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SENSITIVITY TO ACIDIFICATION OF LAKES IN THE CANADIAN SHIELD: ANALYSIS AND INTERPRETATION OF GEOLOGICAL AND ECOLOGICAL DATA FOR 158 WATERSHEDS IN SOUTHERN QUEBEC

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SENSITIVITY TO ACIDIFICATION OF LAKES IN THE CANADIAN SHIELD: ANALYSIS AND INTERPRETATION OF GEOLOGICAL AND ECOLOGICAL DATA FOR 158 WATERSHEDS IN SOUTHERN QUEBEC

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ABSTRACT

Geological, physiographic and vegetation data for 158 watersheds extending from the Ottawa River to the Saguenay fjord in the Canadian Shield, were analysed and interpreted to determine which variables influence the ecosystem's sensitivity to incoming acidic precipitation. Lakes within the watersheds were sampled during the winter of 1982 by the Inland Waters Directorate, Québec Region. The physicochemical data generated was subsequently analysed (Bobée et al, 1983).

A descriptive analysis of the ecological data of the study area revealed existing interrelationships between altitude, total precipitation and the presence of certain types of forest cover.

Correlation analysis between ecological and water quality variables showed that the lake altitude, the average annual rainfall, the lake's position in relation to a SW-NE axis, and the relative surface area of open conifer stands was closely correlated with the mineralization variables (Ca, Mg, K, alkalinity, conductivity, total cations and total anions).

Discriminant analysis used to interpret geological variables showed that, for the most part, the chemical composition of the lakes is influenced by the bedrock type. Discriminant functions, using lake physiocochemical variables, allowed for the lakes to be classified into five groups corresponding to bedrock types found within the watersheds (calc-silicate rock, marble; anorthosite, gabbro, diorite; migmatite, paragneiss, gneiss; mangerite, monzonite; granite and quartzite).

A combination of correspondence factorial analysis and classification techniques provided a spatial behaviour analysis of all ecological variables (physiography, surficial deposits, vegetation and geology). The analysis permitted classification of watersheds into five groups corresponding to five major sensitivity to acid precipitation zones. These zones, based solely on ecological and geological variables, compare with those proposed by Bobée et al (1983) based upon physicochemical data.

PREFACE

This report represents the results of a research study conducted by the Lands Directorate, Quebec Region, and the Institut national de recherche scientifique - eau (INRS-Eau) of the University of Quebec. The report presents analyses leading to a comprehensive evaluation of the ecological relationships which exist among the aquatic and terrestrial elements of ecosystems sensitive to acid precipitation in southwestern Quebec. These ecosystems receive a high annual loading of acid precipitation and are now subject to long-term monitoring and assessment by the Environmental Conservation Service of Environment Canada. This research was supported from 1982 to 1984 by resources from the federal Long Range Transport of Airborne Pollutants (LRTAP) program.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
PREFACE	v
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xii
1. INTRODUCTION	1
1.1 Objectives of the study	3
2. BIOPHYSICAL FRAMEWORK OF THE STUDY	5
2.1 Geology and Unconsolidated Deposits of the Laurentian Uplands	6
2.2 Soils	9
2.3 Climate of Southern Quebec	10
2.4 Vegetation of Southern Quebec	11
2.4.1 Boreal Forest Region	13
a) Laurentide-Onatchiway Section	
b) Missinaibi-Cabonga Section	
2.4.2 Southeastern Mixed Forest Region	16
a) Middle Ottawa Section	
b) Laurentian Forest Section	
c) Saguenay Forest Section	
3. DATA ACQUISITION	18
4. ANALYSIS OF ECOLOGICAL AND GEOLOGICAL VARIABLES	19
4.1 Physical Variables	19
4.1.1 Physiographic Variables	21
4.1.2 Variables Relating to Nature and Thickness of Unconsolidated Deposits	25

TABLE OF CONTENTS
(cont'd)

		Page
	4.2 Vegetation Variables	31
	4.3 Geological Variables	38
	4.4 Conclusions	40
5.	ANALYSIS OF RELATIONSHIPS BETWEEN PHYSICOCHEMICAL VARIABLES OF LAKE WATER QUALITY AND ECOLOGICAL VARIABLES	42
	5.1 Methods Used	43
	5.2 Identification of Relationships	44
	5.3 General Analysis of Interrelationships	48
	5.4 Conclusion	54
6.	RELATIONSHIPS BETWEEN GEOLOGICAL VARIABLES AND PHYSICOCHEMICAL VARIABLES	55
	6.1 Methods Used	55
	6.2 Results of Discriminant Analysis	59
	6.3 Conclusions	64
7.	ANALYSIS OF INTERRELATIONSHIPS BETWEEN ECOLOGICAL AND GEOLOGICAL VARIABLES	65
	7.1 Methods Used	66
	7.2 Analysis of Interrelationships Between Variables	69
	7.2.1 Grouping of Variable Points	72
	7.2.2 Composition of Groups	72
	7.2.3 Supplementary Variables	77
	7.3 Determination of Homogeneous Zones	77
	7.4 Conclusions	84
8.	CONCLUSIONS AND RECOMMENDATIONS	85
	8.1 Importance of Geological and Ecological Variables	86
	8.2 Relations Between Ecological Variables and Water-Quality Variables	86

TABLE OF CONTENTS
(cont'd)

		Page
8.3	Relations Between Geological and Physicochemical Variables	87
8.4	Analysis of Relationships Between Geological and Ecological Variables	88
8.5	Review of Study Objectives	88
8.6	Recommendations	89
REFERENCES		92
APPENDIX A:	Watersheds Inventoried, Location, and Geology	95
APPENDIX B:	Statistical Methods	105
APPENDIX C:	Geological and Ecological Characteristics of the Watersheds	111

LIST OF TABLES

		Page
Table 3.1:	Data Inventoried for the Study: Types, Sources and Value of Information	20
Table 4.1:	Descriptive Statistics Relating to Physiographical Variables of the 158 Watersheds in the Study Area	23
Table 4.2:	Distribution of Units of Area ≥ 0.1% of the Watershed by Type and Thickness of Deposits, Slope and Drainage	28
Table 4.3:	Number, Mean and Standard Deviation of Watershed Areas ≥ 0.1% by Type of Deposits, Slope and Drainage	30
Table 4.4:	Frequency Distribution of Various Types of Deposits by Relative Area Occupied Within the Watershed	32
Table 4.5:	Distribution of Units of Watershed Area ≥ 0.1% by Type and Density of Vegetation	35
Table 4.6:	Number, Mean and Standard Deviation of Watershed Areas ≥ 0.1% by Type of Vegetation	36
Table 4.7:	Frequency Distribution of Number of Watersheds by Type of Vegetation and Relative Area	37
Table 5.1:	Correlation Coefficients Significantly Different from Zero (5% Level) Between Various Types of Deposits and Physicochemical Variables	45

LIST OF TABLES
(cont'd)

Page

Table 5.2: Correlation Coefficients Significantly Different from Zero (5% Level) Between Physicochemical Variables and Ecological Variables 47

Tables 5.3: Composition of the Eight Groups of Variable Points Obtained by Application of CA to PCA Factors 52

Table 6.1: Results of Discriminant Analysis: Wilks' Lambda for each of the Variables, Correlation Between the Variables and the Discriminant Function and Coefficients of the Discriminant Function 60

Table 6.2: Results of the Classification Obtained by Discriminant Analysis 61

Table 7.1: Lower and Upper Thresholds Used for Coding Variables in Three Classes 68

Table 7.2: Distribution of Classes of Variables Among the Six CA Groups 71

Table 7.3: Classification of Ecological Variables by Variation Profile 73

Table 7.4: Variable Points Contributing to the Formation of Watershed Groups 80

Table 7.5: Distribution of Watersheds by Classification in Five Groups and by Location Within the Five Zones Previously Defined by Bobée et al (1983) 83

LIST OF FIGURES

		Page
Figure 1.1:	Location of the 158 Watersheds Inventoried	2
Figure 2.1:	Relative Position of the Grenville Orogeny in Geological History	7
Figure 2.2:	Geological Divisions of Quebec	8
Figure 2.3:	Mean Annual Total Precipitation 1941-1970 (mm)	12
Figure 2.4:	Forest Regions of Quebec (After Rowe, 1972)	14
Figure 2.5:	Forest Sections of Southern Quebec	15
Figure 4.1:	Frequency Histograms of Physiographical Variables for the Study Area	22
Figure 4.2:	Classification of Watersheds by Lake Altitude	24
Figure 4.3:	Classification of Watersheds by Mean Annual Precipitation	26
Figure 4.4:	Classification of Watersheds by Dominant Deposit (Occupying the Largest Percentage Area Within Each Watershed)	33
Figure 4.5:	Classification of Watersheds by Dominant Type of Vegetation	39
Figure 4.6:	Classification of Watersheds by Ten Groups of Bedrock Types	41

LIST OF FIGURES
(cont'd)

		Page
Figure 5.1:	Representation in the Plan of Axes 1 and 2 of the Factors of Variables Obtained by Principal Component Analysis (PCA) Applied to the Matrix of Spearman Correlation Coefficients	50
Figure 5.2:	Clustering of the Factors of Variables Obtained by PCA Applied to the Matrix of Spearman Correlation Coefficients	52
Figure 6.1:	Classification of Watershed by Five Groups of Bedrock Types	57
Figure 6.2:	Representation in Canonical Space of Centroids of Watershed Groups and Distribution of Watershed by Geological Group for Each of the Adherence Surfaces	63
Figure 7.2:	Clustering of Groups of Station Points and Simultaneous Representation in the Plane of Main Axes 1 and 2 of the Centres of the Groups of Station Points and of the Groups of Variable Points	79
Figure 7.3:	Classification of Watersheds in Five Groups Defined in the Study and Boundaries of the Zones Define by Bobée et al (1983)	82

1. INTRODUCTION

Rapid industrial growth, the use of different sources of energy, and the consequent increase of pollution in all forms are now forcing all North Americans to identify and quantify the capacity of the environment to absorb, transform, and recycle all those substances used and discarded by man. It is becoming increasingly urgent that determination of the thresholds at which irreversible damage to the existing environmental balance occurs is ascertained.

Because of this deterioration of the environment and, in particular, its scope, governments at all decision levels must begin working together at once to identify and analyse the various sources of pollution, the capacity of the natural environment to recycle them, and the material and potential limits on the environment beyond which we cannot go.

During the winter of 1982 (from January 10 to March 3), as part of a research program on acid rain, the Inland Waters Directorate, Quebec Region, collected water samples from 185 lakes located in the southeastern part of the Canadian Shield, in a strip 150 km wide extending from the Ottawa River to the Saguenay fjord (Figure 1.1).

The primary objective of this sampling was to assess acid levels in the waters of Quebec's lakes within a region known to be extremely sensitive to acidification and exposed to high levels of acid fallout of atmospheric origin, and to examine the importance of climatic, physiographic, geological, and geomorphological conditions in controlling acid levels in these lakes. The results obtained from this sampling were to be used in establishing a rational, integrated data-gathering network which would make it possible to monitor the evolution in the quality of Quebec's surface waters in the time and space to detect any trends in the evolution.

A study by Bobée et al (1983), dealing with the analysis and interpretation of the physicochemical data collected during sampling, showed that the majority of the lakes in the study area are sensitive to acidification by precipitation and that the most acidic lakes lie within the most sensitive zone identified, primarily in the St-Maurice Valley, Portneuf

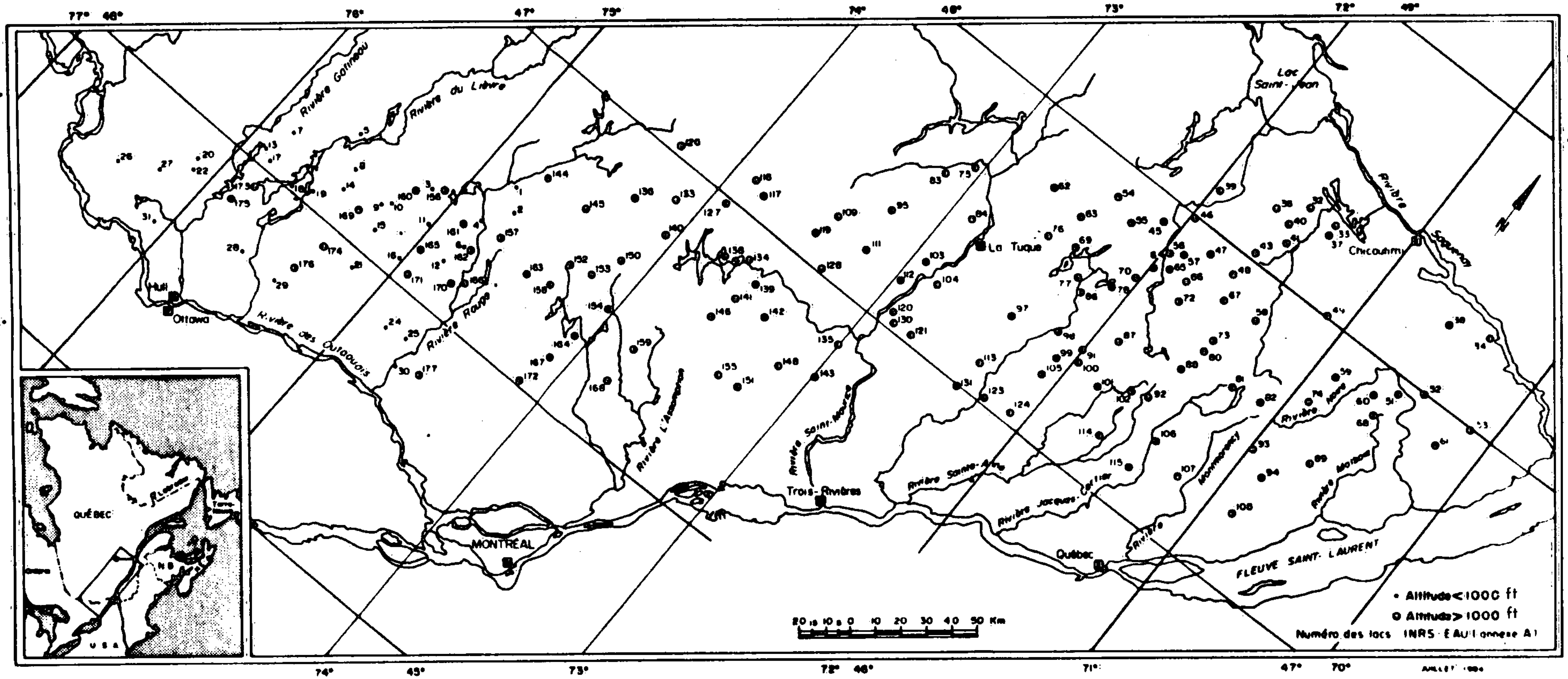


Figure 1.1: Location of the 158 Watersheds Inventoried

Park and Laurentide Park. The SW-NE gradient observed for sulphates is interpreted as the result of long-range atmospheric transport. The application of chemical acidification models, however, failed to indicate whether acidification of the lakes is a recent development. The application of multivariate analysis methods permitted classification of the lakes in five groups, on the basis of which five zones of differing sensitivity to acidification were identified. Following analysis of the data, a method was described for the establishment of a data-gathering network, and various possible sampling plans were proposed.

Initially, 185 lakes were selected; this number was later reduced to 177, since eight of the lakes inspected did not meet the selection criteria described in Bobée et al (1983). Of this number, this study retains 158, since nineteen showed unacceptable ion levels or were too dark in colour (excessive organic acid content). The lakes (or watersheds), together with their geographic coordinates and geological characteristics, are listed in Appendix A and located in Figure 1.1.

The role of the Lands Directorate, in collaboration with the Inland Waters Directorate, in this acid rain research project is to produce detailed descriptions of the terrestrial ecosystems of each of the watersheds basins selected. This region (southwestern Quebec) was selected not only because of the gradient it shows in terms of sensitivity and precipitation acidity, but also because it is representative of the wide ecological variability of the Canadian Shield.

1.1 Objectives of the Study

The data collected during characterization of the 158 watersheds selected for the study are analysed and interpreted in relation to the following objectives:

- Identification of the types of terrestrial ecosystems sensitive to acid precipitation. Evaluation and definition, on the basis of environmental variables, of the zones most severely affected or threatened by the effects of acid fallout. This will provide an estimate of the areas vulnerable to or already affected by the processes of acidification.

- Identification and determination of the geological and ecological variables (physiography and vegetation) which significantly influence the sensitivity of terrestrial and aquatic ecosystems to acid rain. The spatial behaviour of all of these variables is described in general terms and homogeneous zones are defined within the study area on the basis of their level of sensitivity and their capacity to neutralize or modify acid atmospheric input.

- Determination, by means of the physicochemical variables of water quality, of the resistance of the bedrock in each watershed to weathering and its effect on the buffering capacity and sensitivity of the various physical environments.

- Determination of the role played by unconsolidated deposits (thickness, type, distribution) on the buffering capacity or sensitivity of the terrestrial ecosystems. The slope and drainage associated with each type of deposit is considered.

- Determination, by study of the interrelations between variables, of the role played by vegetation in response to acid precipitation. An attempt is made to determine whether there is any significant difference in the quality of water from lakes in watersheds in which the dominant forest cover is coniferous and those in which the dominant cover is deciduous.

In addition to the principal objectives, there are two other uses for the results of the study:

- The ecological and geological data inventoried will be added to the data bank maintained by the Inland Waters Directorate on the physicochemical characteristics of lake waters.

- The determination of the types of ecosystems vulnerable to the effects of acid precipitation will be of value in assessing the accuracy and precision of various recently-published sensitivity maps (United States - Canada, 1983).

Following a general description of the ecological framework of the study (Chapter 2), a brief review of the methodology used (Chapter 3), and an analysis of the information content of each of the variables examined (Chapter 4), the authors attempt, by means of various statistical methods, to establish relationships between the different types of variables considered. In Chapter 5, the relationships between physicochemical variables of water quality and the ecological variables are examined. Relationships between physicochemical and geological variables are dealt with in Chapter 6. Finally, Chapter 7 consists of a general, integrated analysis of all the environmental variables (physiography, geology, and vegetation).

2. ECOLOGICAL FRAMEWORK OF THE STUDY

The study area is located entirely within the Canadian Shield, in the southeastern portion commonly known as the Laurentian Plateau or Laurentian Chain. The general relief shows no truly contrasting forms; the surface, the vestige of an ancient peneplain or 'pediplain', is gently rolling, producing altitudes of 250 to 750 metres (Rousseau, 1974). The surface of this plateau is dominated by two mountain masses: the Laurentide Park massif north of Quebec City, which rises to 1165 m, and Mont Tremblant northwest of Montreal, which attains an altitude of 967 m (Bobée et al, 1983).

The plateau's surface is slashed by a number of fractures of a regional scale, including the Saguenay Fjord, the Jacques-Cartier Valley, the St. Maurice Valley and the Gatineau Valley. In addition, a multitude of small local fractures crisscross the surface of the plateau.

The Laurentian Plateau is the product of one of the four orogenies of the Precambrian, the Grenvillian orogeny, dating from approximately 950 million years ago (Figure 2.1). The rocks of the Grenville Province extend over an area approximately 320 km wide along the north shore of the St. Lawrence River and the Gulf of St. Lawrence, and cover approximately 30 to 40% of Quebec.

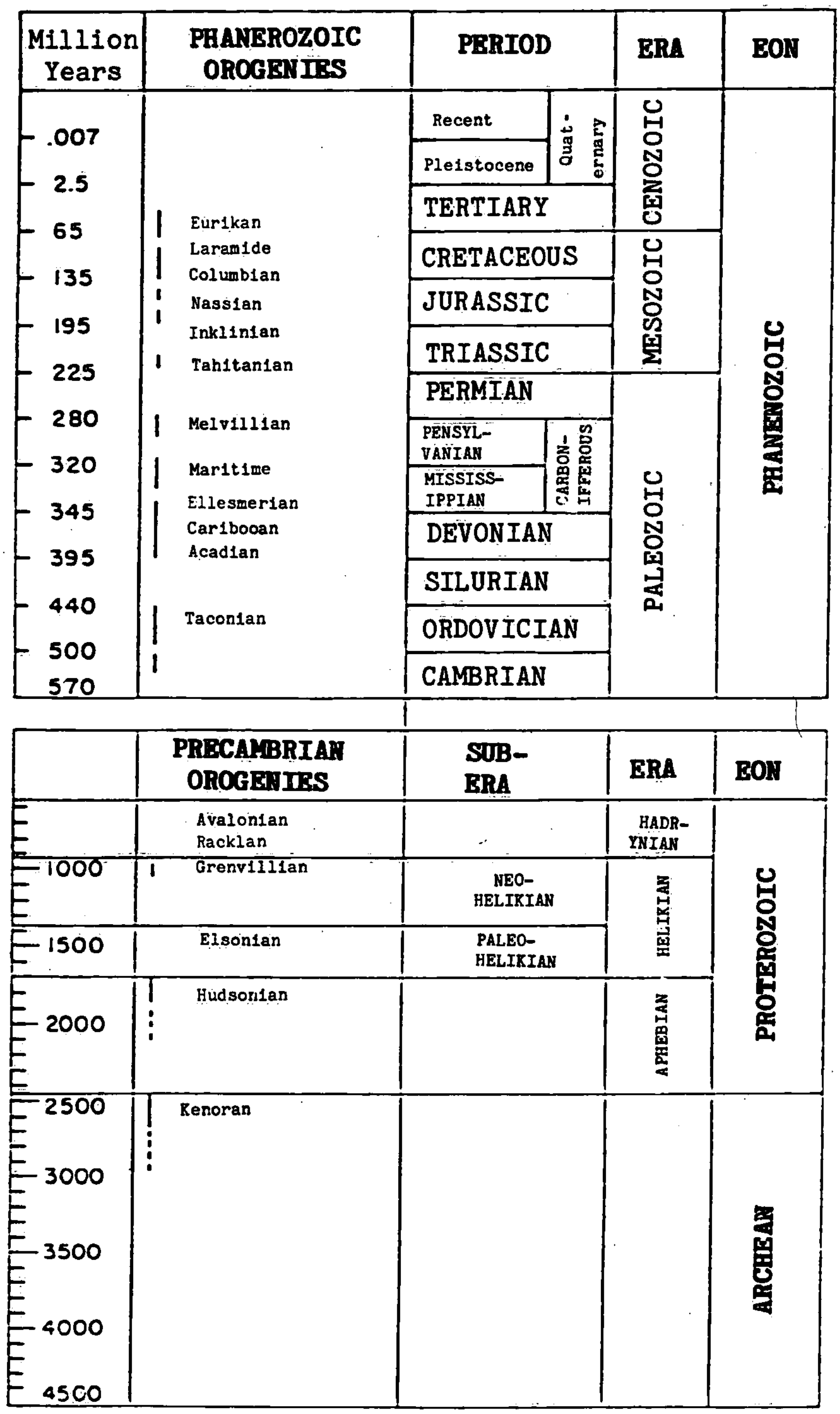
2.1 Geology and Unconsolidated Deposits of the Laurentian Uplands

The rocks of the Precambrian, the oldest and longest period of geological history, occupy most of Quebec and form the Laurentian Plateau or Laurentian Uplands. The mineralogical and structural characteristics of most of these rocks correspond to phenomena believed to have occurred at high temperatures and pressures. In the southern portion of Grenville Province (Figure 2.2), the rock formations run in a generally north-northeast direction, while in the northern portion they run northeast, forming a transition zone between the Grenville and Superior Provinces.

The lithology is characterized primarily by plutonic rocks (granite and associated rocks); eruptive, sedimentary, and metamorphic rocks are also present. For the most part, these rocks are crystalline and resistant to weathering. Most rocks are igneous (anorthosite, gabbro, granite, syenite) or metamorphic (gneiss, paragneiss, and quartzite).

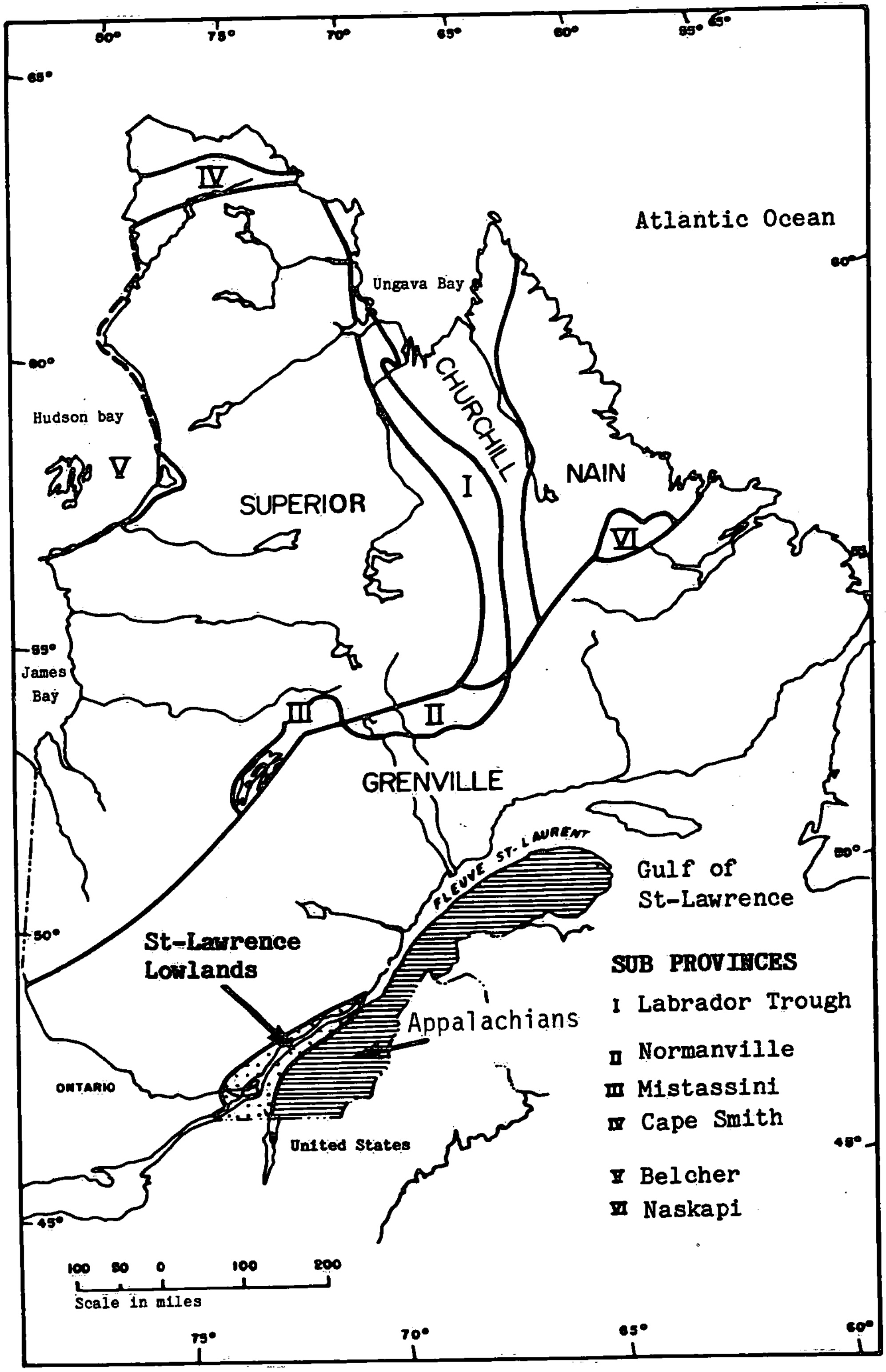
Plutonic rocks (or intrusive igneous rocks) are produced by slow crystallization of magma at a certain depth and are generally coarse-grained, equant in texture, and homogeneous in large volumes. Metamorphic rocks are produced by the transformation of a rock in the solid or plastic state as a result of an elevation in temperature or pressure, with crystallization of new minerals and acquisition of specific textures and structures in response to physical or chemical conditions different from those which presided over the formation of the original rock (Foucault and Raoult, 1980). The original rocks involved may be igneous, sedimentary or metamorphic in origin.

The Laurentian area received its final shaping during the last great glaciation of the Quaternary, which ended approximately 11,000 years ago. Glacial movement or flow at that time was southward or south 10°E. This glaciation produced a transformation in the physiography of the plateau through the deposition of ground moraine unconsolidated deposits. This



Source: Government of Canada (1974)

Figure 2.1: Relative Position of the Grenvillian Orogeny in Geology History



Source: Government of Canada
(1974)

Figure 2.2: Geological Divisions of Quebec

unsorted material, consisting of rock debris in a generally sandy matrix, is the product of glacier scour and abrasion of the surface of the Laurentian plateau.

The unconsolidated materials deposited over this vast extent of acid rock created conditions favourable to the formation of lakes and bogs by modifying the hydrographic system, blocking valleys and causing stagnation of water in depressions and plains. These unconsolidated deposits vary in average thickness from 2 to 8 metres. However, in valley bottoms or fractures, they may be tens of metres thick. On the highest ridges and on steep or abrupt slopes, however, deposits vary from 0 to 2 metres in thickness.

Morainal deposits generally reflect the nature of the bedrock on which they are deposited. Since the bedrock consists almost exclusively of igneous (plutonic) and metamorphic rocks, this region is part of a vast area classified as extremely sensitive to acid precipitation. Shilts (1981), in this study on the sensitivity of bedrock to acid precipitation, describes the glacial processes and their consequences as follows:

> "In Canada, the simple relationship of soils to underlying bedrock has been distorted by glaciers which have transported debris from one type of bedrock onto areas where the rock may have a different composition".

Since this region has been subjected to a number of glaciation episodes, and in certain parts of the plateau, are found carbonate rock outliers, it is concluded that the glacial transport may distort the sensitivity patterns that are derived solely from the bedrock information.

2.2 Soils

The study area falls within Quebec's extensive Podzol Zone. In fact, most of Quebec's soils show very advanced podzolization (Grandtner, 1966). The Laurentian Uplands are covered almost entirely by soils of this nature. Typically, podzolic soils have developed on coarse- to medium-textured acid parent materials, under forest and heath vegetation, in cold to very cold, and wet to very wet climates (Government of Canada, 1978).

Unfortunately, very little data and studies are available on the soils of this area of the Laurentian Plateau. Most of the studies on Quebec's soils have been performed for the very specific purpose of characterizing the agricultural soils of the St. Lawrence lowlands. As a result, the authors have been unable to include in the study any data relating to the soils of the watersheds selected. A field program to characterize the soils and geochemistry of 35 of these studied watersheds was initiated in 1984.

2.3 Climate of Southern Quebec

The annual temperature of the Quebec climate shows a gradual decline from south to north and from the valleys and lowlands to the plateaus and mountain masses. There is also a contrast between the climate of eastern and western Quebec. These variations in temperature thus reflect varied geographical conditions and meteorological situations. In addition, according to Wilson (1971), other factors, including differences in soil, slope angle and orientation, surface form and altitude, degree of exposure to wind, precipitation, clouds, and fog, nature of the vegetation, size and shape of cleared areas, and proximity to bodies of water, combine to produce a mosaic of local climates.

In October in northern Quebec, and in November in the southern portion of the province, the mean temperature drops below 0°C. The mean daily temperature in January varies between -15.0°C in Laurentide Park north of Quebec City and -12.5°C north of Hull. Winter is very cold throughout Quebec, with minimum January temperatures of -22.5°C at La Tuque, -17.5°C near Hull, and -22.5°C around St-Agathe des Monts (Houde, 1978).

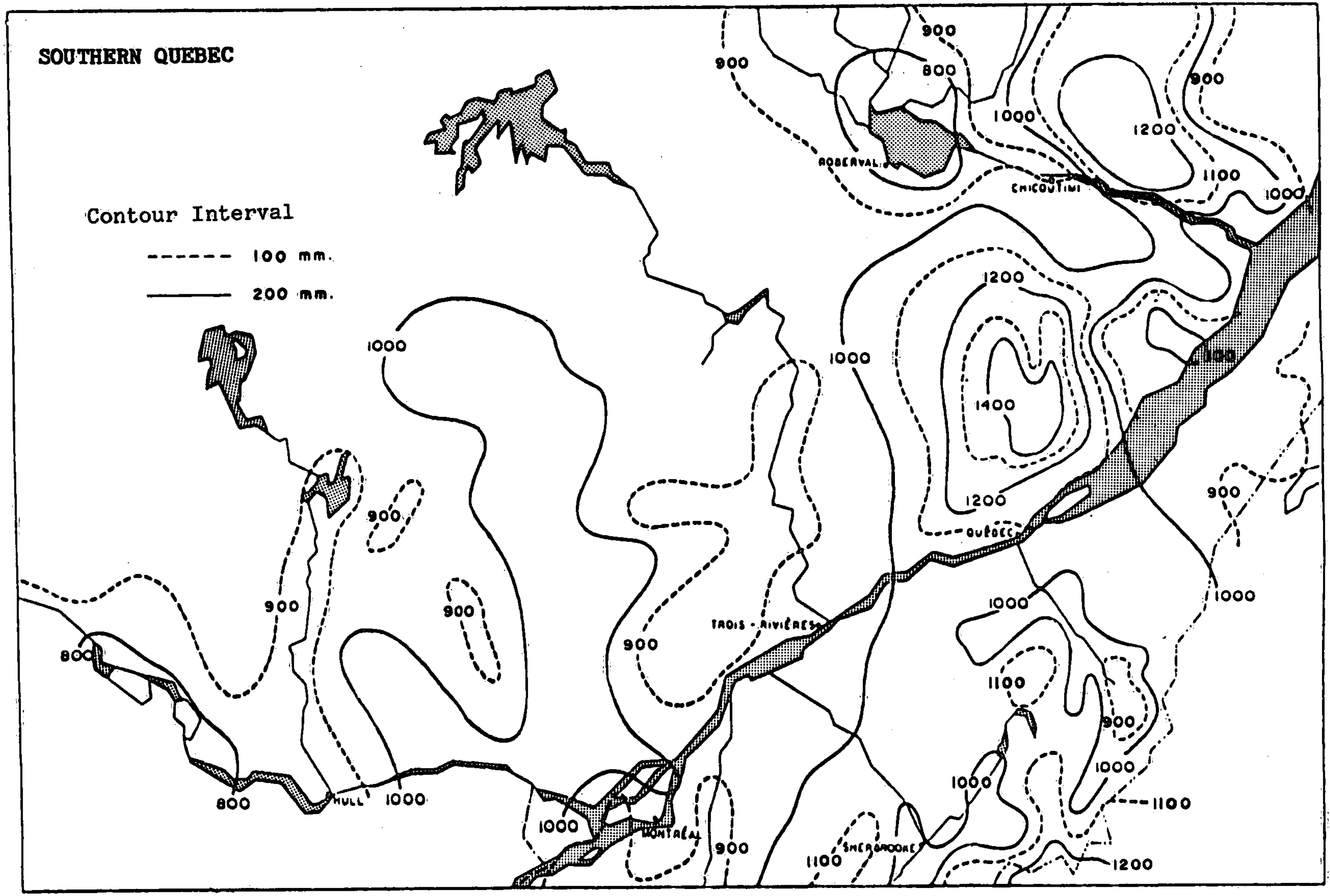
Mean temperatures in July, the hottest month of the year, range from between 15.0°C and 21.0°C on the Laurentian Plateau, to 15.0°C north of Quebec City, 20.8°C north of Hull, and 17.5°C around La Tuque. In summary, from June to August, the Laurentian Shield shows little spatial variation in mean temperatures.

Southern Quebec receives a great deal of rain and snow. The annual total precipitation varies from 900 mm in the Montreal and St. Maurice regions to over 1400 mm on the high peaks of the Laurentians (Figure 2.3). The major influences governing the monthly distribution of precipitation relate to the origin of depressions, the proximity of sources of moisture, and the orientation of relief (Houde, 1978). In addition, locally, the average distribution of summer rain varies with altitude. An increase of approximately 10 mm of precipitation for every 150 m in altitude is present. The exposure or orientation of relief is the second factor: slopes exposed to the wind receive more rain.

Most of the precipitation falls during the summer months. In fact, warm, humid atmospheric systems from the southwest cross Quebec more frequently during these months. Western Quebec is particularly affected by these systems. Although winter is still the driest period, it snows heavily from November until April. The contrast between east and west in the amount of precipitation observed is more marked with respect to snow than to total precipitation. It is also noted that a decrease from east to west in winter precipitation exists. This contrast is due primarily to the fact that the winter storms coming off the ocean affect eastern Quebec in particular, leaving major accumulations of snow (up to 500 cm in north-northeastern Quebec). The wet, in contrast, with an average snow cover of 300 cm, is more frequently swept by depressions of a continental nature, from the west or northwest, which are unlikely to be affected by their passage over the entirely or partially frozen inland waters of the Great Lakes. Snow accounts for approximately 25 to 30% of the mean annual total precipitation in the southwestern portion of the Province and as much as 30 to 35% in Laurentide Park. The climate of southern Quebec is thus generally a continental climate, characterized by a wide range of extreme temperatures, heavy precipitation and the influence of the winter snow cover.

2.4 Vegetation of Southern Quebec

Rowe (1972), as a basis for primary descriptive data, has been used as a reference work; it defines the principal forest regions of Canada characterized by general uniformity in the appearance and distribution of



Source: Houde (1978)

Figure 2.3: Mean Annual Total Precipitation 1941-1970 (mm)

dominant plant species. In addition to the eight forest regions described by Rowe, four additional floristic regions (Government of Canada, 1978), were consulted in this study in an effort to illustrate more clearly the physiographic differences in Quebec's relief and to define more fully the spatial variations in appearance and composition of the associated vegetation groupings.

Four of these twelve regions are found in Quebec (Figure 2.4). This study incorporates areas falling within only the boreal forest region and the southeastern mixed forest region (Great Lakes-St. Lawrence forest).

2.4.1 Boreal Forest Region

This region comprises the greater part of the forested area of Canada, forming a continuous belt from Newfoundland and the Labrador coast westward to the Rocky Mountains and northwestward to Alaska.

The white and the black spruce are characteristic species; other less prominent but equally representative conifers are tamarack, balsam fir, and jack pine. This region also has a number of deciduous species, particularly the white birch, trembling aspen, and balsam poplar. In the east, a considerable admixture of species from the great Lakes-St. Lawrence forest, such as eastern white and red pine, yellow birch, sugar maple, black ash, and eastern white cedar, occurs. The boreal forest region is subdivided into forty-five sections or geographic zones distinguished by vegetation and physiography. Two of these sections (Figure 2.5), are described briefly below and occur within the limits of our study area. Most of the following descriptions of the forest sections are taken almost in their entirety from Rowe (1972).

a) Laurentide-Onatchiway Section (Section 5, Figure 2.5)

This section includes the Laurentian uplands north and northeast of Quebec City. The forests are predominantly coniferous. Balsam fir dominates on hill slopes and in other moist well-drained sites, while black spruce is prominent on thin-soiled plateaus and on poorly-drained land. White spruce is

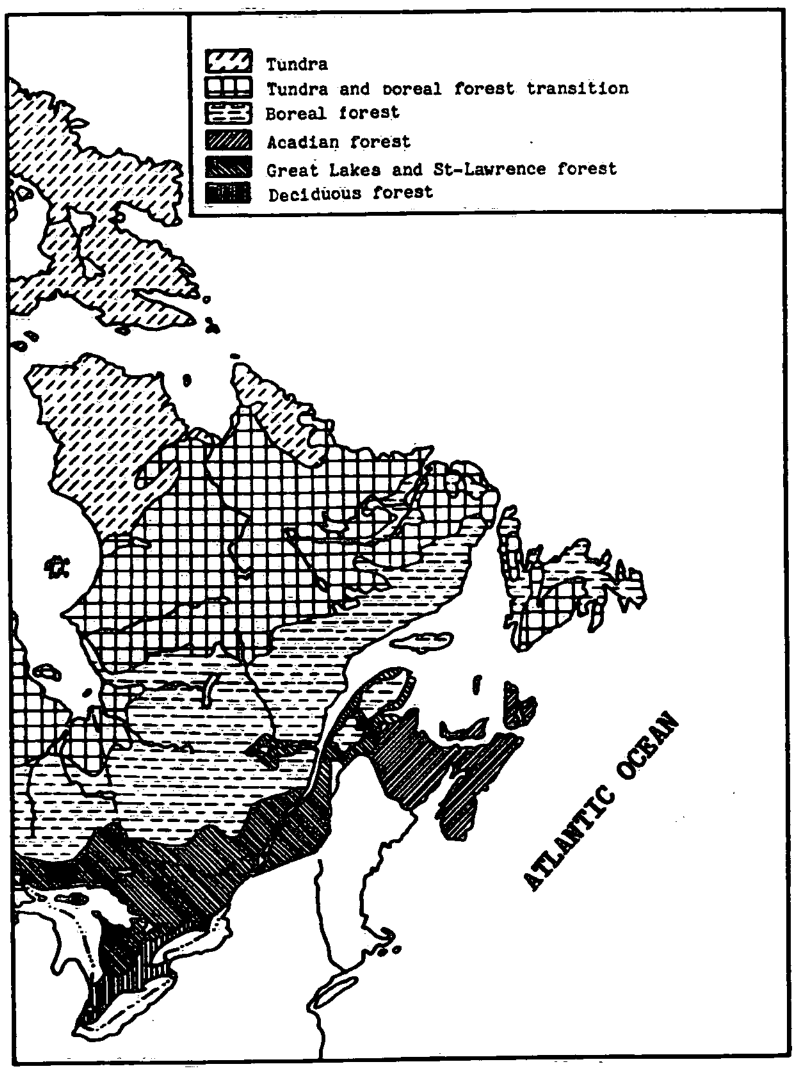


Figure 2.4: Forest Regions of Quebec (After Rowe, 1972)

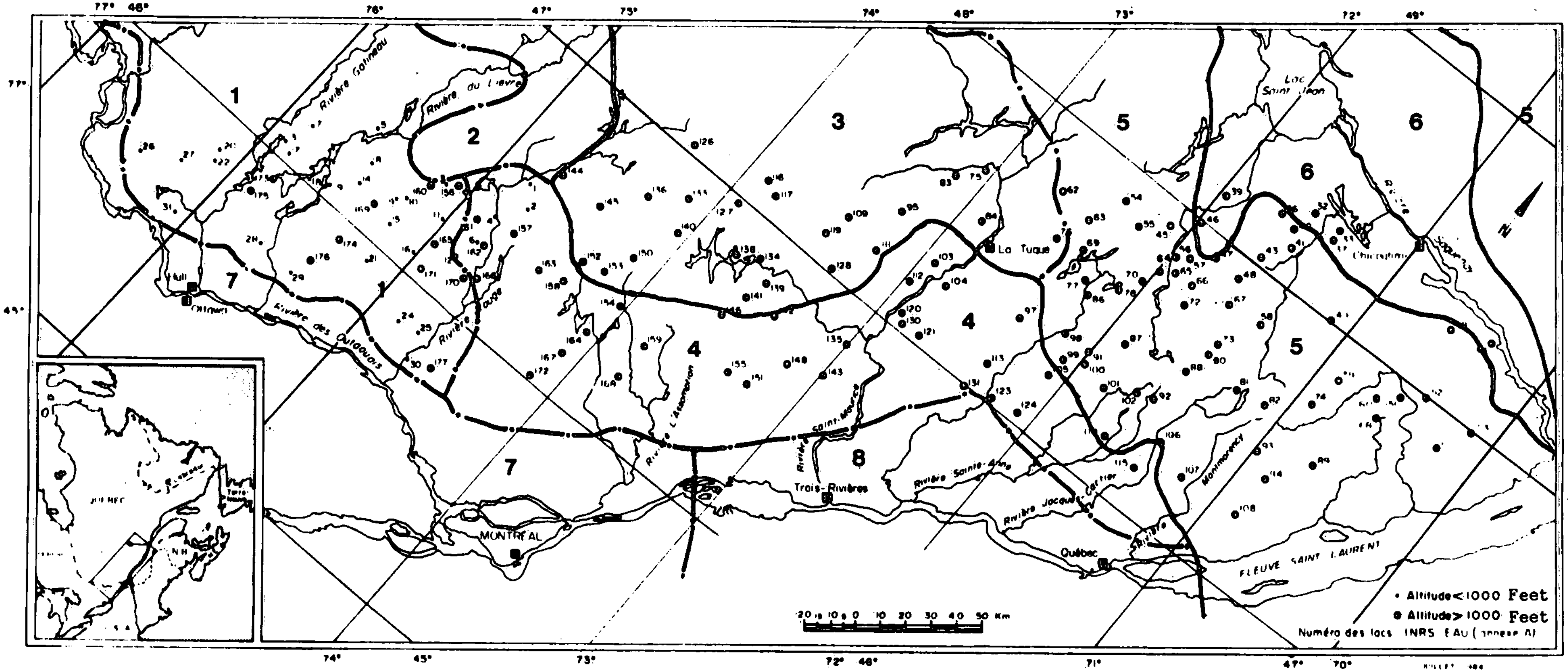


Figure 2.5: Forest Sections of Southern Quebec

Source: Rowe, (1972)

1 Outaouais
2 Algonquin-Pontiac
3 Missinaibi-Cabonga
4 Laurentian
5 Laurentides-Onatchiway
6 Saguenay
7 Upper St-Lawrence
8 Mid St-Lawrence

Limit of Sections

Limit of Regions

distributed throughout, though of little numerical importance. White birch is the common hardwood associate of the fir and spruce; trembling aspen and the jack pine are secondary species which dominate where fires have been frequent, especially surrounding the Lake St. John Lowland. Balsam poplar, eastern white cedar, eastern white pine, and tamarack are locally common while several of the tolerant hardwoods - sugar maple and yellow birch - occur at low altitudes in the southern parts.

b) Missinaibi-Cabonga Section (Section 3, Figure 2.5)

it stretches from the middle St. Maurice Valley along the higher southward slopes of the Laurentians in Quebec to the south side of Lake Abitibi, and westward to a point just northeast of Lake Superior. The predominant forest is mixed, consisting of an association of balsam fir, black spruce and white birch, with scattered white spruce and trembling aspen, this appearing as a dominant type on middle slopes. Occasionally on heavier-textured ridges and on upper north slopes in particular, are groves or solitary sugar maples, and yellow birch - a condition most commonly encountered in this area of Quebec. On rocky shores, and also on ridges, there are some eastern white and red pine, though these species were mostly removed by logging several decades ago.

Sandy terraces along rivers are dominated by jack pine, which also associates with black spruce on poor, rocky soils. The black spruce, with tamarack, covers large areas of wet organic soils, and eastern white cedar accompanies black spruce in a common lowland association. There are numerous occurrences of black ash and white elm; red spruce is scattered along the southern boundary of Quebec.

2.4.2 Southeastern Mixed Forest Region

Along the Great Lakes and the St. Lawrence River Valley lies a forest of a very mixed nature, characterized by eastern white and red pine, eastern hemlock, and yellow birch. With these are associated certain dominant broadleaved species common to the deciduous forest region, such as sugar maple, red maple, red oak, basswood, and white elm. Other wide-ranging species are the eastern white cedar and largetooth aspen, and to a lesser extent, beech, white oak, butternut, and white ash. Boreal species, such as the white and the black spruce, balsam fir, jack pine, trembling aspen, balsam poplar, and white birch are intermixed in this forest region. The southeastern mixed forest region is subdivided into sixteen sections or geographic zones described by Rowe (1972). However, only three fall within the limits of this study. These are: the Middle Ottawa Forest Section, the Laurentian Forest Section, and the Saguenay Forest Section (Figure 2.5).

a) Middle Ottawa Forest Section (Section 1, Figure 2.5)

The usual components of these upland forests are sugar maple, beech, yellow birch, red maple, and eastern hemlock, almost always accompanied by eastern white pine and red pine. The last two species also dominate dry ridges and sand flats in association with jack pine. Varying numbers of white spruce, balsam fir, trembling aspen, white birch, red oak, and basswood are present throughout.

Hardwood and mixed-hardwood swamps in which appear eastern white cedar, tamarack, black spruce, black ash, red maple, and white elm are common. A number of more southerly species, not common, are butternut, bitternut hickory, bur oak, white ash, and black cherry.

b) Laurentian Forest Section (Section 4, Figure 2.5)

The Laurentian forest section occupies a zone of transition between the boreal and the deciduous regions. Its southern boundary is defined geologically by the abrupt transition from Precambrian rocks to the sedimentary limestone of the St. Lawrence Valley and by the general northern limit of the post-glacial Champlain Sea deposits. Its northern edge coincides roughly with the limits of distribution of red spruce and red oak.

The forest cover is much like that of the Acadian forest region. It is largely composed of upland tolerant hardwood stands with mixedwoods and softwoods in the valleys, the dominant species on hillslopes being yellow birch, sugar maple, red spruce, balsam fir, red maple, and white birch.

Eastern hemlock, beech, and white spruce are also distributed throughout. Historically, the forest contained extensive eastern white pine, and there is still a consistent representation of this species although it is no longer important. Black spruce occupies poorly-drained peatlands accompanied by eastern white cedar and tamarack, with occasional black ash.

c) Saguenay Forest Section (Section 6, Figure 2.5)

The Saguenay forest section includes only about 5% of the watersheds inventoried in this study. However, the watersheds in this section can be associated with the boreal forest (Laurentide-Onatchiway section), since they are located near its northeastern border. In general, the topography and vegetation characteristics of these wastersheds are similar: high rugged relief, dominated by the black and the white spruce, with some deciduous species including white birch, trembling aspen, and balsam poplar.

A detailed description of the various environments encountered in the 158 watersheds inventoried has been undertaken. This reveals the wide diversity in the physiographic, geological, pedological, climatic, and biogeographical variations of the territory in which they are found. As a result, the authors have chosen to limit the study to description of the ecological complexity of the territory in terms of homogeneous regions, and to simple indication and characterization of the dominant variations.

3. DATA ACQUISITION

The geological and ecological characteristics of the 158 watersheds in the study were inventoried to determine the importance of climatic, physiographical, geological, and floristic conditions in controlling acid levels in lakes. As part of this process, all possible relevant information (descriptive and quantitative) was collected (Table 3.1). Four stages were involved in identifying, collecting, analysing, and interpreting these data:

(a) The first stage consisted of collecting all the existing information (regarding the physicochemical characteristics of the water, geology, and vegetation) and compiling available documentation.

(b) Preliminary photointerpretation of the watersheds enabled the authors to identify, define, and map the principal terrestrial characteristics in terms of morphology, hydrography, and forest cover. At the same time, the thickness and types of deposits were identified and the authors performed qualitative and quantitative assessments of the slopes and of drainage. Finally, representative sites were selected for field investigation.

(c) The field surveys were performed and completed in June of 1983. These involved flying over and photographing the watersheds, verifying the precision and accuracy of the data collected during the preliminary photointerpretation, visiting predetermined sites (problem cases), and collecting additional notes and information.

(d) After each watershed inspection, all the data, both old and new, was compiled, corrected and transferred to the acetates of the initial photointerpretation. The descriptive data were standardized and quantified by eliminating redundant information and measuring all the areas defined on the acetates. The data were then coded and computer-processed.

4. ANALYSIS OF ECOLOGICAL AND GEOLOGICAL VARIABLES

This chapter is a brief analysis of the information provided by each of the variables considered in this study in terms of the type of information which they provide (physical, vegetation, and geological variables).

4.1 Physical variables

The physical variables analyzed in this section are divided into two categories: the physiographic variables inventoried in the earlier study by

Table 3.1

Data Inventoried for the Study: Types, Sources and Value of Information

Type Of Data	Information Collected	Principal Sources	Value
Physiography	Coordinates (longitude, latitude) Altitude (lake)	- Maps at 1:20 000	High altitudes promote cloud formation and thus influence the amount of precipitation received by a region
	Watershed area (WA) Lake area (LA) Wetland area (BA)	- Planimetry from aerial photos	Study of ratios of surface area may be directly related to the total atmospheric acid loading received by the Watershed.
	WA/LA WA/BA	- Ratio of areas	The acid loading received by the lake and the rate of renewal of lake water (output).
Geology	Geological nature of the bedrock of each watershed	- Maps of mineral deposits in Quebec - Ministère de l'Energie et des Ressources (Gouv. du Québec); geological reports - Geological Survey of Canada	The chemical characteristics of bedrock largely determine the impact of each type on precipitation water quality.
Unconsolidated Deposits	- Type of unconsolidated deposits (area) - Thickness - Slope - Drainage	- Photointerpretation and field surveys	Used to reassess watershed sensitivity patterns derived solely from information on bedrock geology. Factors considered include thickness, slope, drainage and type of unconsolidated deposits, all of which influence water contact time in the watershed.
Vegetation	Type of forest cover: density and area	- Gouvernement du Québec, Service de l'inventaire forestier and/or photointerpretation	Vegetation reflects generally the climatic, hydrological and pedological conditions of a region
	Disturbances: - natural: fire, windfalls, epidemics, beaver dams - man-made: partial cuts, clearcuts, wood roads, dams, cottages		Useful for measuring the effects of the plant cover and of disturbances on water quality in lakes within the watershed
Climate	Temperature: - annual mean	- Gouvernement du Québec, Ministère des Richesses naturelles, Service de météorologie	Spring stress is greater if snow fraction is higher and thaw time shorter
	Precipitation: - annual mean, snow fraction	- Government of Canada, Atmospheric Environment Service	Precipitation quality (sulphate input) may be related to water quality Climate influences soil types and vegetation
Lake Water Quality	Physicochemical data on lake water: Concentration of constituents	Bobée et al (1983)	Permits assessment of lake water quality, acidity, buffering capacity, mineralization

Bobée et al (1983) and those relating to the thickness and nature of the unconsolidated deposits.

4.1.1 Physiographic variables

The variables measured are longitude, latitude, lake altitude, watershed area, lake area, the ratio of watershed area/lake area, bog area, and mean annual precipitation (1931-1960). Figure 4.1 shows frequency histograms of the six variables for the entire study area. The principal statistical characteristics (mean, standard deviation, coefficient of variation, median, minimum, maximum) of these variables are given in Table 4.1.

The altitude of the lakes varies between 168 and 975 m, with a mean value of 438 m (Table 4.1). The high-altitude lakes (>600 m) are located in the northeastern portion of the study area, primarily in Laurentide Park north of Quebec City, while the low-altitude lakes (<300 m) are in the southwestern portion, located in the Ottawa Valley (Figure 4.2).

Mean annual precipitation totals between 85 and 165 cm (Table 4.1). The spatial configuration obtained by classifying lakes on the basis of precipitation values (Figure 4.3) resembles that obtained by classifying the lakes on the basis of altitude, with the exception of the lowest precipitation values (between 80 and 90 cm), which occur primarily in association with those lakes at altitudes of between 300 and 400 m. In the Ottawa Valley where the lower-altitude lakes are found, precipitation is between 90 and 100 cm, or slightly below the mean for the study area (106 cm).

Since all the lakes selected are located at the heads of their respective drainage basins, watershed area is generally low; 119 (75%) watersheds have areas of less than 1.5 km^2 (Figure 4.1), while only six watersheds have areas of over 3.5 km^2. The lakes are small, 67% having areas of less than 0.16 km^2 (Figure 4.1). The ratio of watershed area/lake area obtained varies from 2.4 to 45.3 (Table 4.1), but ranges, in most cases, between 4 and 10 (Figure 4.1).

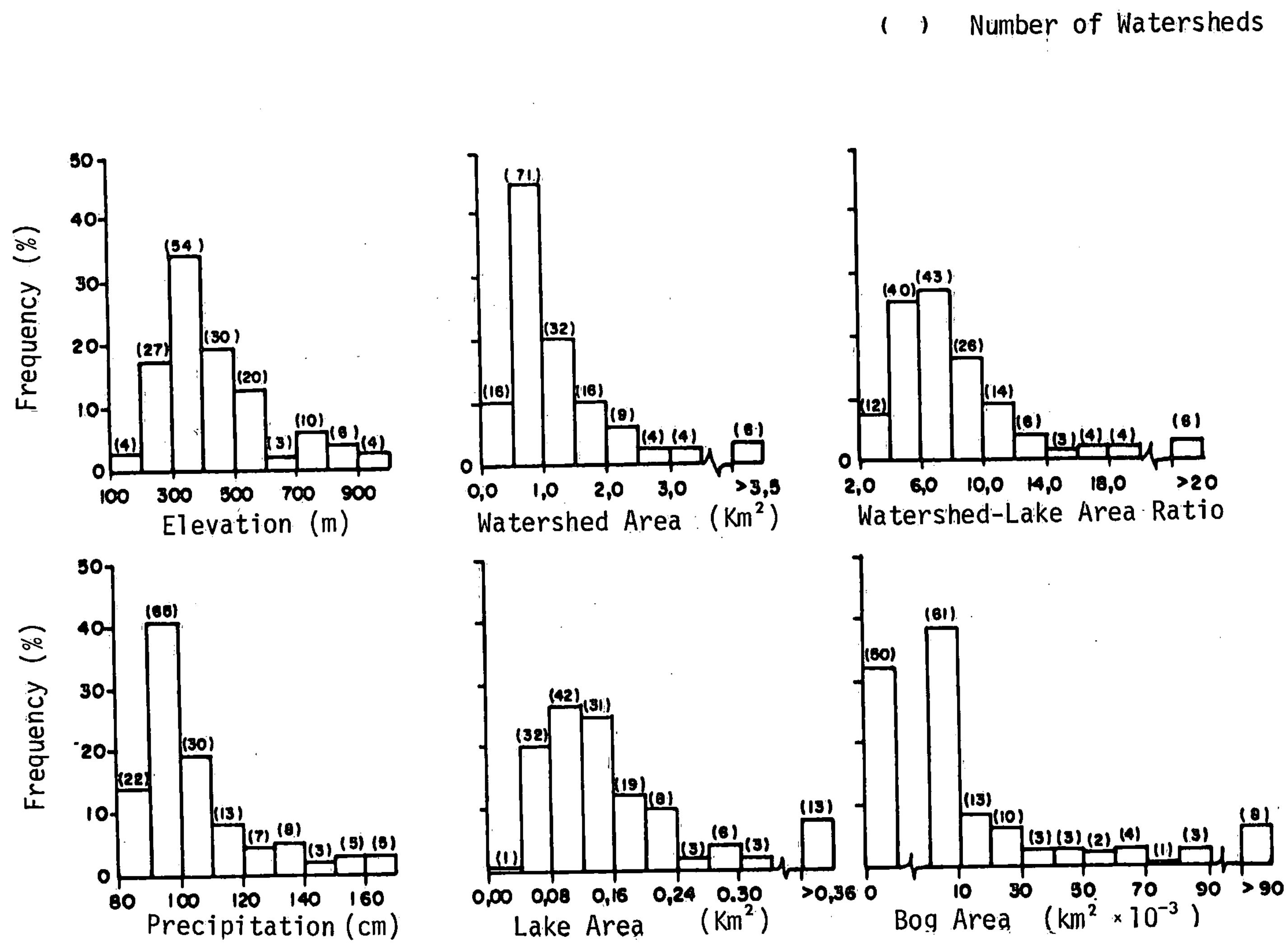


Figure 4.1: Frequency histograms of physiographic variables for the study area.

Variable	Mean	Standard Deviation	Coefficient of Variation (%)	Median	Minimum	Maximum
Altitude (m)	438	179	40.7	396	168	975
Watershed Area (km^2)	1.30	1.21	92.9	0.93	0.26	10.9
Lake Area (km^2)	0.165	0.117	70.7	0.13	0.03	0.70
Bog Area (km^2)	0.020	0.037	184	0.007	0.00	0.22
Mean Annual Precipitation (mm)	105.6	19.8	18.8	98.8	85.0	165.0
$\frac{\text{(Watershed Area)}}{\text{(Lake Area)}}$	8.69	5.99	69.0	6.95	2.42	45.3

Table 4.1
Descriptive Statistics Relating to Physiographic Variables of the 158 Watersheds in the Study Area

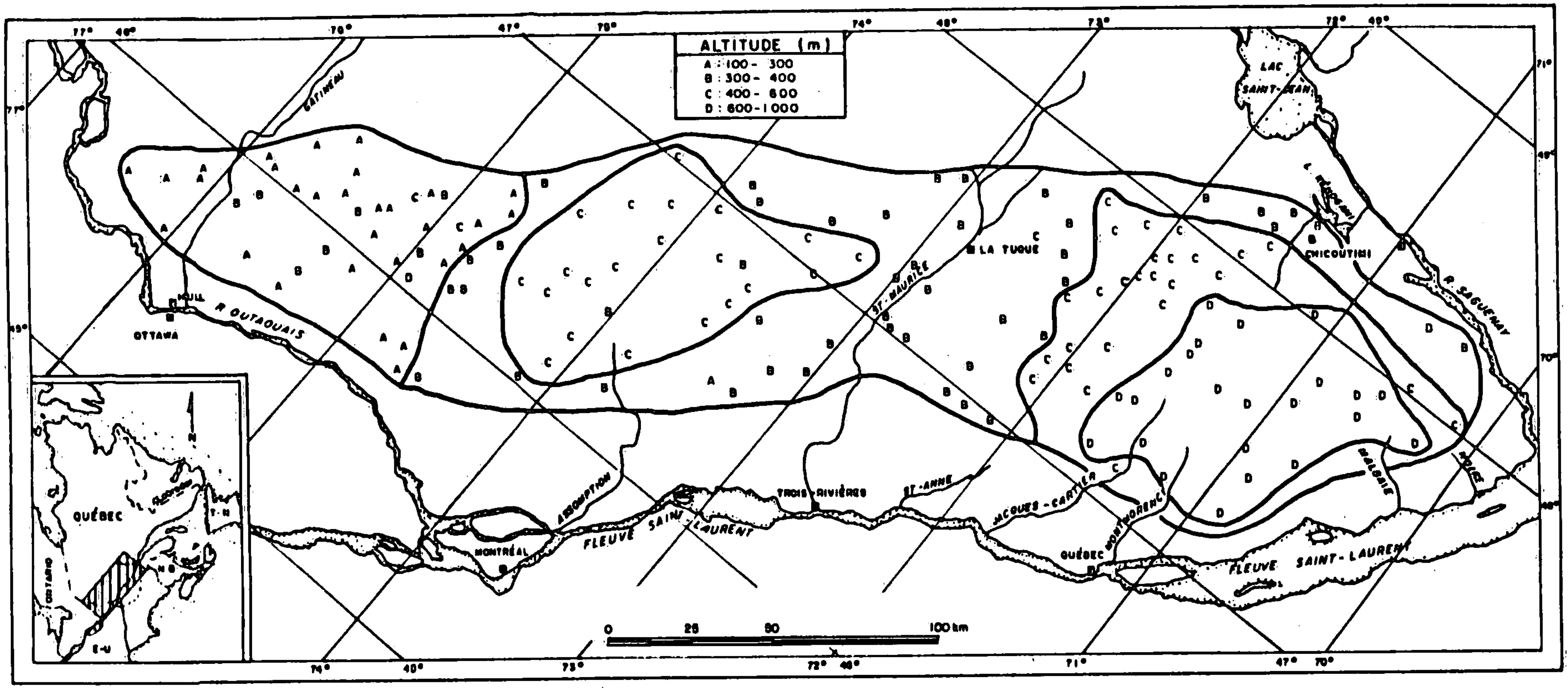


Figure 4.2: Classification of Watersheds by Lake Altitude

One of the criteria applied in selecting lakes was the absence of bogs in the watershed. Bog areas in the watersheds are generally very low, 70% (110) of the watersheds having of area of 0.01 km^2 or less (Figure 4.1). However, nine watersheds with total bog areas of over 0.9 km^2 are present.

4.1.2 Variables Relating to Nature and Thickness of Unconsolidated Deposits

This group of variables consists of measurements taken within the watershed in areas occupied by various types of deposits in relation to slope and drainage classes. The deposits distinguished include:

- rock outcrop (R)
- rock outcrop with thin layer of moraine (R+tD)
- less than 0.5 m moraine over bedrock (tD/R)
- 0.5 to 1 m moraine (tD)
- over 1 m moraine (TD)
- over 30 cm organic deposits (ORG)
- sand and gravel (S + G)

The types of deposits are identified in the following slope classes:

1-	flat terrain	(0 to 2%)
2-	gentle slope	(2 to 10%)
3-	moderate slope	(10 to 30%)
4-	steep slope	(30 to 80%)
5-	very steep to abrupt slope	(>80%)

The types of deposits are ranked in the following drainage classes:

1- excessive, rapid
2- very good
3- good
4- moderate
5- poor
6- very poor

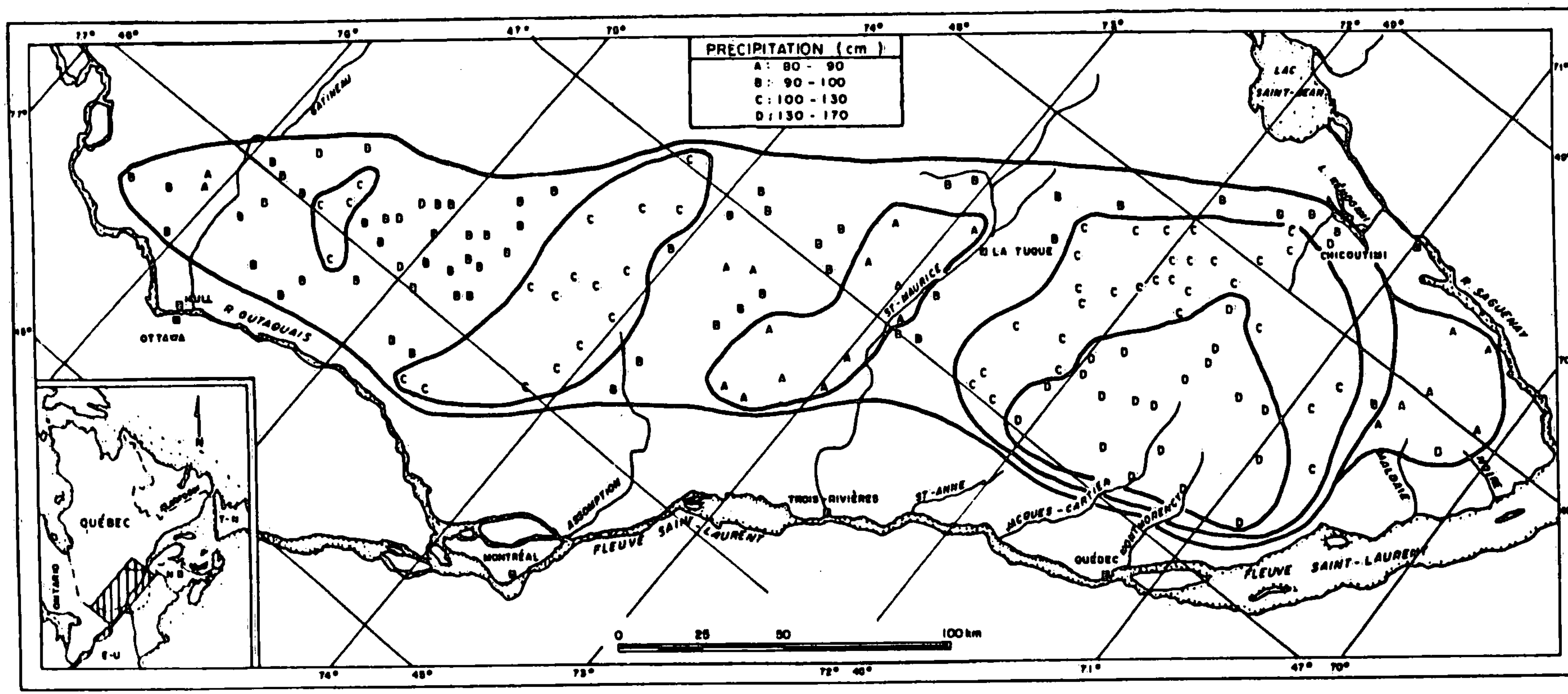


Figure 4.3: Classification of Watersheds by Mean Annual Precipitation

The relative importance (in terms of area) of each of the classes present was determined for each of the watersheds. An examination of the distribution of the units belonging to the various classes throughout the study area reveals that the units are confined to a limited number of deposit-slope-drainage combinations (Table 4.2).

By counting the various classes in this way, it becomes possible to establish the existence of a relationship between the type and thickness of the deposit and the slope, and between the type and thickness of the deposit and the drainage. In fact, for each deposit type and thickness, with the exception of sand and gravel, the following slope and drainage classes predominate:

Deposit	R	R+tD	tD/R	tD	TD		ORG
Slope	5	5	4	3	2	1	1
Drainage	1	1.2	2	2.3	4.5	5	6

The reason for the existence of a relationship of this nature is readily apparent; rock outcrops normally occur in conjunction with very steep slopes and very good drainage, while surfaces covered by thick layers of moraine or organic material are poorly drained and have gentle slopes.

Because of the low number of units of area observed for certain deposit-slope-drainage combinations, the variables were regrouped. Slope classes were reduced to three:

- gentle (G): 1 and 2
- intermediate (I): 3
- steep (S): 4 and 5

Table 4.2
Distribution of Units of Area ≥ 0.1% of the Watershed
by Type and Thickness of Deposits, Slope and Drainage

Slope	Drainage	Deposits						
		R	R+tD	tD/R	tD	TD	ORG	S+G
1	1							
	2							1
	3					1		5
	4					4		2
	5			1	6	107	1	5
	6					4	107	
2	1							
	2			1				5
	3			21	74	104		4
	4			3	32	133		3
	5				1	6		
	6							
3	1	4	4	1				
	2		4	51	117	14		5
	3			25	112	58		
	4				8	6		
	5							
	6							
4	1	2	4					2
	2	1	13	137	45			2
	3							
	4							
	5							
	6							
5	1	30	63	2				
	2		68	25				
	3							
	4							
	5							
	6							

R: rock outcrop
R+tD: rock outcrop and thin layer of moraine
tD/R: less than 0.5 m moraine over bedrock
tD: 0.5 to 1 m moraine
TD: over 1 m moraine
ORG: over 30 cm organic deposits
S+G: sand and gravel

Drainage classes as well were reduced to three:

- rapid (r): 1 and 2
- good (g): 3
- poor (p): 4, 5 and 6

With this regrouping, and the elimination of variables for which insufficient measurements (20) are available, 16 variables representing various deposit-slope-drainage combinations were selected. A list of these variables, with the number of measurements for each and the means and standard deviations of these measurements, appears in Table 4.3.

In order to make maximum use of the information collected, all the data relating to each type of deposit has been grouped independently of slope and drainage. The number of watersheds for which there are measurements, together with the mean and standard deviation of the measurements, are shown in Table 4.3. In addition, because of the small number of measurements obtained for the variable R, the data for the variables R and R+tD (Table 4.3) are grouped. The frequency distribution of the various types of surface deposits by their relative area occupied within the watershed is given in Table 4.4.

Of the 16 variables relating to the various types of deposits, slope and drainage (as given in Table 4.3) only seven variables are observed to be present in over 65% (103) of the watersheds of the study area. These variables are R+tD (S-r), tD/R (S-r), tD (I-r), tD (I-g), TD (G-g), TD (G-p) and ORG (G-p). Once again it can be seen that deposits R+tD and tD/R are characterized primarily by steep slopes and rapid drainage, while the ORG deposits are associated with gentle slopes and poor drainage. Deposits tD and TD are also characterized by given slope classes (intermediate for tD and intermediate to gentle for TD); in contrast, drainage is either rapid or good for tD and either good or poor for TD.

On examination of the relative importance of the various types of deposits, as presented in Table 4.4, one will note that rock outcrops (R) and organic deposits (ORG), when they are present, occupy a very small relative area (<10%). Deposits tD/R, tD, TD and S+G are comparable in terms of area.

Table 4.3
Number, Mean and Standard Deviation of Watershed Areas ≥ 0.1%
by Type of Deposits, Slope and Drainage

Type of Deposit[1-2]	Number of Watersheds	Mean	Standard Deviation
R (S-r)	31	4.6	5.3
R+tD (S-r)	111	14.2	11.7
tD/R (G-g)	21	3.2	3.9
tD/R (I-r)	51	8.6	6.5
tD/R (I-g)	25	5.7	7.1
tD/R (S-r)	140	18.9	11.4
tD (G-p)	35	7.2	12.1
tD (G-g)	74	6.3	7.3
tD (I-r)	117	10.7	8.2
tD (I-g)	112	13.9	11.4
tD (S-r)	45	9.6	11.1
TD (G-p)	138	12.6	9.6
TD (G-g)	104	14.3	11.2
TD (I-r)	14	8.9	6.2
TD (I-g)	58	10.4	11.1
ORG (G-p)	108	1.9	2.2
R	31	4.8	5.5
R+tD	111	14.4	12.0
R+R+tD	115	15.2	13.3
tD/R	145	22.6	12.8
tD	154	26.0	15.1
TD	147	27.1	20.8
ORG	108	1.9	2.2
S+G	8	25.5	17.2

1 For a brief description of the types of deposits, see Table 4.2

2 The letters in parentheses designate the slope and drainage

Slope		Drainage	
G	gentle	r	rapid
I	intermediate	g	good
S	steep	p	poor

Even if R is grouped with R+tD, the areas for this type of deposit are generally smaller than for the other three.

An examination of the geographical distribution of the deposits (Figure 4.4), reveals that deposits R+(R+td) and tD/R occur primarily in four zones. The first two zones, located in the northeast portion of the study area, lie within a high-altitude region (Figure 4.2). In contrast, the other two zones, which occur in the southwestern portion of the study area, correspond to the regions with the lowest altitudes ($<$300 m). This observation indicates that the thickness of unconsolidated deposits in the study area is not necessarily related to altitude but, instead, to the local morphology of relief.

4.2 Vegetation Variables

This set of variables groups the managements of the areas occupied by various types of vegetation within the watershed which are classified in two categories, depending on whether or not distinctions are included as to vegetation density. In the first category, are the following:

- coniferous forest cover (CF)
- deciduous forest cover (DF)
- mixed (MX)
- coniferous forest cover; partial cut
- deciduous forest cover; partial cut

The term "mixed" applies to the simultaneous presence of coniferous and deciduous species in proportions of from 25 to 75%. For each of these five variables, five classes of forest cover density are distinguished:

1- under 25%
2- between 25 and 40%
3- between 40 and 60%
4- between 60 and 80%
5- over 80%

Relative Area (%)	Type of Deposit							
	R	R+tD	R+R+tD	tD/R	tD	TD	ORG	S+G
< 0,1	127	47	43	13	4	11	50	150
0,1 - 10	25	53	52	25	27	36	107	2
10 - 20	6	29	31	34	31	27	1	2
20 - 30		15	17	51	37	32		2
30 - 40		7	6	25	29	17		1
40 - 50		7	7	6	19	13		1
50 - 60			1	1	8	6		
60 - 70			1	3	2	7		
70 - 80					1	6		
80 - 90						2		
90 - 100						1		

Table 4.4
Frequency Distribution of Various Types of Deposits by Relative Area Occupied Within the Watershed

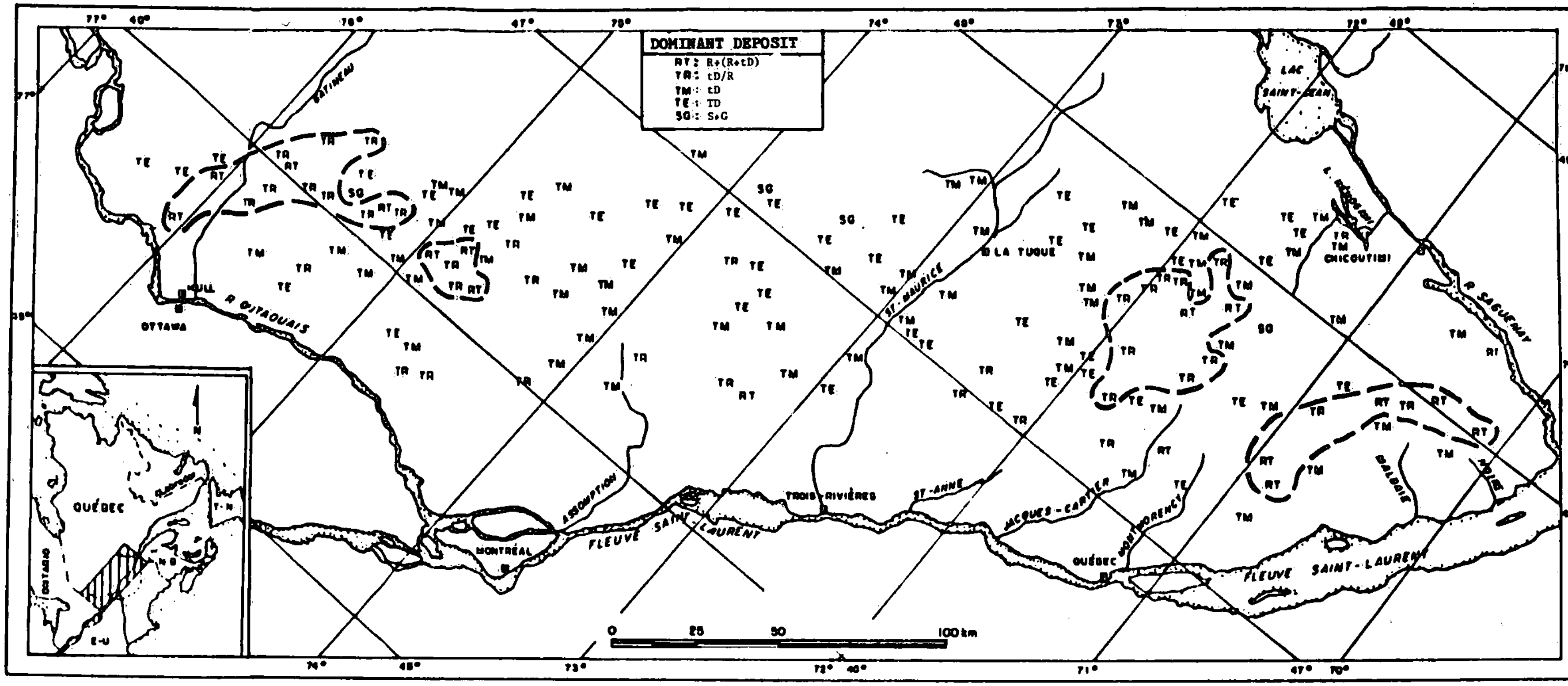


Figure 4.4: Classification of Watersheds by Dominant Deposit (Occupying the Largest Percentage Within Each Watershed)

The other variables are as follows:

- clearcut; no regeneration
- clearcut; CF regeneration
- clearcut; DF regeneration
- clearcut; MX regeneration
- bare dry
- bare wet
- tall shrubs
- low shrubs

The number of units on which these different types of vegetation are present, as presented in Table 4.5, show the relative importance of the variables considered. It is noted that the majority of the variables are present in a low number of watersheds. The only types of vegetation present to a major extent are coniferous and deciduous forest cover in densities 3 and 4 and low shrubs.

In view of the low number of units on which the different types of vegetation occur, certain variables were regrouped. For coniferous forest cover and deciduous forest cover, classes 2 and 3 and classes 4 and 5 were combined to form only two classes of density (open and dense). The partial-cut and clearcut categories were regrouped into a single variable. In addition, tall shrubs, low shrubs and bare wet areas were regrouped as wetland vegetation variables (WV). The number, mean and standard deviation of these new variables, shown in Table 4.6, and their frequency distribution in relation to relative area within the watershed (shown in Table 4.7) enabled characterization of these types of vegetation and assessment of their relative importance.

The number of watersheds in which the new groupings of types of vegetation occur is relatively high (over 60% of the watersheds), with the exception of cut area, which is lower (83) (Table 4.6). In contrast, where cutting has taken place, the area affected is generally large (averaging 32% of watershed area).

Table 4.5
Distribution of Units of Watershed Area ≥ 0.1% by
Type and Density of Vegetation

Type of Vegetation	Density of Vegetation					Total
	1	2	3	4	5	
coniferous (CF)	0	21	114	104	22	144
deciduous (DF)	2	36	108	119	45	140
mixed (MX)	0	0	2	2	1	4
CF; partial cut	0	1	5	0	0	6
DF; partial cut	0	15	18	3	0	25
clearcut, no regeneration	-	-	-	-	-	38
clearcut, CF regeneration	-	-	-	-	-	25
clearcut, DF regeneration	-	-	-	-	-	9
clearcut; MX regeneration	-	-	-	-	-	30
bare dry	-	-	-	-	-	13
bare wet	-	-	-	-	-	6
tall shrubs	-	-	-	-	-	46
low shrubs	-	-	-	-	-	96

Table 4.6
Number, Mean and Standard Deviation of Watershed Areas ≥ 0.1%
by Type of Vegetation

Type of Vegetation	Number of Watersheds	Mean	Standard Deviation
coniferous (O)	114	14.7	14.1
coniferous (O)	109	17.6	17.3
deciduous (O)	112	17.1	16.3
deciduous (D)	119	41.1	25.6
partial cut + clearcut	83	32.3	25.3
bare wet + shrubs	111	2.4	2.8

(O) density of forest cover 25 to 60%
(D) density of forest cover over 60%

Table 4.7
Frequency Distribution of Number of Watersheds by Type of Vegetation and Relative Area

Relative Area (%)	Type of Vegetation[1]					
	CF(O)	CF(D)	DF(O)	DF(D)	PCC	WV
< 0.1	44	49	46	39	75	47
0.1 - 10	60	51	50	20	22	109
10 - 20	25	19	27	13	14	1
20 - 30	11	16	15	12	11	1
30 - 40	9	11	10	11	4	0
40 - 50	6	5	3	14	12	0
50 - 60	2	4	4	13	7	0
60 - 70	1	2	2	18	3	0
70 - 80	0	0	1	12	7	0
80 - 90	0	1	0	6	2	0
90 - 100	0	0	0	0	1	0

1 (O): density of forest cover 25 to 60%
(D): density of forest cover over 60%
PCC: partial cut + clearcut
WV : tall shrubs + low shrubs + bare wet

On comparison of the mean areas occupied by each of the groupings of types of vegetation (Table 4.6), it was noted that wetland vegetation has the lowest mean area (2.4%), while dense deciduous forest cover has the highest (41.1%). In a large number of watersheds (49), the relative area occupied by dense deciduous forest cover is over 50% (Table 4.7). In contrast, in nearly all of the watersheds, the relative area occupied by wetland vegetation is under 10%.

Exclusion of cut area (PCC) and wetland vegetation (WV), reveals that dense deciduous forest cover is the dominant type of vegetation in most of the watersheds of the study area (Figure 4.5) especially in the northeastern portion, where the altitude is high and precipitation heavy.

4.3 Geological Variables

Bedrock types present in the watersheds of the study area were identified from geological reports and geological maps at various scales (Gouvernement du Québec, 1969; Avramtchev and Marcoux, 1980) and the relative area which they occupy within the watershed was also determined (Appendix A).

The various types of bedrock identified were then combined into ten groups on the basis of their resistance to weathering, sensitivity to acid loading and buffering capacity. These groups consist primarily of the following:

1- marble and calc-silicate rock
2- anorthosite, gabbro, anorthosite, metagabbro
3- diorite, pyroxene diorite, gneissic diorite
4- migmatites, biotite migmatites, gneiss-veined migmatites, paragneiss and associated granites, plagioclase migmatites, hornblende migmatites
5- paragneiss, Grenville paragneiss, paragneiss and associated igneous rocks, mixed amphibole paragneisses, mixed paragneisses
6- gneiss, intermediate gneisses, gneissic complex, graphitic gneisses, injection gneiss
7- biotite gneiss, pyroxene gneiss, amphibole gneiss, quartz gneiss, hornblende gneiss, sillimanite gneiss and garnet

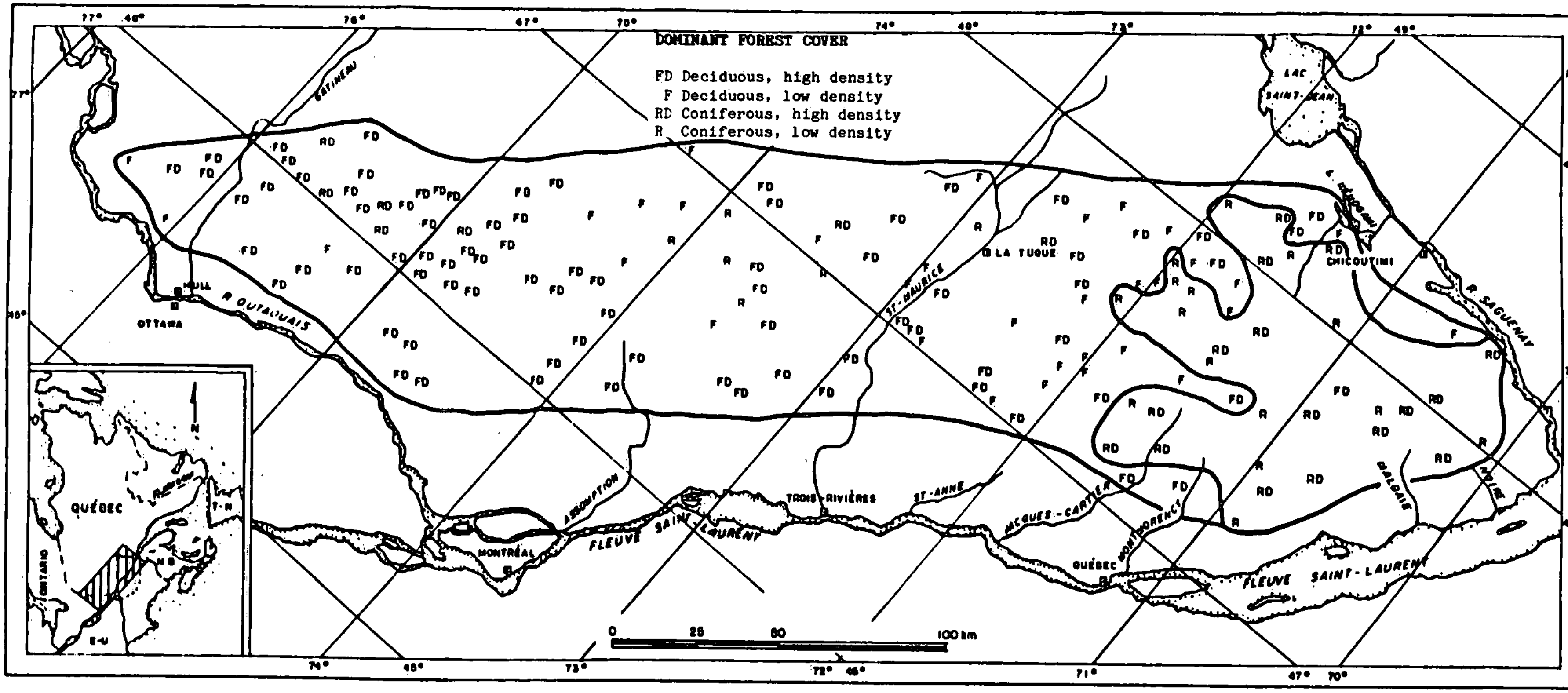


Figure 4.5: Classification of Watersheds by Dominant Type of Vegetation (Represented, in Each Watershed, by the Type of Vegetation Occupying the Highest Percentage Area)

8- mangerite, monzonite, charnockitic migmatites, charnockitic gneisses, syenite, charnockitic granulites, pyroxene monzonite
9- granite with pegmatite, granitic gneisses, granodiorite, biotite granite
10- quartzite, quartzofeldspathic paragneiss

For each of the watersheds in which are found more than one type of bedrock from different groups, an assessment of the dominant group was performed (Figure 4.6). This estimate takes into account, in part, the size of the area occupied by the bedrock (Appendix A) and, in particular, the resistance of these rocks to weathering. The higher the number of the group, the higher the resistance. The distribution of the watersheds by the predominate bedrock is as follows:

Bedrock group	1	2	3	4	5	6	7	8	9	10
Number of Watersheds	9	8	7	18	17	11	12	62	11	3

Group 8, which consists primarily of mangerite and monzonite, is found in the majority of watersheds in the study area (Figure 4.6). This group marks two principal zones, one of which, the largest, covers the entire northeastern portion of the study area, while the other covers a small area near La Tuque, on either side of the St. Maurice River.

4.4 Conclusions

- Altitude and precipitation are variables which mark clearly-defined zones within the study area. In certain sectors, these zones are superimposed, indicating that these variables are interrelated (Figure 4.2 and 4.3).

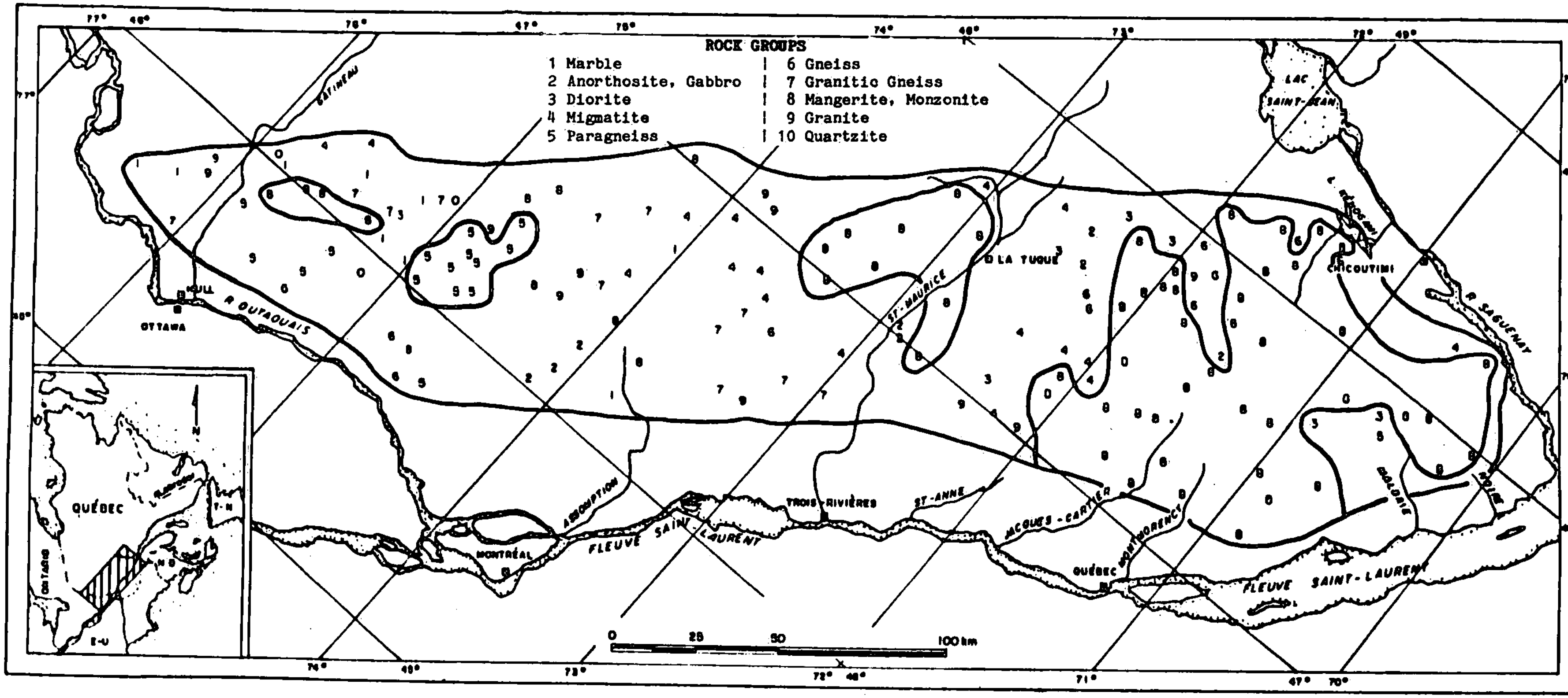


Figure 4.6: Classification of Watersheds by Ten Groups of Bedrock Types

- Unconsolidated deposits, divided into four classes on the basis of thickness (< 0.1, 0.1-0.5, 0.5-1.0, > 1.0 m), are distributed within the study area in relation to the morphology of the structural relief.

- The data in this study confirm that bare surfaces or surfaces covered by a thin layer of moraine (< 0.1 m) are generally associated with steep slopes (> 30%) and very good drainage, while surfaces covered by an appreciable layer of moraine (> 0.5 m) are generally poorly drained, with gentle slopes.

- Surfaces covered by a thin layer of moraine (R+D and tD/R) are found primarily in high-altitude zones. However, in the Ottawa Valley, where the altitude is relatively low (< 300 m), this type of deposit is dominant in a large number of watersheds.

- In the majority of the watersheds of the study area, the dominant type of vegetation consists of deciduous forest cover, with cover density of over 60%. In contrast, coniferous forest cover is dominant in the northeastern portion, where the altitude is high and precipitation heavy.

- The bedrock types found are primarily charnockitic (mangerite, monzonite, and migmatites). These are present primarily in the northeastern portion of the study area.

5. ANALYSIS OF RELATIONSHIPS BETWEEN PHYSICOCHEMICAL VARIABLES OF LAKE WATER QUALITY AND ECOLOGICAL VARIABLES

This chapter focusses on classical statistical methods (Pearson correlation, Spearman correlation, principal component analysis) to identify and interpret the relationships between each of the physicochemical variables measured in water (pH, conductivity, concentration of major ions, concentration of metals, colour) and each of the physiographic variables (altitude, lake or watershed area, ratio of watershed area/lake area), variables relating to the nature and thickness of unconsolidated deposits (type of deposit, slope, drainage) and vegetation variables (coniferous or deciduous forest cover, cut area, shrubs).

5.1 Methods used

In order to identify possible relationships between physicochemical variables and ecological variables, the Pearson and Spearman correlation coefficients for each pair of variables were calculated and examined as to the significance levels. Appendix B contains a brief description of the formulae used to calculate these coefficients and their significance tests. It should be noted that, when parameter values do not have a normal distribution, the Spearman non-parametric correlation coefficient generally gives better results than the Pearson parametric coefficient, since the Spearman coefficient is calculated on the basis of rank order. Simultaneous calculation of these two types of correlation facilitates the search for possible relationships between pairs of parameters, without requiring continual verification of distribution normality.

In order to synthesize the interrelations between variables, the principal component analysis method was used and applied to the matrix of Spearman correlation coefficients. This method makes it possible to summarize, in reduced space, the greater part of the variability of a dispersion matrix of a large number of descriptors and thus to determine the amount of variance explained by the first main axes (Legendre and Legendre, 1979).

In order to permit more objective and systematic examination of the proximities between the variable points within the factorial space, the cluster analysis (CA) method was used as developed by Jambu (1978). This method makes it possible to group the points in classes automatically and on the basis of selected aggregation criteria, and to organize the groups of points in a way which will permit visualization of the classification hierarchy.

For physicochemical data, 16 variables were selected: pH, Ca, Mg, Na, K, alkalinity, SO_4, Cl, NO_3, Al, Mn, Fe, colour, conductivity, total cations, and total anions. The following 19 variables were selected as ecological variables: altitude, watershed area, lake area, bog area, precipitation, ratio of watershed area/lake area, lake orientation in relation to the SW-NE axis and to the NW-SE axis, area of deposits R+(R+tD), tD/R, tD, TD and ORG, areas of open or dense coniferous forest cover, open or dense deciduous forest cover, cut area (partial and clearcut) and area of wetland vegetation (WV).

In order to determine whether slope or drainage are important variables with respect to deposits, a second correlation analysis was performed between a group of physicochemical variables consisting of total cations, pH, H^+ ions, alkalinity, sulphates, aluminium, manganese, iron, colour, and the group of deposit variables for various slope and drainage classes.

5.2 Identification of Relationships

Pearson and Spearman correlation coefficients were calculated between physicochemical variables and deposit variables for various slope or drainage classes. Examination of the correlation coefficients significantly different from zero, presented in Table 5.1, shows that few relationships are observed between the physicochemical variables and the variables relating to deposits. The most obvious relationships are those involving colour and certain types of deposits. Colour is negatively correlated with R + tD (S-r), tD/R (S-r) and tD (I-r), and positively with TD (G-p) and TD (G-g). This relationship indicates that the variation in colour is dependent on the presence of thick morainal deposits, while drainage and slope factors have less influence. As regards the relationships observed between the other physicochemical variables and the deposit variables, they are generally limited to a single type of correlation (Pearson or Spearman) and are relatively weak. The absence of obvious relationships between these two groups of variables shows that the distinction of different slope or drainage classes does not improve the relationships. It must therefore be concluded that, in analysing the correlations between variables, it is preferable to group the data by type of deposit, with no distinction as to slope or drainage.

Analysis of the correlations between the 19 ecological variables and the 16 physicochemical variables defined above (Section 5.1), permits the

Table 5.1

Correlation Coefficients Significantly Different From Zero (5% Level) Between Various Types of Deposits and Physicochemical Variables

Deposit Variable[1]	Physicochemical Variable									
	No.	Total	pH	H^+	Alk	SO_4	Al	Mn	Fe	Colour
R (S-r)	31	2						0.35		
R+tD (S-r)	111			0.19			0.18			-0.26
							0.16			-0.26
tD/R (G-g)	21									
tD/R (I-r)	51									
tD/R (I-g)	25									
			0.36	-0.36	0.35					
tD/R (S-r)	140								-0.22	-0.22
		0.15							-0.19	-0.18
tD (G-p)	35									
tD (G-g)	74									
tD (I-r)	117									-0.19
										-0.20
tD (I-g)	112	-0.16								
tD (S-r)	45									
TD (G-p)	138		-0.15							0.44
									0.18	0.39
TD (G-p)	104						0.18			0.33
							0.16			0.27
TD (I-r)	14	-0.56								
TD (I-g)	58									

[1] For identification of deposits, see Table 4.2.
The letters in parentheses designate slope and drainage (see Table 4.3).

[2] Upper line of each box - Pearson correlation
Lower line of each box - Spearman correlation

identification of relationships between specific environmental characteristics and water quality. Examination of the Pearson and Spearman correlations between these two groups of variables, presented in Table 5.2, reveals that, of the ecological variables considered, altitude, precipitation, and orientation in relation to the SW-NE axis are those most strongly linked to the largest number of physicochemical variables. These variables are negatively correlated to Ca, Mg, K, alkalinity, SO_4, Cl and hence to total cations, total anions and conductivity; they are positively correlated to H^+, NO_3, Al and Fe.

It should be noted that the observation of a correlation between two variables does not necessarily indicate a cause and effect relationship between these two variables. Altitude and precipitation may explain some variations in lake water mineralization. On the other hand, the observed correlation between mineralization and orientation in relation to the SW-NE axis may be explained by other factors, including variations in geological structure, relief, and precipitation.

The other physiographic variables, including watershed area, lake area, bog area, and ratio of watershed area/lake area, are not correlated to the mineralization variables, but rather to such variables as colour, iron, aluminium and manganese.

The physical variables describing the type of deposit do not appear to be correlated to the mineralization variables, with the exception of thin moraine over bedrock (tD/R), in which are observed Spearman correlation coefficients significantly different from zero. In fact, with the exception of tD, these variables are correlated primarily with colour, iron and, to a certain point, manganese. Colour and iron increase when the area of thick moraine (TD) or organic deposits (ORG) increases, and decreases when the area of bedrock and thin moraine (R+(R+tD) and tD/R) increases. It thus appears that colour and iron are the only physicochemical variables, of those considered, which may be correlated to mineral level and water contact time within the watershed.

The absence of observed relationships between mineralization and type of deposits may seem difficult to explain at first. Mineralization would be

Table 5.2
Correlation Coefficients Significantly Different from Zero (5% Level) Between Physiocochemical Variables and Ecological Variables

Ecological Variable	Physicochemical Variable														
	Total Cations	Total Anions	Conductivity	H^+	Ca	Mg	Na	K	Alk	SO_4	Cl	NO_3	Al	Mn	Fe
altitude	-0.46 -0.62	-0.45 [1] -0.60	-0.34 -0.38	0.26 0.53	-0.45 -0.62	-0.44 -0.62		-0.37 -0.36	-0.40 -0.52	-0.50 -0.57	-0.25 -0.29	0.22 0.24	0.39 0.46		0.19 0.28
watershed area				0.17	-0.13		0.14					0.20 0.30	0.33 0.18		0.23 0.15
lake area											-0.24 -0.24		-0.18	-0.17 -0.16	
bog area			-0.15	0.18									0.14 0.15	0.14 0.17	0.23 0.28
precipitation	-0.30 -0.40	-0.29 -0.38	-0.20 -0.14	0.28 0.33	-0.29 -0.42	-0.33 -0.45		-0.14	-0.28 -0.32	-0.29 -0.29	-0.26 -0.23	0.32 0.26	0.41 0.35		0.21 0.28
WA/LA				0.29 0.14			0.25	-0.14			0.28 0.24	0.24 0.41	0.53 0.44	0.34 0.23	0.30 0.33
SW, NE	-0.50 -0.46	-0.50 -0.48	-0.27 -0.15	0.19 0.39	-0.49 -0.46	-0.53 -0.57	0.15 0.16	-0.25 -0.23	-0.40 -0.33	-0.74 -0.80	-0.41 -0.42	0.25 0.28	0.32 0.44	-0.18	0.14 0.16
NW, SE	0.28 0.35	0.27 0.33	0.30 0.35	-0.21 -0.27	0.25 0.33	0.29 0.32	0.29 0.29	0.37 0.41	0.31 0.38			-0.18	-0.31 -0.26		
R + (R+tD)													0.17	-0.14	
tD/R	0.22	0.22	0.14 0.28	-0.22	-0.22	0.14 0.17	0.16		0.17	0.15 0.15			0.24 0.17		-0.21 -0.19
tD								-0.15 -0.16							
TD														0.19 0.21	0.20 0.28
ORG			-0.16 -0.18	0.16							0.16 0.14			0.15 0.15	0.15 0.25
CF(0)	-0.25 -0.27	-0.26 -0.29	-0.16	-0.16 0.34	-0.24 -0.28	-0.26 -0.30		-0.15	-0.23 -0.26	-0.27 -0.28			0.24 0.27		0.22
CF(D)			0.15							-0.18		0.18	0.14	-0.14 -0.20	
DF(0)	-0.16	-0.18 -0.13		0.16	-0.16	-0.23 -0.19			-0.15	-0.19 -0.16	-0.30 0.33				
DF(0)	-0.40 -0.45	-0.40 -0.45	-0.26 -0.23	0.26 0.49	-0.39	-0.44 -0.48			-0.35 0.38	-0.44 0.47	-0.32 0.29	0.22 0.29	0.33 0.44		0.18 0.28
PC + CC	-0.21 0.28	-0.20 -0.27	-0.15	0.34	-0.22	-0.20 -0.27	0.14		-0.20 0.25	-0.17 -0.26		0.16 0.21	-0.29 0.39	0.20	0.30 0.32
WV											0.14			0.18	0.15 0.23

1
- Pearson correlation
- Spearman correlation

expected to increase in regions covered by a thick layer of moraine (associated with gentle slopes and poor drainage) because of the abundance of minerals and longer contact time. This should promote mineral exchange. Also, the inverse phenomenon would be expected to occur in watersheds with extensive areas of barren outcrops or rock covered by a thin layer of moraine (associated with steep slopes and good drainage). An explanation might be that the effects cause by the variations in deposits are masked by other, more significant effects relating to either geological or physiographical factors. The watersheds, in which are found outcrops or rock covered by a thin layer of moraine, can be divided essentially between two major zones (located in the northeastern and southwestern portions of the study area). Here, the altitude, precipitation and geology are very different (Figure 4.2, 4.3 and 4.4). This heterogeneity in the distribution of deposits may be responsible for the absence of relationships between mineralization and deposit type.

Of the group of variables describing vegetation types, dense deciduous forest cover (DF(D)), open coniferous forest cover (CF(O)), and cut area (PC+CC) are the three most clearly correlated to mineralization variables. These mineralization variables are correlated positively with DF(D) and negatively with CF(O) and PC+CC.

As regards the H^+ variable, it is noted that pH increases with increases in the area of dense deciduous forest cover (DF(D)) and when there is an increase in the area of open coniferous forest cover (CF(O)) of cut area (PC+CC). These correlations thus indicate a link between pH and type of vegetation, dense deciduous forest cover being associated with high-pH waters and open coniferous forest cover (density 25 to 60%) with low-pH waters.

5.3 General Analysis of Interrelationships

The matrix of Spearman correlation coefficients, calculated on the basis of the data obtained for the 35 variables considered (19 ecological and 16 physicochemical variables), is the dispersion matrix to which is applied principal component analysis (PCA). With this method, the total variability of the data expressed by the correlation matrix is redistributed in descending order over a smaller number of orthogonal factors, thus making it possible to represent the interrelations between the variables more simply. As a result of the transformation obtained, the variables are represented by points in a new system of orthogonal axes in which the distance between the points is indicative of the intensity of the relationship. Proximity between two points indicates a positive correlation between the variables, while distance may be interpreted as a negative correlation of the absence of a relationship.

The variability explained on the first main axes is as follows:

	1	2	3	4	5	6	7	8
Explained Variability (%)	27.0	12.7	8.9	7.8	6.2	4.6	3.7	3.7
Cumulative Explained Variability (%)	27.0	39.7	48.6	56.4	62.6	67.2	70.9	74.6

Representation of the variable points in the plane of main axes 1 and 2 (Figure 5.1), with 39.7% explained variability, makes it possible to express the general trends. On axis 1, an opposition is observed between, on the one hand, the group consisting of the following variables: Ca, Mg, K, SO_4, alkalinity, total cations, total anions, conductivity, and dense deciduous forest cover, and, on the other, the group consisting of H^+, altitude, precipitation, and SW-NE position. Axis 1 thus expresses the mineralization of the lakes and the environmental factors related to this mineralization. At one end of Axis 2, colour and relative areas of bog, organic deposits, wetland vegetation (WV), and thick moraine are found; at the other extremity of the axis, are noted points representing the areas of bedrock and bedrock + thin moraine (R+(R+td)) and thin moraine over rock (tD/R). Water colour and the environmental factors relating to the presence of organic substances are thus explained by axis 2.

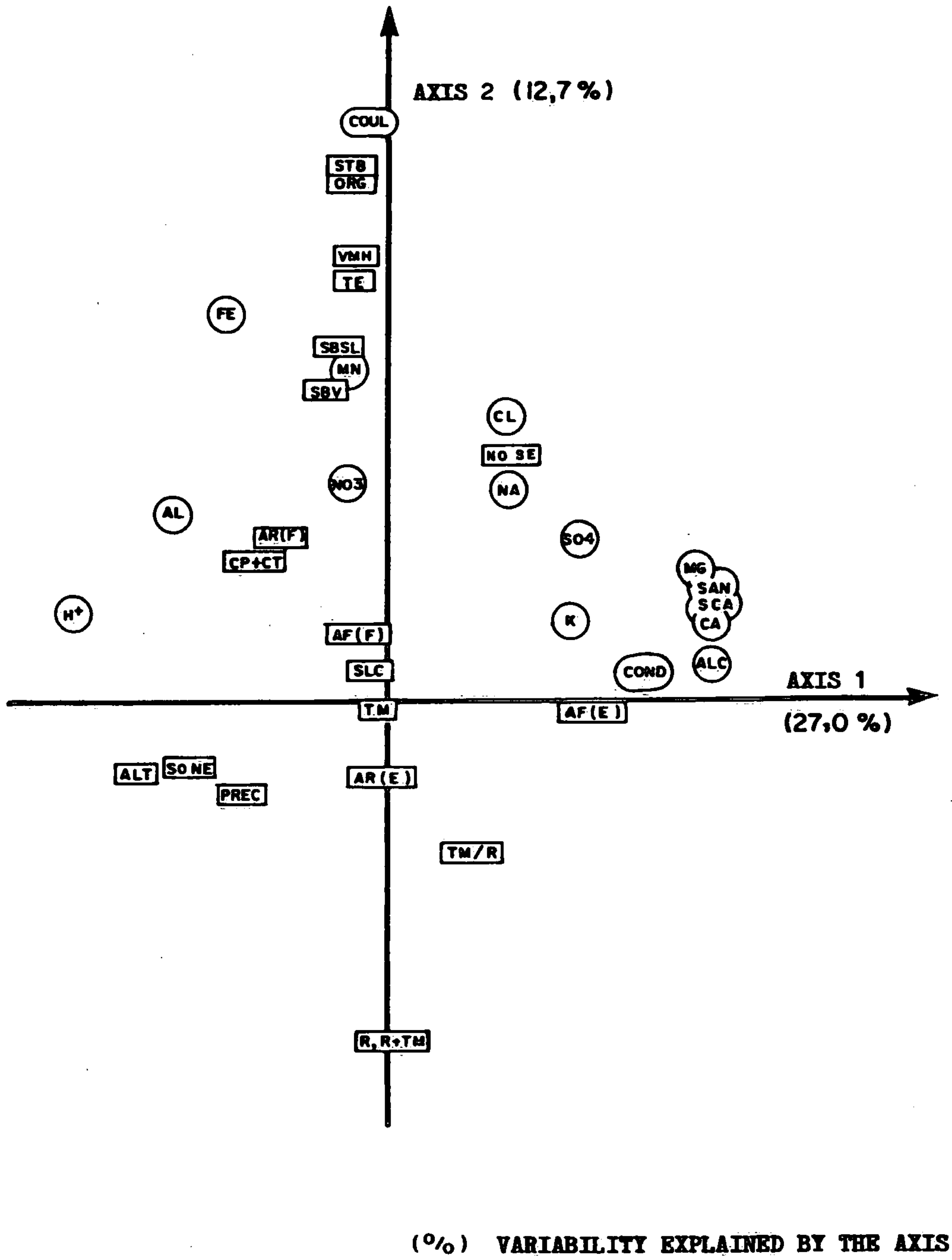


Figure 5.1: Representation in the Plane of Axes 1 and 2 of the Factors of Variables Obtained by Principal Component Analysis (PCA) Applied to the Matrix of Spearman Correlation Coefficients

In order to examine the proximities between the variable points systematically and objectively, cluster analysis was applied to the coordinates of the variable points on the first eight factorial axes. In this way, was obtained a classification of the variable points in eight groups; a hierarchical branching diagram is shown in Figure 5.2 and the composition of the eight groups of variable points is defined in Table 5.3.

If one looks at the projections of the points on the first eight factorial axes, a grouping of points is obtained which is different from that obtained by considering their projection in the plane of the first two main axes. By considering eight factorial axes, a higher proportion of the total variance, or 74.6%, is accounted for. The true distances between points is more accurately calculated. In selecting the number of factorial axes to be considered, however, the inclusion of non-significant axes may complicate the interpretations by introducing a certain amount of background noise.

By grouping the closest points, it becomes easier to identify positively-correlated variables. For example, the composition of group A indicates that the mineralization variables (Ca, Mg, K, Na, alkalinity, conductivity, total cations, total anions) and position in relation to the SW-NE axis are interrelated. The observed correlation with the latter variable appears to indicate that lake mineralization increases with distance from the St. Lawrence River. However, this relation may be skewed by a heterogeneous mixture, along this axis, of the slightly mineralized lakes in the northeastern portion with the highly mineralized lakes in the southwest.

It is noted that H^+ is grouped with Al, Mn, Fe, colour, PC + CC and TD. The presence of H^+ in this group is difficult to explain if one examines the position of point H^+, in relation to the other points, in the plane of the first two main axes (Figure 5.1). The grouping performed by CA reflects the distances calculated from projections on eight factorial axes. The projection of the points in a plane does not accurately reflect the true distances. The distance of the H^+ group from the centre of gravity of this cloud of points is less than that separating it from the centre of gravity of any other cloud of points. The H^+ group should thus be interpreted as a similarity of variations with a set of variables, H^+ being more closely related to Al and

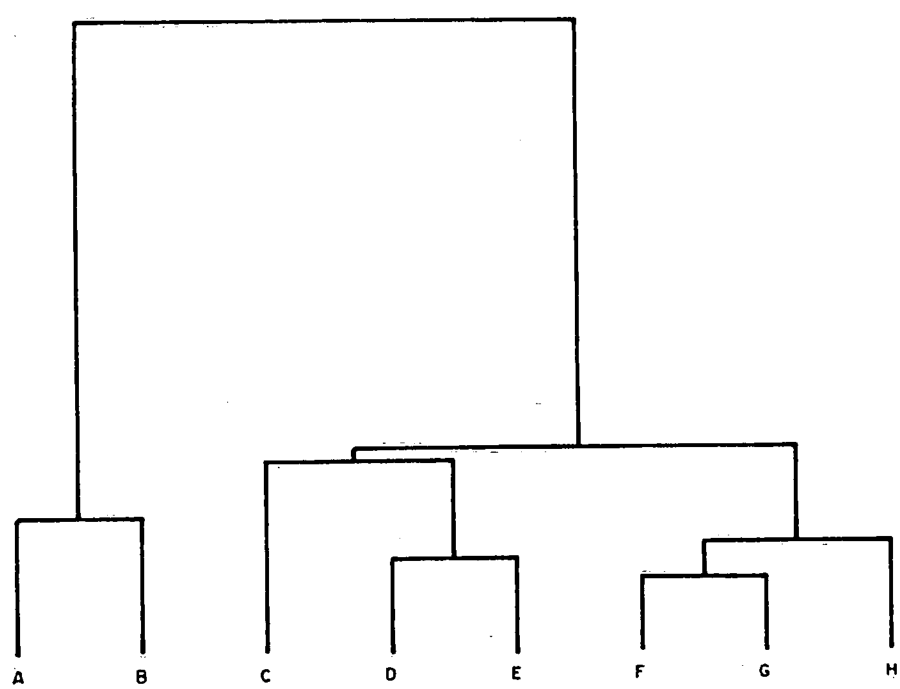
Table 5.3

Composition of the Eight Groups of Variable Points Obtained by Application of CA to PCA Factors

Group	Composition
A	conductivity, total cations, total anions, Ca, Mg, Na, K, alkalinity, NW-SE
B	SO_4, Cl, DF(D)
C	Al, Mn, Fe, colour, H^+, PC+CC, TD
D	ORG, bog area, WV
E	Watershed area, lake area
F	altitude, precipitation, CF(D), SW-NE
G	WA/LA, tD, NO_3, CF(O), DF(O)
H	tD/R, R + (R+tD)

Figure 5.2

Clustering of the Factors of Variables Obtained by PCA Applied to the Matrix of Spearman Correlation Coefficients



PC+CC than to Mn, Fe, TD and colour. The observed relations with the presence of cut area and thick moraine are difficult to interpret.

The data relating to cut area may be unreliable, since they refer to areas logged to varying extents over a relatively long period of time (greater than 10 years). The presence of TD in this group is much more the result of this variable's correlation with colour, manganese and iron than with the H^+ ion (Table 5.2).

Examination of the composition of each of the groups reveals certain correlations noted previously between ecological variables and physicochemical variables. For example, close relationship exists between the relative area of bogs, organic deposits, and wetland vegetation. Altitude, precipitation, and area of dense coniferous forest cover are well defined in relation to the SW-NE axis. The composition of group G shows that the ratio of WA/LA, open deciduous forest cover, open coniferous forest cover, thin moraine, and nitrates are interrelated. The presence of thin moraine over bedrock (tD/R) is also associated with the presence of bedrock and bedrock + thin moraine (R+(R+tD)).

On moving to a higher level in the classification hierarchy and considering a smaller number of groups (four, for example), one can identify other interrelationships between lower-level variables. By combining groups F, G and H, one observes a relationship between the deposits of thin moraine (tD, tD/R, R+(R+tD)), coniferous forest cover (O or D), open deciduous forest cover, altitude, precipitation, the ratio of WA/LA, position in relation to the SW/NE axis, and nitrates. In addition, by combining groups D and E, it is noted that watershed and lake area are correlated primarily to the presence of organic deposits, bogs and wetland vegetation. The composition of groups A and B shows that dense deciduous forest cover and position in relation to the NW-SE axis (distance from the St. Lawrence River) are physiographical variables most closely related to water mineralization variables.

It has been noted that, in this type of factorial representation, proximity between two points could be interpreted as an indication of the presence of a positive correlation between these two variables. In contrast, a negative correlation or absence of correlation between the two variables is reflected by distance between the two points representing these variables.

To identify the groups of negatively interrelated variables, first were calculated the distances between the centres of the groups and noted the groups of points farthest apart from one another. The greatest intergroup distances are obtained for A-F, B-F, D-H and E-H. The opposition on axis 1 between group F and groups A and B (Figure 5.1) indicates that the variables of group F (altitude, precipitation, NW-SE position, dense coniferous forest cover) are inversely correlated to mineralization variables (Ca, Mg, Na, K, alkalinity, conductivity, total cations, total anions). This indication is consistent with the observation noted in the table of correlation coefficients between variables (Table 5.2). It is also deduced that the variables of group H (tD/R, R+(R+tD)) are inversely correlated to the variables of group D (ORG, bog area, WV) and E (WA, LA), from their opposition on axis 2 (Figure 5.1).

5.4 Conclusion

In summary, analysis of the interrelations between variables through the combined use of principal component analysis and cluster analysis has enabled identification of the principal correlations between ecological variables and water quality variables. These correlations include:

- The area of thick moraine associated with the variables relating to the presence of organic materials (bogs, organic deposits, wetlands vegetation) is positively related to colour, manganese and iron.

- The variables describing the classes of deposit thickness show a slight relation to lake mineralization and pH.

- The ecological variables most closely related to lake mineralization and pH are altitude, precipitation, SW-NE position, area of open coniferous forest cover, area of dense deciduous forest cover, and cut area. Mineralization and pH increase as altitude, precipitation, cut area, and area of open coniferous forest cover decrease and as area of dense deciduous forest cover increases; this increase in mineralization follows a NE-SW gradient.

° Sulphate concentrations in the lakes vary inversely with altitude, precipitation and SW-NE position and indirectly with the rate of mineralization. The data do not yet enable distinguishing the importance of the influence of the ecological variables (altitude and precipitation) and geological variables as compared to distance from sulphate sources (SW-NE position).

° The data collected do not enable identification, for a given type of deposit, the possible effect of slope and drainage on the rate of lake mineralization and on watershed neutralization capacity.

6. RELATIONSHIPS BETWEEN GEOLOGICAL VARIABLES AND PHYSICOCHEMICAL VARIABLES

The analyses performed in the preceding chapter enabled identification of a number of correlations between the physicochemical variables measured in the water of the lakes and the ecological variables measured in the watersheds. The statistical methods used (Spearman correlations, principal component analysis) were appropriate to the type of data available. However, the geological data collected in these study could not be included in the preceding analysis because of their qualitative nature. In this chapter, discriminant analysis is used to examine the possible correlations between geological variables of the environment and the physicochemical variables of lake water quality.

6.1 Methods Used

Discriminant analysis is a statistical technique which makes it possible to separate known groups of objects on the basis of a series of measurements for the purpose of describing and interpreting the adherence of each element to different groups (Legendre and Legendre, 1979). Involved in this case are five groups of bedrock types established on the basis of the ten groups previously established in Section 4.3. These groups consist primarily of the following bedrock types:

- group 1: marble and calc-silicate rock (group 1)
- group 2: anorthosite, gabbro (group 2) and diorite (group 3)
- group 3: migmatites (group 4), paragneiss (group 5), gneiss (group 6) and granitic gneiss (group 7)
- group 4: mangerite and monzonite (group 8)
- group 5: granite (group 9) and quartzite (group 10)

The new distribution of the watersheds and description of the location of these groups in the study area are given in the following:

Watershed Group	1	2	3	4	5
Number of Watersheds	9	15	58	62	14

Group 3, which includes the migmatites, paragneisses and gneisses, is now comparable in size to group 4. These two groups occur in 76% (120) of the watersheds. The geographical distribution of the five groups of bedrock types, presented in Figure 6.1, shows that groups 3 and 4 mark well-defined zones. Group 3 occurs primarily in four zones: the first (A) is located west of the Rouge River, on a level with St. Jovite; the second (B) lies west and northwest of the Matawin Reservoir; the third (C) is located in an area extending east of the Assomption River as far as the St. Maurice Valley; while the last (D), which is smaller, is located west of Laurentide Park. Group 4 consists primarily of two zones, the larger of which covers the entire northeastern portion of the study area, while the smaller covers an area west of La Tuque.

The measurements used to discriminate between the lakes are physicochemical variables most likely to be closely correlated to the

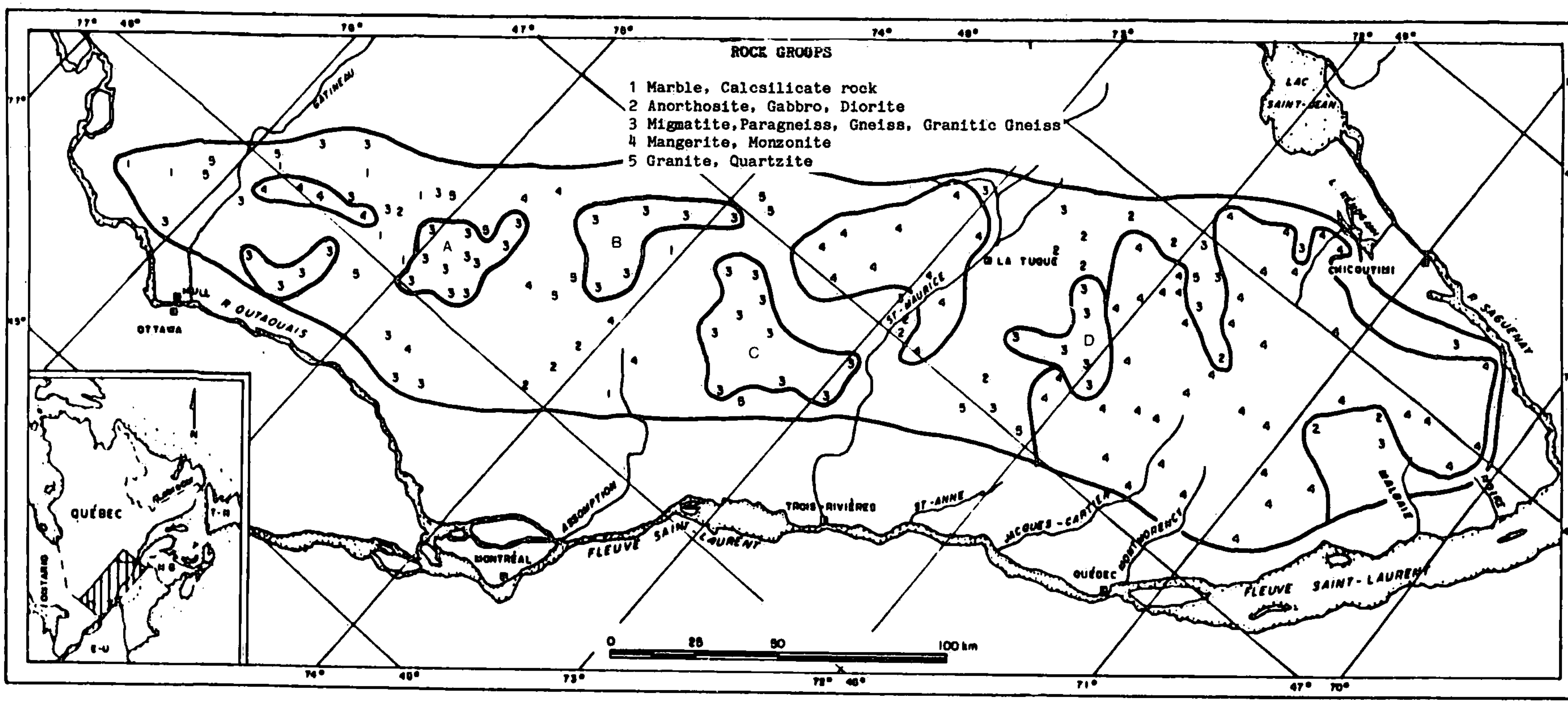


Figure 6.1: Classification of Watersheds by Five Groups of Bedrock Types

mineralogical composition of bedrock. These variables are calcium, magnesium, sodium, potassium, H^+ ions, sulphates, aluminium, manganese, and iron.

The method consists of finding linear combinations of discriminating descriptors (or "functions"), which maximize the difference between the groups and minimize the variability within each group (Legendre and Legendre, 1979). This involves locating values and vectors of the matrix which describe the ratio of intergroup dispersion to intragroup dispersion. In this way a representation is obtained of the objects in which the first canonical axis indicates the direction of greatest variability between the centroids of the groups, and so forth for the successive canonical axes.

A useful test in discriminant analysis is Wilks' lambda, which makes it possible to determine whether the groups show significant differences in terms of the position of their centroids. The more discriminating a variable is for analysis, the lower the value of lambda. A Fisher test is then applied to the lambda values to determine the level of significance of a descriptor as a discriminant variable.

The coefficients of these discriminant functions express the relative contribution of variables to the discriminant function. A physical sense may then be attributed to the canonical axes on the basis of the high values of the coefficients. However, it is often preferable to use the level of correlation between the variable and the discriminant function to interpret the canonical axes.

Classification coefficients are calculated for each of the groups on the basis of the coordinates of the objects in the canonical space. These coefficients are then converted into probabilities of adherence to a given group. The calculation program used is drawn from the SPSS package (Nie et al, 1975). In this program, an object is classified in the group to which it has the highest probability of adherence. For each of the objects, one can thus compare the predicted adherence with the actual adherence to a group. This comparison enables verification of the success rate of the discriminant variables in classifying objects in a certain number of groups.

6.2 Results of Discriminant Analysis

Discriminant analysis was applied to data obtained on all lakes in the study area for the nine physicochemical variables listed in the Section 6.1. The data relating to lakes 17, 26, 27 and 29, which are located in the Ottawa Valley, were eliminated from the analysis; preliminary examination indicated that the extremely high calcium and magnesium levels for these lakes might skew the results of the analysis. In addition, these four lakes were considered by Bobée et al (1983) as non-representative of zone 5. In the data, it is noted that manganese values are missing for lakes 98, 99 and 105, and aluminium, manganese and iron values for lake 73. Since the method requires a complete table of data, it was considered preferable to replace these missing values with the mean for the variable rather than to exclude these four lakes.

Application of discriminant analysis with the five geological groups produced four discriminant functions explaining 60.3%, 29.2%, 8.4% and 2.1% respectively of the total variability. Only the first two functions, with 89.5% of the total variability, were retained for interpretation, the Wilks' lambda test having shown that the other two functions are not significant. The coefficients of these two discriminant functions are presented in Table 6.1.

The two discriminant functions are interpreted by first determining the most discriminating variables. The Fisher test performed by means of the Wilks' lambda calculation (Table 6.1) shows that the most discriminating variables for the five geological groups are calcium, magnesium, potassium, sulphates, aluminium and, to a lesser degree, hydrogen ions.

The coefficients of the discriminant functions presenting the highest values are generally associated with the variables identified by the Wilks' test as the most discriminating. However, the non-significant variables (sodium, iron and manganese) occasionally present high coefficients, particularly on function 2. Since these high coefficients are sometimes difficult to interpret, it is best to refer to the level of correlation between the variables and the discriminant functions (Table 6.1). The

Table 6.1

Results of Discriminant Analysis: Wilks' Lambda for Each of the Variables, Correlation Between the Variable and the Discriminant Function and Coefficients of the Discriminant Function

Variables	Wilks' Lambda	Correlation Between the Variable and the Discriminant Function		Coefficients of the Discriminant Function	
		Function 1	Function 2	Function 1	Function 2
Ca	0.84**	0.51	0.49	-0.11	1.05
Mg	0.90**	0.45	0.14	-0.23	-0.27
Na	0.97	0.07	-0.29	-0.05	-0.71
K	0.84**	0.57	0.32	0.71	0.23
H^+	0.92*	-0.27	0.00	0.48	-0.44
SO4	0.86**	0.54	0.20	0.65	-0.15
Al	0.85**	-0.52	0.26	-1.07	0.94
Mn	0.99	-0.00	-0.04	0.24	-0.44
Fe	0.97	-0.20	0.02	0.08	0.29

Result of Fisher test:

* level of discrimination significant below the 5% confidence level

** level of discrimination significant below the 1% confidence level

Table 6.2
Results of the Classification Obtained by Discriminant Analysis

Geological Groups	Number of Lakes per Group	Number of Lakes Classified in the Predicted Group				
		1	2	3	4	5
1	6	4 (66.7)	0 (0)	1 (16.7)	1 (16.7)	0 (0)
2	15	0 (0)	8 (53.3)	4 (26.7)	3 (20.0)	0 (0)
3	57	3 (5.3)	10 (17.5)	27 (47.4)	5 (8.8)	12 (21.1)
4	62	0 (0)	15 (24.2)	4 (6.5)	39 (62.9)	4 (6.5)
5	14	1 (7.1)	3 (21.4)	1 (7.1)	2 (14.3)	7 (50.0)

( ) Percentage of the number of lakes classified in the predicted group

Percentage of all lakes correctly classified: 55.19

correlation coefficients calculated between the variables and the functions enable interpretation and attribution of a physical sense to the discriminant functions. For example, by retaining only those correlation coefficients greater than 0.25, it is noted that function 1 enables separation of the watersheds by ascending values of calcium, magnesium, potassium, and sulphates and by descending values of aluminium and hydrogen ions. Function 2 permits further discrimination on the basis of ascending values of calcium, potassium and aluminium.

The 154 watersheds may be represented in the canonical space defined by the two discriminant functions. When the surfaces defined by the geological groups overlap (as is the case here), it is preferable, for purposes of interpretation, to represent only the centroids of the groups (Figure 6.2) and to indicate the distribution of the watersheds by their geological group for each of the adherence surfaces. It is noted that the centroids of groups 3 and 5 are very close to one another and distant from the centroids of groups 2 and 4 on axis 1. Group 1 is distinguished from the other groups by its extreme position on axis 2.

The lakes in groups 1 (marble, calc-silicate rock), 3 (migmatites, paragneiss, gneiss and granitic gneisses), and 5 (granite and quartzite) are characterized by high calcium, magnesium, potassium, and sulphate levels and low aluminium and H^+ levels. The lakes in groups 2 (anorthosite, gabbro, and diorite) and 4 (mangerite and monzonite), in contrast, are characterized by low calcium, magnesium, potassium and sulphate levels and high aluminium and H^+ ion levels. The lakes in groups 3 and 5 show very similar characteristics; however, the lakes in group 1 are clearly distinguished from the lakes in groups 3 and 5 by their much higher calcium levels. Group 4 is distinguished from group 2 by higher aluminium and potassium levels.

A comparison of actual adherence in the geological groups with the adherence predicted on the basis of discriminant analysis, reveals that 55% of the lakes are classified identically (Table 6.2). It should be noted that the discriminant analysis is based solely on the dominant bedrock type in each watershed (Figure 6.1). The non-dominant bedrock may weather more readily than the dominant bedrock type used to classify the watersheds. This

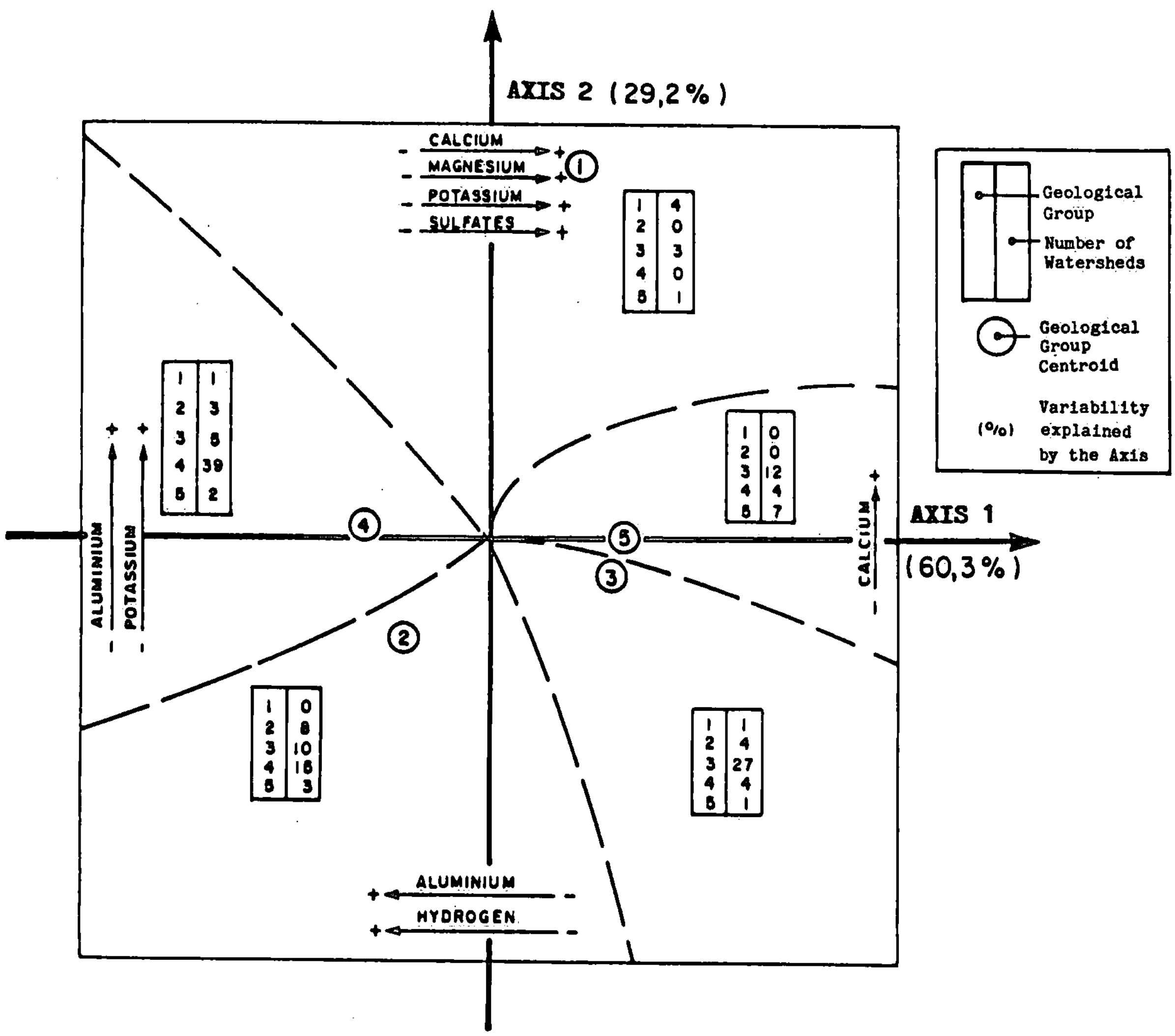


Figure 6.2: Representation in Canonical Space of Centroids of Watersheds Groups and Distribution of Watersheds by Geological Group for Each of the Adherence Surfaces

possibility may thus explain, the observed difference between predicted and observed adherence. The level of agreement obtained by discriminant analysis reflects the influence of geology on the chemical composition of the lake water closely, despite the great heterogeneity of the dominant bedrock in the study area (Appendix A) and despite the choice of dominant bedrock type in each watershed (which was based on the area occupied and the resistance of the bedrock to weathering).

6.3 Conclusions

° A significant proportion of the chemical composition of lake waters can be explained by the geology of the bedrock in each watershed. Discriminant analysis of the physicochemical data, following an initial classification of the lakes into five groups on the basis of geological characteristics, indicates that 55% of the lakes fall within this classification.

° The physicochemical variables showing the highest degree of discrimination are calcium, magnesium, potassium, sulphates, aluminium and H^+ ions.

° The presence of sulphate as a major discriminating variable can be interpreted as the result of computer-based classification of the variables and can be explained in two ways by:

- possible sulphate input from certain rock types (such as pyrite, chalcopyrite, and metallic sulphides) even in very small quantities;

- a SW-NE gradient of atmospheric sulphate inputs, associated with the mineralization gradient already observed in this direction (Section 5.3). The effect of this variable may be amplified by a coincidence between sulphate concentration values and values related to mineralization.

° The lakes of group 1 (marble, calc-silicate rock), 3 (migmatites, paragneiss and granitic gneisses), and 5 (granite and quartzite) are distinguished from the lakes of groups 2 (anorthosite, gabbro, diorite) and 4 (mangerite and monzonite) by their higher calcium, magnesium, potassium, and sulphate levels and lower aluminium and H^+ ion levels. Do the granites and the quartzites generate higher Ca, Mg and SO_4 levels than the anorthosites, gabbros and diorites? This appears to contradict bedrock mapping in Shilts (1981) and may be explained by the presence of two or more types of bedrock (Appendix A) is a watershed or by the mineralogical composition of the unconsolidated deposits, which may differ in nature from the bedrock in a given watershed.

° The lack of information on the mineralogical and chemical composition of the unconsolidated deposits and the diversity of the geological composition of a number of watersheds may explain the lack of discrimination observed between groups 3 and 5 and between groups 2 and 4.

This analysis could be refined by means of a more detailed classification of the bedrock types or by grouping certain rocks in other groups. Identification of the dominant bedrock is sometimes difficult when a number of different types of bedrock are present in a watershed. In addition, the composition of the unconsolidated deposits has been assumed to be the same as that of the underlying bedrock. In some watersheds, glacial transport may have significantly affected the mineralogical composition of the deposits.

7. ANALYSIS OF INTERRELATIONSHIPS BETWEEN ECOLOGICAL AND GEOLOGICAL VARIABLES

The preceding analysis enabled identification of relationships between water quality and certain variables (physiography, vegetation) and geological variables. In the following section, other statistical techniques (homogenization of data, correspondence factor analysis), area used (a) to perform an overall analysis of the relationships between physiography, vegetation and geology (b) to identify zones within the study are which are homogeneous in relation to these variables; and (c) to describe these zones in terms of their sensitivity to acidifcation.

7.1 Methods Used

Correspondence factor analysis (CFA) and cluster analysis (CA) are the two multivariate statistical techniques selected to analyse the spatial behaviour of all of the ecological variables. A description of the principal characteristics of these two methods is given by Lachance et al (1979).

Correspondence factor analysis (Benzecri et al, 1976; Lebart and Fenelon, 1973) is a method which permits the development of synthetic representations of large two-dimensional tables and the description of their principal characteristics. It involves principal component analysis based on one specific measurement among representative points; this method has a number of advantages over principal component analysis including symmetry and stability, in particular.

Briefly, CFA makes it possible to determine the main axes of the cloud of variable points and of the cloud of stationary points and then to project the points in each cloud simultaneously in each of the planes of the main axes considered two by two. In this type of representation, the proximity of two variable points or two stationary points indicates similarity of variation or behaviour. By superimposing the planes of the axes obtained for the variables and those obtained for the variables and those obtained for the sampled points, it becomes possible to characterize each group of points by one or more variables based on their proximity to or distance from the group of sampling points. In fact, because of the barycentric principle specific to CFA, each sampling point is in projection on an axis, the barycentre, to within one coefficient, of the sampling points (or variable points).

Another characteristic of CFA relates to the possibility of including supplementary points (representing variables or sampling points) in the analysis. These points do not affect the analysis and do not influence the determination of the main axes; however, they can be represented graphically in factorial space. Their position in factorial space may be of useful assistance in interpretation.

Following application of CFA, the proximities between the points in factorial space can be examined more objectively and more systematically through the use of the cluster analysis method (Jambu, 1978). As previously mentioned, CA makes it possible to use the distances between each pair of points to group the observation points or variable points in classes, automatically and on the basis of selected aggregation criteria, and to arrange the groups of points in such a way as to permit visualization of the classification hierarchy.

The approach used in achieving this objective consists of selecting, from all of the available data, a number of ecological variables which are important in determining sensitivity to acidification and which show a wide enough range of variation to permit such analysis. Selected for this analysis are the 19 ecological variables used in the preceding analysis of Section 5.1, plus the ten geological variables corresponding to the ten groups of bedrock types defined in Section 4.3. In order to include interpretive elements, the four physicochemical variables (pH, SO_4, alkalinity, Ca + Mg) are also retained (i.e. those used in Bobée et al (1983)) to define homogeneous zones in the study area. However, these four variables are considered in the analysis as supplementary variables.

The data matrix on the basis of which the analysis of spatial variability is to be performed includes a large number of variables with different scales and ranges of variation. In order to permit application of the CFA method, the data were homogenized by means of binary coding. In this coding, each value obtained for a variable is transformed into a vector containing "0"s and a "1". The size of the vector is equal to the interval. The position of the "1" in the vector thus indicates the variation interval in which the value of the parameter occurs.

For the 19 ecological variables and the four physicochemical variables, three equiprobable classes (that is, of generally identical size) were distinguished. The thresholds used for coding these variables in three classes are given in Table 7.1. Class 1 represents a variable value below or equal to the lower threshold; class 2, a value above the lower threshold and below or equal to the upper threshold; and class 3, a value above the upper

Table 7.1
Lower and Upper Thresholds Used for Coding
Variables in Three Classes

Variables	Thresholds	
	Lower	Upper
Active		
altitude (m)	350	480.0
watershed area (km^2)	0.710	1.220
lake area (km^2)	0.102	0.167
bog area (km^2)	0.001	0.015
precipitation (mm)	1000.0	1100.0
WA/LA	6.06	8.6
SW, NE	1.8	13.0
NW, SE	-4.3	6.0
R + (R+tD) (%)	2.1	3.65
tD/R (%)	13.0	26.2
tD (%)	17.0	31.4
TD (%)	12.5	29.0
ORG (%)	0.15	1.05
CF(O) (%)	1.6	10.5
CF(D) (%)	0.7	13.0
DF(O) (%)	1.3	11.7
DF(D) (%)	7.0	48.5
PC + CC (%)	0.2	27.0
WV (%)	0.25	1.6
Supplementary		
pH	5.85	6.35
Ca + Mg (ueg/1)	140.0	240.0
alkalinity (ueg/1)	55.0	145.0
SO_4 (ueq/1)	85.0	119.0

threshold. For example, an altitude value of 290 m is replaced by the vector (1, 0, 0), while a value of 390 m is expressed by (0, 1, 0).

For the geological variables, the data collected (Appendix A) were arranged in a table of ten columns, each column corresponding to one of the groups defined above and representing the relative surface area occupied within the watershed by one of the types of bedrock in the groups. The geological data thus indicate presence-absence within the ten groups of bedrock types. This table is thus analogous to the table of binary data obtained from the other ecological variables and can be juxtaposed to it for CFA analysis.

7.2 Analysis of Interrelationships Between Variables

CFA was applied to the table of binary data, which has 67 columns (199 ecological variables divided into three classes and 10 geological variables) and 158 lines (watersheds). By means of this method, we obtain a synthetic representation in a factorial space of this enormous set of values. The main axes of this space explains the following percentages of variability, in descending order:

Factorial Axis	1	2	3	4	5
Relative Variability (%)	8.9	8.6	6.1	5.4	5.1
Cumulative Relative Variability (%)	8.9	17.5	23.6	29.0	34.1

These main axes explain low percentages of variability; as a result, one must consider at least 15 axes in order to explain approximately 65%.

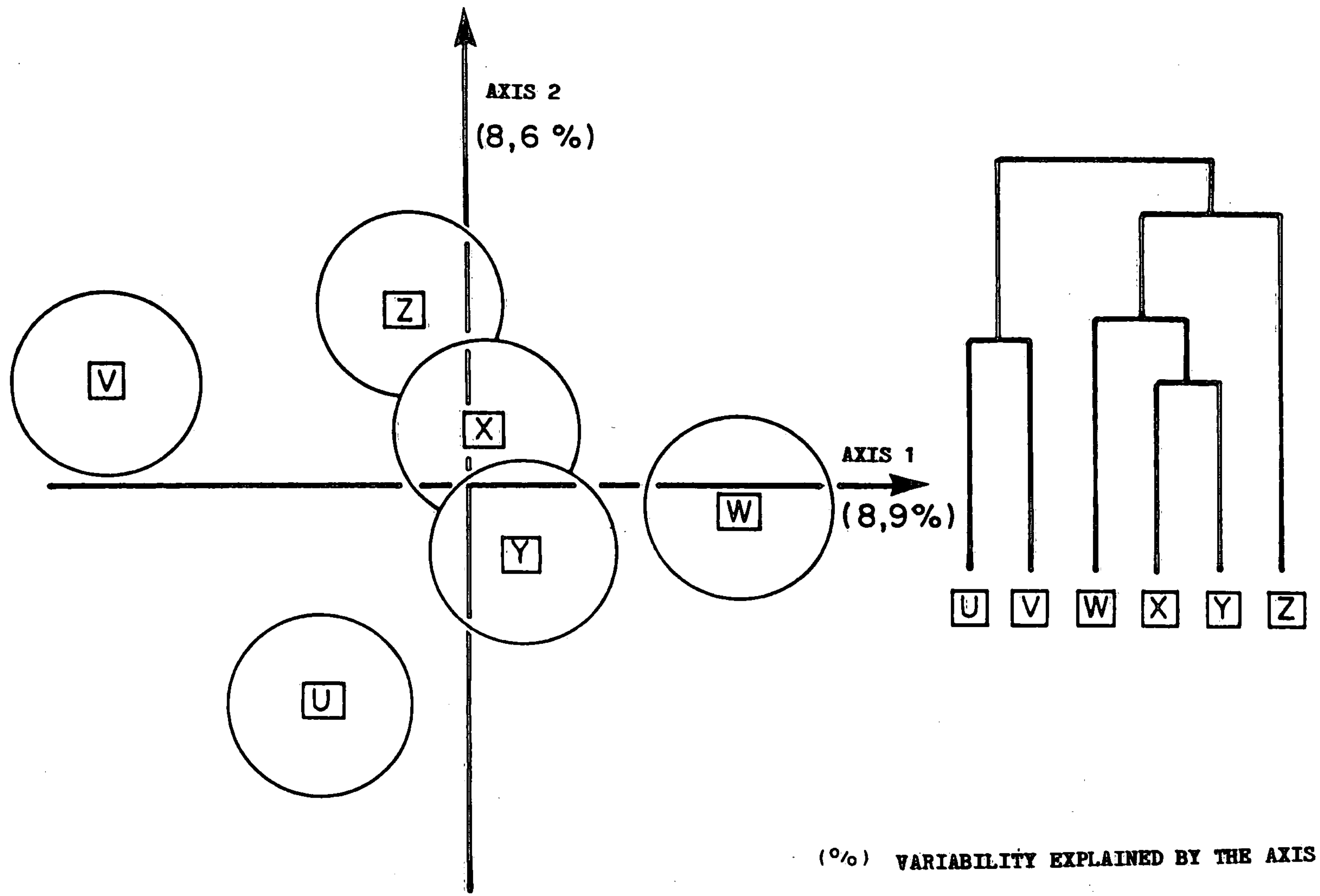


Figure 7.1: Clustering of Groups of Variable Points and Representation in the Plane of Main Axes 1 and 2 of the Centres of Gravity of the Groups of Variable Points

Table 7.2
Distribution of Classes of Variables Among the Six CA Groups

Variables	Classes of Variables Within Group					
	U	V	W	X	Y	Z
altitude	H		I			L
watershed area	I			L	H	
lake area				I	H	L
bog area		L	H		I	
precipitation	H			I		L
WA/LA				L	I	H
SW, NE	H		I			L
NW, SE	L		H		I	
R + (R+tD)	H		L			I
tD/R			L	I		H
tD			L	H		I
TD	L		H			I
ORG		L	H		I	
CF(O)	H				I	L
CF(D)	H				L	I
DF(O)				L	H	I
DF(D)	L		I			H
PC + CC	H		I			L
WV		L	H		I	
Bedrock group: 1						*
2				*		
3					*	
4			*			
5						*
6				*		
7				*		
8	*					
9						*
10						*
ph	L		I			H
Ca + Mg	L		I			H
Alkalinity	L		I			H
SO4	L		I			H

L: low values
I: intermediate values
H: high values
*: presence of this group's bedrock types in the CA group

7.2.1 Grouping of Variable Points

Projection of the variable points in the planes of the first main axes considered two by two makes it generally possible to describe the principal interrelationships between variables and to attribute a physical sense to the first main axes. However, examination of the proximities between the points, on which interpretation is based, is difficult because of the large number of points represented (67) and the large number of factorial axes to be considered (15). CA was therefore applied to the coordinates of the variable points in factorial space in order to analyse the proximities between variable points. In this way, was obtained a classification of the variable points in six groups (Figure 7.1). Examination of the composition of the six groups (Table 7.2) and of the positions of the centres of these groups in the plane of the main axes (Figure 7.1) makes it possible to interpret the interrelationships between the groups and to attribute a physical sense to the first factorial axis.

7.2.2 Composition of the Groups

Axis 1 reveals opposition primarily between groups V and W, while axis 2 is determined primarily by the opposition between groups U and Z (Figure 7.1). Based on the composition of groups V and W, which include the points representing small and large areas of bog, organic deposits, and wetland vegetation (Table 7.2) respectively, it can be seen that main axis 1 explains the spatial variability of the ecological factors related to the presence of organic substances. The distribution in groups U and Z of the low and high values for the SW-NE variable indicates that axis 2 expresses the evolution of the ecological factors in relation to the SW-NE axis (position of the lakes in the study area).

The variables which are closely related among themselves can be identified by determining whether the points representing the same class or the opposite class appear in the same group or in a nearby group. Thus are found relative areas of bog and organic deposits and the presence of wetland vegetation that are associated over their entire variation interval, since the points representing the low, intermediate and high classes occur in groups V,

Table 7.3
Classification of Ecological Variables by Variation Profile

Variation Profile Values: Low	Intermediate	High	Composition
V	Y	W	bog area, organic deposits, WV
Z	W	U	altitude, cut area, SW-NE position
U	W	Z	dense deciduous forest cover
Z	X	U	precipitation
Z	Y	U	open coniferous forest cover
Y	Z	U	dense coniferous forest cover
W	Z	U	R + (R+tD)
U	Z	W	TD
W	X	Z	tD/R
W	Z	X	tD
X	U	Y	watershed area
Z	X	Y	lake area
X	Y	Z	watershed area/lake area
X	Z	Y	open deciduous forest cover
U	Y	Z	NW-SE position

Set of Interrelated Variables

Y and W respectively. Another group of interrelated variables is composed of altitude, SW-NE position, cut area, and dense deciduous forest cover, indicating that altitude and cut area increase along the SW-NE axis, while dense deciduous forest cover, indicating that altitude and cut area increase along the SW-NE axis, while dense deciduous areas decrease.

By examining the distribution within the groups of low, intermediate and high values, six sets of variables can be identified which are more or less interrelated (Table 7.3). The first set consists of the relative areas of bog, organic deposits, and wetland vegetation, which are very closely correlated variables. The amount of precipitation, open coniferous forest cover, and dense coniferous forest cover belong to the second set, since their spatial evolution is generally similar to that of altitude.

The third set is formed of the variables R + (R+tD) and TD. The relative area of thick moraine decreases as the area of bedrock and bedrock + thin moraine increases in a given watershed. In the fourth set, are placed the variables tD/R and tD which are inversely related only at the intermediate- and high-value levels. The fifth set includes watershed area, lake area, ratio of watershed area/lake area, and area of open deciduous forest cover. No explanation for the association of the variables is apparent. The NW-SW variable, reflecting distance from the St. Lawrence River, seems to be a particular case.

The points representing the geological variables are distributed through each of the groups with the exception of group V (Table 7.2). Because of the lesser weight given to these variables in the analysis (in fact, only one variable divided into 10 groups is dealt with here and it may have a specific spatial behaviour), these variables generally have a relatively low representation quality. Their explained variability (relative contribution) on the first 15 main axes is as follows:

Group of Bedrock Types	1	2	3	4	5	6	7	8	9	10
Explained Variability	0.20	0.68	0.10	0.46	0.32	0.50	0.48	0.53	0.13	0.35

The explained variability for the bedrock types of groups 1, 3 and 9 is far too low, if one considers that explained for all of the 67 variable points (0.65). The points representing these three groups of bedrock types thus occur near the centre of the cloud of points and the adherence of a point to a given group may have no physical significance. As regards the other groups of bedrock types for which the explained variability is relatively low (4, 5, 6, 7, 8, 10), their position in the factorial space may be interpreted, but with caution.

The bedrock types of group 8, which include mangerite, monzonite, and charnockitic rocks and are found in abundance in the study area (Section 4.3), belong to group U. The composition of group U indicates that these types of bedrocks predominate in the northeastern portion of the study area and that they are located in a zone with:

- high precipitation and altitude values;
- large expanses of coniferous forest cover (both open and dense), cut area, bedrock and thin moraine over bedrock (R + (R+tD)); and
- small areas of thick moraine and dense deciduous forest cover.

The bedrock types of group 4 include migmatites (grey), gneiss-veined migmatites and paragneisses and associated granites (Section 4.3). The point representing these types of bedrock falls within group W (Table 7.2); these types of bedrock thus predominate in the centre of the study area (intermediate value for SW-NE position), where are found many large areas of thick moraine organic deposits, bogs, wetlands vegetation, and small areas of the various categories of thin moraine (tD, tD/R, R+(R+tD)).

In group Z, are found the bedrock types of groups 1, 5, 9 and 10, which are very different in nature (Section 4.3). In fact, marble and calc-silicate rocks (group 1) are much less resistant to weathering than the Grenville paragneisses (group 5); the latter are also less resistant to weathering than the granites, granitic gneisses and granodiorites (group 9) and the quartzites (group 10). The composition of group Z indicates that these four groups of bedrock types occur in abundance in the southwestern portion of the study area, the most heterogeneous zone. In this zone, altitude, precipitation, cut area, area of open coniferous forest cover, and area of lakes show low values, while the ratios of wathershed area/lake area and areas of thin moraine over bedrock, and of dense deciduous forest cover show high values.

The bedrock types, of groups 2, 6 and 7 occuring within group X (Table 7.2), are the following:

Group of Bedrock Types	Type of Bedrock
2	anorthosite, gabbro, gabbro anorthosite
6	gneiss, grey gneiss, gneissic complex
7	biotite geniss, pyroxene gneiss, granitic gneisses, amphibole gneiss

Based on the composition of group X, it is noted that these bedrock types are associated with the presence of large areas of thin morained and smaller areas of thin moraine over rock. The watershed areas, ratios of watershed area/lake area, and areas of open deciduous forest cover show low values. The location of the groups of bedrock types in relation to the SW-NE axis is relatively poorly defined.

Diorite and pyroxene diorite (group 3 rocks) occur in group Y (Table 7.2). The association of these types of bedrock with the ecological characteristics of this group is also poorly defined because of the low explained variability for the point representing these types of bedrock.

7.2.3 Supplementary Variables

With the data selected for the analysis of spatial variability, four supplementary variables were included: the physicochemical variables (pH, SO_4, alkalinity, Ca + Mg) used in Bobée et al (1983). Like the active variables, they were subjected to binary coding; the thresholds used to distribute them in three classes are show in Table 7.1.

Working from the CFA results, the position, in the factorial space, of the points representing the classes of these variables was calculated and their position in terms of proximity to the six groups of active variables was interpreted.

The distribution of the supplementary variable points within the groups is shown in Table 7.2. It is noted that the points representing the low-, intermediate-, and high-value classes of these variables occur in groups U, W, and Z respectively. The positions of these three groups in the factorial space express the evolution in relation to the SW-NE axis of such ecological factors as altitude, precipitation, cut area, areas of dense deciduous forest cover, and open and dense coniferous forest cover. The distribution of the supplementary points among these three groups indicates that physicochemical variables have high values in the southwestern portion and decline gradually towards the northeast. Altitude, precipitation, and type of vegetation (dense deciduous forest cover, open and dense coniferous forest cover, cut area) thus appear to be the ecological variables most closely related to the spatial behaviour of the four physicochemical variables considered.

7.3 Determination of Homogeneous Zones

Using the coordinates of the stationary points on the first 15 factorial axes, CA was applied to obtain a classification of the watersheds in five groups. A hierarchical branching diagram, as shown in Figure 7.2, indicates the structure of the hierarchy such that groups 1 and 5 are farthest removed from the other groups, while groups 2, 3 and 4 are less clearly distinguished among themselves.

The significance of the classification obtained can be interpreted by representing the centres of the groups of variable points and of the groups of stationary points simultaneously in factorial space and by examining the proximities between variable points and groups of stationary points (Figure 7.2). In fact, as a result of one of the properties of CFA (barycentric effect), the proximity of a group of stationary points implies a contribution by these variable points to the formation of the groups of stationary points.

If one examines Figure 7.2, the formation of group 1 is noted to be the result of a high contribution from the variable points within group U (Table 7.2). For each of the watersheds groups, the contribution of each of the variable points was calculated and classified as very high, high or low (Table 7.4).

Examination of the contributions of the variable points to the formation of the groups of watersheds makes it possible to define the principal characteristics of each of these groups. Group 1 is seen to be characterized by high values for SW-NE position, altitude, and precipitation. This group is located in the northeastern portion of the study area. The dominant bedrock types are from group 8 (mangerite, monzonite, charnockitic rocks) which is relatively close to the St. Lawrence River (low NW-SE values). The relative areas of bog, organic deposits, wetland vegetation, and dense deciduous forest cover are very low, while those of dense coniferous forest cover and cut area are relatively high. Group 5, just the opposite is located in the southwestern portion of the study area (low SW-NE values), lies at a lower altitude, and receives less precipitation. The vegetation consists primarily of dense deciduous forest cover, and bedrock types are from group 10 (quartzites). Groups 2, 3 and 4 fall generally within the limits of the principal characteristics of groups 1 and 5. However, these three groups are differentiated from one another by their varying areas of bog, organic

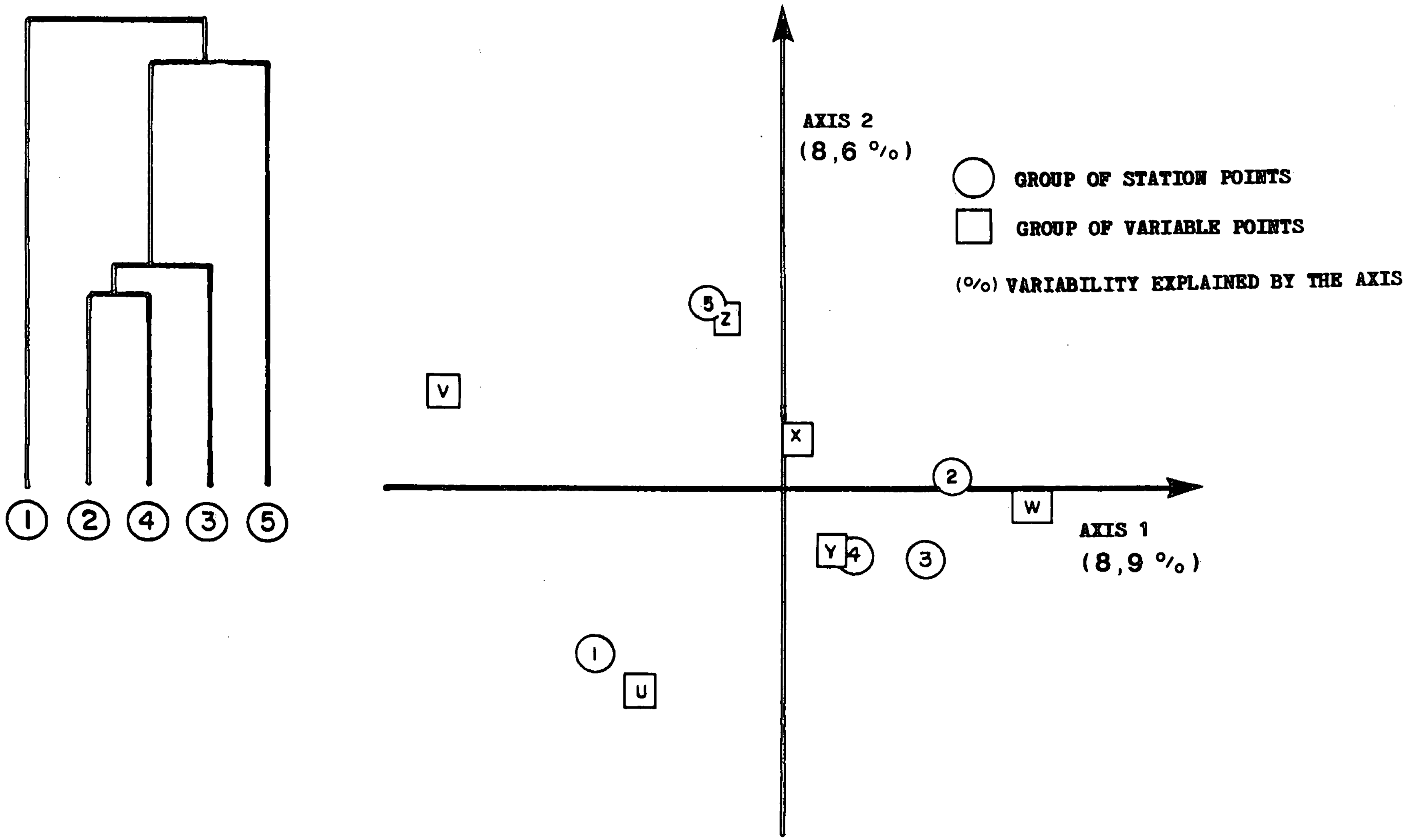


Figure 7.2: Clustering of Groups of Stationary Points and Simultaneous Representation in the Plane of Main Axes 1 and 2 of the Centres of Gravity of the Groups of Stationary Points and of the Groups of Variable Points

Table 7.4
Variable Points Contribution to the Formation of Watershed Groups

Variables	Watershed Groups				
	1	2	3	4	5
altitude	H**	I	I	H	L*
watershed area		I		H*	L
lake area		I	H		
bog area	L	H**	I	H**	
precipitation	H**	I*			L**
WA/LA				H	L
SW, NE	H**	I*	I*		L**
NW, SE	L		H	H	
R + (R+tD)	H	L	L*	I**	
tD/R		L	L	I	
tD			L		
TD			H*	I*	
ORG	L	H**		H	
CF(O)		H			L
CF(D)	H		L	I	
DF(O)			H		I
DF(D)	L	I**			H**
PC + CC	H		I,H		L
WV	L	H*	I	H	L
Bedrock types group: 1					
2		X			
3					
4			X		
5					
6					
7					
8	X*				
9					
10					X

**: very strong contribution
* : strong contribution
: weak contribution
X : presence of this group's bedrock types in the group of watersheds

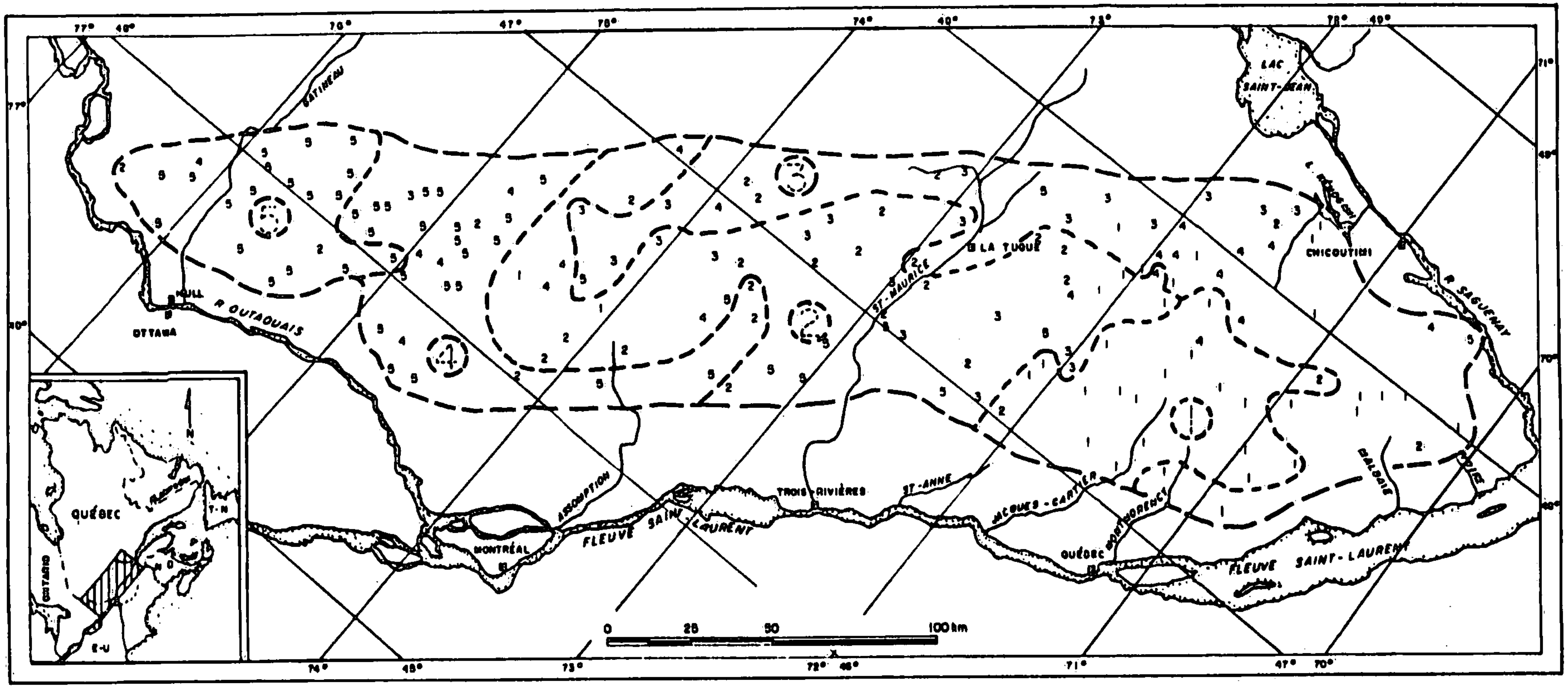
deposits, wetland vegetation (WV), bedrock and bedrock + thin moraine and thick moraine, and by their different geological composition. More precise and detailed characterizations of each of the groups may be obtained by referring to the mean values and standard deviations calculated for each of the variables, as presented in Appendix C.

The group to which each watershed belongs has been indicated on the map of the study area (Figure 7.3). The five geographical zones defined by Bobée et al (1983) are also shown on this figure. As previously recognized on the basis of analysis of the group characteristics, one can see that the watersheds of group 5 are located in the Ottawa Valley, in the southwestern portion of the study area, while the watersheds of group 1 define a zone corresponding essentially with Laurentide Park, north of Quebec City. The watersheds of groups 2, 3 and 4 are scattered throughout the central portion of the study area.

Examination of the distribution of the watersheds of the various groups within the previously defined zones (Figure 7.3) reveals certain differences. First, it is immediately evident that the region defined by the watersheds of group 5 covers zones 4 and 5 almost completely, while the region in which the watersheds of group 1 occur, includes zone 1 and extends farther east into zone 3.

If one examines the distribution of the watersheds of the five groups in the previously defined zones (Table 7.5) in greater detail, it is noted that zones 1 and 5, with 20 and 21 lakes respectively, have over 85% of their watersheds classified in the same way. Of the other three zones, only zone 2 has a majority of its watersheds classified in the corresponding group. Considering the study area as a whole, 40.5% of the watersheds are classified in groups corresponding to the previously defined zones.

The five geographic zones were defined by Bobée et al (1983) on the basis of both their adherence to a physicochemically homogeneous group and prior familiarity with the physiography of the region. In fact, only 65% of the lakes in the study area, for which the group was determined on the basis of physicochemical characteristics, corresponds to the zone. The definition of



Zones determined by Bobée et al

Figure 7.3: Classification of Watersheds in Five Groups Defined in the Study and Boundaries of the Zones Defined by Bobée et al (1983)

Table 7.5
Distribution of Watersheds by Classification in Five Groups and by Location Within the Five Zones Previously Defined by Bobée et al (1983)

Zone Determined on the Basis of Physicochemical Characteristics	Number of Lakes per Zone	Number of Lakes Classified in Groups 1-5				
		1	2	3	4	5
1	20	17 (85.0)	2 (10.0)	0 (0.0)	1 (5.0)	0 (0.0)
2	44	5 (11.4)	16 (36.4)	12 (27.3)	6 (13.6)	5 (11.4)
3	43	15 (34.9)	7 (16.3)	9 (20.9)	9 (20.9)	3 (7.0)
4	30	0 (0.0)	4 (13.3)	1 (3.3)	4 (13.3)	21 (70.0)
5	21	0 (0.0)	2 (9.5)	0 (0.0)	1 (4.8)	18 (85.7)

( ) percentage of watersheds classified in accordance with the previous zoning geographic zones, while somewhat arbitrary, was useful in defining the sampling plan for a future data-gathering network designed to monitor surface water acidification.

It is possible to redefine other geographic zones on the basis of the homogeneous zones determined in the study. For example, one could consider only three geographic zones by grouping the regions covered by groups 2, 3 and 4 which all have somewhat similar characteristics. Zone 5 would include the entire southwestern portion of the study area (previous zones 4 and 5), while zone 1 would include the previous zone 1 and extent northeastward into the previous zone 3.

7.4 Conclusions

- Study of the interrelations between the ecological and geological variables reveals the following points:
  - the variables relating to the presence of organic deposits and wetland vegetation are strongly interrelated;
  - a strong interrelation is observed among the following variables: altitude, precipitation, SW-NE position, cut area, area of dense deciduous forest cover, and area of open coniferous forest cover; the variables included in this group appear to be the most closely related to lake mineralization.

- Analysis of the spatial behaviour of all the ecological variables (geology, physiography, vegetation) enables distinguishing of five homogeneous groups of watersheds within the study area.

- This classification of the watersheds in five homogeneous groups compares well with the previous zoning by Bobée et al (1983) on the basis of the physicochemical characteristics of lakes; 41% of the watersheds are classified in groups corresponding to the previously defined zones.

- The zone defined by group 1 is located in the northeastern portion of the study area and is characterized by high altitude, heavy precipitation, large expanses of dense coniferous forest cover, cut area (clearcut and partial cut), and small areas of organic deposits, wetland vegetation, and dense deciduous forest cover. The dominant bedrock types here are mangerite, monzonite, and associated charnockitic rocks.

- The zone defined by group 5 is located in the southwestern portion of the study area and shows the opposite characteristics to those of group 1. It is characterized primarily by lower-altitude watersheds, lighter precipitation, and large areas of dense deciduous forest cover. The dominant bedrock types are marble, calc-silicate rocks, gneiss, Grenville paragneiss, granites and quartzites.

- The zones corresponding to groups 2, 3 and 4 are less well defined than zones lands are scattered throughout the central portion of the study area. These three groups of watersheds are differentiated by their varying areas of organic deposits, wetland vegetation, rock and thin moraine, thick moraine, and by their different geological composition.

This new zoning, developed on the basis of a set of ecological variables, makes it possible to define more clearly the boundaries of the areas most sensitive (zone 1) or least sensitive (zone 5) to acidification. It is possible, thus to identify homogeneous zones in terms of sensitivity to acidification on the basis of a set of ecological and geological characteristics.

8. CONCLUSIONS AND RECOMMENDATIONS

The geological and ecological characterization of the watersheds of 158 lakes in southern Quebec has made it possible, following analysis and interpretation of all of the variables, to isolate and identify a number of relationships between these variables and the physicochemical parameters of water quality.

First the principal conclusions of each chapter are reviewed. Next, is examined the question of whether the aims and objectives of the study have been met. Finally a list of general and specific recommendations is presented.

8.1 Importance of Geological and Ecological Variables (Section 4.4).

Detailed analysis of the inventoried data reveals that:

- Altitude and rate of precipitation are interrelated variables. Their variations mark clearly defined homogeneous zones within the study area.

- Vegetation within the study area appears to be related to altitude and precipitation.

  - In the northeastern portion, where altitude is high and precipitation heavy, coniferous forest cover predominates.

  - Farther west and in most of the study area, deciduous forest cover dominates, with an average cover density of over 60%.

- The principal types of bedrock found in the study area are charnockitic (mangerite, monzonite, and charnockitic migmatites). Of secondary occurrence are migmatites, and thirdly, paragneiss and Grenville gneiss.

8.2 Relationships Between Ecological Variables and Water-Quality Variables (Section 5.4)

- The ecological variables most closely related to the rate of mineralization and pH of lake waters are altitude, precipitation, SW-NE position, area of open coniferous forest cover, area of dense deciduous forest cover, and cut area.

- Sulphate concentrations in the lakes vary inversely with altitude, precipitation, and SW-NE position, and indirectly with the rate of mineralization.

- The variables describing deposit thickness show a slight relationship to lake mineralization and pH. The data collected do not enable identification, for a given type of deposit, the effect of slope and drainage on lake pH and mineralization.

8.3 Relationships Between Geological and Physicochemical Variables (Section 6.3)

- The physicochemical characteristics of the water in 55% of the lakes studied can be explained by the geology of the bedrock. In fact, discriminant analysis of the physicochemical data, following an initial classification of the watersheds into five groups on the basis of geological characteristics, indicates that 55% of the lakes studies fall within this classification.

- The physicochemical variables showing the highest degree of discrimination in the study of the relationships existing between geological characteristics and water quality are: calcium, magnesium, potassium, sulphates, aluminium, and, to a lesser extent, hydrogen ions.

- The watersheds classified in group 1 (calc-silicate bedrock types and marble), group 3 (migmatites, paragneiss, and gneiss), and group 5 (granite and quartzite) are characterized by lake waters in which calcium, magnesium, potassium and sulphate levels are higher and aluminium and hydrogen ions lower than the waters of the watersheds in which are noted the presence of group 2 bedrock types (anorthosite, gabbro and diorite) and group 4 bedrock types (mangerite and monzonite).

- The presence of sulphates as a major discriminant variable can be explained in two ways:

  - input from various natural environmental sources, including certain types of bedrock (pyrite, chalcopyrite);
  - the important influence of atmospheric sulphate input, which decreases in relation to a SW-NE gradient.

8.4 Analysis of Relationships Between Geological and Ecological Variables (Section 7.4)

General analysis of the relationships between the geological and ecological data has enabled definition of homogeneous zones within the study area and characterization of these zones in terms of their sensitivity to acidification.

In this way, it has been possible to establish:

- Relationships between the following variables: altitude, precipitation, SW-NE position, cut area, area of dense deciduous forest cover, and area of open coniferous forest cover. These variables appear to be closely related to the rate of lake mineralization.
- A classification of the watersheds in five homogeneous groups on the basis of the spatial behaviour of all of the ecological variables. This classification compares well with that defined by Bobée et al (1983); 41% of the watersheds occurring in homogeneous groups correspond precisely to the previous defined zones.
- A better characterization of the regions of high sensitivity (zone 1) or low sensitivity (zone 5) to acidification. Zones 2, 3 and 4, which are less well defined, occupy the central portion of the study area and are characterized by varying areas of organic deposits, wetland vegetation, and unconsolidated deposits, and by different types of bedrock.

8.5 Review of Study Objectives

Through the use of various types of analysis, many of the aims and objectives established at the beginning of the study were achieved. For example, the principal physiographical variables which may affect (increase, decrease) the level of sensitivity and the buffering capacity of the terrestrial ecosystem are identified.

A relationship has been established between types of vegetation and the rate of lake mineralization. In those watersheds where areas of dense deciduous forest cover occupy the greater proportion of the total area, the lake water is more highly mineralized than in those watersheds where areas of dense coniferous tree cover predominate (50% of the total area).

By means of discriminant analysis, certain types of bedrock which may be partially responsible for the level of calcium, magnesium, potassium, sulphates, aluminium, and hydrogen ion concentrations in the lake water are also identified.

Finally, by means of description and analysis of geological and ecological characteristics of the terrestrial ecosystems, five homogeneous zones of sensitivity are identified and defined: zone 1 representing high sensitivity, zone 5 low sensitivity, and zones 2, 3 and 4 transition zones. However, on the basis of the data inventoried it is not possible to distinguish and identify the possible effect of the thickness, slope, and drainage of unconsolidated deposits on sensitivity and their capacity to neutralize acidic atmospheric fallout. This inability is due largely to the absence of data relating to the type, mineralogical composition, and physical and chemical properties of the unconsolidated parent deposits and of the soils present. These data could not be analysed because they were not available; the field studies up to 1984 did not include collection of this type of information; however they have since been initiated in a subset of 35 watershed basins.

8.6 Recommendations

In order to achieve a better understanding of the impact of acid precipitation on the various types of terrestrial and aquatic ecosystems, it is essential that an attempt be made to identify all the ecological characteristics which may or may not make a zone (or watershed) sensitive to the effects of acid precipitation. To this end, and in order to determine the influence and impact of the variables not considered in the present study (including the nature and physical and chemical properties of the soils), it is recommended that these studies be conducted:

(a) Assess the potential effect of the slope, drainage, thickness and nature of deposits and soils on the sensitivity and buffering capacity of ecosystems;

° by analysing and comparing only geologically and ecologically homogeneous watersheds, in order to permit analysis of slope, drainage, thickness and nature of unconsolidated deposits as explanatory variables;

° by determining the hydrological characteristics (infiltration, surface runoff) of each watershed in order to assess water contact time with bedrock, soils and unconsolidated deposits;

° by measuring more accurately the areas and volume (in some cases) of bogs and soils with high organic contents and measuring the pH of seepage water in situ at different depths.

(b) Identify and describe the lithological and pedological variables controlling the sensitivity of ecosystems to acid precipitation:

° by sampling and analysing the various pedological horizons and base deposits on which they have developed in order to determine their cation exchange capacity and to identify their principal exchangeable bases;

° by identifying, for each watershed, the minerological and chemical constituents of the various geological formations and overlying unconsolidated deposits in order to discover whether certain metals, such as pyrite and chalcopyrite, are present and possibly contributing substantially to sulphate input into the watershed.

(c) Distinguish the effect of the various types of vegetation on the sensitivity of the ecosystems and on their neutralizing capacity:

° by identifying the presence of each type of humus encountered, verifying their possible relations with the various types of vegetation present in the watershed, assessing the cation exchange capacity of each type, and identifying their exchangeable bases;

- by determining whether different types of vegetation can influence the buffering capacity of a watershed when the surface deposits and bedrock are of comparable mineralogical composition.

(d) Assess the influence of glacial transport of unconsolidated deposits:

- by determining to what extent the mineralogical composition of the unconsolidated deposits is representative of the mineralogical composition of the underlying or surrounding bedrock.

Following application of these recommendations, it may be possible to identify and assess quantitatively the variables and processes responsible for the acidification or neutralizing capacity of watersheds and thus to explain more fully the spatial variation in the water quality of the lakes of southern Quebec.

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APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No. N	N1	N2	Name of Lake	Coordinates Longitude (W)	Latitude (N)	Geology (Relative Importance)
1	1	10	Lac de l'Aqueduc	74°47'30"	46°32'30"	Charnockitic Gneiss (100%)
2	2	17	Baldwin	74°43'30"	46°27'30"	Paragneiss (35%) Monzonite (35%), Granite (30%)
3	3	21	Tortu	75°07'00"	46°20'00"	Quartz Gneiss, Amphibole and Pyroxene (70%), Quartz (30%)
4	4	23	Baillargé	74°49'00"	46°19'40"	Paragneiss (25%), Monzonite (25%), Granite (50%)
5	5	26	David	75°35'00"	46°18'30"	Granite (50%), Migmatite (50%)
6	6	32	S.N. # 60775	74°47'30"	46°15'00"	Paragneiss (40%), Monzonite (30%), Granite (30%)
7	7	35	S.N. # 42734	75°45'00"	46°12'00"	Migmatite (100%)
8	8	37	S.N. # A6960	75°29'00"	46°13'00"	Crystalline Limestone (20%), Biotite Gneiss (80%)
9	9	38	Castilly	75°16'00"	46°10'30"	Biotite and Porphyroblastic Gneiss (100%)
10	10	39	Kidney	75°14'00"	46°12'30"	Syenite (80%), Diorite (20%)
11	11	40	Metcalfe	75°00'00"	46°14'00"	Migmatite (80%), Diorite (20%)
12	12	42	Lac à l'Ours	74°50'30"	46°10'00"	Paragneiss (40%), Monzonite (30%), Granite (30%)
13	13	45	S.N. # 42888	75°54'00"	46°03'30"	Quartzite and Quartzofeldspathic Paragneiss (100%)
14	14	48	Trouvé	75°27'30"	46°07'30"	Hornblende Gneiss (100%)
15	15	50	Sourire	75°12'30"	46°07'30"	Quartzite (50%), Crystalline Limestone (50%)
16	16	51	Griffin	75°01'00"	46°04'30"	Gneissic Diorite (50%), Crystalline Limestone (50%)
17	17	57	S.N. # 603	75°50'00"	46°02'00"	Marble (50%), Charnockitic Gneiss (50%)
18	18	58	S.N. # 42839	75°40'00"	46°01'00"	Migmatite (60%), Granite (40%)
19	19	59	Perch	75°33'20"	46°02'40"	Monzonite (100%)
20	20	68	Bohème	76°07'00"	45°52'30"	Granite With Pegmatite (100%)

N: Lake No   N1: Lake No, INRS-Eau   N2: Lake No, Environment Canada

APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No. N	N1	N2	Name of Lake	Coordinates Longitude (W)	Latitude (N)	Geology (Relative Importance)
21	21	75	Blais	75°10'00"	45°56'00"	Quartz (100%)
22	22	82	Sowden	76°05'30"	45°50'00"	Granite With Pegmatite (100%)
23	24	92	Lac aux Trois Pointes	74°50'00"	45°10'00"	Gneiss (100%)
24	25	93	Éléphant	74°43'00"	45°52'00"	Monzonite (100%)
25	26	95	S.N. # 71370	76°24'00"	45°52'00"	Paragneiss (50%), Crystalline Limestone (50%)
26	27	96	Carlot	76°13'00"	45°45'30"	Paragneiss (50%), Crystalline Limestone (50%)
27	28	101	Shéridan	75°37'30"	45°44'00"	Mixed Amphibolite Paragneiss (100%)
28	29	102	S.N. # 56003	75°25'00"	45°43'30"	Graphitic Gneiss (50%), Quartz (50%)
29	30	108	Carrier	74°44'00"	45°46'00"	Red Gneiss (50%), Granite (50%)
30	31	124	Clair	76°04'00"	45°36'00"	Amphibole Gneiss (50%), Quartzite (50%)
31	32	2	Glacé	71°32'00"	48°16'30"	Monzonite (50%), Granite With Pegmatite (50%)
32	33	3	Quatrième	71°22'00"	48°17'00"	Mangerite (100%)
33	34	5	S.N. # 34670	70°21'40"	48°17'50"	Mangerite (100%)
34	36	8	Lac des Vases	71°40'00"	48°12'30"	Granite With Pegmatite (50%), Mangerite (50%)
35	37	10	S.N. # 86728	71°22'30"	48°14'30"	Gneissic Complex (100%)
36	38	16	Cazot	70°34'30"	48°15'00"	Migmatite (100%)
37	39	20	Lac des Deux Clubs	71°58'00"	48°07'30"	Mangerite (100%)
38	40	23	Chouinard	71°34'00"	48°11'00"	Gneissic Complex (50%), Mangerite (50%)
39	41	24	Rolland	71°31'30"	48°07'30"	Mangerite (100%)
40	43	41	Cadieux	71°36'00"	48°02'00"	Mangerite (100%)

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APPENDIX A

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41	45	58	Sibyllin	72°05'30"	47°54'40"	Diorite, Granodiorite (100%)
42	46	59	Consor	71°58'40"	47°59'50"	Gneissic Complex (100%)
43	47	61	Tréteau	71°47'40"	47°55'20"	Mangerite (50%), Gneissic Complex (50%)
44	48	62	Harvey	71°38'00"	47°55'00"	Mangerite (100%)
45	49	66	S.N. # 86663	71°06'30"	48°00'30"	Charnockitic Gneiss (100%)
46	51	70	S.N. # 35662	70°33'30"	47°56'20"	Charnockitic Gneiss (100%)
47	52	71	Cantin	70°27'00"	47°59'50"	Mangerite (100%)
48	53	75	Noire	70°08'30"	47°59'50"	Mangerite (100%)
49	54	78	Oreille	72°21'30"	47°53'00"	Diorite, Granodiorite (100%)
50	55	79	Chômeur	72°13'00"	47°50'00"	Mangerite (100%)
51	56	81	Tourlay	71°58'00"	47°50'30"	Mangerite (100%)
52	57	82	Magny	71°54'30"	47°52'00"	Granite With Pegmatite (100%)
53	58	86	Migneault	71°23°10"	47°50'30"	Mangerite (100%)
54	59	89	Pilote	70°52'30"	47°51'30"	Charnockitic Gneiss (100%)
55	60	91	S.N. # 35694	70°39'30"	47°53'20"	Mangerite (50%), Diorite (50%)
56	61	94	Thomas	70°14'30"	47°53'00"	Charnockitic Gneiss (100%)
57	62	97	Purcell	72°38'30"	47°45'40"	Biotite Migmatite (50%), Gneissic Complex (50%)
58	63	99	Armand	72°26'30"	47°44'10"	Anorthosite, Gabbro Anorthosite (50%), Diorite (25%), Granodiorite (25%)
59	64	102	Flavien	71°59'00"	47°45'30"	Mangerite (100%)

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APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No. N	N1	N2	Name of Lake	Coordinates Longitude (W)	Latitude (N)	Geology (Relative Importance)
60	65	103	Dulong	71°55'00"	47°47'20"	Mangerite (100%)
61	66	104	Daniel	71°48'20"	47°47'20"	Gneissic Complex (100%)
62	67	105	Montraya	71°35'00"	47°49'20"	Mangerite (100%)
63	68	113	S.N. # 35759	70°35'40"	47°49'30"	Mixed Paragneisses, Amphibolite (50%), Granitic Gneiss (50%)
64	69	122	S.N. # 87482	72°22'00"	47°38'40"	Gabbro, Metagabbro, Amphibolite (100%)
65	70	125	Congré	72°01'40"	47°42'00"	Mangerite (100%)
66	72	127	Lemaine	71°46'10"	47°43'10"	Charnockitic Gneiss (100%)
67	73	129	Ecureuil	71°29'40"	47°41'00"	Anorthosite (70%), Mangerite (30%)
68	74	133	des Enfers	70°54'30"	47°43'40"	Mangerite (50%), Diorite (25%), Granodiorite (25%)
69	75	141	S.N. # 92844	73°02'30"	47°38'30"	Migmatite (100%)
70	76	145	Panache	72°31'00"	47°36'40"	Injection Gneiss (50%), Diorite (25%), Granodiorite (25%)
71	77	147	S.N. # 87422	72°15'30"	47°33'40"	Gneissic Complex (100%)
72	78	148	du Casse-ligne	72°05'40"	47°37'00"	Mangerite (100%)
73	80	153	S.N. # 7810	71°30'00"	47°38'15"	Mangerite (75%), Anorthosite (25%)
74	81	154	du Wapiti	71°15'30"	47°36'10"	Charnockitic Gneiss (100%)
75	82	156	Fantôme	71°06'10"	47°37'20"	Mangerite (100%)
76	83	164	Weddy	73°08'30"	47°33'40"	Gneissic Complex (50%), Charnockitic Gneiss (50%)
77	84	166	Cap	72°52'40"	47°29'30"	Charnockitic Gneiss (100%)
78	86	172	S.N. 87388	72°12'00"	47°32'00"	Gneissic Complex (100%)
79	87	174	Lac du Nirvana	71°53'00"	47°28'50"	Mangerite (100%)

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APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

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N	N1	N2	Name of Lake	Longitude (W)	Latitude (N)	Geology (Relative Importance)
80	88	176	Tapp	71°33'20"	47°32'30"	Mangerite (100%)
81	89	183	S.N. # 87388	70°42'00"	47°33'00"	Charnockitic Gneiss (100%)
82	91	197	Guernon	72°00'30"	47°22'30"	Migmatite (100%)
83	92	200	Veilleux	71°34'30"	47°23'40"	Mangerite (100%)
84	93	205	McLeod	70°58'40"	47°28'00"	Mangerite (100%)
85	94	206	Pied des Monts	70°51'20"	47°24'20"	Charnockitic Gneiss (100%)
86	95	213	Fauvette	73°14'00"	47°20'20"	Charnockitic Migmatite (100%)
87	97	219	S.N. # 90997	72°23'10"	47°18'30"	Migmatite (100%)
88	98	221	Garneau	72°09'30"	47°22'20"	Migmatite (100%)
89	99	222	Alphonse	72°04'30"	47°17'30"	Mangerite (100%)
90	100	223	en Zigzag	71°58'50"	47°20'00"	Migmatite (100%)
91	101	224	Lagou	71°49'20"	47°18'15"	Mangerite (100%)
92	102	225	Gosselin	71°40'00"	47°22'00"	Mangerite (100%)
93	103	241	Lacet	72°55'30"	47°16'30"	Charnockitic Gneiss (100%)
94	104	242	S.N. 86928	72°48'00"	47°13'30"	Charnockitic Gneiss (100%)
95	105	248	Haut	72°05'00"	47°13'00"	Mangerite (100%)
96	106	253	Bonneville	71°24'00"	47°16'40"	Mangerite (100%)
97	107	255	du Bec Croche	71°12'00"	47°13'50"	Charnockitic Gneiss (100%)
98	108	257	Turpin	70°57'20"	47°14'20"	Charnockitic Gneiss (100%)
99	109	263	S.N. # 41472	73°25'10"	47°12'00"	Charnockitic Gneiss (100%)

N: Lake No N1: Lake No, INRS-Eau N2: Lake No, Environment Canada

APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No.				Coordinates		
N	N1	N2	Name of Lake	Longitude (W)	Latitude (N)	Geology (Relative Importance)
100	111	265	Vachon	73°12'20"	47°10'20"	Charnockitic Gneiss (100%)
101	112	267	du Camp	72°58'00"	47°09'30"	Paragneiss (50%), Biotite Granite (50%)
102	113	271	des Lépiotes	72°22'20"	47°06'30"	Diorite (35%), Granodiorite (35%), Migmatite (30%)
103	114	277	S.N. # 25448	71°39'00"	47°10'50"	Mangerite (100%)
104	115	279	Saint-Guillaume	71°25'30"	47°09'00"	Mangerite And Charnockitic Gneiss (100%)
105	116	287	S.N. 86445	73°52'30"	47°06'40"	Granite With Pegmatite (100%)
106	117	288	Nolette	73°47'30"	47°05'00"	Granite With Pegmatite (100%)
107	119	290	du Nénuphar	73°27'30"	47°06'00"	Charnockitic Gneiss (100%)
108	120	295	S.N. # 91010	72°53'30"	47°03'30"	Biotite Granite (80%), Gabbro (20%)
109	121	296	Tom	72°44'40"	47°02'30"	Charnockitic Gneiss And Charnockite (100%)
110	123	300	à Charles	72°14'00"	47°01'30"	Migmatites (100%)
111	124	301	Najoua	72°05'00"	47°02'30"	Granites With Pegmatite (100%)
112	126	312	Turc	74°17'00"	47°02'20"	Granite (50%), Syenite (50%)
113	127	316	Ricard	73°45'00"	46°58'50"	Migmatite (100%)
114	128	319	de l'Epervier	73°19'00"	47°01'00"	Charnockitic Gneiss (100%)
115	130	321	Enard	72°51'00"	47°01'40"	Paragneiss (90%), Metagabbrro (10%)
116	131	326	Arcale	72°23'00"	46°59'00"	Granite With Pegmatite (100%)
117	133	340	de l'Isle	74°07'40"	46°52'40"	Migmatite (100%)
118	134	344	du Baril	73°38'00"	46°52'40"	Migmatite (100%)
119	135	349	Eclair	73°00'10"	46°51'00"	Plagioclase Migmatite, Hornblende, Biotite (100%)

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APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No. N	N1	N2	Name of Lake	Coordinates Longitude (W)	Latitude (N)	Geology (Relative Importance)
120	136	356	Adanys	74°19'30"	46°48'20"	Pyroxene Gneiss (100%)
121	138	360	de la Pomme	73°45'00"	46°50'00"	Migmatite (100%)
122	139	363	Leech	73°31'40"	46°49'30"	Migmatite (100%)
123	140	375	S.N. # 36724	74°02'40"	46°45'30"	Paragneiss (50%), Marble (50%)
124	141	379	Clut	73°33'40"	46°44'20"	Amphibole Gneiss, Biotite, Pyroxene (100%)
125	142	380	des Joncs	73°23'00"	46°45'00"	Intermediate Gneiss (100%)
126	143	383	S.N. # 54990	72°59'20"	46°42'30"	Pyroxene Gneiss And Hornblende (100%)
127	144	388	des Jésultes	74°41'40"	46°38'30"	Paragneiss (35%), Monzonite (35%), Granite (30%)
128	145	390	Daulé	74°26'30"	46°38'30"	Pyroxene And Sillimanite Gneiss And Garnet (60%), Charnockitic Granulite (40%)
129	146	396	Ecartant	73°35'40"	46°38'00"	Amphibole Gneiss, Biotite And Pyroxene (100%)
130	148	400	Thibert	73°10'00"	46°39'00"	Biotite Gneissic Complex, Amphibole And Hornblende (100%)
131	150	409	Petit lac Vasseur	74°08'30"	46°34'40"	Marble (25%), Migmatite (25%), Paragneiss (50%)
132	151	416	S.N. # 53814	73°15'30"	46°29'30"	Granitic Gneiss (100%)
133	152	426	Bois-Francs	74°19'00"	46°27'00"	Granitic Gneiss (50%), Quartzite (50%)
134	153	427	Laurent	74°12'00"	46°28'30"	Biotite Gneiss, Pyroxene And Hornblende (100%)
135	154	428	Casse-Ligne	74°01'30"	46°25'10"	Pyroxene Monzonite (100%)
136	155	433	Cailloux	73°22'20"	46°29'20"	Granitic Gneiss, Pyroxene Gneiss (60%), Quartzite (40%)
137	156	438	Dupré	75°04'00"	46°21'30"	Quartzite (100%)
138	157	441	General White	74°41'00"	46°22'00"	Grenville Paragneiss (35%), Monzonite (35%), Granite (30%)
139	158	444	Honoré	74°19'30"	46°21'20"	Granitic Gneiss (100%)

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APPENDIX A

WATERSHEDS INVENTORIED, LOCATION, AND GEOLOGY

Lake No. N	N1	N2	Name of Lake	Coordinates Longitude (W)	Latitude (N)	Geology (Relative Importance)
140	159	448	Pintac	73°47'40"	46°22'00"	Charnockitic Gneiss (100%)
141	160	455	Colour	75°10'30"	46°17'30"	Pyroxene Diorite (35%), Granodiorite (35%), Crystalline Limestone (30%)
142	161	457	Anita	74°53'00"	46°19'00"	Paragneiss (30%), Monzonite (40%), Granite (30%)
143	162	458	Vigné	74°45'30"	46°15'40"	Paragneiss (30%), Monzonite (40%), Granite (30%)
144	163	461	Poisson	74°28'00"	46°17'30"	Mangerite (100%)
145	164	464	Copping	74°04'10"	46°16'00"	Anorthosite And Anorthositic Gabbro (100%)
146	165	475	S.N. # 19222	74°58'00"	46°08'30"	Paragneiss (30%), Monzonite (40%), Granite (30%)
147	166	477	S.N. # 60100	74°40'30"	46°09'00"	Paragneiss (30%), Monzonite (40%), Granite (30%)
148	167	482	Truite Rouge	74°05'00"	46°09'00"	Gabbro Anorthosite (100%)
149	168	484	S.N. # 53665	73°47'00"	46°13'30"	Paragneiss (50%), Silicate Carbonates (50%)
150	169	491	des Papillons	75°20'00"	46°06'30"	Syenite (100%)
151	170	496	Vinet	74°43'40"	46°07'30"	Paragneiss (30%), Monzonite (40%), Granite (30%)
152	171	512	Chevreuil	74°56'00"	46°03'00"	Paragneiss (30%), Monzonite (40%), Granite (30%)
153	172	518	Léon	74°08'00"	46°01'00"	Anorthosite (100%)
154	173	522	S.N. # 56511	75°48'20"	45°55'40"	Monzonite (100%)
155	174	526	Thomas	75°20'40"	45°55'30"	Monzonite (100%)
156	175	539	Duck	75°51'30"	45°50'30"	Paragneiss (35%), Migmatite (35%), Quartzite (30%)
157	176	543	Graham	75°23'00"	45°47'40"	Paragneiss (50%), Monzonite (50%)
158	177	549	S.N. # 1952	74°33'00"	45°47'30"	Paragneiss (30%), Monzonite (40%), Granite (30%)

N: Lake No N1: Lake No, INRS-Eau N2: Lake No, Environment Canada

APPENDIX B

STATISTICAL METHODS

B. Statistical Methods

The correlation coefficient, indicating the intensity of the relation which exists between two variables, which is most commonly used is the Pearson parametric coefficient (r). It is obtained by the following formula:

$$r = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N} (x_i - \bar{x})^2 . \sum_{i=1}^{N} (y_i - \bar{y})^2}$$

where $\bar{x}$ and $\bar{y}$ are the mean of samples x_i and y_i, and N is the number of measurements.

Through the application of a significance test, one can determine whether r is significantly different from zero. The hypothesis H_0 to be verified is $\rho = 0$. The alternative hypothesis is $H_1 \ : \rho \neq 0$, which can be broken down into $\rho > 0$ (H_1) and $\rho < 0$ $(H_1.)$.

The following value is then calculated:

$$t = \frac{r}{\sqrt{(1 - r^2) / (N - 2)}}$$

Since this quantity has a Student distribution with (N-2) degrees of freedom, this value can be compared to the critical value $t\ (N-2; \alpha/2)$.

- if $-t\ (N-2; \alpha/2) < t < t\ (N-2; \alpha/2)$, H_0 is accepted at the significance level

- if $t > t(N-2; \alpha/2)$, H_0 is rejected giving $H_1: \rho > 0$
- if $t < -t(N-2; \alpha/2)$, H_0 is rejected giving $H_1: \rho < 0$.

In order to use the Pearson correlation coefficient, one must ensure that variables x and y have a normal distribution. However, the Spearman non-parametric correlation coefficient, which is calculated on the basis of rank order, does not require verification of distribution normality.

The Spearman correlation coefficient (r_s) is given by:

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^2}{N(N^2 - 1)}$$

where d_i is the difference in rank order between observation x_i and observation$_i$.

In the same way as for r, one can determine whether r_s is significantly different from zero.

- When N is sufficiently large ($N > 10$), one calculates the following quantity:

$$t = r_s \sqrt{\frac{N-2}{1 - r_s^2}}$$

Since this quantity has a Student distribution with (N-2) degrees of freedom, this value can be compared to the critical value $t(N-2; \alpha/2)$. As seen above, hypothesis H_0 ($r_s = 0$) is accepted if the calculated value (t) falls within the acceptance zone between

$-t\ (N-2;\alpha\ /2)$ and $t\ (N-2;\alpha\ /2)$. Hypothesis H_o is rejected if $|t|$ is greater than $t(N-2;\alpha\ /2)$.

- When N is small ($N < 10$), r_s is compared with a critical value r_o obtained from tables. There is, in fact, a table of values for $r_o\ (N;\alpha\ )$ which $|r_s|$ exceeds in only α % of all cases. Hypothesis H_o (r_s =o) is accepted if $|r_s| < r_o\ (N;\alpha\ /2)$. Hypothesis H_o is rejected if $|r_s| > r_o\ (N;\alpha\ /2)$.

- When N is between 10 and 30, either method can be used to determine whether r_s is significantly different from zero. The results obtained are similar.

APPENDIX C

GEOLOGICAL AND ECOLOGICAL CHARACTERISTICS OF THE WATERSHEDS

Table C.1
Ecological Characteristics of Watersheds in the Study Area: Mean and Standard Deviation for Each Homogeneous Group

Variables	Homogeneous Group									
	1		2		3		4		5	
altitute (m)	645	(179)	408	(136)	396	(60)	465	(156)	303	(67)
W area (km^2)	1.47	(1.92)	1.19	(0.67)	1.36	(0.75)	2.09	(1.36)	0.85	(0.44)
lake area (km^2)	0.14	(0.10)	0.15	(0.11)	0.23	(0.14)	0.20	(0.14)	0.15	(0.10)
bog area (km^2)	0.011	(0.037)	0.044	(0.046)	0.013	(0.023)	0.044	(0.048)	0.004	(0.006)
precipitation (cm)	126.6	(26.3)	97.3	(10.9)	101.4	(14.0)	106.4	(14.6)	96.1	(6.3)
WA/LA	10.5	(6.3)	8.9	(3.8)	6.1	(1.3)	12.8	(11.3)	6.5	(2.9)
SW-NE	7.9	(3.6)	0.66	(5.6)	2.6	(4.7)	1.8	(7.7)	-6.3	(5.2)
SW-NW	1.8	(1.5)	2.9	(1.6)	3.5	(1.3)	3.4	(1.1)	2.8	(1.2)
R + (R+tD) (%)	19.7	(13.8)	7.5	(13.5)	1.5	(2.3)	6.1	(4.4)	13.4	(13.7)
tD/R (%)	24.9	(14.1)	15.3	(15.9)	12.1	(11.1)	23.9	(7.7)	23.7	(12.7)
tD (%)	24.3	(12.6)	28.4	(19.8)	19.1	(14.4)	29.3	(13.6)	25.3	(15.2)
TD (%)	17.5	(18.3)	30.4	(25.6)	47.6	(19.4)	24.9	(10.2)	17.5	(16.4)
ORG (%)	0.47	(1.15)	3.34	(2.97)	0.66	(0.62)	2.16	(1.86)	0.54	(1.05)
CF(O) (%)	16.0	(18.9)	13.5	(12.5)	9.5	(10.0)	13.9	(14.7)	3.5	(5.7)
CF(D) (%)	20.6	(20.9)	11.1	(13.1)	5.1	(10.5)	8.7	(12.0)	11.2	(16.6)
DF(D) (%)	8.9	(13.6)	13.9	(13.6)	26.2	(19.7)	16.3	(20.6)	5.0	(7.6)
DF(D) (%)	8.9	(14.0)	39.9	(19.8)	12.4	(18.8)	23.8	(28.3)	54.3	(25.5)
PC + CC (%)	31.5	(30.5)	4.2	(10.1)	28.2	(19.1)	22.6	(28.8)	6.2	(15.5)
WV (%)	0.7	(1.4)	3.2	(2.7)	1.7	(4.4)	2.6	(2.2)	1.0	(1.7)

( ) standard deviation

Table C.2
Geological Characteristics of Watersheds in the Study Area:
Mean and Standard Deviation of Relative Areas

Type of Bedrock	Homogeneous Group									
	1		2		3		4		5	
1	0.0	(0.0)	1.6	(9.0)	4.8	(13.0)	0.0	(0.0)	5.7	(15.7)
2	0.7	(4.1)	13.5	(34.0)	2.7	(10.8)	3.3	(15.3)	0.0	(0.0)
3	2.0	(9.1)	1.9	(7.6)	7.3	(16.5)	0.0	(0.0)	1.5	(7.8)
4	0.0	(0.0)	10.6	(30.2)	28.4	(45.2)	9.5	(30.1)	9.6	(26.9)
5	1.4	(8.2)	4.0	(13.1)	8.6	(23.4)	3.3	(10.6)	13.6	(21.7)
6	6.8	(24.0)	9.7	(27.1)	2.3	(10.7)	9.5	(30.1)	5.3	(18.7)
7	0.0	(0.0)	8.1	(26.1)	2.7	(12.8)	4.8	(21.8)	16.2	(34.6)
8	82.2	(30.0)	31.5	(43.8)	26.8	(39.8)	45.2	(46.3)	22.2	(31.8)
9	2.0	(9.1)	19.0	(36.3)	16.4	(22.8)	21.9	(36.6)	16.6	(24.6)
10	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	2.4	(10.9)	9.4	(26.6)

( ) standard deviation