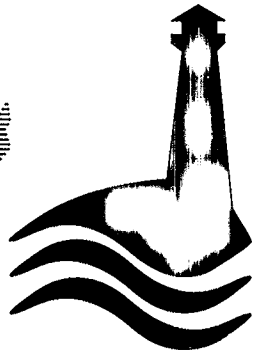
Environment Canada
Atmospheric Environment Service

Environnement Canada
Service de l'environnement atmosphérique

Atlantic Region / Région de l'Atlantique



Environment Canada
Atmospheric Environment Service

ACID RAIN AND SNOW AT KEJIMKUJIK, N.S. DURING 1986

C.L. Pettipas
B.L. Beattie

Report: MAES 3-87

August 1987

Scientific Services Division
Atlantic Region
Atmospheric Environment Service
Bedford, N.S.

Table of Contents

List of Figures ii

List of Tables iii

1. Introduction 1

2. Analysis of Data for 1986 2

2.1 Annual Summary 2

2.2 Seasonal Summary 4

2.3 Main Source Regions 5

3. Comparison with 1985 7

4. Summary 8

Acknowledgements 9

References 9

List of Figures

Figure 1: pH of Precipitation at Kejimkujik, N.S. January - April 1986

Figure 2: pH of Precipitation at Kejimkujik, N.S. May - August 1986

Figure 3: pH of Precipitation at Kejimkujik, N.S. September - December 1986

Figure 4: Map Showing Seven Source Regions of Precipitation at Kejimkujik, N.S.

Figure 5: Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. for 1986

Figure 6: Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. January - April 1986

Figure 7: Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. May - August 1986

Figure 8: Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. September - December 1986

Figure 9: Average pH of Precipitation Received at Kejimkujik N.S. from Six Main Source Regions by Four-Month Periods During 1986

Figure 10: Hydrogen Ion Wet Deposition Received at Kejimkujik N.S. from Six Main Source Regions by Four-Month Periods During 1986

Figure 11: Number of Occurrences of Precipitation pH Received at Kejimkujik, N.S. from Six Main Source Regions During 1986

Figure 12: Annual Average pH of Precipitation Received at Kejimkujik, N.S. 1980-1986

List of Tables

Table 1: Summary of Precipitation Events at Kejimkujik, N.S. During 1986

Table 2: Analysis of Precipitation Events by Precipitation Type for Kejimkujik, N.S. During 1986

Table 3: Sample Statistics of Precipitation pH Received at Kejimkujik, N.S. from Six Main Source Regions During 1986

1. Introduction

The Atmospheric Environment Service of Environment Canada has operated a precipitation sampling station in Kejimkujik National Park in southwestern Nova Scotia since May 1979. Daily precipitation samples are collected at the station and analyzed for acidity (pH) and the concentration of various chemical constituents, such as sulphates and nitrates. In addition, the pH of precipitation has been determined on-site since December 1983. Each Tuesday, Environment Canada issues a weekly bulletin (The Acid Rain Report) which summarizes the information gathered on-site during the previous week and includes a list of the source areas of the airborne pollutants associated with each precipitation event. These reports show that precipitation pH varies considerably from event to event and that acidity levels are generally correlated with the levels of emissions from upwind source areas.

The pH value is a measure of the acidity (hydrogen ion concentration) of the precipitation. The pH scale ranges from 0 (extremely acidic) to 14 (extremely alkaline). A pH value of 7 is neutral. The scale is logarithmic, so there is a ten-fold difference between integers. For example, a pH of 5 is ten times more acidic than a pH of 6.

Clean precipitation, which is not contaminated by pollutants, is slightly acidic by nature, with a pH of approximately 5.6. Precipitation that is more acidic than clean precipitation is called "acid precipitation". Although remote areas of the world receive acid precipitation (in the slightly acidic range), much higher acidity levels are found in and downwind of industrialized regions (Galloway, 1985). For example, most of eastern Canada receives acid precipitation with average pH values ranging from 4.2 to 4.5.

Environmental damage to lakes and streams is usually observed in acid sensitive areas that regularly receive precipitation with pH less than 4.7. Readings of 4.2 and below are considered strongly acidic and are not uncommon at Kejimkujik. Readings of less than 4.0 are considered to be serious events, although they do not constitute an immediate danger to human health or property. The effects of acid rain and snow are generally cumulative over time, although fish kills have been observed after low pH events and after the melting of acidic snow (MOI, 1983).

2. Analysis of Data for 1986

2.1 Annual Summary

The variations in precipitation pH at Kejimkujik, N.S. during 1986 are shown in Figures 1-3. Each figure is a plot of the pH value of the precipitation against the day of the year for a four month period; January to April, May to August and September to December. Different types of precipitation (rain, snow or mixed) are indicated symbolically. Lines representing the following three significant pH levels are also indicated on each figure:

1. normal or clean precipitation (pH = 5.6)
2. damaging pH level (pH = 4.7)
3. seriously acidic level (pH = 4.0)

The Figures show that none of the precipitation events at Kejimkujik in 1986 were in the clean pH range and that most were within the slightly acidic or damaging ranges. A significant number were in the seriously acidic pH range. Table 1 summarizes these events:

Table 1: Summary of Precipitation Events at Kejimkujik, N.S. During 1986

Level of pH	pH Range	Number of Occurrences	Percentage
Normal (clean)	pH > 5.6	0	0.0%
Slightly Acidic	4.7 < pH <= 5.6	63	42.6%
Damaging	4.0 < pH <= 4.7	63	42.6%
Seriously Acidic	pH <= 4.0	22	14.9%

Very low pH values (high acidity) are generally associated with events that produce only a small amount of precipitation. The total acid deposition from these events may not be as large as for other, higher pH events with more precipitation. The deposition of acid (mg/m^2) for each event is calculated by converting the precipitation pH into a hydrogen ion concentration (mg/l) and multiplying by the amount of precipitation (mm). A water equivalent in millimetres is used for snow by assuming that 1 cm of snow is equivalent to 1 mm of water.

To calculate the average pH value over a number of events, a precipitation-weighted average hydrogen ion concentration is determined by summing the hydrogen ion deposition for each event and then dividing by the total precipitation from the events. The average hydrogen ion concentration is then converted into an average precipitation-weighted pH value.

The annual average precipitation-weighted pH at Kejimkujik, N.S. in 1986 was 4.5. This was calculated for 148 precipitation days which produced 1440.2 mm of precipitation during the year. The overall resultant hydrogen ion deposition was 49.0 mg/m^2 (.49 kg/ha).

Different precipitation types accounted for significantly different amounts of the total deposition of acid. Table 2 separates precipitation into three types : rain, snow and mixed (rain and snow in one day).

Table 2: Analysis of Precipitation Events by Precipitation Type for Kejimkujik, N.S. During 1986

Type of Precipitation	Number of Days	pH Value	Deposition of Acid(mg/m^2)	Percentage Deposition
Rain	102	4.41	43.3	88.5%
Snow	35	4.79	3.1	6.3%
Mixed	11	4.70	2.6	5.2%

The precipitation events were then categorized by their pH value (pH <= 4.0, 4.0 < pH <= 4.7, and pH > 4.7) and by the main source region. This identified those regions which were considered to be the main sources of acidifying pollutants, as determined by the meteorologist who prepared the Acid Rain Report. The regions are shown in Figure 4 and defined as:

GL: Great Lakes States and Southern Ontario
MID: U.S. Midwest
ONT: North and Central Ontario
QUE: Quebec and Labrador
E.CST: U.S. East Coast
MRT: Maritimes and Newfoundland
ATL: Atlantic Ocean and New England

The results are plotted in Figure 5. Each pie represents a pH range and each slice represents a different region which is labelled just outside of the slice. The number, printed immediately after each region name, represents the number of days that region was the main source of acidifying pollutants for precipitation pH in the range indicated. The percentage of the pie is printed next, indicating how much of the pH range is being represented. Although the U.S. Midwest (MID region) was not identified as a main source of pollutants for any events in 1986, it was included on some charts because it was one of the important sources in past years.

It is clear that for highly acidic precipitation, pH <= 4.0, the U.S. East Coast accounts for half of the events in 1986. This area becomes significantly less important in the higher pH ranges; for example, in the pH > 4.7 range, it is the main source region for less than 7% of the events. A similar pattern is evident for the Great Lakes/Southern Ontario region, although it is not responsible for as large a percentage of the very low pH occurrences. In 1985 this pattern also occurred for the U.S. Midwest region, which was a more frequent source of precipitation with pH <= 4.0 than the U.S. East Coast.

In contrast, the Atlantic Ocean/New England region, which was the main source region for less than a quarter of the events with pH <= 4.0, becomes the most important main source region for the higher pH ranges and accounted for almost three quarters of events with pH > 4.7. Similarly, the Maritimes/Newfoundland region, although not frequently identified as a main source region, becomes more important as pH increases.

2.2 Seasonal Summary

The data were grouped into four-month periods: January to April, May to August and September to December. In the first period, January to April, the average precipitation-weighted pH was 4.77. During this period, the total deposition of acid was 9.1 mg/m^2 and occurred during 55 days with precipitation. The second four-month period, from May to August, experienced an average precipitation-weighted pH of 4.21 and a total deposition of 30.2 mg/m^2 from 50 days with precipitation. Finally, the last period had an average precipitation-weighted pH of 4.64 and a total acid deposition of 9.6 mg/m^2 after 43 precipitation days.

Figures 6,7 and 8 show, for each of the four-month periods, how frequently the main source regions are identified within the pH ranges. The patterns are similar to those described in the Annual Summary and shown in Figure 5, with some exceptions. The period from January to April was much less acidic than the rest of the year with no occurrences of pH events at or below 4.0. For the May to August period the lowest pH range was dominated by the U.S. East Coast. The Atlantic Ocean and New England region and the Maritimes and Newfoundland region were the only pollutant contributors in the range pH > 4.7. From September to December, the U.S. East Coast was responsible for more than 70% of the events in the range pH <= 4.0 range with the remainder coming from the Great Lakes/Southern Ontario region. In some cases data may represent only a small number of precipitation days.

2.3 Main Source Regions

The data for the precipitation events were then sorted by main source region. The average precipitation-weighted pH for each main source region was calculated for the whole year as well as for four-month periods. The results are plotted in Figure 9, with the main source regions ordered by decreasing average annual precipitation-weighted pH. The main source region producing the most acidic precipitation (average annual pH of 4.1) was the U.S. East Coast. The least acidic precipitation (average annual pH of 4.8) was from the Maritimes and Newfoundland region. As can be observed in the graph, the average pH was lower in the May-August period than in the January - April period. This indicates that the winter in 1986 experienced cleaner precipitation than the summer, the opposite to what occurred in 1985 (Webber and Beattie, 1986).

It is the total deposition of acid from precipitation that causes the long term damage to the environment (MOI, 1983). Figure 10 is a comparison of the main source regions of hydrogen ion wet deposition for Kejimkujik during 1986. The Atlantic Ocean/New England region and the U.S. East Coast region contributed comparatively large amounts of deposition. Hydrogen ion wet deposition from the remaining four regions was relatively insignificant. Although the precipitation events from the Atlantic region were generally less acidic than those from the U.S. East Coast region, the total annual deposition was larger. This is the result of a greater amount of precipitation from events where the Atlantic region was identified as the source.

Although precipitation amounts are important in determining which regions will contribute the most to deposition, the level of industrialization is also important. A comparison of deposition amounts and associated precipitation amounts, by region, shows that precipitation events from the more industrialized regions (U.S. East Coast and Great Lakes) make a larger contribution to the total acid deposition than would be anticipated, based on their contribution to the total precipitation amount. The opposite is true for events from less industrialized regions. For example, precipitation events from the U.S. East Coast region contributed almost 32% of the annual deposition, but less than 14% of the annual precipitation was associated with these events. On the other hand, events from the Atlantic Ocean/New England region, which contributed 58% of the annual deposition, were associated with over 75% of the annual precipitation. Similar statements apply to the four-month periods during 1986.

The number of occurrences of pH values attributed to each main source region is plotted in Figure 11. These six plots give an indication of how the pH values are distributed for each main source region. However, they should not be used to determine average pH values. Precipitation-weighted values must be used for this, not the arithmetic average. Note that North/Central Ontario and Maritimes/Newfoundland regions have small amounts of data. Table 3 provides some sample statistics for each main source region.

Table 3: Sample Statistics of Precipitation pH Received at Kejimkujik, N.S. from Six Main Source Regions During 1986

Main Source Region	No. of Events	Min pH	Max pH	Ave pH	Annual Precipitation	Total Deposition
E.CST	29	3.4	5.1	4.1	200.1 mm	15.5 mg/m^2
GL	11	3.6	5.5	4.2	33.9 mm	2.1 mg/m^2
ONT	7	3.5	5.5	4.5	47.0 mm	1.5 mg/m^2
ATL	79	3.3	5.5	4.6	1084.6 mm	28.3 mg/m^2
QUE	16	3.9	5.0	4.7	57.8 mm	1.3 mg/m^2
MRT	6	4.2	5.4	4.8	16.8 mm	0.3 mg/m^2

3. Comparison with 1985

In 1985 the average annual precipitation-weighted pH was 4.40 (Webber and Beattie, 1986) compared to 4.47 in 1986, which indicates that, overall, the average acidity of precipitation had dropped by about 14% in 1986. The winter precipitation (January to April) of 1986 was less acidic than the summer precipitation (May to August), which was the opposite to what occurred in 1985. Annual precipitation amounts increased by 11% in 1986 and there were 9 more days with precipitation than in 1985.

Deposition values, rather than pH, indicate a clearer picture of the cumulative contamination to the area. The annual acid deposition at Kejimkujik was down by 2.4 mg/m^2, a decrease of almost 5% from 1985 to 1986. It should be noted that 1985 was the most acidic year at Kejimkujik, with the lowest average annual pH (Figure 12) and the highest acidic deposition of the years 1980 - 1986 (1980-1983 data were obtained from Vet and Sukloff (see Acknowledgements) and 1984 data from Vet et al, 1986). The drop in acidity levels from 1985 to 1986 may indicate that 1985 was an anomalously acidic year and that acidity levels began to return to lower values in 1986.

In 1985 The U.S Midwest region produced the lowest average pH of all identified main source regions, pH = 3.9, and accounted for 7.5 mg of acid deposition per square meter in Kejimkujik. In 1986 this region was not identified as a main source region, presumably due to the difference in weather patterns from one year to the next. Three of the seven main source regions (ONT, E.CST, ATL) increased their deposition on the area from 1985 to 1986.

4. Summary

The average precipitation - weighted pH for 1986 at Kejimkujik National Park in southwestern Nova Scotia was 4.5, with the lowest four-month average in May-August and the highest in January-April. The most acidic events of the year, with a pH of 3.3, were one hundred and fifty times more acidic than the least acidic events (pH of 5.5). Almost 15% of the events were seriously acidic (pH <= 4.0). The largest proportion of seriously acidic precipitation events during the year had acquired acidifying pollutants from the U.S. East Coast region. That is, the air mass which produced these events at Kejimkujik was determined to have acquired them from this region. In contrast, the largest percentage of precipitation that was only slightly acidic (pH > 4.7) had as its main source the Atlantic Ocean/New England region.

In comparison with the previous year, Kejimkujik experienced 5% less acid deposition and a higher average precipitation pH in 1986. This decrease in acidity is a partial return to the lower levels reported before 1985, which was the most acidic year at Kejimkujik in the period from 1980 to 1986.

Acknowledgements

Bernie Flynn -Preparation of Figures 1 - 3
Mike Webber -Calculation of 1985 results
Gilles Desautels -Providing data from The Acid Rain Report for 1985 and 1986
Fraser MacNeil -Assistance with data handling and reviewing the report
Bill Richards and John Bursey -Reviewing the report
Bob Vet and Bill Sukloff -Providing 1980-1983 annual pH and hydrogen ion deposition (and confirming the 1985 values) from the Atmospheric Environment Service's quality controlled data set

References

Galloway, J.N. 1985. "Precipitation Composition in Remote Areas." Presented at the International Symposium on Acid Precipitation (Muskoka Conference), September 1985.

MOI. 1983. Impact Assessment. Final report of Work Group I, established under the Canada-United States Memorandum of Intent on Transboundary Air Pollution.

Vet, R.J.; W. B. Sukloff; M.E. Still and R. Gilbert. 1986. Canadian Air and Precipitation Monitoring Network (CAPMoN) Precipitation Chemistry Data Summary 1983-1984. Report: AQRB-86-001-M. Atmospheric Environment Service, Downsview, Ont.

Webber, M.A.P. and B.L. Beattie. 1986. Acid Rain and Snow at Kejimkujik, N.S. During 1985. Report # MAES 5-86. Atmospheric Environment Service, Bedford, N.S.

Figure 1

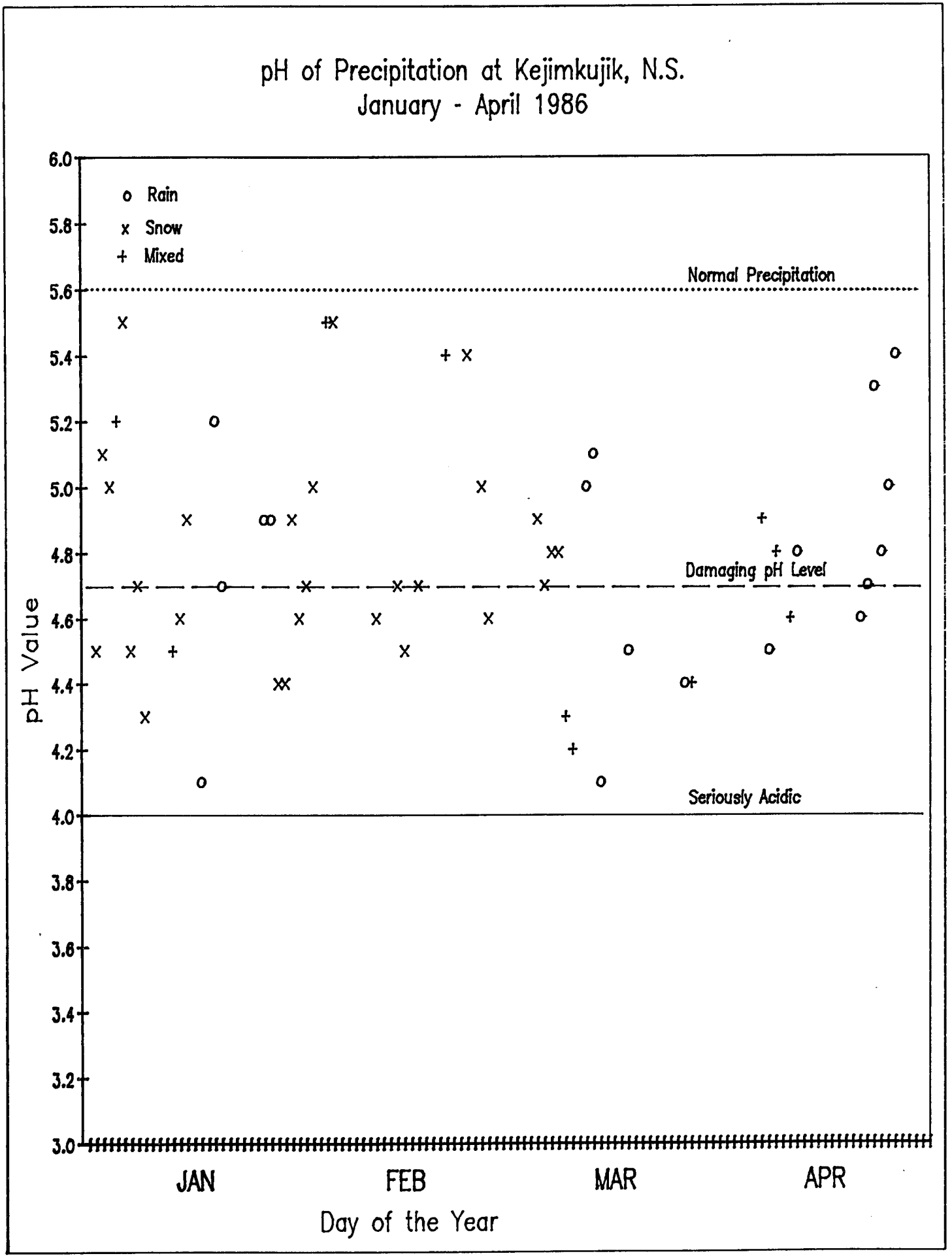

pH of Precipitation at Kejimkujik, N.S.
January - April 1986
o Rain
x Snow
+ Mixed
Normal Precipitation
Damaging pH Level
Seriously Acidic
pH Value
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
JAN
FEB
MAR
APR
Day of the Year

Figure 2

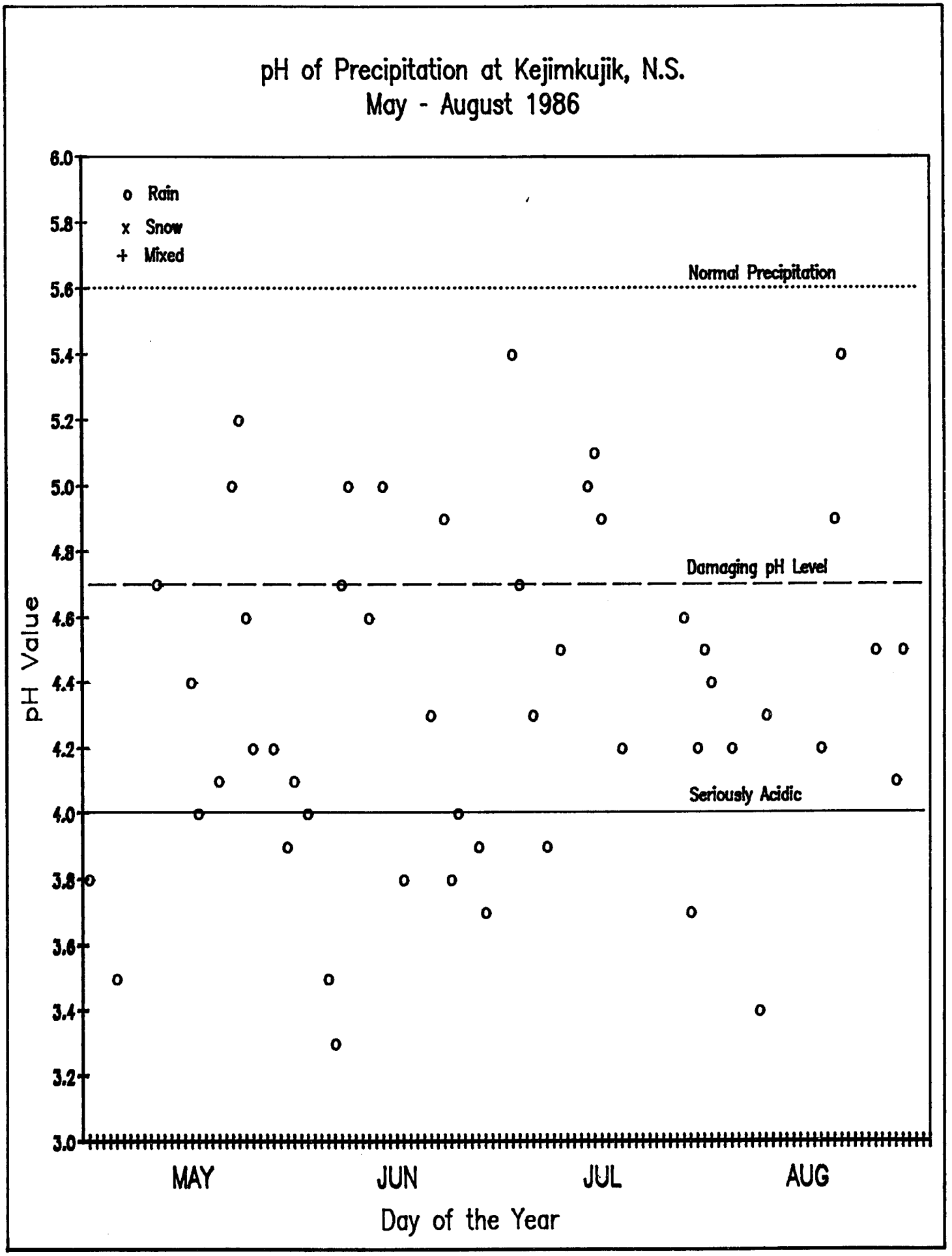

pH of Precipitation at Kejimkujik, N.S.
May - August 1986
o Rain
x Snow
+ Mixed
Normal Precipitation
Damaging pH Level
Seriously Acidic
pH Value
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
MAY
JUN
JUL
AUG
Day of the Year

Figure 3

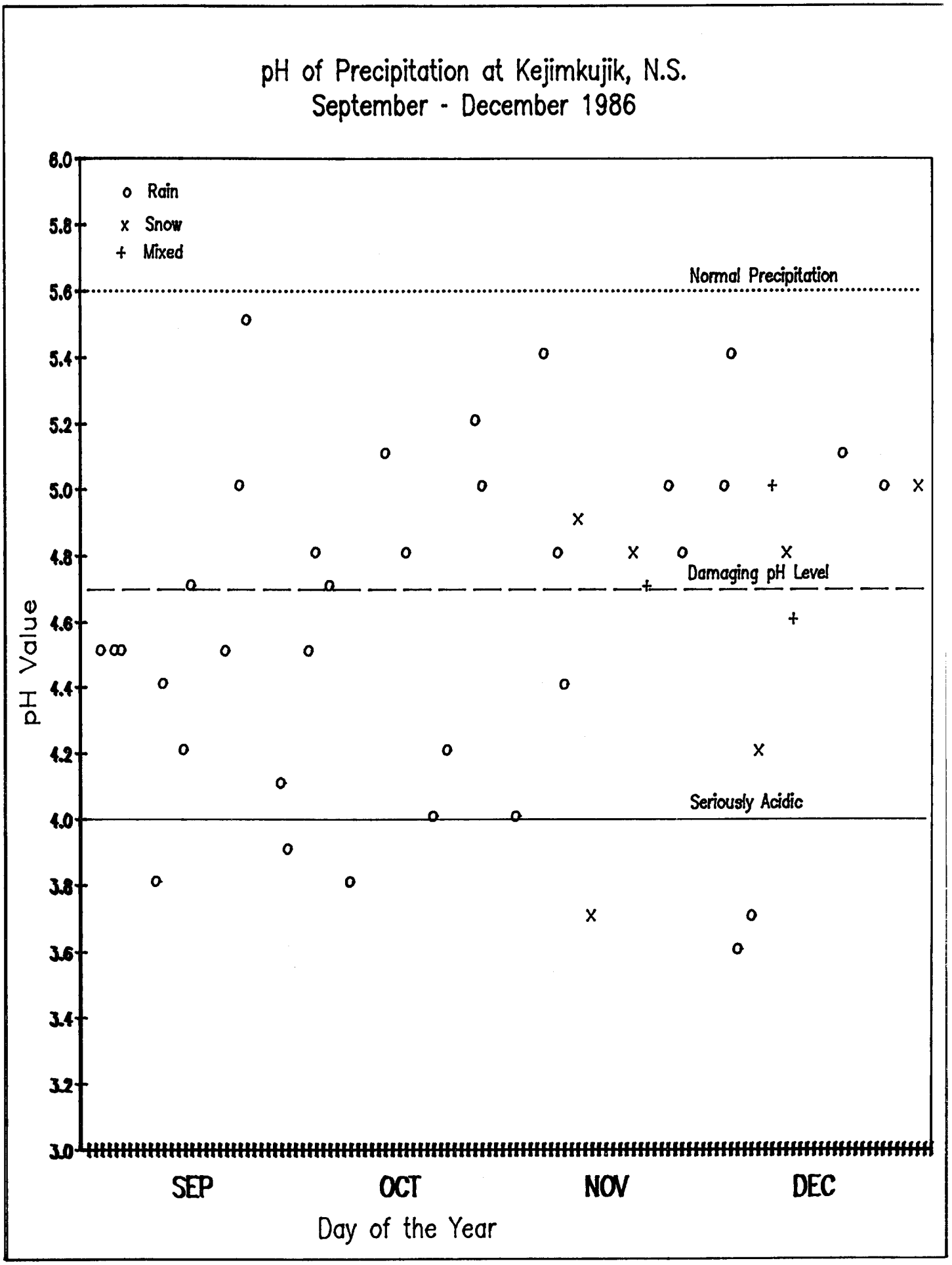

pH of Precipitation at Kejimkujik, N.S.
September - December 1986
o Rain
x Snow
+ Mixed
Normal Precipitation
Damaging pH Level
Seriously Acidic
pH Value
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
SEP
OCT
NOV
DEC
Day of the Year

Figure 4

Map Showing Seven Source Regions of Precipitation at Kejimkujik, N.S.

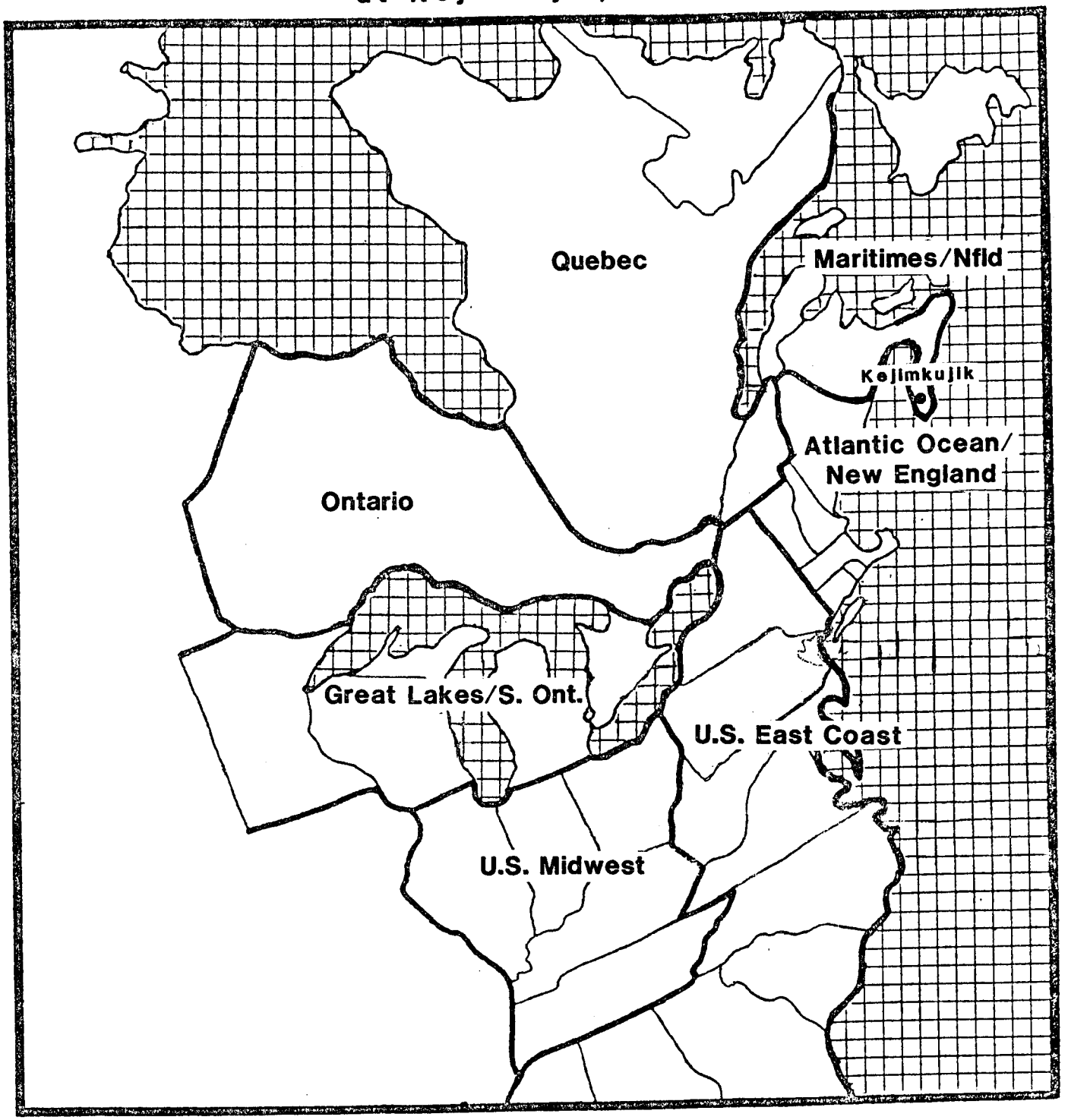


Figure 5

Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. for 1986

Main Source Region

GL: Great Lakes

Mid: U.S. Midwest

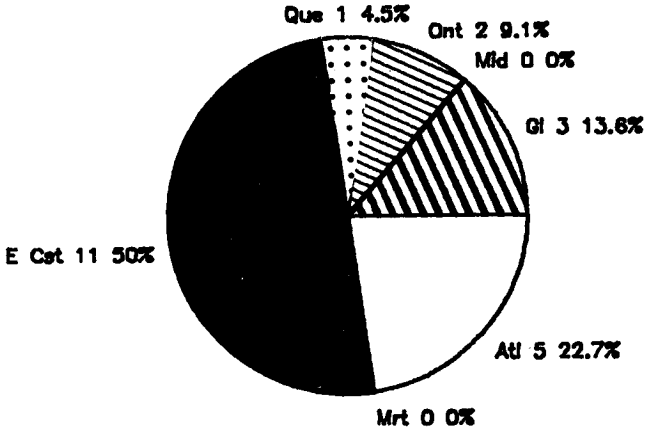
Ont: Ontario

Que: Quebec

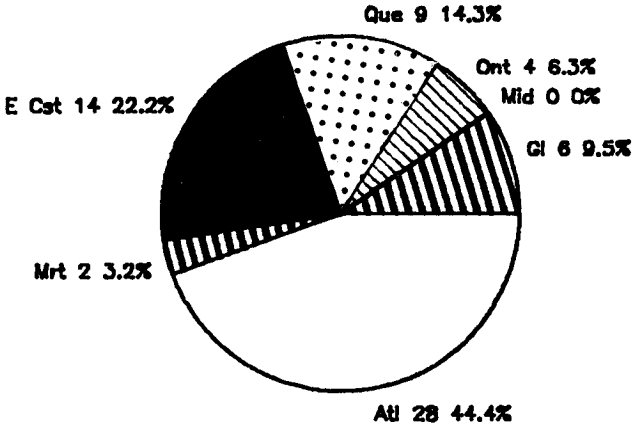
E Cst: U.S. East Coast

Mrt: Maritimes

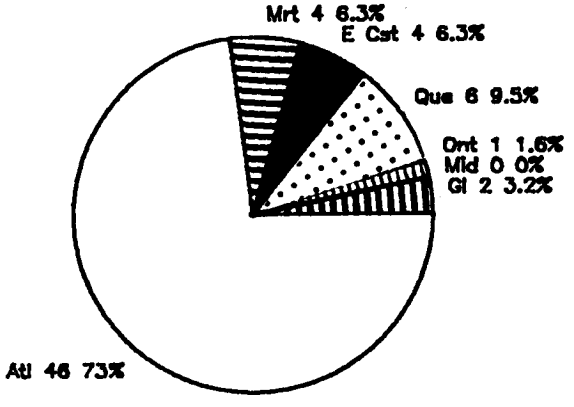
Atl: Atlantic Ocean



pH <= 4.0



4.0 < pH <= 4.7



pH > 4.7

Figure 6

Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. January - April 1986

Main Source Region

GL: Great Lakes

Mid: U.S. Midwest

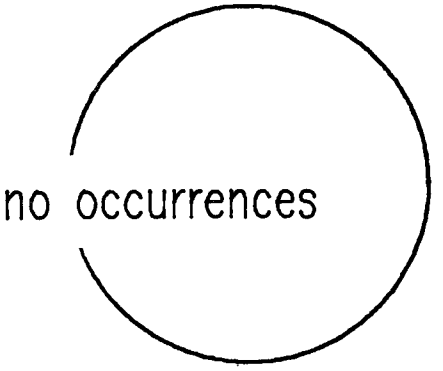
Ont: Ontario

Que: Quebec

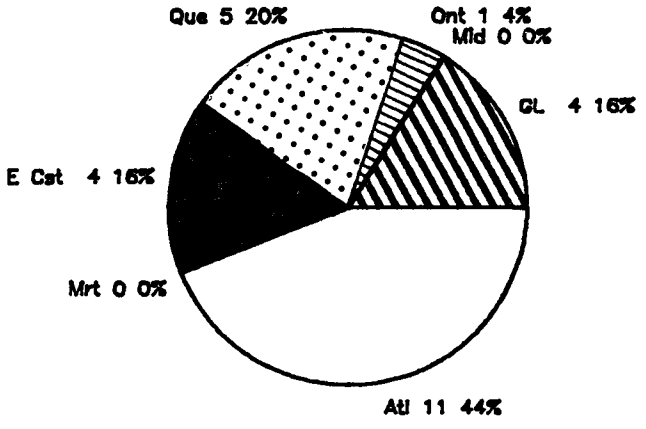
E Cst: U.S. East Coast

Mrt: Maritimes

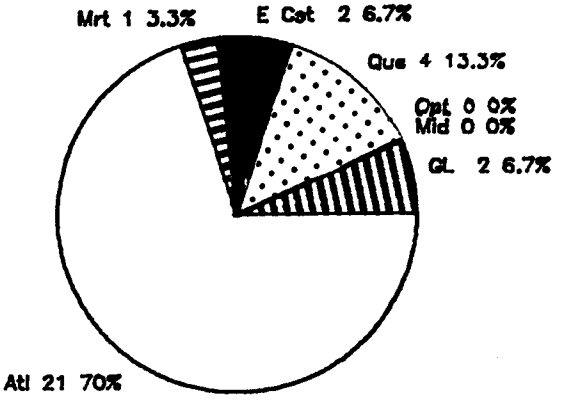
Atl: Atlantic Ocean



pH <= 4.0



4.0 <= pH <= 4.7



pH > 4.7

Figure 7

Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. May - August 1986

Main Source Region

GL: Great Lakes

Mid: U.S. Midwest

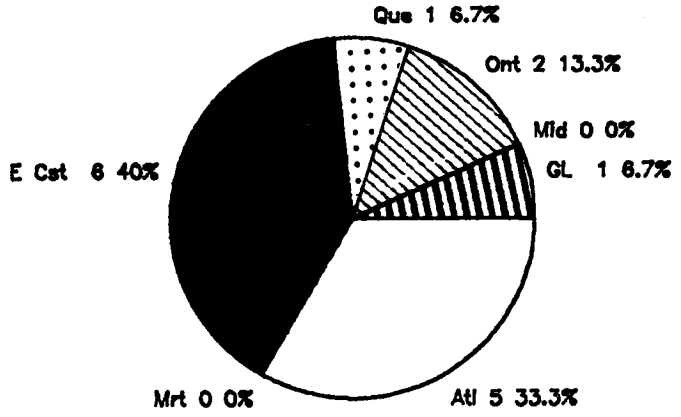
Ont: Ontario

Que: Quebec

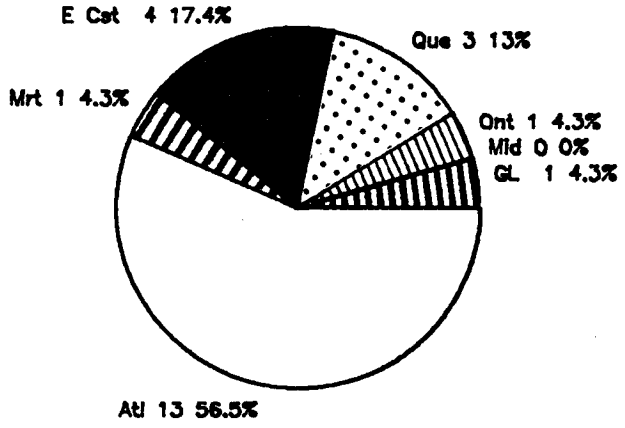
E Cst: U.S. East Coast

Mrt: Maritimes

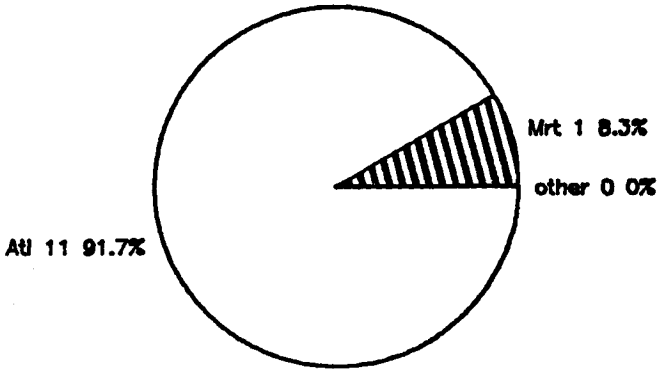
Atl: Atlantic Ocean



pH <= 4.0



4.0 < pH <= 4.7



pH > 4.7

Figure 8

Frequency of Occurrence of Main Source Regions of Precipitation pH at Kejimkujik, N.S. September - December 1986

Main Source Region

GL: Great Lakes

Mid: U.S. Midwest

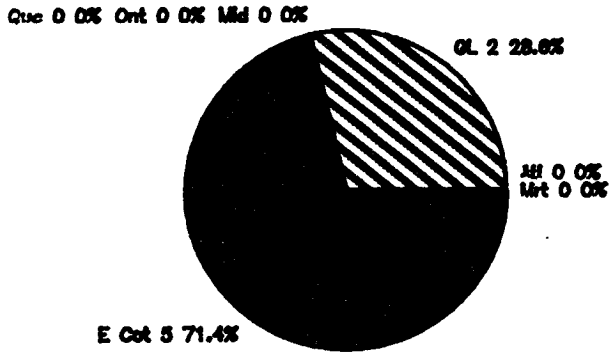
Ont: Ontario

Que: Quebec

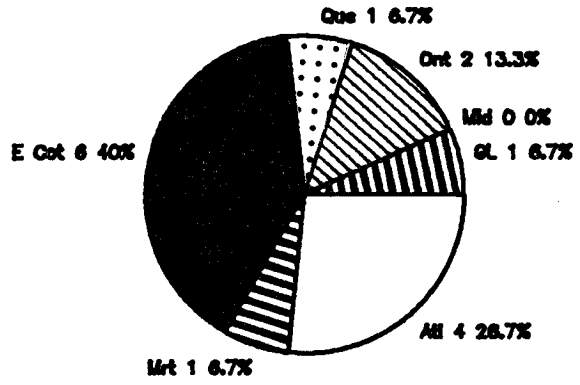
E Cst: U.S. East Coast

Mrt: Maritimes

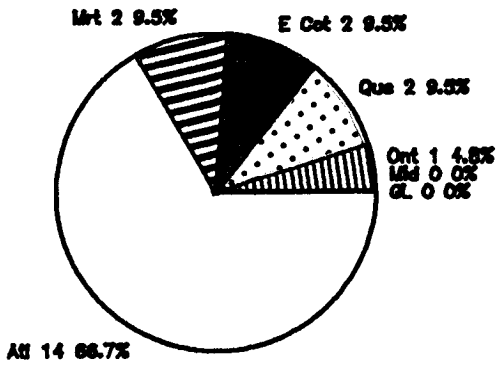
Atl: Atlantic Ocean



pH <= 4.0



4.0 < pH <= 4.7



pH > 4.7

Figure 9

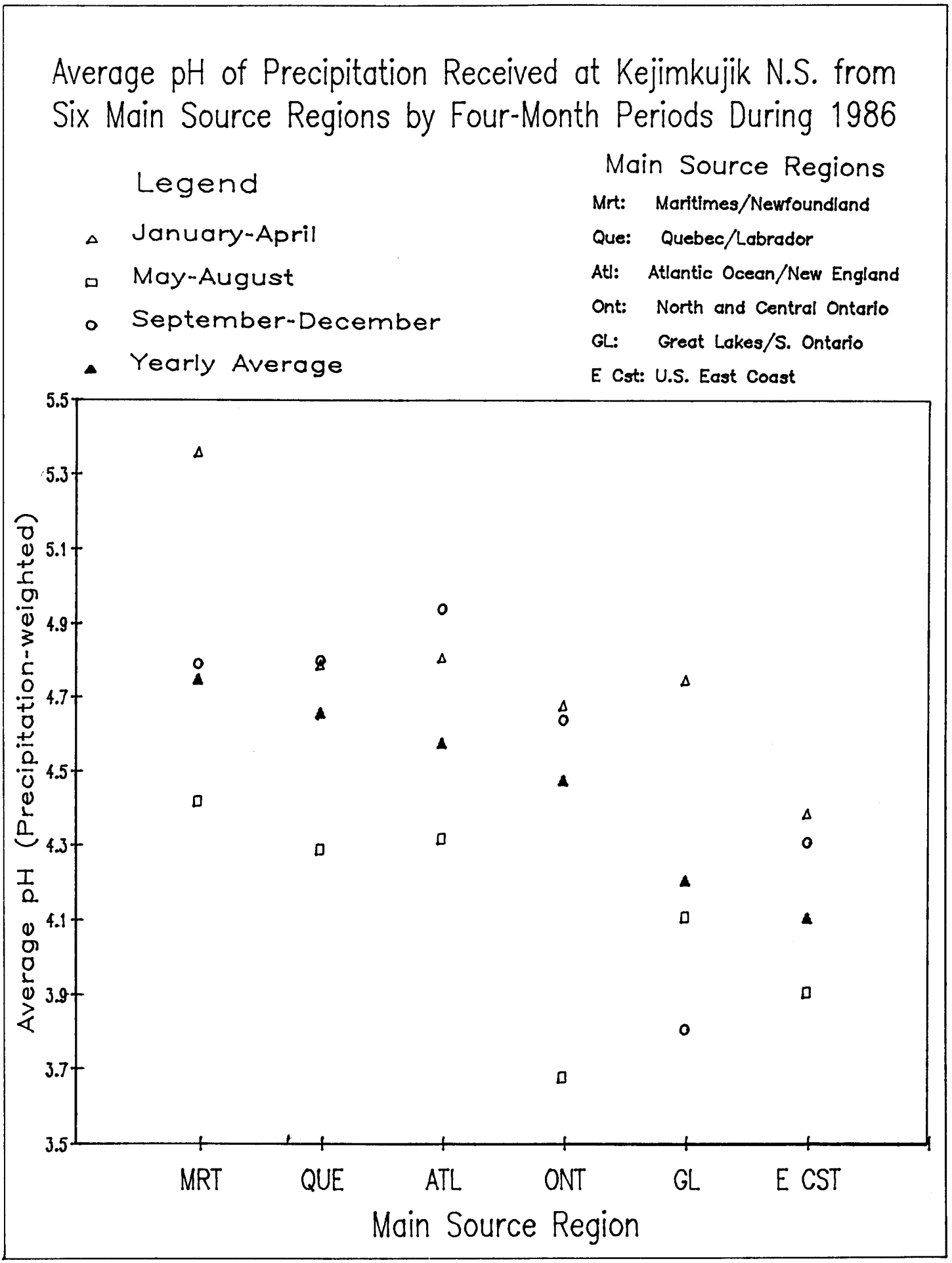

Average pH of Precipitation Received at Kejimkujik N.S. from Six Main Source Regions by Four-Month Periods During 1986
Legend
January-April
May-August
September-December
Yearly Average
Main Source Regions
Mrt: Maritimes/Newfoundland
Que: Quebec/Labrador
Atl: Atlantic Ocean/New England
Ont: North and Central Ontario
GL: Great Lakes/S. Ontario
E Cst: U.S. East Coast
Average pH (Precipitation-weighted)
5.5
5.3
5.1
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
MRT
QUE
ATL
ONT
GL
E CST
Main Source Region

Figure 10

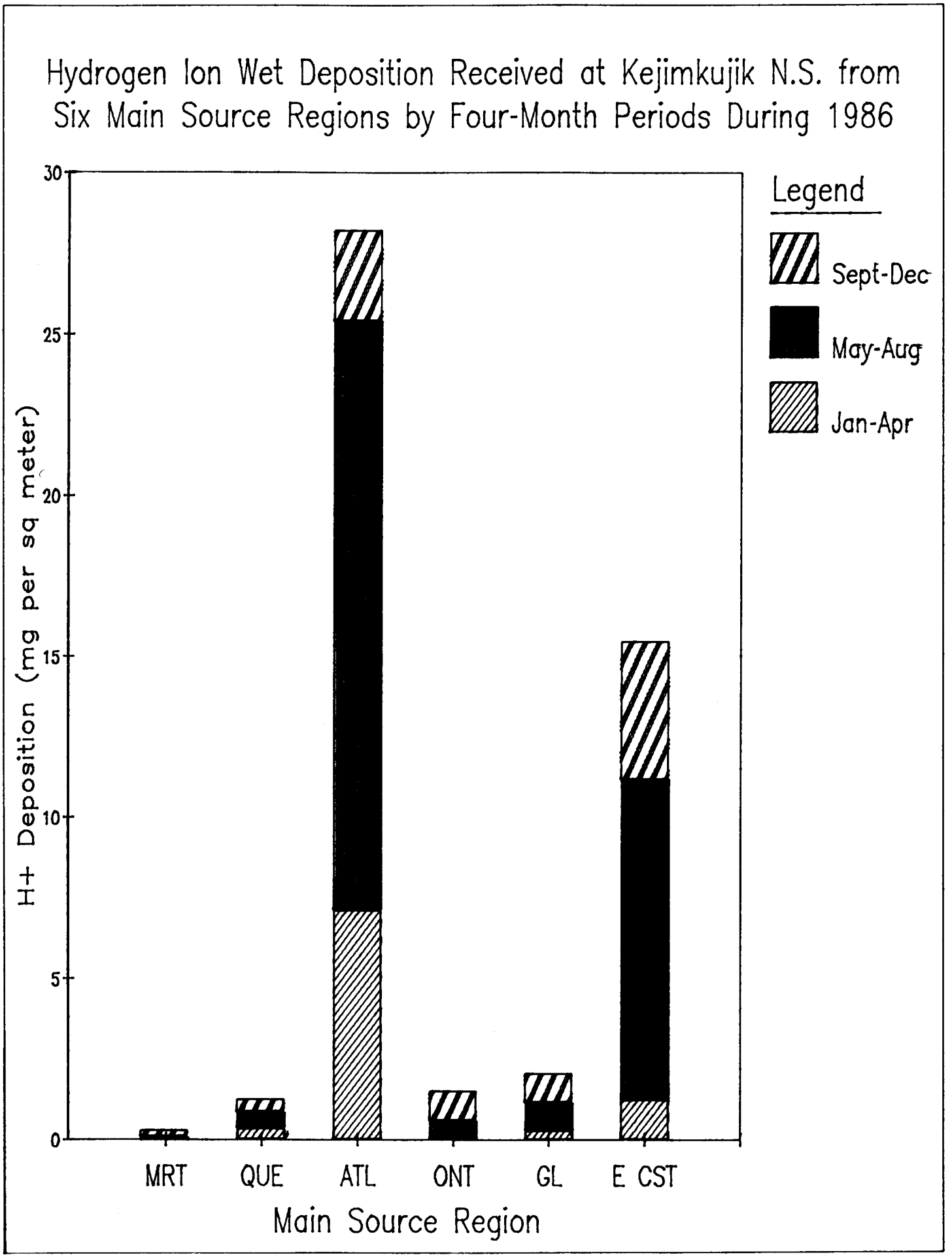

Hydrogen Ion Wet Deposition Received at Kejimkujik N.S. from Six Main Source Regions by Four-Month Periods During 1986
Legend
Sept-Dec
May-Aug
Jan-Apr
H+ Deposition (mg per sq meter)
0
5
10
15
20
25
30
MRT
QUE
ATL
ONT
GL
E CST
Main Source Region

Figure 11

Number of Occurrences of Precipitation pH Received at Kejimkujik, N.S. from Six Main Source Regions During 1986

Figure 11a

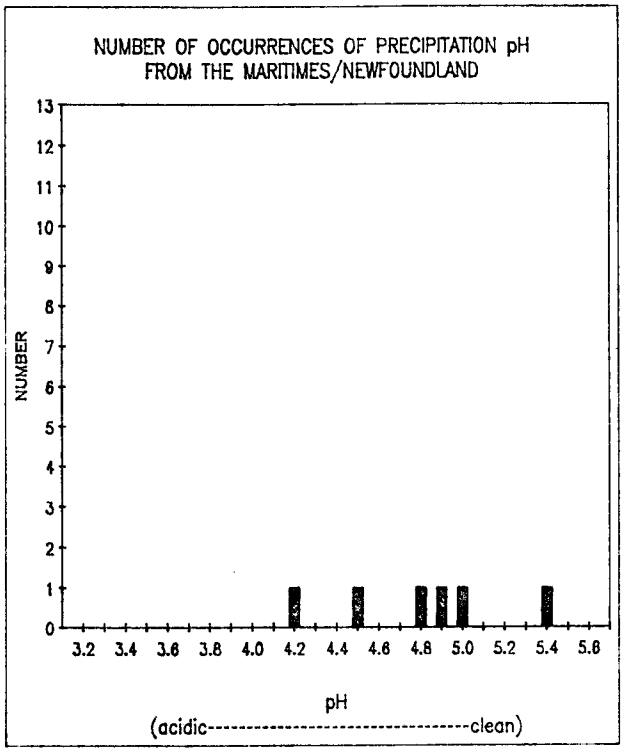


Figure 11b

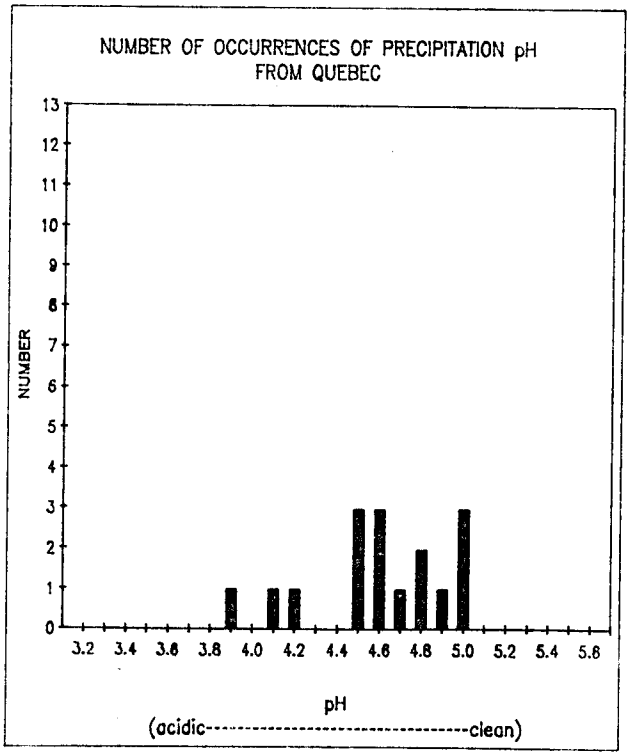
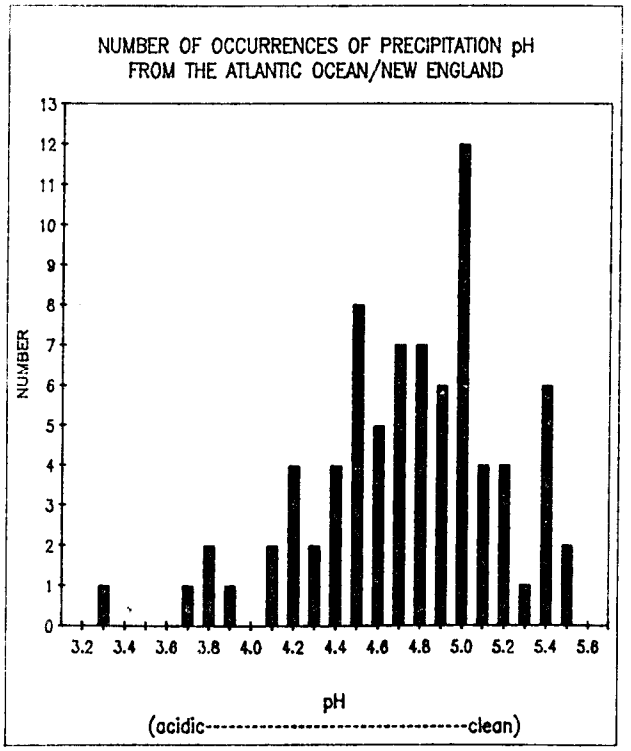


Figure 11c



Number of Occurrences of Precipitation pH Received at Kejimkujik, N.S. from Six Main Source Regions During 1986

Figure 11d

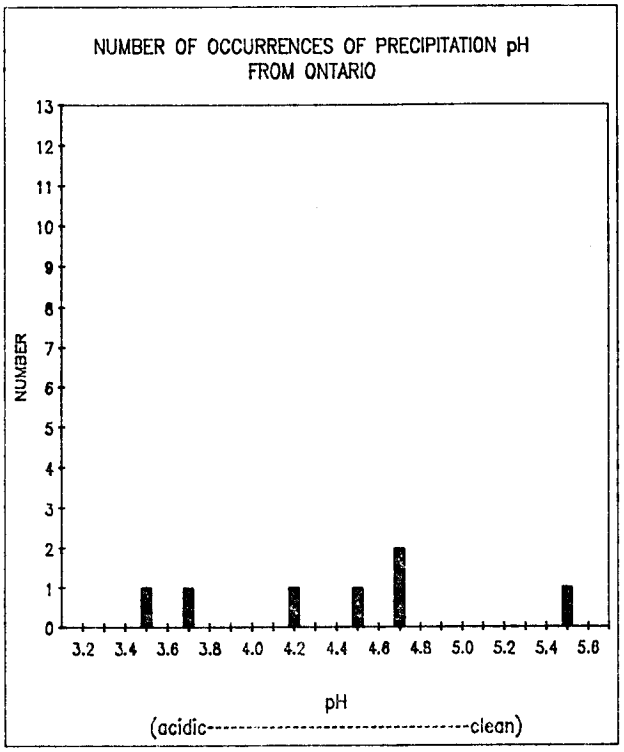


Figure 11e

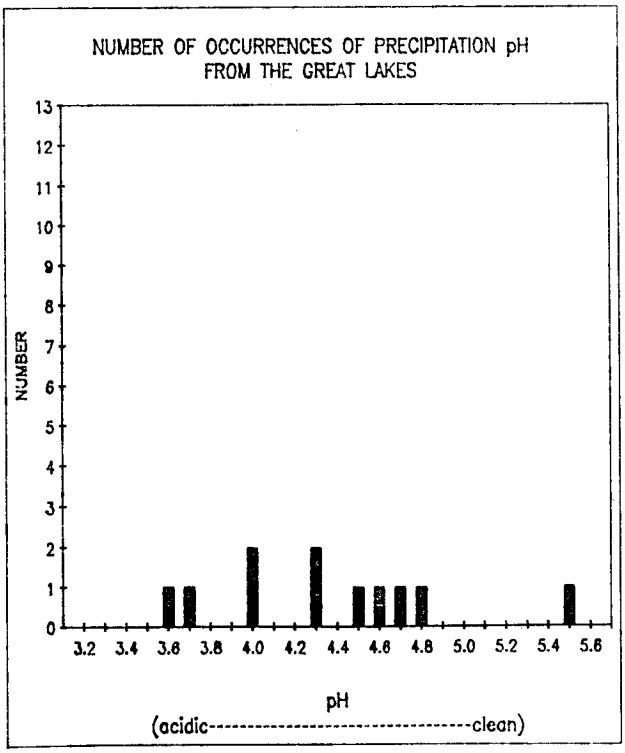


Figure 11f

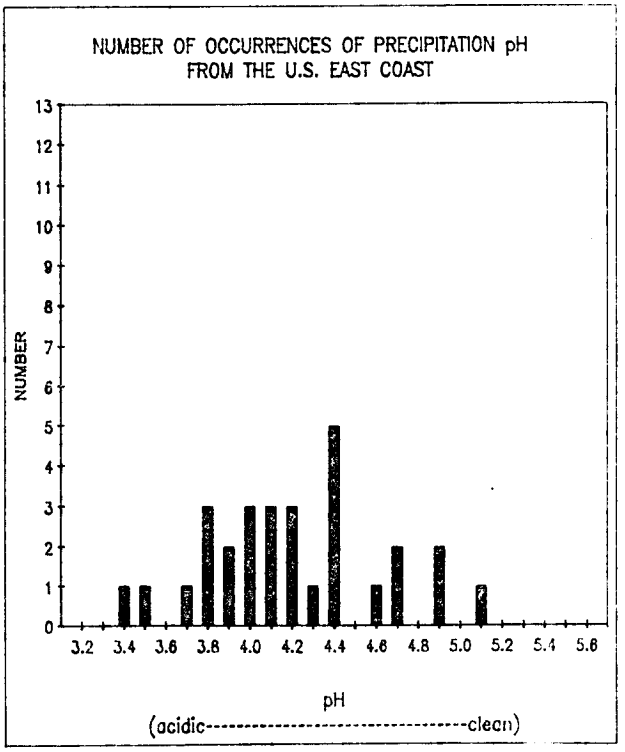
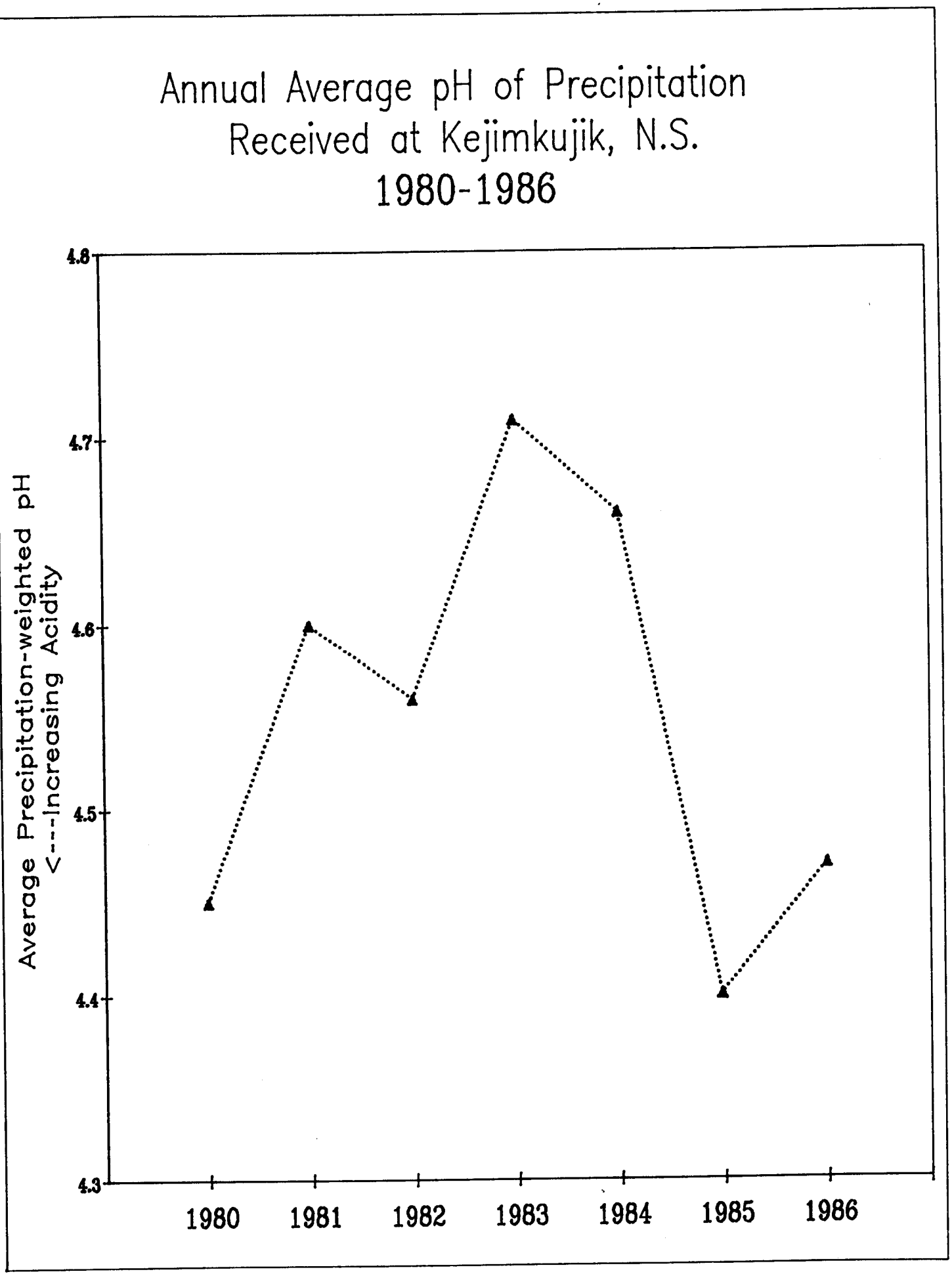


Figure 12


Annual Average pH of Precipitation
Received at Kejimkujik, N.S.
1980-1986
Average Precipitation-weighted pH
<---Increasing Acidity
4.8
4.7
4.6
4.5
4.4
4.3
1980
1981
1982
1983
1984
1985
1986