

**THE SENSITIVITY OF ALBERTA LAKES  
AND SOILS TO ACIDIC DEPOSITION  
- OVERVIEW REPORT -**

Prepared by:

*C.J. Palmer, Ph.D.*  
Soil Protection Branch  
Earth Sciences Division  
and  
*D.O. Trew, B.Sc.*  
Water Quality Control Branch  
Pollution Control Division  
Alberta Environment

June 1987



## EXECUTIVE SUMMARY

This report identifies regions of lakes and soils in Alberta which may be sensitive to acidic deposition, and describes the current quality of precipitation falling over the province.

Based on a four-tiered scale of total alkalinity concentrations, 90.6% of the 982 lakes assessed were rated as having a low sensitivity to acidic deposition. Those lakes rated as highly sensitive were located in three areas:

- 1) the Canadian Shield (the extreme northeastern corner of the province),
- 2) certain areas of the Rocky Mountain National Parks, notably Jasper, and
- 3) miscellaneous upland regions in the northern part of the province including the Caribou Mountains and the Birch Mountains.

Two assessments of terrestrial sensitivity were undertaken. The first identifies the combined potential of soils and bedrock to reduce (neutralize) the effects of acidic deposition before its entry into the aquatic system. The results of this analysis revealed that the terrain of approximately 86.2% of the province could be classified as having low to moderate sensitivity, with approximately 11.3% classified as highly sensitive (the remaining percentage represents standing surface water). These highly sensitive areas corresponded well with the zones of highly sensitive lakes.

The second assessment of terrestrial sensitivity examined the effects of acidic deposition on the topsoil itself, and its ability to sustain plant growth. High sensitivities occur over approximately 22.7% of the surface area of the province and were identified in peatlands throughout the northeastern area of the province, in the sandy soils of the Canadian Shield and elsewhere, and in certain areas of the Rocky Mountain National Parks.

Monthly chemical analyses of Alberta precipitation have been undertaken since 1978. Although significant emissions of acid-forming gases occur in Alberta, the provincial precipitation has a mean annual pH of 5.5, close to the theoretical (i.e. unpolluted) value of 5.6. This is much less acidic than precipitation falling over eastern North America (pH 4.1-4.4) or northern Europe (pH 4.0-4.5). It has been hypothesized that the acid end-products are neutralized in the atmosphere by wind-blown, alkaline dust and soil.

Uncertainties remain with respect to the acidification issue in Alberta. These include: the significance of wet versus dry deposition to total acidity, the contribution to acidity of various dissolved inorganic nitrogen components in precipitation, and the acid loadings which the various ecosystems in Alberta can withstand.

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY .....	i
TABLE OF CONTENTS .....	iii
LIST OF FIGURES .....	iv
LIST OF TABLES .....	v
1.0 INTRODUCTION .....	1
1.1 Study Background .....	1
1.2 Formation of "Acid Rain" .....	2
2.0 LAKE SENSITIVITY TO ACIDIC DEPOSITION .....	3
2.1 Mapping Criteria and Procedures .....	3
2.2 Map Interpretation .....	5
3.0 POTENTIAL OF SOILS AND GEOLOGY TO REDUCE THE ACIDITY OF ATMOSPHERIC DEPOSITION .....	17
3.1 Mapping Criteria and Procedures .....	17
3.2 Map Interpretation .....	19
4.0 SOIL SENSITIVITY TO ACIDIC DEPOSITION .....	20
4.1 Mapping Criteria and Procedures .....	20
4.2 Map Interpretation .....	24
5.0 PRESENT LEVELS OF ACIDIC DEPOSITION IN ALBERTA .....	28
5.1 Precipitation Quality .....	28
5.2 Wet Deposition Rates .....	31
5.3 Dry Deposition Rates .....	33
5.4 Interpretation of Deposition Rates .....	35
6.0 FUTURE TRENDS .....	41
7.0 CONCLUSIONS .....	42
8.0 REFERENCES .....	43

LIST OF FIGURES

	Page
1. Map of 14 geographic regions of Alberta .....	7
2. Sensitivity of Alberta lakes to acidification as determined by alkalinity values. ....	9
3. Sensitivity of Alberta lakes to acidification as determined by calcium values. ....	11
4. Sensitivity of Alberta lakes to acidification as determined by pH values. ....	15
5. Potential of Alberta soils and geology to reduce the acidity of atmospheric deposition. ....	21
6. Sensitivity of Alberta soils to acidic deposition. ....	25

LIST OF TABLES

	Page
1. Wet deposition (kilograms/hectare/year) at Alberta stations and selected Canadian stations (1978-82) .....	32
2. Wet, dry and total sulphate deposition (kilograms/hectare/year) at Alberta stations for 1982 ...	36
3. Soil affecting acidic deposition expressed as hydrogen (kiloequivalents or kilograms/hectare/year) at Alberta stations and selected Canadian stations for 1982 .....	39





## 1.0 INTRODUCTION

### 1.1 Study Background

Acidic deposition, or "acid rain" as it is described in popular terms, is the documented cause of serious environmental problems in eastern Canada, northeastern United States and northern Europe. In these regions, profound chemical and biological changes have occurred in both terrestrial and aquatic ecosystems resulting in significant economic and aesthetic impacts. In western Canada, the atmospheric emission rates of acid-forming substances are lower, and little evidence of ecosystem damage is available at this time. However, public awareness of this issue is growing and the need for surveillance is clear.

In 1981, the National Research Council of Canada recommended that regional surveys of aquatic and terrestrial ecosystems in western Canada be conducted in order to identify those which might be sensitive to acidic deposition. In April 1981, the Technical Committee on Western Canada - Long Range Transport of Atmospheric Pollutants (LRTAP) was established by the governments of British Columbia, Alberta, Saskatchewan, Manitoba, Northwest Territories and Canada to address the acidic deposition/LRTAP issue. This committee subsequently instituted a coordinated program to map ecosystem sensitivities in the four western provinces, the Yukon and the Northwest Territories. In Alberta, the aquatic assessment was carried out by the Water Quality Control Branch of the Pollution Control Division, Environmental Protection Services, Alberta Environment, and the soil assessment by the Alberta Research Council under contract to the Earth Sciences Division of Alberta Environment.

The objective of this report is to summarize the results of the two mapping programs, and to present the information in a semi-technical format. To enhance the reader's perspective on this issue, this summary also includes a discussion of the present precipitation quality and acidic deposition rates in Alberta and the potential for acidic impacts to our sensitive ecosystems. Where appropriate, selective comparisons are made between Alberta data and data from areas of higher acidic deposition rates in eastern Canada.

## 1.2 Formation of "Acid Rain"

The generic term "acid rain" has been defined as rain, hail, sleet or snow with a pH less than 5.6. Although the background pH of precipitation is somewhat variable, the theoretical or normal pH is considered to be approximately 5.6. This occurs because unpolluted rainwater is normally a dilute solution of carbonic acid, formed by the dissolution of atmospheric carbon dioxide ( $\text{CO}_2$ ) in water. The pH of 5.6 is controlled subsequently by the concentration of  $\text{CO}_2$  in the air, its degree of dissolution and the degree of ionization of the dissolved  $\text{CO}_2$  in the rainwater.

"Acid rain" is generated from different acid precursors in the atmosphere. For instance, it may result from the atmospheric oxidation and hydrolysis of sulphur dioxide ( $\text{SO}_2$ ) emissions to sulphuric acid ( $\text{H}_2\text{SO}_4$ ). The subsequent chemical dissociation of this acid and the release of hydrogen ions ( $\text{H}^+$ ) may lower the pH below 5.6. Similar processes convert emissions of nitrogen oxides ( $\text{NO}_x$ ) to nitric acid ( $\text{HNO}_3$ ).

Sulphur dioxide emissions are associated with oil and gas production, electric power production and other industrial operations. Oxides of nitrogen are also derived from these sources, although additional substantial emissions are associated with the operation of motor vehicles. Furthermore, both types of compounds are created in smaller amounts by natural processes, such as organic decomposition.

The newly-formed acidic materials and their precursors can be removed from the atmosphere by two separate processes. The sulphuric and nitric acids can be removed directly by precipitation, or wet deposition, which is known to be the primary removal process occurring in eastern North America. The second process is called dry deposition. Acids are created when gaseous or aerosol sulphur and nitrogen compounds react directly with surface water or with the moisture on plant and soil surfaces. In certain regions of the world this can be the more important removal process, and may represent the major contribution to the total acidic deposition. As will be discussed later, the measurement of both processes is critical to the understanding of this issue in western Canada. Accordingly, the term "acidic deposition" will be used to denote both the wet and dry processes of deposition.

## 2.0 LAKE SENSITIVITY TO ACIDIC DEPOSITION

### 2.1 Mapping Criteria and Procedures

The data for aquatic sensitivity mapping were collected in two phases. The first phase included the office compilation of existing

water quality data for 875 Alberta lakes. These historical data were obtained from the Alberta Research Council, the University of Alberta, Parks Canada, Alberta Fish and Wildlife Division, and Alberta Environment's Water Quality Control Branch. Only data collected during the open water period of May 1 to October 31 of each year were included in the analysis. Most of the data utilized were collected between 1973 and 1983.

A review of this historical data base identified some unavoidable deficiencies. Standard quality control considerations cannot apply when historical data produced from different laboratories are combined for the purpose of a single interpretation years later. However, the best attempts have been made to screen this data base for consistency. Futhermore, there were some areas of the province for which data were sparse or non-existent. In general, the data base for southern and central Alberta was sufficient for this analysis but data availability was more erratic for the northern regions.

Accordingly, the second phase consisted of a preliminary lake sampling program to augment and upgrade the historical data base. A total of 107 lakes situated primarily in the northern half of the province was selected for sampling. Upon completion of the field work all historical and current data were tabulated and summarized. Unfortunately, there still remain certain areas of the province for which no reliable data exist.

In compliance with Western Canada-LRTAP recommendations, and to ensure basic continuity with similar mapping projects completed in other parts of Canada, three chemical variables formed the mapping

criteria: calcium, pH and total alkalinity. Calcium is an alkaline earth metal, and is one of the most abundant ionic constituents of freshwater. Certain of its associated dissolved salts provide buffering capacity against acidity. The pH measurement indicates the balance between acids and bases in water and is an expression of the free hydrogen ion concentration (or acidity) in solution. Total alkalinity is a direct measurement of a water's capacity to neutralize an acid, and is usually due to the bicarbonate and carbonate salts of alkaline metals and alkaline earth metals (i.e., sodium, potassium, calcium, magnesium).

For each variable, the degree of sensitivity was rated from low to high, based on concentration levels or pH values provided initially by Western Canada - LRTAP. The zones of differing sensitivity were defined originally on 1:2 000 000 scale base maps by a simple interpolation procedure. It is important to note that this procedure has provided a preliminary overview of lake sensitivities in Alberta, although acquisition of more and better quality data could alter the size and shape of certain zones.

## 2.2 Map Interpretation

In order to facilitate analysis and discussion of results, the province was divided into 14 geographic regions (Figure 1). Although it can be divided into 36 physiographic zones (Atlas of Alberta 1969), this large number of analytical units would only complicate a provincial overview report such as this one.

Sensitivity maps, based on alkalinity and calcium concentrations, and pH values, are presented in Figures 2 to 4. Areas for which data are unavailable or unreliable are delineated as "no data". The sensitivity intervals for each variable are defined in the legend on each map.

Based on total alkalinity (Figure 2), lakes situated in the Birch Mountains area of the Fort McMurray region, and many lakes in the Caribou Mountains region, were categorized as moderately to highly sensitive (less than 20 mg/L). There are also many sensitive lakes in the Canadian Shield region near Lake Athabasca and in the Jasper National Park region. Small numbers of sensitive lakes occur around Lesser Slave Lake in the Swan Hills region and within Waterton Lakes National Park. Ninety-two lakes, or 9.4% of the total sample, were classified as moderately or highly sensitive based upon the alkalinity criterion.

Areas containing lakes that were moderately to highly sensitive based on calcium values (less than 8 mg/L) included all of the Caribou Mountains region, sections of the Birch Mountains and Muskeg Mountain Uplands in the Fort McMurray region, and the Canadian Shield region around Lake Athabasca (Figure 3). Localized areas that were considered sensitive to acidification occur in the Grande Prairie and Swan Hills regions and in the Jasper and Waterton Lakes National Parks regions. One hundred and eighty-three lakes, or 18.6% of the total sample, were classified as moderately or highly sensitive based upon the calcium criterion.

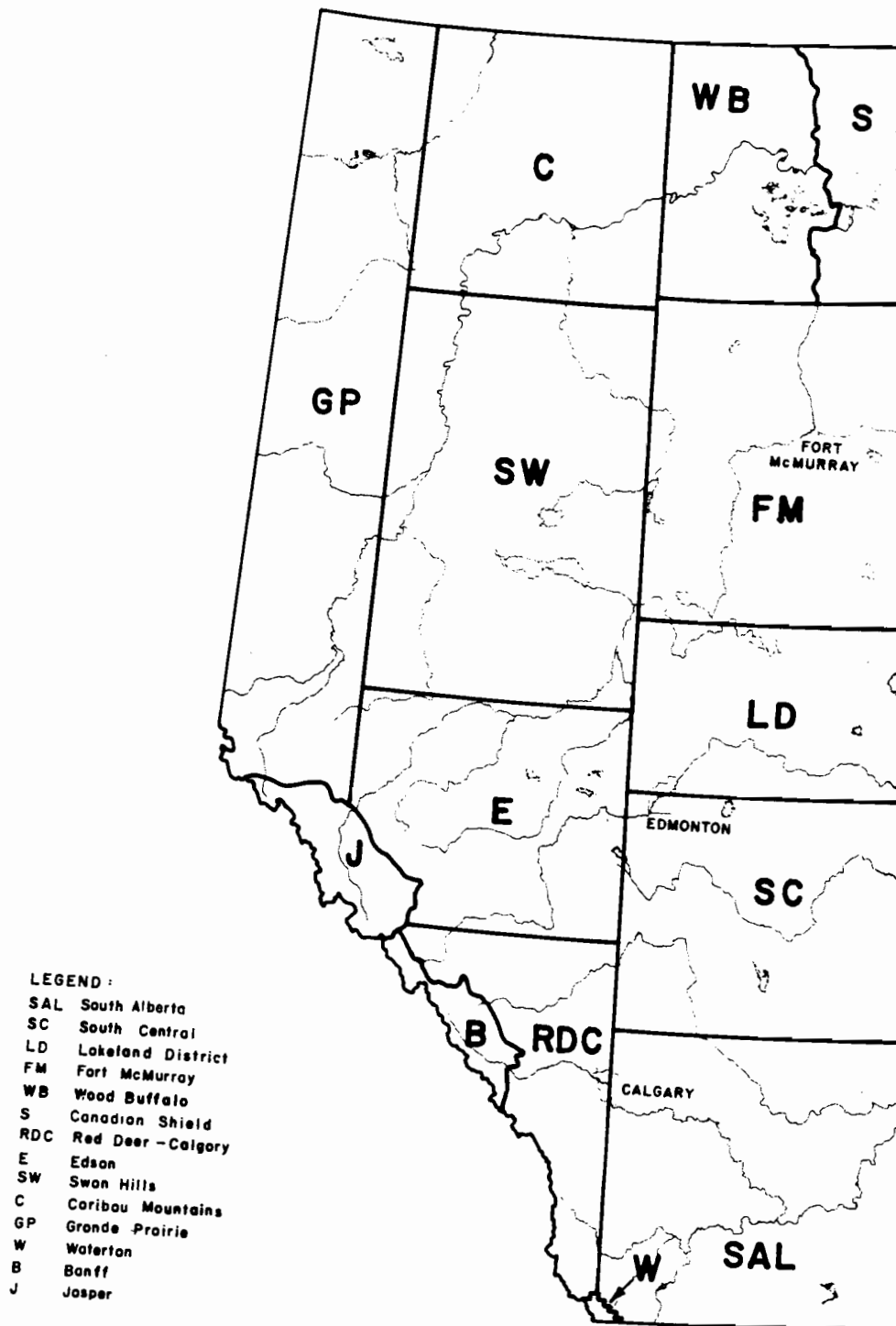


Figure 1. Delineation of regions.





The total land area of the province with lakes of pH less than 7.0 was slightly smaller than the area with lakes of low calcium or low alkalinity; however, similar regions were involved. The areas dominated by lakes with low pH included the Canadian Shield region, the southern part of the Caribou Mountains region, and the uplands of the Grande Prairie region (Figure 4). The Fort McMurray region and Jasper National Park have less extensive areas containing such lakes. One hundred and sixty-three lakes, or 17.0% of the total sample, were classified as moderately or highly sensitive based upon the pH criterion.

These findings suggest that lakes in widely diverse areas of the province may be potentially sensitive to the effects of acidic deposition. However, these criteria were developed originally for the chemically uniform waters of the extensive Canadian Shield in eastern Canada, whereas in Alberta the Canadian Shield represents a very small portion of the total area of the province. The highly variable nature of the surface and bedrock geology of Alberta generates unique ratios of major ions (i.e., calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate) in our surface waters, and the proportions of organic and inorganic constituents are equally variable. Consequently, the use of criteria developed for a single physiographic region elsewhere is not necessarily appropriate for the measurement of the acid-buffering capabilities of surface waters in Alberta.

Two examples illustrate the potential for confusion. In the first case, lakes situated in the southern regions of Alberta are

generally well buffered and hence rather insensitive to the effects of acidic deposition. The presence of carbonate-rich bedrock overlain by calcareous tills is reflected in the high alkalinity values of these waters. Calcium and magnesium bicarbonate waters predominate in most southern regions of Alberta except in the South-Central region, where the ionic contents of the more saline lakes are dominated by sodium sulphate. Within this latter region, three lakes that were identified as sensitive based on their low calcium values are actually well buffered due to the presence of sodium bicarbonate, and their total alkalinity values are among the highest in the province (ranging from 6 080 to 24 395 mg/L).

In the second case, lakes with low pH values may be classified as sensitive, but this does not preclude the possibility that buffering systems other than the carbonate-bicarbonate-carbonic acid system are operating within that lower pH range. These other systems may include weak organic acids and their salts, or hydroxide complexes of metals such as aluminum and iron. A number of the northern upland lakes classified as sensitive based upon pH were highly-coloured, muskeg-type lakes with a high natural acidity, but with poorly understood and perhaps different buffering characteristics.

In the overall analysis of aquatic sensitivity in Alberta, it is the measurement of total alkalinity which provides the most direct overview of current provincial conditions. In general, lakes in the southern and central areas of the province are well buffered against acidic deposition, but lakes in certain areas of the Rocky Mountain national parks, the Canadian Shield area, and the northern upland areas appear sensitive.

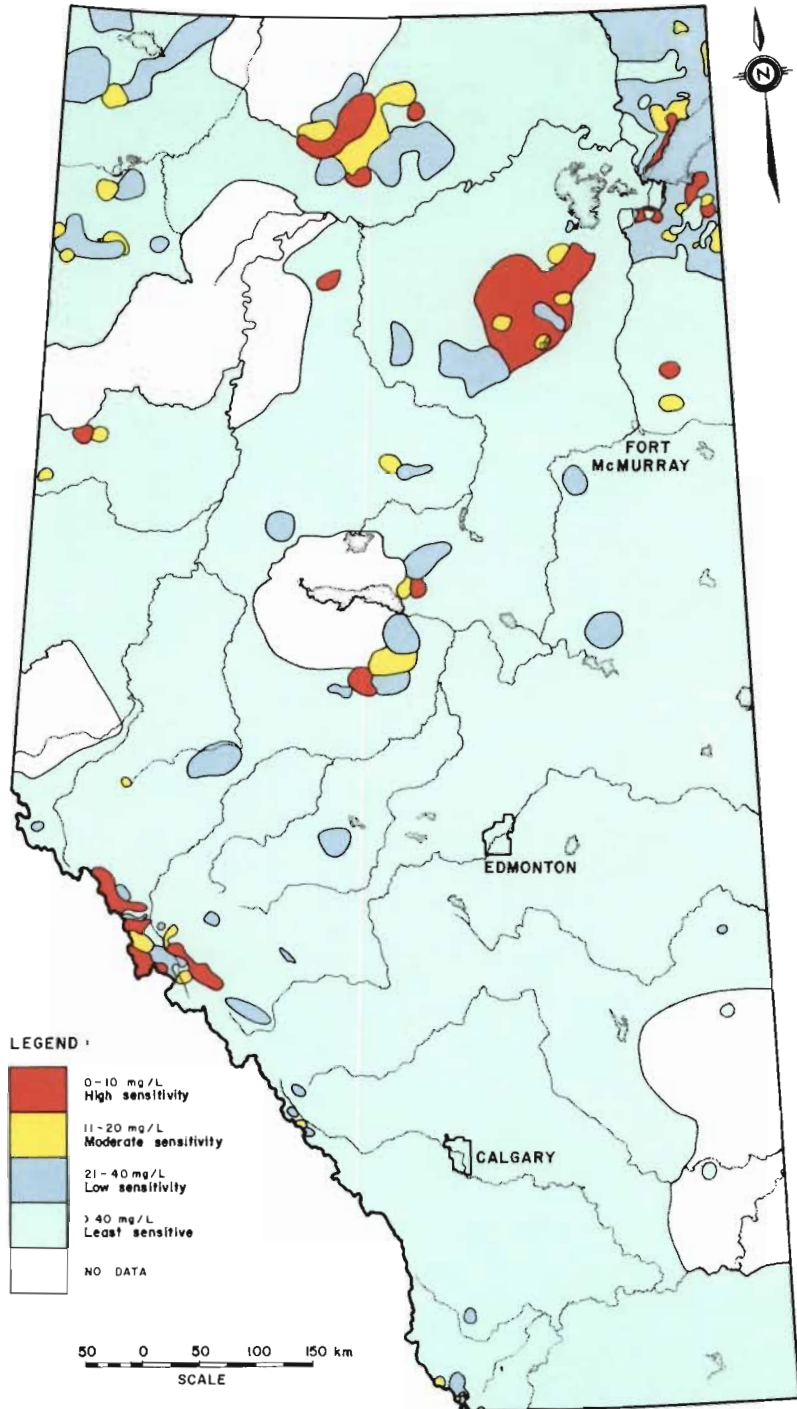


Figure 2. Sensitivity of Alberta lakes to acidification as determined by alkalinity values.



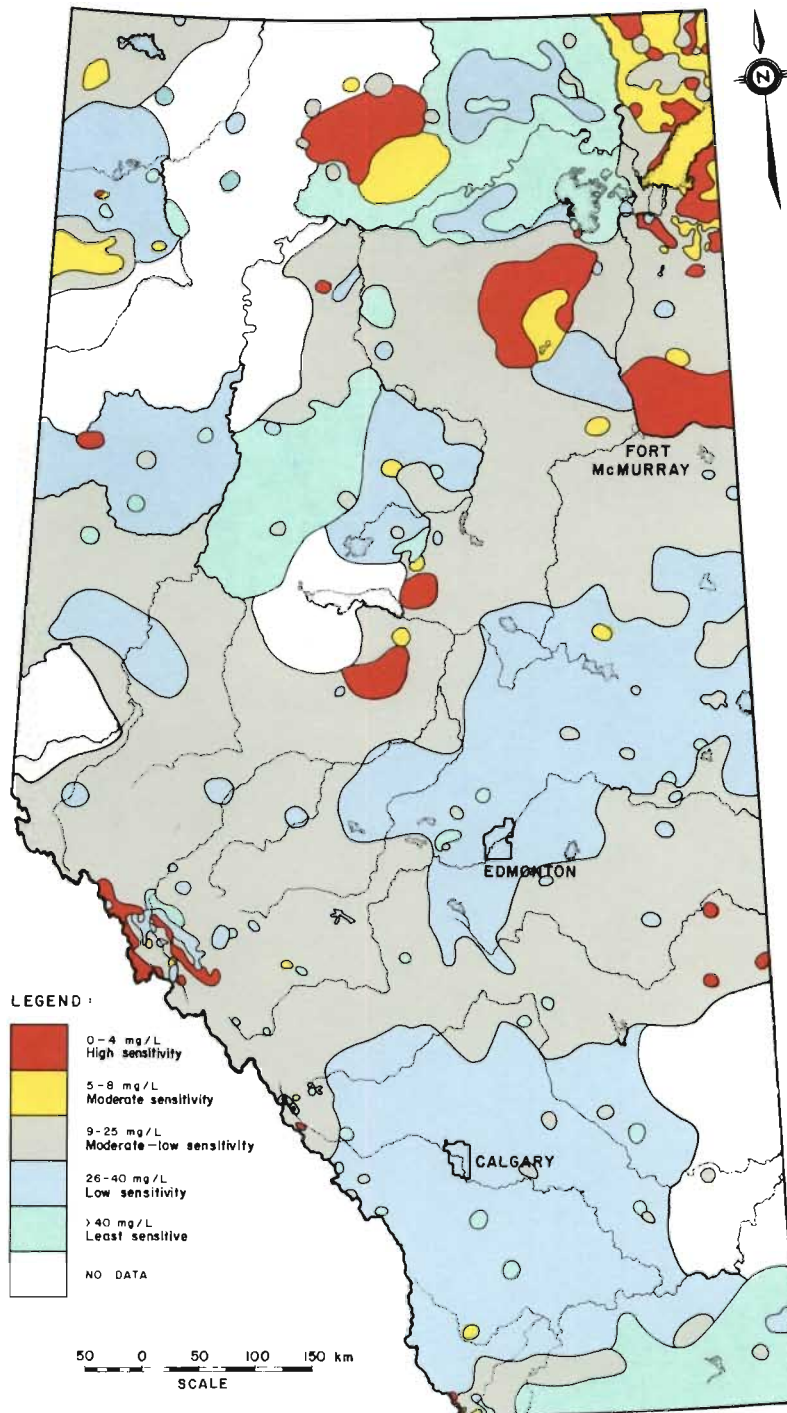


Figure 3. Sensitivity of Alberta lakes to acidification as determined by calcium values.



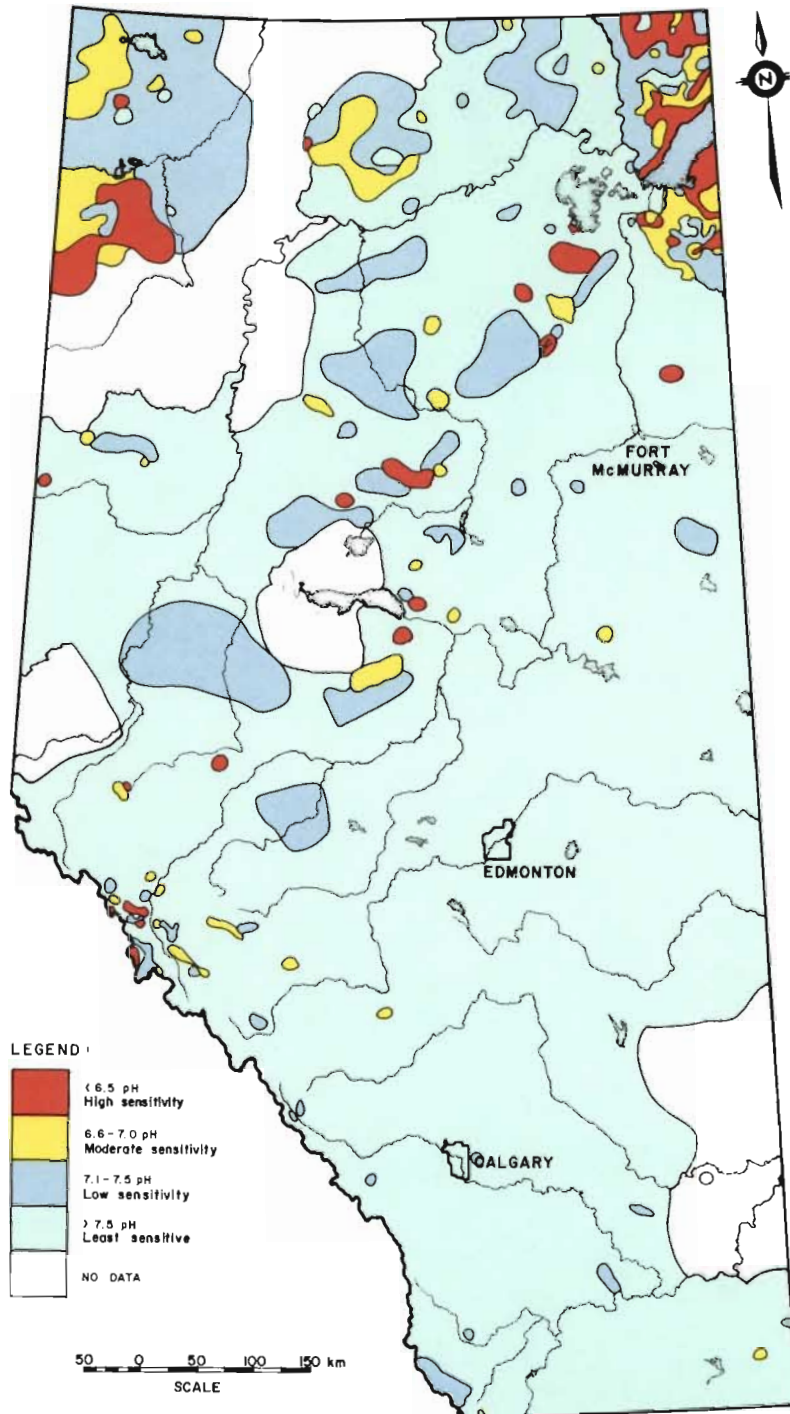


Figure 4. Sensivity of Alberta lakes to acidification as determined by pH values.





### 3.0 POTENTIAL OF SOILS AND GEOLOGY TO REDUCE THE ACIDITY OF ATMOSPHERIC DEPOSITION

#### 3.1 Mapping Criteria and Procedures

Sensitivity maps have also been prepared to identify the potential effects of acidic deposition on our terrestrial environment. Because of the integral relationship between surface waters and their watersheds, two maps have been prepared. One of these maps identifies the combined potential of soils and underlying bedrock to reduce the effects of acidic deposition before its entry into the aquatic regime. A second soil sensitivity map has been prepared to identify the potential effects of acidic deposition on the topsoil itself and its ability to sustain plant growth (see Section 4.0). Both maps were published originally by Holowaychuk and Fessenden (1987).

The criteria used to rate the potentials of soils and bedrock to reduce the acidity of atmospheric deposition were adopted jointly by all western participants in this evaluation. As in the aquatic evaluation, these criteria were developed originally in eastern Canada to delineate regions that were sensitive or susceptible to the inputs of acidic deposition. The criteria are based on combinations of soil depth, exchangeable base content of subsoil material, bedrock type, parent material type, and soil drainage class. As no established criteria had been developed for organic soils (peatlands), provisional criteria were developed for Alberta and used in producing this map.

The initial task was to prepare a provincial soils base map to depict the areal distribution of soils and to assemble pertinent descriptive information that could be used for interpretation of these data. This was accomplished by assembling and synthesizing all of the provincial soils, geological and physiographic information that was available. In all, 215 distinct soil groupings were characterized. As was the case for the aquatic data base, the quality and detail of the soils information that was available for the southern half of the province, the Peace River area and the Rocky Mountain national parks was quite good. However, less information was available for the far north, the northeastern area, and the eastern mountain slopes area.

The soils base map depicts the areal distribution of various soils occurring in the province. Each map unit encompasses areas in which a certain soil is dominant. Usually, however, other intermixed soils are included in the map unit delineations, some constituting more than 20 percent of each unit. In such cases the most extensive of the latter soils is considered to be a subdominant component of the map unit in question. The overall rating for a map unit predominantly reflects the rating for the dominant soil.

The detailed soil base map (1:2 000 000 scale) is contained in Holowaychuk and Fessenden (1986). For the purpose of this overview, the pertinent sensitivity data have been extracted and applied to smaller scale maps to facilitate comparisons with the aquatic sensitivity maps.

### 3.2 Map Interpretation

Expressed as a percentage of the total surface area of the province, soils with high potential to reduce acidity occupy 64.4% of the area, soils with medium potential occupy 21.8%, and soils with low potential occupy 11.3%. Most of the southern half of the province, the southern Grande Prairie and western Swan Hills regions, and parts of the Wood Buffalo region are occupied by soils with a high potential to reduce acidity (Figure 5). With the exception of Wood Buffalo, soils in these regions have developed mainly from moderately calcareous glacial deposits. Within all regions, however, there are localized sandy areas that have a low base content with a medium or low potential to neutralize acidity.

Soils with medium potential are located predominantly in the Clear Hills Upland, the northeastern Swan Hills region, extensive areas of the Fort McMurray region, parts of the eastern slopes of the Rocky Mountains and, to some extent, the Rocky Mountain national parks. Soils with low potential to reduce acidity are located predominantly in the Caribou Mountains, the Cameron Hills of the Grande Prairie region, the Canadian Shield, the Birch Mountains of the Fort McMurray region, Jasper and Banff National Parks, and are associated with several peatland systems and sandy-textured acid (Dystric Brunisol) soils.

A comparison of this map with the lake sensitivity map based on alkalinity (Figure 2) indicates many similarities in the location of highly sensitive lakes and those soil regions of low acid-reducing potential. Minor exceptions exist, for example, the location of some

highly sensitive lakes in the Swan Hills region where soils of low neutralizing potential are not identified. This anomaly may be due to the fact that the lakes in question are associated with a subdominant soil type with a low potential to neutralize acidity. Detailed delineations of soil types have not yet been made in this area. Conversely, the acquisition of updated water quality data for this area may indicate lower sensitivities than those suggested by the historical data base.

This observation also highlights the importance of recognizing that, due to the scale of the provincial sensitivity maps, only general conclusions can be drawn. The sensitivity of any particular watershed is, of course, dependent on the localized conditions for that watershed. These conditions might be quite different from the general conditions in the region.

#### 4.0 SOIL SENSITIVITY TO ACIDIC DEPOSITION

##### 4.1 Mapping Criteria and Procedures

The sensitivities of mineral soils to acidic deposition, in terms of their capability to sustain plant growth, were interpreted according to criteria that were developed cooperatively by the western Canada participants. No similar mapping exercises have been attempted yet for eastern Canada.

The sensitivity of three soil processes (sensitivity to base loss, sensitivity to acidification, and sensitivity to the solubilization of aluminum) were rated separately for each soil type.

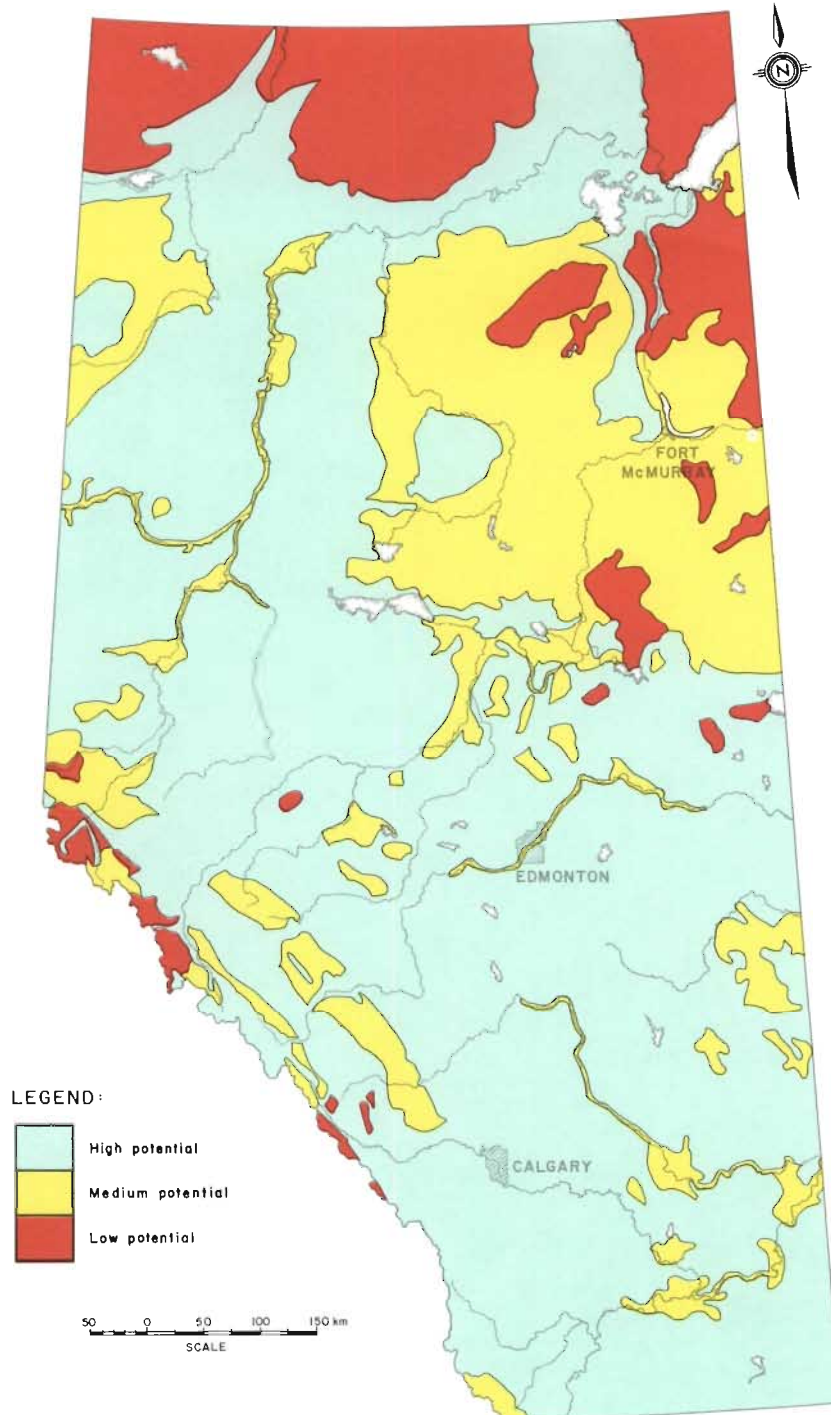


Figure 5. Potential of Alberta soils and geology to reduce the acidity of atmospheric deposition.



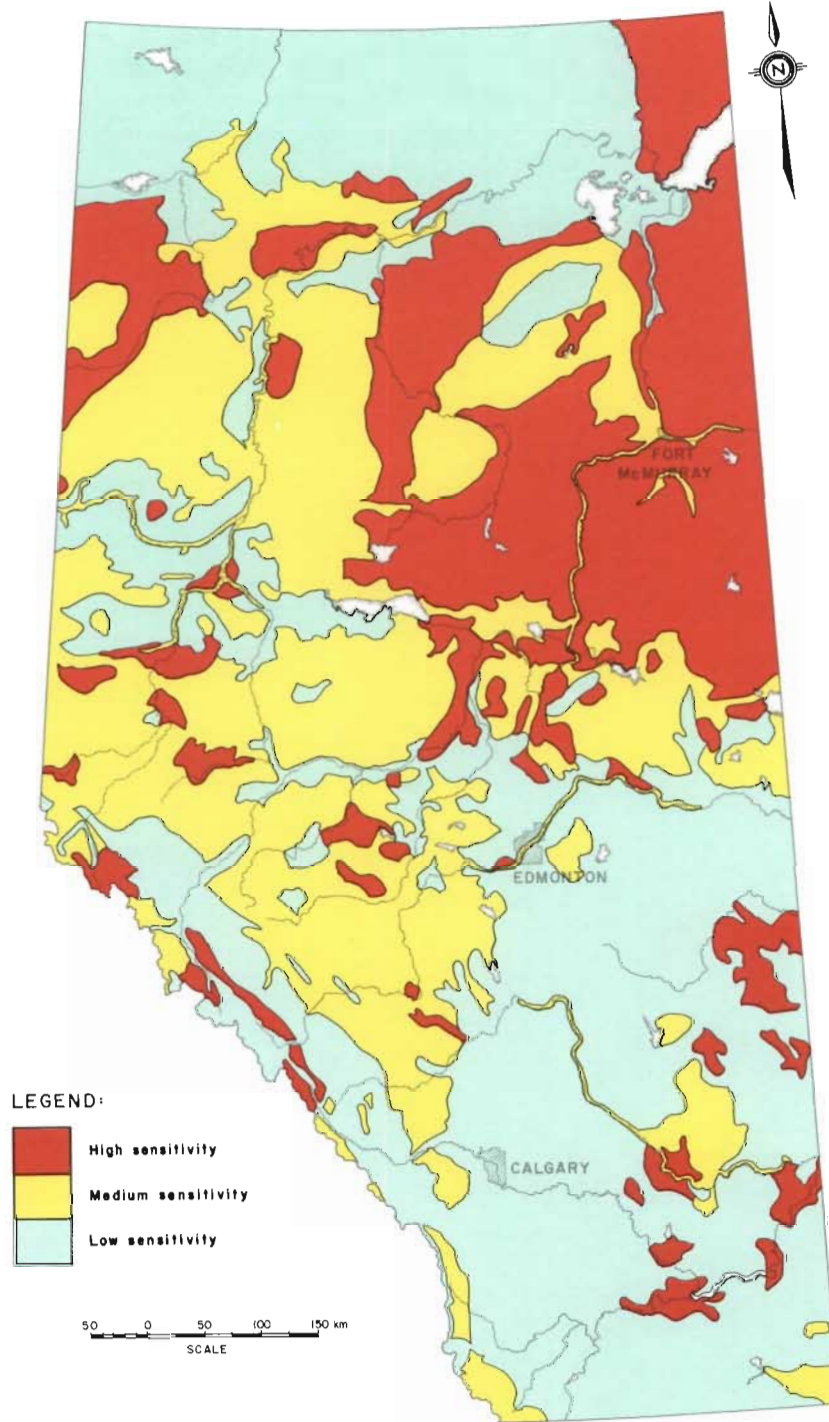


Figure 6. Sensitivity of Alberta soils to acidic deposition.





These individual process ratings were combined subsequently into an overall sensitivity rating. In general terms, soils that were considered to have low base reserves of calcium, magnesium and potassium (as shown by low cation exchange capacity and low pH) and which had a high potential for the solubilization of aluminum were rated as highly sensitive to acidic deposition. Soils that were considered to have high base reserves (as shown by a high cation exchange capacity and high pH) were rated as being of low sensitivity to acidic deposition.

It is important to note that only the topsoil properties were considered when rating soils as to their sensitivity to acidification, whereas subsoil characteristics were incorporated in the previous "potential to neutralize" maps. The topsoil is the layer considered to have the greatest influence on plant growth. However, topsoils highly sensitive to acidic deposition might be underlain with calcareous subsoil or bedrock material having a high potential to neutralize acidity. Consequently, the two soil maps do not necessarily coincide.

Another important factor pertinent to the interpretation of the soil sensitivity map is that no specific guidelines for rating organic soils (peatlands) were developed by the western Canada participants. Because large areas in northern Alberta are occupied by organic soils, it was decided by this province that at least a preliminary attempt should be made to rate these soils with regard to their sensitivities. Accordingly, a provisional set of criteria was developed and applied. It is important also to note that the

following assumptions and interpretations were based on general information reported in the scientific literature and on rather meagre soil survey data for the peatland areas. There is a need for extensive field testing and data collection.

The approach taken was to recognize three peatland system categories (Eutrophic, Mesotrophic and Oligotrophic) that were defined on the basis of the pH level and base cation content of such systems. Eutrophic peatland systems, such as those with slightly acid to mildly alkaline reaction and relative high base cation content, are considered to be of low sensitivity.

Only the Mesotrophic peatland systems are rated as being of high sensitivity. These organic soils have low to intermediate pH and base cation content, and are considered to be the predominant kind in Alberta. These soils are poorly buffered in the lower pH range and a small addition of acidic material has been shown to produce an appreciable decrease in pH.

The Oligotrophic peatland systems, those with the lowest pH and base cation content, are considered to be of low sensitivity, because they are well buffered in the extremely acid range by aluminum and humic acid buffering systems.

#### 4.2 Map Interpretation

Expressed as a percentage of the total surface area of the province, soils of high sensitivity occupy 22.7%, soils of medium sensitivity occupy 30.6%, and soils of low sensitivity occupy 44.4%. The remaining percentage represents standing surface water (Figure 6).

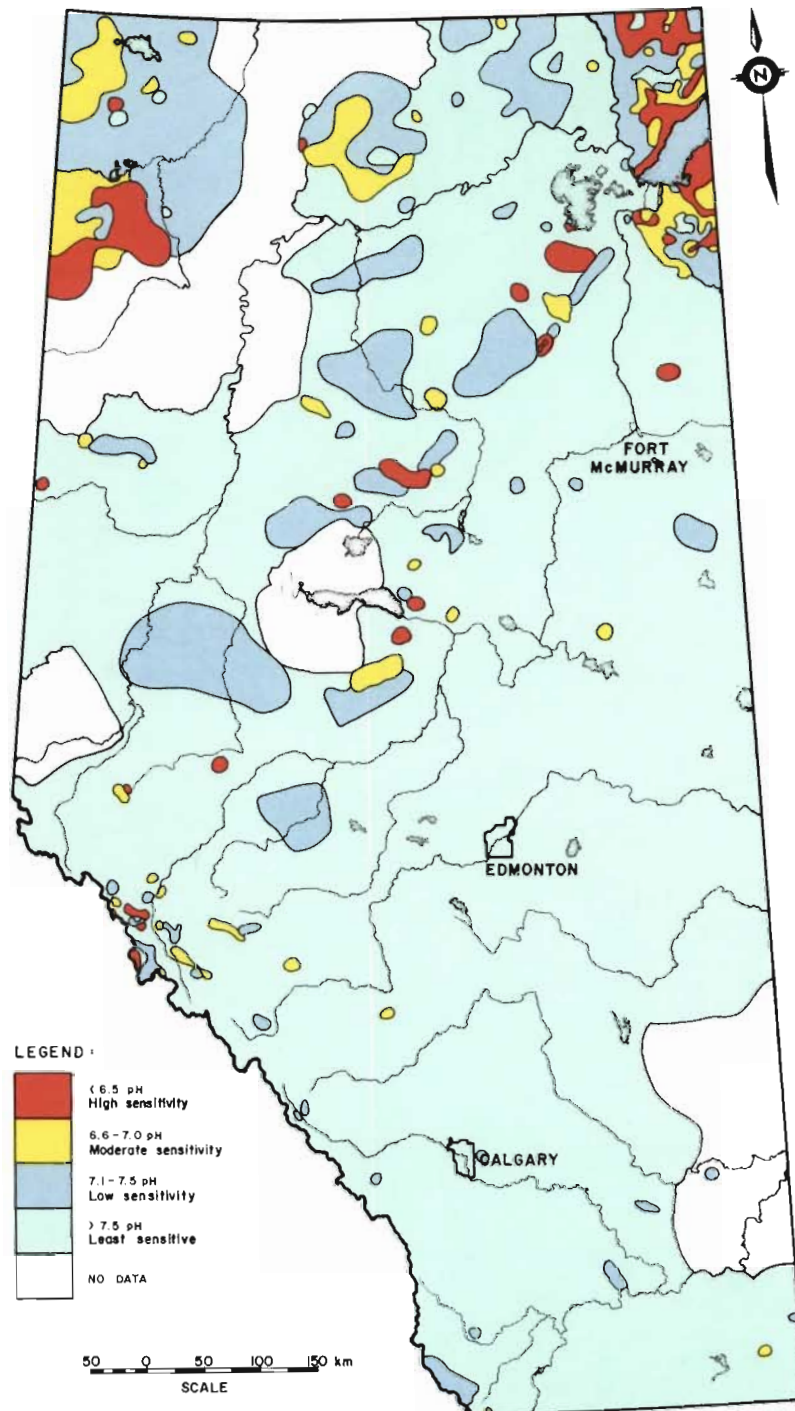


Figure 4. Sensivity of Alberta lakes to acidification as determined by pH values.



The major groups of soils comprising the high sensitivity category are Mesotrophic peatlands located in the Clear Hills Uplands of the Grande Prairie region and throughout much of the Fort McMurray region, the acidic sandy soils located in that portion of the Canadian Shield region south of Lake Athabasca, areas of non-carbonate rocks in the Jasper and Banff regions, and the granite-type rocks of the Canadian Shield. The remaining areas of highly sensitive soils are scattered throughout the province and mainly consist of the sandier Chernozemic, Luvisolic and Brunisolic soils.

The major groups of soils placed in the medium sensitivity category are the grey wooded soils (Orthic Gray Luvisols, Brunisolic and Podzolic Gray Luvisols). These soils cover extensive areas in the Lakeland, Grande Prairie, Swan Hills, Edson and Red Deer - Calgary regions of the province; taken together they constitute almost one-quarter of the area of the province. There are also large areas of Solonetz and Solonetzic Gray Luvisol soils in the northwestern regions of the province that are classed as being of medium sensitivity.

The brown, dark brown, and black soils of the Chernozemic order, the most productive agricultural soils in the southern and central regions of the province, are primarily rated as being of low sensitivity. The remaining peatland systems, predominantly located in the northern Grande Prairie, Caribou Mountains and Wood Buffalo regions, are also placed in this category of sensitivity.

Because of the different purpose and physical basis for compiling this map, no attempt will be made to relate it to the aquatic sensitivity map.

## 5.0 PRESENT LEVELS OF ACIDIC DEPOSITION IN ALBERTA

### 5.1 Precipitation Quality

In Alberta, routine chemical analyses of precipitation have been undertaken since 1978. Eleven precipitation monitoring stations have been in operation since that time. These included six Alberta Environment stations located at Beaverlodge, Calgary, Edmonton, Red Deer, Suffield and Whitecourt, and five Environment Canada stations located at Coronation, Edson, Fort McMurray, Lethbridge and Rocky Mountain House. By means of precipitation event samples bulked over monthly intervals, these installations monitor those chemical characteristics of precipitation which may be influenced by industrialization in the province or long range transport of pollutants into the province.

An analysis of monitoring data collected between 1978-82 reveals that the dominant ionic constituents of the precipitation falling over Alberta are calcium, sulphate and ammonium, unlike the precipitation in eastern North America which is dominated by sulphate, hydrogen, and nitrate. The overall pattern of ionic dominance in Alberta is as follows: calcium > sulphate > ammonium > magnesium > nitrate > sodium > bicarbonate > chloride > potassium > hydrogen. The order varies slightly from year to year and from station to station (Bertram et al. 1986).

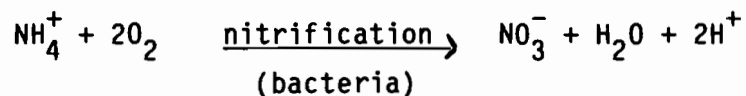
The main significance of this pattern is that hydrogen ion concentrations, the measurement of actual acidity, represent a minor component of Alberta precipitation. The monitoring data reveal that the precipitation falling over this province has an overall annual average pH of 5.5, which is close to the theoretical value of 5.6. This is also much less acidic than the precipitation falling over eastern North America (pH 4.1-4.4) or northern Europe (pH 4.0-4.5) (National Research Council 1983; Swedish Ministry of Agriculture 1982). (Note: a pH change of one unit, such as from pH 6.0 to pH 5.0, indicates a tenfold increase in acidity). Only 5% of the Alberta samples had pH values less than 5.0.

Within the province, certain geographic variations in precipitation quality are also evident. The precipitation in southern Alberta has a higher ionic content, especially of calcium, sulphate, and ammonium, than that found in northern and central Alberta. In addition, the average pH decreases from pH 6.1 in the south to pH 5.2 in the northwest. The presence of high calcium ion concentration, in association with low hydrogen ion concentration, suggests that at least part of the soluble calcium compounds in Alberta precipitation could be alkaline in nature, thus providing a neutralizing capacity against the man-made contributions to precipitation acidity (Bertram et al. 1986). It is believed that wind-blown calcareous dust and soil could be the major sources of these alkaline materials.

Another major characteristic of Alberta precipitation is the apparent lack of any relationship between sulphate concentrations and acidity. In other regions where acidification studies have been

conducted, higher sulphate concentrations in precipitation have been related to increases in hydrogen ion concentrations. As a result, sulphate has often been used as a surrogate for acidity. However, this is not the case in Alberta. No significant correlations have been observed between the variations of hydrogen ion concentration (acidity) and those of either sulphate or nitrate. The significance of this fact to the control of acidic deposition is discussed in Section 5.4.

Although precipitation in Alberta has very little actual acidity, it does have another significant component with acidifying potential. This component is the ammonium ion. Ammonium may be converted in soil and water to the nitrate ion by microorganisms in a process called nitrification. The byproduct of this reaction is the release of two hydrogen ions:



The acidification of soil through the addition of ammonium-based nitrogen fertilizers is an example of this process well known to agriculturalists. The acidifying effect of ammonium addition to soil can be somewhat offset or reduced by other complex biological or chemical soil processes. Nevertheless, it remains important to consider this component of precipitation when estimating overall acid additions to the environment.



## 5.2 Wet Deposition Rates

The data collected at the eleven monitoring stations also allow the calculation of areal deposition rates of certain atmospheric chemicals. From a knowledge of chemical concentrations and precipitation volumes, one can calculate the total mass of a substance deposited per unit area during a given observation period. This is important because areal deposition rates have been related empirically to the degree of environmental change and thus can be used to determine the extent of acidification. As in other areas of environmental management, the total mass of a substance introduced into an ecosystem, as well as its concentration, should be identified in order to define fully its potential impact.

Based upon the observation period 1978-82, the average wet hydrogen ion deposition rate in Alberta was estimated at 0.015 kilograms per hectare per year (Table 1). As is the case for hydrogen ion concentrations, this deposition rate is much lower than hydrogen ion deposition rates observed in eastern Canada, which, at selected sites, ranged from 0.432 to 0.804 kilograms per hectare per year (Lau 1985).

Since sulphate concentration has been directly linked with acidity in the precipitation falling over eastern North America and northern Europe, most jurisdictions and scientific investigations have used the sulphate deposition rate as a key variable in the analysis of the acidification issue. Although this concept may not be applicable to Alberta for the reasons discussed in Section 5.1, a comparison of sulphate deposition rates between these regions is of some value.

TABLE 1 Wet deposition (kilograms/hectare/year) at Alberta stations and selected Canadian stations (1978 - 82)<sup>1</sup>

	Wet Sulphate	Wet Hydrogen	Wet Nitrate	Wet Ammonium
<u>Alberta</u>				
Beaverlodge	6.8	0.031	3.2	3.1
Calgary	15.5	0.004	5.8	3.6
Coronation	8.0	0.011	4.6	1.2
Edmonton	8.9	0.017	4.6	2.3
Edson	9.0	0.033	3.1	0.8
Fort McMurray	8.0	0.010	3.6	0.3
Lethbridge	11.5	0.003	7.6	2.2
Red Deer	9.4	0.022	5.2	3.1
Rocky Mtn House	10.3	0.013	3.7	2.0
Suffield	9.9	0.009	4.6	5.4
Whitecourt	10.5	0.015	4.3	1.2
Average	9.8	0.015	4.6	2.3
<u>Other Provinces</u>				
Prince George (B.C.)	10.6	0.009	3.1	1.8
Revelstoke (B.C.)	6.5	0.060	3.9	0.6
Cree Lake (Sask.)	4.4	0.036	2.0	0.6
Wynyard (Sask.)	8.2	0.001	5.7	0.2
The Pas (Man.)	7.1	0.003	3.6	0.7
Bissett (Man.)	7.6	0.046	4.1	0.7
Simcoe (Ont.)	52.5	0.804	35.0	5.7
Maniwaki (Que.)	32.2	0.515	20.3	5.6
Quebec City (Que.)	57.2	0.573	25.8	6.4
Truro (N.S.)	30.0	0.432	10.9	2.5

1. Lau (1985)

Based upon the observation period of 1978-82, the average wet sulphate deposition in Alberta was estimated as 9.8 kg per hectare per year. This is well below the rate of 20 kg per hectare per year which is the target amount recommended by the Canadian Government (Bangay and Harris 1983) to protect moderately sensitive surface waters, and which has been observed in certain regions to be the rate beyond which damage becomes apparent. By comparison, the existing wet sulphate deposition rates for the selected sites in eastern Canada ranged from 30.0 to 57.2 kilograms per hectare per year (Table 1). From these data it is clear that the ratio of hydrogen ion to sulphate ion ( $H^+ : SO_4^{=}$ ) in Alberta precipitation is one order of magnitude less than the ratio observed in eastern Canada. Thus, each kilogram of wet sulphate deposited over Alberta has a much smaller acidity associated with it than the same amount falling over Ontario or Quebec.

The average wet ammonium deposition in Alberta was 2.3 kg per hectare per year, and for nitrate it was 4.6 kg per hectare per year. No guidelines for the wet deposition of hydrogen, ammonium or nitrate have been developed yet in Canada.

### 5.3 Dry Deposition Rates

In contrast to our knowledge of wet deposition rates in Alberta, considerable uncertainty exists with regard to acid additions due to dry deposition. The cause of this uncertainty is the difficulty encountered in making dry deposition measurements. The rate of dry deposition is dependent on a number of factors including atmospheric stability, wind speeds, concentration of acid-forming

gases, surface roughness, and type and condition of vegetation or soils. The mechanisms involved in dry deposition are extremely complex and difficult to quantify. Few measured data are available to describe this process in western Canada.

Several approaches have been used to estimate dry deposition rates. One method has been to place artificial substrates such as surgical gauze coated with lead dioxide and allow these to react with air pollutants for a period of time. Sulphur dioxide gas, for example, is oxidized by lead dioxide to lead sulphate which can be measured subsequently in the laboratory. Containers of wet and dry soil have also been used as dry deposition collectors. Although these methods do give relative estimates of potential dry deposition, they must be considered as estimates only. Both have been attempted in Alberta, but only for localized areas around point sources.

Another approach has been to estimate dry deposition rates using mathematical models. Dry deposition models have been developed for estimating localized deposition from industrial point sources as well as for estimating long range transport of pollutants on a regional scale. These models are often very complex and consider many of the variables that control dry deposition. Although the accuracy of their predictions has not been verified completely for Alberta conditions, they can provide an initial overview of the dry deposition process.

Using one such model, the average dry deposition of sulphate at the eleven Alberta precipitation monitoring sites was estimated at 16.4 kg per hectare per year for 1982 (Kociuba 1984). This is more

than 200% of the wet deposition rate of sulphate for the same year (Table 2). In eastern Canada dry deposition is estimated as only 40% to 50% of wet deposition.

It is important to note that the true acidifying potential of dry deposition is unknown. In Alberta, much of the sulphate in dry deposition may be derived from neutral salts. Alternately, the acids that do result from this sulphate may be neutralized by alkaline atmospheric dust, as appears to happen with wet deposition of sulphate. Both the acidification and neutralization potentials of dry deposition remain unquantified.

#### 5.4 Interpretation of Deposition Rates

No regional scale effects have been observed in Alberta from acid-forming emissions. This is in contrast to many regions of eastern Canada where significant effects from acidic deposition have been identified, particularly for aquatic ecosystems. Measurable effects have occurred in areas where higher acidic deposition rates (greater than 20 kg per hectare, expressed as wet sulphate) coincide with highly sensitive ecosystems. No measured effects have been identified where either of these two components is missing. For example, well buffered soils and lakes can tolerate relatively high levels of acidic deposition without impairment to their quality. Conversely, highly sensitive soils and lakes may not be at risk if acidic deposition levels are low. Therefore, the two basic questions are: do we have high acidic deposition rates in any region of Alberta?

TABLE 2 Wet, dry, and total sulphate deposition  
(kilograms/hectare/year) at Alberta stations for 1982

	Wet <sup>1</sup> Sulphate	Dry <sup>2</sup> Sulphate	Total Sulphate
<u>Alberta</u>			
Beaverlodge	4.6	4.8	9.4
Calgary	9.9	20.7	30.6
Coronation	8.6	18.6	27.2
Edmonton	7.5	21.0	28.5
Edson	9.5	18.6	28.1
Fort McMurray	6.1	21.0	27.1
Lethbridge	5.8	13.8	19.6
Red Deer	7.3	12.3	19.6
Rocky Mtn House	8.3	20.2	28.5
Suffield	3.3	7.2	10.5
Whitecourt	11.2	21.9	33.1
Average	7.5	16.4	23.8

<sup>1</sup> Lau (1985)

<sup>2</sup> Kociuba (1984)

If so, are highly sensitive ecosystems located in these regions of high deposition?

The only criterion against which Alberta deposition rates can be compared is the sulphate criterion developed for eastern Canada. As shown in Table 1, the annual wet deposition of sulphate in Alberta for all sites was below the target loading of 20 kilograms per hectare per year. However, it is likely that the total deposition is a more relevant variable with respect to the acidification issue. Although a target loading for total deposition has not yet been established in Canada, the dry/wet deposition ratio of 50% in eastern Canada discussed previously suggests a total sulphate deposition target of 30 kilograms per hectare per year. At most monitoring sites in Alberta (Table 2) the estimated total sulphate deposition for 1982 approaches this figure, and in two cases (Calgary and Whitecourt) slightly exceeds the value. This is due primarily to the higher rates of dry deposition estimated to occur in Alberta. Neither location is associated with extensive areas of highly sensitive lakes or soils.

Left unqualified, the preceding paragraph might prompt unfounded speculation regarding the acidification issue in Alberta. However, several important factors must be considered for a full interpretation. First, the precipitation data base for Alberta indicates that there is no relationship between acidity (hydrogen ion concentration) and sulphate concentration. Therefore the target loading based on sulphate is not appropriate for Alberta. Second, the relative proportion of hydrogen ion to sulphate ion in Alberta precipitation is much lower than that observed in eastern Canada and,

consequently whatever acidity is associated with sulphate is much lower in Alberta. Third, the uncertainty in the dry deposition estimate and the acidity associated with dry deposition are unknown, and the latter may be as low as that associated with wet deposition. These factors point to the need for the development of appropriate acidification criteria for Alberta. Recently, the Technical Committee on Western Canada - Long Range Transport of Atmospheric Pollutants initiated this task for all western provinces and territories. The issue has also been discussed in the scientific literature (Sandhu and Blower 1986).

A more comprehensive approach would be to consider all components of precipitation contributing to actual effective acidity. A similar technique has been applied by soil scientists to certain areas of eastern Canada (Coote et al. 1981), and requires the solution of a complex chemical equation so that the major components of acidic deposition are equated to hydrogen ion concentrations. These components include wet hydrogen ion deposition, the potential contribution from the nitrification of ammonium in soil, and the modifying effect of plant uptake of nitrate. This technique has been applied to the Alberta and Canada precipitation data bases, except that dry deposition was excluded from the analysis because of the uncertainty associated with its measurement and acid content.

The estimated effective acidic loadings in Alberta are shown in Table 3, which presents data for the 1982 observation year. Although not shown, it is important to note that the relative contribution of hydrogen ion from precipitation to the total acidity



TABLE 3 Soil affecting acidic deposition<sup>1</sup> expressed as hydrogen (kiloequivalents or kilograms/hectare/year) at Alberta stations and selected Canadian stations for 1982

<u>Alberta</u>	
Beaverlodge	0.14
Calgary	0.23
Coronation	0.04
Edmonton	0.10
Edson	0.04
Fort McMurray	0.00
Lethbridge	0.06
Red Deer	0.13
Rocky Mtn House	0.15
Suffield	0.02
Whitecourt	0.03
<hr/>	
Average	0.09
<hr/>	
<u>Other Provinces</u>	
Prince George (B.C.)	0.06
Revelstoke (B.C.)	0.08
Cree Lake (Sask.)	0.06
Wynyard (Sask.)	0.00
The Pas (Man.)	0.00
Bissett (Man.)	0.06
Simcoe (Ont.)	0.93
Maniwaki (Que.)	0.61
Quebec City (Que.)	0.41
Truro (N.S.)	0.45

<sup>1</sup> Calculated soil affecting acidity (as hydrogen) from precipitation.  
 $= H^+ + NH_4^+$  (adjusted) -  $NO_3^-$  (adjusted)  
 $= (H^+/1) + (1.15 \times NH_4^+/18) - (0.7 \times NO_3^-/62)$   
 (Coote et al. 1981)

is comparatively small. According to this calculation, the potential contribution to acidity from wet ammonium is the most important component, and ammonium is the greatest at Calgary, Rocky Mountain House, Beaverlodge and Red Deer. Emissions of ammonium from comparable agricultural areas have been shown to cause soil acidification in other regions (van Breemen et al. 1982).

The range of effective acidic deposition rates via wet deposition at the Alberta sites is estimated to be between 0.00 and 0.23 kilograms of hydrogen ion per hectare per year. (Note: the calculated value of 0.00 results from low hydrogen and ammonium deposition combined with somewhat higher nitrate deposition). In comparison, rates of effective acidic deposition for eastern Canada (Table 3) range from 0.41 to 0.93 kilograms of hydrogen ion per hectare per year, and hydrogen ion is the major contributor to acidity.

Although there are no standards with which these rates can be compared, it is evident that the effective acidic deposition rates in Alberta are much lower than those causing impacts in eastern Canada. The stations of highest acidic loadings in this province generally do not coincide with the most sensitive ecosystems. For example, the Fort McMurray region is an area of sensitive lakes and soils, yet the effective acidic deposition rate at the sampling site within the City of Ft. McMurray appears to be the lowest. However, no conclusive statements can be made until more regional deposition data become available, and until the effective acidity concept is more rigorously evaluated for Alberta.

## 6.0 FUTURE TRENDS

The information presented in the preceding pages suggests that there are acid-sensitive natural resources in Alberta. However, there is no conclusive evidence of significant impacts at this time. A final question is: how will future development in western Canada affect this situation?

This is a complex question, invoking many secondary questions and issues related to the location and magnitude of future point sources, the nature of atmospheric dispersion and transport, the influence of technology on the recovery efficiencies of acid-forming precursors, the level of economic activity, and the nature of government pollution control regulations. Many of these issues are presently under review, so only a preliminary overview of future conditions can be presented here. Furthermore, our limited knowledge of the quantitative dynamics of wet ammonium cycling through the atmosphere and of the entire dry deposition process, makes it impossible to predict future trends for these components of acidic deposition. The following comments pertain to existing anthropogenic point-source emissions only.

The major sources of sulphur dioxide emissions in Alberta are the natural gas processing industries, oil sands plants, and coal-fired electric generating stations. Sour gas plants produce about 50% of the total. However, as a result of Alberta Environment's air pollution control program, industrial sulphur dioxide emissions have decreased by approximately 15% during the period from 1974 (625,610 tonnes) to 1985 (530,564 tonnes). This decrease occurred

during a period when the number of licensed industrial sources increased from 77 to 180. Using the philosophy of "best practicable technology" for recovery, projected SO<sub>2</sub> emissions for the year 2000 are now estimated at 410,000 tonnes (Colley and Poon 1982). Therefore, one can be cautiously optimistic about the future influence of this source of acidity.

In relative terms, sulphur dioxide emissions in Alberta are much lower than in many other provinces. Although Alberta processes twice as much sulphur-containing material as Ontario, Quebec and Manitoba combined, sulphur dioxide emissions in Alberta are one-quarter of the total from these three provinces. The reason for this is that Alberta Environment has enforced regulations on sulphur dioxide emissions that are among the most stringent in all of Canada, and Alberta's industries recover a higher percentage of the sulphur contaminant.

## 7.0 CONCLUSIONS

Regions of lakes and soils sensitive to acidic deposition have been identified in Alberta. These regions are not receiving what may be considered to be high levels of effective or wet acidic loadings, although uncertainties related to the full understanding of this issue remain. Environmental monitoring and research into emission control technology, acidic deposition processes, and environmental effects of acidic deposition will continue to be priorities for the Alberta government.

## 8.0 REFERENCES

- Alberta Environment. 1979. Industrial Sulphur Emissions Inventory for Alberta (1974-78). Research Secretariat, Edmonton. 21p.
- Alberta Environment, Pollution Control Division. 1986. Industrial Sulphur Emissions Inventory for Alberta (1981-85). Air Quality Control Branch, Edmonton. Draft Report.
- Bangay, G.E. and C.I. Harris (Co-Chairmen). 1983. Memorandum of Intent on transboundary air pollution. Impact Assessment Work Group I. Final Report. 509 pp.
- Bertram, H.L., N.C. Das, and Y.K. Lau. 1986. Precipitation Chemistry Measurement in Alberta. Water, Air and Soil Pollution 30:231-237.
- Colley, D.G. and R.W. Poon. 1982. Alberta sulphur dioxide emission forecast 1980-2000. Prepared for the Alberta Department of the Environment, Research Management Division by Western Research. RMD Report 82/16, 1001 pp.
- Coote, D.R., D. Siminovitch, S. Shah Singh, and C. Wang 1981. The significance of acid rain to agriculture in Eastern Canada. Agriculture Canada LRRRI Contribution No. 119, 26 pp.
- Erickson, P.E.K. 1987. An assessment of the potential sensitivity of Alberta lakes to acidic deposition. Water Quality Control Branch, Alberta Environment, Edmonton. 102 p.
- Government of Alberta and University of Alberta. 1969. Atlas of Alberta. Published by the University of Alberta Press in Association with the University of Toronto Press. Edmonton. 158 p.
- Holowaychuk, N. and R.J. Fessenden. 1986. The sensitivity of Alberta soils to acid deposition and their potential to reduce the acidity of atmospheric deposition. Terrain Sciences Department, Alta. Res. Council. 63 p. Draft Report.
- Kociuba, P.J. 1984. Estimate of sulphate deposition for Alberta. Atmospheric Environment Service, Environment Canada, Edmonton, Alberta. 6 pp.
- Lau, Y.K. 1985. A 5 - year (1978-82) summary of precipitation measurements in Alberta. Alberta Environment, Air Quality Control Branch, Edmonton. 67 p.

- Lau, Y.K. and N.C. Das. 1985. Precipitation quality monitoring in Alberta. IN: Proceedings of the 1985 Joint Annual Meeting. CPNS and PNWIS of the Air Pollution Control Section, Calgary, Alberta. November, 1985.
- National Research Council of Canada. 1981. Acidification in the Canadian aquatic environment: Scientific criteria for assessing the effects of acidic deposition on aquatic ecosystems. Publication NRCC No. 18475, Environmental Secretariat, Ottawa. 369 pp.
- National Research Council. 1983. Acid Deposition, Atmospheric Process in Eastern North America. Report by the Committee on Atmospheric Transport and Chemical Transformation in Acid Precipitation. National Academy, Washington, D.C. 373 pp.
- Sandhu, H.S. and L. Blower. 1986. Acid-forming Emissions in Alberta, Canada. Environmental Management. Vol. 10:689-695.
- Swedish Ministry of Agriculture. 1982. Acidification Today and Tomorrow a Swedish Study prepared for the 1982 Stockholm Conference on the Acidification of the Environment. Sweden. 231 pp.
- Van Breemen, N., Burrough, P.A., Velthorst, E.J., Van Dobben, H.F., de Witt, Toke, Riddler, T.B., and Reijnders, H.F.R. 1982. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. Nature 299:548-550.