized Solonetz - Ae≥2 cm, intact columnar Bnt or Bn Solod - Ae≥2 cm, distinct AB or BA (disintegrating Bnt)	B.SZ - Black Solonetz BL.SS - Black Solodized Solonetz BL.SO -Black Solod
Organic - Composed dominantly of organic materials; most are water saturated for prolonged periods.	Mesisol - Dominantly mesic Fibrisol - Dominantly fibric	T.F. - Terric Fibrisol T.M. - Terric Mesisol TF.M - Terric Fibric Mesisol TM.F - Terric Mesic Fibrisol TY.F - Typic Fibrisol M.F - Mesic Fibrisol TY.M - Typic Mesisol F.M - Fibric Mesisol

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

4.3 SOIL AND LAND COVER MAP

Soil types, land use and distribution of surface water bodies are shown on the map ‘Land Systems, Land Cover and Soil Sensitivity to Acid Inputs in the Edmonton West Map Sheet’ (back pocket). The surficial materials consist mainly of glacial till, glaciolacustrine, glaciofluvial and fluvioeolian deposits. (‘Fluvioeolian’ refers to a complex of glaciofluvial deposits with eolian deposits occurring as blankets and dunes.) Landscapes range from undulating to hummocky. A legend accompanying the map indicates the dominant and minor soil series within each Land System, along with the parent materials and landscape features.

Land cover in the study area was categorized as cultivated, grassland, shrubland, treed land, wetland or other land. The distribution and extent of these land cover types is indicated in the Land System map (back pocket).

4.4 DESCRIPTION OF SAMPLED SOILS

Locations and descriptions of soils sampled in the study area are presented in Appendix A. Analytical data for the soils are presented in Appendix B.

4.5 SURFACE WATERS

The largest water bodies in the area are Cooking, Bittern, Ministik, Big, Coal, Big Hay, Manawan, Joseph and Oliver Lakes. Pigeon Lake is considerably larger than these, but only a very small portion of the lake occurs within the Edmonton West study area. Lakes are most numerous in the southeast part of the study area. Lakes are relatively common immediately southwest of Edmonton, and are less common in the far southwest, west and northwest. There are very few water bodies of significant size east and northeast of Edmonton.

Many of the lakes in the study area have data reported in the Alberta Environment Online Lake Water Quality Data database (Table 5). The sensitivity of these lakes to acidification was based on the criteria provided by Palmer and Trew (1987), which is based on the total alkalinity of the lake water. The criteria are:

High Sensitivity	Alkalinity 0-4 mg L^{-1}
Moderate Sensitivity	Alkalinity 5-8 mg L^{-1}
Moderate - Low Sensitivity	Alkalinity 9-25 mg L^{-1}
Low Sensitivity	Alkalinity 26-40 mg L^{-1}
Least Sensitive	Alkalinity >40 mg L^{-1}

Based on the water quality of lakes reported in the Edmonton West study area, all lakes have alkalinity levels that greatly exceed levels in the above criteria and can be regarded as “Least Sensitive”. Palmer and Trew (1987) did not categorize any lakes in the Edmonton area as being more sensitive than the “Least Sensitive”.

The Alberta environment database does not include data for many of the small lakes in the Edmonton area. The two sampled lakes (Longhurst and Unnamed) were characterized by high pH. Additional water chemistry data was not obtained for these samples as high pH values correlate with high alkalinity, and the lakes were therefore considered to be in the ‘Least sensitive’ category.

It was concluded that all, or almost all, surface waters in the Edmonton West can be categorized as having Low sensitivity to acidifying inputs. Derivation of critical loads was not, therefore, carried out for any of the surface waters in the study area.

Table 5. Water Chemistry of Lakes in the Edmonton West Study Area

Lake	Location	pH	Ca (mg L^{-1})	Alkalinity (mg L^{-1} $CaCO_3$)	TDS (mg L^{-1})	EC (μS cm^{-1})	Acidification Sensitivity
Big Island	16/17-53-22-W4	9.4	23	132	227	390	Low
Big Lake	53-25&26-W4	8.9	48	141	348	564	Low
Bittern	7-47-21-W4	-	-	914	1,830	-	Low
Boag	30-52-22-W4	9.4	28	132	235	390	Low
Coal	27-47-23-W4	8.8	31	200	288	470	Low
Cooking	13-51-22-W4	8.8	22	419	927	1,410	Low
Half Moon	6-52-21-W4	8.7	19	136	156	294	Low
Islet	2-52-20-W4	8.4	32	167	173	316	Low
Joseph	6-50-21-W4	7.9	25	109	117	214	Low
Long Lake	15-47-27-W4	8.8	20	115	133	244	Low
Longhurst[z]	36-51-1-W5	8.4	-	-	-	-	Low
Looking Back	15-50-22-W4	8.9	36	302	1,011	-	Low
Manawan	5-57-25-W4	8.9	44	107	379	612	Low
Ministik	34-50-21-W4	9.1	53	752	2,428	-	Low
Pigeon	10/14-47-28-W4	8.4	26	144	155	290	Low
Telford	36-49-25-W4	-	-	140	298	-	Low
Twin Island	10-52-22-W4	-	-	256	754	-	Low
Unnamed[z]	32-51-27-W4	8.3	-	-	-	-	Low
Wizard	5-48-27-W4	8.3	28	158	177	330	Low

[z] Lakes sampled in the study area; all other lake data from Alberta Environment Online Lake Water Quality Data database.

5.0 CRITICAL LOAD DETERMINATIONS FOR SOILS

5.1 EMPIRICAL METHOD

The empirical method as adapted in the UK from the Skokloster approach (Section 2.4) was applied to soils in the Edmonton West study area. The application of this approach begins with allocation of a soil to a particular sensitivity and critical load class (Table 6). This scheme places clay minerals in the second class. However, the exchange capacity and exchangeable cations carried by clay minerals are not taken into account, and placing a clayey soil into Class 2 was not considered as being appropriate (Hornung et al. 1995). Therefore, a particle size classification was developed for modifying the initial mineralogically-based classes (Table 7). In addition to the soil textural modifiers, various other factors were considered in determining the final classification ratings for different soil types (Table 8). As an example, a soil overlying quartzite bedrock would be allocated to Class 1 in the Skokloster classification system.

However, if the soil was poorly drained and loamy-sand in texture, it would be allocated to Class 2, with a higher critical load. Similarly, if the soil was a deep sand, it would also be allocated to Class 2.

Table 6. Mineralogical Classification and Critical Loads for Soils (0-0.5 m) According to the Skokloster Classification [z]

Class	Dominant Weatherable Minerals	Critical Load ($kmol\ H^+\ ha^{-1}\ yr^{-1}$)
1	Quartz, rutile, anatase, kaolinite, gibbsite, orthoclase	< 0.2
2	Muscovite, plagioclase, illite, montmorillonite, vermiculite	0.2 – 0.5
3	Amphibole, chlorite, biotite, epidote, glaucophane	0.5 – 1.0
4	Olivine, garnets, pyroxenes, epidote	1.0 – 2.0
5	Carbonates	> 2.0

[z] After Nilsson and Grennfelt (1988) and Sverdrup and Warfvinge (1988)

Table 7. Allocation to Skokloster Material Class Based on Particle Size Class [z]

Particle size class	Soil material class
Sand, loamy sand, sandy loam, (sandy) silt loam	Class 2
Clay loam, sandy clay loam, silt loam	Class 3
Clay, silty clay, sandy clay	Class 4

[z] After Hornung et al. (1995).

Table 8. Factors Causing a Decrease or Increase in Critical Loads of Acidity for Soils [z]

Factor	Decrease	Increase
Precipitation	High	Low
Vegetation	Coniferous forest	Deciduous forest
Elevation slope	High	Low
Soil texture	See Table 7	See Table 7
Soil drainage	Free	Impeded
Soil/till depth	Shallow	Thick
Sulphate adsorption capacity	Low	High
Base cation deposition	Low	High

[z] After Nilsson and Grennfelt (1988) and Hornung et al. (1995).

The combination of mineralogical and particle size classes of sand to sandy loam soils in the study area would result in allocation to a critical load category of 0.2-0.5 kmol $ha^{-1}\ yr^{-1}$ (class 2). In the UK approach, the critical load is either increased or decreased, depending on various modifying factors, as indicated above. The factors of low precipitation, low elevation, and thick soil would increase the critical load. However, the factors of free drainage and low sulphate adsorption capacity serve to reduce the critical load. The base cation deposition rate is another modifying factor; the level in the study area, however, is of intermediate magnitude (Cheng et al. 1997) and therefore has little impact on the overall rating. The factors more or less balance each other, and we therefore deduce that very sandy soils (sand, loamy sand) likely have a critical load in the range of 0.2 - 0.5 kmol $ha^{-1} yr^{-1}$. This would apply particularly to soils with low organic matter content. The classification for sandy loam soils is likely in the upper part of the range, and possibly in the 0.5-1.0 kmol $ha^{-1} yr^{-1}$ range. Allocation of soil units using this empirical method leads to the assignment of critical loads in the Edmonton West study area as presented in Table 9.

Table 9. Critical Loads of Soils in the Edmonton West Area Based on the Empirical Method

Texture	Soil Series	Critical Load
Very coarse	Primula, Nestow, Mundare, Helliwell	0.2-0.5 kmol $ha^{-1} yr^{-1}$
Moderately coarse	Peace Hills, Redwater	0.5-1.0 kmol $ha^{-1} yr^{-1}$
Medium to moderately fine	Series on till	1.0-2.0 kmol $ha^{-1} yr^{-1}$
Fine	Glaciolacustrine clays	>2.0 kmol $ha^{-1} yr^{-1}$

5.2 STEADY STATE MASS BALANCE METHOD

5.2.1 Model Description

The Steady State Mass Balance (SSMB) model considers the soil as consisting of one compartment equal to the thickness of the root zone (generally 30-50 cm or more in forest soils), and calculates critical loads in relation to critical chemical values related to element concentrations leaching from the root zone. The calculation of critical loads using the SSMB model is based on a balance of sources of acidity against sinks for acidity and sources of alkalinity, and uses a formulation of the charge balance of ions in the soil leachate.

Sverdrup and de Vries (1994) and de Vries (1991) provided description and derivation of the model, and the model as applied in Europe is described in UBA (2004). The method was applied in calculating critical loads of acid deposition for forest soils in eastern Canada and most recently in Manitoba and Saskatchewan forested areas (Aherne and Watmough 2006). Some model assumptions in an earlier approach, applied in the study of critical loads in the Provost-Esther area in Alberta (Turchenek and Abboud 2001), differ from those applied in the recent Canadian studies. The method applied herein is as described in the Canadian studies, with emphasis on the Manitoba/Saskatchewan study, from which some of the input data were obtained. The critical load of acidity arising from sulphur, CL(S), and from nitrogen, CL(N), is described by the following equation:

$$CL(S) + CL(N) = BC_{dep} - Cl_{dep} + BC_w - BC_u + N_i + N_u + N_{de} - Alk_{le(crit)} \qquad (5)$$

where, BC_{dep} is base cation deposition ($BC = Ca^{2+} + Mg^{2+} + K^+ + Na^+$), Cl_{dep} is Cl^- deposition, BC_w is base cation weathering, N_i is nitrogen immobilization, N_u is nitrogen uptake by vegetation, and N_{de} is denitrification. $Alk_{le(crit)}$, the critical alkalinity leaching (also referred to as critical acid neutralizing capacity) is estimated from the critical base cation to aluminum ratio (BC:Al) in the soil solution that leaches through the system along with a term that describes the gibbsite equilibrium, which is assumed to control the Al concentration.

Critical load has also been defined in terms of potential acidity as:

$$CL(Ac_{pot}) = BC_w - BC_u + N_i + N_u + N_{de} - Alk_{le(crit)} \qquad (6)$$

BC_{dep} nor Cl_{dep} are not considered in the definition because they are ecosystem properties and can change over time (UBA, 2004). The nitrogen terms have been assumed to be nil or very close to nil in applications to Canadian soils, and removal of base cations is generally not considered. In forest soils, base cations would be removed by harvesting; in grassland situations, this term would be minimal as the main export of cations would be via livestock. Since cations are not removed, the BC_u term is considered to be nil. The critical load potential acidity is then defined as:

$$CL(Ac_{pot}) = BC_w - Alk_{le(crit)} \qquad (7)$$

Critical 'Alkalinity leaching' ($Alk_{le(crit)}$) can be defined in terms of soil acidity as follows:

$$Alk_{le(crit)} = -Al_{le(crit)} - H_{le(crit)} = -Q \bullet ([Al]_{crit} + [H]_{crit}) \qquad (8)$$

Q is the precipitation surplus, or water leaving the root zone (m^3/ha/yr), and the square brackets denote concentrations (in eq/m^3).

The relationship between Al and H is defined by the gibbsite equilibrium:

$$[Al] = K_{gibb} \bullet [H]^3 \text{ or } [H] = ([Al]/K_{gibb})^{1/3} \qquad (9)$$

The $Alk_{le(crit)}$ term is then defined as,

$$\begin{aligned} Alk_{le(crit)} = & -Q^{2/3} \bullet \{1.5 \bullet (BC_{dep} + BC_w - BC_u)/((BC{:}Al)_{crit} \bullet K_{gibb})\}^{1/3} \\ & - 1.5 \bullet (BC_{dep} + BC_w - BC_u)/(BC{:}Al)_{crit}) \end{aligned} \qquad (10)$$

where Q is the precipitation surplus, or water leaving the root zone ($m^3\ ha^{-1}\ yr^{-1}$). Values for the parameters are presented in the following section. K_{gibb} is the gibbsite equilibrium constant.

The incorporation of these relationships in the CL expression (equation 8) provides the SSMB equation for critical load of acidity in mol $ha^{-1}\ yr^{-1}$, as follows:

$$\begin{aligned} CL(Ac_{pot}) = & BC_w + \{1.5 \bullet (Bc_w + BC_{dep} - BC_u)/((BC{:}Al)_{crit} \bullet Kgibb)\}^{1/3} \bullet Q^{2/3} \\ & + 1.5 \bullet (BC_w + BC_{dep} - BC_u)/(BC{:}Al)_{crit}) \end{aligned} \qquad (11)$$

Q is the precipitation surplus, or water leaving the root zone ($m^3\ ha^{-1}\ yr^{-1}$). Values for the parameters are presented in the following section.

The full derivation of the equation and the explanation of factors used in the $ANC_{le(crit)}$ term can be found in UBA (2004).

5.2.2 Data for Critical Load Calculations

Precipitation Surplus (Q)

Q is calculated as the precipitation minus the sum of interception evaporation by vegetation, the actual soil evaporation and the actual transpiration (water uptake) in the root zone. The precipitation surplus term is discussed in Section 5.3.1.3. The SSMB calculations were carried out for a 75 cm soil layer, which is consistent with the approach elsewhere in Canada (Aherne and Watmough 2006). For the ARC model (Section 5.3.1.3), the estimate is 780 m^3 ha^{-1} yr^{-1} for percolation out of the 25 cm soil layer, and the estimate for percolation below the 75 cm depth is 200 m^3 ha^{-1} yr^{-1}.

Gibbsite Equilibrium Constant (K_{gibb})

The value of K_{gibb} depends on soil type and the organic matter content. The value for soils with low organic matter ranges from 300 - 3,000 m^6 mol^{-2} (UBA 2004). K_{gibb} = 300 m^6 mol_c^{-2} was applied in modelling for the Edmonton West grid cell.

Weathering Rates (BCw)

A number of options for estimating weathering rates are presented by the Task Force on Mapping (1996) and more recently in UBA (2004), and were previously described in detail by Sverdrup and de Vries (1994) and Sverdrup (1990). Application of these methods to data presented by Sverdrup (1990) for sandy soils suggests that the weathering rate is in the range of 0.05 to 0.4 $kmol_c$ ha^{-1} yr^{-1} for a 1 metre soil layer, or about 0.01 to 0.1 $kmol_c$ ha^{-1} yr^{-1} for a 0.25 metre layer. A value of 0.07 $kmol_c$ ha^{-1} yr^{-1} for a 0.25 m layer has been determined for sandy soils in Minnesota by Bloom and Grigal (1985), and was subsequently considered as a suitable approximation for sandy soils in Alberta by Abboud and Turchenek (1990), Turchenek and Abboud (2001) and Turchenek et al. (1994). This rate was therefore applied to soils in the Edmonton West grid cell.

In keeping with SSMB applications in other parts of Canada, a 0.75 m soil layer was applied in modelling. Although most plant roots generally occur within the uppermost soil horizon, the depth of soil exploited by roots can be much deeper. Weathering rates are described further in Section 5.3.1.1. The weathering rate of 0.07 $kmol_c$ ha^{-1} yr^{-1} 0.25 m^{-1} (from Turchenek and Abboud 2001) was applied in the case of sandy soils. The equivalent 0.75 m weathering rate is 0.21 $kmol_c$ ha^{-1} yr^{-1} (210 mol_c ha^{-1} yr^{-1} applied in the model). For other textures, the weathering rates were as follows (expressed as mol ha^{-1} yr^{-1}): loamy sand to sand soil – 300; sandy loam – 450; loam – 750; clay loam – 1,500; and clay or heavy clay – 3,000.

Growth Uptake or Export of Base Cations (Bc_u)

Over a long-term, the net uptake of base cations (BC_u, Ca, Mg and K, with Na excluded) is equal to that stored in vegetative biomass. In the case of grasslands, annual growth (biomass) is returned to the soil each year, and cation storage levels in biomass are considered to be negligible. Nutrients can also be “exported” from soils through livestock grazing and removal of livestock from the land. Little data is available for nutrient removal rates from rangelands by animals. Heady and Child (1994) reported exports of 0.025 to 0.035 $kmol_c$ ha^{-1} yr^{-1} of base cations from rangelands in New Mexico. These data suggest that export of nutrients by beef production is low, and rates for northern climates on poor soils would likely be even lower, due to lower stocking rates. Therefore, base cation export by animals is considered as negligible for purposes of deriving critical loads by the SSMB or other methods, and was set to zero in the model runs.

BC:Al Ratio

Base cation to aluminum ratios used in the calculations was 1, 10, 45 and 250 (see Section 2.2.2).

5.2.3 Critical Load Calculations

Critical loads were calculated using the SSMB model (equation 8) for a 0.75 m soil layer. Critical load calculation by the SSMB method was not conducted on the basis of properties of the soil samples, but rather on the basis of weathering rates of broad soil groupings (sand, sand to loamy sand, sandy loam, loam, and clay loam soils) and on regional variation in climate expressed as variation in precipitation surplus. Base cation export was assumed to be negligible.

The results of SSMB calculations (Table 10) showed that critical loads at the BC:Al ratio of 2 are one and a half to two times greater than those at BC:Al ratios of 10. (Note: The expression ‘BC’ is used heretofore, although it is equivalent to ‘Bc’ defined above.) However, increasing the BC:Al ratio beyond 10 reduced the critical load only slightly. The lowest critical loads were obtained for the sandy to loamy sand soils.

Table 10. Critical Load Calculations by the SSMB Method

Soil Type	Texture Group	Soil Texture Group	Major Soil Series[Z]	Critical Load (kmol ha^{-1} yr^{-1})			
				BC:Al 1	BC:Al 10	BC:Al 45	BC:Al 250
Eluviated Dystric Brunisol Eluviated Eutric Brunisol	Very Coarse	Sand, Loamy Sand	Nestow Primula Tiger Lily	0.6	0.3	0.2	0.2
Eluviated Black Chernozem Dark Gray Chernozem	Very Coarse - Moderately Coarse	Loamy Sand	Helliwell Mundare	0.7	0.4	0.4	0.3
Orthic Black Chernozem Eluviated Black Chernozem Dark Gray Chernozem Dark Gray Luvisol	Moderately Coarse	Sandy Loam	Peace Hills Elk Point	1.0	0.6	0.5	0.5
Black Chernozem Eluviated Black Chernozem Dark Gray Chernozem Gray Luvisol	Medium	Loam, Silt Loam	Ponoka Hobbema Glory	1.6	1.0	0.8	0.8
Orthic Gray Luvisol Dark Gray Luvisol Orthic Black Chernozem Eluviated Black Chernozem Dark Gray Chernozem Black Solodized Solonetz Solonetzic Black Chernozem	Medium, Moderately Fine	Sandy Clay Loam Clay Loam	Benalto Breton Cooking lake Dnister Uncas Rolly View Angus Ridge Falun Highvale Camrose Kavanagh Kehiwin Spedden Winterburn	2.9	1.8	1.6	1.5
Orthic Black Chernozem Eluviated Black Chernozem Dark Gray Chernozem Black Solonetz	Fine, Very Fine	Clay Heavy Clay	Malmo Macola Duagh Wetaskiwin	5.6	3.6	3.2	3.1

[Z] “Major soil” occurring in study area Land Systems, from Table 2.

5.3 ARC MODEL

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 and Abboud (1988), and Abboud et al (2002). This model is adapted from the Bloom and Grigal (1985) model, and modified to a two-layer model by calculation of acidification in the LFH and the mineral layers separately. Other modifications include 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.

5.3.1 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.

5.3.1.1 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 use the following equations (developed for mineral soils from a correlation of pH values using data from Pauls et al. (1996)) was 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 (12)
for mineral horizons: $pH(H_2O) = 0.94\ pH(CaCl_2) + 0.72$ $R^2 = 0.984$, n= 130 samples (13)

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).

$$\text{Log}\ \gamma_i = -AZ_i^2\ [\{I/(1+I^{0.5})\} - 0.3\ I] \qquad (14)$$

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).

$$I = 0.013\ EC \tag{15}$$

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 11. 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] Source: Abboud et al. (2002)

The input data for soil pH, CEC, and sum of bases were the values for the LFH layer (usually less than 25 cm) and the weighted mean values of mineral soil horizons within 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 and Abboud (1988).

5.3.1.2 Acid Deposition Data

The ARC model was applied using the PAI values 0.1, 0.2, 0.3, 0.5, 0.7 and 1.0 kmol ha^{-1} yr^{-1}. These values were recommended for model application by the Alberta Environment staff and encompass 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.

5.3.1.3 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 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.

5.3.1.4 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.

5.3.1.5 Effect of Weathering

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

$$r = r_o 10^{-0.5(pH-pHo)} \tag{16}$$

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 of 5.0 was applied in the equation.

5.3.1.6 Summary of Data Inputs

The starting parameters for soils used in simulations are given in Table 12. The taxonomy and some general descriptive features of the soils are indicated along with input data described previously.

5.3.2 Computations

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

$$S = I - A - C – W \tag{17}$$

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).

5.3.3 Changes 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 East grid Cell (Abboud and Turchenek 2008). 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.

Application as a Two-Layer Model

The ARC model was modified to account for the acid interaction with the LFH layer. This modification necessitated the calculation of evapotranspiration and precipitation values for both LFH and mineral layers. The ‘precipitation’ number for the mineral layer was assumed to be equivalent to the quantity of percolation water passing through the LFH layer. The acid input is assumed to react with the LFH layers thereby acidifying their soil solutions and contributing the acidity to the mineral layer. Buffering in the LFH layers was assumed to arise from surface reactions (exchange, adsorption and complexation) and solution carbonate reactions. It was considered that there was no weathering in LFH layers and that there was no water buffering as in peat soils.

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(H2O) 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 seems 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.

Table 12. Input Data for Soil Acidification Simulations with the ARC Model

System Definition Variables	**Soil Data**						
Land System	Redwater Plain/ Halfway Lake Dunefield	Redwater Plain	Graminia Plain	Graminia Plain	Pipestone Upland	Pipestone Upland	Yeoford Plain Falun Plain
Sites	11, 13, 14, 20, 21, 22	12	1, 2	3	23, 25	24	26, 27
Soil Subgroup	Eluviated Dystric Brunisol	Eluviated Dystric Brunisol	Eluviated Dystric Brunisol	Orthic Dark Gray	Orthic Dark Gray	Orthic Black	Orthic Gray Luvisol
Soil Series	Nestow	Nestow (Forage)	Nestow	Helliwell	Helliwell	Peace Hills	Breton
Texture 0-25 cm	Sand	Sand	Loamy Fine Sand	Loamy Sand	Loamy Sand	Sandy Loam	Loam - Silt Loam
Precipitation (cm yr^{-1})	50	50	50	50	50	50	50
Litter ET (cm yr^{-1})	14	0	19	18	18	0	19
Perc below 25 cm (cm yr^{-1})	22	23	18	19	19	18	13
Years of Iteration	300	300	300	300	300	300	300
Increment of Years	1	1	1	1	1	1	1
PAI (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	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	0.1, 0.2, 0.3, 0.5, 0.7, 1.0
LFH							
LFH (cm)	1.5	0	6	5	6	0	7
LFH pH (CaCl$_2$)	4.5	-	5.9	6.6	5.7	-	6.1
LFH pH (H$_2$O)	4.87	-	6.21	6.89	6.02	-	6.41
LFH Bases (kmol$_c$ ha^{-1})	3.0	-	27.2	26.9	16.0	-	27.1
LFH CEC (kmol$_c$ ha^{-1})	8.5	-	43.2	38.7	26.4	-	41.3
Activity Coefficient of Al^{1+}	0.916	0.916	0.916	0.894	0.894	0.894	0.898
Activity Coefficient of Al^{2+}	0.705	0.705	0.705	0.638	0.638	0.638	0.650
Activity Coefficient of Al^{3+}	0.457	0.457	0.457	0.380	0.380	0.380	0.380
Slope of pH-BS LFH Equation	3.76	3.76	3.76	3.76	3.76	3.76	3.76
Mineral 0-25 cm	25	25	25	25	25	25	25
Mineral Soil pH (CaCl$_2$)	4.7	5.0	5.3	6.0	4.8	5.2	5.3
Mineral Soil pH (H$_2$O)	5.14	5.42	5.70	6.36	5.23	5.61	5.70
Mineral Bases (kmol$_c$ ha^{-1})	61.7	225.8	209.5	325.1	225.9	583.3	436.9
Mineral CEC (kmol$_c$ ha^{-1})	141.8	394.0	340.9	423.8	435.0	1024.7	778.3
Activity Coefficient of Al^{3+}	0.64	0.72	0.54	0.46	0.47	0.48	0.36
Activity Coefficient of Al^{2+}	0.82	0.86	0.75	0.70	0.72	0.72	0.63
Activity Coefficient of Al^{1+}	0.95	0.96	0.93	0.92	0.92	0.92	0.89
Slope of pH-BS Mineral Eqn.	2.06	2.06	2.06	3.38	3.38	3.38	2.27
CO$_2$ Partial Pressure (atm)	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Weathering (kmol$_c$ ha^{-1} yr^{-1})	0.07	0.07	0.10	0.10	0.10	0.15	0.25

Table 12. Input Data for Soil Acidification Simulations with the ARC Model

System Definition Variables	**Soil Data**						
Land System	**Islet Upland**	**Islet Upland**	**Islet Upland**	**George Lake Plain**	**George Lake Plain**	**George Lake Plain**	**George Lake Plain**
Sites	5	6, 7, 8, 9, 10	18, 19	4	15	17	16
Soil Subgroup	Dark Gray Luvisol	Orthic Gray Luvisol	Orthic Gray Luvisol	Dark Gray Luvisol	Orthic Gray Luvisol	Orthic Gray Luvisol	Orthic Gray Luvisol
Soil Series	Uncas	Cooking Lake	Cooking Lake (Forage)	Cooking Lake	Cooking Lake	Cooking Lake	Cooking Lake (Forage)
Texture 0 - 25 cm	Sandy Loam - Loam	Sandy Loam	Loam	Loamy Sand - Sandy Loam	Loam	Very Fine Sandy Loam	Very Fine Sandy Loam
Precipitation (cm yr^{-1})	50	50	50	50	50	50	50
Litter ET (cm yr^{-1})	19	20	0	18	20	20	0
Perc below 25 cm (cm yr^{-1})	14	14	18	14	14	16	18
Years of Iteration	300	300	300	300	300	300	300
Increment of Years	1	1	1	1	1	1	1
PAI (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	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	0.1, 0.2, 0.3, 0.5, 0.7, 1.0
LFH							
LFH (cm)	6	10	0	4	12	10	0
LFH pH (CaCl$_2$)	5.7	6.2	-	6.1	6.3	5.4	-
LFH pH (H$_2$O)	6.02	6.50	-	6.41	6.60	5.73	-
LFH Bases (kmol$_c$ ha^{-1})	35.8	86.4	-	28.9	94.2	46.2	-
LFH CEC (kmol$_c$ ha^{-1})	63.4	129.7	-	45.7	154.3	98.2	-
Activity Coefficient of Al^{3+}	0.898	0.898	0.898	0.898	0.898	0.898	0.898
Activity Coefficient of Al^{2+}	0.650	0.650	0.650	0.650	0.650	0.650	0.650
Activity Coefficient of Al^{1+}	0.380	0.380	0.380	0.380	0.380	0.380	0.380
Slope of pH-BS LFH Equation	3.76	3.76	3.76	3.76	3.76	3.76	3.76
Mineral 0-25 cm							
Mineral Soil pH (CaCl$_2$)	4.1	5.0	5.9	4.1	5.3	3.9	4.3
Mineral Soil pH (H$_2$O)	4.57	5.42	6.27	4.57	5.70	4.39	4.76
Mineral Bases (kmol$_c$ ha^{-1})	287.5	225.8	418.5	174.5	219.6	124.7	224.7
Mineral CEC (kmol$_c$ ha^{-1})	681.5	394.0	662.6	899.3	398.4	622.1	766.9
Activity Coefficient of Al^{3+}	0.62	0.54	0.43	0.35	0.40	0.49	0.50
Activity Coefficient of Al^{2+}	0.80	0.75	0.69	0.63	0.66	0.72	0.73
Activity Coefficient of Al^{1+}	0.95	0.93	0.91	0.89	0.90	0.92	0.93
Slope of pH-BS Mineral Eqn.	2.27	2.27	2.27	2.27	2.27	2.27	2.27
CO$_2$ Partial Pressure (atm)	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Weathering (kmol$_c$ ha^{-1} yr^{-1})	0.15	0.15	0.25	0.10	0.25	0.20	0.20

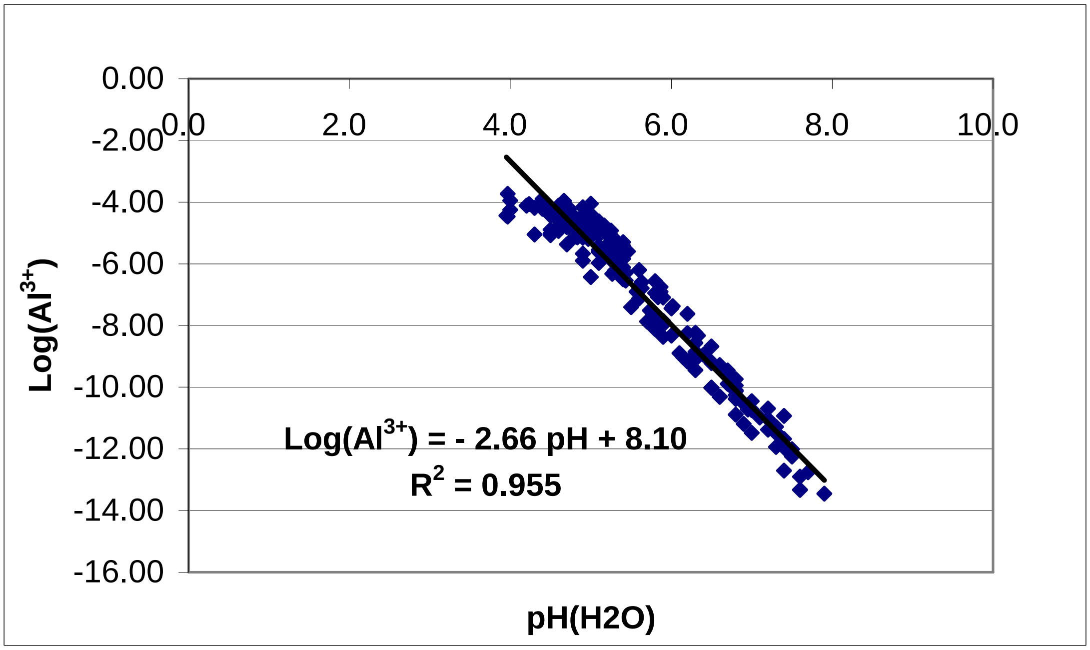


Figure 1. Al Solubility in Mineral Horizons

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 West grid cell were:

for LFH horizons: $\log[Al^{3+}] = -2.72\ pH(H_2O) + 8.03$ $R^2 = 0.923$, n= 65 samples (14)
for 0-25 cm layer: $\log[Al^{3+}] = 2.66\ pH(H_2O) + 8.10$ $R^2 = 0.955$, n= 130 samples (15)

BC:Al Ratios

The relationship between BC:Al ratios and pH for mineral soil layers was 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.

The BC:Al and pH relationships were derived for both the mineral and the LFH layers of soils. The equations applied in modelling the soils of the Edmonton West 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)

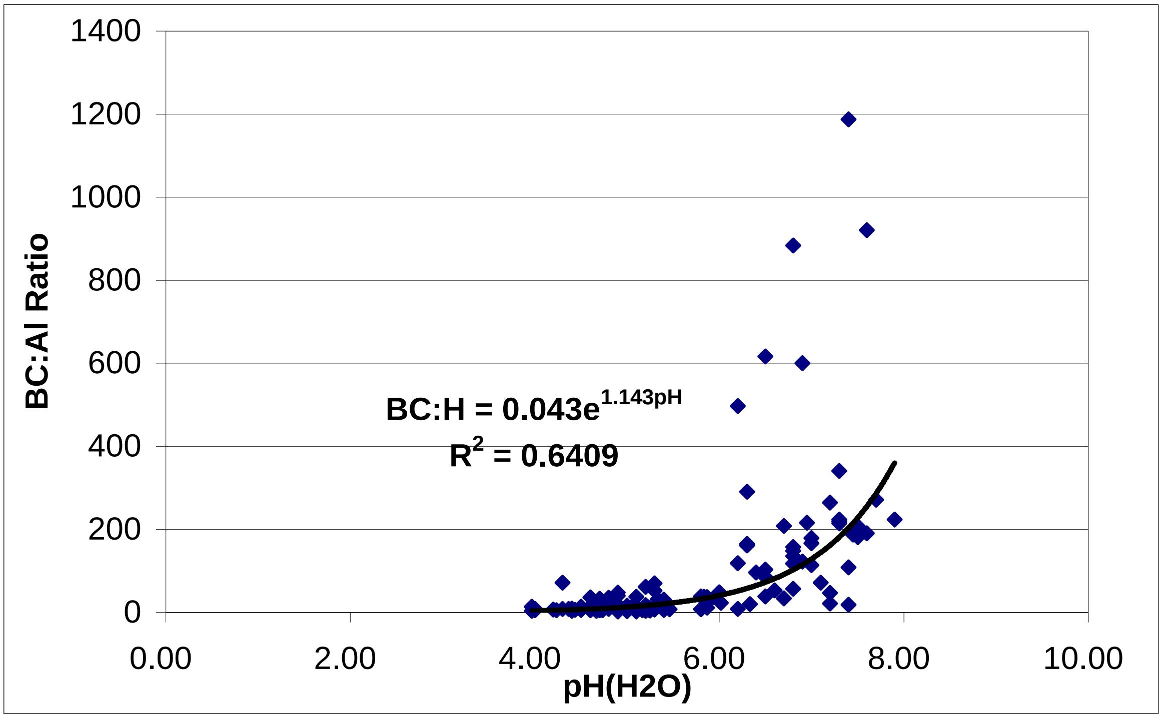


Figure 2. BC:Al Ratio for Mineral Horizons

5.3.4 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.

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 13. Example of Output from the ARC Model Simulation 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	5.4	2.84E-05	0.57	21	1.0	0.1	0.00E+00	0.00E+00	0.0	225.8	Redwater Plain
1	5.4	2.84E-05	0.57	21	1.0	0.1	0.00E+00	0.00E+00	0.9	224.9	Redwater Plain
2	5.4	2.77E-05	0.57	21	1.0	0.1	1.59E-04	5.27E-04	0.9	223.9	Redwater Plain
3	5.4	2.71E-05	0.57	21	1.0	0.1	3.18E-04	1.05E-03	0.9	223.0	Redwater Plain

5.3.5 Model Output

The ARC model predictions of critical loads for critical chemical values reached after 50 and 100 years of acid deposition were derived from tabulated model output data for a 300 year period, and are presented in Table 14. Table 14 shows the changes in relation to given acid deposition inputs for four time periods. An example of model outputs is also presented in diagrammatic form in the charts in Figure 3.

Table 14. Changes in Soil Chemistry in Relation to Different Acid Inputs

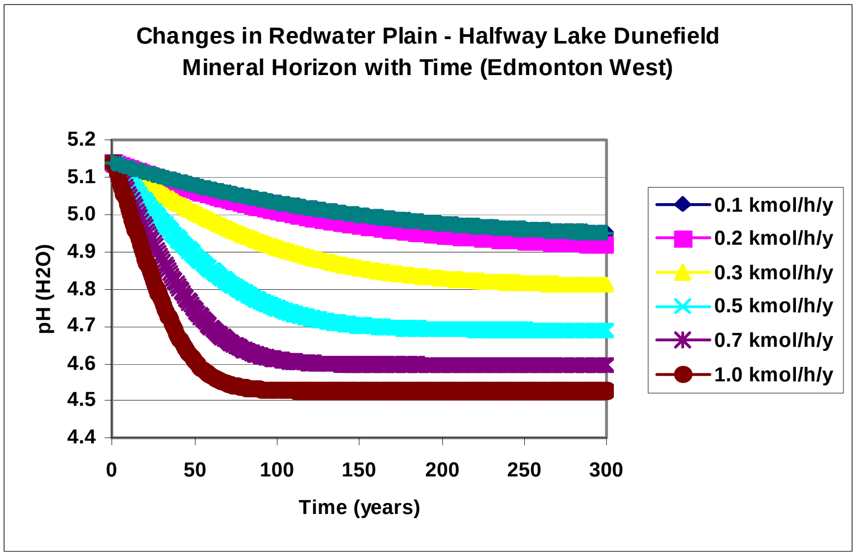
Acid Input	pH				Base Saturation				BC:Al Ratio			
kmol ha^{-1} yr^{-1}	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr
Yeoford Plain/Falun Plain – Breton												
0.1	5.7	5.7	5.7	5.7	0.56	0.56	0.56	0.56	29	29	29	29
0.2	5.7	5.7	5.7	5.7	0.56	0.56	0.56	0.56	29	29	29	29
0.3	5.7	5.7	5.7	5.7	0.56	0.56	0.56	0.56	29	29	29	29
0.5	5.7	5.7	5.7	5.7	0.56	0.56	0.56	0.56	29	29	29	29
0.7	5.7	5.7	5.7	5.6	0.56	0.56	0.56	0.53	29	29	29	27
1.0	5.7	5.7	5.6	5.4	0.56	0.56	0.53	0.44	29	29	27	24
Graminia Plain 1 – Nestow												
0.1	5.7	5.7	5.7	5.7	0.61	0.61	0.61	0.61	29	29	29	29
0.2	5.7	5.7	5.7	5.7	0.61	0.61	0.61	0.61	29	29	29	29
0.3	5.7	5.7	5.7	5.7	0.61	0.61	0.61	0.61	29	29	29	29
0.5	5.7	5.7	5.7	5.6	0.61	0.61	0.60	0.54	29	29	28	25
0.7	5.7	5.7	5.6	5.3	0.61	0.61	0.56	0.41	29	29	26	18
1.0	5.7	5.7	5.4	4.9	0.61	0.61	0.49	0.21	29	29	22	11
Graminia Plain 2 – Helliwell												
0.1	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
0.2	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
0.3	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
0.5	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
0.7	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
1.0	6.4	6.4	6.4	6.4	0.77	0.77	0.77	0.77	65	65	65	65
George Lake Plain 1 – Cooking Lake												
0.1	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
0.2	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
0.3	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
0.5	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
0.7	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
1.0	4.6	4.6	4.6	4.6	0.19	0.19	0.19	0.19	8	8	8	8
Islet Upland 1 - Uncas												
0.1	4.6	4.6	4.6	4.6	0.42	0.42	0.42	0.42	8	8	8	8
0.2	4.6	4.6	4.6	4.6	0.42	0.42	0.42	0.42	8	8	8	8
0.3	4.6	4.6	4.6	4.6	0.42	0.42	0.42	0.42	8	8	8	8
0.5	4.6	4.6	4.6	4.6	0.42	0.42	0.42	0.42	8	8	8	8
0.7	4.6	4.6	4.6	4.6	0.42	0.42	0.42	0.42	8	8	8	8
1.0	4.6	4.6	4.5	4.5	0.42	0.42	0.41	0.39	8	8	8	7
Islet Upland 2 – Cooking Lake												
0.1	5.4	5.4	5.4	5.4	0.57	0.57	0.57	0.57	21	21	21	21
0.2	5.4	5.4	5.4	5.4	0.57	0.57	0.57	0.57	21	21	21	21
0.3	5.4	5.4	5.4	5.4	0.57	0.57	0.57	0.57	21	21	21	21
0.5	5.4	5.4	5.4	5.4	0.57	0.57	0.57	0.57	21	21	21	21
0.7	5.4	5.4	5.4	5.4	0.57	0.57	0.57	0.57	21	21	21	21

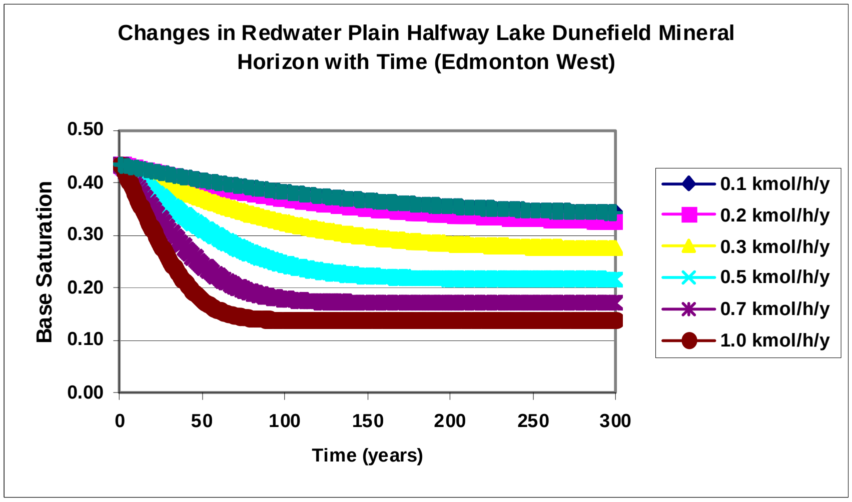
Table 14. Changes in Soil Chemistry in Relation to Different Acid Inputs

Acid Input	pH				Base Saturation				BC:Al Ratio			
kmol ha^{-1} yr^{-1}	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr
1.0	5.4	5.4	5.4	5.2	0.57	0.57	0.57	0.49	21	21	21	17
George Lake Plain 2 – Cooking Lake												
0.1	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.55	29	29	29	29
0.2	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.55	29	29	29	29
0.3	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.55	29	29	29	29
0.5	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.55	29	29	29	29
0.7	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.55	29	29	29	29
1.0	5.7	5.7	5.7	5.7	0.55	0.55	0.55	0.54	29	29	29	29
George Lake Plain 3 – Cooking Lake (Acidic)												
0.1	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
0.2	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
0.3	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
0.5	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
0.7	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
1.0	4.4	4.4	4.4	4.4	0.20	0.20	0.20	0.20	7	7	7	7
George Lake Plain 4 – Cooking Lake (Forage)												
0.1	4.8	4.8	4.8	4.8	0.29	0.29	0.29	0.29	10	10	10	10
0.2	4.8	4.8	4.8	4.8	0.29	0.29	0.29	0.29	10	10	10	10
0.3	4.8	4.8	4.8	4.8	0.29	0.29	0.29	0.29	10	10	10	10
0.5	4.8	4.8	4.8	4.8	0.29	0.29	0.28	0.29	10	10	10	10
0.7	4.8	4.8	4.7	4.5	0.29	0.27	0.25	0.17	10	10	9	7
1.0	4.8	4.7	4.6	4.3	0.29	0.25	0.21	0.05	10	9	8	6
Islet Upland 3 - Cooking Lake (Forage)												
0.1	6.3	6.3	6.2	6.2	0.63	0.63	0.62	0.60	55	54	53	51
0.2	6.3	6.2	6.2	6.1	0.63	0.62	0.61	0.57	55	53	51	46
0.3	6.3	6.2	6.2	6.0	0.63	0.61	0.59	0.53	55	52	49	42
0.5	6.3	6.2	6.1	5.9	0.63	0.60	0.56	0.46	55	50	46	35
0.7	6.3	6.2	6.1	5.7	0.63	0.58	0.54	0.39	55	48	43	29
1.0	6.3	6.1	6.0	5.5	0.63	0.56	0.50	0.27	55	46	39	22
Pipestone Upland 1 – Helliwell												
0.1	5.2	5.2	5.2	5.2	0.52	0.52	0.52	0.52	16	16	16	16
0.2	5.2	5.2	5.2	5.2	0.52	0.52	0.52	0.52	16	16	16	16
0.3	5.2	5.2	5.2	5.2	0.52	0.52	0.52	0.51	16	16	16	16
0.5	5.2	5.2	5.1	4.9	0.52	0.51	0.49	0.43	16	16	14	11
0.7	5.2	5.1	5.0	4.7	0.52	0.49	0.45	0.37	16	15	13	9
1.0	5.2	5.0	4.8	4.6	0.52	0.46	0.40	0.33	16	13	10	8
Pipestone Upland 2 – Peace Hills												
0.1	5.6	5.6	5.6	5.5	0.57	0.57	0.56	0.55	25	25	25	24
0.2	5.6	5.6	5.5	5.4	0.57	0.56	0.55	0.52	25	25	24	21
0.3	5.6	5.6	5.5	5.4	0.57	0.56	0.54	0.50	25	24	23	19
0.5	5.6	5.4	5.4	5.2	0.57	0.55	0.52	0.44	25	23	21	16
0.7	5.6	5.5	5.4	5.0	0.57	0.54	0.51	0.39	25	23	20	13
1.0	5.6	5.4	5.3	4.7	0.57	0.52	0.48	0.30	25	21	18	9
Redwater Plain/Halfway Lake Dunefield - Nestow												
0.1	5.1	5.1	5.0	5.0	0.44	0.41	0.38	0.34	15	14	14	12
0.2	5.1	5.1	5.0	4.9	0.44	0.40	0.37	0.33	15	14	13	12
0.3	5.1	5.0	4.9	4.8	0.44	0.38	0.33	0.28	15	13	12	11
0.5	5.1	4.9	4.7	4.7	0.44	0.31	0.25	0.22	15	12	10	9
0.7	5.1	4.7	4.6	4.6	0.44	0.24	0.18	0.17	15	10	8	8

Table 14. Changes in Soil Chemistry in Relation to Different Acid Inputs

Acid Input	pH				Base Saturation				BC:Al Ratio			
kmol ha^{-1} yr^{-1}	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr	0 yr	50 yr	100 yr	300 yr
1.0	5.1	4.6	4.5	4.5	0.44	0.18	0.14	0.14	15	8	8	8
Redwater Plain - Nestow (Forage)												
0.1	5.4	5.4	5.4	5.4	0.57	0.57	0.56	0.54	21	21	20	19
0.2	5.4	5.4	5.3	5.2	0.57	0.56	0.54	0.47	21	20	19	16
0.3	5.4	5.4	5.3	5.0	0.57	0.54	0.51	3.9	21	19	18	14
0.5	5.4	5.3	5.2	4.8	0.57	0.52	0.46	0.25	21	18	16	10
0.7	5.4	5.3	5.1	4.5	0.57	0.49	0.41	0.11	21	17	14	7
1.0	5.4	5.2	4.9	4.2	0.57	0.45	0.34	0.00	21	16	12	5





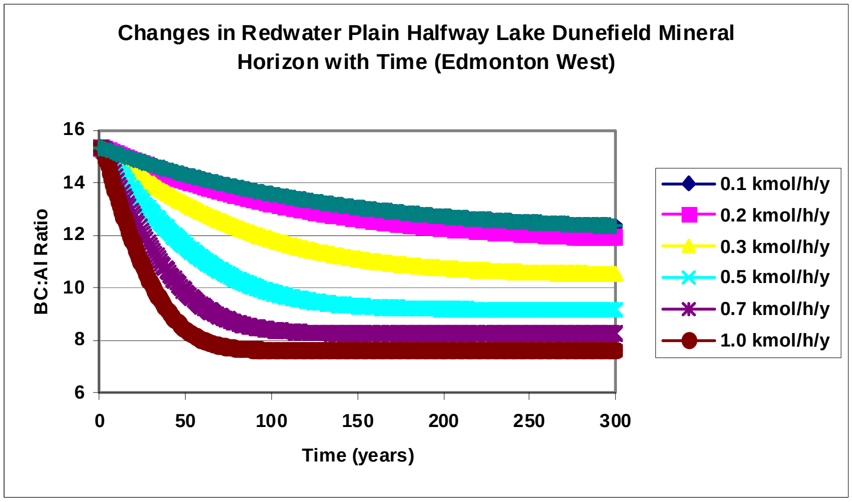


Figure 3. Example of Soil Chemistry Changes Over Time

5.3.6 Critical Chemical Values for the Soil Groups

The rationale for selecting critical chemical values was described in Section 2.2. In order to derive critical loads, the threshold level for a change in a chemical parameter must be selected, as well as the period over which this change can occur. Once a threshold is reached, however, soil chemistry would be negatively affected. A level of protection of the soil was considered whereby only a percentage of a parameter in question would be affected, well before the critical load is reached. This approach was applied in developing critical loads in the Oil Sands area, upon the suggestion of the NO_X/SO_2 Management Working Group of the Cumulative Environmental Management Association (Abboud et al. 2002). Levels of 75% of the original soil value, and the mid-point between the original value and the literature-based critical load, were examined. The more protective of these levels is recommended in the examination of critical loads for the Edmonton West grid cell, namely application of the 75% case as the soil critical load. Acidification (i.e., PAI) levels resulting in these thresholds being reached within 50 and 100 years were derived from the model data. The lower value of the BC:Al ratio or base saturation percentage is suggested as the critical load. PAI levels required to reach the full critical chemical values were also examined, including the critical values of pH(H_2O) 4.0 and 5.6, for forested and grassland soils respectively. Table 15 shows the critical chemical values established or calculated for the various soil groups.

Table 15. Critical Chemical Values Calculated from Initial Soil Data

Site	Soil Series	Mineral Critical Chemical Value[Z]							
		pH_{hi}[Y]	pH_h = 4.0 or 5.6	$BSat_i$	$BSat_i$ 75%	BSat=0.1	$BC:Al_i$	$BC:Al_i$ 75%	BC:Al=1 or 45
Luvisols									
Yeoford Plain/Falun Plain	Breton	5.7	4.0	0.56	0.42	0.1	29	22	1
George Lake Plain 1	Cooking Lake	46	4.0	0.19	0.14	0.1	8	6	1
Islet Upland 1	Uncas	4.6	4.0	0.42	0.32	0.1	8	6	1
Islet Upland 2	Cooking Lake	5.4	4.0	0.57	0.43	0.1	21	16	1
George Lake Plain 2	Cooking Lake	5.7	4.0	0.55	0.41	0.1	29	22	1
George Lake Plain 3	Cooking Lake (Acidic)	4.4	4.0	0.20	0.15	0.1	7	5	1
George Lake Plain 4	Cooking Lake (Forage)	4.8	4.0	0.29	0.22	0.1	10	8	1
Islet Upland 3	Cooking Lake (Forage)	6.3	4.0	0.63	0.47	0.1	58	44	1
Brunisols									
Graminia Plain 1	Nestow	5.7	4.0	0.61	0.46	0.1	16	12	1
Redwater Plain/ Halfway Lake Dunefield	Nestow	5.1	4.0	0.44	0.33	0.1	15	11	1
Redwater Plain	Nestow (Forage)	5.4	4.0	0.57	0.43	0.1	21	16	1
Chernozems									
Graminia Plain 2	Helliwell	6.4	5.6	0.77	0.58	0.1	65	49	45
Pipestone Upland 1	Helliwell	5.2	5.6	0.52	0.39	0.1	16	12	45
Pipestone Plain 2	Peace Hills	5.6	5.6	0.57	0.43	0.1	26	20	45

[Z] Critical chemical value for the 25 cm surface soil layer.

[Y] Abbreviations: pH_h - soil pH measured in H_2O solution; pH_{hi} - initial pH_h; BSat - base saturation percentage; $Bsat_i$ - initial BSat; BC:Al - base cation to aluminum ratio in soil solution; $BC:Al_i$ – initial BC:Al.

5.3.7 Critical Load Derivation

The time frame within which changes in soil chemistry occur is an important consideration in using dynamic models to derive critical loads. Decisions are required as to whether critical values of soil chemical parameters may be reached in only a few years, or over a longer period. Fifty and one hundred year time periods were selected for these decisions. Fifty years is a relatively short period, and its selection is based on the view that it is of sufficient length to enable detection of an actual acidification trend and to initiate measures to counteract the trend. One hundred years is a longer time frame that results in a lower critical load, and it therefore provides a greater measure of protection.

The ARC model predictions of critical loads for critical chemical values reached after 50 and 100 years of acid deposition were derived from the tabulated model output (Table 14), and are presented in Table 16.

The lowest critical loads were obtained for the 75% case of the BC:Al ratio. Applying the principle of selecting the lowest of the calculated critical loads, the BC:Al ratio would therefore provide the basis of critical loads for soils in the study area. The highest critical loads were obtained for the Luvisolic and Chernozemic soils. Although the Chernozemic soils included in this investigation are very coarse to coarse textured, acid buffering is provided by the relatively high organic matter content which contributes a large supply of exchangeable cations in addition to that associated with the mineral component alone. Acid buffering in Luvisols is likely influenced by their finer textures as compared to the Brunisols and Chernozems. The Brunisols in the Edmonton West area have low organic matter and clay content, and they therefore have the least acid buffering capacity.

Table 16. ARC Model Predictions of Critical Loads for Critical Chemical Values Reached after 50 and 100 Years of Acid Deposition

Site	**Soil Series**	**Time (years)**	**Mineral Critical Load Value[Z] (kmol H$^+$ ha^{-1} yr^{-1})**				
			pH$_h$[Y]	**BSat$_i$x0.75**	**BSat=0.1, 0.5**	**BC:Al$_i$x0.75**	**BC:Al=1 or 45**
Luvisols							
Yeoford Plain/ Falun Plain	Breton	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
George Lake Plain 1	Cooking Lake	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
Islet Upland 1	Uncas	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
Islet Upland 2	Cooking Lake	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
George Lake Plain 2	Cooking Lake	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
George Lake Plain 3	Cooking Lake (Acidic)	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
George Lake Plain 4	Cooking Lake (Forage)	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
Islet Upland 3	Cooking Lake (Forage)	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	0.8	>1
Brunisols							
Graminia Plain 1	Nestow	50	>1	>1	>1	>1	>1
		100	>1	>1	>1	>1	>1
Redwater Plain/Halfway Lake Dunefield	Nestow	50	>1	0.7	>1	0.7	>1
		100	>1	0.6	>1	0.5	>1
Redwater Plain	Nestow (Forage)	50	>1	>1	>1	1	>1
		100	>1	0.8	>1	0.7	>1
Chernozems							
Graminia Plain 2	Helliwell	50	>1	>1	>1	>1	>1[V]
		100	>1	>1	>1	>1	>1[V]
Pipestone Upland 1	Helliwell	50	-[X]	>1	>1	>1[W]	>1[V]
		100	-[X]	>1	>1	0.8[W]	>1[V]
Pipestone Upland 2	Peace Hills	50	-[X]	>1	>1	>1[W]	>1[V]
		100	-[X]	>1	>1	0.8[W]	>1[V]

[Z] Symbols: BSat - base saturation; BC:Al - base cation to Al ratio; i - the initial, or model input value; 75% - percentage of the initial value.

[Y] pH$_h$ values are 4.0 for Luvisols and Brunisols, and 5.6 for Chernozems; BC:Al critical values are 1 for Luvisols and Brunisols, and 45 for Chernozems.

[X] Chernozemic soils with critical pH of 5.6; initial pH values of these soils were <5.6.

[W] Critical load based on 75% reduction of BC:Al ratio. However, the initial values are less than the BC:Al critical chemical value of 45 for Chernozemic soils.

[V] Chernozemic soils with BC:Al CCV of 45. All other soils have BC:Al CCV of 1.

5.4 COMPARISON OF METHODS OF CRITICAL LOAD DERIVATION

Critical loads for sandy soils in the Edmonton West study area, as determined by the Empirical, Steady State Mass Balance and ARC models are summarized in Table 17.

Table 17. Comparison of Critical Loads Derived by Different Methods

CL Derivation Method and Criterion	**Critical Load (kmol ha^{-1} yr^{-1})**						
Land System	Yeoford/ Falun Plain	Graminia Plain 1	Graminia Plain 2	George Lake Plain 1	Islet Upland 1	Islet Upland 2	George Lake Plain 2
Sites	13, 16, 18	17	11	12	19	5, 6, 7, 8, BR	3
Empirical	1-2	0.2-0.5	0.5-1.0	1-2	1-2	1-2	1-2
SSMB	2.9	0.7	0.4	2.9	2.9	2.9	2.9
ARC pH_{50}	>1	>1	>1	>1	>1	>1	>1
ARC pH_{100}	>1	>1	>1	>1	>1	>1	>1
ARC $BSat_{50}$	>1	>1	>1	>1	>1	>1	>1
ARC $BSat_{100}$	>1	>1	>1	>1	>1	>1	>1
ARC BC:Al_{50}	>1	>1	>1	>1	>1	>1	>1
ARC BC:Al_{100}	>1	>1	>1	>1	>1	>1	>1
Land System	George Lake Plain 3	George Lake Plain 4	Islet Upland 3	Pipestone Upland 1	Pipestone Upland 2	Redwater Plain/Halfway Lake Dunefield	Redwater Plain
Sites	4	1	24	22	25	9, 10, 23, 26	15
Empirical	1-2	1-2	1-2	0.5-1.0	0.5-1.0	0.2-0.5	0.2-0.5
SSMB	2.9	2.9	2.9	0.4	0.5	0.6	0.6
ARC pH_{50}	>1	>1	>1	-[z]	-[z]	>1	>1
ARC pH_{100}	>1	>1	>1	-[z]	-[z]	>1	>1
ARC $BSat_{50}$	>1	>1	>1	>1	>1	0.7	>1
ARC $BSat_{100}$	>1	>1	>1	>1	>1	0.6	0.8
ARC BC:Al_{50}	>1	>1	>1	>1	>1	0.7	1
ARC BC:Al_{100}	>1	>1	0.8	0.8	0.8	0.5	0.7

[z] Chernozemic soils with critical pH of 5.6; initial pH values of these soils were <5.6.

The highest critical loads were obtained with the Empirical and the SSMB approaches for the medium to moderately fine textured Luvisolic soils typical of the George Lake Plain and the Islet Upland land systems. Critical loads based on the ARC model were generally greater than 1 kmol ha^{-1} yr^{-1}, which is in general agreement with the Empirical and SSMB results.

Moderately coarse textured soils of the Graminia Upland and the Pipestone Upland had critical loads in the range of 0.5-1.0 kmol ha^{-1} yr^{-1} based on the Empirical and SSMB models, but the loads were mainly >1 kmol ha^{-1} yr^{-1} based on the ARC model. The soil in Graminia Plain 1 was coarser textured than that of Graminia Plain 2, and had a comparatively lower critical load. For this soil, the ARC load was also >1 kmol ha^{-1} yr^{-1}. The differences between the ARC model results and the Empirical and SSMB results are attributed to the buffering provided by organic matter in these soils, which is included in the ARC model but not in the other approaches. That is, since the critical loads determined with the ARC model are based on cation exchange buffering, the influence of both organic matter and mineral exchangeable ions is included.

The lowest critical loads were derived for the Nestow soils of the Redwater Plain and the Halfway Lake Dunefield. The critical load is 0.5 kmol ha^{-1} yr^{-1} based on the ARC model, 0.2-0.5 kmol ha^{-1} yr^{-1} based on the Empirical approach, and 0.6 kmol ha^{-1} yr^{-1} based on the SSMB approach. Redwater Plain 2 is also characterized by the Nestow soil series, but it is a cultivated soil with forage cover, and it has a slightly higher critical load than the undisturbed Nestow soils.

With respect to critical chemical criteria, the lowest critical loads were obtained for the BC:AL$_{100}$ ratio. Critical loads according to the ARC BC:AL$_{50}$ criterion were commonly similar to those of the Empirical approach, while the SSMB CLs were consistently higher than both of these. However, the SSMB CLs were generally lower than those based on the ARC pH criteria.

Both the Empirical and SSMB approaches to setting critical loads are based on maintaining steady-state over a very long time. They are based on replenishment of base cations in soil by weathering. Steady state methods represent the worst case, and cannot provide a basis for establishment of target loads, which need to be defined in terms of a timescale within which an ecosystem will not be affected (Jenkins et al. 2003). A considerable amount of buffering capability is provided by cations on the cation exchange complex. For protection of soils in the relatively short term, simulation of soil chemistry by dynamic modelling based on cation exchange buffering, as well as weathering, provides more relevant predictions than methods based on weathering alone.

6.0 ACIDIFICATION SENSITIVITY

6.1 SENSITIVITY CLASSES

Previous sections of this report have focused on deriving the critical load for individual soil profiles or groups of very similar profiles. The profiles for which critical loads were derived in this study can be considered to be representative of the various soil series examined. For mapping purposes, however, the critical loads were considered in terms of sensitivity classes by applying an approach developed for the Provost-Esther critical loads study (Abboud et al., 2002). The approach uses both 50 and 100 year model results, and links the critical load determinations to sensitivity classes and to mapping of the loads.

The critical loads were assigned to a sensitivity class that could more or less be equated with critical loads for application in Alberta (Clean Air Strategic Alliance and Alberta Environment 1999). These critical loads are 0.25 kmol ha^{-1} yr^{-1} for Sensitive soils, 0.50 kmol ha^{-1} yr^{-1} for Moderately Sensitive soils, and 1.00 kmol ha^{-1} yr^{-1} for Low Sensitivity soils. Turchenek and Abboud (2001) suggested critical load and sensitivity classes as follows:

≤0.2 kmol ha^{-1} yr^{-1}; critical chemical value reached within 100 years	Sensitive
0.2 to 0.5 kmol ha^{-1} yr^{-1}; critical chemical value within 50 years	Sensitive
0.2 to 0.5 kmol ha^{-1} yr^{-1}; critical chemical value within 100 years	Moderate Sensitivity
0.5 to 1.0 kmol ha^{-1} yr^{-1}; critical chemical value within 50 years	Moderate Sensitivity
0.5 to 1.0 kmol ha^{-1} yr^{-1}; critical chemical value within 100 years	Low Sensitivity
>1.0 kmol ha^{-1} yr^{-1}; critical chemical value within 50 years	Low Sensitivity

The lower value of base saturation or BC:Al critical loads obtained by modelling was used to determine the sensitivity category. The above categories of soil sensitivity indicate, for example, that if BSat or BC:Al is reduced to 75% of the original value within 100 years at a Potential Acid Input level of ≤0.2 kmol ha^{-1} yr^{-1}, than the soil would be regarded as Sensitive. If 0.2 to 0.5 kmol ha^{-1} yr^{-1} reduces these soil properties to the critical chemical values within 50 years, then the soil would also be regarded as Sensitive. However, if 50 to 100 years is required at this latter level, than the soil would be allocated to the Moderate Sensitivity class.

This approach enables the allocation of a specific soil profile to a sensitivity class. The above criteria were applied to the eighteen representative soils or soil groups to which the ARC model was applied, and compared to acidification sensitivity criteria of Holowaychuk and Fessenden (1987). Results are presented in Table 18, along with Holowaychuk and Fessenden (H-F) ratings.

The H-F sensitivity rating in the above table is based directly on the sensitivity map of Holowaychuk and Fessenden (1987). On this map, the Islet Upland Land System (also known as the Cooking Lake moraine) and the North Saskatchewan River Valley were identified as having soils with potentially Moderate Sensitivity, and the Graminia Plain Land System was rated as having (High) Sensitive soils. The ARC modelling results suggest that the predominantly Luvisolic soils of the Islet Upland have Low Sensitivity to acidification. Other differences between the Holowaychuk-Fessenden mapping and the ARC model results pertain to the sandy Brunisolic soils of the Redwater Plain, Halfway Lake Dunefield and Eldorena Plain.

These are mapped as having Low Sensitivity in the Holowaychuk-Fessenden map. In the current study, some of the soils that characterize these Land Systems were indicated as having Moderate Sensitivity according to the ARC model.

Table 18. Critical Loads and Derived Sensitivity Classes

Land System	Soil Series	pH_c[z]	pH_h	Texture 0-25 cm	50 Yr CL	100 Yr CL	H-F Class	Sensitivity Class
Luvisols								
Islet Upland 1	Uncas	4.1	4.6	Sandy Loam - Loam	>1	>1	M	L
Islet Upland 2	Cooking Lake	5.0	5.4	Sandy Loam	>1	>1	M	L
Islet Upland 3	Cooking Lake (Forage)	5.9	6.3	Loam	>1	0.6	M	L
George Lake Plain 1	Uncas	4.1	4.6	Loamy Sand - Sandy Loam	>1	>1	M	L
George Lake Plain 2	Cooking Lake	5.3	5.7	Loam	>1	>1	M	L
George Lake Plain 3	Cooking Lake	3.9	4.4	Very Fine Sandy Loam	>1	>1	M	L
George Lake Plain 4	Cooking Lake (Forage)	4.3	4.8	Very Fine Sandy Loam	>1	>1	M	L
Yeoford Plain/ Falun Plain	Breton	5.3	5.7	Loam - Silt Loam	>1	>1	M	L
Brunisols								
Redwater Plain / Halfway Lake Dunefield	Nestow	4.7	5.1	Sand	0.7	0.5	L	M
Redwater Plain (Forage)	Nestow	5.0	5.4	Sand	1	0.7	L	L
Graminia Plain 1	Nestow	5.3	5.7	Loamy Fine Sand	>1	>1	L(H)	L
Chernozems								
Graminia Plain 2	Helliwell	6.0	6.4	Loamy Sand	>1	>1	L	L
Pipestone Upland 1	Helliwell	4.8	5.2	Loamy Sand	>1	0.8	L	L
Pipestone Upland 2	Peace Hills	5.2	5.6	Sandy Loam	>1	0.8	L	L

[z] Abbreviations: pH_c - $pH(CaCl_2)$; pH_h - $pH(H_2O)$; CL - critical load; H-F Class - Holowaychuk-Fessenden sensitivity class (H – high, M – moderate, L – low, L(H) – Low and High)

Differences in the sensitivity classes are related to the level of detail of soil mapping. In the case of the sandy soil areas in the Redwater Plain, Halfway Lake Dunefield and Eldorena Plain, the H-F map legend indicates that the soils have high organic matter content and high exchangeable cation content. These properties are associated with the finer textured soils that also occur in these Land Systems. However, there appears to have been very limited soil profile information for the sandiest soils in the region. These were mapped as 'Dune Sand' soils in the soil survey of the Edmonton sheet (Bowser et al. 1962), and were also apparently assumed to be characterized by relatively high organic matter and associated buffering capacity in sensitivity mapping. Since the publication of the acidification sensitivity map by Holowaychuk and Fessenden (1987), more detailed mapping has been carried out for the AGRASID (Agricultural Region of Alberta Soil Information Database) program (Alberta Soil Information Centre 2007). The sandy soils on eolian deposits were mapped as Eluviated Eutric Brunisols

(Primula Soil Series). In the current study, the soil profiles sampled were Eluviated Dystric Brunisols and were designated as the Nestow Soil Series. It is likely that both of these soil series occur in the sandy landscapes of the Edmonton West grid cell, with the more acidic Nestow Soil Series being relatively more sensitive than the Primula Soil Series.

With regard to differences in the H-F map and the ARC model results for the Luvisolic soils of the Islet Upland and the Brunisolic soils of the Graminia Plain, the buffering capacity of the litter layer in these soils appears to be a major factor affecting sensitivity. In applying the ARC model, the effect of acid input on the litter was first calculated. The water percolating through the litter was thus reduced in acidity, and the impact on the mineral surface horizon(s) was diminished. The critical loads were based on the chemical effect on the mineral part of the soil (0-25 cm) and not on the litter. Consequently, the Luvisols under native forest in the Edmonton West grid cell were determined to have Low Sensitivity to acidification.

6.2 SENSITIVITY MAP

From the results in Table 19, critical loads mapping was based on assignment of the most acid sensitive soil series to categories as follows:

Nestow (Primula)	Moderate
All others	Low

In assigning sensitivity categories to Land Systems, the derivation of critical loads for the Edmonton East map sheet was also considered. The Redwater Plain and Eldorena Plain Land Systems were determined to have a component of Sensitive soils along with both Moderate and Low Sensitivity soils. The proportions were estimated by assigning half of the Nestow and Primula soils to the Sensitive category, and the other half to the Moderate category. While no Sensitive categories were determined in the Edmonton West map area, it was assumed that some Sensitive soils do occur, and the proportions applied in the Edmonton East map sheet were also applied in the Edmonton West sheet. This approach also ensured that these Land Systems would be mapped uniformly across the boundary of these two map sheets.

A map depicting the Land Systems, land cover and soil sensitivity to acid inputs in the Edmonton West map sheet was developed based on soils and land cover information as described in Sections 3.1 and 3.3. The proportions of land cover in each Land System under the categories of Cultivated, Trees, Shrubs, Grasslands, Wetlands and Other Lands are provided in Appendix C.

The soil rating for sensitivity to acid inputs, as determined in the previous section, was superimposed on the land cover information. Proportions of soil series within Land Systems were estimated from information provided in Table 2, and from this, the proportions of soils in Moderate to Sensitive (Nestow and Primula and Low (all other soils) acidification sensitivity categories were derived. The sensitivity ratings were applied only to soils under grassland, tree, and shrub land cover types. Wetlands and cultivated soils were not rated, nor were lands categorized as ‘Other Lands’.

Table 19. Acidification Sensitivity of Land Systems in the Edmonton West Grid Cell

LAND SYSTEM	LAND SYSTEM DESCRIPTION	MAJOR SOILS	MINOR SOILS	ACIDIFICATION SENSITIVITY
05.00.09 Battle River Valley	Landscape is valley bottom with some confined floodplain. Regosols developed on undifferentiated material. Minor soils include coarse textured soils. Significant eroded soils present.	Miscellaneous Eroded	Milk River-AA (Cumulic Regosol)	Low - 51% Cultivated - 20% Wetland - 25% Other - 4%
05.3d.01 Morinville Plain	Landscape is undulating. Black Solonetz developed on medium textured till and fine textured water-laid sediments. Minor soils include Chernozems and Gleysols.	Camrose (Black Solodized Solonetz) Duagh (Black Solonetz)	Angus Ridge (Eluviated Black Chernozem) Gleysols/Water	Low - 32% Cultivated - 67% Wetland - 1%
05.3d.07 Namao Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments and medium textured water-laid sediments.	Malmo (Eluviated Black Chernozem) Ponoka (Eluviated Black Chernozem)	Angus Ridge (Eluviated Black Chernozem) Mico (Orthic Dark Gray Chernozem)	Low - 27% Cultivated - 69% Wetland – 1% Other - 2%
05.3d.09 Partridge Plain	Landscape is undulating. Black Chernozems developed on medium textured till. Minor soils include Gleysols.	Angus Ridge (Eluviated Black Chernozem)	Rolly View (Orthic Dark Gray Chernozem) Gleysols/Water	Low - 28% Cultivated - 72%
05.3d.10 Cawes Plain	Landscape is undulating. Black Chernozems developed on medium textured till.	Angus Ridge (Eluviated Black Chernozem)	Hobbema (Eluviated Black Chernozem) Rolly View (Orthic Dark Gray Chernozem)	Low - 16% Cultivated - 83% Other - 1%
05.3d.11 Pointe-aux-Pins Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments.	Malmo (Eluviated Black Chernozem)	Angus Ridge (Eluviated Black Chernozem) Looma (Orthic Dark Gray Chernozem)	Low - 25% Cultivated - 72% Other - 3%
05.3d.14 City of Edmonton	City of Edmonton.	Disturbed Lands		Low - 19% Cultivated - 27% Wetland - 2% Other - 52%
05.3d.18 Spruce Grove Plain	Landscape is undulating with some peatlands. Dark Gray Chernozems developed on medium textured water-laid sediments. Minor soils include Organic and fine textured soils.	Winterburn (Orthic Dark Gray)	Organics Malmo (Eluviated Black Chernozem)	Low - 36% Cultivated - 53% Wetland - 7% Other - 4%
05.3d.19 Longhurst Plain	Landscape is undulating with some peatlands. Dark Gray Chernozems developed on medium textured water-laid sediments. Minor soils include Organic and coarse textured soils.	Winterburn (Orthic Dark Gray)	Redwater (Orthic Dark Gray Chernozem) Organics	Low - 26% Cultivated - 71% Wetland – 1% Other - 2%
05.3d.20 Graminia Plain	Landscape is undulating with some duned. Dark Gray Luvisols developed on coarse textured sediments. Minor soils include Organic.	Elk Point (Dark Gray Luvisol) Tiger Lily (Orthic Gray Luvisol)	Organics	Low - 57% Cultivated - 42% Wetland - 1%

Table 19. Acidification Sensitivity of Land Systems in the Edmonton West Grid Cell

LAND SYSTEM	LAND SYSTEM DESCRIPTION	MAJOR SOILS	MINOR SOILS	ACIDIFICATION SENSITIVITY
05.3d.21 Calmar Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments.	Malmo (Eluviated Black Chernozem)	Ponoka (Eluviated Black Chernozem) Looma (Orthic Dark Gray Chernozem)	Low - 9% Cultivated - 88% Other - 3%
05.3d.22 Watelet Plain	Landscape is undulating. Black Chernozems and Black Solonetz developed on medium textured till and medium textured softrock.	Angus Ridge (Eluviated Black Chernozem) Kavanagh (Black Solodized Solonetz)	Hobbema Rolly View (Orthic Dark Gray Chernozem)	Low - 20% Cultivated - 76% Other - 4%
05.3d.26 Big Hay Plain	Landscape is undulating with some level, closed basin. Black Chernozems and Black Solonetz developed on medium textured till and fine textured water-laid sediments. Minor soils include Gleysols.	Angus Ridge (Eluviated Black Chernozem) Wetaskiwin (Black Solodized Solonetz)	Malmo (Eluviated Black Chernozem) Gleysols/Water	Low - 42% Cultivated - 54% Wetland - 3& Other - 1%
05.3d.27 Ferlow Plain	Landscape is hummocky. Black Chernozems developed on medium textured till. Minor soils include Gleysols.	Angus Ridge (Eluviated Black Chernozem)	Rolly View (Orthic Dark Gray Chernozem) Gleysols/Water	Low - 34% Cultivated - 65% Wetland - 1%
05.3d.28 Pipestone Upland	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments and medium textured water-laid sediments. Minor soils include Gleysols.	Peace Hills (Orthic Black Chernozem) Ponoka (Eluviated Black Chernozem)	Gleysols/Water	Low - 43% Cultivated - 55% Wetland - 1% Other - 1%
05.3d.30 Bigstone Plain	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments and medium textured material over medium textured till. Minor soils include Gleysols.	Peace Hills (Orthic Black Chernozem) Hobbema (Eluviated Black Chernozem)	Ponoka (Eluviated Black Chernozem) Gleysols/Water	Low - 20% Cultivated - 80%
05.3d.31 Samson Lake Plain	Landscape is undulating. Black Chernozems developed on fine textured water-laid sediments. Minor soils include Solonetz and Gleysols.	Malmo (Eluviated Black Chernozem)	Gleysols/Water Gleysols/Water	Low - 41% Cultivated - 58% Wetland - 1%
05.3d.50 Looma Upland	Landscape is hummocky. Dark Gray Chernozems and Dark Gray Luvisols developed on medium textured till. Minor soils include Gleysols and fine textured soils.	Uncas (Dark Gray Luvisol)) Uncas (Dark Gray Luvisol)	Mico (Orthic Dark Gray Chernozem) Gleysols/Water	Low - 57% Cultivated - 42% Wetland - 1%
05.4a.15 Ryley Plain	Landscape is undulating. Black Solonetz developed on medium textured till. Minor soils include Chernozems and Gleysols.	Camrose (Black Solodized Solonetz)	Norma (Solonetzic Black Chernozem) Gleysols/Water	Low - 35% Cultivated - 36% Wetland - 29%
05.6.01 Islet Upland	Landscape is hummocky. Dark Gray and Dark Gray Luvisols developed on medium textured till. Minor soils include Gleysols, Chernozems and fine textured soils.	Cooking Lake (Orthic Gray Luvisol) Uncas (Dark Gray Luvisol)	Gleysols/Water Mico (Orthic Dark Gray Chernozem)	Low - 68% Cultivated - 21% Wetland - 11%

Table 19. Acidification Sensitivity of Land Systems in the Edmonton West Grid Cell

LAND SYSTEM	LAND SYSTEM DESCRIPTION	MAJOR SOILS	MINOR SOILS	ACIDIFICATION SENSITIVITY
06.00.03 North Saskatchewan River Valley	Landscape is inclined <10% exposed bedrock with some numerous water bodies and undulating.	Miscellaneous Eroded		Low - 54% Cultivated - 29% Wetland - 16% Other - 1%
06.1b.02 Yeoford Plain	Landscape is undulating with some rolling and hummocky. Dark Gray and Gray Luvisols developed on medium textured till. Minor soils include Chernozems.	Benalto (Dark Gray Luvisol) Breton (Orthic Gray Luvisol)	Falun (Orthic Dark Gray Chernozem) Keephills (Dark Gray Luvisol)	Low - 44% Cultivated - 56%
06.1b.03 Pigeon Lake	Large water body.	N/A	N/A	Water - 100%
06.1c.12 Falun Plain	Landscape is undulating. Dark Gray Luvisols and Dark Gray Chernozems developed on medium textured till. Minor soils include Organic.	Benalto (Dark Gray Luvisol) Falun (Orthic Dark Gray Chernozem)	Breton (Orthic Gray Luvisol) Organics	Low - 41% Cultivated - 57% Wetland - 2%
06.1d.02 George Lake Plain	Landscape is hummocky with some numerous water bodies. Gray Luvisols and Gray Solonetz developed on medium textured till. Minor soils include Gleysols.	Cooking Lake (Orthic Gray Luvisol) Dnister (Gray Solodized Solonetz)	Nakamun (Solonetzic Gray Luvisol) Gleysols/Water	Low - 64% Cultivated - 36%
06.1d.08 Onoway Upland	Landscape is hummocky. Gray and Dark Gray Luvisols developed on medium textured till. Minor soils include Organic and Chernozems.	Cooking Lake (Orthic Gray Luvisol) Uncas (Dark Gray Luvisol)	Organics Miscellaneous Coarse Textured Soils	Low - 67% Cultivated - 30% Wetland - 3%
06.1d.20 Mink Lake Plain	Landscape is hummocky. Gray Luvisols developed on medium textured water-laid sediments.	Glory (Orthic Gray Luvisol) Highvale (Orthic Gray Luvisol)	Carvel (Dark Gray Luvisol) Keephills (Dark Gray Luvisol)	Low - 53% Cultivated - 47%
06.1d.21 Pemburton Hill Plain	Landscape is undulating. Dark Gray Luvisols developed on very fine textured water-laid sediments and areas of moderately fine textured till. Minor soils include Gleysols.	Macola (Dark Gray Luvisol)	Boscombe (Gleyed Dark Gray Luvisol) Gleysols/Water	Low - 72% Cultivated - 28%
06.2a.05 Redwater Plain	Landscape is undulating with some duned. Black Chernozems developed on coarse textured sediments. Minor soils include Brunisols.	Mundare (Orthic Black Chernozem)	Primula (Eluviated Eutric Brunisol) Peace Hills (Orthic Black Chernozem)	Low - 28% Moderate - 34% Sensitive - 7% Cultivated - 31%
06.2a.09 Halfway Lake Dunefield	Landscape is undulating and duned. Brunisols and Dark Gray Chernozems developed on coarse textured sediments. Minor soils include Organic and Gleysols.	Primula (Eluviated Eutric Brunisol) Helliwell (Orthic Dark Gray Chernozem)	Organics Gleysols/Water	Low - 36% Moderate - 38% Sensitive -17% Cultivated - 9%
06.2a.11 Eldorena Plain	Landscape is undulating with some duned. Black Chernozems and Brunisols developed on coarse textured sediments.	Peace Hills (Orthic Black Chernozem) Primula (Eluviated Eutric Brunisol)	Manatokan-AA (Terric Mesisol) Mundare (Orthic Black Chernozem)	Low - 39% Moderate - 25% Sensitive -17% Cultivated - 18

Table 19. Acidification Sensitivity of Land Systems in the Edmonton West Grid Cell

LAND SYSTEM	LAND SYSTEM DESCRIPTION	MAJOR SOILS	MINOR SOILS	ACIDIFICATION SENSITIVITY
06.2b.17 Pakan Plain	Landscape is undulating. Black Chernozems developed on medium textured water-laid sediments. Minor soils include Solonetz.	Ponoka (Eluviated Black Chernozem)	Hobbema (Eluviated Black Chernozem) Kavanagh (Black Solodized Solonetz)	Low - 69% Cultivated - 27% Other - 4%
06.2c.25 Thorhild Plain	Landscape is undulating. Dark Gray Luvisols and Dark Gray Chernozems developed on medium textured till. Minor soils include Gleysols.	Spedden (Orthic Dark Gray Chernozem) Kehiwin (Dark Gray Luvisol)	La Corey (Orthic Gray Luvisol) Gleysols/Water	Low - 46% Cultivated - 54%

The sensitivity category proportions in the various Land Systems are given in Table 20. Only the Redwater Plain, Eldorena Plain and the Halfway Lake Dunefield Land Systems were assigned components of the Sensitive or Moderate categories, as indicated above. The derivation of percentages of different sensitivity classes in these Land Systems is provided in Appendix D.

For purposes of developing a soil sensitivity map, the Land Systems with Sensitive and/or Moderate inclusions were grouped together such that there were two Sensitivity categories on the map. These generalized categories, and the Land Systems in the categories, are indicated in Table 20.

Table 20. Land System Acidification Sensitivity Categories

Acidification Sensitivity Category	Land System
Low - Moderate - Sensitive Mix	Redwater Plain Halfway Lake Dunefield Eldorena Plain
Low	All other Land Systems

The above sensitivity categories were identified by colour coding on the critical loads map. The information from Table 20 is presented as a legend on the map. The map is provided on a CD as well as in hard copy form in the back pocket of this report.

7.0 CONCLUSIONS

The objective of this study was to derive critical loads for soils in the Edmonton West map sheet, an area identified as possibly having significant areas of Sensitive and Moderate Sensitivity soils in the sensitivity classification of Holowaychuk and Fessenden (1987). Critical loads as low as 0.7 kmol H^+ ha^{-1} yr^{-1} over a 50 year assessment period, and 0.5 kmol H^+ ha^{-1} yr^{-1} over a 100 year assessment period were estimated by application of the ARC soil acidification model. Most soils were determined to have critical loads greater than 1.0 kmol H^+ ha^{-1} yr^{-1}. Critical loads determined by two other methods, namely the empirical method and the Steady State Mass Balance method, both based mainly on weathering estimates, were in general agreement with critical loads based on the ARC model.

Portions of three land systems in the Edmonton 83H West Half grid cell were characterized as having a component of Sensitive and Moderately Sensitive soils. These are the Redwater Plain, Halfway Lake Dunefield, and Eldorena Plain. Other Land Systems likely have small components of Sensitive and Moderately Sensitive soils, but of too low extent to enable mapping at the scale applied in this assessment. The assignment of Sensitive, Moderate and Low Sensitivity categories was applied only to lands classified as having grassland, tree or shrub cover, on the basis of 1993-1995 land use mapping by the Prairie Farm Rehabilitation Administration. Sensitive soils account for 0.65% and Moderately Sensitive soils account for 2.3% of the entire grid cell area. As defined in the Acid Deposition Management Framework (Clean Air Strategic Alliance and Alberta Environment 1999), this finding does not support the assignment of this grid cell to a Sensitive or Moderate Sensitivity rating.

8.0 REFERENCES CITED

Abboud, S.A. and L.W. Turchenek. 1990. Assessment of present and potential effects of acidic and acidifying air pollutants on Alberta soils. *In* Acidic deposition: sulfur and nitrogen oxides, The Alberta Government/Industry Acid Deposition Research Program (ADRP). A.H. Legge and S.V. Krupa (Eds). Lewis Publishers, Chelsea, Michigan. pp. 555-605.

Abboud, S.A. and L.W. Turchenek. 2009. Site-specific critical loads of acid deposition on soils in the Edmonton 83H East map sheet, Alberta. Prepared for Alberta Environment. Land Monitoring Team. Edmonton, AB. 61 pp, appendices and map.

Abboud, S. A., L. W. Turchenek, L.W. and Halsey, L.A. 2002. Critical loads of acid deposition on soils in the Athabasca Oil Sands Region, Alberta. Prep. By Alberta Research Council, AMEC Earth & Environmental Ltd., and University of Alberta, for NOx-SO_2 Management Working Group, Cumulative Environmental Management Association. Edmonton, AB.

Aherne, J. and S.A. Watmough. 2006. Calculating critical loads of acid deposition for forest soils in Manitoba and Saskatchewan. PN1372. Canadian Council of Ministers of the Environment. Ottawa.

Alberta Soil Information Centre, Alberta Agriculture and Rural Development. 2007. Agriculture Region of Alberta Soil Inventory Database (AGRASID 3.0). http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903).

Bache, B.W. 1980. The acidification of soils. In T.C. Hutchinson and M. Havas (eds.) Effects of Acid Precipitation of Terrestrial Ecosystems. Plenum Press, New York. Pp. 183 - 202.

Bloom, P.R. and D.F. Grigal. 1985. Modelling soil response to acid deposition in nonsulfate adsorbing soils. Journal of Environmental Quality 14: 489-495.

Bothe, R.A. and C. Abraham. 1993. Evaporation and evapotranspiration in Alberta 1986 to 1992 addendum. Surface Water Assessment Branch, Alberta Environmental Protection. Edmonton, Alberta.

Bowser, W.E. et al. 1962. Soil Survey of Edmonton Sheet (83H). Canada Department of Agriculture. Alberta Soil Survey Report No. 21.

Cheng, L. and R.P. Angle. 1996. Model-calculated interannual variability of concentration, deposition and transboundary transport of anthropogenic sulphur and nitrogen in Alberta. Atmos. Environ. 23: 4,021-4,030.

Cheng, L., R.P. Angle, E. Peake and H.S. Sandhu. 1995. Effective acidity modelling to establish acidic deposition objectives and manage emissions. Atmos. Environ. 29: 383-392.

Cheng, L., K. McDonald, D. Fox and R. Angle. 1997. Total potential acid input in Alberta. The Target Loading Subgroup SO_2 Management Project Team Alberta Clean Air Strategic Alliance. 1494-A9701.

Clean Air Strategic Alliance and Alberta Environment. 1999. Application of Critical, Target and Monitoring Loads for the Evaluation and Management of Acid Deposition. Publication No. T/472. Alberta Environment, Edmonton, Alberta. 67 pp.

Cronan, C.S. and D.F. Grigal. 1995. Use of calcium/aluminum ratios as indicators of stress in forest ecosystems. J. Environ. Qual. 24: 209-226.

Cronan, C.S. and C.L. Schofield. 1990. Relationships between aqueous aluminum and acidic deposition in forested watersheds of North America and northern Europe. Environ. Sci. Technol. 24: 1100-1105.

de Vries, W. 1991. Methodologies for the assessment and mapping of critical loads and of the impact of abatement strategies on forest soils. Rpt 46. DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Wageningen, The Netherlands. 109 pp.

de Vries, W. 1993. Average critical loads for nitrogen and sulfur and it use in acidification abatement policy in the Netherlands. Water, Air and Soil Pollut. 68: 399-434.

Downing, R.J., J.-P. Hettelingh and P.A.M. de Smet (eds.). 1993. Calculation and mapping of critical loads in Europe: Status Report 1993. RIVM Rep. 259101003. Bilthoven, The Netherlands. 163 pp.

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull. Report and national map at 1:7,500,000 scale. (Also website http://www.ec.gc.ca/soer-ree/English/Framework/NarDesc/praire_e.cfm)

Edmeades, D.C., D.M. Wheeler, and R.A. Christie. 1991. The effects of aluminium and pH on the growth of a range of temperate grass species and cultivars. Dev. Plant Soil Sci. 45: 913-924.

Environment Canada. 1993. Canadian Climate Normals, 1961 - 1990. Atmospheric Environment Service.

Environment Canada, 2006. Canadian Climate Normals and Averages 1971-2000. Atmospheric Environment Service [online]. Available: http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

Heady, H.F. and R.D. Child. 1994. Rangeland ecology and management. Westview Press, Boulder. 521 pp.

Henderhot, W.H., H. Lalande and M. Duquette. 1993. Soil reaction and exchange acidity. Chapter 16 in Canadian Society of Soil Science (M. Carter, ed.), Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton.

Henriksen, A., L. Lien and T.S. Traaen. 1990. Critical loads for surface waters - chemical criteria for inputs of strong acids. Acid Rain Research Report 22/1990. Norwegian Institute for Water Research, Oslo. 45 pp.

Henriksen, A., M. Posch, H. Hultberg and L. Lien. 1995. Critical loads of acidity for surface waters: Can the ANC_{limit} be considered variable? Water, Air Soil Pollut. 21: 1591-1601.

Holowaychuk, N. and R.J. Fessenden. 1987. Soil sensitivity to acid deposition and the potential of soils and geology in Alberta to reduce the acidity of acidic inputs. Earth Sciences Report 87-1, Alta Res. Council, Edmonton. 38 pp.

Hornung, M. K.R. Bull, M. Cresser, J. Hall, S.J. Langan, P. Loveland and C. Smith. 1995. An empirical map of critical loads of acidity for soils in Great Britain. Environ. Pollution. 90: 301-310.

Hoyt, P.B., M. Nyborg and H. Ukrainetz. 1981. Degradation by acidification. Proc. 18th Annual Soil Science Workshop. 1981 February 24-25. Edmonton, Alberta. pp. 47-71.

Jenkins, A., B. J. Cosby, R. C. Ferrier, T. Larssen, and M. Posch. 2003. Assessing emission reduction targets with dynamic models: deriving target load functions for use in integrated assessment. Hydrology and Earth System Sciences 7: 609-617.

Kalra, Y.P. and D.G. Maynard. 1991. Methods manual for forest soil and plant analysis. Northwest Region, Information Report NOR-X-319. Forestry Canada, Northwestern Region, Northern Forestry Centre, Edmonton, Alberta. 116 pp.

Levine, E.R. and E.J. Ciolkosz. 1988. Computer simulation of soil sensitivity to acid rain. Soil Sci. Soc. Amer. J. 52: 209-215.

Lindsay, W.L. 1979. Chemical equilibria in soils. Wiley, New York.

Maynard, D.G. 1996. Critical and target loading of soils and vegetation in Alberta. Final report of the Target Loading Subgroup. Edmonton, Alberta. 48 pp.

McBride, M.B. 1994. Environmental chemistry of soils. Oxford Univ. Press, New York. 406 pp.

McKeague, J.A., ed. 1978. Manual on Soil Sampling and Methods of Analysis, 2nd edition. Ottawa: Canadian Society of Soil Science. 212 pp.

Miewes, K.J., P.K. Khanna and B. Ulrich. 1986. Parameters for describing soil acidification and their relevance to the stability of forest ecosystems. For. Ecol. Manage. 15: 161-179.

Nilsson, S.I. 1986. Critical deposition limits for forest soils. In J. Nilsson, ed., Critical Loads For Sulphur and Nitrogen, report from a Nordic working group. Copenhagen: Nordic Council. 151 pp.

Nilsson, S.I. and P. Grennfelt (eds.). 1988. Critical Loads For Sulphur and Nitrogen. NORD 1988:97, Nordic Council of ministers. Copenhagen, Denmark. 418 pp.

Palmer, C.J. and D.O Trew. 1987. The sensitivity of Alberta lakes and soils to acidic deposition: Overview report. Prep. for Environment Protection Services, Alberta Environment. 28 pp.

Pauls, R.W., S.A. Abboud and L.W. Turchenek. 1996. Pollutant deposition impacts on lichens, mosses, wood and soil in the Athabasca oil sands area. Prepared for Syncrude Canada Ltd., Fort McMurray, Alberta, by Alberta Research Council. 223 pp. and Appendix Volume.

Penney, D.C., M. Nyborg, P.B. Hoyt, W.A. Rice, B. Siemens and D.H. Laverty. 1977. An assessment of the soil acidity problem in Alberta and northeastern British Columbia. Proc. 15th Annual Soil Science Workshop. 1977 February 1-2. Edmonton, Alberta. pp. 179-189.

PFRA. 2001. PFRA Generalized Land Cover. Prairie Farm Rehabilitation Administration. Regina, SK. Available: http://www.agri-peri.ir/english/workshop/supporting%20research%20articles/PFRA%20Land%20Cover.pdf

Posch, M., P.A.M. de Smet J.-P. Hettelingh, and R.J. Downing (eds.). 1995. Calculation and mapping of critical thresholds in Europe: Status Report 1995. RIVM Rep. 259101004. Bilthoven, The Netherlands. 198 pp.

Posch, M., J.-P. Hettelingh and J. Slootweg (eds.). 2003. Manual for dynamic modelling of soil resources to atmospheric acid deposition. Report 259101012/2003. ICP M&M Coordination Center for Effects. Netherlands Environmental Assessment Agency. Bilthoven, The Netherlands. 163 pp.

Posch, M., P.A.M. de Smet J.-P. Hettelingh, and R.J. Downing (eds.). 1997. Calculation and mapping of critical thresholds in Europe: Status Report 1997. RIVM Rep. 259101007. Bilthoven, The Netherlands. 163 pp.

Saffran, K. A. and Trew, D. O. 1996. Sensitivity of Alberta lakes to acidifying deposition: an update of sensitivity maps with emphasis on 109 northern lakes. Water Sciences Branch, Water Management Division, Alberta Environmental Protection. 70 pp.

Schindler, D.G. 1996. The response of aquatic systems in Alberta to acidifying emissions. Final report of the Target Loading Subgroup. Edmonton, Alberta. 47 pp.

Soil Classification Working Group. 1998. The Canadian system of soil classification. Third Edition. Agriculture and Agri-Food Canada Publication 1646. NRC Research Press, Ottawa. 187 pp.

Strong, W., B.K. Calverley, A.J. Richard and G.R. Stewart. 1993. Characterization of wetlands in the settled areas of Alberta. Prepared for Wetlands Management Steering Committee. Alberta Water Resources Commission, Alberta Environmental Protection, Alberta Agriculture, Food and Rural Development, Alberta Municipal Affairs, and Alberta Transportation and Utilities. Edmonton.

Strong W.L. and J.M. Thompson. 1995. Ecodistricts of Alberta : Summary of biophysical attributes. Prep. for Alberta Environmental Protection, Resource Data Division. Publ. No. T/319. Edmonton.

Sverdrup, H. 1990. The kinetics of base cation release due to chemical weathering. Lund University Press. Lund, Sweden. 246 pp.

Sverdrup, H. and P. Warfvinge. 1988. Assessment of critical loads of acid deposition on forest soils. Pages 81-130 *in* J. Nilsson (ed.) Critical loads for sulphur and nitrogen. Nordic Council of Ministers and The United Nations Economic Commission for Europe (ECE).

Sverdrup, H. and W. de Vries. 1994. Calculating critical loads for acidity with the simple mass balance method. Water, Air and Soil Pollut. 72: 143-162.

Sverdrup, H., W. de Vries and A. Henriksen. 1990. Mapping critical loads - Guidance to criteria, methods and examples for mapping critical loads and areas where they have been exceeded. Task Force on mapping, with the assistance of The United Nations Economic Commission for Europe, Bad Harzburg, FRG. 124 pp.

Sverdrup, H. and P. Warfvinge. 1993. The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio. Reports in Ecology and Environmental Engineering: 2. Lund University. 108 pp.

Tajek, J., W.W. Pettapiece and K.E. Toogood. 1989. Water supplying capacity of Alberta soils. Alberta Institute of Pedology Publ. M-89-2. Edmonton. Land Resource Research Centre Publ. 89-117. 24 pp.

Task Force on Mapping. 1996. Manual on mapping critical levels/loads and geographical areas where they are exceeded. UN/ECE Convention on Long-Range Transboundary Air Pollution. Federal Environment Agency (Umweltbundesamt), Berlin. 142 pp. + Appendices.

Task Force on Modelling and Mapping. 2004. Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. UNECE Convention on Long-Range Transboundary Air Pollution. Available at: http://www.icpmapping.org.

Turchenek, L.W. and S.A. Abboud. 1988. Application of a computer simulation model to determination of target loadings for acid deposition on soils. Prep. for Research Management Div., Alberta Environment by Alberta Research Council, Edmonton. 86 pp.

Turchenek, L.W. and S.A. Abboud. 2001. Site-specific critical loads of acid deposition on soils in the Provost-Esther area, Alberta. Prep. for Science and Technology Branch, Environmental Sciences Division, Alberta Environment. Calgary, Alberta. 128 pp.

Turchenek, L.W., S.A. Abboud, R. Xie and G. Lutwick. 1994. Acid deposition impacts on Alberta soils: long term response, critical loads and target loading (Year 2 Results). In Acid Deposition Program Progress Reports (1992-93). Section No. 4, pp. 1-72.

Turchenek, L.W., S.A. Abboud, C.J. Tomas, R.J. Fessenden, and N. Holowaychuk. 1987. Effects of acid deposition on soils in Alberta. Prepared for the Acid Deposition Research Program by the Alberta Research Council, Edmonton. ADRP-B-05-87. Calgary, Canada. 202 pp.

Ulrich, B., K.J. Meiwes, N. Konig and P.K. Khanna. 1984. Untersuchungsverfahren und Kriterion zur Bewertung der Versauerung und ihrer Folgen in Waldboden. Forst. u. Holzwirt 39: 278-286.

UBA (Umweltbundesamt). 2004. Manual on methodologies and criteria for modelling and mapping critical loads & levels and air pollution effects, risks and trends. Umweltbundesamt Texte 52/04, Berlin. Available: www.icpmapping.org

United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution. 2006. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Part IIIa. Sampling and analysis of soil. International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. Available: http://www.icp-forests.org/pdf/Chapt_3a_2006(1).pdf

United States Natural Resources Conservation Service. 1999. Soil taxonomy : a basic system of soil classification for making and interpreting soil surveys, 2nd ed. Prep. by soil survey staff. Agriculture Handbook (United States. Dept. of Agriculture) No. 436. U.S. Dept. of Agriculture, Natural Resources, Washington, DC. 869 pp. Available: http://soils.usda.gov/classification/taxonomy/main.htm

Warfvinge, P. and H. Sverdrup. 1992. Calculating critical loads of acid deposition with PROFILE - a steady-state soil chemistry model. Water, Air and Soil Pollut. 63: 119-143.

WBK & Associates Inc. 2006. 2004 Acid Deposition Assessment for Alberta – A Report of the Acid Deposition Assessment Group. Alberta Environment. Edmonton, AB.

APPENDICES

APPENDIX A: SOIL PROFILE DESCRIPTIONS

SITE 1

Location: LSD 13 – NW 11 – T 51 – R 26 – W4M
Classification:
  Subgroup: Eluviated Dystric Brunisol
  Series: Nestow
Land System Graminia Plain
Landform:
  Genetic Material: Eolian
  Surface Expression: Ridged; 10-15% slopes
Drainage/ Perviousness: Rapidly drained; high perviousness
Site Features: Southeast aspect; non-stony
Vegetation: Aspen with a few old jack pine trees; wild rose, green alder, grasses, wintergreen, other forbs
Profile Description:

LFH	4 - 0 cm	Newly fallen aspen leaves over moderately decomposed litter
Ahe	0 - 6 cm	Dark grayish brown (10YR 4/2 dry); sand; single grain to weak granular; very friable to loose; abundant, fine roots; no coarse fragments
Ae	6 - 16 cm	Grayish brown (10YR 5/2 dry); loamy sand; single grain; loose; plentiful fine roots; no coarse fragments
Bm	16 - 30+ cm	Brown (10YR 5/3 dry); loamy sand; single grain; loose; few fine roots; no coarse fragments

SITE 2

Location: LSD 16 – NW 17 – T 51 – R 26 – W4M
Classification:
  Subgroup: Eluviated Dystric Brunisol
  Series: Nestow
Land System Graminia Plain
Landform:
  Genetic Material: Eolian; overlying glaciofluvial
  Surface Expression: Ridged; 10-15% slopes
Drainage/ Perviousness: Rapidly drained; high perviousness
Site Features: Northeast aspect; mid slope position; non-stony
Vegetation: White birch – some jack pine nearby; dense green alder understory; no ground vegetation
Profile Description:

LFH	8 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ahe	0 - 2 cm	Dark gray (10YR 4.5/1 dry); loamy fine sand; single grain to weak granular; very friable to loose; abundant, fine roots; no coarse fragments
Ae	2 - 9 cm	Grayish brown (10YR 5/2 dry); loamy fine sand; single grain; loose; plentiful fine roots; no coarse fragments
AB	9 - 20 cm	Brown (10YR 5/3 dry); loamy fine sand; single grain; loose; few fine roots; no coarse fragments
Bm	20 - 30+ cm	Pale brown (10YR 5.5/3 dry); loamy fine sand; single grain; loose; very few roots; no coarse fragments

SITE 3

Location:	LSD 5 – NW 21 – T 51 – R 27 – W4M
Classification:	
Subgroup:	Dark Gray Chernozem
Series:	Helliwell
Land System	Graminia Plain
Landform:	
Genetic Material:	Glaciofluvial; possibly reworked by wind
Surface Expression:	Undulating; 3-5% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	Northeast aspect; mid slope position; non-stony
Vegetation:	Aspen; dense shrub understory with some forbs

Profile Description:

LFH	5 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ah	0 - 12 cm	Dark gray (10YR 4/1 dry); loamy sand; single grain to weak granular; very friable to loose; abundant, fine roots; no coarse fragments
Ae	12 - 21 cm	Light brownish gray (10YR 6/2 dry); loamy sand; single grain; loose; plentiful fine roots; no coarse fragments
Bm	21 - 30+ cm	Pale brown (10YR 5.5/3 dry); loamy sand; single grain; loose; very few roots; no coarse fragments

Site 4

Location:	LSD 9 – NE 24 – T 55 – R 1 – W5M
Classification:	
Subgroup:	Dark Gray Luvisol
Series:	Uncas
Land System	George Lake Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Moderately well drained; medium perviousness
Site Features:	Southwest aspect; mid slope position; moderately stony
Vegetation:	Aspen; dense shrub (rose and green alder) understory with some forbs

Profile Description:

LFH	4 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ah	0 - 8 cm	Dark gray (10YR 4/1 dry); loamy sand to sandy loam; medium granular; very friable; abundant, fine roots; few coarse fragments
Ae	8 - 32 cm	Gray to light gray (10YR 6/1 dry); sandy loam to loam; strong, medium platy; friable; plentiful fine roots; few coarse fragments
Bt	32+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky; firm; very few roots; few coarse fragments

SITE 5

Location: LSD 14 – NW 12 – T 52 – R 21 – W4M
Classification:
  Subgroup: Dark Gray Luvisol
  Series: Uncas
Land System Islet Upland
Landform:
  Genetic Material: Glacial till
  Surface Expression: Hummocky; 15-20% slopes
Drainage/ Perviousness: Well drained; medium perviousness
Site Features: West aspect; mid slope position; moderately stony
Vegetation: Aspen; some white spruce; dense shrub understory (rose, green alder, cranberry); wintergreen; some forbs

Profile Description:

LFH	6 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ah	0 - 4 cm	Dark gray (10YR 4/1 dry); sandy loam to loam; granular; very friable; abundant, fine roots; few coarse fragments
Ahe	4 - 13 cm	Gray (10YR 5/1 dry); sandy loam to loam; weak platy; very friable; plentiful fine roots; few coarse fragments
Ae	13 - 25 cm	Light brownish gray (10YR 6.5/2 dry); sandy loam; moderate, medium platy; very friable; plentiful fine roots; few coarse fragments
Bt	25 - 30+ cm	Brown (10YR 5/3 dry); clay loamy; moderate, medium subangular blocky; firm; few roots; few coarse fragments

Site 6

Location: LSD 3 – SW 19 – T 52 – R 20 – W4M
Classification:
  Subgroup: Orthic Gray Luvisol
  Series: Cooking Lake
Land System Islet Upland
Landform:
  Genetic Material: Glacial till
  Surface Expression: Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness: Moderately well drained; medium perviousness
Site Features: West aspect; mid slope position; moderately stony
Vegetation: Aspen; dense shrub understory with some forbs; some grassy patches

Profile Description:

LFH	10 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ahe	0 - 2 cm	Dark gray (10YR 4/1 dry); sandy loam; medium platy; very friable; abundant, fine roots; few coarse fragments
Ae	2 - 27 cm	Light brownish gray (10YR 6/2 dry); sandy loam; strong, medium platy; friable; plentiful fine roots; few coarse fragments
Bt	32+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky

SITE 7

Location:	LSD 16 – NE 34 – T 52 – R 21 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Hummocky; 15-20% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Northwest aspect; mid slope position; moderately stony
Vegetation:	Aspen; dense shrub understory; sparse ground vegetation

Profile Description:

LFH	12 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ahe	0 - 3 cm	Dark gray (10YR 4/1 dry); sandy loam; granular; very friable; abundant, fine roots; few coarse fragments
Ae	3 - 22 cm	Light brownish gray (10YR 6/2 dry); sandy loam; moderate, medium platy; very friable; plentiful fine roots; few coarse fragments
AB	22 - 25 cm	Grayish brown (10YR 5.5/3 dry); loam; moderate, medium subangular blocky; friable; plentiful fine roots; few coarse fragments
Bt	25+ cm	Brown (10YR 5/3 dry); clay loamy; moderate, medium subangular blocky; firm; few roots; few coarse fragments

Site 8

Location:	LSD 9 – NE 36 – T 49 – R 21 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Moderately well drained; medium perviousness
Site Features:	Southwest aspect; mid slope position; moderately stony
Vegetation:	Aspen; dense shrub understory with some forbs; some grassy patches

Profile Description:

LFH	12 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ae	0 - 28 cm	Light brownish gray (10YR 6/2 dry); sandy loam; moderate, medium platy; friable; plentiful fine roots; few coarse fragments
Bt	28+ cm	Brown (10YR 5/3 dry); clay loam; moderate, medium subangular blocky

SITE 9

Location:	LSD 16 – NE 11 – T 50 – R 21 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating to hummocky; 6-9% slopes; steep breaks to wetlands adjacent
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Southwest aspect; mid slope position; moderately stony
Vegetation:	Aspen; shrubs; some forbs; somewhat open canopy

Profile Description:

LFH	8 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ae	0 - 20 cm	Light brownish gray (10YR 6/2 dry); sandy loam; moderate, medium platy; friable; plentiful fine roots; few coarse fragments
AB	20 - 24 cm	Grayish brown (10YR 5/2 dry); loam to clay loam; weak medium, subangular blocky; friable; plentiful fine roots; plentiful coarse fragments (pebbles, small stones)
Bt	24 - 30+ cm	Brown (10YR 5/3 dry); clay loam; moderate, medium subangular blocky; firm; few roots; plentiful coarse fragments (pebbles, small stones)

Site 10

Location:	LSD 13 – NW 34 – T 50 – R 21 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Moderately well drained; medium perviousness
Site Features:	East aspect; mid slope position; slightly stony
Vegetation:	Aspen with some white spruce; dense shrub understory; some forbs

Profile Description:

LFH	10 - 0 cm	Newly fallen leaves over moderately decomposed litter
Ahe	0 - 3 cm	Dark gray (10YR 4/1 dry); sandy loam; medium platy; very friable; abundant, fine roots; few coarse fragments
Ae	3 - 25 cm	Grayish brown (10YR 5/2 dry); sandy loam; moderate, medium platy; friable; plentiful fine roots; few coarse fragments
Bt	25 - 30+ cm	Brown (10YR 4.5/3 dry); clay loam; moderate, medium subangular blocky

SITE11

Location: LSD 9 – NE 23 – T 56 – R 21 – W4M
Classification:
  Subgroup: Eluviated Dystric Brunisol
  Series: Nestow
Land System Redwater Plain
Landform:
  Genetic Material: Eolian (wind reworked glaciofluvial)
  Surface Expression: Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness: Rapidly drained; high perviousness
Site Features: Southwest aspect; lower slope position; non stony
Vegetation: Jack pine/aspen; few shrubs; patchy grasses, lichens; few forbs

Profile Description:

LF	2 - 0 cm	Pine needles, lichens and grass litter
Ahe	0 - 7 cm	Dark gray (10YR 4.5/1 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Ae	7 - 18 cm	Pale brown (10YR 6/3 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Bm	18 - 30+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; few fine roots; no coarse fragments

Site 12

Location: LSD 1 – NE 15 – T 57 – R 21 – W4M
Classification:
  Subgroup: Eluviated Dystric Brunisol
  Series: Nestow
Land System Redwater Plain
Landform:
  Genetic Material: Eolian (wind reworked glaciofluvial)
  Surface Expression: Undulating to ridged; 6-9% slopes
Drainage/ Perviousness: Rapidly drained; high perviousness
Site Features: East aspect; mid slope position; slightly stony
Vegetation: Forage; mostly grasses, minor legumes

Profile Description:

Ap	0 - 15 cm	Grayish brown to light brownish gray (10YR 5/2 and 6/2 dry); sand to sandy loam; single grain; loose; abundant, fine roots; no coarse fragments
Bm	15 - 30+ cm	Brown (10YR 5/3 dry); sand; single grain; loose; very few roots

SITE 13

Location:	LSD 13 – NW 19 – T 57 – R 20 – W4M
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Series:	Nestow
Land System	Eldorena Plain
Landform:	
Genetic Material:	Eolian
Surface Expression:	Hummocky to ridged; 10-15% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	South aspect; upper slope position; non stony
Vegetation:	Jack pine; bearberry; lichens; some grasses; few forbs

Profile Description:

LF	4 - 0 cm	Pine needle - lichen litter
Ahe	0 - 2 cm	Gray (10YR 5/1 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Ae	2 - 25 cm	Pale brown (10YR 6/3 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Bm	25 - 30+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; few fine roots; no coarse fragments

SITE 14

Location:	LSD 3 – SW 3 – T 57 – R 22 – W4M
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Series:	Nestow
Land System	Redwater Plain
Landform:	
Genetic Material:	Glaciofluvial (surface wind reworked)
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	West aspect; mid slope position; non stony
Vegetation:	Jack pine; some white spruce and aspen; few shrubs; grasses, lichens; few forbs

Profile Description:

LF	<1 cm	Pine needles, lichens and grass litter
Ae	0 - 8 cm	Grayish brown (10YR 5/2 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Bm	8 - 25+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; few fine roots; no coarse fragments

SITE 15

Location:	LSD 1 – SE 34 – T 57 – R 1 – W5M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	George Lake Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	East aspect; mid slope position; slightly stony
Vegetation:	Aspen; dense rose and alder understory; few forbs

Profile Description:

LF	12 - 0 cm	Newly fallen leaves over dense, felty FH layer
Ah	0 - 1 cm	Very dark grayish brown (10YR 3/2 dry); loam; granular
Ae	1 - 26 cm	Light brownish gray (10YR 6/2 dry); loam; moderate, medium platy; friable; abundant roots; few coarse fragments
Bt	26 - 30+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky; firm; few fine roots; few coarse fragments

SITE 16

Location:	LSD 13 – NW 12 – T 58 – R 1 – W5M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	George Lake Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	East aspect; mid slope position; slightly stony
Vegetation:	Forage; grass/clover mix

Profile Description:

Ap	0 - 25 cm	Grayish brown (10YR 5/2 dry); very fine sandy loam; granular; friable
Bt	25 - 30+ cm	Dark brown (10YR 4/3 dry); loam; moderate, medium subangular blocky; friable; few fine roots; few coarse fragments

SITE 17

Location:	LSD 16 – NE 11 – T 58 – R 1 – W5M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	George Lake Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	West aspect; mid slope position; slightly stony
Vegetation:	Aspen; dense rose and alder understory; forbs and grasses

Profile Description:

LF	10 - 0 cm	Newly fallen leaves over moderately decomposed FH layer
Ae	0 - 25 cm	Light gray (10YR 6.5/1 dry); loam; moderate, medium platy; friable; abundant roots; few coarse fragments
Bt	25 - 30+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky; firm; few fine roots; few coarse fragments

SITE 18

Location:	LSD 13 – NW 19 – T 52 – R 20 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Hummocky; 10-15% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Southeast aspect; mid slope position; slightly stony
Vegetation:	Forage; grass only; not cut or grazed

Profile Description:

Ap	0 - 25 cm	Grayish brown (10YR 5/2 dry); loam to very fine sandy loam; granular; friable
AB		Some remnant AB at base of Ap
Bt	25 - 30+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky; friable; few fine roots; few coarse fragments

SITE 19

Location:	LSD 1 – SE 24 – T 52 – R 21 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Cooking Lake
Land System	Islet Upland
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Hummocky; 6-9, with some 10-15% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	West aspect; mid slope position; slightly stony
Vegetation:	Forage; grass only; not cut or grazed; grass headed; not cut or grazed

Profile Description:

Ap/Ae	0 - 12 cm	Grayish brown (10YR 5/2 dry); loam to silty loam; granular; friable; grass thatch at surface
Ae	12-21 cm	Light brownish gray (10YR 6/2 dry); loam to silty loam; moderate, medium platy; friable
Bt	21 - 30+ cm	Dark brown (10YR 4/3 dry); clay loam; moderate, medium subangular blocky; friable; few fine roots; few coarse fragments

SITE 20

Location:	LSD 12 – SW 30 – T 56 – R 20 – W4M
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Series:	Nestow
Land System	Redwater Plain
Landform:	
Genetic Material:	Eolian
Surface Expression:	Hummocky; 10-15% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	South aspect; upper slope position; non stony
Vegetation:	Jack pine; bearberry; lichen; some grassy areas

Profile Description:

LF	<1 - 0 cm	Pine needle – lichen litter
Ahe	0 - 1 cm	Gray (10YR 5/1 dry); sand; single grain; loose; few fine roots; no coarse fragments
Ae	1 - 7 cm	Pale brown (10YR 6/3 dry); sand; single grain; loose; few fine roots; no coarse fragments
Bm	7 - 25+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; very few roots; no coarse fragments

SITE 21

Location:	LSD 1 – SE 16 – T 58 – R 23 – W4M
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Series:	Nestow
Land System	Halfway Lake Dunefield
Landform:	
Genetic Material:	Eolian
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	Southwest aspect; upper slope position; non stony
Vegetation:	Jack pine (sparse cover); bearberry; lichen; some grassy areas; lightly grazed

Profile Description:

LF	<1 - 0 cm	Pine needle – lichen litter
Ahe	0 - 4 cm	Dark gray (10YR 4/1 dry); sand; single grain; loose; plentiful fine roots; no coarse fragments
Ae	4 - 18 cm	Brown (10YR 5/3 dry); sand; single grain; loose; few fine roots; no coarse fragments
Bm	18 - 25+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; very few roots; no coarse fragments

SITE 22

Location:	LSD 12 – SW 30 – T 56 – R 20 – W4M
Classification:	
Subgroup:	Eluviated Dystric Brunisol
Series:	Nestow
Land System	Halfway Lake Dunefield
Landform:	
Genetic Material:	Eolian
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	Southeast aspect; upper slope position; non stony
Vegetation:	Jack pine; bearberry; lichen

Profile Description:

LF	<1 - 0 cm	Pine needle – lichen litter
Ahe	0 - 6 cm	Dark gray (10YR 4/1 dry); sand; single grain; loose; few fine roots; no coarse fragments
Ae	6 - 22 cm	Pale brown (10YR 6/3 dry); sand; single grain; loose; few fine roots; no coarse fragments
Bm	22 - 25+ cm	Yellowish brown (10YR 5/4 dry); sand; single grain; loose; very few roots; no coarse fragments

SITE 23

Location:	LSD 16 – NE 33 – T 47 – R 24 – W4M
Classification:	
Subgroup:	Orthic Dark Gray Chernozem
Series:	Helliwell
Land System	Pipestone Upland
Landform:	
Genetic Material:	Eolian
Surface Expression:	Hummocky; 10-15% slopes; low relief
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	East aspect; mid slope position; non stony
Vegetation:	Aspen; shrub understory with dense grass cover;

Profile Description:

LFH	8 - 0 cm	Newly fallen aspen leaves over moderately decomposed litter
Ah	0 - 22 cm	Dark gray (10YR 4/1 dry); loamy sand to sand; granular to single grain; very friable; abundant fine roots; no coarse fragments
Bm	22 - 25+ cm	Grayish brown (10YR 5/2 dry); loamy sand to sand; single grain; very friable; very few roots; no coarse fragments

SITE 24

Location:	LSD 1 – SE 10 – T 47 – R 24 – W4M
Classification:	
Subgroup:	Orthic Black Chernozem
Series:	Peace Hills
Land System	Pipestone Upland
Landform:	
Genetic Material:	Eolian
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	Southwest aspect; mid slope position; non stony
Vegetation:	Aspen (open); dense shrubs and grasses

Profile Description:

Ah	0 – 40 cm	Black (10YR 2.5/1 dry); loamy sand; weak granular; very friable; abundant fine roots; no coarse fragments
Bm	40+ cm	Dark grayish brown to brown; loamy sand

SITE 25

Location:	LSD 4 – SW 27 - T 46 – R 24 – W4M
Classification:	
Subgroup:	Orthic Dark Gray Chernozem
Series:	Helliwell
Land System	Pipestone Upland
Landform:	
Genetic Material:	Glaciofluvial; may be wind influenced
Surface Expression:	Hummocky; 16-20% slopes; some slopes close to 30%
Drainage/ Perviousness:	Rapidly drained; high perviousness
Site Features:	North aspect; mid slope position; non stony
Vegetation:	Aspen; some white birch; dense shrub understory; no ground cover

Profile Description:

LFH	4 - 0 cm	Newly fallen aspen leaves over moderately decomposed litter
Ahe	0 - 25 cm	Grayish brown (10YR 4.5/2 dry); sand; single grain; loose; abundant fine roots; no coarse fragments
Ae	25 - 35 cm	Brown (10YR 5/3 dry); sand; single grain; loose; few fine roots; no coarse fragments
Bm	35+ cm	Brown to yellowish brown; sand

SITE 26

Location:	LSD 13 – NW 23 – T 47 – R 28 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Breton
Land System	Yeoford Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating to hummocky; 6-9% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Northeast aspect; mid slope position; slightly stony
Vegetation:	Aspen; dense shrub understory; some forbs

Profile Description:

LF	8 - 0 cm	Newly fallen leaves over moderately decomposed FH layer
Ahe	0 - 4 cm	Dark gray (10YR 4/1 dry); loam; weak, medium platy; friable; abundant roots; few coarse fragments
Ae	4 - 30 cm	Light gray (10YR 6.5/2 dry); loam; moderate, medium platy; friable; abundant roots; few coarse fragments
Bt	30+ cm	Brown (10YR 4.5/3 dry); clay loam; moderate, medium subangular blocky; firm; few fine roots; few coarse fragments

SITE 27

Location:	LSD 4 – SW 3 – T 48 – R 27 – W4M
Classification:	
Subgroup:	Orthic Gray Luvisol
Series:	Breton
Land System	Falun Plain
Landform:	
Genetic Material:	Glacial till
Surface Expression:	Undulating; 2-5% slopes
Drainage/ Perviousness:	Well drained; medium perviousness
Site Features:	Northeast aspect; mid slope position; slightly stony
Vegetation:	Aspen; some large white spruce; shrubs; some forbs, grasses

Profile Description:

LF	6 - 0 cm	Newly fallen leaves over moderately decomposed FH layer
Ahe	0 - 4 cm	Dark gray (10YR 4.5/1 dry); loam to silty loam; weak, medium platy; friable; abundant roots; few coarse fragments
Ae	4 - 22 cm	Light brownish gray (10YR 6/2 dry); loam to silty loam; moderate, medium platy; friable; plentiful roots; few coarse fragments
Bt	22 - 25+ cm	Brown (10YR 4.5/3 dry); clay loam; moderate, medium subangular blocky; firm; few fine roots; few coarse fragments

APPENDIX B: SOIL CHEMICAL DATA

Table B1. pH and Exchangeable Cation Data for Soils Sampled in the Edmonton West Grid Cell

Site	Classification	Soil Series	Horizon	Depth (cm)	PH ($CaCl_2$)	Exchangeable Cations and Cation Exchange Capacity (cmol kg^{-1})									Base Saturation
						Na	K	Ca	Mg	Al	Fe	Mn	CEC^z	BC^z	
ED1	E.DYB	Nestow	LF	4-0	5.7	<0.01	2.76	28.1	8.78	<0.03	0.03	0.90	54.6	39.7	0.73
ED1			Ahe/Ae/Bm	0-30	5.2	<0.01	0.22	4.94	1.02	<0.03	<0.01	0.03	10.0	6.2	0.62
ED1			Bm	45-50	5.4										
ED2	E.DYB	Nestow	LF	8-0	6.1	<0.01	3.99	42.5	12.6	<0.03	0.03	5.32	80.6	59	**0.73**
ED2			Ae/AB/Bm	0-30	5.5	<0.01	0.27	4.42	1.11	<0.03	<0.01	0.05	8.8	5.8	**0.66**
ED2			Bm	45-50	5.5										
ED3	O.DG	Helliwell	LF	5-0	6.6	<0.01	4.45	47.5	11.5	<0.03	<0.01	0.74	77.3	63.4	**0.82**
ED3			Ah/Ae/Bm	0-30	6.0	<0.01	0.38	7.47	1.60	<0.03	<0.01	0.05	11.7	9.5	**0.81**
ED4	D.GL	Cooking Lake	LF	LF	6.1	<0.01	3.79	61.7	15.3	<0.03	<0.01	1.42	114	81	**0.71**
ED4			Ah/Ae	0-30	4.1	0.42	0.22	3.42	1.03	0.21	<0.01	0.03	25.7	5.1	0.20
ED5	D.GL	Uncas	LF	6-0	5.7	<0.01	3.84	46.3	16.6	0.07	<0.01	1.88	106	67	**0.63**
ED5			Ah/Ahe/Ae	0-25	4.1	0.07	0.38	4.42	3.46	<0.03	<0.01	0.08	19.5	8.3	**0.43**
ED6	O.GL	Cooking Lake	LF	2-0	5.9	<0.01	4.20	66.8	12.4	0.12	0.06	1.73	116	83	**0.72**
ED6			Ahe/Ae	0-27	4.8	<0.01	0.27	4.99	1.60	<0.03	<0.01	0.06	11.9	6.9	**0.58**
ED7	O.GL	Cooking Lake	LF	12-0	6.2	<0.01	3.62	73.7	12.8	<0.03	<0.01	1.38	127	90	0.71
ED7			Ahe/Ae/AB	0-25	4.8	<0.01	0.34	4.23	1.22	<0.03	<0.01	0.06	10.7	5.8	0.54
ED8	O.GL	Cooking Lake	LF	12-0	6.3	<0.01	3.55	86.9	13.2	0.21	0.17	0.98	125	104	**0.83**
ED8			Ae	0-27	5.1	<0.01	0.39	3.54	0.97	<0.03	<0.01	0.04	8.0	4.9	0.61
ED9	O.GL	Cooking Lake	LF	8-0	6.3	<0.01	3.99	68.6	20.5	<0.03	<0.01	0.91	130	93	**0.72**
ED9			Ae/AB	0-24	5.0	<0.01	0.56	5.01	2.44	<0.03	<0.01	0.05	12.8	8.0	**0.62**
ED10	O.GL	Cooking Lake	LF	10-0	6.1	<0.01	2.31	73.8	12.0	<0.03	0.04	1.07	126	88	**0.70**
ED10			Ahe/Ae	0-25	5.3	<0.01	0.45	6.11	0.94	<0.03	<0.01	0.09	12.8	7.5	**0.58**
ED11	E.DYB	Nestow	LF	2-0	4.5	<0.01	1.99	17.5	3.76	0.07	<0.01	1.91	59.6	23	**0.39**
ED11			Ahe/Ae/Bm	0-30	4.8	<0.01	0.11	1.85	0.35	<0.03	<0.01	0.02	4.3	2.3	**0.53**
ED12	E.DYB	Nestow	Ap	0-25	4.9	<0.01	0.09	1.72	0.26	<0.03	<0.01	<0.02	3.5	2.1	**0.60**
ED13	E.DYB	Nestow	LF	4-0	4.6	<0.01	1.16	21.0	4.71	0.09	<0.01	2.52	64.2	26.9	**0.42**
ED13			Ahe/Ae	0-25	4.7	<0.01	0.09	1.72	0.22	<0.03	<0.01	0.03	4.8	2.0	**0.42**
ED14	E.DYB	Nestow	Ae/Bm	0-25	4.4	<0.01	0.09	1.97	0.36	<0.03	<0.01	0.05	5.1	2.4	**0.47**
ED15	O.GL	Cooking Lake	LF	12-0	6.3	<0.01	4.82	71.3	16.1	<0.03	<0.01	1.83	129	92	**0.72**
ED15			Ah/Ae	0-25	5.3	<0.01	0.40	5.58	1.13	<0.03	<0.01	0.09	12.3	7.1	**0.58**
ED16	O.GL	Cooking Lake	Ap	0-25	4.3	0.62	0.34	4.39	1.64	<0.03	<0.01	0.14	22.7	7.0	0.31
ED17	O.GL	Cooking Lake	LF	10-0	5.4	0.08	4.35	38.2	12.9	0.08	<0.01	3.77	98.2	56	**0.57**
ED17			Ae	0-25	3.9	0.26	0.22	2.23	0.99	0.23	<0.01	0.10	17.8	3.7	0.21
ED18	O.GL	Cooking Lake	Ap	0-25	6.1	<0.01	0.68	13.2	2.67	<0.03	<0.01	0.05	24.5	16.5	0.67

[z] CEC – cation exchange capacity determined by buffered pH 7.0 ammonium acetate. BC – exchangeable base cations. Base Saturation – BEC/CEC

Appendix Table B1. pH and Exchangeable Cation Data for Soils Sampled in the Edmonton West Grid Cell (concluded)

Site	Classification	Soil Series	Horizon	Depth (cm)	PH ($CaCl_2$)	Exchangeable Cations and Cation Exchange Capacity (cmol kg^{-1})									Base Saturation
						Na	K	Ca	Mg	Al	Fe	Mn	EC	BC	
ED19	O.GL	Cooking Lake	Ap/Ae/Bt	0-25	5.7	0.02	0.43	7.64	2.22	<0.03	<0.01	0.04	16.3	10.3	0.63
ED20	E.DYB	Nestow	Ae/Bm	0-25	4.7	<0.01	0.09	1.17	0.20	<0.03	<0.01	0.02	3.4	1.5	0.43
ED21	E.DYB	Nestow	Ahe/Ae/Bm	0-25	5.0	<0.01	0.05	1.30	0.18	<0.03	<0.01	0.02	3.2	1.5	**0.48**
ED22	E.DYB	Nestow	LF	1-0	4.5	<0.01	0.52	6.50	1.15	0.04	0.02	0.50	20.6	8.2	**0.40**
ED22			Ahe/Ae/Bm	0-25	4.7	<0.01	0.03	0.83	0.12	<0.03	<0.01	<0.02	2.6	1.0	**0.38**
ED23	O.DG	Helliwell	LF	8-0	5.5	<0.01	1.12	19.9	3.75	0.06	0.04	0.44	37.3	24.7	**0.66**
ED23			Ah/Bm	0-25	4.6	<0.01	0.18	3.69	0.59	<0.03	<0.01	0.10	9.4	4.5	0.48
ED24	O.B	Peace Hills	Ah	0-25	5.2	<0.01	0.60	14.1	2.42	<0.03	<0.01	0.04	29.3	17.1	**0.58**
ED25	O.DG	Helliwell	LF	4-0	6.1	<0.01	1.23	29.6	8.04	<0.03	<0.01	0.44	57.4	38.9	**0.68**
ED25			Ahe	0-25	5.0	<0.01	0.24	6.67	1.71	<0.03	<0.01	0.07	14.6	8.6	**0.59**
ED26	O.GL	Breton	LFH	8-0	6.0	<0.01	2.07	31.8	6.62	<0.03	<0.01	0.71	64.8	40.5	**0.63**
ED26			Ahe/Ae	0-25	5.2	<0.01	0.76	11.0	2.53	<0.03	<0.01	0.16	25.2	14.3	**0.57**
ED27	O.GL	Breton	LFH	6-0	6.2	<0.01	2.25	29.4	4.63	<0.03	<0.01	0.75	51.1	36.3	**0.71**
ED27			Ahe/Ae	0-25	5.5	<0.01	0.65	10.3	1.63	<0.03	<0.01	0.14	22.7	12.6	0.55

Table B2. Water Extractable Ions in Soils Sampled in the Edmonton West Grid Cell.

Site	Depth (cm)	H2O Sat'n [z] (%)	pH	EC[z] (dS m^{-1})	Al	Ca	Fe	K	Mg	Mn	Na	S
					(mg L^{-1})							
ED1	LF	241	6.0	0.94	2.1	213	1.5	190	66.0	7.3	3.9	21.0
ED1	0-30	42.8	6.6	0.21	0.6	57.6	0.3	7.0	9.3	1.1	8.3	7.9
ED2	LF	298	6.6	1.30	0.8	286	0.7	250	87.8	25.1	4.3	21.5
ED2	0-30	44.8	6.8	0.25	0.6	72.3	0.3	10.6	14.0	2.9	6.2	7.7
ED3	LF	324	7.0	1.39	0.4	272	0.3	381	71.3	2.3	4.8	19.9
ED3	0-30	55.6	7.0	0.43	0.3	116	0.2	32.4	24.5	1.7	4.9	12.2
ED4	LF	378	6.6	1.09	0.5	250	0.3	170	64.7	6.4	3.6	20.9
ED4	0-30	66.0	5.2	1.02	4.9	9.0	1.6	0.7	1.7	0.2	24.4	11.0
ED5	LF	434	5.8	0.84	1.2	158	0.7	137	59.6	9.2	3.6	23.3
ED5	0-25	54.0	4.9	0.12	3.7	16.9	5.8	5.6	7.0	0.6	11.3	10.8
ED6	LF	460	6.1	1.22	1.1	327	0.8	203	60.5	9.0	4.7	35.4
ED6	0-27	42.4	5.8	0.13	2.8	35.3	3.7	6.2	6.6	0.7	6.4	9.4
ED7	LF	400	6.8	1.11	0.4	279	0.2	165	52.1	5.6	3.3	19.9
ED7	0-25	46.4	5.7	0.16	2.2	38.1	2.3	11.6	7.4	1.2	5.3	9.3
ED8	LF	350	6.8	1.07	0.7	317	0.5	173	51.6	3.5	4.4	19.1
ED8	0-27	42.0	6.1	0.17	2.1	47.4	1.8	17.4	8.5	1.3	4.3	6.9
ED9	LF	400	6.9	1.05	0.2	204	0.1	187	68.5	2.7	4.1	16.4
ED9	0-24	40.8	6.0	0.17	1.1	37.1	4.5	14.1	10.6	1.0	5.8	7.9
ED10	LF	304	6.6	0.96	0.5	278	0.3	101	48.3	4.3	5.2	20.1
ED10	0-25	44.8	6.4	0.29	0.5	87.2	0.2	9.7	10.7	2.6	6.3	13.5
ED11	LF	535	5.0	0.39	2.6	68.7	0.9	79.2	12.9	7.4	2.7	22.4
ED11	0-30	43.2	5.8	0.18	2.8	39.6	1.6	6.9	5.7	0.8	6.1	32.2
ED12	0-25	36.0	6.0	0.08	22.1	21.7	14.5	8.5	4.5	0.2	5.5	5.9
ED13	LF	432	4.9	0.40	3.4	112	1.1	53.0	24.0	15.2	2.8	16.9
ED13	0-25	40.4	5.8	0.21	5.0	43.7	5.8	6.5	5.1	4.0	6.4	6.9
ED14	0-25	38.8	6.0	0.17	8.0	34.5	5.6	6.2	6.4	4.5	7.1	13.0
ED15	LF	425	6.6	2.04	0.5	355	0.3	284	89.2	12.3	4.4	19.1
ED15	0-25	48.8	6.6	0.48	0.3	105	1.0	12.2	17.3	14.3	5.4	11.3
ED16	Ap	60.4	5.5	0.40	0.7	33.0	25.8	1.9	8.3	3.8	71.8	14.5
ED17	LF	396	6.0	1.75	1.7	219	1.7	229	78.4	41.6	8.5	29.0

[z] H2O Sat'n – moisture content of saturated soil sample (percent by weight); EC – electrical conductivity of saturated paste extract.

Table B2. Water Extractable Ions in Soils Sampled in the Edmonton West Grid Cell (concluded)

Site	Depth (cm)	H2O Sat'n (%)	pH	EC (dS m^{-1})	Al	Ca	Fe	K	Mg	Mn	Na	S
					(mg L^{-1})							
ED17	0-25	46.4	4.6	0.23	3.5	14.4	3.7	2.7	3.9	2.2	39.4	15.1
ED18	0-25	61.6	7.2	0.59	<0.1	130	0.1	20.0	22.2	3.1	5.7	10.3
ED19	0-25	50.0	6.7	0.64	0.2	134	0.6	8.5	27.6	10.7	10.8	7.3
ED20	0-25	37.2	6.2	0.11	5.5	15.1	3.3	5.4	2.4	2.5	6.4	3.4
ED21	0-25	38.4	6.6	0.12	0.5	18.3	0.3	2.7	3.0	3.1	4.2	2.8
ED22	LF	132	5.0	0.50	2.9	82.5	1.7	61.5	14.5	9.8	4.2	13.8
ED22	0-25	34.4	6.2	0.13	2.2	20.1	1.3	4.4	3.6	4.6	6.4	4.4
ED23	LF	120	6.1	1.23	2.0	251	2.3	103	50.8	6.9	4.3	21.2
ED23	0-25	48.0	5.6	0.29	2.7	61.2	2.1	7.7	9.4	8.6	5.9	11.0
ED24	0-25	68.4	6.4	0.44	1.4	83.0	0.8	21.2	14.5	1.9	5.9	8.9
ED25	LF	162	6.8	1.70	0.5	294	0.4	103	88.3	5.4	5.2	17.7
ED25	0-25	55.2	5.9	0.46	1.9	99.5	3.6	10.3	22.6	4.6	7.1	13.9
ED26	LFH	169	6.6	1.90	<0.1	365	0.8	129	74.2	15.1	5.7	16.4
ED26	0-25	58.0	6.5	0.74	0.2	156	0.7	24.6	25.8	16.3	5.7	11.5
ED27	LFH	214	6.4	1.87	0.4	356	0.7	160	58.7	8.2	4.1	16.8
ED27	0-25	81.5	6.2	0.85	0.4	197	5.3	20.2	27.9	9.8	5.0	10.8

APPENDIX C: AREAS OF LAND SYSTEMS AND LAND COVER TYPES

Table C. Areas of Land Systems and Land Cover Types in the Edmonton West Grid Cell

Land System	Total Area	Cultivated		Grassland		Trees		Shrubs		Wetland		Other Land	
	(ha)	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%
Battle River Valley	5,786	1,137	19.66	1,165	20.14	1,812	31.31	19	0.32	1,428	24.68	225	3.88
Big Hay Plain	18,781	10,156	54.08	6,916	36.82	954	5.08	0	0.00	580	3.09	175	0.93
Bigstone Plain	14,135	11,271	79.74	1,611	11.40	949	6.71	284	2.01	20	0.14	0	0.00
Calmar Plain	45,788	40,465	88.38	2,477	5.41	1,141	2.49	293	0.64	12	0.03	1,399	3.05
Cawes Plain	23,901	19,890	83.22	3,106	13.00	448	1.87	174	0.73	7	0.03	276	1.16
City of Edmonton	78,227	20,949	26.78	7,880	10.07	6,609	8.45	1,125	1.44	1,249	1.60	40,413	51.66
Eldorena Plain	7,356	1,299	17.66	2,277	30.96	3,698	50.27	43	0.59	27	0.37	11	0.15
Falun Plain	17,204	9,867	57.35	1,939	11.27	4,288	24.93	789	4.58	321	1.87	0	0.00
Ferlow Plain	24,482	15,804	64.55	7,398	30.22	967	3.95	0	0.00	281	1.15	33	0.13
George Lake Plain	7,267	2,646	36.41	1,826	25.13	2,757	37.94	3	0.04	34	0.47	1	0.02
Graminia Plain	18,052	7,536	41.75	5,169	28.63	4,346	24.08	796	4.41	204	1.13	0	0.00
Halfway Lake Dunefield	4,185	357	8.52	1,152	27.54	2,648	63.28	0	0.00	28	0.66	0	0.00
Islet Upland	43,855	9,389	21.41	6,867	15.66	22,787	51.96	15	0.03	4,785	10.91	12	0.03
Longhurst Plain	13,919	9,830	70.62	2,394	17.20	994	7.14	276	1.98	130	0.93	296	2.12
Looma Upland	40,195	16,636	41.39	11,682	29.06	10,801	26.87	568	1.41	468	1.17	40	0.10
Mink Lake Plain	1,158	611	52.71	303	26.15	170	14.65	75	6.49	0	0.00	0	0.00
Morinville Plain	52,306	35,220	67.33	8,865	16.95	7,583	14.50	122	0.23	294	0.56	222	0.42
Namao Plain	112,098	77,823	69.42	16,108	14.37	15,005	13.39	347	0.31	967	0.86	1,848	1.65
North Saskatchewan River Valley	7,343	2,111	28.74	827	11.26	2,858	38.92	238	3.24	1,202	16.37	108	1.47
Onoway Upland	7,682	2,288	29.79	2,689	35.00	2,217	28.86	294	3.83	194	2.52	0	0.00
Pakan Plain	175	49	27.72	44	24.96	82	46.76	0	0.00	0	0.00	1	0.57
Partridge Plain	12,585	9,092	72.24	1,624	12.90	1,732	13.76	42	0.33	39	0.31	57	0.45
Pemburton Hill Plain	47	33	71.30	7	14.40	4	7.92	3	6.38	0	0.00	0	0.00
Pigeon Lake	638	0	0.00	0	0.00	0	0.00	0	0.00	638	100.00	0	0.00
Pipestone Upland	19,879	10,896	54.81	6,238	31.38	2,466	12.41	62	0.31	104	0.52	111	0.56
Pointe-aux-Pins Plain	20,383	14,693	72.09	2,678	13.14	2,220	10.89	231	1.13	27	0.13	533	2.62
Redwater Plain	41,212	12,594	30.56	14,798	35.91	12,784	31.02	312	0.76	342	0.83	381	0.92
Ryley Plain	10,541	3,797	36.03	3,497	33.18	232	2.20	0	0.00	3,013	28.58	1	0.01
Samson Lake Plain	921	538	58.38	319	34.63	47	5.07	0	0.00	14	1.49	4	0.44
Spruce Grove Plain	24,066	12,822	53.28	4,503	18.71	3,140	13.05	1,017	4.23	939	3.90	1,646	6.84
Thorhild Plain	509	274	53.80	118	23.13	116	22.88	0	0.00	0	0.00	1	0.20
Watelet Plain	58,693	44,352	75.57	7,319	12.47	3,319	5.66	837	1.43	292	0.50	2,575	4.39
Yeoford Plain	4,081	2,279	55.83	248	6.08	1,094	26.80	442	10.83	19	0.47	0	0.00
Miscellaneous[Z]	163	82	50.23	32	19.50	31	19.07	4	2.68	10	6.21	4	2.32
Total	737,613	406,786		134,076		120,299		8,411		17,668		50,373	

APPENDIX D: LAND AREA ESTIMATION OF SENSITIVITY CLASSES

LAND AREA ESTIMATION OF SENSITIVITY CLASSES

Three Land Systems in the Edmonton West grid cell were found to include Soil Series to be Sensitive or Moderately Sensitive to acidification according to the ARC model. The Primula (Eluviated Eutric Brunisol) and Nestow (Eluviated Dystric Brunisol) are considered together as being Sensitive to Moderately Sensitive to acidification. The Helliwell (Orthic Dark Gray Chernozem) and Mundare (Orthic Black Chernozem) Soil Series are rated as being of Moderate to Low sensitivity. The table below indicates the sensitivity classes of these soils, as well their estimated proportions in five Land Systems. The assignment of proportions was as follows:

- Land System with a major soil and two minor soils: the major soil is estimated to constitute 70% of the Land System, and the minor soils are estimated to constitute 15% each.
- Land System with two major soil series and two minor soil series: the major soils are estimated to each constitute 35% of the Land System, and the minor soils are estimated to constitute 15% each. If water is associated with Organic soils, the ratio is 40-40-20.

Soil Series	**Mundare**	**Primula (Nestow)**	**Peace Hills**	**Helliwell**	**Manatokan, Misc. Organics**
Series Sensitivity	M-L	S-M	L	M-L	L
Redwater Plain	70%	15%	15%		
Eldorena Plain	15%	35%	35%		15%
Halfway Lake Dunefield		40%		40%	20%

The above percentages of Soil Series in the Land Systems were then compared to the land cover data (Appendix C). It was assumed that the cultivated lands were occupied by the soils with the highest agricultural capability, and that land with shrub, tree and grassland cover would have the sandiest soils, namely Mundare, Helliwell and Primula/Nestow. Also, percent areas of each of the occurrences of Primula//Nestow, Helliwell and Mundare were halved and assigned to two sensitivity classes because of their dual ratings. For example, Primula/Nestow is rated Sensitive to Moderately Sensitive; therefore, half their areas were assigned to each of these sensitivity ratings. Details of the rating derivations are provided below for the five Land Systems with Moderate and Sensitive ratings.

Redwater Plain

- Cultivated – 31%; Peace Hills - 15%; Mundare - 16%
- Other – 1%; not rated
- Grassland , Shrubs and Trees – 68%; 15% Primula; 53% Mundare
- Sensitive – Half of Primula (7-8%)
- Moderate Sensitivity – Half of Primula (7-8%) and half of Mundare (26%)
- Low Sensitivity – Half of Mundare (27%)
- Summary: Sensitive - 7-8%; Moderate - 33%; Low - 27%; Not Rated - 33%

Eldorena Plain

- Cultivated – 18%; Peace Hills - 18%
- Other – <1%; not rated
- Grassland , Shrubs and Trees – 82%; 17% Peace Hills; 35% Primula; 15% Mundare; 15% Mantokan
- Sensitive – Half of Primula (17-18%)
- Moderate Sensitivity – Half of Primula (17-18%) and half of Mundare (7-8%);
- Low Sensitivity – Half of Mundare (7-8%), Peace Hills, non-cultivated - 17%, Manatokan - 15%
- Summary: Sensitive – 17-18%; Moderate - 25%; Low - 39%; Not Rated - 19%

Halfway Lake Dunefield

- Cultivated – 8%; Helliwell - 9%
- Other – <1%; not rated
- Organics – 20%
- Grassland , Shrubs and Trees – 71%; 40% Primula; 31-32% Helliwell
- Sensitive – Half of Primula (20%)
- Moderate Sensitivity – Half of Primula (20%) and half of Helliwell (16%)
- Low Sensitivity – Half of Helliwell (16%); Organics – 20%
- Summary: Sensitive - 20%; Moderate - 36%; Low - 36%; Not Rated - 8%

BASELINE SOIL AND TERRAIN MAPS