

Canadian Technical Report of
Fisheries and Aquatic Sciences 1023

August 1981

SAMPLING, ANALYSIS, AND DATA EVALUATION OF PRECIPITATION AT
ST. ANDREWS, NEW BRUNSWICK, CANADA, 1978-80

by

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This is the one hundred and thirty-eighth Technical Report from
the Biological Station, St. Andrews, N.B.

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Cat. No. Fs 97-6/1023 ISSN 0706-6457

Correct citation for this publication:

Sergeant, D. B., V. Zitko, and L. E. Burridge. 1981. Sampling, analysis, and data evaluation of precipitation at St. Andrews, New Brunswick, Canada, 1978-80. Can. Tech. Rep. Fish. Aquat. Sci. 1023, iii + 26 p.

ABSTRACT

Sergeant, D. B., V. Zitko, and L. E. Burridge. 1981. Sampling, analysis, and data evaluation of precipitation at St. Andrews, New Brunswick, Canada, 1978-80. Can. Tech. Rep. Fish. Aquat. Sci. 1023, iii + 26 p.

Previous, short-duration studies in southeastern New Brunswick indicated that the precipitation is acidic (geometric mean pH 3.84 in 1977 and 4.61 in 1976). Few inorganics in the precipitation had been measured. In this study, conducted during June-October 1978 and during July 1979-July 1980, each precipitation event was sampled (total 123). In addition to pH and volume, conductivity and the concentrations of Ca, Mg, Na, K, Cl, SO₄, NO₂ + NO₃, total P, NH₄, Cu, Zn, Cd, Pb, Mn, and Fe were determined during June-October 1978.

The geometric mean pH's were 4.45 and 4.23 in the 1978 and 1979-80 studies, respectively. Of the total 123 samples taken during 1978-80, 26% had pH between 3.0-4.0, 43% between pH 4.0-4.5, 22% between pH 4.5-5.0, and 9% between pH 5.0-6.0, with only one value greater than pH 5.6. The fall and winter values tended to be higher than the spring and summer values. The concentrations of the major ions were low except for SO₄ which was 22.6 mg/L in one sample. The concentration ranges of Cu, Zn, Cd, Pb, Mn, and Fe were 0.3-51.0, 5.8-87.6, 0.1-3.59, 0.1-62.5, 0.3-12.7, and 1.4-143.0 µg/L, respectively. The origin and air parcel trajectory for each 1978 precipitation event showed a correlation between the direction of the trajectory and the acidity of the precipitation. Lower pH values were associated with events approaching from the south through southwest. Correlations among the precipitation characteristics are discussed.

July-August data for 1976-80 indicate no trend of pH values. All data for June 1978-July 1980 yield an annual decrease of 0.18 pH units, but the correlation coefficient is only 0.260.

Key words: Acid rain, pH, major ions, heavy metals

RÉSUMÉ

Sergeant, D. B., V. Zitko, and L. E. Burridge. 1981. Sampling, analysis, and data evaluation of precipitation at St. Andrews, New Brunswick, Canada, 1978-80. Can. Tech. Rep. Fish. Aquat. Sci. 1023, iii + 26 p.

Des études de courte durée menées antérieurement dans le sud-est du Nouveau-Brunswick avaient montré que les précipitations étaient acides (moyenne géométrique du pH 3,84 en 1977 et 4,61 en 1976). Peu de substances inorganiques avaient été mise en évidence dans les précipitations. Au cours de la présente étude, menée de juin à octobre 1978 et de juillet 1979 à juillet 1980, des échantillons ont été prélevés au cours de chaque précipitation (123 au total). En plus du pH et du volume, on a déterminé la conductivité et les concentrations de Ca, Mg, Na, K, Cl, SO₄, NO₂ + NO₃, P total, NH₄, Cu, Zn, Cd, Pb, Mn et Fe de juin à octobre 1978.

Lors des études de 1978 et de 1979-1980, la moyenne géométrique du pH se chiffrait à 4,45 et 4,23 respectivement. Le pH des 123 échantillons prélevés entre 1978 et 1980 se répartissait comme suit: 26% des échantillons avaient un pH entre 3 et 4, 43% entre 4 et 4,5, 22% entre 4,5 et 5 et 9% entre 5 et 6, une seule valeur dépassant 5,6. Les valeurs de l'automne et de l'hiver tenaient à être supérieures à celle du printemps et de l'été. Les concentrations des principaux ions étaient faibles, à l'exception de celle des ions SO₄, qui se chiffrait à 22,6 mg/L dans un échantillon. Les concentrations de Cu, Zn, Cd, Pb, Mn et Fe variaient respectivement entre 0,3 et 51; 5,8 et 87,6; 0,1 et 3,59; 0,1 et 62,5; 0,3 et 12,7; et 1,4 et 143 mg/L. En examinant l'origine et la trajectoire des particules atmosphériques lors de chaque précipitation de 1978, on a établi une corrélation entre la direction de la trajectoire et l'acidité de la précipitation. Les valeurs plus faibles de pH ont été rattachées aux précipitations venant du sud par le sud-ouest. Les corrélations entre les caractéristiques des précipitations sont examinées.

Les données pour juillet-août de 1976 à 1980 n'indiquent aucune tendance pour les valeurs du pH. Toutes les données pour juin 1978-juillet 1980 font état d'une diminution annuelle de 0,18 unités de pH, mais le coefficient de corrélation est seulement de 0,260.

INTRODUCTION

This report is one of a continuing series of published and unpublished reports that characterize the acid precipitation problem in southern New Brunswick (Table 1). Most of the data are for the St. Andrews location, but some data are available for the surrounding area (Zitko and Carson, unpubl. data). The major emphasis of the chemical analyses was placed on the 1978 samples (Table 2). The locations of precipitation monitoring stations in New Brunswick and Nova Scotia are indicated in Fig. 1.

MATERIALS AND METHODS

SAMPLING OF PRECIPITATION

Precipitation samples were collected and analyzed by using the procedures described previously (Sergeant and Zitko 1978). Between June and October 1978, 24 rainwater samples were collected. Between July 1979 and July 1980, 99 samples, some of which were snow, sleet, and freezing rain, were taken. Tables 3 and 4 give the exact dates of sampling and the data obtained for each sample.

For the 1978 samples, a 20-mL aliquot was transferred to a 250-mL polyethylene bottle (nitric acid washed), acidified with 2-3 drops of Aristar nitric acid, and stored in a freezer at -20°C until analyzed for heavy metals.

A second aliquot was withdrawn and pH and the specific conductance were determined. The specific conductance apparatus was a modified version of that described by Bertenshaw (1977).

The remainder of the sample, if any, was refrigerated at 4°C. When five or six samples had accumulated, they were sent to the Water Quality Branch laboratory in Moncton, N.B., for determination of pH, conductivity, and major cations and anions.

ANALYSIS OF RAINWATER SAMPLES FOR HEAVY METALS

A Perkin Elmer 503 equipped with an HGA 2100 Graphite Furnace was used in the determination of the heavy metals in the 1978 rainwater samples. Pyro- and graphite tubes were used, depending on the metal being determined. Appropriate standards in acid medium were used for construction of the calibration graphs. An NBS water standard was analyzed along with the samples as a check on the analysis conditions and validity of the results. Samples were analyzed for Cu, Zn, Cd, Pb, Mn, and Fe. For the most part a 20- μ L was sufficient to obtain a graphite furnace-A.A. response. Acid-washed, disposable pipette tips were used for all injections (Eppendorf Pipette). The graphite furnace operating conditions are given in Table 5, analyses of the NBS standard in Table 6.

Ionic balance calculations performed by the Water Quality Branch in Moncton to validate analyses indicated that there were no analytical problems. Some of the smaller samples could not be validated because of lack of material.

RESULTS AND DISCUSSION

pH

pH data for 1978-80 indicate a decreasing trend with a slope of 0.18 units per year (Fig. 2) and a correlation coefficient of -0.260. The trend is statistically significant because of the large number of samples, but the correlation coefficient is quite low. Time explains only about 25% of the overall variance and it appears that the data do not allow trend projections. At the same time, pH of precipitation in July-August in the years 1976-80 indicates no trend (Table 1).

When monthly mean pH's of St. Andrews precipitation were compared (Table 7) with monthly pH of composite precipitation samples for Saint John and Acadia Forestry Experimental Station (Acadia FES), near Fredericton, some differences were observed. St. Andrews monthly pH values agreed closely with those observed for Saint John over the August-November 1979 and May-June 1980 periods. In between these (December 1979-April 1980), Saint John experienced elevated pH relative to both St. Andrews and Acadia FES. These December 1979-April 1980 data for Saint John do not represent the true picture of the precipitation received in this area of eastern Canada over this time period.

Some pH values of rainwater reported in the literature are shown in Table 8 for comparison with our data. The pH's for St. Andrews are very similar to those measured in other areas where the acid precipitation problem is currently being studied. In particular, our range of pH is very similar to that reported by Cogbill and Likens (1974) and close to those reported by Anlauf et al. (1976) for Saint John. The value for Whitehorse (Yukon Territory) is shown as an example of a truly remote sampling location. It gives background measurements for an area of "clean" non-acid precipitation.

Eight episodes (two or three consecutive precipitation events) of extremely acidic precipitation ($\text{pH} < 4.0$) were observed during the July 1979-July 1980 study period. These are shown in Table 4. Only one episode was observed during the 1978 study period (Table 3, samples R8, R9, R10).

CONDUCTIVITY

Conductivity versus time (Fig. 3) shows considerable fluctuations in the time period when sample R8 was obtained. The mean conductivity for the 1978 samples is very similar to that observed by Granat (1978) for the period 1973-75 in Sweden and also comparable to the 1977-78 values for Charlottetown and Saint John, N.B. (Table 9). The highest conductivity was measured in sample R8 (Table 3). Elevated levels of heavy metals, major ions, and a low pH (i.e. high concentration of hydrogen ions) were observed for this sample.

The volume of precipitation is negatively correlated with conductivity (Fig. 4). A similar dilution effect is observed for SO_4 (Fig. 5), NO_x (Fig. 6) and NH_4 (Fig. 7), Cu (Fig. 8), Zn (Fig. 9), Pb (Fig. 10), Mn (Fig. 11), Fe (Fig. 12) and Cd (Fig. 13).

AMMONIUM (NH_4)

The observed concentrations of NH_4 are in agreement with Granat's (1972) Swedish data for the northern station, but not with his 1978 Sjöängen, Sweden, data, which are five times higher (Table 10). The St. Andrews and Nashwaak watershed (approx. 160 km from here) data are also similar. However, NH_4 concentrations at St. Andrews are lower than at two other New Brunswick locations (Saint John and Charlo).

NITRATE AND NITRITE (NO_x)

As with NH_4 , St. Andrews data are in good agreement with other N.B. and N.S. locations as well as with the remote location in Whitehorse (Table 11), but are lower than those for more industrialized area, e.g. Great Lakes, Holland, Sweden, and New York-New Hampshire-Tennessee.

TOTAL PHOSPHORUS (P)

Values for total P are low and very similar to those found for Kekimkujik (Anon. 1979). Except for the low end of the range (Table 12) and the low end of the range of the Nashwaak values, all other values were higher (10-100 times) than the St. Andrews mean value.

CALCIUM (Ca)

The St. Andrews range and mean values are low and similar to those found for Hubbard Brook, Kejimkujik, and the coastal rural areas (Table 13). The values for St. Andrews are approximately five times lower than those recorded for the N.Y.-N.H.-Tenn. area (Cogbill and Likens 1974) and those of the European network stations (Granat 1972). Values for our location were 30-50 times lower than those in the lower Great Lakes region (Kuntz 1978; Shiomi and Kuntz 1973) and for the continental urban scenario (Wolaver 1972).

MAGNESIUM (Mg)

The Mg data in Table 14 indicate that the geometric mean is not significantly different from the European network values (Granat 1972). It is, however, considerably above the isolated Whitehorse value and the Hubbard Brook value.

As was the case with other parameters, the Mg concentrations in samples R8 and R9 are elevated. Values as high as these, 9 and 7 mg/L, were not reported in any of the literature examined.

SODIUM (Na)

St. Andrews 1978 values compare best with Wolaver's (1972) values for the coastal rural and continental rural scenarios (Table 15). At the same time, they are more than an order of magnitude lower than the Sable Island, N.S. values, but Sable Island receives a great deal of sea spray, contributing Na to the samples.

POTASSIUM (K)

St. Andrews values were similar to those for Charlo and Saint John, but double those of Kejimkujik (Table 16). As with Na, this could indicate pollution from industrial sources or from sea salt. Higher values are reported for the more

heavily industrialized or populated regions - Germany, Great Lakes, and California.

CHLORIDE (Cl)

Cl values are comparable to Great Lakes, other Canadian Maritime locations (excluding Sable Island), and Yonkers, N.Y. (Table 17).

SULFATE (SO_4)

No correction for sea salt contribution to our data in Table 3 was made. Calculations performed on some of the 1978 samples indicated that the differences were not significant.

Mean value for SO_4 at St. Andrews (Table 18) agrees best with Wolaver's (1972) continental rural data, with the Hubbard Brook data of Likens (1975), and the N.Y.-N.H.-Tenn. data of Cogbill and Likens (1974). Based on these SO_4 data and the pH data comparison of Table 8, it appears that St. Andrews receives precipitation of the same acidity as the northeastern United States.

The rate of SO_4 deposition at our location for the 1978 study period was found to be 1727.8 g/ha/mo or 2.1 g/ m^2/yr . This was compared to deposition rates for other locations (Table 19). The deposition rate at St. Andrews tends toward the lower end of values reported in the literature. When expressed as S (sulfur) deposition, we found 0.7 g/ m^2/yr which was 21% of the deposition of S found at this location in 1975-76 (Zitko and Carson, unpubl.).

CADMIUM (Cd)

Examination of Table 20 indicates that St. Andrews values agree best with Schlesinger et al.'s (1974) data for Montane, N.H., and Struempler's (1976) data for Chadron, Nebraska - both values are low. Relative to Saint John, and the other New Brunswick and Nova Scotia locations, the values at St. Andrews are noticeably lower. The mean value found was significantly lower than the mean observed previously by Zitko and Carson (unpubl.) at this location.

LEAD (Pb)

The mean value for St. Andrews is of the same order of magnitude as the samples for other New Brunswick locations, but at the same time is three times the Whitehorse value (Table 21). The 1978 mean was also 2.4 times higher than the Pb concentration observed by Zitko and Carson (unpubl.) during their 1970-71 studies. This may be indicative of an increase in atmospheric Pb pollution. This Pb input must be due to long-range transport and rainout.

Urban areas receive much higher Pb inputs. For example, at Pasadena, California, a Pb value of 663 $\mu\text{g}/\text{L}$ was recorded and in Holland values for daily and monthly samples were in the 200 $\mu\text{g}/\text{L}$ range. Our one value of 62.5 indicates an urban or industrial contribution to the precipitation and is similar to the Montane, N.H. values. The best match as far as the range of St. Andrews Pb values is with the Montane, N.H. values of 1971.

It appears that Pb has a greater tendency than Cd to be transported over a long range.

COPPER (Cu)

St. Andrews data are similar to those of other Maritimes locations and about three times higher than at Whitehorse (Table 22). Single events approached the Cu levels found for highly populated and industrialized areas.

IRON (Fe)

The concentration of Fe at St. Andrews was of the same relative order of magnitude as that found for Charlo and Saint John (Table 23). At the same time, the St. Andrews values are less than those observed in Germany, the U.K. and SE Ontario (industrialized areas). The 1978 mean Fe concentration was about 40% of the value observed during 1970-71 in our area (Zitko and Carson, unpubl.).

MANGANESE (Mn)

There is a paucity of Mn data in the literature. St. Andrews levels (Table 24) are comparable to California values, but nowhere near the elevated values observed for U.S., German, and U.K. locations.

ZINC (Zn)

Due to analytical difficulties, Zn values in Table 25 may be overestimated about 70%. We do not routinely analyze for Zn at the $\mu\text{g/L}$ level in our laboratory.

The concentrations are of the same order reported previously by Zitko and Carson (unpubl. data) for the St. Andrews area in 1970-71, higher than at other Canadian Maritime locations and at Whitehorse, but somewhat lower than reported for 32 U.S. locations (Lazarus et al. 1970) and significantly lower than the values reported for Holland and the U.K.

HEAVY METALS SUMMARY

In precipitation at St. Andrews, the concentrations of Cd and Mn are low and those of Pb, Cu, Fe, and Zn are moderate. The order of heavy metal deposition was Zn > Fe > Pb > Cu > Mn > Cd during the 1978 monitoring period. Deposition rates for St. Andrews were compared to one remote and two industrialized areas (Table 26). Despite slight differences the St. Andrews values are comparable with Chadron, Nebraska values representative of a remote location. St. Andrews values were much lower for most heavy metals compared to locations near steelworks and base metal smelters.

METEOROLOGY OF 1978 RAINWATER SAMPLING EVENTS

To relate the chemical composition of the rainwater to the area traversed by the storm, it was necessary to have air parcel trajectories calculated for 2-3 d prior to the precipitation event. The calculations are subject to some uncertainties and errors (Smith and Hunt 1978; Pack et al. 1978; A.D.J. O'Neill (pers. comm.)). In this study, the trajectories were computed from the geostrophic winds at the 850 mb (millibar) level, which are themselves estimated from the appropriate Environment Canada, Atmospheric Environment Service, upper atmosphere analyses. These air parcel

trajectories are shown in Appendices 1-5 for the months June through October 1978.

For pH 4.2-4.5 (Table 3) one cannot identify the approach direction of the storm. In preparing the pH-direction correlation chart it was assumed that a value in this range was a positive correlation. For storm fronts approaching from the south or west the hypothesis is that there should be a positive correlation between direction and low pH values ($\text{pH} < 4.5$). A similar positive correlation should occur for storms approaching from the northwest through eastern quadrants, but this should be a positive correlation with higher pH values ($\text{pH} > 4.2$).

The data appear to support this hypothesis. Sixty-nine percent of the values from the south through west quadrant correlate with events of low pH and 91% of the values from the northwest to east sector correlate with higher pH readings ($\text{pH} > 4.2$). In the case of the non-correlating values in the south to west quadrant, four of the storms passed up the northeast coast of the United States and all had uncharacteristically high pH. This could have been a freak occurrence or could have been an indication of a seasonal effect - colder fall air, slower moving front, greater rainout of pollutants over the northeastern United States prior to the storm traversing our sampling location (Fig. 14).

From our data we can therefore safely assume that storms approaching from the quadrant south through west will bring more acidic precipitation events than those approaching from the northwest through east quadrants. At the same time, all storm fronts approaching from the west to northwest (45°) sector should also bring acidic precipitation as they must pass through Sudbury or industrialized southern Ontario.

For the storms approaching from the northwest through east quadrants the pH never approached 5.6-5.7 (equilibrium with atmospheric CO_2). In spite of limited industrial activity in the areas traversed by the approaching storm fronts, pH values 4.22, 4.51, and 4.60 were observed. Sulfur contributions from tidal flats (Grey and Jensen 1972) cannot be ruled out at this time. It is also possible that a "constant concentration" of pollutant laden particulate matter is present over most of North America and Europe.

Photochemical processes that occur over the forest canopy, resulting in formation of HNO_3 (Bottenheim and Strausz 1980), must be considered as well. A similar directional correlation was observed for SO_4 , Pb, Fe, Cu, Zn, Mn, and Cd. No correlation was found for conductivity.

CORRELATION ANALYSES OF THE RAINWATER DATA

The data of Table 3 were reduced to eliminate those with missing parameters. In the case of pH, SO_4 , Cl, NO_x , Ca, Mg, Na, K, and NH_4 , only 9 of the 24 samples remained. For pH, conductivity (St. Andrews) and metal concentrations, the number of samples (N) was reduced from only 24 to 20. The results of the correlation analysis are presented in Table 27.

As expected, SO_4 was the single most important variable affecting pH of precipitation. The inclusion of additional ions further improved the

correlation. Several of the best multiple regressions are given below (concentrations are in mg/L).

$$1) \text{ pH} = 5.17 - 0.20[\text{SO}_4] + 0.012[\text{Cl}] - 0.24[\text{NO}_x]$$

$$2) \text{ pH} = 5.32 - 0.33[\text{SO}_4] + 0.05[\text{Cl}] - 0.12[\text{NO}_x] \\ + 1.45[\text{NH}_4]$$

$$3) \text{ pH} = 4.4 - 0.20[\text{SO}_4] - 0.15[\text{Cl}] + 0.27[\text{NO}_x] \\ - 1.30[\text{Ca}] + 12.79[\text{Mg}] - 0.61[\text{Na}] \\ + 0.18[\text{NH}_4]$$

$$4) \text{ pH} = 4.54 - 0.27[\text{SO}_4] - 0.57[\text{Cl}] + 0.59[\text{NO}_x] \\ - 1.65[\text{Ca}] + 13.47[\text{Mg}] - 0.64[\text{K}] \\ + 0.57[\text{NH}_4]$$

ACKNOWLEDGMENTS

The authors thank Drs. R. H. Peterson and D. W. McLeese for their comments, Dr. T. Pollock of the Water Quality Branch, Moncton, N.B. for his analyses of rainwater samples, Mr. J. Hull for rain gauge data, Dr. A. D. J. O'Neill, AES, Atlantic Region for determining the air parcel trajectories, Messrs. Cunningham and McMullion for preparing the figures, Ms. B. McCullough and Mrs. J. Hurley for typing the manuscript, and Ms. R. Garnett for editing the manuscript.

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Table 1. Geometric mean pH recorded at St. Andrews and vicinity, 1975-80.

Study period	Geometric mean pH	Reference
May-Mar. 1975-76	4.18	Zitko & Carson, unpubl.
July-Aug. 1976	4.61	Sergeant & Zitko (1978)
July-Aug. 1977	3.84	"
June-Oct. 1978	4.45	This study
July-Aug. 1978	4.06	" "
July-July 1979-80	4.23	" "
July-Aug. 1979	4.32	" "
June-Oct. 1979	4.11	" "
Fall 1979	4.27	" "
Winter 1979-80	4.49	" "
Spring 1980	4.15	" "
Summer 1979-80	4.13	" "

Table 2. Concentration ranges of ions in precipitation recorded at St. Andrews, June-October 1978.

Ion	Range (mg/L)
Ca	<0.10 - 0.40
Mg	<0.10 - 0.80
K	<0.10 - 0.30
Na	0.40 - 1.80
Cl	0.40 - 3.50
SO ₄	<1.00 - 22.6
Total P	0.004- 0.98
NO ₃ + NO ₂	<0.01 - 1.8
NH ₄	0.01 - 2.3
<u>(µg/L)</u>	
Cu	0.3- 51.0
Zn	5.8- 87.6
Cd	0.1- 3.59
Pb	0.1- 62.5
Mn	0.3- 12.7
Fe	1.4-143.0

Table 3. 1978 rainwater data.

Parameter measured ^a	R1	R2	R3	R4	R5	R6
Day no. ^d	174	179	180	182	185	192
Volume precipitation (mL)	136	215	110	1000	255	510
pH-St. Andrews (pH units)	3.98	4.29	4.51	4.92	4.94	3.97
pH-Moncton W.Q.B. (pH units)	3.90	4.10	4.50	4.80	4.80	3.90
Conductivity-Moncton ($\mu\text{SIE}/\text{cm}$)	67.0	39.0	32.0	9.7	16.0	67.0
Conductivity-St. Andrews ($\mu\text{SIE}/\text{cm}$)	55.6	32.1	31.1	11.6	15.0	57.1
Ca (mg/L)	--	--	--	.100	.200	.200
Mg (mg/L)	--	--	--	<.100	.100	<.100
K (mg/L)	.100	.100	--	<.100	<.100	.100
Na (mg/L)	.700	.400	--	.500	1.300	.600
Cl (mg/L)	.700	.400	3.500	.800	2.500	.900
SO ₄ (mg/L)	6.20	--	--	1.00	1.00	6.20
Total P (mg/L) ^c	--	.015	--	.009	.006	.004
NO ₃ + NO ₂ (NO _x) (mg/L)	--	--	--	.100	--	.650
NH ₄ (mg/L)	--	--	--	.010	--	.500
Cu (ug/L)	32.0	11.6	44.1	51.1	3.3	11.0
Zn (ug/L)	87.6	59.3	55.7	31.5	23.4	36.8
Cd (ug/L)	.30	.24	.38	.11	.03	.33
Pb (ug/L)	21.8	14.0	7.4	1.0	3.2	26.9
Mn (ug/L)	3.80	5.60	4.90	1.60	1.80	5.50
Fe (ug/L)	32.5	34.1	30.3	109.0	8.0	71.0
mm precipitation	2.3	4.3	1.5	.0	5.6	8.9
	R7	R8	R9	R10	R11	R12
Day no. ^d	199	205	209	214	217	239
Volume precipitation (mL)	170	290	205	43	370	55
pH-St. Andrews (pH units)	4.43	3.57	3.84	3.50	4.06	5.24
pH-Moncton W.Q.B. (pH units)	4.60	3.40	3.90	--	4.50	5.60
Conductivity-Moncton ($\mu\text{SIE}/\text{cm}$)	23.0	190.0	--	--	20.0	16.0
Conductivity-St. Andrews ($\mu\text{SIE}/\text{cm}$)	14.7	200.0	71.4	142.9	21.7	18.5
Ca (mg/L)	--	--	--	--	--	.400
Mg (mg/L)	--	7.500	8.000	.300	.100	.150
K (mg/L)	.100	--	--	--	.200	--
Na (mg/L)	1.700	--	--	--	.800	--
Cl (mg/L)	.600	--	--	--	1.200	2.500
SO ₄ (mg/L)	--	22.60	6.00	13.70	2.00	--
Total P (mg/L) ^c	.980	.090	.020	--	.055	--
NO ₃ + NO ₂ (NO _x) (mg/L)	--	1.800	1.000	.010	1.400	--
NH ₄ (mg/L)	--	2.300	.500	--	.065	--
Cu (ug/L)	7.3	25.5	18.0	--	16.9	--
Zn (ug/L)	26.7	58.6	44.9	--	22.1	--
Cd (ug/L)	3.59	.92	.60	--	.33	--
Pb (ug/L)	7.1	62.5	32.2	--	10.2	--
Mn (ug/L)	3.70	12.70	5.00	--	2.60	--
Fe (ug/L)	24.8	143.0	80.5	--	13.5	--
mm precipitation	2.8	5.1	3.3	.8	5.0	--

Table 3. (cont'd.)

Parameter measured ^a	R13	R14	R15	R16	R17	R18
Day no. ^d	241	250	252	254	255	256
Volume precipitation (mL)	438	1000	1000	128	748	350
pH-St. Andrews (pH units)	3.88	4.22	4.41	4.60	4.10	5.06
pH-Moncton W.Q.B. (pH units)	4.10	4.10	4.30	4.50	4.00	5.10
Conductivity-Moncton ($\mu\text{SIE}/\text{cm}$)	43.0	44.0	39.0	20.0	58.0	8.4
Conductivity-St. Andrews ($\mu\text{SIE}/\text{cm}$)	45.5	53.4	35.0	21.9	58.6	11.3
Ca (mg/L)	.100	.200	.100	<.100	.100	<.100
Mg (mg/L)	.100	.120	.150	<.100	<.100	<.100
K (mg/L)	.200	.100	.100	.300	.200	.100
Na (mg/L)	1.200	1.000	1.800	.800	.900	.500
Cl (mg/L)	1.500	1.500	3.000	.700	1.300	.800
SO ₄ (mg/L)	4.40	4.30	2.20	2.20	5.00	1.00
Total P (mg/L) ^c	.010 ^b	.006	.009	--	.004	.006
NO ₃ + NO ₂ (NO _x) (mg/L)	.360 ^b	.600	.590	.020	.810	.070
NH ₄ (mg/L)	.210 ^b	<.200	.080	.005	>.200	.030
Cu ($\mu\text{g}/\text{L}$)	4.5	.9	1.7	--	3.0	5.0
Zn ($\mu\text{g}/\text{L}$)	18.5	13.9	9.4	--	12.6	5.8
Cd ($\mu\text{g}/\text{L}$)	.18	.13	.06	--	.12	.03
Pb ($\mu\text{g}/\text{L}$)	11.4	17.7	18.4	--	16.7	3.4
Mn ($\mu\text{g}/\text{L}$)	2.20	3.40	1.50	--	2.80	1.10
Fe ($\mu\text{g}/\text{L}$)	17.3	16.0	21.7	--	12.8	1.4
mm precipitation	6.6	19.8	.0	36.0	12.8	8.0

	R19	R20	R21	R22	R23	R24
Day no. ^d	275	278	279	280	289	297
Volume precipitation (mL)	840	1000	49	1000	1000	315
pH-St. Andrews (pH units)	5.28	5.23	4.87	5.03	5.09	4.52
pH-Moncton W.Q.B. (pH units)	5.10	.00	.00	.00	.00	.00
Conductivity-Moncton ($\mu\text{SIE}/\text{cm}$)	15.0	.0	.0	.0	.0	.0
Conductivity-St. Andrews ($\mu\text{SIE}/\text{cm}$)	34.4	13.2	20.6	12.5	15.5	35.7
Ca (mg/L)	.100	--	--	--	--	--
Mg (mg/L)	.200	--	--	--	--	--
K (mg/L)	.100	--	--	--	--	--
Na (mg/L)	1.600	--	--	--	--	--
Cl (mg/L)	2.500	--	--	--	--	--
SO ₄ (mg/L)	1.30	--	--	--	--	--
Total P (mg/L) ^c	.007	--	--	--	--	--
NO ₃ + NO ₂ (NO _x) (mg/L)	.070	--	--	--	--	--
NH ₄ (mg/L)	.030	--	--	--	--	--
Cu ($\mu\text{g}/\text{L}$)	--	.5	14.9	.5	.3	12.0
Zn ($\mu\text{g}/\text{L}$)	--	.0	42.0	.0	7.4	18.2
Cd ($\mu\text{g}/\text{L}$)	--	.03	.27	.00	.01	.16
Pb ($\mu\text{g}/\text{L}$)	--	.6	4.8	1.0	.1	13.8
Mn ($\mu\text{g}/\text{L}$)	--	.50	3.30	.30	.60	2.60
Fe ($\mu\text{g}/\text{L}$)	--	5.1	10.4	9.3	2.6	9.0
mm precipitation	14.3	26.0	1.2	26.8	58.4	8.0

^aIndicates that the sample volume was depleted before analysis could be performed for this parameter. Samples R20-24 were not sent to IWD for analysis.

^bR13 has high NO_x and NH₄ values; reason unknown.

^cThe bottle blank for nutrients showed Total P at 0.005 mg/L as only compound greater than detection limit.

^dRelative to December 31, 1977.

Table 4. July 1979-July 1980 St. Andrews, N.B. precipitation data.

Sampling date (day/month/year)	Day no. ^a	Volume precipitation (mm)	pH	Sampling date (day/month/year)	Day no. ^a	Volume precipitation (mm)	pH
26/07/79	558	790	4.42	10/03/80 ^c	800	1120	4.13
01/08/79	578	530	3.83 ^b	11/03/80	801	1080	4.66
02/08/79	579	820	3.95	14/03/80	804	850	4.93
03/08/79	580	90	3.80	17/03/80 ^c	807	960	5.26
07/08/79	584	335	4.12	18/03/80	808	1085	5.08
13/08/79 ^c	590	1100	4.59	19/03/80	809	98	4.91
14/08/79	591	1090	4.84	27/03/80	817	230	4.23
15/08/79	592	330	4.10	31/03/80 ^c	821	270	4.06
20/08/79 ^c	597	Overflow	4.50	08/04/80 ^c	829	1070	4.47
21/08/79	598	83	5.88	11/04/80	832	722	4.58
28/08/79	605	340	3.74	14/04/80 ^c	835	260	3.74 ^b
30/08/79	607	570	4.53	15/04/80	836	51	3.97
04/09/79	612	450	4.36	16/04/80	837	322	5.03
07/09/79	615	Overflow	5.03	17/04/80	838	650	4.04
11/09/79	619	277	4.28	21/04/80	842	319	4.01
20/09/79	628	398	3.95	22/04/80	843	500	4.35
24/09/79 ^c	632	Overflow	4.68	23/04/80	844	818	4.21
01/10/79 ^c	637	202	4.50	24/04/80	845	98	4.20
02/10/79	640	Overflow	4.77	28/04/80 ^c	849	74	3.76
04/10/79	642	"	4.70	30/04/80	850	1070	4.58
09/10/79	647	"	4.55	01/05/80	852	181	4.08
11/10/79	649	930	4.33	05/05/80 ^c	856	595	4.31
05/10/79 ^c	653	330	4.16	08/05/80	859	120	3.67 ^b
18/10/79	656	110	3.83	09/05/80	860	685	3.89
25/10/79	663	210	4.23	14/05/80	865	255	3.89
29/10/79 ^c	667	Overflow	4.45	15-16/05/80	867	137	4.09
30/10/79	668	575	4.14	19/05/80 ^c	870	478	4.15
05/11/79 ^c	674	Overflow	4.79	02/06/80 ^c	884	203	3.70 ^b
07/11/79	676	68	3.81 ^b	03/06/80	885	74	3.90
08/11/79	677	168	4.04	04/06/80	886	950	4.32
13/11/79 ^c	682	Overflow	4.01	05/06/80	887	136	4.32
14/11/79	683	242	4.27	06/06/80	888	68	4.52
15/11/79	684	160	4.37	09/06/80 ^c	889	877	4.32
20/11/79 ^c	689	270	3.87 ^b	10/06/80	890	845	4.08
21/11/79	690	660	3.86	16/06/80 ^c	898	975	4.11
26/11/79 ^c	695	135	3.63	21/06/80	903	452	4.38
27/11/79	696	750	4.42	23/06/80 ^c	905	75	4.33
07/12/79	706	567	4.58	27/06/80	909	78	3.49
10/12/79 ^c	709	78	4.08	30/06/80	912	405	4.08
11/12/79	710	43	4.16	03/07/80	915	425	3.81 ^b
14/12/79	713	126	4.24	07/07/80 ^c	919	195	3.55
17/12/79	716	788	4.53	09/07/80	921	775	4.08
18/12/79	717	118	4.91	14/07/80 ^c	926	1030	4.09
14/01/80 ^c	744	42	3.79	18/07/80	927	65	3.59 ^b
21/01/80 ^c	751	247	4.06	21/07/80	933	635	3.61
23/01/80	753	271	4.70	22/07/80	934	500	4.03
18/02/80 ^c	779	737	4.56	23/07/80	935	205	3.74
25/02/80 ^c	786	550	4.41	24/07/80	936	200	4.05
29/02/80	790	72	4.37	25/07/80	937	80	4.60
06/03/80	796	210	3.80				

^aRelative to December 31, 1977.^bEpisode of extremely acidic precipitation.^cWeekend precipitation collection.

Table 5. Graphite furnace analysis conditions for determination of heavy metals in rainwater.

Element	Drying temperature °C and time (s)	Charring temperature °C and time (s)	Atomization temperature °C and time (s)
Mn	175 15	900 20	2550 8
Cu	170 20	600 10	2700 6
Fe	180 20	900 10	2700 6
Zn	180 20	300 20	2500 6
Cd	170 20	300 25	2100 6
Pb	120 12	650 10	2200 6

Table 6. Quality control data on NBS Standard Reference Material 1643 (Trace Elements in Water) which was run with precipitation samples.

Element	Concentration ng/g NBS	Concentration ng/g determined on NBS standard
Cd	8 ± 1	7.1
Cu	16 ± 1	16.6
Fe	75 ± 1	77.0
Pb	20 ± 1	19.3
Mn	29 ± 1	27.9
Zn	65 ± 1	110.1 (68.0 ^a)

^aZero intercept of linearly regressed Zn curve was at 42.0 ng/g.
Subtracting 42.0 ng/g from the determined value yields the 68.0 ng/g value for the NBS standard and is proximate to the certified value.

Table 7. Comparison of 1979-80 monthly pH's at St. Andrews, Saint John, and Acadia Forestry Experimental Station, N.B.

Month	Arithmetic mean pH St. Andrews	Composite pH Saint John ^a	Composite pH Acadia Forestry Experimental Station
August 1979	4.4	4.2	
September 1979	4.5	4.3	
October 1979	4.4	4.2	
November 1979	4.1	4.2	4.3
December 1979	4.4	5.5	4.4
January 1980	4.2	6.9	4.5
February 1980	4.4	5.1	4.8
March 1980	4.6	6.1	4.6
April 1980	4.2	5.8	4.3
May 1980	4.0	4.3	4.0
June 1980	4.1	4.5	4.2

^aFrom CANSAP data sheets.

Table 8. pH comparison data.

Location	Date	pH	Reference
Heerhugowaard, Noord Holland	Daily	4.04-7.10	Slanina et al. 1979
Colorado, U.S.A.	1975-78	3.7-6.8	Lewis & Grant 1980
Hubbard Brook Expt. Forest	1963-74	4.12	Likens 1975
Sjöängen, Sweden	1973-75	4.3	Granat 1978
Truro, N.S.	Apr. 1975	4.0-4.5	Shaw 1979
Hubbard Brook, N.H.	1965-66	4.1	Fisher et al. 1968
Sable Island, N.S.	1975	4.28-6.55	Olson et al. 1976
Hubbard Brook, N.H.	1970-71	4.03	Likens & Bormann 1974
Ithaca, N.Y.	1970-71	3.98	Likens & Bormann 1974
Aurora, N.Y.	1970-71	4.02	Likens & Bormann 1974
Northeastern U.S.	--	4.0-4.2	Overrein 1977
N.Y. Metropolitan area	1975-76	4.28	Wolff et al. 1979
Sydney, Australia	1975-76	4.0-5.5	Scott 1978
Sweden, Station 23 Pl SW ^a	--	4.66	Granat 1972
Belgium, Station 526 u ^a	--	4.42	Granat 1972
France, Station 703 LM ^a	--	4.80	Granat 1972
Pasadena, California	1976-77	4.06 (2.79-5.32)	Liljestrand & Morgan 1978
N.Y.-N.H.-Tennessee	1972-73	4.05-4.19	Cogbill & Likens 1974
Yonkers, N.Y.	1974	4.1 (3.4-4.9)	Jacobson et al. 1976
Saint John, N.B.	Nov. 22/73	3.68-4.06	Anlauf et al. 1976
Saint John, N.B.	July 15/74	3.9-5.4	Anlauf et al. 1976
Saint John, N.B.	July 18-20/74	3.4-4.33	Anlauf et al. 1976
Sable Island, N.S.	1975-77	4.79	Wiltshire 1979
Halifax Coastal, N.S.	1972-73	5.1	Wiltshire 1979
Sydney Rural, N.S.	1972-73	5.1	Wiltshire 1979
Shelburne, N.S.	1975-78	4.55	Wiltshire 1979
Halifax Urban, N.S.	1972-73	4.3	Wiltshire 1979
Sydney Urban, N.S.	1972-73	5.2	Wiltshire 1979
O.S.A. Lake (La Cloche Mtns.)	1972	3.9	Beamish 1974
O.S.A. Lake (La Cloche Mtns.)	1972-73	4.3	Beamish 1974
U.K. (7 non-urban sites)	1972-73	3.5-5.9	Cawse 1974
Saint John, N.B.	1977-78	3.9-6.1	Anon. 1979
Charlo, N.B.	1977-78	4.1-5.8	Anon. 1979
Kejimkujik, N.S.	1978	4.3-4.6	Anon. 1979
Sable Island, N.S.	1976-78	4.0-6.0	Anon. 1979
Whitehorse, Yukon	1977-78	5.8-7.2	Anon. 1979
St. Andrews, N.B.	1975-76	4.22	Zitko & Carson, Unpubl.
St. Andrews, N.B.	1976	4.61	Sergeant & Zitko 1978
St. Andrews, N.B.	1977	3.88	Sergeant & Zitko 1978
Nashwaak, N.B.	1973-76	3.72-6.50	Anon. 1978
St. Andrews, N.B.	1978	4.45 (3.5-5.24) ^b	This study

^aData from the European Atmospheric Chemistry Network.

^bGeometric mean.

Table 9. Conductivity comparison data.

Location	Date	Conductivity (μmho or $\mu\text{SIE/cm}$)	Reference
Lake Erie	Summer 1970-76	54	Kuntz 1978
Sjöängen, Sweden	1973-75	28	Granat 1978
Sweden, Station 2 Ki N	--	12	Granat 1972
Sweden, Station 23 Pl SW	--	45	Granat 1972
Belgium, Station 526 u	--	37	Granat 1972
France, Station 703 LM	--	19	Granat 1972
Yonkers, N.Y.	1974	47.7(6.8-162)	Jacobson et al. 1976
Saint John, N.B.	Nov. 22/73	—	Anlauf et al. 1976
Saint John, N.B.	July 15/74	42-70	Anlauf et al. 1976
Saint John, N.B.	July 18-20/74	53-210	Anlauf et al. 1976
Saint John, N.B.	1977-78	37	Anon. 1979
Charlo, N.B.	1977-78	32	Anon. 1979
Kejimkujik, N.S.	1978	22	Anon. 1979
Sable Island, N.S.	1976-78	126	Anon. 1979
Whitehorse, Yukon	1977-78	17	Anon. 1979
St. Andrews, N.B.	1978	30.79	This study

Table 10. NH_4 comparison data.

Location	Date	Concentration NH_4 (mg/L)	Reference
Lake Erie	Summer 1970-76	0.61	Kuntz 1978
Lake Ontario Basin	1970-71	0.62	Shiomii & Kuntz 1973
Holland	Daily	1.7-64.6	Slanina et al. 1979
Coastal Rural, U.S.	--	0.031-0.072	Wolaver 1972
Coastal Urban, U.S.	--	0.03-0.99	Wolaver 1972
Continental Rural, U.S.	--	0.03-0.13	Wolaver 1972
Continental Urban, U.S.	--	0.03-0.20	Wolaver 1972
Hubbard Brook, N.H.	1964-1974	0.22	Likens 1975
Sjöängen, Sweden	1973-1975	0.55	Granat 1978
Pasadena, California	1976-1977	0.56 (0.005-0.87)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.10	Granat 1972
Sweden, Station 23 Pl SW	--	0.82	Granat 1972
Belgium, Station 526 u	--	0.43	Granat 1972
France, Station 703 LM	--	0.26	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-1973	0.19-0.42	Cogbill & Likens 1974
Saint John, N.B.	Nov. 22/73	0.5-2.8	Anlauf et al. 1976
Saint John, N.B.	July 15/74	1.1-3.1	Anlauf et al. 1976
Saint John, N.B.	July 18-20/74	0.7-2.4	Anlauf et al. 1976
Saint John, N.B.	1977-78	0.218	Anon. 1979
Charlo, N.B.	1977-78	0.272	Anon. 1979
Kejimkujik, N.S.	1978	0.084	Anon. 1979
Sable Island, N.S.	1976-78	0.056	Anon. 1979
Whitehorse, Yukon	1977-78	0.260	Anon. 1979
Nashwaak, N.B.	1973-76	0.08	Anon. 1978
St. Andrews, N.B.	1978	0.10 (0.005-2.3)	This study

Table 11. NO₃ + NO₂ (NO_X) comparison data.

Location	Date	Concentration	Reference
		NO _X (mg/L)	
Lake Erie	Summer 1970-76	1.06	Kuntz 1978
Lake Ontario Basin	1970-71	1.53	Shiomii & Kuntz 1973
Hubbard Brook, N.H.	1964-74	1.47	Likens 1975
Sjöängen, Sweden	1973-75	0.99	Granat 1978
Hubbard Brook, N.H.	1964-1966	0.0-3.0	Fisher et al. 1968
Sable Island, N.S.	1975	0.2-1.4	Olson et al. 1976
Pasadena, California	1976-1977	4.65 (0.68-117.8)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.31	Granat 1972
Sweden, Station 23 Pl SW	--	1.98	Granat 1972
Belgium, Station 526 u	--	2.23	Granat 1972
France, Station 703 LM	--	1.98	Granat 1972
N.Y.-N.H.-Tennessee, U.S.	1972-73	1.24-3.27	Cogbill & Likens 1974
Yonkers, N.Y.	1974	4.4(<1-44.0)	Jacobson et al. 1976
Saint John, N.B.	Nov. 22/73	0.8-2.7	Anlauf et al. 1976
Saint John, N.B.	July 15/74	2.4-3.6	Anlauf et al. 1976
Saint John, N.B.	July 18-20/74	0.7-12.3	Anlauf et al. 1976
Saint John, N.B.	1977-78	0.349	Anon. 1979
Charlo, N.B.	1977-78	0.270	Anon. 1979
Kejimkujik, N.S.	1978	0.242	Anon. 1979
Sable Island, N.S.	1976-78	0.201	Anon. 1979
Whitehorse, Yukon	1977-78	0.226	Anon. 1979
Nashwaak, N.B.	1973-76	0.01-1.72	Anon. 1979
St. Andrews, N.B.	1978	0.252 (<0.01-1.8)	This study

Table 12. Total P comparison data.

Location	Date	Total P (mg/L)	Reference
Lake Erie	Summer 1970-76	0.068	Kuntz 1978
Lake Ontario Basin	1970-71	0.058	Shiomii & Kuntz 1973
Saint John, N.B.	1977-78	0.062	Anon. 1979
Charlo, N.B.	1977-78	0.038	Anon. 1979
Kejimkujik, N.S.	1978	0.003	Anon. 1979
Sable Island, N.S.	1976-78	0.060	Anon. 1979
Whitehorse, Yukon	1977-78	0.139	Anon. 1979
Nashwaak, N.B.	1973-76	0.001-.175	Anon. 1978
St. Andrews, N.B.	1978	0.0015 (0.004-0.98)	This study

Table 13. Ca comparison data.

Location	Date	Ca (mg/L)	Reference
Lake Erie	1970-76	3.43	Kuntz 1978
Lake Ontario Basin	1970-71	5.04	Shiomi & Kuntz 1973
Holland	Monthly	1.04-6.5	Slanina et al. 1979
Coastal Rural, U.S.	--	0.06-0.32	Wolaver 1972
Coastal Urban, U.S.	--	0.10-0.71	Wolaver 1972
Continental Rural, U.S.	--	0.26-2.47	Wolaver 1972
Continental Urban, U.S.	--	0.60-4.02	Wolaver 1972
Hubbard Brook, N.H.	1963-1974	0.16	Likens 1975
Sjöängen, Sweden	1973-1975	0.52	Granat 1978
Pasadena, California	1976-1977	0.19 (0.01-1.7)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.64	Granat 1972
Sweden, Station 23 Pl SW	--	0.84	Granat 1972
Belgium, Station 526 u	--	1.32	Granat 1972
France, Station 703 LM	--	0.68	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-1973	0.20-0.83	Cogbill & Likens 1974
U.K. (all sites)	1972-73	0.13-4.6 ^a	Cawse 1974
Saint John, N.B.	1977-78	0.46	Anon. 1979
Charlo, N.B.	1977-78	0.37	Anon. 1979
Kejimkujik, N.S.	1978	0.09	Anon. 1979
Sable Island, N.S.	1976-78	0.69	Anon. 1979
Whitehorse, Yukon	1977-78	0.97	Anon. 1979
St. Andrews, N.B.	1978	0.137 (<0.10-0.40)	This study

^aIn reaching this range, we dropped out their top value of 49.8 as possibly being in error, contamination problem.

Table 14. Mg comparison data.

Location	Date	Mg (mg/L)	Reference
Lake Erie	Summer 1970-76	0.57	Kuntz 1978
Lake Ontario Basin	1970-71	0.82	Shiomi & Kuntz 1973
Hubbard Brook, N.H.	1963-1974	0.04	Likens 1975
Sjöängen, Sweden	1973-1975	0.17	Granat 1978
Pasadena, California	1976-1977	0.80 (0.004-0.7)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.12	Granat 1972
Sweden, Station 23 Pl SW	--	0.36	Granat 1972
Belgium, Station 526 u	--	0.36	Granat 1972
France, Station 703 LM	--	0.39	Granat 1972
N.Y.-N.H.-Tenn. U.S.	1972-1973	0.03-0.13	Cogbill & Likens 1974
Saint John, N.B.	1977-78	0.18	Anon. 1979
Charlo, N.B.	1977-78	0.06	Anon. 1979
Kejimkujik, N.S.	1978	0.03	Anon. 1979
Sable Island, N.S.	1976-78	1.84	Anon. 1979
Whitehorse, Yukon	1977-78	0.12	Anon. 1979
St. Andrews, N.B.	1978	0.215 (<0.10-8.0)	This study

Table 15. Na comparison data.

Location	Date	Na (mg/L)	Reference
Lake Erie	Summer 1970-76	0.97	Kuntz 1978
Lake Ontario Basin	1970-71	2.69	Shiomi & Kuntz 1973
Holland	Daily	0.51-30.5	Slanina et al. 1979
Holland	Monthly	1.9-16.2	Slanina et al. 1979
Coastal Rural, U.S.	--	0.5-2.43	Wolaver 1972
Coastal Urban, U.S.	--	0.08-0.48	Wolaver 1972
Continental Rural, U.S.	--	0.07-0.79	Wolaver 1972
Continental Urban, U.S.	--	0.09-0.86	Wolaver 1972
Hubbard Brook, N.H.	1963-74	0.12	Likens 1975
Sjöängen, Sweden	1973-75	0.35	Granat 1978
Pasadena, California	1976-77	0.58 (0.02-8.97)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.30	Granat 1972
Sweden, Station 23 Pl SW	--	1.96	Granat 1972
Belgium, Station 526 u	--	0.97	Granat 1972
France, Station 703 LM	--	0.92	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-73	0.05-0.15	Cogbill & Likens 1974
Heidelberg, Germany	1971	0.76	Bogen 1974
U.K. (all sites)	1972-73	1.7-108	Cawse 1974
Saint John, N.B.	1977-78	1.0	Anon. 1979
Charlo, N.B.	1977-78	0.6	Anon. 1979
Kejimkujik, N.S.	1978	0.2	Anon. 1979
Sable Island, N.S.	1976-78	16.54	Anon. 1979
Whitehorse, Yukon	1977-78	0.4	Anon. 1979
St. Andrews, N.B.	1978	0.886 (0.4-1.8)	This study

Table 16. K Comparison data.

Location	Date	K (mg/L)	Reference
Lake Erie	Summer 1970-76	0.42	Kuntz 1978
Lake Ontario Basin	1970-71	0.56	Shiomi & Kuntz 1973
Coastal Rural, U.S.	--	0.09-0.17	Wolaver 1972
Coastal Urban, U.S.	--	0.08-0.12	Wolaver 1972
Continental Rural, U.S.	--	0.08-0.37	Wolaver 1972
Continental Urban, U.S.	--	0.09-0.29	Wolaver 1972
Hubbard Brook, N.H.	1963-74	0.07	Likens 1975
Sjöängen, Sweden	1973-75	0.12	Granat 1978
Pasadena, California	1976-77	0.08 (0.007-1.84)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.20	Granat 1972
Sweden, Station 23 Pl SW	--	0.27	Granat 1972
Belgium, Station 526 u	--	0.23	Granat 1972
France, Station 703 LM	--	0.16	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-73	0.07-0.09	Cogbill & Likens 1974
Heidelberg, Germany	1971	0.8	Bogen 1974
Saint John, N.B.	1977-78	0.12	Anon. 1979
Charlo, N.B.	1977-78	0.17	Anon. 1979
Kejimkujik, N.S.	1978	0.06	Anon. 1979
Sable Island, N.S.	1976-78	0.65	Anon. 1979
Whitehorse, Yukon	1977-78	0.19	Anon. 1979
St. Andrews, N.B.	1978	0.125	This study

Table 17. Cl comparison data.

Location	Date	Cl (mg/L)	Reference
Lake Erie	Summer 1970-76	1.11	Kuntz 1978
Lake Ontario Basin	1970-71	1.60	Shiomii & Kuntz 1973
Holland	Daily	1.2-73.8	Slanina et al. 1979
Holland	Monthly	4.3-12.4	Slanina et al. 1979
Coastal Rural, U.S.	--	0.9-4.39	Wolaver 1972
Coastal Urban, U.S.	--	0.05-2.38	Wolaver 1972
Continental Rural, U.S.	--	0.16-1.08	Wolaver 1972
Continental Urban, U.S.	--	0.18-2.36	Wolaver 1972
Hubbard Brook, N.H.	1965-74	0.47	Likens 1975
Sjöängen, Sweden	1973-75	0.64	Granat 1978
Pasadena, California	1976-77	1.03 (0.04-16.33)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	0.39	Granat 1972
Sweden, Station 23 Pl SW	--	3.48	Granat 1972
Belgium, Station 526 u	--	1.95	Granat 1972
France, Station 703 LM	--	2.13	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-73	0.15-0.47	Cogbill & Likens 1974
Yonkers, N.Y.	1974	1.2 (<1-7)	Jacobson et al. 1976
Saint John, N.B.	July 15/74	0.1-1.8	Anlauf et al. 1976
Saint John, N.B.	July 18-20/74	0.1-4.0	Anlauf et al. 1976
Heidelberg, Germany	1971	1.5	Bogen 1974
Saint John, N.B.	1977-78	1.2	Anon. 1979
Charlo, N.B.	1977-78	0.9	Anon. 1979
Kejimkujik, N.S.	1978	0.3	Anon. 1979
Sable Island, N.S.	1976-78	27.8	Anon. 1979
Whitehorse, Yukon	1977-78	0.59	Anon. 1979
St. Andrews, N.B.	1978	1.25	This study

Table 18. SO₄ comparison data.

Location	Date	SO ₄ (mg/L)	Reference
Lake Erie	Summer 1970-76	7.60	Kuntz 1978
Lake Ontario Basin	1970-71	10.01	Shiomii & Kuntz 1973
Holland	Daily	3.7-43.8	Slanina et al. 1979
Coastal Rural, U.S.	--	0.3-1.30	Wolaver 1972
Coastal Urban, U.S.	--	1.4-1.89	Wolaver 1972
Continental Rural, U.S.	--	0.1-4.18	Wolaver 1972
Continental Urban, U.S.	--	0.85-8.42	Wolaver 1972
Hubbard Brook, N.H.	1964-74	2.9	Likens 1975
Sjöängen, Sweden	1973-75	6.62	Granat 1978
Shelburne, N.S.	Apr. 1975-	0.0-9.0	Shaw 1979
Hubbard Brook, N.H.	1964-66	1.5-6.5	Fisher et al. 1968
Sable Island, N.S.	1975	1.8-6.7	Olson et al. 1976
Pasadena, California	1976-77	2.88 (0.72-41.3)	Liljestrand & Morgan 1978
Sweden, Station 2 Ki N	--	2.01	Granat 1972
Sweden, Station 23 Pl SW	--	4.90	Granat 1972
Belgium, Station 526 u	--	6.05	Granat 1972
France, Station 703 LM	--	2.78	Granat 1972
N.Y.-N.H.-Tenn., U.S.	1972-73	3.19-4.96	Cogbill & Likens 1974
Yonkers, N.Y.	1974	4.8 (<1-20)	Jacobson et al. 1976
Saint John, N.B.	Nov. 22/73 uncorr.	5.7-11.5	Anlauf et al. 1976
Saint John, N.B.	July 15/74	6.4-11.4	Anlauf et al. 1976
Saint John, N.B.	July 18-20/79	4.8-17.2	Anlauf et al. 1976
Sable Island, N.S.	1975-76	1.72	Wiltshire 1979
Halifax-Sydney, N.S.	1972-77	3.6-7.29	Wiltshire 1979
OSA Lake (La Cloche Mtn.)	1972	11.0	Beamish 1974
OSA Lake (La Cloche Mtn.)	1972-73	7.0	Beamish 1974
Saint John, N.B.	1977-78	4.8	Anon. 1979
Charlo, N.B.	1977-78	4.3.9	Anon. 1979
Kejimkujik, N.S.	1978	2.1	Anon. 1979
Sable Island, N.S.	1976-78	6.0	Anon. 1979
Whitehorse, Yukon	1977-78	2.3	Anon. 1979
St. Andrews, N.B.	May 1975-Mar. 76	10.2	Zitko & Carson, unpubl.
St. Andrews, N.B.	1976 July/Aug.	6.51	Anon. 1977
St. Andrews, N.B.	1977	2.30	Sergeant & Zitko 1978
St. Andrews, N.B.	1978	3.35 (1.0-22.6)	This study

Table 19. SO₄ deposition rates at several locations (wet precipitation only).

Location	SO ₄ deposition g/ha/mo	Reference
St. Andrews, N.B.	1728	This study
Canadian Maritimes (May 1977-Mar. 1978)	2200-3200	Shaw (1979)
Labrador/east Newfoundland	1800	"
Maniwaki, Que.	2000	"
Europe	1000-5000	"
Sable Island, N.S. (1975-77)	1900	Wiltshire (1979)
Shelburne, N.S. (Apr. 1975-Apr. 1978)	2756	"
Halifax coastal, N.S. 1972-73	2725	"
Halifax urban, N.S. 1972-73	6408	"

Table 20. Cd comparison data (N.D. - non-detectable).

Location	Date	Cd (mg/L)	Reference
Chicago (South side), Ill.	June 28/68	193.2	Harrison 1970
Gary-(East Interchange) Ind.	June 26/68	43.0	Harrison 1970
LaPorte, Indiana	June 26/68	24.6	Harrison 1970
Lake Erie	Summer 1970-76	1.0	Kuntz 1978
Lake Ontario Basin	1970-71	1.0	Shiomi & Kuntz 1973
Holland	Monthly	0.7-11.0	Slanina et al. 1979
OSA Lake, LaCloche Mtns.	1972-73	<0.1	Beamish 1974
Montane, N.H.	1971	0.1-2.3	Schlesinger et al. 1974
Chadron, Nebraska	1973	0.26	Struempler 1976
U.K. (all sites)	1972-73	<0.3-43	Cawse 1974
Saint John, N.B.	1977-78	2	Anon. 1979
Charlo, N.B.	1977-78	2	Anon. 1979
Kejimkujik, N.S.	1978	1	Anon. 1979
Sable Island, N.S.	1976-78	8	Anon. 1979
Whitehorse, Yukon	1977-78	2	Anon. 1979
St. Andrews, N.B.	1970-71	0.57	Zitko & Carson, unpubl.
St. Andrews, N.B.	1978	0.164 (N.D.-3.59)	This study

Table 21. Pb comparison data.

Location	Date	Concentration Pb $\mu\text{g}/\text{L}$	Reference
Chicago, Illinois	June 26/68	45.3	Harrison 1970
Gary, Indiana	June 26/68	24.5	Harrison 1970
LaPorte, Indiana	June 26/68	20.9	Harrison 1970
Lake Erie	Summer 1970-76	6.0	Kuntz 1978
Lake Ontario Basin	1970-71	20.0	Shiomi & Kuntz 1973
Holland	Daily	28-235	Slanina et al. 1979
Holland	Monthly	52-200	Slanina et al. 1979
Pasadena, California	1976-77	74.6 (3.7-663)	Liljestrand & Morgan 1978
OSA Lake (LaCloche Mtn.)	1972	23.0	Beamish 1974
OSA Lake (LaCloche Mtn.)	1972-73	25.0	Beamish 1974
Montane, N.H.	1971	4-67.7	Schlesinger et al. 1974
Chadron, Nebraska	1973	<4.3	Struempler 1976
32 Stns. in U.S.	1966-67	34	Lazarus et al. 1970
U.K. (all sites)	1972-73	41 (6.7-110)	Cawse 1974
Saint John, N.B.	1977-78	12	Anon. 1979
Charlo, N.B.	1977-78	15	Anon. 1979
Kejimkujik, N.S.	1978	8	Anon. 1979
Sable Island, N.S.	1976-78	5	Anon. 1979
Whitehorse, Yukon	1977-78	2	Anon. 1979
St. Andrews, N.B.	1970-71	2.77	Zitko & Carson, unpubl.
St. Andrews, N.B.	1978	6.59 (0.1-62.5)	This study

Table 22. Cu comparison data.

Location	Date	Concentration Cu $\mu\text{g}/\text{L}$	Reference
Chicago, Illinois	June 26/68	43.7	Harrison 1970
Gary, Indiana	June 26/68	38.7	Harrison 1970
LaPorte, Indiana	June 26/68	10.9	Harrison 1970
Lake Erie	Summer 1970-76	4.0	Kuntz 1978
Lake Ontario Basin	1970-71	6.0	Shiomi & Kuntz 1973
Holland	Monthly	11-38	Slanina et al. 1979
OSA Lake (LaCloche Mtn.)	1972	5.0	Beamish 1974
OSA Lake (LaCloche Mtn.)	1972-73	9.0	Beamish 1974
Chadron, Nebraska	1973	4.5	Struempler 1976
32 Stns. in U.S.	1966-67	21	Lazarus et al. 1970
U.K. (all sites)	1972-73	8.2-52	Cawse 1974
Saint John, N.B.	1977-78	3	Anon. 1979
Charlo, N.B.	1977-78	2	Anon. 1979
Kejimkujik, N.S.	1978	5	Anon. 1979
Sable Island, N.S.	1976-78	12	Anon. 1979
Whitehorse, Yukon	1977-78	2	Anon. 1979
St. Andrews, N.B.	1970-71	6.44	Zitko & Carson, unpubl.
St. Andrews, N.B.	1978	5.87 (0.3-51.0)	This study

Table 23. Fe comparison data.

Location	Date	Concentration Fe $\mu\text{g/L}$	Reference
Lake Erie	Summer 1970-76	12.0	Kuntz 1978
Lake Ontario Basin	1970-71	34.0	Shiomi & Kuntz 1973
Holland	Monthly	10.33-7.2	Slanina et al. 1979
Pasadena, California	1976-77	20.1 (1.4-128.5)	Liljestrand & Morgan 1978
OSA Lake, LaCloche Mtns.	1972	15.0	Beamish 1974
OSA Lake, LaCloche Mtns.	1972-73	30.0	Beamish 1974
SE Ontario	--	130-1800	Sorenson et al. 1974
Heidelberg, Germany	1971	1750	Bogen 1974
U.K. (all sites)	1972-73	63-2700	Cawse 1974
Saint John, N.B.	1977-78	21	Anon. 1979
Charlo, N.B.	1977-78	15	Anon. 1979
Kejimkujik, N.S.	1978	7	Anon. 1979
Sable Island, N.S.	1976-78	47	Anon. 1979
Whitehorse, Yukon	1977-78	4	Anon. 1979
St. Andrews, N.B.	1970-71	45	Zitko & Carson, unpubl.
St. Andrews, N.B.	1978	17.78 (1.4-143.0)	This study

Table 24. Mn comparison data.

Location	Date	Concentration Mn $\mu\text{g/L}$	Reference
Pasadena, California	1976-77	1.8 (<.11-21.43)	Liljestrand & Morgan 1978
Heidelberg, Germany	1971	25.3	Bogen 1974
Chadron, Nebraska	1973	5.4	Struempler 1976
32 Stns. in U.S.	1966-67	12	Lazarus et al. 1970
U.K. (all sites)	1972-73	1.2-77	Cawse 1974
St. Andrews, N.B.	1978	2.35 (0.3-12.7)	This study

Table 25. Zn comparison data.

Location	Date	Concentration Zn $\mu\text{g/L}$	Reference
Lake Erie	Summer 1970-76	62.0	Kuntz 1978
Lake Ontario Basin	1970-71	80.0	Shiomi & Kuntz 1973
Holland	Monthly	103-730	Slanina et al. 1979
OSA Lake, LaCloche Mtns.	1972	25.0	Beamish 1974
OSA Lake, LaCloche Mtns.	1972-73	39.0	Beamish 1974
Chadron, Nebraska	1973	10.0	Struempler 1976
32 Stns. in U.S.	1966-67	107	Lazarus et al. 1970
U.K. (all sites)	1972-73	18-380	Cawse 1974
Saint John, N.B.	1977-78	10	Anon. 1979
Charlo, N.B.	1977-78	10	Anon. 1979
Kejimkujik, N.S.	1978	9	Anon. 1979
Sable Island, N.S.	1976-78	9	Anon. 1979
Whitehorse, Yukon	1977-78	7	Anon. 1979
St. Andrews, N.B.	1970-71	35.6	Zitko & Carson, unpubl.
St. Andrews, N.B.	1978	31.91 (5.8-87.6)	This study

Table 26. Comparison of heavy metal deposition rates at several locations.

Heavy metal	Deposition in g/ha/mo				
	St. Andrews, N.B.		Frederiksvaerk, Denmark ^b	Chadron, Nebraska, USA ^c	Flin Flon, Manitoba, Canada ^d
	1978 study	Zitko & Carson 1971 ^a			
Zn	16.5	31.0	35.7	3.3	1176
Fe	9.2	3.9	128.6	-	161
Pb	3.4	2.3	8.6	1.6	33.4
Cu	3.0	5.6	1.6	1.5	89.2
Mn	1.2	-	17.6	1.8	7.1
Cd	0.1	0.5	0.1	0.1	3.6

^aUnpublished.

^bCalculated from Pilegaard (1979) for 7 km from steelworks.

^cStruempler (1976).

^dCalculated from Franzin et al. (1979) assuming distance of 4-5 km from smelter.

Table 27. Tabulation of correlation coefficients calculated during examination of 1978 rainwater data.

Dependent variable	Independent variable(s)	Correlation coefficient
pH	Cl	0.08410
pH	Ca	0.44945
pH	Mg	0.49348
pH	Na	0.00709
pH	K	0.27166
pH	NH ₄	0.75452
pH	NO _x	0.77529
pH	SO ₄	0.89831
pH	SO ₄ , Cl, NO _x	0.90153
pH	SO ₄ , Cl, NO _x , NH ₄	0.91846
NO	Ca, Mg, Na, K	0.77059
Cl	Ca, Mg, Na, K	0.82257
pH	SO ₄ , Cl, NO _x , Ca, Mg, Na, NH ₄	0.99738
pH	SO ₄ , Cl, NO _x , Ca, Mg, K, NH ₄	0.99731
pH	SO ₄ , NO _x , NH ₄	0.88957
pH	SO ₄	0.66045
pH	NO _x	0.79176
pH	NH ₄	0.60302
Conductivity	pH, volume precipitation	0.73925
Conductivity	pH, mm precipitation	0.73561
Conductivity	Fe	0.70381
Conductivity	Mn	0.88169
Conductivity	Pb	0.95973
Conductivity	Zn	0.47310
Pb	Mn	0.88356
Pb	Fe	0.71329
Mn	Fe	0.73493
Cu	Fe	0.58625
Cu	Zn	0.73544
Pb	Fe, Mn	0.88857

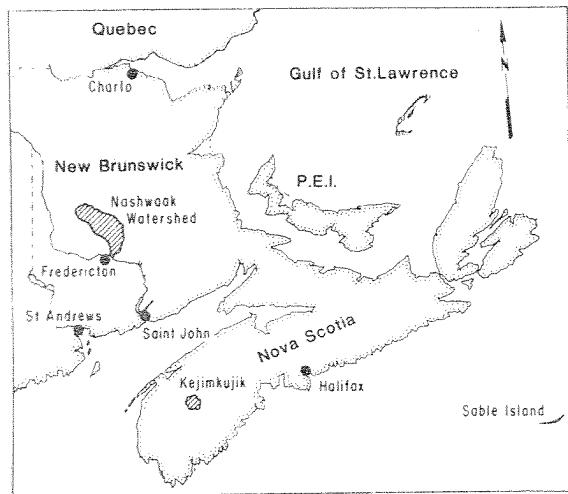


Fig. 1. Sampling locations in New Brunswick and Nova Scotia, Canada.

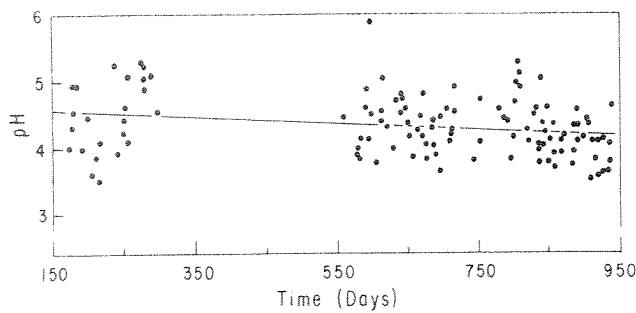


Fig. 2. pH of precipitation versus time (relative to December 31, 1977) for the 1978-80 sampling periods - trend line is shown.

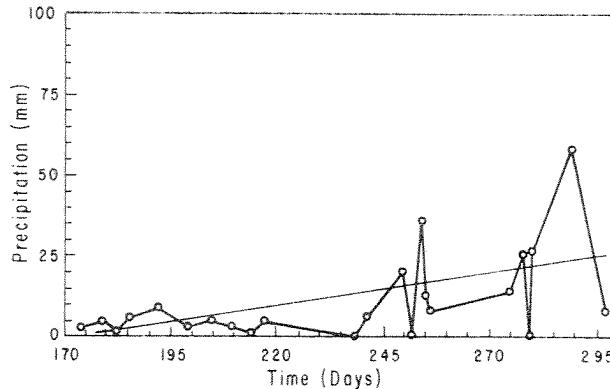


Fig. 4. Millimeters (mm) of precipitation versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

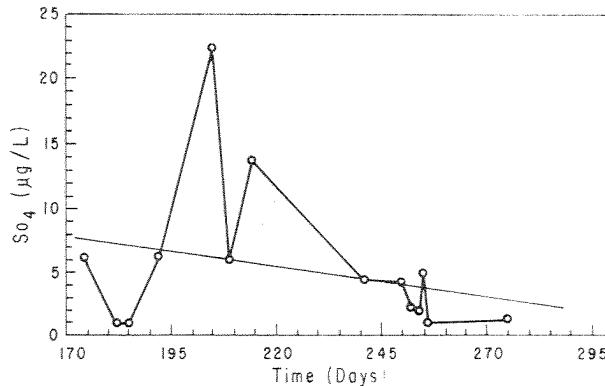


Fig. 5. SO_4 concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

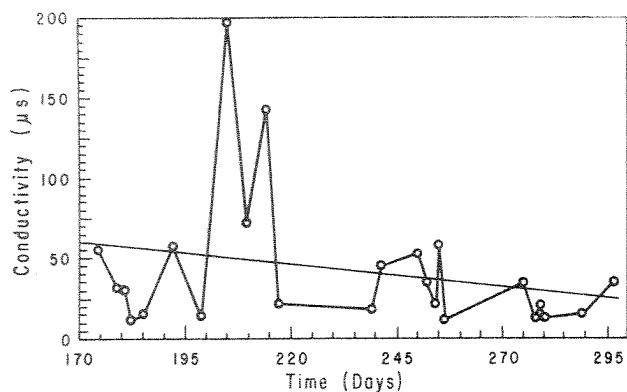


Fig. 3. Conductivity of rain water versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

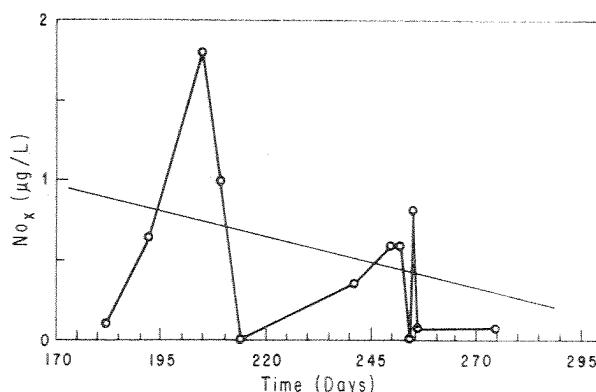


Fig. 6. NO_x concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

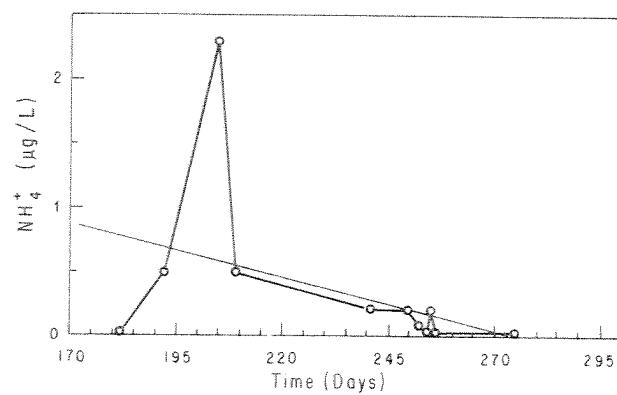


Fig. 7. NH₄ concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

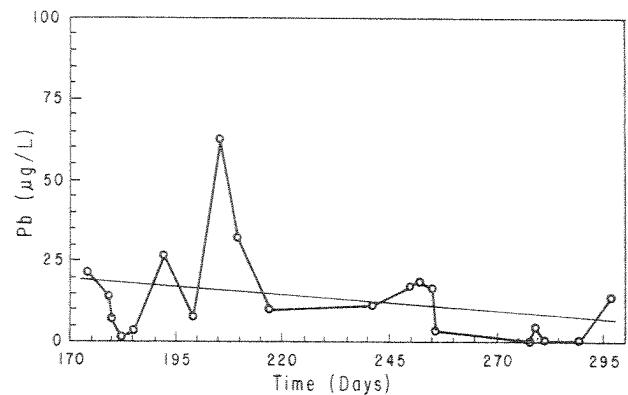


Fig. 10. Pb concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

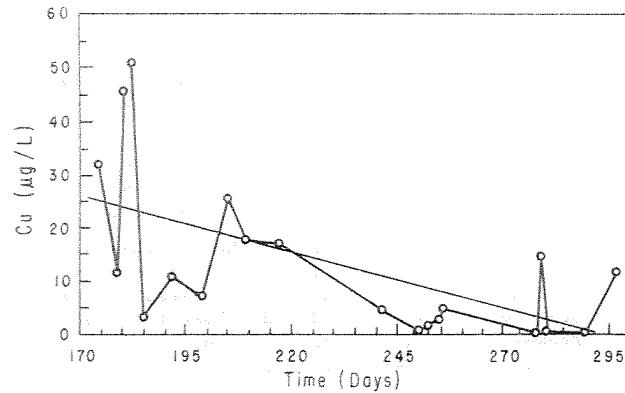


Fig. 8. Cu concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

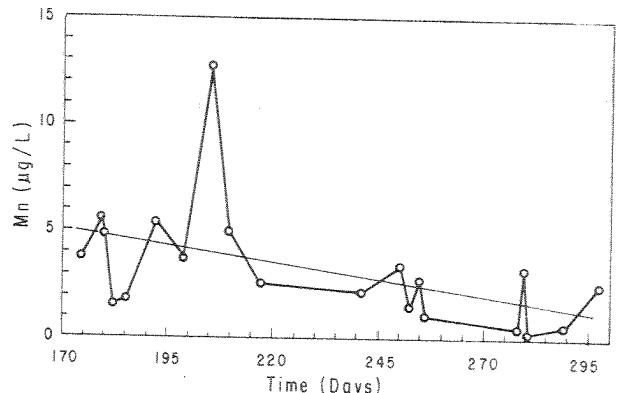


Fig. 11. Mn concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

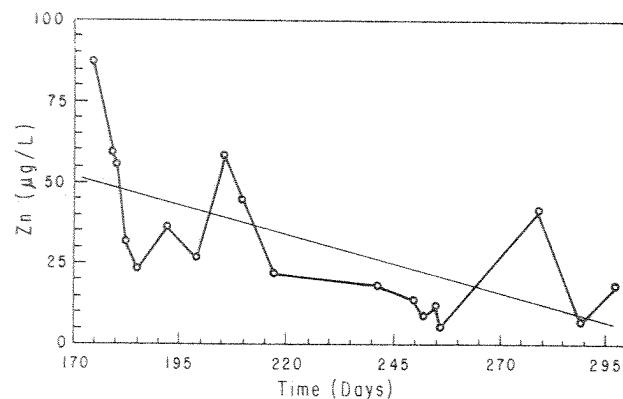


Fig. 9. Zn concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

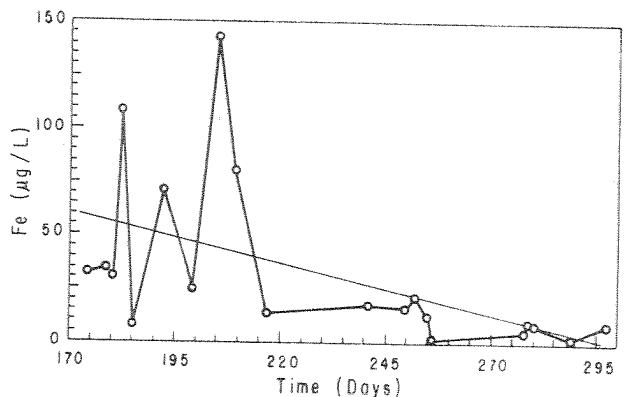


Fig. 12. Fe concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

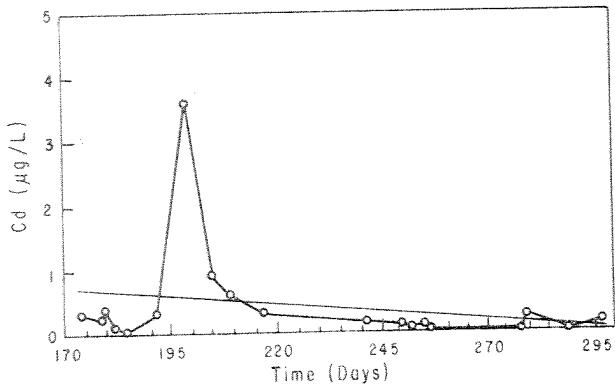


Fig. 13. Cd concentration versus time (relative to December 31, 1977) for the 1978 sampling period - trend line is shown.

Note: Day 100 = April 10, 1978
 Day 200 = July 19, 1978
 Day 300 = October 27, 1978

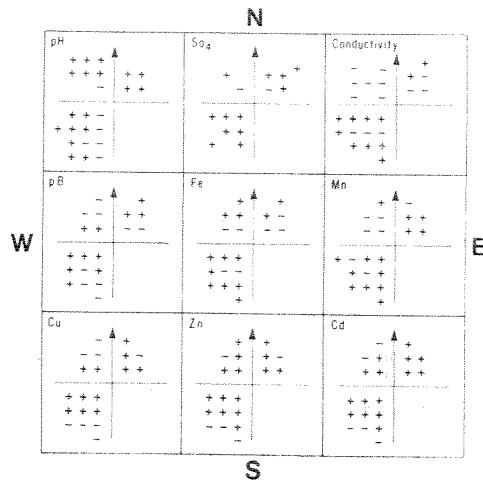
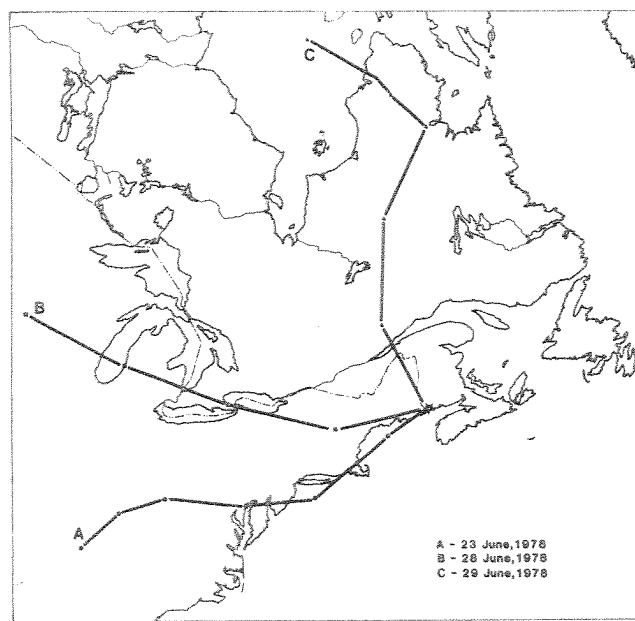


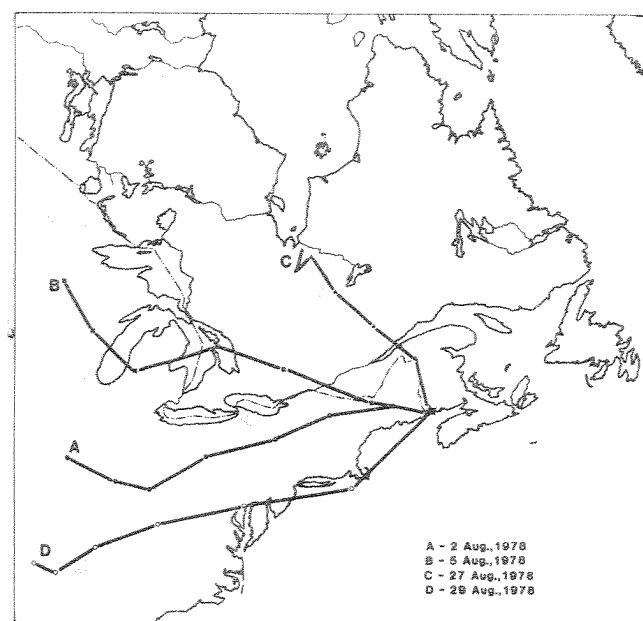
Fig. 14. Correlation of various parameters measured with the air parcel trajectory computed for 2-3 d prior to the precipitation event;

- + indicates a value higher than a set criterion for the parameter investigated and hypothesis proposed and therefore agreement with the hypothesis;
- indicates a value contrary to the hypothesis. For example, the hypothesis for pH is that storms approaching from the south through west quadrant should be of low pH (<4.2) and those from the northwest through east quadrant should be of high pH (>4.5). See text for discussion of values between pH 4.2 and 4.5.

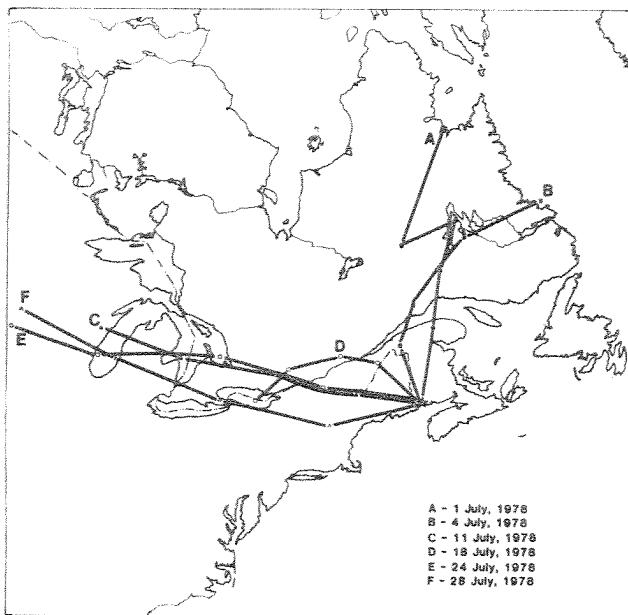
Criterion for SO_4 , conductivity, Pb, Fe, Mn, Cu, Zn, and Cd were 2.5 mg/L, 15 $\mu\text{S}/\text{cm}$, 10, 10, 2, 10, 25, and 0.2 $\mu\text{g}/\text{L}$, respectively.



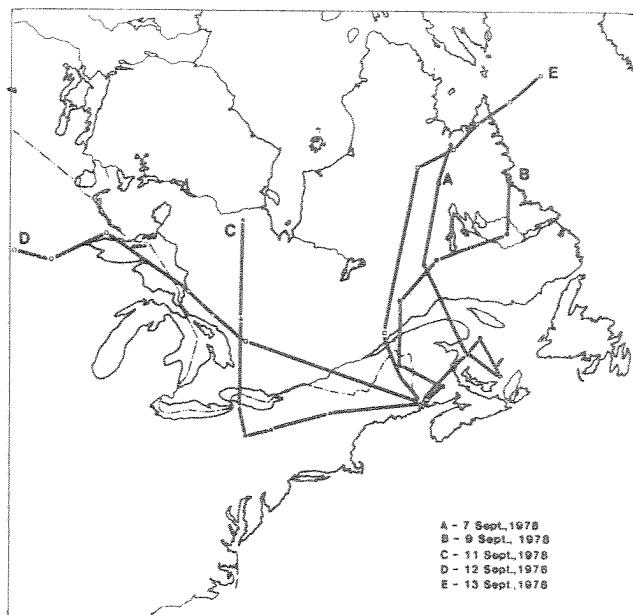
Appendix 1. Air parcel trajectories at the 850 Mb level, June 1978, for 2-3 d prior to the precipitation event, computed by the Atmospheric Environment Service of Environment Canada, Atlantic Region.



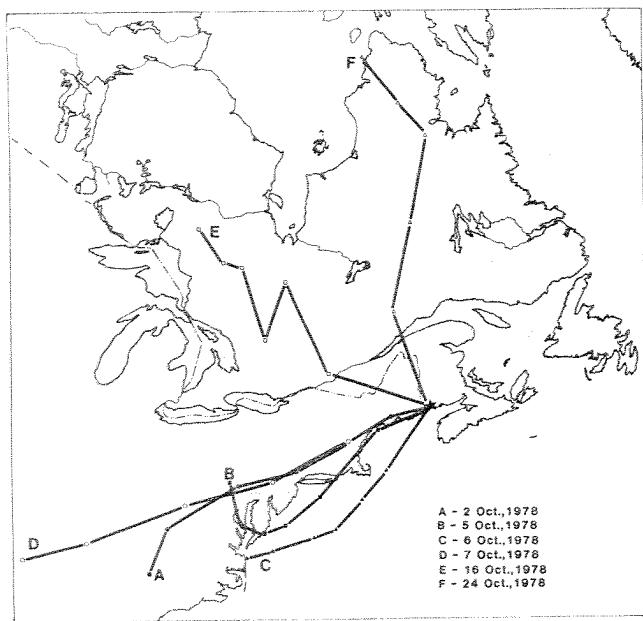
Appendix 3. Air parcel trajectories at the 850 Mb level, August 1978, for 2-3 d prior to the precipitation event, computed by the Atmospheric Environment Service of Environment Canada, Atlantic Region.



Appendix 2. Air parcel trajectories at the 850 Mb level, July 1978, for 2-3 d prior to the precipitation event, computed by the Atmospheric Environment Service of Environment Canada, Atlantic Region.



Appendix 4. Air parcel trajectories at the 850 Mb level, September 1978, for 2-3 d prior to the precipitation event, computed by the Atmospheric Environment Service of Environment Canada, Atlantic Region.



Appendix 5. Air parcel trajectories at the 850 Mb level, October 1978, for 2-3 d prior to the precipitation event, computed by the Atmospheric Environment Service of Environment Canada, Atlantic Region.