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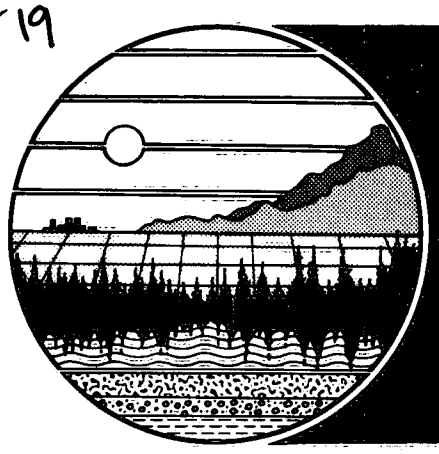

LANDS DIRECTORATE

DIRECTION GÉNÉRALE DES TERRES

CHARACTERISTICS OF TERRESTRIAL ECOSYSTEMS IMPINGED BY ACID PRECIPITATION ACROSS CANADA

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CHARACTÉRISTICS OF TERRESTRIAL ECOSYSTEMS IMPINGED BY ACID PRECIPITATION ACROSS CANADA

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Les caractéristiques des écosystèmes terrestres touchées par les précipitations acides au Canada

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Acidified precipitation now impinges about 28% or 2.5 million km^2 of the land area of Canada. This report provides background ecological data on the nature of these impingement areas. A computerized, environmental data base of geographic information has been utilized to summarize quantitative information on the types of soils, vegetation, and surficial geology of land receiving precipitation with a mean annual acidity of less than pH 5.6. The annual levels of precipitation are also reported within these areas.

Over 79% of impingement areas have surficial morainal and glaciofluvial deposits often associated with poorly-buffered, acidified podzolic or brunisolic soils or almost bare rock. Affected vegetation may include over one million km^2 of boreal forest and 472 000 km^2 of mixed hardwood/softwood and hardwood forests. The precipitation in these areas is mainly in either the 50-80 or 80-110 cm/year ranges.

Analyses are presented for areas in eastern and western Canada with potential acid precipitation sensitive terrain including Podzols, Brunisols, and rockland that have moraine and glaciofluvial deposits. Areas in Northern Canada that may be sensitive to acid precipitation are also examined, indicating that about 37% of the area north of 60° latitude has high potential sensitivity to acid precipitation. In the West, about 31% of the landscape may be highly sensitive to acid precipitation.

RÉSUMÉ

Les précipitations acides touchent maintenant 28% de la superficie du Canada, ou 2,5 millions de km^2. Le présent rapport fournit des données écologiques fondamentales sur la nature des régions ainsi touchées. Une base de données géographiques a servi à condenser les renseignements d'ordre quantitatif sur les sols, la végétation et la géologie de surface des régions où le pH annuel moyen des précipitations est inférieur à 5,6. La pluviosité dans ces régions est aussi donnée.

Plus de 79% des superficies touchées sont constituées en surface de dépôts fluvio-glaciaires et de moraines ainsi que de brunisols, ou de podzols acidifiés, ou de roche presque nue. Plus d'un million km^2 sont couverts de forêts boréales et 472 000 km^2 de forêts mixtes ou de forêts de feuillus. La précipitation y est surtout de 50 à 80 ou de 80 à 110 cm/an.

Les régions de l'ouest et de l'est du Canada, constituées de Podzols, de Brunisols et de lithosols où on trouve des dépôts fluvio-glaciaires et des moraines, sont identifiées. Au nord du Canada il y a des régions aussi qui sont très vulnérables; presque 37% du territoire au nord de 60° de latitude est inclus. A l'ouest du Canada, presque 31% du territoire est très sensible aux précipitations acides.

PREFACE

This report examines the characteristics of the terrestrial environment across Canada of those areas where annual mean levels of precipitation acidity now are less than pH 5.6. These data are designed to assist in development of an appreciation of the environments now receiving acid precipitation impingement and to assist in the quantification of environmental impacts. The data used in this analysis are highly generalized, with a primary data source being the 1:15 000 000 maps presented in the National Atlas of Canada (1974). Due to such generalization, data concerning some small but possibly significant units have been deleted. The process of computerization and data base input and retrieval also introduces a variety of small errors. The interpretations and assumptions made are those that the author considered useful and informative, recognizing that some colleagues will disagree and would prefer more analysis or additions of other types of data that have become available since the inception of this study in February 1980.

As this study neared completion, further work by Cowell, Lucas and Rubec (1981) has provided a more detailed review and analysis of terrestrial sensitivity to acid precipitation in eastern Canada. The latter study utilizes the 1:1 000 000 Ecodistrict data base developed by the Lands Directorate of Environment Canada. Maps of forest cation nutrient sensitivity and aquatic input sensitivity to acid precipitation are developed in Cowell et al (1981) and presented in the Interim Report of the United States-Canada Impact Assessment Working Group (1981b).

Data on bedrock sensitivity were not incorporated into the data analysis presented here; an excellent study by Shilts (1981) should be referred to for a more detailed review of this aspect of terrestrial sensitivity. Revised versions of acid precipitation distribution in Canada such as Environment Canada (1981) and Clair et al (1981) have also been prepared based on more extensive data from the Canada Network for Sampling of Precipitation (CANSAP).

Acid precipitation research efforts in federal and provincial agencies in Canada are subject to continuing refinement and modification of interpretations as new data are gathered. However, the overall picture remains unchanged -- acid precipitation continues to be an awesome environmental problem in many areas of Canada. The author would welcome suggestions and clarifications on the information presented in this working paper. A future revision will incorporate more detailed terrestrial data from the Ecodistrict data base in western and northern regions as well as other new literature.

INTRODUCTION

The evaluation of the impacts of Long-Range Transported Air Pollution (LRTAP), or "acid precipitation", on the terrestrial and aquatic environments of Canada is the subject of intense research by scientists in federal and provincial agencies. This research will provide an overview of the environmental, social, and economic impacts of acid precipitation as background information for air quality treaty negotiations between Canada and the United States commencing in June 1981. This report outlines preliminary data describing the ecological characteristics of lands across Canada currently believed to be receiving significant quantities of acidified precipitation each year. It provides information on the soils, vegetation, surficial geology, annual precipitation levels, and range of precipitation acidity in areas of Canada with a mean annual precipitation pH less than 5.6. This pH value is widely regarded as an identifying characteristic of precipitation with airborne pollution levels exceeding natural conditions.

ACID PRECIPITATION DISTRIBUTION IN CANADA

Airborne pollution levels in eastern North America are now measured by precipitation sampling networks. In Canada, the CANSAP program has 54 stations in a network providing measurements of precipitation chemistry including pH and H_2SO_4 concentration. Only a few years of useful data exist for some of these stations; hence, maps produced of mean annual precipitation pH must only be accepted as the best currently available data. In northern areas in particular, distribution levels are somewhat questionable; due to a lack of data, distribution isolines may be altered as future data become available.

In order to evaluate the lands affected by acid precipitation, a map of mean annual precipitation pH in Figure 1, as produced by Environment Canada (1979) has been utilized. This map has appeared in several popular articles including Rosencranz (1980). Annual precipitation acidity is not necessarily the best indicator of "acid precipitation", but other maps showing distribution of airborne deposition of H_2SO_4 and HNO_3 were not available during this study; such maps are now being compiled by Environment Canada agencies. Mean annual pH figures also do not account for the potentially serious effects of individual precipitation events, which may have a pH much lower than the annual mean.

TERRESTRIAL SENSITIVITY

The assessment of impacts on aquatic and terrestrial environments requires extensive site-specific data, systematic concepts, and classification systems for defining the location of acid precipitation sensitive areas. Recent reports by the United States-Canada Impact Assessment Work Group (1981) and Cowell, Lucas, and Rubec (1981) outline the state of our understanding of sensitivity and threshold loadings permissible for terrestrial and aquatic systems.

Cowell et al (1981) note that no over-all "ecological" terrestrial sensitivity scheme for the evaluation of acid precipitation impacts has been developed. They note the current development in this direction of the "Ecodistrict" data base in Canada and the

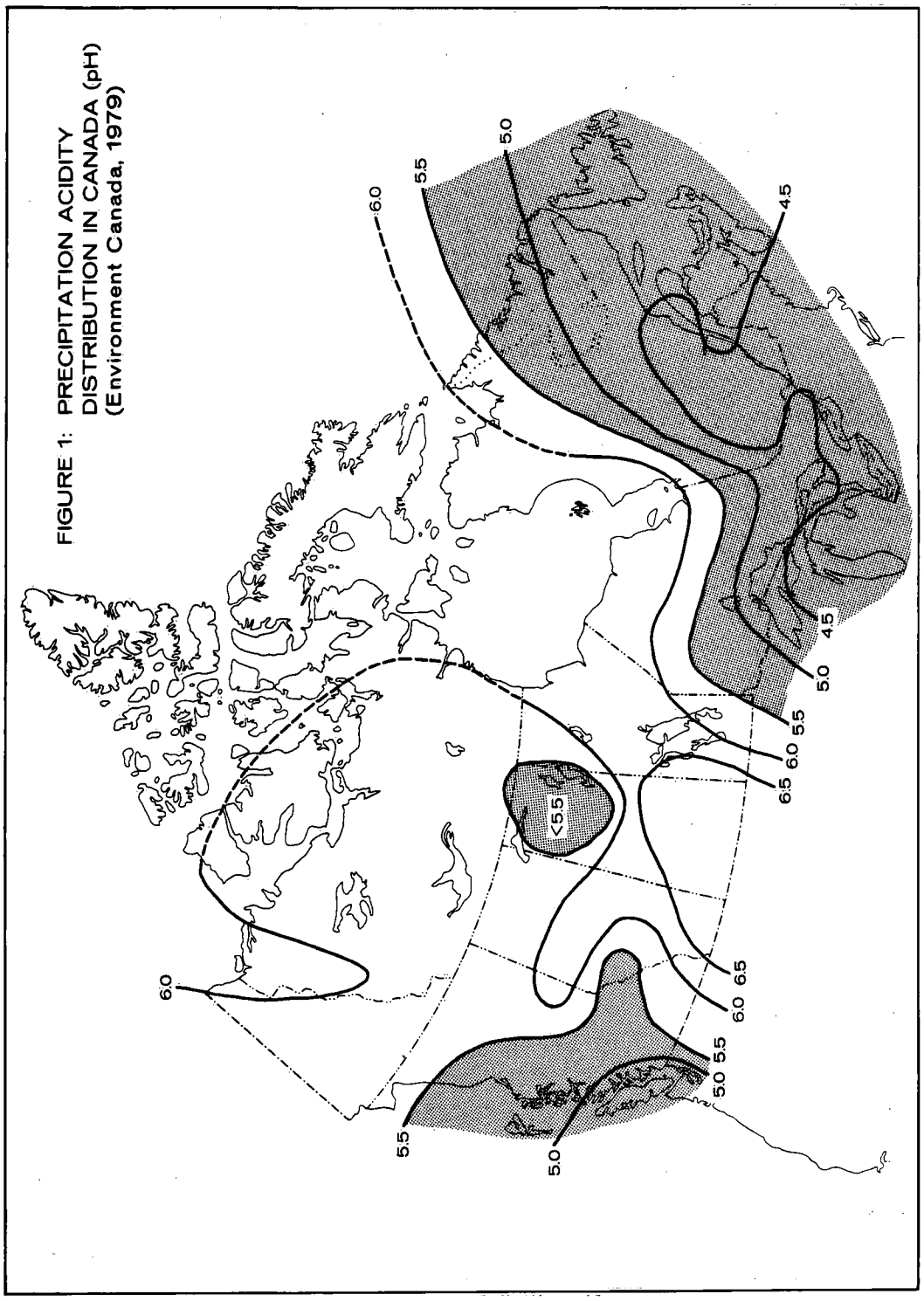

FIGURE 1: PRECIPITATION ACIDITY
DISTRIBUTION IN CANADA (pH)
(Environment Canada, 1979)

"Geoecology" data base in the United States. These geographic information systems provide an opportunity for ecological data integration at uniform scales of 1:1 000 000. Single factor sensitivities dealing with forest and agricultural soils, vegetation, surficial and bedrock geology, and aquatic data are examined. These studies of portions of eastern Canada and the United States have all been limited by lack of consistent, complete data at uniform scales. Cowell et al (1981) have produced an integrated sensitivity map for Ontario and have since undertaken production of such a map for eastern North America.

NATIONAL OVERVIEW OF ACID PRECIPITATION IMPINGED LANDS IN CANADA

The Lands Directorate of Environment Canada has established a computerized, geographic data base of environmental maps covering all of Canada. These maps are entered into the Canada Land Data System (CLDS) at a 1:15 000 000 scale to provide national overview data on the distribution of the major environmental characteristics of Canada. It is recognized that this scale does not provide a mechanism for highly accurate location of site information or for detailed impact assessment; however, use of the CLDS does permit one to generate integrated data sets because each map on the system can be overlayed with any other and polygons can be correlated. These data are most useful for general reporting of the characteristics of selected units. The overlay capabilities and automated computer cartography have fostered a unique opportunity to provide preliminary information on potential impacts of acid precipitation for all areas in Canada simultaneously.

The maps currently available in this CLDS data base include:

A) Surficial Geology showing the distribution of eight classes (National Atlas, 1974):

1) unglaciated;
2) areas of pre-Wisconsin glaciation dominated by ground moraine;
3) partially unglaciated, partially covered by ice from one or more glaciations;
4) areas of dead ice and disintegration moraine and prairie mounds;
5) irregular to arcuate patterned or ribbed moraine;
* 6) glacial lake;
* 7) marine overlap; and
8) ground moraine and glaciofluvial deposits.

B) Dominant Soil Great Groups showing distribution of nine classes (National Atlas, 1974):

1) Chernozems;
2) Solonetz;
3) Luvisols;
4) Podzols;
5) Brunisols;
6) Cryosols;
7) Gleysols;
8) Organics; and
9) Rockland subgroups - areas with soils less than 25 cm over bedrock and with bedrock exposures.

C) Vegetation showing 14 classes (after Rowe, 1972 and National Atlas, 1974):

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* most of these areas have carbonate-bearing materials at this mapping scale.

1) Almost unvegetated rockfields and glaciers with lichens, Avens, and Saxifrages;

2) Stoney lichen-heath with lichens, Ledum, and Bell Heather;

3) Shrub lichen heath with sedges, shrub willow, shrub birch, Vaccinium, and Ledum;

4) Dominated by alpine sedges and grasses with alpine fir, spruce, hemlock, red cedar, and Douglas fir at lower altitudes;

5) Pacific coastal wet forest - Douglas fir, western hemlock, western red cedar, and Sitka spruce on steep mountainous terrain;

6) Interior plateau montane forest with deciduous forest, grasslands in valleys, and lodgepole pine, blue Douglas fir, aspen, and white spruce;

7) Foothills with subalpine Engelmann spruce, alpine fir, and lodgepole pine;

8) Grasslands - grama and wheat grass, bluestem and needlegrass;

9) Parkland - aspen/bur oak with open grasslands, Ponderosa pine and grasslands in British Columbia;

10) Spruce lichen woodland to tundra open woodland - black spruce, Ledum, and lichens;

11) Boreal forest - conifers;

12) Organic terrain - sphagnum, sedge, tamarack, and black spruce;

13) Hardwood forest and mixed forest; and

14) Broadleaf forest - oak, maple, hickory.

D) Mean Annual Precipitation showing 10 classes in cm/year (National Atlas, 1974):

1) less than 10 cm/year;
2) 10-20 cm/year;
3) 20-30 cm/year;
4) 30-40 cm/year;
5) 40-50 cm/year;
6) 50-80 cm/year;
7) 80-110 cm/year;
8) 110-140 cm/year;
9) 140-300 cm/year; and
10) more than 300 cm/year

E) Permafrost Distribution showing seven classes from glacier dominated terrain, including continuous, discontinuous, and permafrost-free zones (National Atlas, 1974).

F) Mean Annual Temperature showing distribution of 11 classes from less than -18°C to greater than +7°C (National Atlas, 1974).

G) Physiography showing 16 classes from mountains to coastal plains (Bostock, 1967).

H) Provincial Boundaries showing the 10 provinces, the Yukon Territory, and the

three Districts and High Arctic Islands of the Northwest Territories.

I) Distribution of Acid Precipitation Sensitive Watersheds (east of Manitoba only) showing three classes (United States - Canada Research Consultation Group, 1979):

a) highly sensitive lakes dominantly;
b) moderately sensitive lakes; and
c) generally few sensitive lakes.

J) Precipitation Mean Annual pH showing six classes (Environment Canada, 1979):

1) equal to or greater than pH 6.5;
2) equal to or greater than 6.0, less than 6.5 ($6.0 \leq pH < 6.5$);
3) equal to or greater than 5.5, less than 6.0 ($5.5 \leq pH < 6.0$);
4) equal to or greater than 5.0, less than 5.5 ($5.0 \leq pH < 5.5$);
*5) equal to or greater than 4.5, less than 5.0 ($4.5 \leq pH < 5.0$);
*6) less than pH 4.5.

*In this study, data analysis is limited to these two simplified classes. These latter two classes are also subdivided into five classes in the computer data base as below:

a) pH 4.8 to< 5.0
b) pH 4.6 to< 4.8
c) pH 4.4 to< 4.6
d) pH 4.2 to< 4.4
e) less than pH 4.2

The major data source for these 1:15 000 000 maps was the National Atlas of Canada (1980) from which generalized map versions were derived. Data retrieval, map analysis, overlay, and reporting were undertaken with the facilities of the Canada Land Data Systems Division of Environment Canada. The sensitive watersheds information for eastern Canada was extracted from the first report of the United States-Canada Research Consultation Group (1979). "Rockland" soils not a distinct soil Great Group like "Podzols", are not identified throughout this report due to their thin and unusually sensitive nature. In most cases these comprise areas of lithic phases of Podzol, Brunisol and other soil Great Groups.

In the sections that follow, data are reported correlating several of the data sets outlined above. This report concentrates on areas of Canada currently receiving acidified precipitation less than pH 5.6.

CHARACTERISTICS OF THE TERRESTRIAL ENVIRONMENT IN CANADA IMPINGED BY ACID PRECIPITATION

In this section, data are presented describing the environment of lands, in each province or territory, that currently have annual mean acid precipitation impingement. Establishment of the nature of acid precipitation impacts on the forested, agricultural, and urban environments in these areas is a complex task. The levels of data currently available make only preliminary evaluations possible.

In general terms, areas with surficial materials comprised of calcareous marine or glacial lake deposits can be considered to

have low sensitivity to acid precipitation. Acids in the precipitation should be well buffered by these deposits. While not universally true, luvisolic and organic soils are also indicative of areas with a higher acid buffering capacity.

The sensitivity of vegetation to acid precipitation is quite difficult to identify; however, the mixed and hardwood forests of southern areas are generally regarded as being less sensitive; organic terrain may also be more tolerant but such terrain has a high occurrence of sensitive lichen species.

Precipitation levels also play a key role in quantifying sensitive lands. For instance, the annual precipitation levels in Atlantic or Pacific coastal environments are very much higher than southern Ontario. Airborne acids in precipitation can be expected to have higher total loadings in these environments than elsewhere. However, these coastal environments also have higher airborne saltspray levels which neutralizes some of these higher acid loadings. Despite low levels of total annual precipitation in the Subarctic and North, effects may be significant on sensitive vegetation in those areas. The link between annual precipitation level and acidity is closely tied to the concept of annual airborne pollution "permissible" loadings. No attempt is made to quantify this aspect other than to note that land areas impinged upon by lower annual acidities in precipitation and higher levels of total annual precipitation are also, in most cases, areas with the highest loadings of airborne H_2SO_4 and HNO_3. What constitutes permissible annual loadings of this airborne pollution remains a difficult question.

Four tables in a similar format are presented within this section. These outline, in 1000's of km^2 and percentages, the characteristics of soils, surficial deposits, vegetation, and annual precipitation levels in impingement areas. These are listed for those areas, within each province or territory as shown on Figure 1, which receive acid precipitation. Acidified precipitation is referred to in four categories:

> pH 5.5 - not acidified
pH 5.0-5.5 - mildly acidified
pH 4.5-4.9 - highly acidified
< pH 4.5 - severely acidified

Our discussion travels from west to east and north. Values on the four tables may not precisely correlate because they are derived from analysis of maps with different sources and variable reliability.

BRITISH COLUMBIA

About 45% (420 000 km^2) of British Columbia is receiving highly to mildly acidified precipitation (pH 4.5-5.5). The majority (97%) of these impingement areas have glaciofluvial or morainal deposits most of which are not carbonate bearing. Steep mountainous terrain combined with poorly-buffered soils categorize much of these areas. Thin, rockland soils and Podzols/Brunisols, which cover 82% of the impingement areas, can be quite sensitive to acid precipitation. Other soils including Luvisols (23%) and Chernozems (4%) are generally well-buffered and tolerant.

The vegetation in areas receiving acidified precipitation in British Columbia falls into three major categories. Alpine forest covers 28% of these lands (118 000 km^2) with alpine sedges, grasses and fescue at higher elevations and alpine fir, white spruce, and hemlock at lower elevations. Another 30% of the impinged portions of the province (126 000 km^2) are coastal forests with Douglas fir, western hemlock, western red cedar, and Sitka spruce on steep, wet slopes. Most of the remaining impingement areas (27%) lie within the drier interior areas of montane forest with alpine fir, Douglas fir, aspen, and spruce.

The amount of rainfall in these impingement areas is distributed into four categories with over 25% on coastal slopes receiving in excess of 140 cm/year. The other 75% of impingement areas receive rainfall annually ranging from 40-50 to 80-110 cm/year.

Acid precipitation sources in British Columbia are largely urban/industrial in the southwest and coal development in the eastern sections of the province. Measurable effects on vegetation are likely minor in most of British Columbia due to the high growth rates of forests, particularly in the wetter, warmer coastal areas. About 83% of the acid precipitation is only mildly acidified (pH 5.0-5.5). The remaining 17% falls onto 70 000 km^2 in the most-populated sectors of the province with annual mean precipitation pH from 4.5-5.0. Effects in this area may eventually become substantial in terms of public health, structural damage, and aquatic conditions. Precipitation acidity in coastal areas may also be neutralized by airborne sea salt.

ALBERTA

Acid precipitation occurs on about 5% of the province of Alberta. Mildly acidified precipitation in the pH 5.0-5.5 annual mean range affects about 34 000 km^2 of mainly glaciofluvial deposits in the western foothill areas of Alberta. This is an area of natural gas development. Emissions of sulphur gases into the atmosphere in this area have significantly increased in recent years. About 32% of these impingement areas have well-buffered luvisolic soils. The remainder is mainly bedrock outcrop (116 000 km^2) and organic bogs/fens (7 000 km^2). The majority of the bedrock outcrops are sedimentary sequences with high carbonate content. Hence, very little of the impingement area of Alberta is likely to be sensitive to acid precipitation.

Vegetation in the impingement areas of Alberta is comprised of three categories. Alpine forests in mountain areas cover 37% of these impingement areas while subalpine forests in the foothills cover another 37%. The remaining areas are comprised of about 9 000 km^2 of boreal forest on thin, rockland soils with black spruce and tamarack in wetter areas.

The mildly acidified precipitation in Alberta has an annual mean pH of 5.0-5.5. The annual total precipitation in impingement areas is usually in the range of 50-80 cm/year with about 14% in the range of 80-110 cm/year.

Effects of acid precipitation on Alberta's forests are unlikely to become highly significant in the next few decades as petroleum exploration and development expand rapidly in the northwestern sectors of the

province. These areas are dominated by well-buffered luvisolic soils or wetlands which are generally more tolerant to acid precipitation impingement than areas described below in northern Saskatchewan.

SASKATCHEWAN

About 31% of the lands in Saskatchewan now receive mildly acidified precipitation with a mean annual pH ranging from 5.0-5.5. About two thirds of these impingement areas, all in northern Saskatchewan, occur on glaciofluvial and morainal deposits with 36% on well-buffered calcareous glacial lake or marine deposits with Brunisolic Luvisols. Most other soils in these impingement areas are Humo-Ferric Podzols and Brunisols.

Vegetation in northern Saskatchewan's impingement areas is dominantly boreal forest (79%) or spruce-lichen woodland (21%). Much of this area is critical winter range for caribou; hence, acid precipitation impacts on lichens, a major food source for caribou, could become significant. This impingement area extends onto about 8 000 km^2 of similar lands in the southern District of MacKenzie, Northwest Territories. A report by Hammer (1980) for the Saskatchewan Environmental Advisory Council reviews potential acid precipitation impacts in the province.

Annual precipitation levels in northern Saskatchewan are relatively low, ranging from 30-50 cm/year in most areas. This reduces the annual loadings of acid inputs to these lands relative to other areas of Canada. However, as tar sands development in Alberta and industrial expansion in Saskatchewan occur over the next few decades, rates of acidification input may increase.

MANITOBA

The lands of Manitoba are virtually free of acid precipitation problems with only about 1% (6 000 km^2) of the province having mildly acidified (pH 5.0-5.5) precipitation on an annual mean basis. These occur predominantly (60%) on areas with well-buffered glacial lake deposits. The remaining 2 000 km^2 of impingement areas are on poorly-buffered glaciofluvial and morainal deposits. Most of the soils in these impinged areas are classified as Podzols.

The vegetation in impingement areas of Manitoba is the spruce-lichen woodland or boreal forest mixed with organic wetlands. Precipitation in these areas is in the relatively low 30-50 cm/year range.

Manitoba is fortunate to have few sources of acidic air pollution (exceptions being smelters in Lynn Lake, Flin Flon, and Thompson). Deposition areas, which are currently very restricted, are dominantly on well-buffered surficial materials. Western sources of long-range air pollution in Canada and the United States are also very few. The effects of acid precipitation in Manitoba should be minimal in the foreseeable future.

ONTARIO

Acidified precipitation is a persistent and serious problem in Ontario. Over 53% (about 504 000 km^2) of the province receives mean annual, severely to mildly acidified precipitation in the less than pH 4.2 to pH 5.5 range. Half of this area (about 258 000 km^2) consists of terrain with poorly-buffered glaciofluvial and morainal deposits. The remainder of the areas in

Ontario receiving acid precipitation have mainly well-buffered, carbonate-bearing deposits from marine overlap and glacial lakes. About 75% of the impingement areas have poorly-buffered soils, classified Podzols or Brunisols, particularly on the Canadian Shield. Much of this area includes thin deposits over Precambrian, poorly-buffered bedrock. Soils in southern Ontario and in the Clay Belt are mainly carbonate-bearing, well-buffered Luvisols.

Vegetation within impingement areas of Ontario fall into three types. Boreal forests cover about 269 000 km^2 in areas on the Canadian Shield while mixed softwood/hardwood forests are found, usually as woodlots, intermixed into 204 000 km^2 of agricultural land in southern Ontario. Another 30 000 km^2 of agricultural lands south of the Canadian Shield are intermixed with hardwood woodlots. Growth reduction effects of acid precipitation on Ontario forests would have a serious impact on the forest products industries of the province.

One third of the acid precipitation impingement areas in Ontario, largely in the south, have annual mean rainfall levels in the 80-110 cm/year range while northward the remaining areas average 50-80 cm/year. The mean annual acidity of this precipitation ranges from less than pH 4.4 on about 10 000 km^2 in the southern section of the province (about 2% of the impingement areas), to pH 4.4-4.6 on another 72 000 km^2 of southern Ontario (14% of impingement areas), to pH 4.6-4.8 on 76 000 km^2 (15% of impingement areas), and pH 4.8-5.0 on another 61 000 km^2 (12%). The remainder of the impingement areas, largely in northern Ontario, receive precipitation with an annual mean pH in the 5.0-5.5 range.

Further areas of northern Ontario not currently having annual means of acidified precipitation, do receive acidified precipitation events. Some of this area has thin, poorly-buffered glaciofluvial and morainal deposits -- some of which can be considered sensitive to acidification. As expansion of fossil fuel use in the United States continues, acidification impacts in northern portions of Ontario will become increasingly significant. Considerable literature now exists outlining known effects of acid precipitation on aquatic systems in northern and especially central Ontario. Southern Ontario is less-affected having generally well-buffered soil and groundwater regimes. Effects of individual acidified precipitation events on crops however, may have significant economic impacts.

QUEBEC

The impacts of acid precipitation on terrestrial and aquatic systems in Quebec may by the most widespread of any Canadian province. Seriously to mildly annual mean acidified precipitation occurs on about 64% of Quebec (about 923 000 km^2). The mean pH of this precipitation ranges from less than pH 4.2 near Montreal up to pH 5.5 in northern Quebec. The majority of the terrain in these areas has poorly-buffered glaciofluvial deposits (73%) and moraines (6%). About 20% of the impingement areas has well-buffered surficial deposits from glacial lakes and marine overlap. The majority of soils in impingement areas are podzolic or brunisolic (72%) or thin materials on rockland (19%). Remaining areas have

have carbonate-bearing luvisolic soils or organic materials.

Boreal forest covers over 548 000 km^2 (59%) of the impingement areas with spruce-lichen woodland on another 235 000 km^2 (25%). Small areas in the far north have alpine vegetation while mixed forest covers about 12% of the impingement areas in the southern portion of the province.

The levels of precipitation in Quebec have a mean range of 80-110 cm/year over 71% of the impingement areas and 40-80 cm/year in the remainder. Acidity of this precipitation annually averages less than pH 4.2 on about 30 000 km^2 in the southern portion of the province. Precipitation in the pH 4.2-4.9 range occurs on another 812 000 km^2 of the province (88% of impingement areas). The rest of the impingement area has precipitation averaging in the pH 5.0-5.5 range, mainly in the northeast part of the province.

Tundra areas of northern Quebec do not currently have acidified precipitation on a mean annual basis, but individual precipitation events may be acidified. Much of the vegetation on this terrain can be considered sensitive; hence, as acidification levels in precipitation increase and are carried even more northward, impacts may become significant there. At present, the most-impinged areas are limited to southern Quebec where rocklands with thin podzolic soils of low buffering capacities are the norm. Effects on aquatic and forest systems are now being documented by federal and provincial agencies in Quebec.

NEW BRUNSWICK

Precipitation throughout the province of New Brunswick has highly acidified annual means ranging from 4.5-4.9. The terrain here is mainly covered by glaciofluvial and morainal deposits (80%). Coastal areas with well-buffered calcareous marine deposits comprise about 20% of New Brunswick's 73 000 km^2. These areas are generally more tolerant to acid precipitation. Podzolic soils are usually found on the uplands with luvisolic soils on the lower coastal areas.

Vegetation on New Brunswick's impingement areas are dominantly mixed hardwood/softwood forest (91%), and some boreal forest (9%) in the northern part of the province. Acid precipitation impacts may become highly significant to the province's main industry -- forest products. Studies on forest growth and species sensitivity have been initiated at research stations in this province. Precipitation levels in this Maritime province are higher than most of Canada, ranging mainly from 80-110 cm/year. About 13% of the province along the Bay of Fundy has even higher levels averaging from 110-140 cm/year. Marine surficial deposits and neutralizing airborne seasalt spray in precipitation along these coastal areas however, may reduce acid precipitaion effects here. Inland areas appear to be the most affected particularly with respect to aquatic systems and forest growth.

NOVA SCOTIA

All of Nova Scotia receives highly acidified precipitation with a mean annual pH of 4.5-4.9. Terrain in most of the province is

comprised of glaciofluvial and morainal deposits with Precambrian bedrock exposures. Podzolic soils cover about 80% of the province with well-buffered luvisolic soils on the remaining 20% where marine deposits are found.

The vegetation of Nova Scotia is dominated by hardwood and mixed hardwood-softwood forests (92%) and a limited area of boreal forest (8%). Like New Brunswick, reduction in forest growth by acidified precipitation could have a longterm detrimental effect on the province's forest industry. Precipitation levels here are very high with 73% of the province averaging 110-140 cm/year. Seasalt spray in precipitation is a significant neutralizing factor in the alteration of precipitation acidity in this province as well.

Nova Scotia's inland fisheries have so far been the most significantly affected portion of the province's ecosystem. Terrestrial and aquatic systems research is in progress by federal and provincial agencies.

PRINCE EDWARD ISLAND

The province of Prince Edward Island is dominated (79%) by about 6 000 km^2 of poorly-buffered glacial moraines which are low in carbonates. The rest of the province has surficial materials comprised of carbonate-bearing marine deposits. Precipitation levels here annually average 80-110 cm/year in the highly acidified range of pH 4.5-4.9. Soils are dominantly podzolic with a limited coverage of mixed hardwood/softwood woodlots.

Most of the province is dominated by agricultural production. Highly acidified individual precipitation events occur in the province; their occurrence could markedly affect the Island's crop production. However, long-term effects on agricultural soils are not likely to be significant due to intensive agricultural land management in the province.

NEWFOUNDLAND AND LABRADOR

Virtually all of the province receives precipitation with a mean annual acidity in the range of pH 4.5-5.5. Of this area, about 253 000 km^2 receives highly acidified precipitation with an annual mean pH from 4.5-4.9 (mainly on the Island of Newfoundland). Northern portions of Labrador have less acidified annual precipitation pH means.

Most of the terrain in the province is covered by glaciofluvial and moraine deposits. About 40% is dominated by bedrock exposures. Carbonate-bearing, well-buffered marine deposits cover small areas along the coast with about 5% of the province having organic terrain.

Vegetation of Newfoundland and Labrador varies widely between maritime coasts, rocky barrens, and arctic mountains. Sparse spruce-lichen woodland covers about 62% of the province with boreal forest comprising a further 26%. Shrub-heath tundra can be found in northern Labrador covering 7% of the province. Precipitation annually averages 80-100 cm/year in southern Labrador and Newfoundland, but decreases northward averaging 50-80 cm/year in 22% of the province. About 11% of the coastal portions of the province receive precipitation averaging 110-140 cm/year.

The impact of acid precipitation on inland aquatic systems in the province have been the most pronounced to date. Fisheries production in some Newfoundland rivers has been severely reduced due to acidification of waters.

SUMMARY OF AREAS IMPINGED BY ACID PRECIPITATION ACROSS SOUTHERN CANADA

A total of over 2 565 000 km^2, or about 27.8% of Canada currently receives precipitation with a mean annual acidity less than pH 5.6. Over 79% of these impingement areas have surficial glaciofluvial or morainal deposits which are generally poorly-buffered to acid-precipitation inputs (Table 1). The remaining 536 000 km^2 (20%) of these impingement areas in Canada, largely in southern Ontario and Quebec, are comprised of carbonate-bearing, well-buffered marine or glacial lake deposits.

Soils within 85% of the impingement areas in Canada are dominantly poorly-buffered, and sensitive (Table 2). Podzolic soils are present on 1 605 000 km^2 (62.6%) of impingement areas; with Brunisols on 102 000 km^2 (4%) and rockland soil subgroups on another 471 000 km^2 (18.4%). The remaining areas of Canada, mainly in southern Ontario and Quebec, are dominated by carbonate-bearing Luvisols (10.3%) and lesser areas of Gleysols, Chernozems, and Organic soils.

Vegetation (Table 3) within areas impinged by acid precipitation is composed of several classes. About 1 075 000 km^2 (41.9% of impingement areas) are boreal forests, perhaps one third of which is commercial forest. Another 505 000 km^2 lie beyond the commercial forest zone as spruce-lichen woodlands (19.7% of impingement lands). In southern Quebec and Ontario, 442 000 km^2 of mainly agricultural lands mixed with hardwood/softwood woodlots are impinged. Associated with the latter are another 30 000 km^2 of intermixed hardwood woodlots.

In the west, 138 000 km^2 of wet coastal forest, (5.4% of impingement areas) and 115 000 km^2 (4.5%) of open interior forest lands are impinged. Minor areas of subalpine foothills, parkland, organic terrain, and arctic heathland are also impinged.

Precipitation levels (Table 4) greatly affect the rates of acidified inputs to terrestrial and aquatic ecosystems. These levels vary from 20-30 cm/year in areas in the District of Mackenzie to over 300 cm/year on the coastal zone of British Columbia. Most areas of major concern in eastern Canada currently receive precipitation averaging 80-110 cm/year (about 1 235 000 km^2). Another 830 000 km^2 across Canada annually receive inputs of 50-80 cm/year of acidified precipitation.

Table 1: Glacial History of Acid Precipitation Impingement Areas in Canada

Province or Territory	Glaciofluvial and Morainal Deposits (000's) km²	% APA	Ribbed and Arcuate Moraine (000's) km²	% APA	Glacial Lake Sediments (000's) km²	% APA	Marine Overlap Deposits (000's) km²	% APA	Total Area Impinged (km²)	Area of Province or Territory (km²)	Area of Province or Territory Impinged (%)
British Columbia (pH 4.5-5.4)	410	97.4	-	-	3	0.8	7	1.7	420 000	931 000	45.1
Alberta (pH 5.0-5.4)	33	95.7	-	-	1	4.2	-	-	34 000	644 000	5.2
Saskatchewan (pH 5.0-5.4)	113	64.4	1	0.7	62	34.8	-	-	176 000	570 000	30.8
Manitoba (pH 5.0-5.4)	2	40.1	1	2.0	3	57.7	-	-	6 000	548 000	1.0
Ontario (pH <4.2-5.4)	258	51.0	-	-	229	45.4	17	3.3	504 000	947 000	53.2
Quebec (pH <4.2-5.4)	677	73.2	54	5.8	149	16.1	43	4.6	923 000	1 449 000	63.7
New Brunswick (pH 4.5-4.9)	58	79.7	-	-	-	-	15	20.2	73 000	73 000	100.0
Nova Scotia (pH 4.5-4.9)	55	100.0	-	-	-	-	-	-	55 000	55 000	100.0
Prince Edward Island (pH 4.5-4.9)	5	78.9	-	-	-	-	1	21.0	6 000	6 000	100.0
Newfoundland and Labrador (pH 4.5-5.4)	309	85.6	45	12.6	-	-	6	1.7	360 000	370 000	97.2
Yukon and Northwest Territories (pH 5.0-5.4)	8	100.0	-	-	-	-	-	-	8 000	3 639 000	0.2
Total Area Impinged by Acid Precipitation	1 928	75.2*	101	3.9*	447	17.4*	89	3.5*	2 565 000	9 232 000	27.8 (% of all of Canada)

* Percentage of land area of Canada now receiving acid precipitation impingement
** APA: Acid Precipitation Impingement Area within the province or Territory

Table 2: Soil Groups Within Acid Precipitation Impingement Areas Across Canada

Province or Territory	Podzols		Brunisols		Lithic Soils (Rockland)		Luvisols		Gleysols		Chernozems		Organics		Total Area Affected	Area of Province or Territory	Area of Province or Territory Affected
	(000's) km²	% APA **	(000's) km²	% APA	(000's) km²	% APA	(000's) km²	% APA	(000's) km²	% APA	(000's) km²	% APA	(000's) km²	% APA	km²	km²	(%)
British Columbia (pH 4.5-5.4)	138	32.8	33	7.8	131	31.2	96	22.8	3	0.7	19	4.4	-	-	420,000	931 000	45.1
Alberta (pH 5.0-5.4)	-	-	-	-	16	47.6	11	32.4	-	-	-	-	7	19.8	34 000	644 000	5.2
Saskatchewan (pH 5.0-5.4)	173	98.4	-	-	2	1.3	-	-	-	-	-	-	<1	0.2	176 000	570 000	30.8
Manitoba (pH 5.0-5.4)	6	99.2	-	-	-	-	-	-	-	-	-	-	-	-	6 000	548 000	1.0
Ontario (pH <4.2-5.4)	339	67.0	34	6.6	6	1.2	93	18.4	28	5.5	-	-	4	0.8	504,000	947 000	53.2
Quebec (pH <4.2-5.4)	630	68.2	35	3.7	176	19.1	30	3.2	6	0.6	-	-	46	4.9	923 000	1 449 000	63.7
New Brunswick (pH 4.5-4.9)	54	73.3	-	-	-	-	19	26.6	-	-	-	-	-	-	73,000	73 000	100.0
Nova Scotia (pH 4.5-4.9)	44	79.9	-	-	-	-	11	20.0	-	-	-	-	-	-	55 000	55 000	100.0
Prince Edward Island (pH 4.5-4.9)	6	100.0	-	-	-	-	-	-	-	-	-	-	-	-	6 000	6 000	100.0
Newfoundland and Labrador (pH 4.5-5.4)	207	57.3	-	-	140	38.8	4	1.1	-	-	-	-	9	2.6	360 000	370 000	97.2
Yukon and Northwest Territories (pH 5.0-5.4)	8	100.0	-	-	-	-	-	-	-	-	-	-	-	-	8,000	3 639 000	0.2
Total Area Impinged by Acid Precipitation	1 605	62.6*	102	4.0*	471	18.4*	264	10.3*	37	1.4*	19	0.7*	67	2.6*	2 565 000	9 232 000	27.8 (% of all of Canada)

* Percentage (%) of all areas across Canada receiving acid precipitation impingement
** APA - Acid Precipitation impingement Area within province or territory

Table 3: Vegetation Within Acid Precipitation Impingement Areas Across Canada

Province or Territory	Alpine Forest and Meadow (000's) km²	% APA **	Coastal Wet Forest (000's) km²	% APA	Interior Open Forest (000's) km²	% APA	Subalpine Foothills Forest (000's) km²	% APA	Mixed Parkland (000's) km²	% APA	Spruce-Lichen Woodland (000's) km²	% APA	Boreal Forest (000's) km²	% APA	Mixed Forest (000's) km²	% APA	Hardwood Forest (000's) km²	% APA	Organic Terrain (000's) km²	% APA	Shrub Lichen Heath (000's)	% APA	Total Area Affected (km²)	Area of Province or Territory km²	Area of Province or Territory Affected (%)
British Columbia (pH 4.5-5.4)	116	27.5	128	30.4	115	27.4	22	5.2	35	8.3	-	-	4	0.8	-	-	-	-	-	-	-	-	420 000	931 000	45.1
Alberta (pH 5.0-5.4)	13	37.4	-	-	-	-	12	36.5	-	-	-	-	9	26.0	-	-	-	-	-	-	-	-	34 000	644 000	5.2
Saskatchewan (pH 5.0-5.4)	-	-	-	-	-	-	-	-	-	-	36	20.5	140	79.4	-	-	-	-	-	-	-	-	176 000	570 000	30.8
Manitoba (pH 5.0-5.4)	-	-	-	-	-	-	-	-	-	-	4	71.8	2	27.3	-	-	-	-	-	-	-	-	6 000	548 000	1.0
Ontario (pH <4.2-5.4)	-	-	-	-	-	-	-	-	-	-	-	-	268	53.2	204	40.5	30	5.9	2	0.2	-	-	504 000	947 000	53.2
Quebec (pH <4.2-5.4)	9	0.9	-	-	-	-	-	-	-	-	235	25.4	548	59.4	114	12.3	-	-	17	1.8	-	-	923 000	1 449 000	63.7
New Brunswick (pH 4.5-4.9)	-	-	-	-	-	-	-	-	-	-	-	-	6	8.8	67	91.1	-	-	-	-	-	-	73 000	73 000	100.0
Nova Scotia (pH 4.5-4.9)	-	-	-	-	-	-	-	-	-	-	-	-	4	7.7	51	92.2	-	-	-	-	-	-	55 000	55 000	100.0
Prince Edward Island (pH 4.5-4.9)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	100.0	-	-	-	-	-	-	6 000	6 000	100.0
Newfoundland and Labrador (pH 4.5-5.4)	-	-	-	-	-	-	-	-	-	-	222	61.6	94	26.0	-	-	-	-	20	5.6	24	6.7	360 000	370 000	97.2
Yukon and Northwest Territories (pH 5.0-5.4)	-	-	-	-	-	-	-	-	-	-	8	100.0	-	-	-	-	-	-	-	-	-	-	8 000	3 639 000	0.2
Total Area Impinged	138	5.4*	128	5.0*	115	4.5*	34	1.3*	35	1.4*	505	19.7*	1,075	41.9*	442	17.2*	30	1.2*	39	1.5*	24	0.9*	2 565 000	9 232 000	27.8* (% of all of Canada

* Perecentage (%) of all areas across Canada receiving acid precipitation impingement
** APA - Acid Precipitation impingement Area within province or territory

Table 4: Distribution of Annual Precipitation Levels in Acid Precipitation Impingement Areas Across Canada

Province or Territory	20-30 cm/yr (000's) km²	% APA **	30-40 cm/yr (000's) km²	% APA	40-50 cm/yr (000's) km²	% APA	50-80 cm/yr (000's) km²	% APA	80-110 cm/yr (000's) km²	% APA	110-140 cm/yr (000's) km²	% APA	140-300 cm/yr (000's) km²	% APA	>300 cm/yr (000's) km²	% APA	Total Area Affected (km²)	Area of Province or Territory (km²)	Area of Province or Territory Affected (%)
British Columbia (pH 4.5-5.4)	-	-	-	-	115	27.4	120	28.4	79	18.8	-	-	92	21.9	14	3.2	420 000	931 000	45.1
Alberta (pH 5.0-5.4)	-	-	-	-	-	-	29	86.1	5	13.8	-	-	-	-	-	-	34 000	644 000	5.2
Saskatchewan (pH 5.0-5.4)	-	-	80	45.3	96	54.4	-	-	-	-	-	-	-	-	-	-	176 000	570 000	30.8
Manitoba (pH 5.0-5.4)	-	-	2	26.6	4	72.5	-	-	-	-	-	-	-	-	-	-	6 000	548 000	1.0
Ontario (pH <4.2-5.4)	-	-	-	-	-	-	336	66.7	168	33.2	-	-	-	-	-	-	504 000	947 000	53.2
Quebec (pH <4.2-5.4)	-	-	-	-	2	0.2	264	28.5	657	71.1	-	-	-	-	-	-	923 000	1 449 000	63.7
New Brunswick (pH 4.5-4.9)	-	-	-	-	-	-	-	-	64	86.8	9	13.1	-	-	-	-	73 000	73 000	100.0
Nova Scotia (pH 4.5-4.9)	-	-	-	-	-	-	-	-	15	27.0	40	72.9	-	-	-	-	55 000	55 000	100.0
Prince Edward Island (pH 4.5-4.9)	-	-	-	-	-	-	-	-	6	100.0	-	-	-	-	-	-	6 000	6 000	100.0
Newfoundland and Labrador (pH 4.5-5.4)	-	-	-	-	-	-	81	22.3	241	67.0	38	10.5	-	-	-	-	360 000	370 000	97.2
Yukon and Northwest Territories (pH 5.0-5.4)	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8 000	3 639 000	0.2
Total Area Impinged by Acid Precipitation	8	0.3*	82	3.2*	217	8.5*	830	32.4*	1,235	48.1*	87	3.4*	92	3.6*	14	0.5*	2 565 000	9 232 000	27.8 (% of all of Canada)

* Percentage (%) of all area across Canada receiving acid precipitation impingement
** APA - Acid Precipitation impingement Area within province or territory

LANDS WITHIN SENSITIVE WATERSHEDS IN EASTERN CANADA

In 1979, the United States-Canada Bilateral Research Consultation Group published an initial overview map (Figure 2) of the location of watersheds in eastern Canada with characteristics indicating sensitivity to acidified precipitation. The overall ecological characteristics of these watersheds are not well documented. In Table 5, preliminary data are outlined identifying the general characteristics of soils, vegetation, glacial history, physiography, annual mean precipitation pH and precipitation levels within these areas.

In Ontario, "highly sensitive" watersheds cover about 7.9% of the province (75 000 km^2). The vegetation in these watersheds is boreal or mixed hardwood/ softwood-dominated forest. Areas on the Canadian Shield (10 000 km^2) are characterized by highlands and rolling hills, generally with podzolic or thin, rockland soils. Areas covered by carbonate-bearing glacial lake deposits comprise about 33 000 km^2 of these watersheds. The soils in these areas are mainly Brunisolic Luvisols. Annual precipitation levels in Ontario's sensitive watersheds are 50-80 cm/year on about 49 000 km^2 and 80-110 cm/year on the remaining 26 000 km^2. The mean acidity in precipitation here is less than pH 4.5 on about 4 000 km^2 in the southwest and pH 4.5-5.4 on about 63 000 km^2. Watersheds in the northwest portion of the province, covering about 8 000 km^2, do no currently receive precipitation with mean annual acidity less than pH 5.6.

In Quebec, sensitive watersheds cover 78% of the province. The vegetation on these 1 129 000 km^2 of land is dominated by three classes: boreal forest, spruce-lichen woodland, and southern hardwoods. Podzolic and thin rockland soils predominate on rolling highlands and rocky plateaux. The precipitation in most of Quebec's sensitive watersheds is in the range of 50-80 or 80-110 cm/year with lower annual levels in northern areas. Precipitation annual mean acidity levels, varying from south to north, range from less than pH 4.5 to over pH 6.5 on these sensitive watersheds. About 364 000 km^2 of the areas of sensitive watersheds in northern Quebec do not currently receive precipitation with mean annual acidity less than pH 5.6, while about 181 000 km^2 in southern watersheds receive precipitation with mean annual acidity less than pH 4.5.

In the Maritimes, about 76.4% of New Brunswick and 31.5% of Nova Scotia are considered to have sensitive watersheds. Sensitive watersheds were not delineated in Prince Edward Island in the United States-Canada Bilateral Research Consultation Group (1979) report. The vegetation within these Maritime areas is dominated by hardwood and mixed softwood forests and lesser areas of boreal forest. The soils in these areas are dominated by poorly-buffered podzolic soils on glacio-fluvial and morainal deposits. Virtually all the sensitive watersheds lie on rolling, rocky hills. Precipitation levels in these two provinces are mainly 80-140 cm/year with acidity ranging from pH 4.5-5.0 on an annual mean basis.

Table 5: Characteristics of Acid Precipitation Sensitive Watersheds in Eastern Canada

	Ontario	Quebec	Nova Scotia	New Brunswick	Newfoundland and Labrador
	Percentage (%) of Province				
Environmental Characteristics of Sensitive Watersheds	7.9	78.2	76.4	31.5	83.2
Vegetation					
1. Hardwood/Softwood Mixed	3.9	1.7	69.3	28.7	-
2. Boreal Forest	4.0	31.2	7.1	2.8	21.3
3. Spruce-Lichen Woodland	-	27.4	-	-	46.8
4. Organic Terrain	-	2.4	-	-	5.1
5. Stoney Lichen Heath	-	0.9	-	-	0.2
6. Shrub Lichen Heath	-	14.6	-	-	9.8
Soils					
1. Podzols	6.7	36.1	65.1	23.7	47.1
2. Brunisols	0.4	0.7	-	-	-
3. Lithic (Rocklands)	0.3	35.9	-	-	33.6
4. Organics	-	4.2	-	-	2.4
5. Luvisols	0.5	1.0	11.3	7.8	0.1
Glacial History					
1. Glaciofluvial or Morainal Deposits	4.4	52.4	76.4	23.5	72.6
2. Hummocky Ground or Arcuate Moraines	-	5.3	-	-	10.6
3. Glacial Lake Deposits	3.5	7.6	-	-	-
4. Areas of Marine Overlap	-	12.9	-	-	-
Physiography					
1. Uplands (Shield)	5.7	4.0	53.2	11.4	20.3
2. Plateaux	-	43.3	-	-	47.5
3. Hills, Highlands	1.8	23.2	16.7	20.1	4.8
4. Plains, Coastal Plains	0.4	-	-	-	1.6
5. Lowlands	-	1.1	6.5	-	4.1
6. Organic Lowlands	-	6.4	-	-	-
7. Mountains	-	0.2	-	-	4.7
Annual Precipitation Level (Mean)					
1. 30-40 cm/yr	-	7.8	-	-	0.3
2. 40-50 cm/yr	-	9.1	-	-	3.7
3. 50-80 cm/yr	5.2	29.4	-	-	13.9
4. 80-110 cm/yr	2.7	31.9	16.3	20.1	56.9
5. 110-140 cm/yr	-	-	60.1	11.4	8.4
Mean Annual Precipitation Acidity					
1. pH 6.0-6.4	-	18.6	-	-	-
2. pH 5.5-5.9	0.8	13.6	-	-	4.1
3. pH 5.0-5.4	2.8	10.1	-	-	21.2
4. pH 4.5-4.9	3.9	19.9	76.4	31.5	57.9
5. pH < 4.5	0.4	16.0	-	-	-
Air Temperature (Mean Annual)					
1. -10 to -7°C	-	3.5	-	-	-
2. -7 to -4°C	-	22.8	-	-	4.3
3. -4 to -1°C	-	21.8	-	-	34.5
4. -1 to +2°C	2.5	22.2	-	-	24.1
5. +2 to +4°C	4.0	6.0	-	0.7	13.7
6. +4 to +7°C	1.4	1.7	52.4	30.8	6.6
7. >+7°C	-	-	24.0	-	-

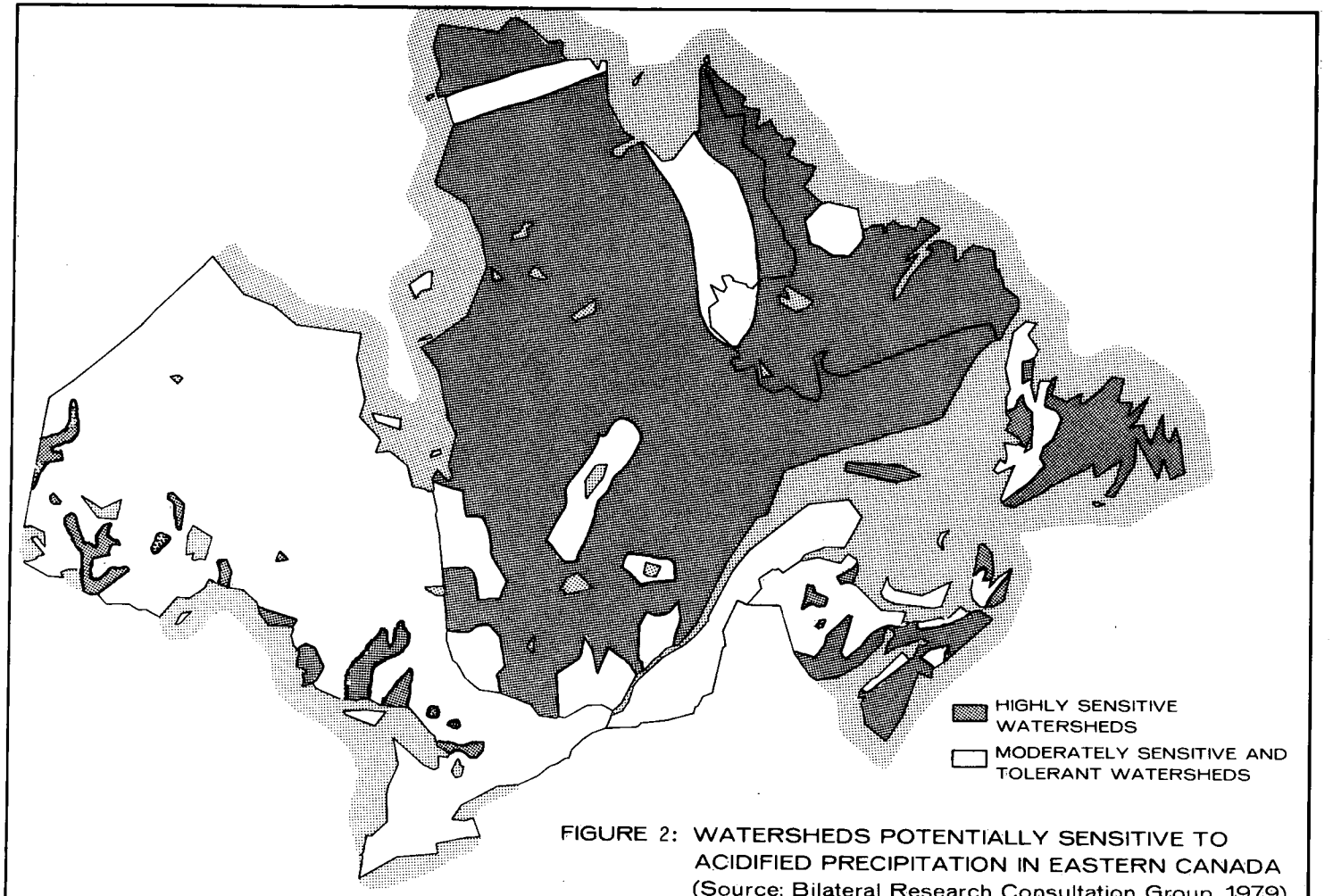

FIGURE 2: WATERSHEDS POTENTIALLY SENSITIVE TO ACIDIFIED PRECIPITATION IN EASTERN CANADA
(Source: Bilateral Research Consultation Group, 1979)

Sensitive watersheds cover over 83% of Newfoundland-Labrador. Vegetation in these watersheds is comprised of organic terrain on 19 000 km^2; boreal forest on 79 000 km^2 spruce-lichen woodland on another 173 000 km^2, and shrub-lichen heathlands on 6 000 km^2 in northern Labrador. Podzolic and thin rockland soils with glaciofluvial and morainal deposits are present in most of the province's sensitive watersheds. Labrador is dominated by rocky plateaux and mountains while the Island of Newfoundland is largely poorly-buffered, rolling Appalachian Shield land. Precipitation in Newfoundland watersheds is mainly in the 80-110 cm/year range with lower levels decreasing northward in Labrador. The acidity of this precipitation annually averages in the range of pH 4.5-5.4 in sensitive watersheds except on about 15 000 km^2 in northern Labrador.

In summary, watersheds considered by the United States-Canada Research Consultation Group (1979) to be highly sensitive to precipitation acidification, cover 1 579 000 km^2 or 54% of the land area of eastern Canada. Boreal forests cover 572 000 km^2; spruce-lichen woodlands cover 570 000 km^2; and shrub-lichen heathlands cover 246 000 km^2 of these watersheds with lesser areas of organic terrain and mixed hardwood/softwood forests. Soils in these watersheds are mainly podzolic or thin rockland subgroups. About 335 000 km^2 have had a glacial history which involved deposition of materials in glacial lakes or by marine overlap; the remainder have glaciofluvial and morainal deposits. Sensitive watersheds in eastern Canada mainly occur in areas of the Canadian Shield with rolling hills or highlands and rocky plateaux.

The precipitation falling in eastern Canada has an annual mena in the acidified range less than pH 5.6, and impinges 1 091 000 km^2 or 69% of the sensitive watersheds in that area. The mean annual levels of this precipitation are in the 50-110 cm/year range.

ACID PRECIPITATION SENSITIVITY AREAS IN WESTERN CANADA

In western Canada, a preliminary map is presented in Figure 3 showing the areas likely to be more sensitive to acid precipitation impingement. This includes areas dominated by podzolic, brunisolic, or gleysolic soils, or barren rockland. Areas with a surficial materials history of marine overlap or lacustrine deposition are excluded because they are generally carbonate-bearing. Areas dominated by organic terrain are also not included. All areas included likely have poorly-buffered, weakly developed acidic soils without significant carbonate content in surficial materials.

Table 6 indicates that about 31% of western Canada may have terrain with "higher" acid precipitation potential sensitivity. These areas are dominated by acidic soils and barren rockland often with thin veneers of glaciofluvial outwash or morainal deposits. Half of this potentially sensitive terrain is dominated by mountainous terrain. Some of this area might not be considered sensitive due to its geological constitution, but this has not been considered here. Belts of metamorphosed, carbonate-bearing bedrock are frequent in these ranges; however, many of these are covered by acidic montane soils without carbonates in the forest rooting zone. Much more detailed analysis is required to refine the sensitivity assessment of these areas.

Most of the lands in northern Saskatchewan and Manitoba that are included in the potentially sensitive area are dominated by Precambrian bedrock with spruce lichen woodland, boreal woodland, or barren lichen heathland. These are likely to be highly sensitive landscapes.

Areas indicated as having "lower" acid precipitation sensitivity are generally dominated by either luvisolic, chernozemic, and solonetzic soils or organic terrain. Areas with a history of carbonate-bearing deposition of surficial materials are also included. For example, much of the interior of British Columbia and boreal areas of Alberta, Saskatchewan and Manitoba have Luvisols. Northern Alberta and northeastern Manitoba are dominantly wetland environments with lower potential sensitivity.

Little reliable data have yet been presented in the literature concerning acid precipitation distribution in western Canada. The areas identified in Figure 1 of this report as receiving acid precipitation impingement in the West are "preliminary". Other more recent version (e.g. Environment Canada, 1981), suggest the areas impinged by acid precipitation are much more extensive. This includes much of British Columbia, northwestern Alberta, northern Saskatchewan and about half of the District of Mackenzie. While this may be questionable, there is no doubt that significant areas of Western Canada are in fact now receiving precipitation with a mean annual acidity less than pH 5.6. Many of these areas are as sensitive as critical areas identified in Eastern Canada.

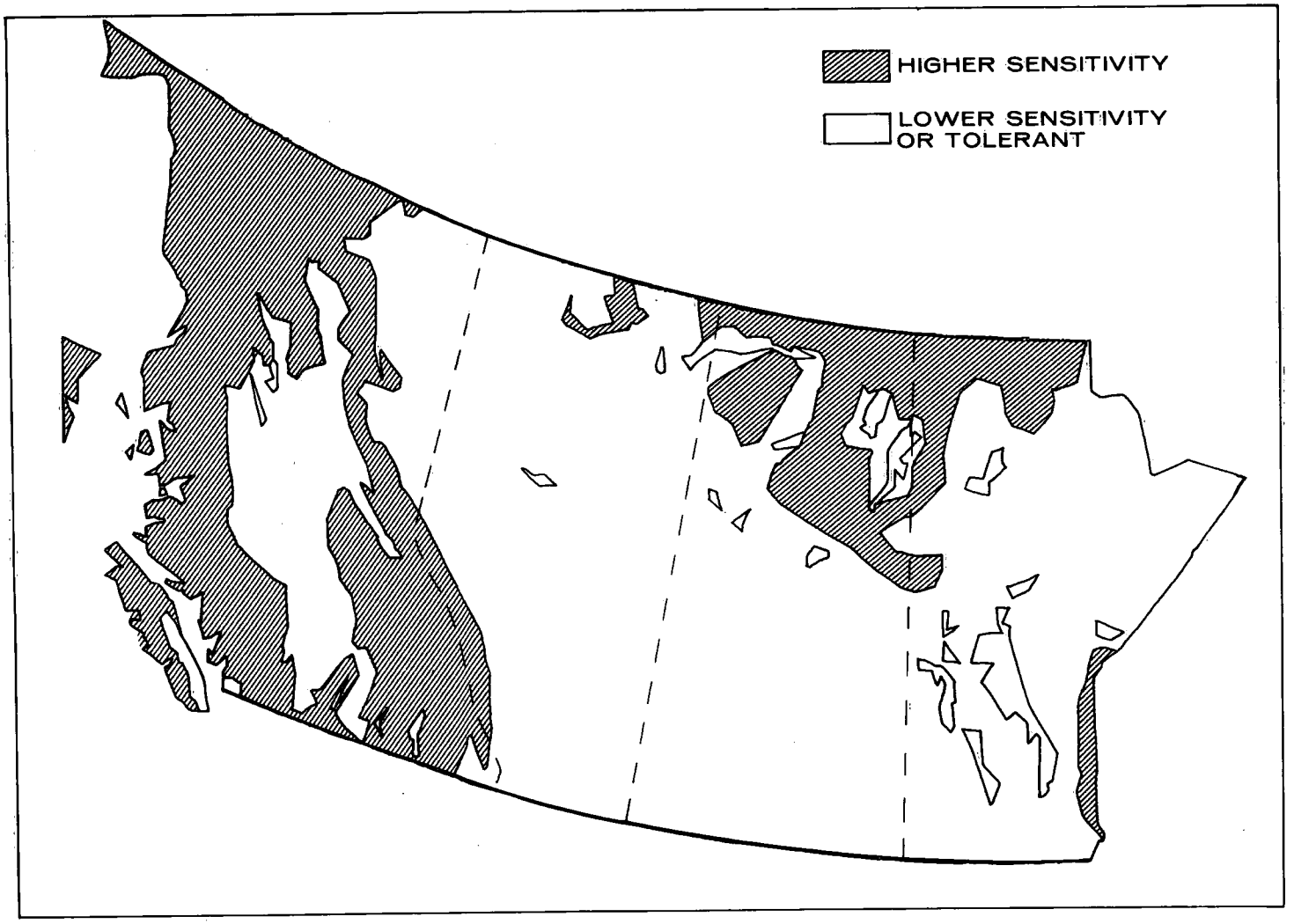

FIGURE 3: AREAS POTENTIALLY MOST SENSITIVE TO ACID PRECIPITATION IN WESTERN CANADA

TABLE 6: Characteristics of Acid Precipitation Potentially Sensitive Terrain in Western Canada

Terrain Characteristic	Area (km^2)	Area (% Western Canada)
Soils		
1. Podzols	361 000	13
2. Brunisols	134 000	5
3. Rockland	316 000	12
4. Gleysols	11 000	1
Glacial History		
1. Glaciofluvial Outwash and Moraine Deposits	804 000	30
2. Ribbed Moraine	18 000	1
Physiography		
1. Mountains	422 000	16
2. Highlands, Foothills	33 000	1
3. Plateaux	112 000	4
4. Mountain Basins	69 000	3
5. Lowlands	18 000	1
6. Coastal Plains	2 000	1
7. Canadian Shield	166 000	6
Vegetation		
1. Lichen Heath	4 000	1
2. Spruce Lichen Woodland	93 000	3
3. Boreal Forest	199 000	7
4. Alpine Meadow/Forests	269 000	10
5. Dry Interior Open Forest	82 000	3
6. Grassland (Ponderosa Pine)	21 000	1
7. Subalpine (Engleman Spruce)	33 000	1
8. Wet Coastal Forest	121 000	4
Total Potentially Sensitive Area (km^2)	822 000	31%
Total Area of B.C., Alta., Sask. and Man. (km^2)	2 693 000	100%

ACID PRECIPITATION SENSITIVITY IN NORTHERN CANADA

The focus of acid precipitation research in Canada is in the east. The extent of acid precipitation occurrence in northern areas of the nation is not well documented due to very few precipitation monitoring stations in this area. If LRTAP becomes more extensive in North America, subarctic and arctic areas may become impinged. While only a small portion (about 8000 km^2) of the Yukon and Northwest Territories currently are believed to receive annual mean acidified precipitation (Environment Canada, 1979), further impingement could eventually affect many other areas that have higher terrestrial sensitivity as outlined below and in Figure 4.

Yukon

Precipitation in the Yukon does not yet have an annual mean less than pH 5.6; thus, it is not considered acidified. However, individual precipitation events may be quite acidified. As development of natural resources in the Yukon Territory occurs, acid precipitation may become a persistent problem.

Acidity measurements of precipitation in the Yukon are very limited but are believed to range from pH 6.0-6.5 in over 95% of the Territory and pH 5.6-5.9 on the remainder. Acid precipitation could become a problem in portions of this territory where mountains and highlands are comprised of non-carbonate-bearing bedrock. The Northern Coastal Plain and Old Crow Flats are covered by marine and glacial lake deposits; these areas are generally tolerant to acidified precipitation. The Territory is dominated by brunisolic soils (68%), barren rocklands (18%), and Cryosols (10%).

Precipitation levels in the Yukon are very low ranging from 20-30 cm/year on 50% of the Territory and 30-50 cm/year on the remainder. Boreal forest covers 55% of the Territory with alpine vegetation in most of the rest.

Northwest Territories

The Northwest Territories (NWT), comprising the Districts of Mackenzie, Keewatin and Franklin, cover over 3 107 000 km^2, or about 35% of Canada's land. Measurement of precipitation acidity here is limited to only a few stations with a short period of operation. Currently, the only areas believed to have consistent levels of mildly acidified precipitation are in the southern portion of the District of MacKenzie. These link with the area, discussed earlier in this paper, for Saskatchewan which has precipitation with a mean annual pH ranging from 5.0-5.5. In the NWT, about 8 000 km^2 is impinged as outlined on Tables 1,2,3, and 4.

These limited impingement areas in the NWT have mainly podzolic soils on glaciofluvial or moraine deposits. Spruce-lichen woodlands, used by barren-ground caribou as winter range, are intermixed with small areas of organic terrain. Hence, effects on sensitive lichen vegetation here could have an impact on the caribou. Precipitation levels in this area are very low, in the range of 20-30 cm/year.

Much of the rest of the NWT has terrain that might be considered sensitive to acid precipitation. Poorly-buffered glaciofluvial

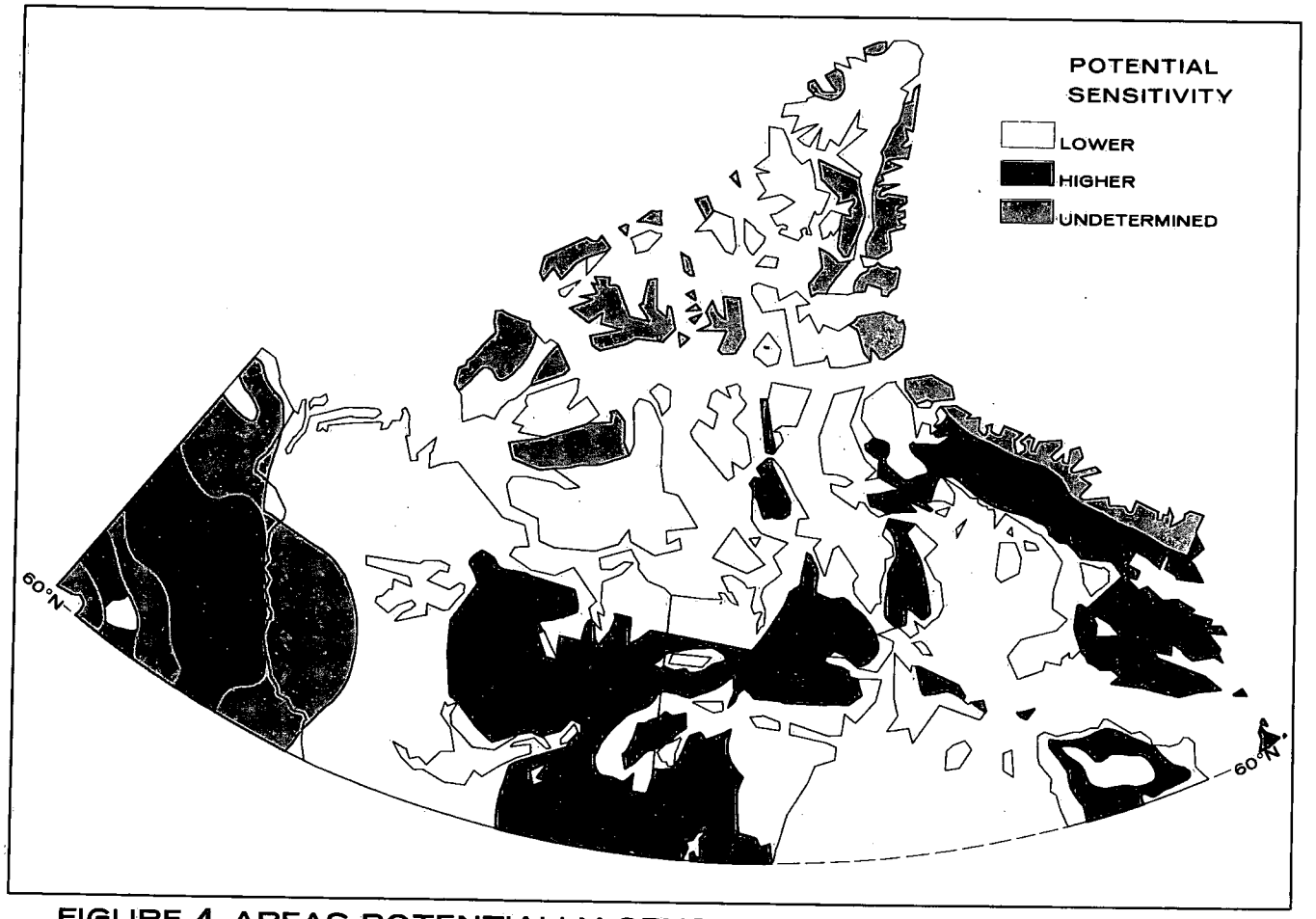

FIGURE 4. AREAS POTENTIALLY SENSITIVE TO ACID PRECIPITATION IN NORTHERN CANADA (FIRST APPROXIMATION)

and moraine deposits with lichen vegetation may be significantly affected by even low annual inputs of mildly acidified rainfall. It is estimated that about 37% of the NWT would fall into this category. However, effects of acid precipitation on cryosolic soils and tundra vegetation have not been documented to date.

Figure 4 indicates areas of potential sensitivity to acid precipitation in Canada north of 60° latitude. These areas are designated "higher", "lower" and "undetermined" sensitivity based on these criteria:

HIGHER - Areas with Precambrian bedrock at or near the surface; areas with Podzols or Brunisols on glacial moraine or glaciofluvial deposits, which may be forested or open tundra; cover 37% of the North. Areas in this category are derived from computer analyses of 1:15 000 000 scale soils and surficial geology data as well as manual interpretation of National Atlas (1974) bedrock geology maps. Numerous small areas of Precambrian bedrock outcrop are excluded.

LOWER - Areas with carbonate-bearing bedrock such as limestone or dolomite at or near the surface; areas with glacial lacustrine or marine deposits on the surface; areas dominated by organic wetlands; these cover 46% of northern Canada. These areas are interpreted using 1:15 000 000 computer analysis of surficial geology information and manual interpretation of National Atlas vegetation, soils, and bedrock geology maps.

UNDETERMINED - Areas with non-marine sedimentary bedrock at or near the surface which may contain carbonates; areas dominated by glaciers and icefields; environments where insufficient information is currently available to assess potential sensitivity; these areas cover 17% of northern Canada.

Long-range transported substances such as heavy metals including lead and mercury, and airborne acids such as H_2SO_4 and HNO_3, as well as soot and organic matter make up the pollutants in many samples taken of Arctic air masses. The source of many of these aerosol substances is injections of polluted, northward-flowing air from the northeastern United States and Europe (Shaw, 1979).

A first approximation of Northern terrestrial sensitivity, presented in Figure 4, is very preliminary and undoubtedly will be subject to considerable revision as refined data is utilized for analysis in this environment. Numerous small bedrock outcrops in marine plains such as southwest Baffin Island, the Queen Maud Gulf and Boothia Peninsula are excluded for simplicity. An analysis of the Ecodistrict data base for this region using an approach similar to Cowell et al (1981) is anticipated.

CONCLUSIONS

The terrestrial environment of approximately 27.8% of Canada's land mass currently receives precipitation with a mean annual acidity of less than pH 5.6. These impingement areas are concentrated in southern Ontario, Quebec, the Atlantic provinces, northern Saskatchewan and western British Columbia. An environmental data base using the Canada Land Data System at Environment Canada has served as a practical technique for the overlay, analysis and retrieval of data on soils, vegetation, surficial materials and a series of environmental information maps covering all of Canada at a 1:15 000 000 scale. These analyses are used to provide physical descriptions of the acid precipitation impingement areas across the nation.

A quantitative, complete set of ecological data concerning acid precipitation impingement areas across Canada is made available in this report. This study using the Canada Land Data System is an example of the data products expected from a more-detailed, 1:1 000 000 "Ecodistrict" data base that is currently being established for acid precipitation terrestrial sensitivity mapping (Cowell et al, 1981).

Integration of data sets has permitted description of the watersheds in eastern Canada identified by the United States-Canada Bilateral Research Consultation Group (1979) as the most sensitive to precipitation acidification. Preliminary acid precipitation sensitivity maps indicate large areas of Canada's west and north have terrain which may be significantly affected should impingement occur. While acid precipitation has been assumed to have major impacts in eastern Canada, sensitive areas in western and northern Canada have received little attention. The data in this study indicate that large areas of northern Manitoba and northern Saskatchewan, western Alberta, and western British Columbia have potentially sensitive terrestrial environments, much of which is now impinged by acid precipitation. Large areas in Canada's North are also sensitive but to date only a small portion of the Yukon or Northwest Territories receives annually acidified precipitation. Terrestrial sensitivity concepts developed for eastern environments and attention to acid precipitation impacts should also be focussed on these western and northern areas in the near future.

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