

Use of winter-time physico-chemical parameters to characterize the waters of four salmon rivers on the north shore of the Lawrence River: the Petit Saguenay, Ste-Marguerite, Escoumins and Petits Escoumins Rivers

by

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Petit Saguenay, Ste-Marguerite, Escoumins
and Petits Escoumins Rivers.

Study presented to
Fisheries and Oceans Canada

by

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1. INTRODUCTION

Over the past dozen years or so, it has been noted both in Scandinavia and the eastern part of North America, that a significant increase has occurred in the acidity of precipitation (Oden, 1976; Likens, 1976). The adverse effects of acid precipitation on the aquatic environment have been demonstrated by a number of researchers (Wright et al., 1976; Altshuller and McBean, 1979; Likens et al., 1979; Stensland, 1980).

In Quebec especially, this problem caused practically no concern until fairly recently (Jones and Bisson, 1980; Lachance and Bobée, 1981). The first research efforts were limited mainly to lacustrine ecosystems on the Canadian Shield, located north of the St. Lawrence River, where the substrate consisted of granitic rocks (Grimard, 1981; Vigneault and Robitaille, 1979).

On the other hand, the effects of acid precipitation on rivers have not been systematically investigated. Moreover, in Quebec, the regions which are known to be most sensitive to acid rain are the source of many rivers in which an abundance of faunal riches are found. Among these are included large populations of anadromous fish such as salmon (Salmo salar) and brook trout (Salvelinus fontinalis).

In Nova Scotia, the salmon has completely disappeared from nine rivers as a probable result of excessively acid waters, and is threatened in a dozen others (Watt, 1980). In addition, mortality levels in salmon fingerlings has reached 38% at the Mersey piscicultural station

(2) in Nova Scotia when the acidic waters are not treated with calcium carbonate (Farmer et al., 1980). Similar phenomena have also been observed in the northeastern U.S. and in southern Norway (Jensen and Snekvik, 1972; Schofield, 1976). In Quebec, no predictive capability exists which would allow one to assess the urgency of the situation in such a way as to enable the adoption of measures for the protection of salmonid habitats and stocks.

In view of the large gaps in our knowledge of the dynamics of the impact of acid rain on the physico-chemical quality of riverine waters and their ichthyofauna, the Canadian Department of Fisheries and Oceans has engaged the firm, S.A.G.E., Ltd. to carry out a study aimed at the acquisition of data concerning the spatial and temporal variations in the physico-chemical quality of the waters of four salmon rivers located on the north shore of the St. Lawrence River. This study thus forms a fundamental part of the efforts by the Department in conserving the salmon resources of eastern Canada.

The present report documents the results of a winter sampling program carried out on the rain and snow precipitation in the rivers, Petit Saguenay, Escoumins, Petits Escoumins, and Ste-Marguerite, from an eco-toxicologic point of view vis-a-vis the local salmon resources. It also presents a series of pertinent recommendations pointing out areas for future research.

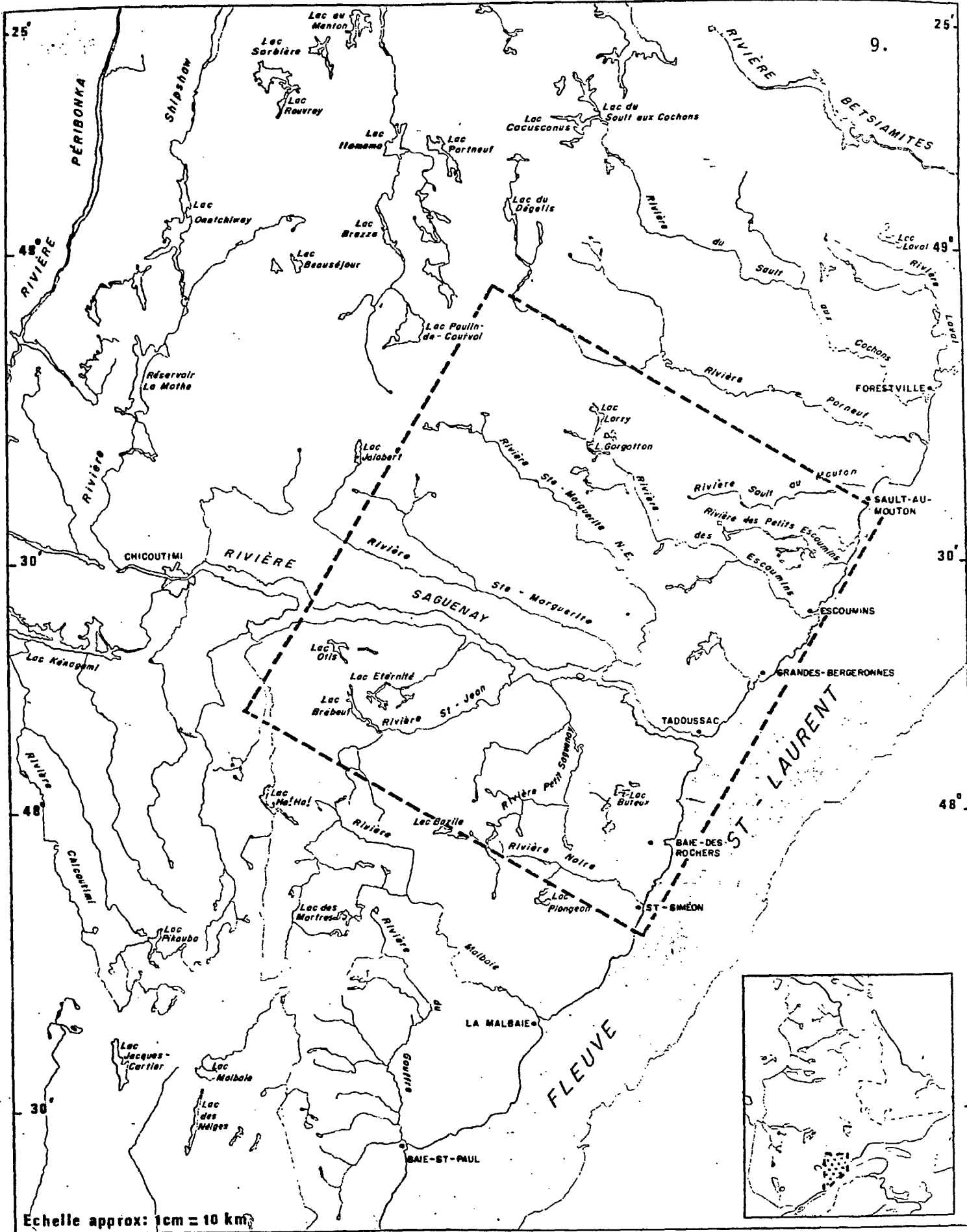


Figure 1 (Location map of the study area)
LOCALISATION DU TERRITOIRE À L'ÉTUDE

2. DESCRIPTION OF THE STUDY AREA

2.1 General description

2.1.1 Geographic location

The study area, through the centre of which flows the Saguenay River, is defined most precisely by the watershed boundaries of the Petit Saguenay, the northeast Ste-Marguerite, the Escoumins, and the Petit Escoumins Rivers (Figure 1).

2.1.2 Climate

Local climatic data were extracted from meteorological statistics kept by the Quebec Ministry of the Environment and Ministry of Natural Resources (Ferland and Gagnon, 1974) pertaining to the climate of central Quebec. They correspond to those of five meteorological stations: Tadoussac, Petit Saguenay, Grandes Bergeronnes, and Escoumins.

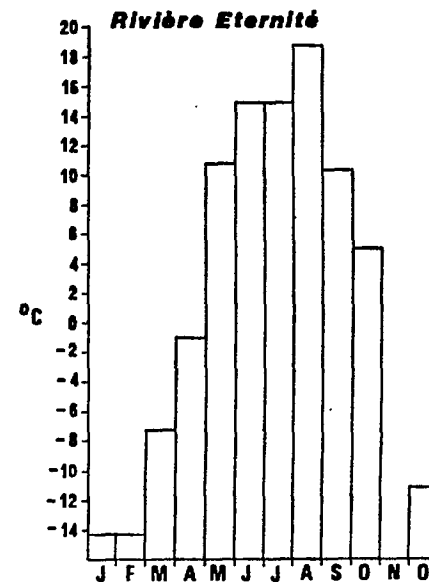
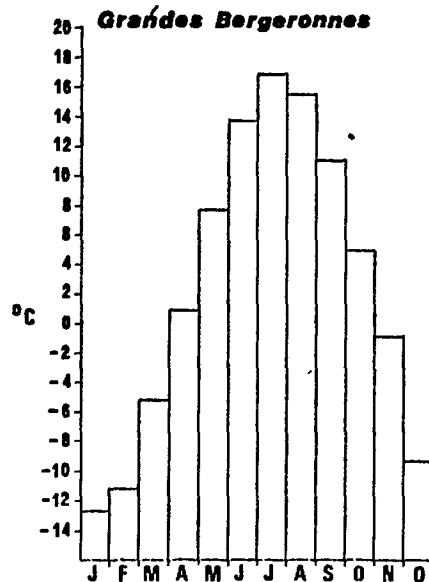
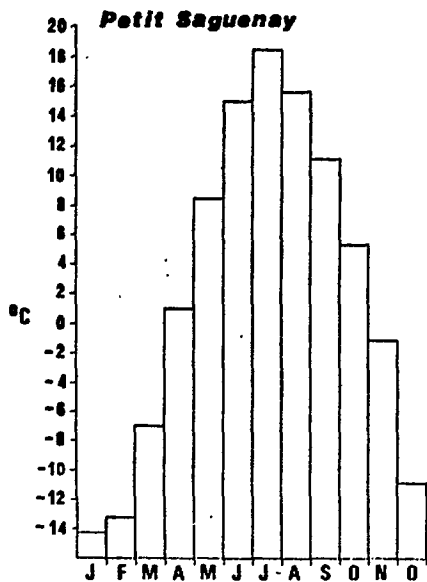
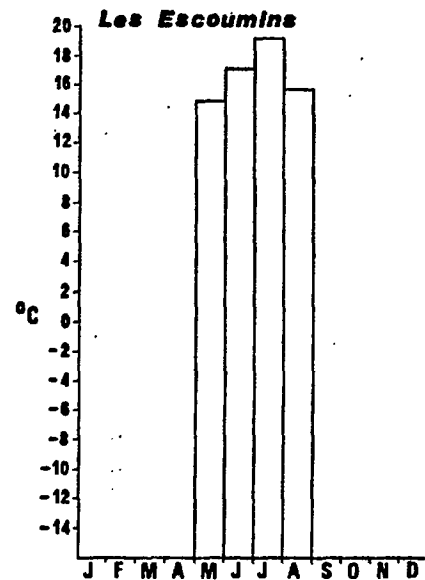
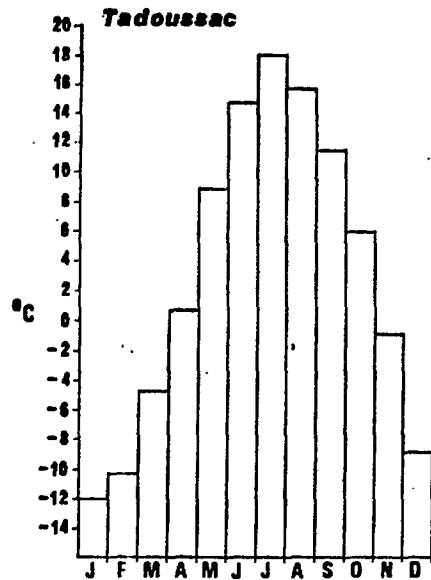
The area is crossed by two mean annual temperature isotherms, that of 2.2°C and 1.5°C, both of which run parallel and to the north of the St. Lawrence River. The mean July temperature lies between 14.0°C and 16.5°C, while that of January is between -11.0°C and -13.5°C. The histograms in Figure 2 show the mean annual temperatures for the areas, which are seen to be relatively uniform.

- (6) Total annual precipitation values for the area are in the order of 80 - 120 cm, with a snow component of 30 - 35%. Total monthly precipitation, as indicated by the histograms in Figure 3, shows that the months of August and July are the wettest, while January and February

FIGURE 2

HISTOGRAMMES DES TEMPÉRATURES MOYENNES MENSUELLES
OBTENUES À CINQ STATIONS MÉTÉOROLOGIQUES DE LA CÔTE NORD

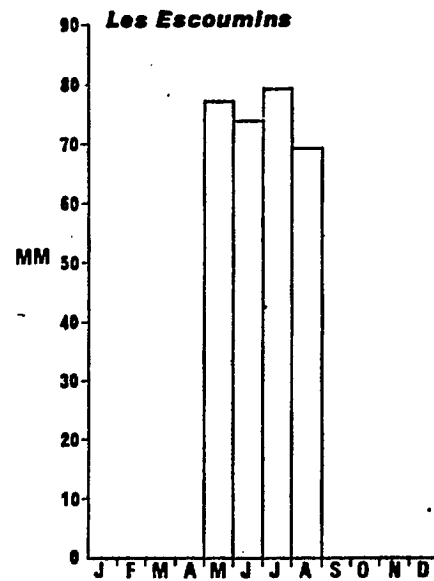
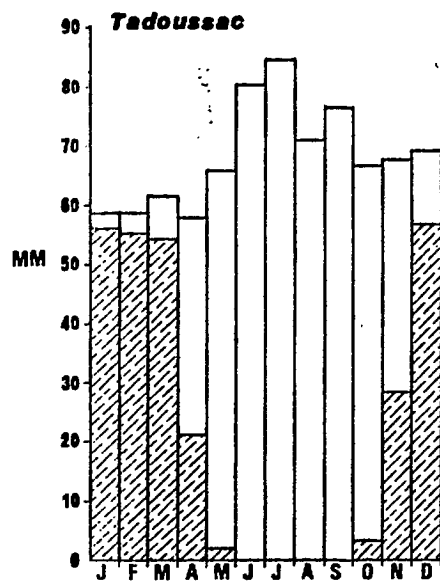
(Histograms of mean monthly temperatures measured at 5 met. stations on the north shore)



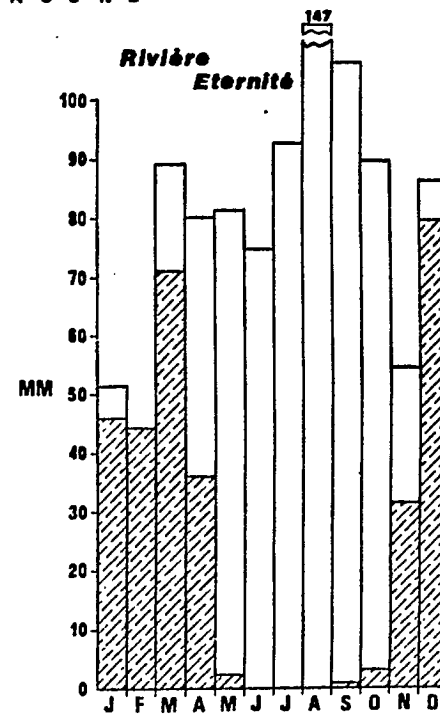
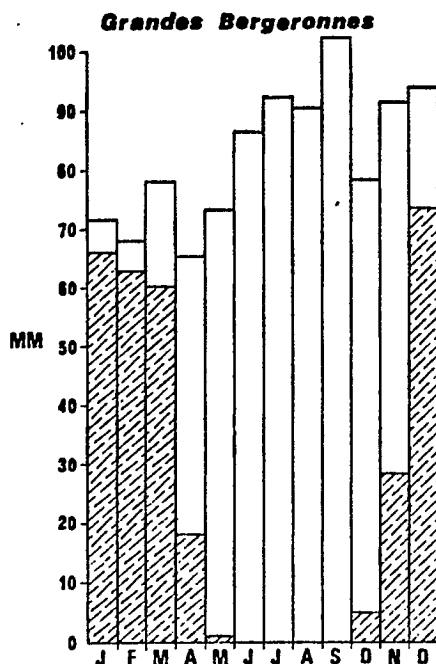
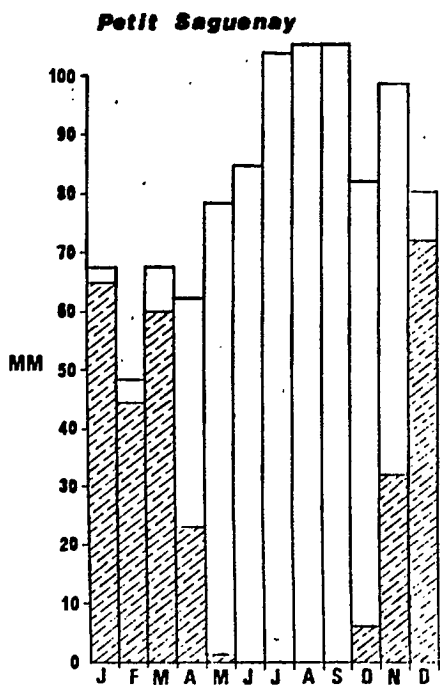
SOURCE: GAGNON ET FERLAND (1974)

FIGURE 3

HISTOGRAMMES DES PRÉCIPITATIONS TOTALES MENSUELLES (Histograms of total monthly precipitation at 5 met. stations on the north shore)
 OBTENUES À CINQ STATIONS MÉTÉOROLOGIQUES DE LA CÔTE NORD (obtained at 5 met. stations on the north shore)



Pluie (rain)
 Neige (snow)



SOURCE: GAGNON ET FERLAND (1974)

are the driest. Maximum 24-hour rainfall is 7.5 cm at a recurrence interval of 10 years, and 8.75 to 10 cm at an interval of 25 years. The annual surface runoff deficit is equivalent to 32 cm in the area, which indicates that the precipitation component which goes toward surface flow and percolation is around 70% annually.

2.2 Geomorphological description

2.2.1 Relief

The area drained by the four rivers involved is situated on the fringes of a large undulating plateau characteristic of the eastern segment of the Canadian Shield. The plateau shows strongly incised lineations of tectonic origin, which give it a broken, hilly aspect. These lineations lie in two directions: WNW - ESE and SW-NE. The WNW - ESE features (e.g. Saguenay, northeast Ste-Marguerite) are much more developed.

The surface of the plateau at an altitude of 400 to 600m is tilted from west to east. The deep entrenchment of the valleys, which is at times spectacular, has allowed their partial infilling by sediments of a glacial, fluvio-glacial, marine, and deltaic nature.

During the progressive retreat of the Goldthwait Sea, these sediments were eroded into terraces by the action of rivers which later took over these pre-glacial valleys (Laurin and Sharma, 1975).

(8) 2.2.2 Surficial sediments

The area is covered in part by sediments deposited during the glacial and post-glacial periods.

The glacial sediments comprise mainly till and fluvio-glacial deposits. The till forms a discontinuous cover of variable thickness over the highlands of the Canadian Shield. In the more low-lying areas, the till is buried below more recent deposits and its presence is revealed only in certain areas where erosion has removed the overlying material. The fluvio-glacial deposits, deposited during the period of ice melting, are concentrated mainly in valleys and depressions, where they take the form of outwash plain and kame terrace deposits. On top of the plateaus, these deposits are present in the form of eskers.

The post-glacial deposits comprise marine clays, deltaic sediments, and recent fluvial sediments. The clays, laid down by the Goldthwait Sea are found in the area at up to elevations of 135 m on average. They are overlain by deltaic and fluvial sands in the valleys. For example, at the north-east Ste-Marguerite River, the marine infilling only reached the 130 m contour, and the deltaic sands are present at up to 150 m. On the other hand, at the Escoumins River, clays are found at up to 120 m altitude and deltaic sediments at close to 152 m.

Some regional geochemical analyses have been conducted on surficial sediments by the Ministry of Natural Resources of Quebec (Laurin and Sharma, 1975). The objective was to determine the concentration ppm of the following minerals: copper, zinc, lead, cobalt,

nickel, silver, manganese, molybdenum, and uranium. Two samples in this study were taken from the Escoumins River, and one from the north-east Ste-Marguerite River. Plotted on a map (Appendix 7), these samples are characterized by a marked dominance of manganese, followed by zinc.

(9) 2.2.3 Rock substrate

In the study area, the bedrock is mainly composed of crystalline rocks typical of the Canadian Shield, and form part of the Grenville geological province. They were formed during the Pre-Cambrian period, i.e. 950 - 150* million years ago. These rocks are composed primarily of gneissic types: migmatites, granite gneiss, grey granite, and charnockite gneiss. To a lesser extent, outcrops of intrusive rocks occur, cutting through these gneisses, and are represented mainly by mangerite.

Tectonic activity involving this rock assemblage has resulted in a network of orthogonal faults, trending northwest and northeast. This pattern has had a strong influence on the local hydrological network.

The chemical analyses carried out under "Project Grenville" (Franconi et al., 1975), show that the gneisses of the region are rather uniform in chemical composition. The gneisses range from 56 to 72% SiO₂, 13 to 19% Al₂O₃, and minor percentages of other components (Table 1).

* This is an obvious error. The Pre-Cambrian ended around 600 million years ago. It began around 4.5 billion years ago.

TABLEAU 1.

COMPOSITION CHIMIQUE DE LA ROCHE-MERE (GNEISS GRIS) DU TERRITOIRE A L'ETUDE *
 (CHEMICAL COMPOSITION OF THE BEDROCK (GRAY GNEISS) OF THE STUDY AREA)

stations oxydes	RJ-203	MF-106	MF-115A	RJ-56	RJ-66	RJ-112	BD-160	BG-21c	CK-4	CK-114 ¹	DB-116 ²	FB-283 ³	FB-300 ³
SiO ₂	65.00	67.00	58.50	65.40	58.70	63.10	55.80	56.81	63.49	63.00	69.47	69.35	72.44
Al ₂ O ₃	15.30	15.95	17.80	15.26	18.90	17.70	18.18	18.60	16.33	16.20	14.17	14.80	13.14
Fe ₂ O ₃	2.31	2.01	2.88	0.95	1.71	1.46	2.12	2.86	1.34	2.41	0.86	2.11	1.65
FeO	3.77	2.29	4.18	4.36	3.57	2.66	4.27	3.67	3.03	3.35	2.26	1.28	1.76
MgO	1.42	1.59	3.25	1.19	2.26	1.66	3.62	2.25	2.25	2.03	1.17	0.50	0.62
CaO	3.70	3.42	6.66	2.69	5.78	4.67	6.78	4.88	4.35	4.48	2.37	1.63	1.71
Na ₂ O	4.00	3.24	3.54	2.85	5.04	5.20	3.86	5.00	3.86	3.90	2.65	3.30	3.02
K ₂ O	2.15	2.90	0.77	5.35	1.70	1.56	1.95	2.05	2.15	2.90	4.96	4.64	3.96
H ₂ O	0.05	0.03	0.05	0.06	0.05	0.03	0.04	0.04	0.05	0.05	0.04	0.02	0.02
H ₂ O	0.42	0.47	0.73	0.65	0.73	0.43	0.70	0.56	0.71	0.38	0.48	0.30	0.33
TiO ₂	0.81	0.51	0.63	0.63	0.72	0.60	0.90	0.88	0.68	0.75	0.38	0.46	0.40
P ₂ O ₅	0.30	0.15	0.21	0.23	0.28	0.33	0.36	0.25	0.17	0.23	0.12	0.08	0.05
MnO	0.14	0.14	0.18	0.11	0.11	0.08	0.14	0.24	0.09	0.14	0.06	0.09	0.05
CO ₂	0.12	0.08	0.10	0.11	0.15	0.06	0.14	0.36	0.10	0.00	0.25	0.16	0.30
total	99.49	99.78	99.48	99.84	99.70	99.54	98.86	98.44	98.60	99.82	99.24	98.72	99.45

1 - Contient un peu de feldspath potassique (contains a bit of potassic feldspar)

2 - Riche en quartz (rich in quartz)

3 - Gneiss gris à grain fin (fine-grained gray gneiss)

* Tiré de Franconi et al. (1975) (from Franconi et al., 1975)

It should be noted that the identification codes shown in this table represent samples originating in a region situated to the north of the study area. However, their representativeness in this case is justifiable considering the uniformity of chemical composition which characterizes the grey gneiss occupying this part of the Grenville geological province (Franconi, pers. comm.).

2.3 Hydrologic description

(12) Some hydrologic characteristics of the rivers are presented in Table 2. The water-shed of the Petits Escoumins River has a much smaller area than that of the three others. It is also noteworthy that two stations on the Petit Saguenay (PS-1) and the Escoumins (ES-1) Rivers are located in the upstream sector of their respective water-sheds while the other sample sites (SM-1, ES-2, and PE-1) are located more downstream and, as a result, are more representative of these watersheds. The hydrologic properties shown in Table 3 focus mostly on the values for mean annual discharge, mean discharge values for the summer and winter seasons, as well as minimum and maximum values recorded for the four rivers studied.

(14) 3. EQUIPMENT AND TECHNIQUES

3.1 Selection of the rivers

The rivers studied in this project were chosen on the grounds of certain common characteristics. They are, in effect, well-known as water courses having a significant salmon population; they are situated in a zone recognized to be sensitive to acid precipitation; they

TABLE 2

SUMMARY HYDROGRAPHY OF THE WATER-COURSES... IN THE STUDY AREA AND
CHARACTERISTICS OF THE SAMPLING STATIONS USED

PARAMETERS WATER-COURSE	LENGTH (km)	AREA OF THE BASIN (m ²)	MAXIMUM ALTITUDE (m)	MEAN SLOPE (%)	SAMPLING STATIONS	
					ALTITUDE (m)	% OF BASIN UPSTREAM OF THE STATION
RIVIERE DES ESCOUMINS	84	797	580	0,66	ES-1 300 ES-2 40	ES-1 45 ES-2 99
RIVIERE DES PETITS ESCOUMINS	26	139	225	0,59	PE-1 70	PE-1 78
RIVIERE PETIT SAGUENAY	75	817	625	0,74	PS-1 275	PS-1 35
RIVIERE SAINTE-MARGUERITE NORD-EST	90	1010	710	0,90	SM-1 190	SM-1 81

TABLE 3
HYDROLOGIC CHARACTERISTICS OF THE RIVERS STUDIED

Rivers		DES ESCOUMINS (N = 15) **	DES PETITS ESCOUMINS *	PETIT SAGUENAY*	STE- MARGUERITE N.E. (N = 6) **
Discharge					
Mean annual disch. (m ³ /s)		15,4	2,70	23,0	31,0
Mean discharge in summer low water period		152,4	26,7	8,68	11,7
Mean discharge in winter low water period		2,58	0,45	2,40	3,23
Minimum recorded discharge		1,47	0,26	1,41	1,90
Maximum recorded discharge		326	57,1	426	575
Start of the breakup	Earliest date	25 mars	---	20 mars	20 mars
	Latest date	29 avril	---	16 avril	16 avril

* Extrapolation by transposition of the drainage basin

** Number of years observed

are situated in the same geomorphic and climatic continuum, and are not affected by any nearby industrial wastes.

The presence of a limnometric station for the Petit Saguenay and Ste-Marguerite Rivers was an equally important factor in the choice of the study area.

3.2 Selection of stations

The choice of the five sampling stations (Appendix 7) was made on the basis of their importance as appropriate sites for salmon spawning. The evaluation technique for these sites was based primarily on characterization by aerial photography of river sections in terms of stream morphology, flow properties, and bed material grain-size properties. These factors led to the classification of the sections and to the choice of the ones showing the best potential for spawning.

The rivers, Petits Escoumins, Petit Saguenay, and Ste-Marguerite have only one sampling site located in their upstream sectors. As for the Escoumins River, two sites are located there, one in the upstream part, and the other near its mouth. This choice was made in order to assess the extent of spatial variations in water quality of this water course.

(15) 3.3 Techniques of sampling and analysis

In all, three series of water and snow samplings were carried out at one month intervals between January 2 and March 17, 1981. These samplings were possible only due to the provision of a helicopter by Fisheries and Oceans Canada.

Polyethylene bottles (1 litre) were filled with water by gradual immersion, while the snow samples were collected by means of a plastic pipe (10 cm in diameter by 1 metre in length) inserted vertically, thus obtaining an integration of the entire snow column. The snow was then transferred to 4.5 litre polypropylene containers.

For the determination of major cations and trace metals in the water, the poly. bottles were first rinsed several times in 15% nitric acid and then in de-ionized water. When the samples were taken, a volume of 5 ml of purified nitric acid (ULTREX) was added to each. For mercury determination, the glass bottles, containing 30 ml of sample, were also frequently washed over a period of several hours, in 15% nitric acid and rinsed afterwards in de-ionized water, after which they were dried at 200°C. After cooling the bottles, a volume of 15 ml nitric acid (HN₃ - 5%) and potassium bichromate (K₂Cr₂O₇ - 0.01%) was added to them in accordance with the method of Feltman (1974). As for the polypropylene bottles used to collect the water samples destined for the analysis of other physico-chemical parameters, these underwent prior washing in de-ionized water.

Transfer of the water and snow samples to the Eco-Research Laboratory in Montreal was done as quickly as possible (24 hrs) in refrigerated condition (temperature about 4°C).

(16) All the physico-chemical parameters associated with the snow samples, except sulphates, were determined using a decanted sub-sample. In the case of the sulphates, the analysis was done on a

filtered sub-sample (Wathman filter no. 41, washed after filtering in de-ionized water).

As for the water samples, these were taken quickly to room temperature, and all analyses were carried out on the day the samples were received at the laboratory. One exception was the samples for metals analysis, which, having been preserved in 0.5% nitric acid (see above), were able to be determined later, but no more than 7 days after.

For the analysis of the metals, using atomic absorption spectrophotometry, the water samples were subjected to acid digestion. A volume of 200 ml of water was evaporated almost to dryness in the presence of 5 ml of HNO_3 high quality concentrate (ULTREX), then heated in a reflux in the presence of concentrated HNO_3 and again evaporated almost to dryness. The residue was dissolved in 50 ml of HNO_3 (0.5%) and used for the determination of major cations (Na, K, Ca, Mg) and trace metals (Al, Cd, Cu, Fe, Mn, Ni, Pb, Zn). The preparation of water samples for mercury analysis by the so-called "cold vapour" method was different from the above. The preparation technique of Best (1979) was adopted, which recommends a more complex acid digestion, followed by a reduction of the Hg^{++} ions with stannous chloride.

In general, the physico-chemical measurements have been done within the time periods prescribed, and in accordance with methods recommended by EPA (1974) and APHA-WPCF (1975), which are listed in Table 4 and given in detail in Appendix 1. In any event, for the deter-

TABLE 4
PHYSICO-CHEMICAL METHODS USED FOR THE ANALYSIS OF WATER AND SNOW
SAMPLED FROM 4 SALMON RIVERS OF THE NORTH SHORE
(WINTER 1981)

PARAMETER	METHODOLOGY	TYPE OF APPARATUS	UNITS OF MEASUREMENT	DETECTION LIMITS
pH	electrometry	ORION pH meter (407A/F)	-	-
alkalinity	titration	ORION pH meter (301A)	mg CaCO ₃ /l	1 mg/l
NH ⁺	potentiometry	ORION ion analyzer (801A) specific electrode HNU (ISE-10-10-00), sensitive to NH ₃ gas	mg N/l	0.01 mg/l
NO ₃ ⁻	potentiometry	ORION ion analyzer (801A) specific electrode ORION (93-07) for NO ₃	mg N/l	0.01 mg/l
NO ₂ ⁻	spectrophotometry	UNICAM spectrophotometer SP 1800 U.V.	mg N/l	0.005 mg/l
SO ²⁻	spectrophotometry	(same as above)	"	0.2 mg/l
Cl ⁻	titration	-	mg/l	0.2 mg/l
organic & inorganic carbon	CO ₂ determination	Beckman 915-B carbon analyzer	mg C/l	0.1 mg/l
conductivity	electrometry	ZETA-METER model D	μmho/cm	1 μmho/cm
colour	visual comparison	Hellige "Aqua tester" model	HAZEN	1 HAZEN unit
turbidity	nephelometry	Hellige turbidometer	mg SiO ₂ /l	0.05 mg SiO ₂ /l
Hg	digestion, atomic absorption (flameless, cold vapour)	Pharmacia mercury monitor, Perkin-Elmer pump	mg/l	0.1 μg/l
Na	digestion, atomic absorption	PERKIN-ELMER (403) atomic absorption spectrophotometer	mg/l	2 μg/l
K	"	"	"	10 μg/l
Ca	"	"	"	"
Mg	"	"	"	1 μg/l
Trace metals Cu, Fe, Ni, Pb	digestion, flameless A.A.	PERKIN-ELMER (403) atomic absorption spectrophotometer, HgA furnace 2100 background noise corrector (deuterium arc)	μg/l	1 μg/l
Al	"	"	μg/l	3 μg/l
Cd	"	"	μg/l	0.1 μg/l
Mn	"	"	μg/l	0.2 μg/l
Zn	"	"	μg/l	0.05 μg/l

mination of the total alkalinity, a method was chosen which allowed calculation of the Gran function from pH measurements compared to the volume of titrant (H_2SO_4 0, 2N) added (Stumm and Morgan, 1970).

(18) 4. RESULTS AND DISCUSSIONS

In the first part of this section, the results relating to surface water quality are presented, while stressing the importance of spatial and temporal variations in the physico-chemical parameters measured. Later on, the results obtained from the snow sampling program are examined in order to estimate the magnitude of contributions from this source.

4.1 Quality of surface waters

The results concerning water quality are given according to sampling date and station in Appendix 2, and are summarized in Table 5, which will be the source used for the data interpretation which follows. In the paragraphs below, after verifying the data quality, an interpretation will be made of the results grouped in three categories: major ions, nutrient elements, and trace metals.

4.1.1 Verification of the validity of the results

The ionic balance presented in Figure 4 shows the respective positions of each of the sampling stations in this regard compared to the line of unit slope. It is clear that the sum of the anions is almost identical to that of the cations. Deviations from this are

QUALITE PHYSICO-CHEMIQUE DES EAUX DE QUATRE RIVIERES A SAUMONS DE
LA COTE-NORD: VALEURS MOYENNES DES TROIS TOURNEES HIVERNALES (1981).

(Physico-chemical quality of water from four salmon rivers of the north shore:
mean values for three winter samplings (1981))

PARAMETRES	PEITIT SAGUENAY (PS-1)	STE-MARGUERITE (SM-1)	DES PETITS ESCOUMINS (PE-1)	DES ESCOUMINS (ES-1)	DES ESCOUMINS (ES-2)
pH (25°C)	6,9	6,7	6,7	6,5	6,7
Hydrogène (H ⁺)	(.137)	(.186)	(.217)	(.334)	(.192)
Conductivité (µS/cm, 25°C)	34	29	33	22	26
C. Organique (C, mg/l)	6,8	5,4	8,2	6,1	5,2
C. Inorganique (C, mg/l)	3,2	1,7	2,9	2,3	2,4
Alcalinité (CaCO ₃ , mg/l)	11,7 (234)	5,3 (106)	8,7 (174)	4,5 (90)	7,3 (146)
Turbidité (SiO ₂ , mg/l)	1,63	1,53	2,55	1,72	1,70
Couleur vraie (Hazen)	22	20	43	37	28
Nitrates (N-NO ₃ , mg/l)	0,62 (44)	0,66 (47)	0,36 (26)	0,77 (55)	0,50 (36)
Ammonium (n-NH ₄ ⁺ , mg/l)	0,05 (4)	0,03 (2)	0,02 (1)	0,04 (3)	0,02 (1)
Chlorures (Cl ⁻ , mg/l)	0,67 (19)	0,84 (24)	0,91 (26)	0,94 (27)	1,05 (30)
Sulfates (SO ₄ ⁻ , mg/l)	7,1 (148)	6,2 (129)	6,7 (139)	5,5 (115)	6,6 (137)
Sodium (Na ⁺ , mg/l)	1,51 (66)	1,44 (63)	2,46 (107)	1,63 (71)	1,97 (86)
Potassium (K ⁺ , mg/l)	0,58 (15)	0,57 (15)	0,82 (21)	0,79 (20)	0,68 (17)
Calcium (Ca ⁺⁺ , mg/l)	4,6 (230)	2,6 (130)	3,8 (190)	2,5 (125)	3,3 (165)
Magnésium (Mg ⁺⁺ , mg/l)	0,80 (66)	0,70 (58)	0,79 (65)	0,75 (62)	0,88 (72)
Fer (Fe, µg/l)	75	90	133	136	213
Manganèse (Mn, µg/l)	2,2	4,1	7,3	5,3	4,2
Aluminium (Al, µg/l)	40	62	89	44	63
Cadmium (Cd, µg/l)	0,1	0,2	0,2	< 0,1	< 0,1
Cuivre (Cu, µg/l)	< 1	< 1	< 1	< 1	< 1
Nickel (Ni, µg/l)	< 1	< 1	< 1	< 1	< 1
Plomb (Pb, µg/l)	4	13	8	6	8
Zinc (Zn, µg/l) **	16,4	30,8	30,0	52,0	30,8
Mercuré (Hg, µg/l) **	< 0,2	< 0,2	0,5	< 0,2	< 0,2

* Les valeurs entre parenthèses sont exprimées en µeq/l. (values in parentheses are in eq/l)

** Ces résultats pour le zinc et le mercure, représentent les valeurs obtenues lors des dosages du dernier échantillonnage du mois de mars seulement.

(these results for zinc and mercury are from values obtained on determinations of the last sampling (March) only).

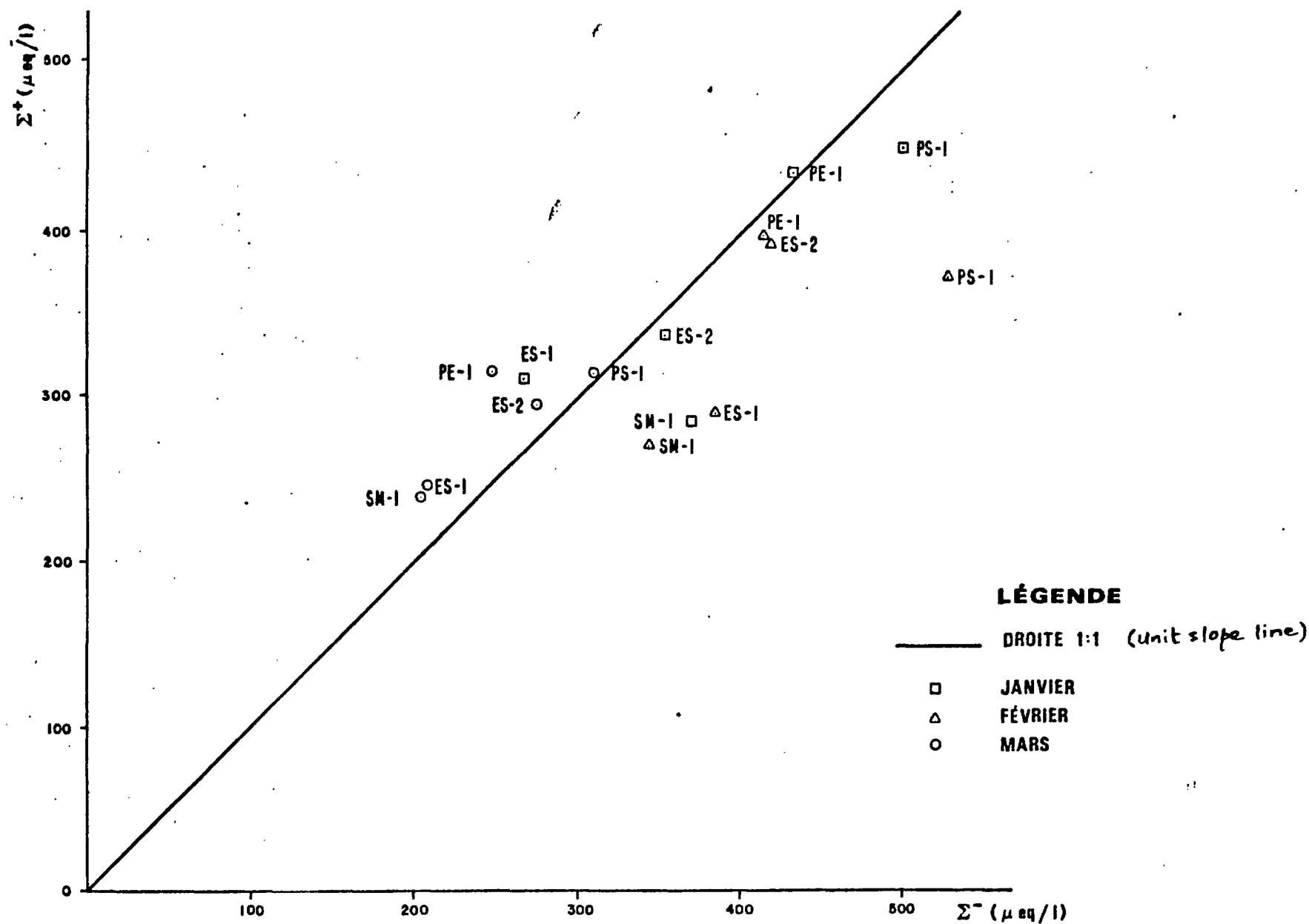
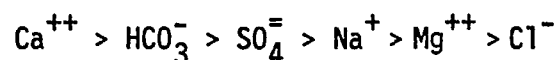


Figure 4: BILAN IONIQUE SELON LA STATION ET LE MOIS D'ECHANTILLONNAGE PAR RAPPORT À LA DROITE 1:1 (Ionic balance according to station and month of sampling compared to the unit slope line)

generally minor, a fact which confirms the precision of the analyses carried out, and also the validity of the choice of parameters measured.

4.1.2 Major ions

Waters, whose conductivity fluctuates around the value of 30 $\mu\text{S/cm}$, are typical of regions in which the local rocks are not readily altered (granite gneiss). The concentrations of the principal ions mentioned in Table 5 are expressed diagrammatically in percentage values in Figures 5 and 6. These figures allow one to establish the following order of importance:



(23) What we have here is essentially a calcium carbonate type water. Calcium comprises, in effect, 50% of the cation total, while bicarbonate comprises 45% of the anions. The alkalinity is, above all, associated with the bicarbonates, since the pH values measured range between 6.5 and 6.9. Total inorganic carbon, which was determined in order to estimate the alkalinity due to the carbonates, shows values ranging from 1.7 to 3.2 mg/l of carbon.

The alkalinity can be proved to be proportional, in oligotrophic waters such as these, to the total inorganic carbon, which in turn represents the sum of the carbonate, bicarbonate, and carbonic acid components. The values obtained are representative of a water which flows over a granitic substrate (4.5 to 11.7 mg CaCO_3/l in alkalinity, and 1.7 - 3.2 mg C/l in inorganic carbon.

It was noted that the sulphate component was relatively high in these waters (33 to 42% of the anion total). It is possible that it is mainly of atmospheric origin since in the drainage basins studied, sedimentary rocks (argillaceous shales, and gypsum capable of supplying sulphate) are very scarce.

As for the very low chloride levels (19 to 30 $\mu\text{eg}/\text{l}$), their provenance might be associated, to a large degree, with marine aerosols formed by the evaporation of droplets of salt water in suspension in the atmosphere (Sasseville and Lachance, 1981).

Among cations, magnesium (58 to 72 $\mu\text{eg}/\text{l}$) and sodium (63 to 107 $\mu\text{eg}/\text{l}$), as well as calcium, all originate in the alteration of local rocks and the dissolution of minerals (ferromagnesian, feldspar, and amphibole) by carbonic acid, which also results from the going into solution of carbon dioxide.

(24) Although potassium is only sixth in abundance among the elements present in igneous rocks (Hem, 1970), it behaves differently from other parameters. In effect, during leaching, in contrast to sodium (which is transported in surface waters), potassium is usually incorporated in stable minerals. As a result, it is scarce in surface waters, with observed contents ranging between 15 and 20 $\mu\text{eq}/\text{l}$.

4.1.3 Nutrient elements and associated factors

Nitrates and ammonia resulting from the oxidation of organic nitrogen are found in very low concentrations, namely, 0.36 to

0.77 mg/l for nitrates, and 0.02 to 0.05 mg/l for ammonia. These concentrations characterize an oligotrophic environment.

The water colour resulting from the leaching of organic debris is due primarily to insoluble humic compounds, to soluble fulvic compounds, and to some metallic ions (manganese and iron). The values obtained are relatively high for oligotrophic waters as they reach as high as 43 Hazen units (station SM-1).

Total organic carbon is also a measure of the amount of organic debris present in water. In oligotrophic environments, the values reach a relatively high plateau, i.e. 5.2 to 8.2 mg/l of carbon.

In contrast to conductivity, turbidity levels, which we associate with the quantity of dissolved substances in the water, is expressed as particle concentrations (silt, clay, organic matter) held in suspension by turbulent flow or Brownian motion. In winter, the turbidity of the rivers visited was around 1.5 to 2.5 mg/l of SiO_2 , which is considered normal for this type of water.

4.1.4 Trace metals

Among the metals analyzed, those having the highest values were iron (75 - 213 $\mu\text{g/l}$), aluminium (40 - 89 $\mu\text{g/l}$), and manganese (2.2 - 7.3 $\mu\text{g/l}$).

(25) Aluminium, if one considers the value given as a quality criterion (100 $\mu\text{g/l}$) for the protection of aquatic life (Appendix 6), is found in rather high quantities in ^{the} oligotrophic waters of the 4 rivers

sampled on the north shore of the St. Lawrence River. In fact, the concentrations detected ranged from 40 to 89 $\mu\text{g}/\text{l}$.

Insofar as iron is concerned, its concentration (75 - 213 $\mu\text{g}/\text{l}$) is far less than the 1.0 mg/l used as a threshold standard by the EPA (1976). It is probably present in the form of organic complexes or as iron hydroxide since at a pH close to neutral values, iron in the ferrous form (Fe^{++}) is scarce and is most likely taken up with other compounds or oxidized (Hem, 1970).

As for manganese, it also is found in quantities much lower (2 to 7 $\mu\text{g}/\text{l}$) than the standard (50 $\mu\text{g}/\text{l}$) recognized by the EPA (1976). In fluvial environments, it exists only in the form of Mn^{++} , which is rather stable (Hem, 1970).

All the other trace metals (Cd, Cu, Zn, Hg, Ni and Pb) were analyzed bearing in mind their potential toxicity for fish fauna. Their abundance was very much less than the stated quality criteria for aquatic organisms (Appendix 6 and EPA, 1976). It must be noted that the results obtained for zinc and mercury, which appear in Table 5, represent values obtained only on determinations involving the last sample collection in March. The raw results on samplings done in the months prior to March are presented, however, in Tables 2.3 and 2.4 of Appendix 2.

Some difficulty in the analysis (due mainly to contamination of the nitric acid used) was encountered in determinations of these parameters involving the first two series of samples, and as a result, it is not possible to use these values for establishing a mean value as in

the other parameters. One can, nevertheless, rely on the values retained since these difficulties had already been resolved near the end of the second series of analyses.

(26) 4.1.5 Spatial and temporal variations

The extent of variations observed from one station to the next, and for each of the sampling episodes is illustrated in Figures 5 and 6.

It is apparent that for the February sampling episode, relatively higher concentrations were noted in several parameters. These rises in concentration values could be explained by a false thaw observed in all the study area at this time. In fact, the maximum temperature at the Grandes-Bergeronnes meteorological station during our sample collection trip reached 7.5°C (Quebec Ministry of the Environment, preliminary data for station 70422840).

During the month of March, the concentration of ions was lower than at other times. This decline was especially noticeable for the bicarbonates, for calcium, and for the sulphates.

The method of analysis of variance, two factors (Appendix 4) was applied in order to expose the relative magnitude and significance of spatial and temporal variations. The results of this analysis are presented in detail in Appendix 5 and, in summary form, in Table 6. The parameters which showed significant variation in the time domain ($P < 0.05$) are as follows: Ca, Mg, SO_4 , Cl, NO_3 , conductivity, and colour. Those showing significant spatial variation consisted only of calcium, sodium,

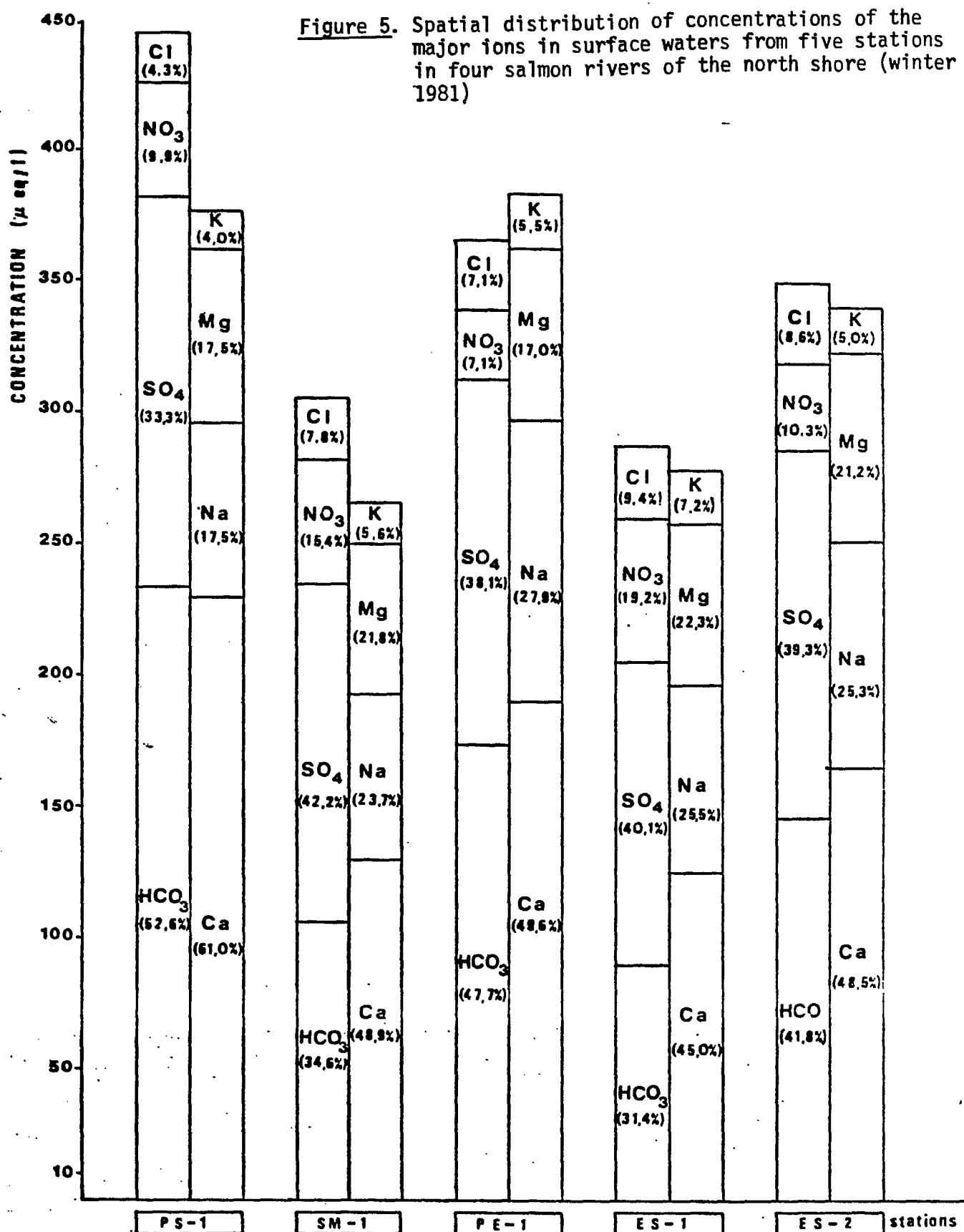


Figure 5 : ÉVOLUTION SPATIALE DE LA CONCENTRATION DES PRINCIPAUX IONS DANS LES EAUX DE SURFACE À CINQ STATIONS, DANS QUATRE RIVIÈRES À SAUMONS DE LA CÔTE-NORD (HIVER 1981)

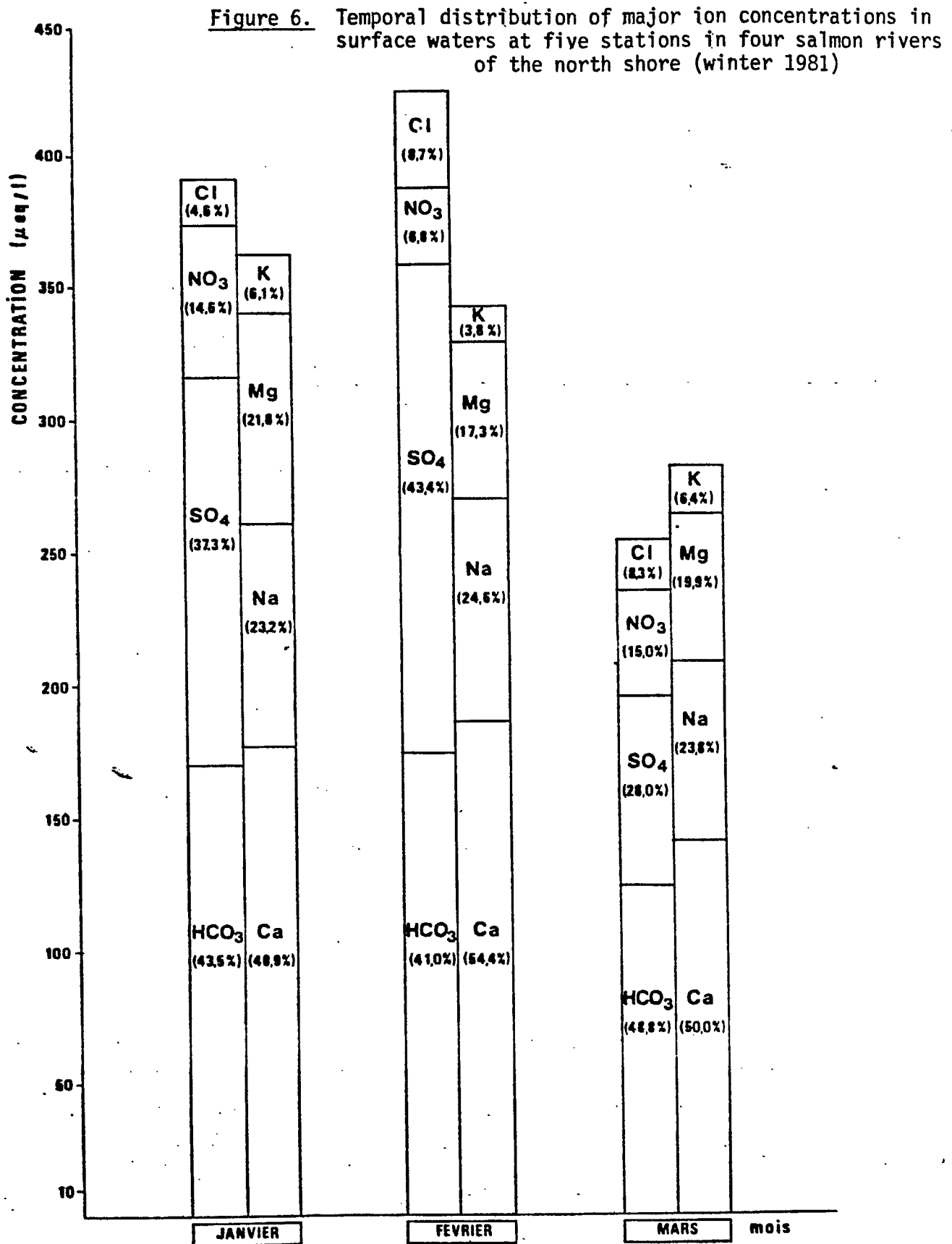


Figure 6: ÉVOLUTION TEMPORELLE DE LA CONCENTRATION DES PRINCIPAUX IONS DANS LES EAUX DE SURFACE À CINQ STATIONS, DANS QUATRE RIVIÈRES À SAUMONS DE LA CÔTE-NORD (HIVER 1981)

TABLE 6
SPATIAL / TEMPORAL COMPARISON BY ANALYSIS OF VARIANCE
(TWO FACTORS) ON PARAMETERS MEASURED IN THE WATERS OF
FOUR SALMON RIVERS OF THE NORTH SHORE (WINTER 1981)

PARAMETER	ANALYSIS OF VARIANCE	
	TIME (2 degrees of freedom)	SPACE (4 degrees of freedom)
pH	NS*	NS
Hydrogène (H ⁺)	NS	NS
Conductivité	<.05	.01
Alcalinité (CaCO ₃)	NS	NS
Turbidité (SiO ₂)	NS	NS
Couleur vraie (Hazen)	<.01	<.01
Nitrates (N-NO ₃ ⁻)	.01	NS
Ammonium (N-NH ₄ ⁺)	NS	NS
Chlorures (Cl ⁻)	<.05	NS
Sulfates (SO ₄ ⁼)	<.01	NS
Sodium (Na ⁺)	NS	<.05
Potassium (K ⁺)	NS	NS
Calcium (Ca ⁺⁺)	<.01	<.01
Magnésium (Mg ⁺⁺)	<.01	NS
Fer (Fe)	NS	NS
Manganèse (Mn)	NS	NS
Aluminium (Al)	NS	NS

* NS - not significantly different from 0 at the 5% confidence level (p > 0.05)

conductivity, and colour. The temporal variations for all parameters appeared to be greater than the spatial variations.

4.2 Snow quality

(28) The chemical analysis of the ground snow samples collected during the winter of 1981 near the sites of the surface water samples was carried out with the aim of estimating, during the course of a subsequent (second) study, the magnitude of contributions of major ions liberated during the spring thaw. The physico-chemical composition of the snow samples is presented in Table 7 which presents, for each of the 5 sample sites, the mean concentrations of the parameters calculated for each of the three separate sampling trips. The values of the parameters measured on each snow sample, as well as the mean and standard deviation for each station are also shown in Appendix 3.

Examination of the table of mean values shows up the following observations:

- The sum of cations is higher than the sum of the anions by a factor of 1.5 to 2. This disparity could have resulted from a lack of analytical precision due to the low values measured, or from the large quantity of other anions which were not measured;
- The conductivities measured are very low (between 8 and 13 $\mu\text{S}/\text{cm}$) and approach values obtained for distilled water;
- pH values are relatively uniform (4.5 - 4.7) and illustrate the acidic nature of these snow samples;

TABLE 7

PHYSICO-CHEMICAL COMPOSITION OF GROUND SNOW SAMPLED IN THE VICINITY OF
THE FIVE SURFACE WATER SAMPLING SITES: MEAN VALUES (WINTER 1981)

PARAMETRES	RIVIERES	PETIT SAGUENAY (PS-1)	STE-MARGUERITE (SM-1)	PETITS ESCOUMINS (PE-1)	DES ESCOUMINS (ES-1)	DES ESCOUMINS (ES-2)
pH (25°C)		4,69	4,55	4,65	4,64	4,60
Hydrogène (H ⁺ , µeq/l)		20,5	28,0	22,2	23,1	25,1
Conductivité (µS/cm, 25°C)		10	13	12	8	10
C. Inorganique (C, mg/l)		<1,0	<1,0	<1,0	<1,0	<1,0
Nitrates (N-NO ₃ ⁻ , mg/l)		0,09 (6)	0,19 (14)	0,13 (9)	0,09 (6)	0,11 (8)
Ammonium (N-NH ₄ ⁺ , mg/l)		0,02 (1)	0,03 (2)	0,10 (1)	0,02 (1)	0,03 (2)
Chlorures (Cl ⁻ , mg/l)		0,33 (9)	0,44 (12)	0,57 (16)	0,23 (6)	0,39 (11)
Sulfates (SO ₄ ²⁻ , mg/l)		1,0 (21)	1,4 (29)	1,3 (27)	0,6 (12)	0,8 (17)
Calcium (Ca ⁺⁺ , mg/l)		0,27 (13)	0,28 (14)	0,11 (5)	0,03 (1)	0,10 (5)
Magnésium (Mg ⁺⁺ , mg/l)		0,034 (3)	0,099 (8)	0,096 (8)	0,018 (1)	0,111 (9)
Sodium (Na ⁺ , mg/l)		0,37 (16)	0,61 (27)	0,61 (27)	0,30 (13)	0,63 (27)
Potassium (K ⁺ , mg/l)		0,11 (3)	0,13 (3)	0,19 (5)	0,35 (9)	0,30 (8)
Σ anions (µeq/l)		36	55	52	24	36
Σ cations (µeq/l)		57	82	69	48	76

NB. The values in parentheses are expressed in µeq/l.

- The principal anion is sulphate. Values obtained (12 - 29 $\mu\text{g}/\text{l}$) are of the same order of magnitude as for the hydrogen ions;
- The values for sodium and chlorine loom relatively large in the physico-chemical composition of the snow from stations SM-1, PE-1, and ES-2.

The stations, PE-1 and ES-2, situated near the St. Lawrence River, are probably influenced by marine aerosols. As for SM-1, the mean values, high in sodium and chlorine, may be explained by the anomalously high values measured in February (1.2 mg/l Na and 0.89 mg/l Cl). This anomaly might be the result of some sort of contamination of the samples during sample collection.

(30) A comparison of values measured, insofar as pH, sulphates, and nitrates are concerned, was made vis-a-vis other values measured for snow by other researchers (Jones and Bisson, 1980; Talbot, 1980). To make the comparison, station PS-1 was selected ^{as} the most representative of the conditions in the study area. The comparison, shown in Table 8, shows that the values obtained for pH and sulphate are of the same order of magnitude as those measured in Laurentides Park, at Lac Laflamme, and in the Cyriac River area. Insofar as nitrate is concerned, the values reported on by Jones and Bisson (1980) are higher by a factor of 3. A large number of factors such as inter-annual fluctuations, differences in sampling procedure, and different climatic conditions (for example, heavier precipitation levels, premature thaws) between the sites sampled, could all be responsible for these differences in concentration levels.

TABLE 8

COMPARISON OF THE VALUES FOR CERTAIN PARAMETERS MEASURED IN
SNOW SAMPLES COLLECTED FROM THE PETIT SAGUENAY AND CYRIAC
RIVERS AND FROM THE LAC LAFLAMME (QUEBEC) AREA

STATIONS	MOIS (MONTH)	PARAMETRES		
		pH	SO ₄ ⁼ (mg/l)	NO ₃ ⁻ (mg/l)
Rivière Petit Saguenay (PS-1)	Janvier 81	4,5	1,0	0,12
	Février 81	5,0	1,1	0,13
	Mars 81	4,7	1,0	< 0,01
Lac Laflamme*	Janvier 80	4,5	0,8	0,37
	Février 80	4,3	-	0,47
	Mars 80	4,6	0,5	0,22
	Avril 80	5,0	0,5	0,16
	Mai 80	5,2	0,5	0,19
Rivière Cyriac**	Janvier 79	5,1	< 1,0	0,28

* Jones et Bisson (1980)

** Talbot (1980)

In order to assess the magnitude of spatial and temporal variations encountered in each of the parameters, an analysis of variance (2 factor) was carried out. The detailed results of the application of this method are presented in Appendix 5. From this analysis, it is clear that the temporal variations are more striking, for all the parameters, than the spatial variations. The differences attributed to temporal variations are significant at below the 5% level for nitrate, ammonia nitrogen, calcium, and magnesium (Table 9). In examining the data obtained for each of the sampling trips (Appendix 3), one should take into account that the temporal variation is strongly affected by the higher values measured in the month of March for the majority of parameters.

(33) Some considerations regarding the phenomenon of ionic migration in snow could serve to show that the values obtained (especially for nitrate, sulphate, and acidity) are large even if they are probably lower than in freshly fallen snow. It is well-known that the main phenomenon responsible for the migration of ions is leaching by rainwaters and snow-melt (Johannessen and Henriksen, 1978; Jones and Bisson, 1980). This migration of ions which occurs slowly during the winter months, becomes very rapid just at the beginning of the thaw. The first fractions of melted snow could contain more than five times the concentrations found in ground snow (Johannessen and Henrikssen, 1978). This spring-time leaching process brings about sudden drops in pH in the run-off waters, low in buffering agents, and thus constitutes a danger, as well, for the survival of salmonid eggs, as will be explored in the next chapter.

TABLE 9

SPATIAL / TEMPORAL COMPARISON BY ANALYSIS OF VARIANCE (2 FACTORS)
OF PARAMETERS MEASURED IN SNOW SAMPLES COLLECTED IN THE VICINITY
OF FOUR SALMON RIVERS OF THE NORTH SHORE (WINTER 1981)

PARAMETRE	ANALYSE DE VARIANCE	
	TEMPS (2 degrés de liberté)	ESPACE (4 degrés de liberté)
pH	NS*	NS
Hydrogène (H^+)	NS	NS
Conductivité	NS	NS
Nitrates ($N-NO_3^-$)	<.05	NS
Ammonium ($N-NH_4^+$)	<.05	NS
Chlorures (Cl^-)	NS	NS
Sulfates (SO_4^-)	NS	NS
Calcium (Ca^{++})	.050	NS
Magnésium (Mg^{++})	<.05	NS
Sodium (Na^+)	NS	NS
Potassium (K^+)	NS	NS

* NS - not significantly different from 0 at the 5% confidence level ($p > 0.05$)

(56)

The mean square of the deviations with respect to time and to space, divided by the mean square of the error, represents a random variable which follows the Fisher law with (n_i-1) , (n_j-1) , and (n_j-1) , (n_i-1) $(n_j-1)^*$ degrees of freedom, respectively. It is thus possible to verify the null hypothesis, H_0 , that the measurements of the parameter at different times and at different stations are samples from the same population (identical means and variances). The alternative hypothesis H_1 is accepted if the measurements of the parameter at different times and at different stations are samples of different populations (different means and variances). In other words, the following hypotheses are tested:

$$H_0: \frac{\sigma_E^2}{\sigma_R^2} = 1, \frac{\sigma_T^2}{\sigma_R^2} = 1$$

$$H_1: \frac{\sigma_E^2}{\sigma_R^2} \neq 1, \frac{\sigma_T^2}{\sigma_R^2} \neq 1$$

in which:

H_0 is the null hypothesis

H_1 is the alternative hypothesis

* Sic. Unbalanced parentheses.

$$\sigma_E^2 = S_E / (nj - 1)$$

$$\sigma_T^2 = S_T / (ni - 1)$$

$$\sigma_R^2 = S_R / (nj - 1) (ni - 1)$$

(57)

The sequence of calculations for testing the validity of the null hypothesis is illustrated in the table below

	Degrees of freedom	Sum of squares	Mean sum of squares	F value
Rows (time)	$ni - 1$	S_T	$S_T / (ni - 1)$	$\frac{S_T / (ni - 1)}{S_R}$
columns (space)	$nj - 1$	S_E	$S_E / (nj - 1)$	$\frac{S_E / (nj - 1)}{S_R}$
residual	$(ni - 1)(nj - 1)$	$S_R = S_{tot} - S_T - S_E$	$S_R / ((ni - 1)(nj - 1))$	
Total	$(ni nj - 1)$	T_{tot}		

The importance of the calculation of S_R is evident. This variable is the residual random error variable obtained by the difference between the total variation and the variation due to time and space. The F- values calculated are ratios of the mean temporal and spatial variabilities to the mean residual variability.

The F- value calculated is then compared with values of F given in tables by Fisher, as a function of the degrees of freedom and of the chosen level of significance. If the F- value calculated is smaller than the theoretical value at a given level of significance, the ratio of the variances is equal to one, and the null hypothesis is confirmed at that level of significance.

(58) On the other hand, if the F- value calculated exceeds the theoretical value, the ratio of the variances is not equal to one, and the null hypothesis is rejected. In other words, this indicates that the measurements of the parameter do not come from the same population and that the difference noted can be attributed to either temporal or spatial effects, or both.

APPENDIX 5

ANNEXE 5.1

RESULTATS DE L'ANALYSE DE VARIANCE A DEUX

CRITERES POUR LES EAUX DE SURFACE

(APPENDIX 5.1 : RESULTS OF THE ANALYSIS OF VARIANCE (TWO FACTORS) FOR THE SURFACE WATER SAMPLES)

PARAMETER	MEAN SUM OF SQUARES			F VALUE	
	TIME (2 degrees of freedom)	SPACE (4 degrees of freedom)	RESIDUAL (8 degrees of freedom)	TIME	SPACE
pH	.002	.053	.015	.13	3.48
H	.001	.016	.006	.22	2.59
Cond.	80.3	69.4	10.9	7.34**	6.35**
Alcalinité	7.0	10.3	6.1	1.14	1.68
Turbidité	1.80	.51	.46	3.87	1.09
Couleur	645	296	22	29.2**	13.4**
NO ₃	.20	.07	.02	8.63**	3.16
NH ₄	.002	.001	.001	3.34	.99
Cl	.66	.06	.11	5.77*	.52
SO ₄	38.6	1.08	1.78	21.6**	.61
Na	.27	.53	.11	2.46	4.92*
K	.16	.04	.05	3.03	.78
Ca	1.13	2.33	.09	12.3**	25.2**
Mg	.11	.014	.006	18.5**	2.33
Fe	15033	6674	4097	3.67	1.63
Mn	3.70	10.4	4.51	.82	2.30
Ae	280	1145	1175	.24	.97

** Significantly different from zero at the 1% level

* Significantly different from zero at the 5% level

(APPENDIX 5.2 : RESULTS OF THE ANALYSIS OF VARIANCE (TWO FACTORS
FOR THE GROUND SNOW SAMPLES)

ANNEXE 5.2

RESULTATS DE L'ANALYSE DE VARIANCE A DEUX
CRITERES POUR LA NEIGE AU SOL.

PARAMETER	MEAN SUM OF SQUARES			F VALUE	
	TIME (2 degrees of freedom)	SPACE (4 degrees of freedom)	RESIDUAL (8 degrees of freedom)	TIME	SPACE
pH	.293	.057	.114	2.56	.50
H	356	25	105	3.38	.24
Cond.	29.4	9.7	9.2	3.18	1.05
NO ₃	.024	.006	.003	7.41*	1.81
NH ₄	.001	<.001	<.001	6.33*	.37
Cl	.022	.049	.060	.37	.81
SO ₄	.35	.31	.10	3.55	3.15
Ca	.070	.037	.016	4.45*	2.31
Mg	.009	.005	.002	4.80*	2.69
Na	.036	.072	.087	.42	.83
K	.018	.031	.030	.59	1.02

* Significativement différent de zéro au niveau de 5%.

(Significantly different from zero at the 5% level)

APPENDIX 6

APPENDIX 6

PRINCIPAL CRITERIA FOR THE PROTECTION OF AQUATIC LIFE

PARAMETERS	CONCENTRATION			REFERENCE
ALKALINITY (CaCO ₃)	G	20	mg/L	US ENVIRONMENTAL PROTECTION AGENCY 44D/9-76-D23
ALDRIN = HEOD (DIELDRIN)	PE	0.001	µg/L	INTERNATIONAL JOINT COMMISSION, 1977
ALUMINIUM (Al)	PE	0.100	mg/L	GREAT LAKES WATER QUALITY BOARD, 1976
NON-IONIZED AMMONIA (NH ₃)	PE	0.02	mg/L	US ENVIRONMENTAL PROTECTION AGENCY 44D/9-76-D23
ARSENIC (As)	PE	0.05	mg/L	ENVIRONMENT CANADA 1978
AZINPHOS-METHYL (GUTHION)	PE	0.005	µg/L	GREAT LAKES WATER QUALITY BOARD 1976
BERYLLIUM (Be)	PE	0.011	mg/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
γ-BHC (LINDANE)	PE	0.01	µg/L	"
PCB	PE	0.001	µg/L	"
CADMIUM (Cd)	PE	0.2	µg/L	ENVIRONMENT CANADA 1979
CAMPHECHLORE (TOXAPHENE)	PE	0.005	µg/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
CHLORDANE (Total)	PE	0.01	µg/L	"
CHROMIUM (Cr)	PE	0.04	mg/L	ENVIRONMENT CANADA 1979
PHENOLITIC COMPOUNDS (PHENOLS)	PE	0.001	mg/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
COPPER (Cu)	PE	0.005	mg/L	GREAT LAKES WATER QUALITY BOARD 1976
CYANIDES (CN)	PE	0.005	mg/L	US ENVIR. PROTECTION AGENCY 44D/9-76-D23
DOT (Total)	PE	0.001	g/L	"
DIAZINON	PE	0.08	g/L	GREAT LAKES WATER QUALITY BOARD 1976
- ENDOSULFAN	PE	0.003	g/L	US ENVIR. PROTECTION AGENCY 44D/9-76-D23
- ENDOSULFAN	PE	0.003	g/L	"
ENDRIN	PE	0.002	g/L	INTERNATIONAL JOINT COMMISSION 1977
IRON (Fe)	PE	0.300	mg/L	GT. LAKES WATER QUALITY BOARD 1976
HEPTACHLORE	PE	0.001	g/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
MALATHION	PE	0.1	g/L	"
SUSPENDED MATTER	PE	25	mg/L	ENVIRONMENTAL STUDIES BOARD 1973, EPA P.73.D33
TOTAL MERCURY (Hg)	PE	0.1	g/L	ENVIRONMENT CANADA 1979
p.p' - METHDXYCHLDR	PE	0.03	g/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
WIREX	PE	0.001	g/L	"
NICKEL (Ni)	PE	0.025	mg/L	GREAT LAKES WATER QUALITY BOARD 1976
DISSOLVED OXYGEN (O ₂)	GE	4.0	mg/L	ENVIRONMENT CANADA, IHD, TECH. BULL. 67, 1972
PARATHION	PE	0.008	g/L	GT. LAKES WATER QUALITY BOARD 1976
pH	GE PE	6.5 9.0		INTERNATIONAL JOINT COMMISSION 1977
TOTAL PHOSPHATE (P)	P	0.025	mg/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
LEAD (Pb)	PE	0.03	mg/L	ENV. STUDIES BOARD 1973, EPA.R3.73.D33
SULPHIDES (H ₂ S)	PE	0.002	mg/L	US ENV. PROTECTION AGENCY 44D/9-76-D23
SURFACTIVES (RBM)	PE	0.5	mg/L	LITTLE, 1977
ZINC (Zn)	PE	0.030	mg/L	GT. LAKES WATER QUALITY BOARD 1976

P = less than PE = less than or equal to G = greater than GE = greater than or equal to
(SOURCE : McNeely et al., 1979)