Acid Precipitation

ENVIRONNEMENT
ET FAUNE
QUÉBEC

Acid Precipitation in Québec: A Status Report (1996)

Québec

GOUVERNEMENT DU QUÉBEC

MINISTÈRE DE L'ENVIRONNEMENT ET DE LA FAUNE

ACID PRECIPITATION IN QUÉBEC:

A STATUS REPORT (1996)

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SUMMARY

Acid precipitation continues to be a major pollution problem that Québec is attempting to curb through emission control programs. As a result of these programs, between 1980 and 1991, total SO_2 emissions dropped from 1.1 million tonnes (MT) to 375 000 tonnes.

In southern Québec, wet sulphate deposition varies from 11 to 31 kg/ha/yr and wet nitrate deposition, from 7 to 25 kg/ha/yr. The mean annual pH of precipitation is around 4.35, which is 18 times more acidic than precipitation in equilibrium with the ambient CO_2 concentration. From 1990 to 1993, an area of approximately 100 700 km^2 received annual sulphate deposition in excess of the target loading of 20 kg/ha/yr, which is considered protective of moderately sensitive ecosystems. From 1985 to 1993, a reduction in sulphate levels in precipitation was noted for all of southern Québec. However, the acidity of precipitation continues to be of concern, as 68% of weekly precipitation has a pH below 4.6. Despite emission reduction programs, over 12 to 15 kg/ha/yr of wet sulphate deposition is expected to fall on southern Québec (i.e., area south of Lake Saint-Jean and the Abitibi region) in 2003.

In terms of biological response, the acidification of surface waters causes a broad spectrum of direct and indirect damages to aquatic organisms, ranging from biological stress to complete disappearance of fish populations in acidified lakes. As acidity increases from pH 6.0 to pH 5.5, 25% of fish species progressively disappear. As the pH drops further from 5.5 to 5.0, the number of fish species declines another 50%. At pH 4.5, the lake is devoid of fish. The most acid-tolerant species begin to show reproductive failure at pH 5.0.

An extrapolation of field measurements for lakes greater than 1 ha in size south of latitude 51 °N indicates that there are probably at least 29 000 acidic lakes (pH $\leq$ 5.5) and over 81 000 acidic and transition lakes (5.5 $<$ pH $\leq$ 6.0) in this territory. While the proposed reductions will cut annual deposition, the reduction will not be enough to meet the critical sulphate loads of between 12 and 15 kg/ha/yr, which would enable the recovery of most low-pH lakes which have been acidified since the turn of the century. However, a large portion of southern Québec is predicted to receive deposition loadings equal to or less than 12 to 15 kg/ha/yr. The reductions will enable the recovery of 64% of the 29 000 acidic lakes and raise the pH to over 6.0 in 40 000 others.

A direct correlation between the acidity and sulphate and nitrate concentrations in precipitation has been noted in forests. Between 1988 and 1994, a 20% decline in SO_4 concentrations in incoming, or incident, precipitation was recorded at the Duchesnay forest station, but mean annual deposition fell only slightly, remaining high at 27.7 kg/ha, mainly due to major fluctuations in the amount of rainfall during the period under study. There has been no notable decline in nitrate concentrations in incident precipitation since 1988, with the mean annual deposition at 22.9 kg/ha. Acid precipitation increases mobile anion (SO_4^{2-}, NO_3^-) input in forest ecosystems. A survey of decline and dieback in sugar maple stands in the Appalachians showed that foliar deficiencies are associated with a Ca^{2+}/Mg^{2+} and K^+/Mg^{2+} imbalance, as well as an imbalance between Ca^{2+} and the soil exchangeable acidity; this imbalance could be caused by acid deposition. Experimental fertilization demonstrated that application of basic cations reduced the proportion of trees showing signs of active decline and continued to benefit the stand as much as four years later. Where farmland is concerned, the effects of acid deposition in Québec are apparently negligible.

Evidence from clinical and epidemiological human studies and animal experiments show that acid aerosols, the primary acid precipitation precursors, affect human health in a direct manner. A number of Canadian epidemiological studies have demonstrated associations between sulphate concentrations and hospital admissions and

between acid aerosols and lung function in adolescents. There is little data on the exposure of the population of Québec to acid aerosols.

Finally, no government study or monitoring program has been conducted to assess acid precipitation-related damages to materials (buildings, structures, monuments, etc.) in Québec.

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1. INTRODUCTION

Public and government concern over acid precipitation has been growing since the late 1970s. Programs aimed at reducing acid precipitation precursor emissions have been introduced, and governments have invested huge sums to gain a better understanding and appreciation of the extent of the problem. Industries have begun adopting cleaner technologies and, as a result, considerable gains have been made, particularly in Québec.

The numerous studies conducted since the creation of the precipitation monitoring networks some fifteen years ago have yielded enough information to quantify the problem more accurately. Research has given us a better understanding of certain aspects of acid precipitation and enabled us to identify knowledge gaps. The emergence of new problems, particularly photochemical smog, shows that Québec remains a sensitive receptor area with respect to long-range transported air pollutants. This therefore seems an appropriate time for the Ministère de l'Environnement et de la Faune (MEF) to take stock of the situation.

The aim of this report, then, is to paint a portrait of acid precipitation in Québec based on the available scientific data. The following chapter discusses the main sources of sulphur dioxides (SO_2) and nitrogen oxides (NO_x). Chapter 3 looks at precipitation quality as interpreted by MEF's monitoring system. Chapter 4 discusses the impacts of acid precipitation on aquatic ecosystems, while Chapter 5 is devoted to how it affects forest ecosystems. The last chapter briefly discusses the adverse effects of acid precipitation on human health, materials and farmland.

Acid precipitation results from the emission, transport and transformation of acidifying substances such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x). While wet deposition of acidifying substances occurs during precipitation, dry deposition (gases and particulates) can also be a major contributor to the acidification of a site.

2. EMISSION SOURCES

Acid precipitation is caused mainly by emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Sulphur dioxide is a gas which is produced by the oxidation of sulphur, a constituent element of fossil fuels and raw material. Nitrogen oxides, primarily nitric oxide (NO), are generated by the burning of fossil fuels and are mainly associated with transportation.

The principal sources of SO_2 emissions are non-ferrous-metal (copper, zinc, aluminum) smelters, the burning of sulphurous fossil fuels, pulp and paper mills, and oil refineries.

2.1 Government Intervention

Over the years, various regulations have been passed in Québec to improve air quality, namely:

- the Regulation respecting pulp and paper effluent (1977);
- the Règlement relatif à l'assainissement de l'air (By-Law 90), adopted by the Montréal Urban Community in 1978;
- the Regulation respecting the quality of the atmosphere, adopted in 1979 for the purpose of establishing ambient air standards, emission standards and control measures for the prevention, elimination or reduction of emissions from stationary sources.

Since oxides of sulphur (SO_x) are the primary contributors to acid precipitation, reduction programs initially targeted SO_2 emissions. In the early 1980s, Québec therefore committed to reduce sulphur dioxide emissions by 30% and joined forces with the other provinces and the federal government to solve the acid precipitation problem.

In 1984, the Québec government continued its crusade against acid-forming pollutants by adopting an acid precipitation policy that targeted a 45% reduction in Québec's 1980 SO_2 emission levels by the end of the 1990s. The Québec Policy on Acid Precipitation thus aimed to cut the province's total SO_2 emissions to 600 000 tonnes (in this report, "tonnes" means "metric tons") per year by the turn of the century.

In follow-up to this new policy, in February 1985 the Québec government adopted two new regulations to amend the Regulation respecting the quality of the atmosphere and the Regulation respecting pulp and paper effluent with a view to limiting SO_2 emissions from copper and zinc smelters and pulp and paper mills respectively.

In June 1989, it made a commitment to further reduce SO_2 emissions by 45% to 55% to achieve an emissions level of around 500 000 tonnes per year by 1995.

In June 1990, the Québec government adopted further amendments to the Regulation respecting the quality of the atmosphere, tightening the sulphur content limit for heavy oil. Then in August 1993, it decided to cap Québec's SO_2 emissions at 500 000 tonnes per year beginning in 1994.

2.2 Sulphur Dioxide Emissions in Québec

Since the implementation of these government policies, there has been a marked decline in industrial SO_2 emissions in Québec.

Table 1 shows SO_2 trends for 1980-1991 by sector of activity. Total emissions dropped from 1 097 900 tonnes in 1980 to 374 600 tonnes in 1991 for an overall reduction of 65.9%, which already exceeds the 55% reduction target set for 1995.

The primary factors contributing to this decline are fewer emissions from copper and zinc smelters (73% reduction), pulp and paper mills (77%) and combustion systems (78%). Transportation and oil refineries also cut their emissions, but to a lesser extent.

In 1991, copper and zinc smelters contributed 56.4% of overall SO_2 emissions in Québec (Table 1), while the burning of fossil fuels accounted for less than half that at 24.8%. The other sectors (aluminum smelters, oil refineries, pulp and paper mills, etc.) were responsible for only 18.8% of the total emissions.

The principal factors contributing to SO_2 emission fluctuations in Québec between 1980 and 1991 are:

- plant closures, particularly oil refineries, cement factories and asbestos mines;
- construction of new plants, especially aluminum smelters;
- construction of sulphuric acid plants to capture SO_2 emissions during copper and zinc smelting;
- replacement of heavy fuel oil by natural gas or other low sulphur fuels in industry;
- application of energy conservation measures;
- tighter limits on the sulphur content of heavy oil;
- modernization plus decreased sulphite pulp production in the pulp and paper industry;
- improvements to various industrial processes and pollution abatement systems, or the installation of such systems.

Table 2 shows SO_2 emission trends in Québec in comparison to the other Canadian provinces. Between 1980 and 1990, Québec cut its emissions of sulphur dioxide by 64.4%, compared with 17.6% in the other Canadian provinces and 23% in the provinces east of Saskatchewan (excluding Québec). In Ontario, SO_2 emissions dropped from 1.8 MT in 1980 to 1.2 MT in 1990 and further to around 900 000 tonnes in 1992 (50% reduction over 1980).

Table 1

SO_2 emission trends in Québec (metric tonnes)

Sector of activity	1980	1985	1990	1991
1. **Industrial processes**				
Cu and Zn smelters	640 900	482 900	191 400	211 200
Aluminum smelters	39 600	19 000	25 600	33 100
Oil refineries	13 200	11 100	8 900	8 300
Pulp and paper mills	33 100	17 700	14 300	7 400
Other industrial processes	24 300	36 700	33 900	21 600
Subtotal:	751 100	567 400	274 100	281 600
2. **Burning of fossil fuels**				
Combustion systems	288 600	83 500	84 600	64 000
Transportation	58 200	35 100	36 100	29 000
TOTAL:	1 097 900	686 000	394 800	374 600

2.3 SO_2 Emission Projections for Québec, Canada and the United States

With respect to the copper and zinc extraction industry, the proposed amendments to the Regulation respecting the quality of the atmosphere would limit SO_2 emissions from the Noranda Minerals copper smelter to 10% of sulphur inputs beginning December 31, 2001.

Aluminum smelters, on the other hand, are predicted to emit 30% (10 000 tonnes) more sulphur dioxide in 2000 compared with 1991 due to the opening of new smelters and increased production in existing ones.

The volume of crude oil processed in Québec refineries should hold steady at 1990 levels until the year 2000, thus causing no significant change in SO_2 emissions.

In the pulp and paper industry, the reduced production of sulphite pulp should cancel out the increase in SO_2 emissions due to the predicted increase in pulp production between now and the year 2000.

According to economic forecasts, other types of industrial plants (e.g. cement factories, iron ore pellet plants and other metallurgical plants) are expected to emit 20 000 more tonnes of sulphur dioxide, essentially through the burning of fossil fuels.

As for combustion systems per se, even if certain projections indicate a 25% or so increase in natural gas consumption, SO_2 emissions associated with this type of fuel are negligible. Heavy oil use is expected to remain relatively constant.

Thus, not only has Québec achieved its SO_2 emissions reduction goal (500 000 tonnes in 1994), but within the next few years, it could also cap these emissions at the current level of around 400 000 tonnes per year.

The chief provisions of the 1991 Canada/United States Air Quality Agreement (Progress Report 1992) in terms of SO_2 emissions control are as follows:

- Canada committed to reduce its SO_2 emissions to 3.2 MT per year by the year 2000 and cap SO_2 emissions in the seven easternmost provinces at 2.3 MT per year as of 1994;

- the United States committed to reduce its annual SO_2 emissions by 9 MT (nearly 40%) by the year 2000. This reduction will be implemented in two phases: 20% in 1995 and 20% in 2000. Total U.S. emissions amounted to 23.4 MT in 1980.

Table 2

SO_2 emission trends in Québec and Canada
(metric tonnes)

Provinces	Year		
	1980	1985	1990
Québec	1 097 900	686 000	394 800
Other provinces	3 552 400	2 993 900	2 927 000
Provinces east of Saskatchewan (excluding Québec)	2 729 300	2 262 400	2 102 000

Those states likely to contribute to acid deposition in Canada are expected to cut their emissions from approximately 14 MT in 1990 to around 7.4 MT in the year 2000. Under conditions of full implementation of the CAAA-1990 (Clean Air Act Amendment), total U.S. sulphur dioxide emissions should be around 14.5 MT in 2010.

2.4 Québec Emissions of Nitrogen Oxides

Table 3 shows NO_x emissions in Québec, Canada and the provinces east of Saskatchewan for 1985 (only year for which data are available). Transportation contributed approximately 80% of all nitrogen oxides emitted in Québec and approximately 64% in Canada as a whole.

By 2005, NO_x emissions in Canada as a whole are predicted to be 6% higher than 1985 levels. The vehicle emissions target should be achieved in 1995, after which overall NO_x emissions will level off, as any increase in the number of vehicles will cancel out the reductions achieved through emission standards. Industrial emissions of nitrogen oxides should also rise due to population growth and greater industrial activity.

Not all provinces will contribute equally to the increase in total emissions production: emission levels are expected to remain more or less at current levels in Québec and Ontario, decline in some provinces and rise in others (CCME 1990).

Table 3

Emissions of nitrogen oxides, 1985 (metric tonnes)

Sector of activity	Québec	Canada	Provinces east of Saskatchewan (excluding Québec)
Industry	6 860	88 931	44 278
Combustion, stationary sources	34 246	593 391	226 455
Transportation	192 759	1 252 901	559 272
Other	6 011	24 269	4 893
TOTAL	239 876	1 959 492	834 898

3. PRECIPITATION MONITORING IN QUÉBEC

3.1 Monitoring Networks

The precipitation sampling program of the Ministère de l'Environnement et de la Faune du Québec (MEF) was created to measure precipitation quality in Québec. The program currently comprises two monitoring networks: the Québec precipitation monitoring network (Réseau d'échantillonnage des précipitations du Québec--REPQ) and the atmospheric monitoring network for agriculture and forested areas (Réseau de mesure des polluants atmosphériques en milieu forestier et agricole du Québec--REMPAFAQ). The objectives of the precipitation monitoring program are to:

- measure and monitor spatial and temporal variations of acid deposition across Québec;

- collect basic data for the purpose of calibrating LRTAP (long-range transport of air pollutants) models. The results yielded by LRTAP models are used to devise and update acid deposition precursor emission control programs.

The first objective consists in:

- assessing the effectiveness of Québec, Canadian and U.S. policies aimed at reducing acid deposition precursor emissions; and

- creating a data bank that will provide scientists with the information needed to study the effects of acidifying substances on ecosystems, human health and buildings.

The REPQ was created in 1981 and currently boasts 23 monitoring stations (Figure 1). The REMPAFAQ was established from 1988 to 1992 and currently includes 16 precipitation sampling stations (Figure 2).

As shown in figures 1 and 2, these monitoring networks are concentrated in southern Québec, i.e., in regions where acid deposition is highest and, consequently, has a greater impact on forest and aquatic ecosystems. The REPQ also has several sampling stations in the area around the Horne copper smelter in Rouyn-Noranda.

Following in the footsteps of other acid deposition monitoring programs, in the 1980s the Québec precipitation sampling program was enhanced with a quality assurance program covering all operations from on-site sampling to the archival storage of information in MEF's computerized data banks. The quality assurance program helped garner Québec's precipitation sampling program national and international recognition.

As yet, MEF does not have a monitoring network for dry deposition, even though dry components are considered to contribute an estimated average of 15% (RMCC 1990) of total (dry plus wet) sulphate deposition in Québec (50% near Rouyn-Noranda) and between 30% and 60% of total NO_x deposition. Measuring dry deposition is a delicate operation as well as being difficult.

3.2 Spatial Distribution of Annual Wet Deposition of Acidifying Substances

Geographically and climatologically, Québec is located directly downwind of major SO_2 and NO_x source areas, including southern Ontario and the northeastern and midwestern United States. The transboundary flow of these pollutants compounds Québec's domestic pollution problem. Oxides of sulphur are the prime contributors to the acidity of precipitation.

According to 1985 estimates (Lelièvre et al. 1985), domestic emissions at the time primarily affected southern Québec, with over 50% of contributions being concentrated near the major emitters. Québec sources contributed less than 40% of acid deposition in central Québec, north of the Abitibi region and the North Shore, while over 40% of deposition in the Témiscamingue and upper Outaouais regions came from Ontario sources. In the rest of Québec, the Ontario component contributed under 25% of most acid deposition. Finally, between 40% and 50% of acid deposition in a large portion of Québec was due to U.S. emission sources.

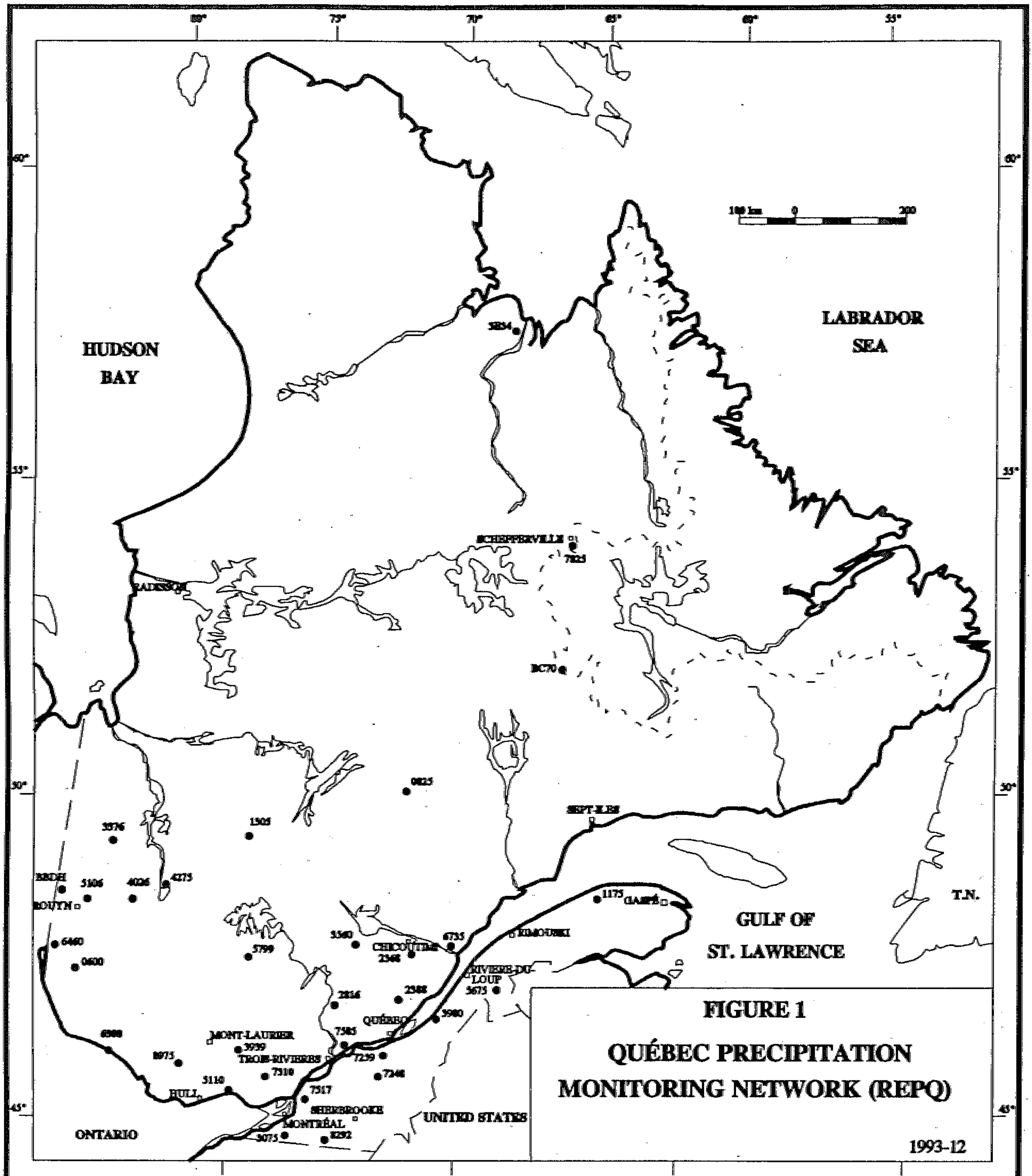

FIGURE 1

QUÉBEC PRECIPITATION MONITORING NETWORK (REPQ)

1993-12

NAME	No. MÉTÉO	No. BQMA
BELLETERRE	0600	04260026
BONNARD	0825	06220009
CAP-SEIZE	1175	02140029
CHAPAIS	1305	08070050
DUPARQUET	BBDH	08980005
FERLAND	2368	06060005
FERMONT	BC70	07230011
FORÊT-MONTMORENCY	2588	05100025
GRANDE-ANSE	2816	05010111
HEMMINGFORD-FOUR-WINDS	3075	03090017
JOUTEL	3576	08010016
KUUJJUAQ-UA	5854	10550001
LAC BOUCHETTE	3560	06160011
LA MACAZA	3939	04020075
LAMARTINE	3980	02600002
LA MORANDIÈRE	4026	08070052
LEBEL-SUR-QUÉVILLON	4275	08070055
MONT-BRUN	5106	04300086
MONTÉBELLO-SEDBERGH	5110	04050002
NOTRE-DAME-DU-LAC	5675	01170014
PARENT-S	5799	04080121
RAPIDES-DES-JOACHIMS	6580	04500067
RÉMIGNY	6460	04300088
SACRÉ-COEUR	6735	06280004
SAINT-FERDINAND	7248	02400020
SAINT-FLAVIEN	7239	02360002
SAINT-HIPPOLYTE	7310	05230117
SAINTE-MADELEINE	7517	05040056
SAINT-NARCISSE	7585	05050090
SCHEFFERVILLE	7825	10570021
SUTTON	8292	03040037
WRIGHT	8975	04080142

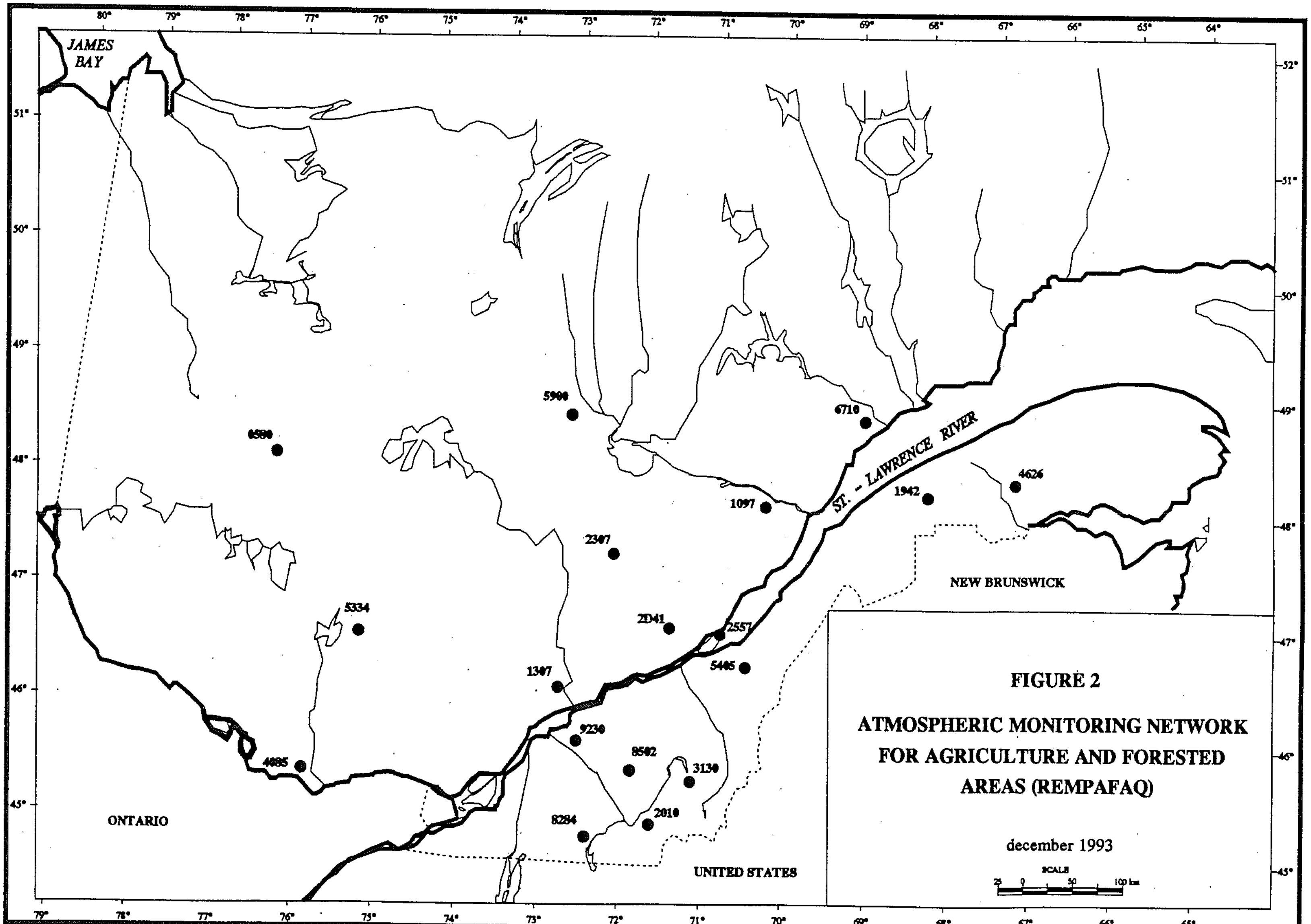

FIGURE 2

ATMOSPHERIC MONITORING NETWORK FOR AGRICULTURE AND FORESTED AREAS (REMPAFAQ)

december 1993

NAME	No. MÉTÉO	No. BQMA
BELL	0580	08070055
CAP-ÉTERNITÉ	1097	06050004
CHARETTE	1307	05300005
CÔTE-OUIMET	1942	02190006
DITTON	2010	05020194
DUCHESNAY	2D41	
ÉDOUARD	2307	05050110
FRANÇOIS	2557	00000068
HILAIRE	3130	03020197
LA PÊCHE	4085	04080221
MARGUERITE	4626	01150018
MONT-SAINT-MICHEL	5334	04060111
N.-D.-DU-ROSAIRE	5405	02310011
PÉMONCA	5900	06190086
ROUTE 385	6710	07060001
STUKELY	8284	03020196
TINGWICK	8502	03010049
ZÉPHIRIN	9230	03020195

The above estimates are based on North American SO_2 emission rates for 1980; since then, Québec and Ontario emissions of SO_2 have declined considerably (over 50%), while reductions in emissions from the United States and the rest of Canada have been relatively less notable. The United States and Canada emitted a total of 28.5 MT of sulphur dioxide in 1980, 25.1 MT in 1985 (-11.9%), and 23.7 MT in 1992 (-16.8%) (Canada/U.S. Agreement 1994).

Environment Canada recently recalculated SO_2 emission contributions (Fenech 1996, personal communication) based on Canadian emission rates for 1994 and U.S. emission projections for 1995. At the Montmorency Experimental Forest north of Québec City, domestic sources were shown to contribute 22% of wet deposition, Ontario sources nearly 20% and U.S. sources 58%. These results indicate that emission cutbacks in Ontario and Québec tipped the balance, increasing the relative contribution of U.S. sources to wet deposition at this particular site.

Figures 3, 4 and 5 respectively show the mean annual wet sulphate (SO_4) and wet nitrate (NO_3) deposition and mean annual pH of precipitation for the period 1990-1993. In southern Québec, wet sulphate deposition ranged from 11 to 31 kg/ha/yr and wet nitrate deposition, from 7 to 25 kg/ha/yr, with the highest levels falling on the southernmost portion of the province and the St. Lawrence Valley.

Relatively high deposition levels were also observed in the Laurentian region north of Québec City, primarily due to the abundant precipitation that falls over this region. Wet nitrate deposition follows a similar spatial distribution pattern as wet sulphate deposition, except in the Abitibi region, which is directly influenced by major SO_2 emitters. During the period under study (1990-1993), more than 20 kg/ha/yr of wet sulphate fell over an average area of 100 700 km^2.

The mean annual pH value of precipitation over the area south of latitude 50°N ranged from 4.28 to 4.60; the average for the territory as a whole was around 4.35, which is 18 times more acidic than precipitation in equilibrium with atmospheric CO_2 (pH 5.6).

3.3 Temporal Variations of Acid Precipitation in Québec

A recent study (Pinard and Boulet 1995) of acid precipitation patterns in Québec examines data collected at 17 precipitation monitoring stations between 1985 and 1993. These stations were chosen for the long temporal observations (9 years or more) conducted over the same period (1985-1993). The main conclusions drawn by the report are presented below.

The percentage change in SO_4 concentrations in precipitation for the period under study (1985-1993) is presented in Figure 6. The magnitude of the trend is shown for each monitoring station. Of the 17 stations sampled, 10 present a significant downward trend (95% confidence level), while there has been no statistically significant trend at the remaining 7 stations.

The greatest reductions in sulphate concentrations were noted on the south shore of the St. Lawrence River in the area extending from the American border to the county of Témiscouata. The average annual decline in SO_4 levels was around 4%. An average decrease of 3% per year was observed along a corridor extending from the Outaouais region (Rapide-des-Joachims) to Lake Saint-Jean. Elsewhere in Québec, sulphate levels dropped to an average of 0.5-2.8% per year during the period 1985-1993.

Acid precipitation patterns in the Abitibi are particularly noteworthy, since this region is directly influenced by SO_2 emissions from Noranda Minerals' Horne copper smelter. Figure 7 shows annual SO_2 emissions from this source as well as mean annual SO_4 concentrations in precipitation at Mont-Brun, approximately 25 km northeast of Rouyn-Noranda. The correlation between SO_2 emissions from the Noranda Minerals smelter and SO_4 levels at Mont-Brun is clear (correlation coefficient 0.80). In 1990, Noranda Minerals cut its SO_2 emissions by over 50%, which seems to be a major contributing factor in the improved quality of precipitation over the Abitibi region. In fact, average SO_4 concentrations at Mont-Brun fell from 51.1 μeq/L to 41.1 μeq/L between the periods 1985-1988 and 1990-1993. This approximately-20% reduction in SO_4 levels in the Abitibi region is attributable to both Québec's SO_2 emissions reduction policy and the efforts of Noranda Minerals.

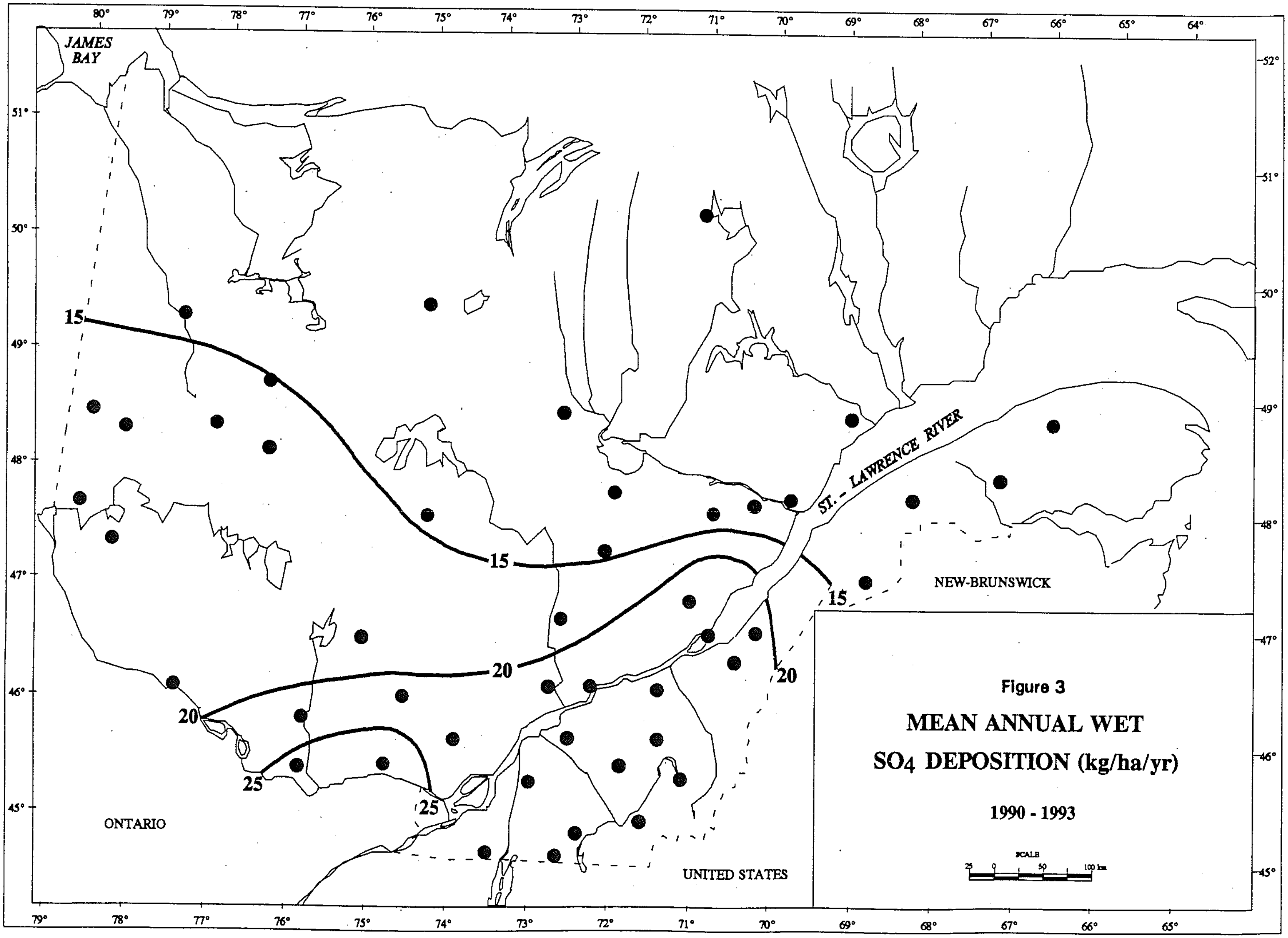

Figure 3

MEAN ANNUAL WET

SO_4 DEPOSITION (kg/ha/yr)

1990 - 1993

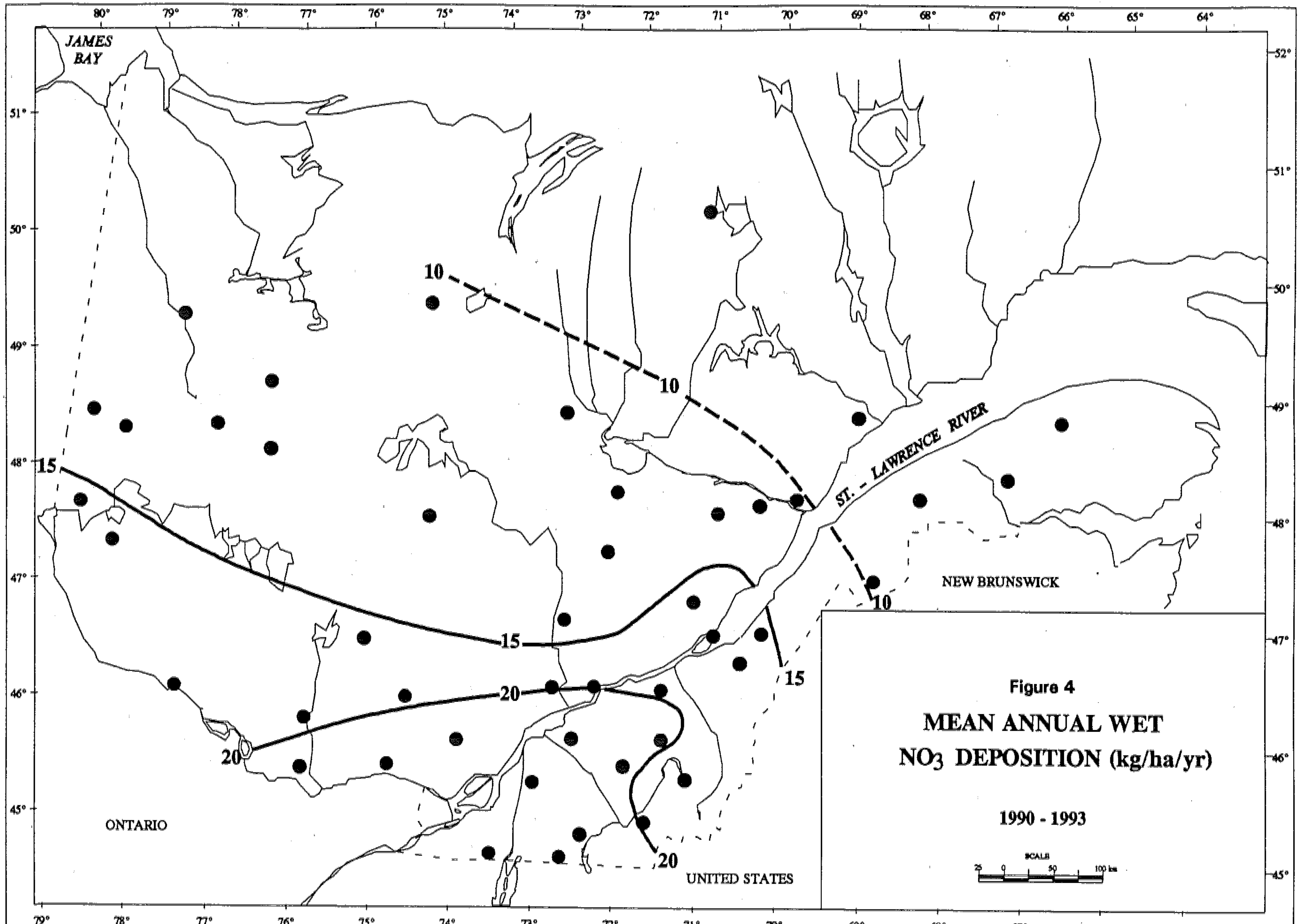

Figure 4
MEAN ANNUAL WET
NO_3 DEPOSITION (kg/ha/yr)
1990 - 1993

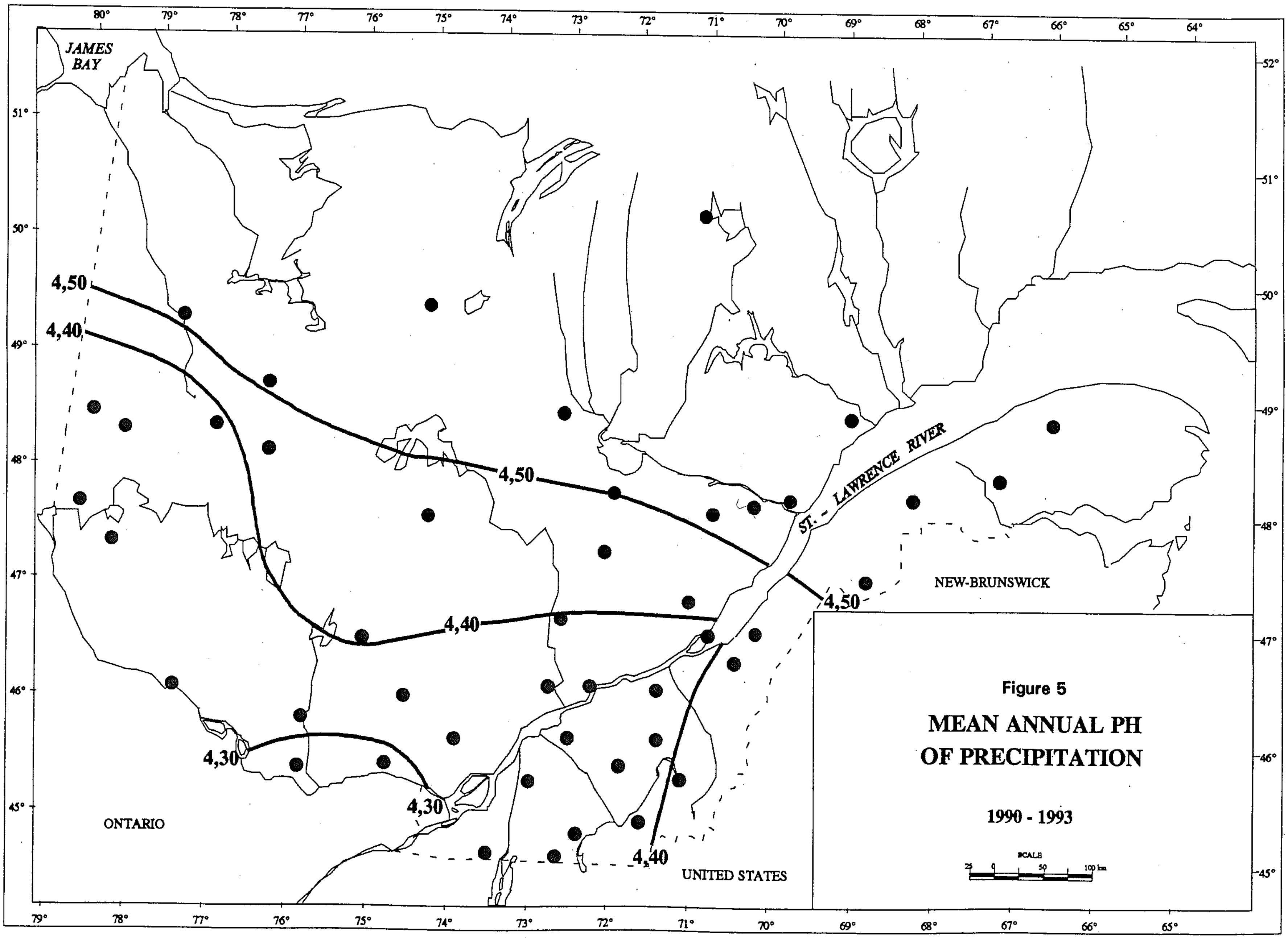

Figure 5

MEAN ANNUAL PH OF PRECIPITATION

1990 - 1993

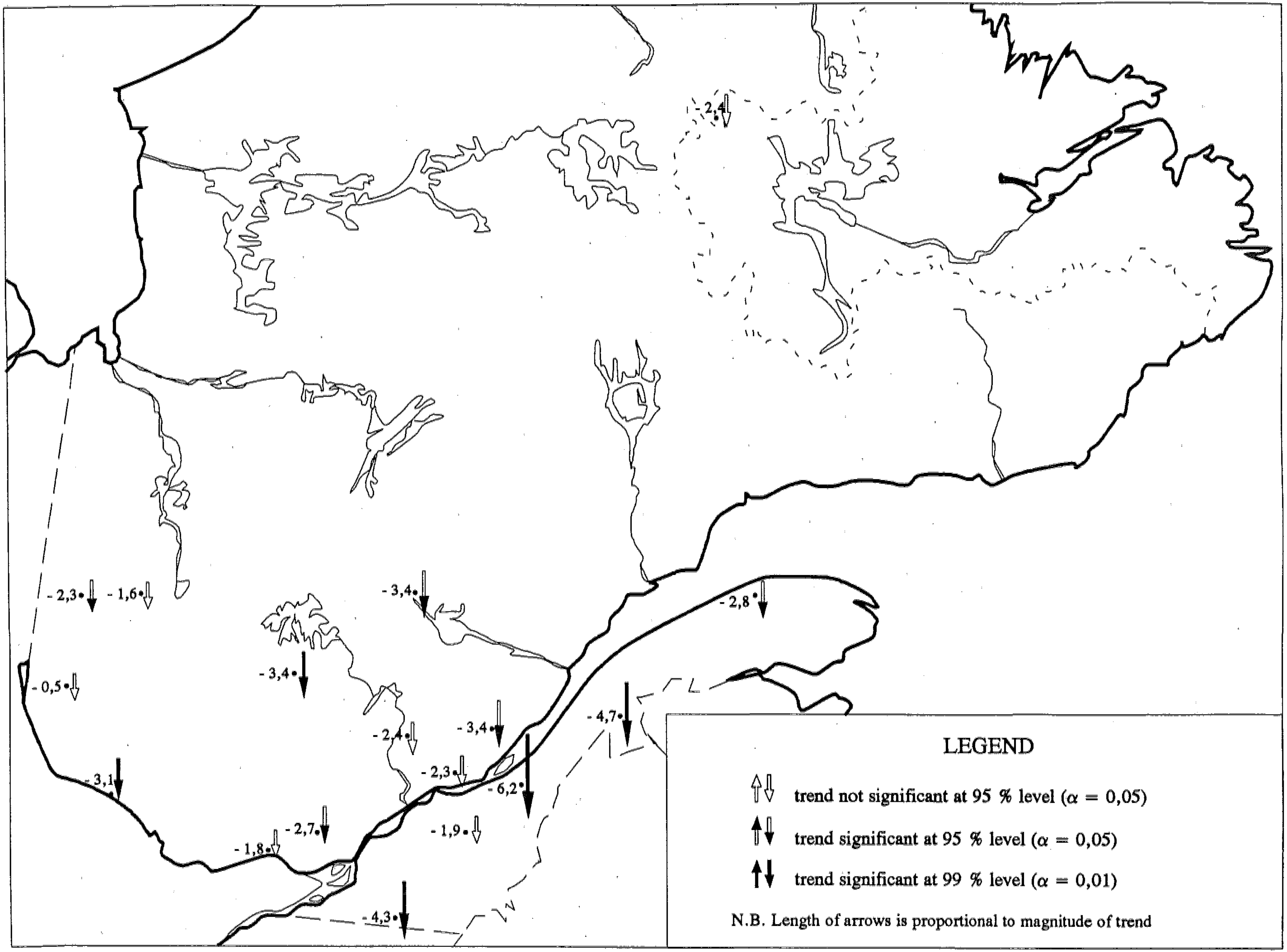

Figure 6 Evolution of weekly SO_4 concentrations in precipitation (mean trend in percent/year), 1985 - 1993

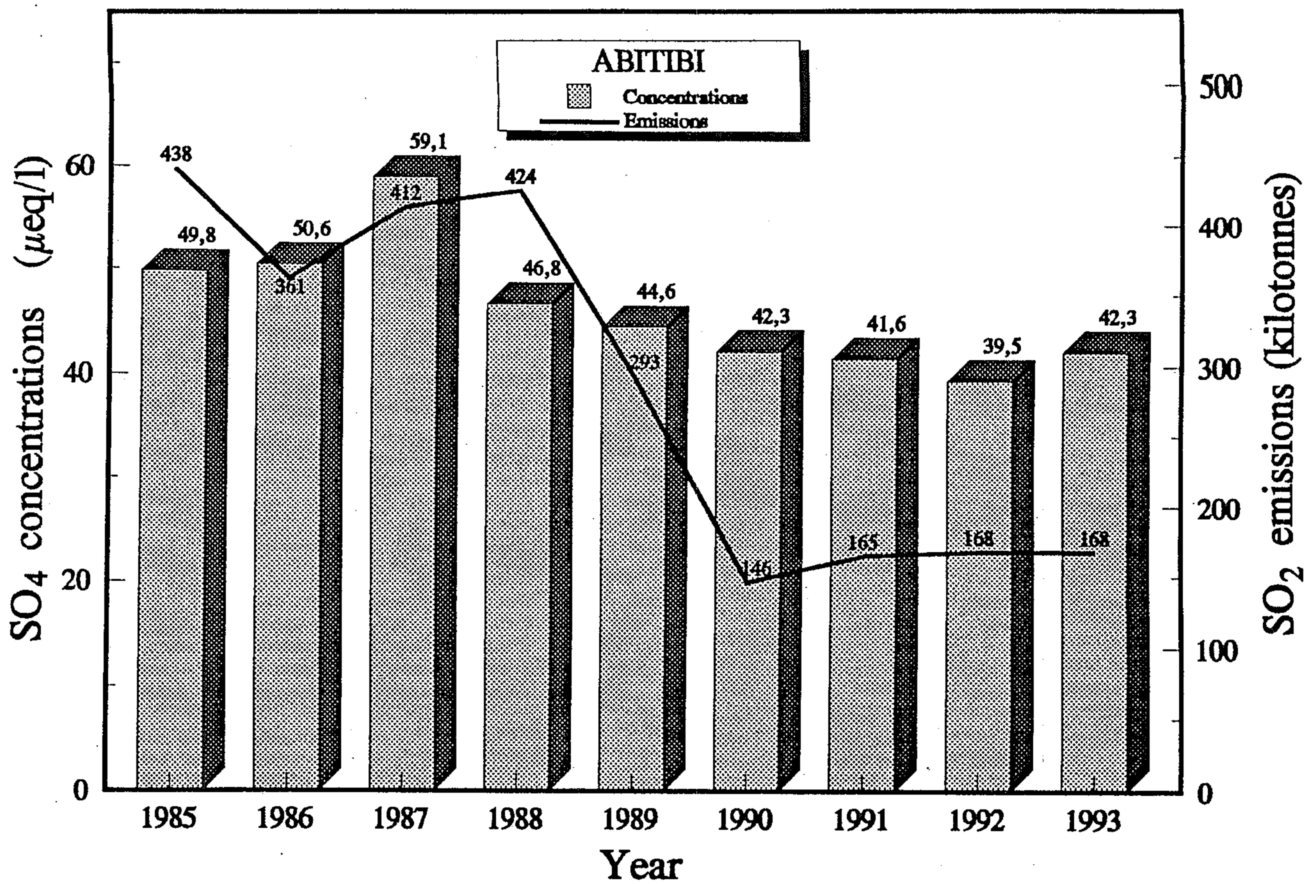

Figure 7 Mean annual SO_4 concentrations in precipitation at Mont-Brun, in the Abitibi region, and annual SO_2 emissions from Noranda Minerals, 1985 - 1993

Figure 8 shows the control regions for monitoring annual trends in two environmental indicators designed to measure the quality of precipitation (Pinard 1989). The two indicators are:

- pH indicator: percentage of weekly precipitation with a pH value of 4.6 or under. The precipitation pH threshold has been set at 4.6, as anything below this value is harmful to acid-sensitive aquatic ecosystems.
- SO_4 indicator: percentage of weekly precipitation with an SO_4 concentration of 32 µeq/L or over. Precipitation with a pH value under 4.6 generally has an SO_4 concentration greater than 32 µeq/L;

Figure 9-A shows a slight decrease in the sulphate indicator in regions 1, 2, 3 and 4 between 1982 and 1993 or, in other words, a slight decrease in the frequency of weekly precipitation with a sulphate concentration greater than 32 µeq/L. This improvement is statistically significant. The greatest improvement was observed in region 4, that is, the vast area stretching from James Bay to the county of Témiscouata, passing through Lake Saint-Jean: the frequency of precipitation registering a sulphate concentration over 32 µeq/L decreased from an average of 55% during the period 1982-1987 to approximately 42% during the period 1988-1993. By comparison, the frequency of precipitation registering sulphate levels in excess of 32 µeq/L for the province as a whole fell from an average of 62% (1982-1987) to 53% (1988-1993).

On average, 68% of weekly precipitation over Québec as a whole has a pH below 4.6 (Figure 9-B). A statistical analysis reveals no improvement in the pH indicator over the years; the frequency of weekly precipitation posing a threat to acid-sensitive aquatic ecosystems was just the same in the early 1990s as during the previous decade. Moreover, close to 81% of weekly precipitation in the Outaouais region and the southernmost portion of Québec (region 1, Figure 8) is potentially harmful to aquatic ecosystems ($pH \leq 4.6$).

3.4 Acid Deposition Projections for the Early 21st Century

What will acid deposition in Québec be like in the early 21st century if Canada and the United States respect their commitments to reduce acid deposition precursor emissions?

The answer may lie in Figure 10, which shows the projected annual wet sulphate deposition for 2003, i.e., after Canada and the United States have met their emission reduction goals (Dupont 1993). Figures are based on Environment Canada model projections (RMCC 1990). A comparison between this map and Figure 3 (annual wet sulphate deposition during the 1990s) shows a clear reduction in the 20 kg/ha/yr isopleth in 2003 compared with the early 1990s. However, a vast territory encompassing the Québec City region and part of the Laurentian, Bois-Francs and Eastern Townships regions will continue to receive wet sulphate deposition loadings greater than 20 kg/ha/yr. A recent study (EPA 1995) conducted using a Eulerian model predicts that a somewhat larger area comprising the Outaouais region will receive more than 20 kg/ha/yr of wet sulphate in 2010; the discrepancy in these model projections may be attributable to the different emission scenarios and models used. The same study shows that an additional 50% reduction in emissions in the power generation sector would result in wet sulphate deposition loadings of between 12 and 18 kg/ha/yr for most of southern Québec.

It is therefore clear that any reduction in acid deposition in Québec beyond the target levels will hinge essentially on the will of our American and Ontario neighbours to cut their SO_2 emissions beyond the reduction goals.

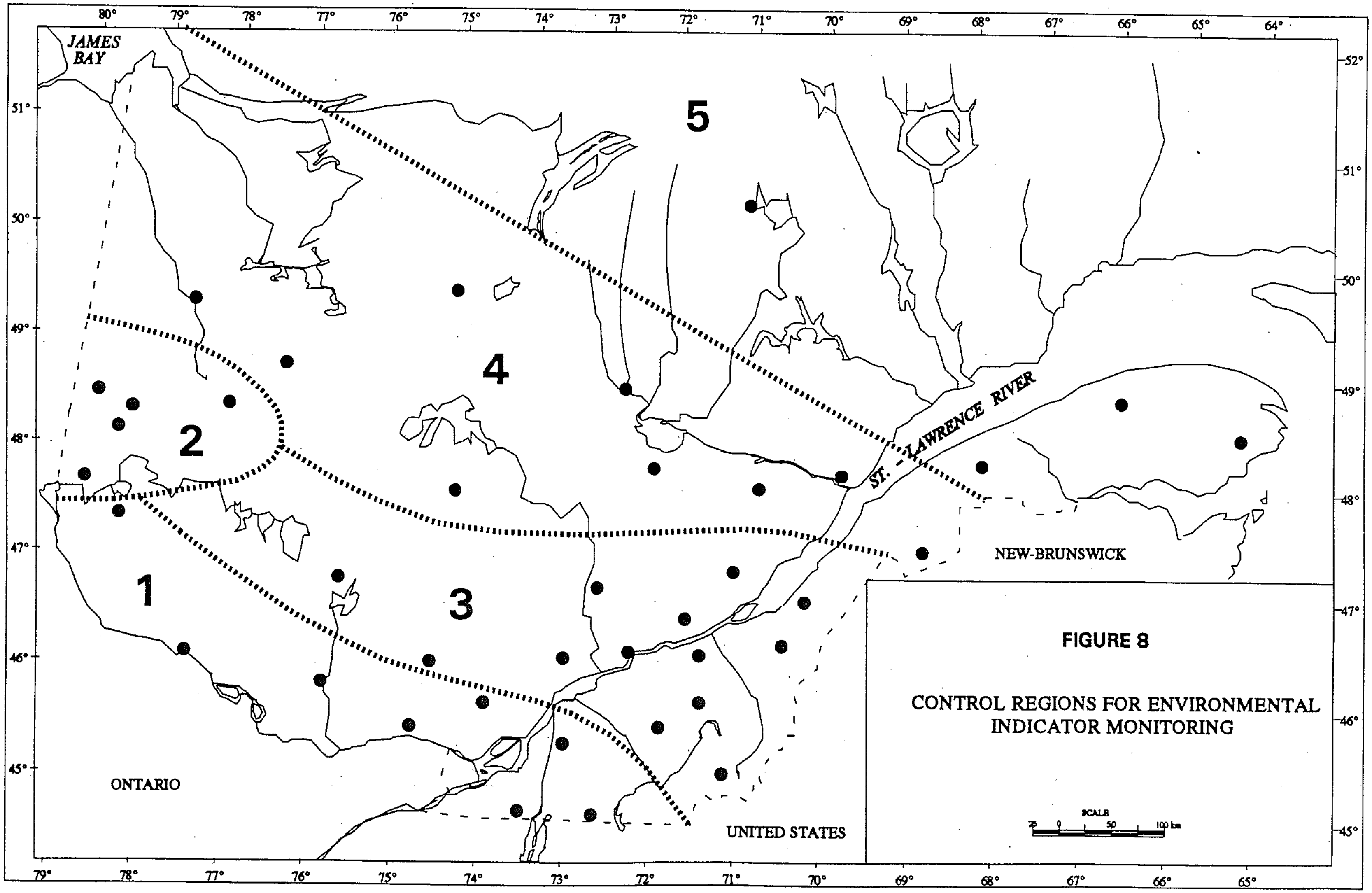

FIGURE 8

CONTROL REGIONS FOR ENVIRONMENTAL INDICATOR MONITORING

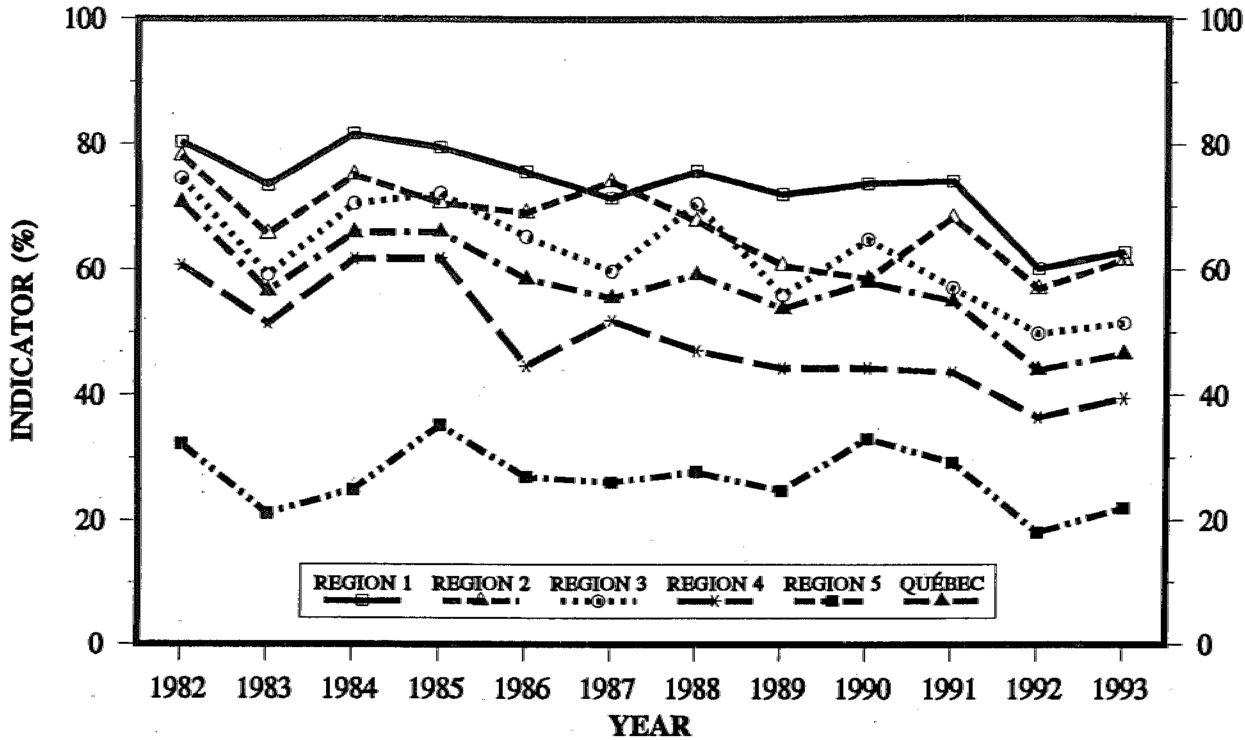

Figure 9-A Annual variation in sulphate indicator

Percentage of weekly precipitation with a sulphate concentration > 32 μeq/l

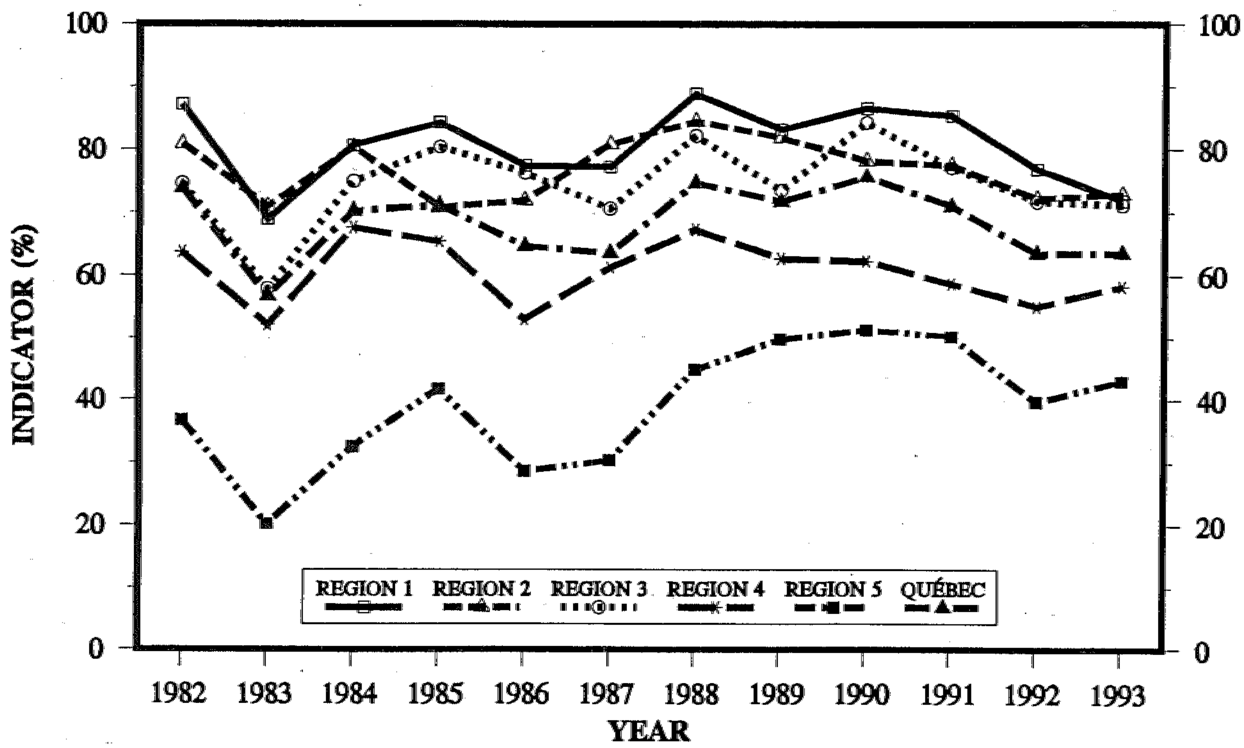

Figure 9-B Annual variation in pH indicator

Percentage of weekly precipitation with pH < 4.6

Figure 10
PREDICTED WET SULPHATE DEPOSITION IN 2003