

STRESS FACTORS: TRENDS AND RECOVERY

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ABSTRACT

Studies of environmental damage from acidification by acid deposition in Canada date from the 1950's. In the late 1960's, acidification of surface waters and other forms of environmental damage near point source emissions in Canada and the United States led to development of Clean Air Acts in both countries and the implementation of various control programs. Sulphur dioxide emissions reached all-time highs around 1970 to 1973 and SO₂ emissions in both countries decreased from that time until the early 1980's. U.S. emissions decreased from about 28 million tonnes to 21 million tonnes from 1973 to 1984 and Canadian emissions decreased from 6.6 to 3.8 million tonnes in the same time period. Canadian emissions are ensured to decrease further as a result of Canada's Sulphur Dioxide Control Program which goes beyond the objectives of the 30% Club.

The aquatic environment has responded favorably to these emission reductions. Sulphate runoff from 12 Nova Scotian and 8 Newfoundland watersheds decreased by nearly 50% in the corresponding time. Rivers in both cases showed an expected increase in pH. Near Sudbury, Ontario, following reductions in emissions from the large smelters, surface water sulphate concentrations have declined and pH of the acidified lakes has increased.

The past reductions in SO₂ and favorable response in the environment is most encouraging but we are still faced with a situation of extensive surface water damage. Lakes in large areas of Eastern Canada have less than 20% of the alkalinity expected from normal weathering processes and as many as 14,000 individual lakes have been acidified. There are examples of the top meter of soil water being acidified by a combination of sulphate and nitrate.

Biological surveys have documented a continuing decline in biological quality of lakes and have documented the loss of aquatic organisms as a result of periodic pH depressions in streams.

In recent years, we have observed decline of sugar maple, our national emblem, in Central and Eastern Canada. The trees have been subjected to attacks by tent caterpillar and severe weather conditions. There is increasing evidence that the decline is caused by a complex interaction of insect damage, weather and stress caused by acidic precipitation.

We can conclude from the eastern North American experience that while emissions and deposition have been reduced and water quality has improved, both the aquatic and forest situations are still far from acceptable.

INTRODUCTION

Over the past few decades, research scientists throughout the world have been providing documentation of the impacts of "acid rain" on the natural and human environment. The thousands of technical reports uniformly present a bleak picture, depicting a wide-spread and pervasive deterioration in the health of terrestrial and aquatic ecosystems, soils, man-made structures and monuments, human health, and so on.

In Canada, primary attention has been directed towards surface waters and their remarkable deterioration, over the last few decades in the eastern part of the country. As a consequence of the scientific information available, Canada is now implementing a SO₂ Control Program which will reduce emissions by 50% in eastern Canada by 1994.

The situation concerning forest ecosystems is less clear. To date there is no conclusive link between the long range transport of air pollution and observed regional forest decline. However, a problem of particular note has been observed in maple stands in the provinces of Ontario, Quebec, and New Brunswick. Although the decline occurs in some of the areas most heavily impacted by LRTAP, natural stresses (climate and insects, in particular) are certainly contributing to the observed deterioration as well.

The purpose of this conference is to bring together scientists and policy makers in order to clarify the state of knowledge and address the policy that may be required by governments to correct unacceptable situations. This paper presents some work on Canadian lakes and streams. The preliminary results indicate that decreases in SO₂ emissions in North America over the past 10-15 years have been coincident with a marked improvement in the quality of some of the surface waters. The importance of this information to policy makers is evident. It appears that reductions in sulphur dioxide emissions can be linked to improved surface water quality in a time frame which is practical in terms of implementing control programs over a decade or so. Further improvement may be expected as the Canadian Control Program becomes fully implemented.

CHANGES IN SO₂ EMISSIONS

In North America, SO₂ emissions reached all time highs between 1970 and 1973. As a result of both Canada and the U.S.A. instituting Clean Air Acts and enforcing more stringent standards for local air quality, a large amount of SO₂ was removed from the stack gases. Large increases in energy costs also encouraged energy conservation and reduced fuel consumption during this period.

Figure I, shows the trend in SO₂ emissions in the United States from 1900-1983 (Environmental Protection Agency, 1985, 1986). There has been a decline of about 30% from 1973 to 1983. This decline is attributed to: stringent new source performance standards; lower sulphur content of the coal consumed; and retrofitting of scrubbers (National Coal Association, 1986), among other things.

Projections for the next decade for U.S. utilities vary from a continuing decline predicted by the National Coal Association, 1986, to increases of as much as 5 million tons unless further control measures are introduced (ICF, 1986).

In Eastern Canada, SO₂ emissions declined by about 50% during the 1970s and early 1980s, Figure 2. Although this decline can be attributed partly to reduced economic activity in the last few years, it has been largely due to SO₂ emission controls to improve air quality near the large non-ferrous smelters in Sudbury. In addition, one of the smelters at Sudbury, INCO Ltd., and the thermal power plants of Ontario Hydro are now operating under special regulations introduced to control the long range transport of SO₂. These regulations are over and above the controls needed to improve local air quality.

A further reduction in Canadian emissions has been assured by the federal/provincial agreements in Canada calling for a 50% reduction in eastern Canadian SO₂ emissions by 1994. Both Canada and the United States still have a long way to go in technology development and technology implementation to achieve the required reductions in the mid-1990's but we are confident that we will achieve our objectives of reducing deposition to acceptable values.

SURFACE WATER CHANGES IN CANADA

The declines in SO₂ emissions have caused a corresponding decrease in deposition in Eastern North America. Table 1 shows changes in the sulphate yields from watersheds in Nova Scotia and Newfoundland (Thompson, 1986). From the early 1970's to the early 1980's the sulphate export from the watersheds measured in the runoff declined by nearly 50%, reflecting the

decline in emissions in the areas upwind of the region. Atmospheric models have calculated an expected deposition reduction of 20-25%. These numbers are in good agreement, considering the expected error in model calculations and in the measurements, and are most encouraging with regard to demonstrating that a reduction in SO₂ emissions leads to reduction in sulphate in surface waters. Table 1 also shows the change in the pH of the rivers in the same time-frame, and indeed, there has been the expected decline in acidity. The water quality is not yet acceptable for a healthy biological community, but there have been improvements.

TABLE 1
Sulphur Dioxide Emission Changes, Sulphate Export from Nova Scotian (12)
and Newfoundland (8) Watersheds, and pH Ranges from Associated Rivers

	<u>1971-1973</u>	<u>1982-1983</u>	<u>Change</u>
SO ₂ Emission in Eastern Canada and the United States (yearly averages)	27.0	20.3	-25%
Watershed Export (kgs SO ₄ /ha/yr)			
A Nova Scotia	39 ± 6.7	21 ± 6.1	-47%
B Newfoundland	32 ± 12	18 ± 8	-44%
pH range of river*			
A Nova Scotia	4.4 to 6.5	4.5 to 6.7	
B Newfoundland	5.5 to 7.7	6.1 to 7.8	

*All rivers decreased in sulphate yield and increased in pH.

Water quality has also improved in lakes in the Sudbury area following the major SO₂ emission reductions by the two largest smelters, INCO Ltd. and Falconbridge Ltd. (70 and 75% reductions respectively) during the 1970's. By 1985, there had been about a 40% reduction in sulfate concentration in one study lake, (Figure 3) (Dillon, 1986) and a corresponding increase in pH from 4.1 to 4.6 (68% decrease in hydrogen ion). Substantial increases in pH were observed for a large number of acidified lakes being monitored in that area in an extensive survey (Figure 4) (Keller & Pitblado, 1985).

Biological recovery has been observed in two study lakes which have shown increased biomass of algae and increased diversity of both algae and zooplankton (Havas, 1986).

Hutchinson & Havas (1986) have also reported recovery of two study lakes near Sudbury. Their study included deposition and lake chemistry data from before the construction of the tall stack by Inco and before large-scale emission reductions began at the smelters. Sulphate declined by 50% and the pH increased from approximately 4.1 to 5.8 in the most affected lake while bulk deposition of sulphate measured during the summer decreased by 75% between 1970 and 1977.

Our modelling calculations predict that other areas in eastern North America have probably experienced some improvement in surface water quality as a result of the emission reductions. However, the result from our Nova Scotia and Newfoundland rivers along with the Sudbury results fully substantiate the position that Canada has taken, that is, reducing SO₂ emissions will lead to decline in acidity of surface waters.

The recent U.S. National Academy of Science (1986) report on trends indicates decreasing concentrations of sulphate in rivers in the northeastern United States. These findings are a further confirmation of the changes that are observed in the Atlantic Provinces of Canada.

CURRENT STATUS OF SURFACE WATERS IN EASTERN CANADA

Chemistry

While the obvious successes of past SO₂ reduction programs are encouraging, we must be aware of the fact that the present sulphate deposition is too high and present water quality is not acceptable.

Figure 5, (Jeffries, 1986) shows the status of surface waters as measured by the ratio of alkalinity to calcium (Ca) plus magnesium (Mg). There are many mechanisms used to explain the surface water acidification problem but regardless of which mechanisms are causing acidification to occur, the ratio of alkalinity to calcium plus magnesium has been reduced, either by decreases in alkalinity, increases in Ca and Mg or both. Under normal weathering processes, the ratio will be unity. If the ratio becomes zero, then alkalinity has been exhausted and we regard the lake to have been acidified. Acidified lakes are devoid of fish and have reached an end-point with regards to biological damage. However, lakes which still retain some alkalinity, nevertheless suffer biological damage. The map is based on about 8,000 sample points.

Large areas of Ontario and Quebec fall within the 0.2 contour for the ratio. This means that the surface waters have less than 20% of the alkalinity which we would expect from normal weathering processes. Surface waters in Nova Scotia have been severely affected with a ratio of zero being common and much of Newfoundland has also been damaged.

Within the most affected areas, some waters have been acidified. Our latest projection is that as many as 14,000 lakes have been acidified. It is our goal to see these ratios increase and eventually arrive back at the natural value of close to unity.

The cause of the low alkalinity values can be seen in Figure 6. The values of the ratio of sulphate to calcium plus magnesium mirrors the alkalinity ratios in Figure 5. As the alkalinity declines, it is replaced by sulphate. The areas of lowest alkalinity / (Ca plus Mg) ratios are also the areas of highest sulphate deposition.

New findings on ground water quality are of considerable concern to us. At one of our study sites near Sault Ste. Marie, Ontario, soil waters, down to about one meter have been acidified with a complete loss of alkalinity at times. The lost alkalinity has been largely replaced by sulfate. During the most extreme conditions, nitrate contributes to the alkalinity loss as well. The depth of acidic ground water extends to below the depth of the root zone of the forest cover. Figure 7 shows the chemical composition of the water during periods of heavy rain and spring runoff when the ground water becomes fully acidified (Johnston, 1986). In March, the ground water was influenced by a heavy spring rain with low pH. Subsequently, alkalinity recovered slightly until the onset of spring melt in mid-April, when the alkalinity again fell to zero.

Biology

The current water chemistry in many of our lakes is detrimental to biological life even though some alkalinity remains. Rooke and Mackie (1984), have recorded the recent collapse of a mollusc species in a lake under study in central Canada. This is an important observation because it confirms that the biological quality of the lake is deteriorating with time. Another recent report of biological damage is based on extensive baseline data collected over forty years ago in Algonquin Provincial Park in Ontario. Acid sensitive species of stream invertebrates have been eliminated. This has been caused by repeated short term pH depressions in the stream rather than by long term acidification (Hall, 1986). This important observation demonstrates the loss of biological quality under chemical stress conditions.

Sugar Maple Decline

Over the past few years there have been reports of decline in sugar maples (Acer saccharum) in the provinces of Ontario, Quebec and New Brunswick. A number of maple syrup producers have gone out of business and other farmers are concerned for the future of their trees.

Preliminary investigations have not shown any obvious disease or insect-related causes for the decline. Some of the areas affected have been subjected to forest tent caterpillar attacks and severe weather conditions have occurred since 1980. However, one detailed study (McLaughlin, 1985) has found that the trees currently suffering decline have decreased in growth over the past four decades and the effects of acidic precipitation have been included in the stress factors causing the decline.

Environmental Monitoring

Canada recognizes the fundamental need to have programs in place which will measure the environmental response resulting from the activities of the members of the 30% Club. Consequently we strongly support the work group initiative to establish an international monitoring program and we commend Norway for taking the lead to establish the data bank for an international surface water monitoring program.

CONCLUSIONS

We have observed reduced acidification of surface waters as a result of SO₂ emission reductions. Chemical and biological quality of surface waters have improved in study lakes.

However, in heavily impacted areas, the current deposition of sulphate is too high and the biological quality of some surface waters is still deteriorating.

Surface waters in extensive areas of eastern Canada are badly damaged with alkalinity values of less than 20% of the expected natural value. Sulphate has been shown as the cause of the lost alkalinity.

Acidification of ground water by acid deposition has been found and is of particular concern to Canada with regard to the health of our forests. Both sulphate and nitrate contribute to this acidification.

A decline of sugar maples across Eastern Canada has not been explained but preliminary studies indicate that "acid rain" is one of the stress factors involved in the problem.

The scientific basis for the sulphur dioxide control policies of the 30% Club have been fully supported by field observations.

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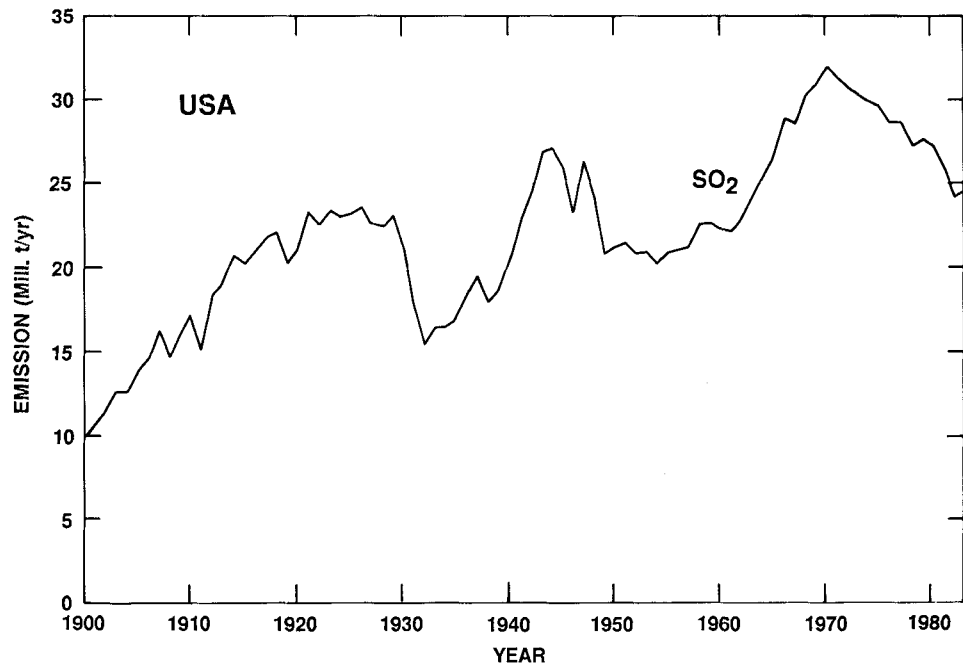


Fig. 1 Sulphur dioxide emissions in United States from 1900 - 1983

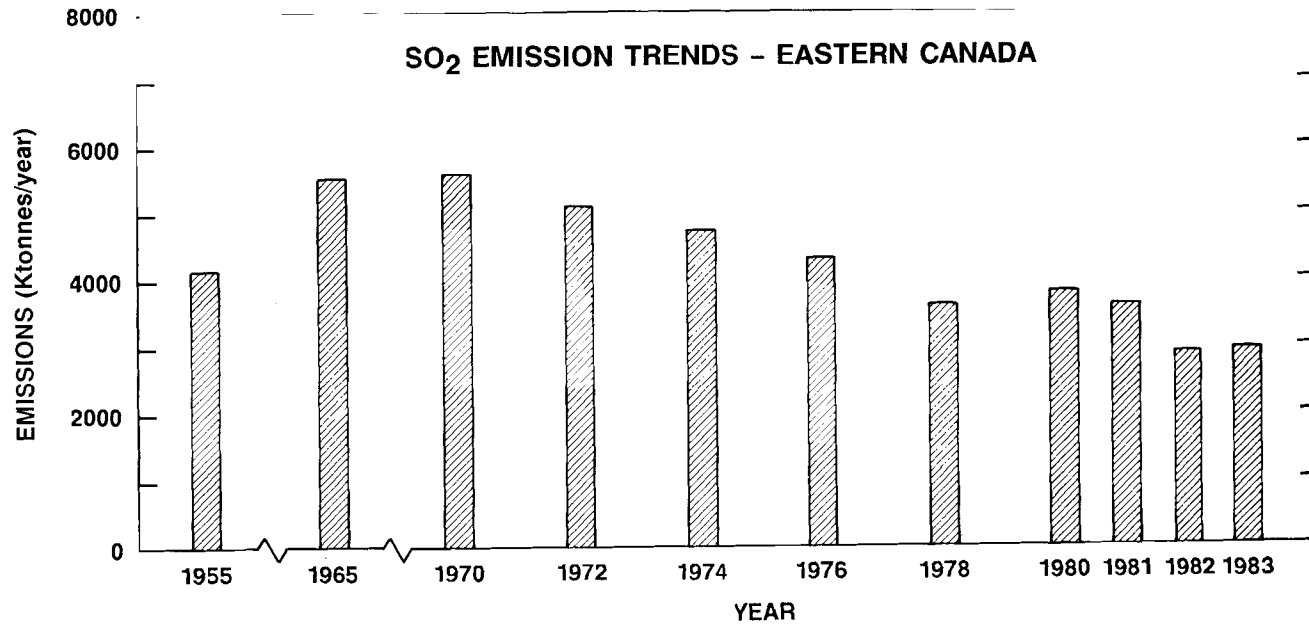


Fig. 2 Sulphur dioxide emissions in Canada from 1955 - 1983

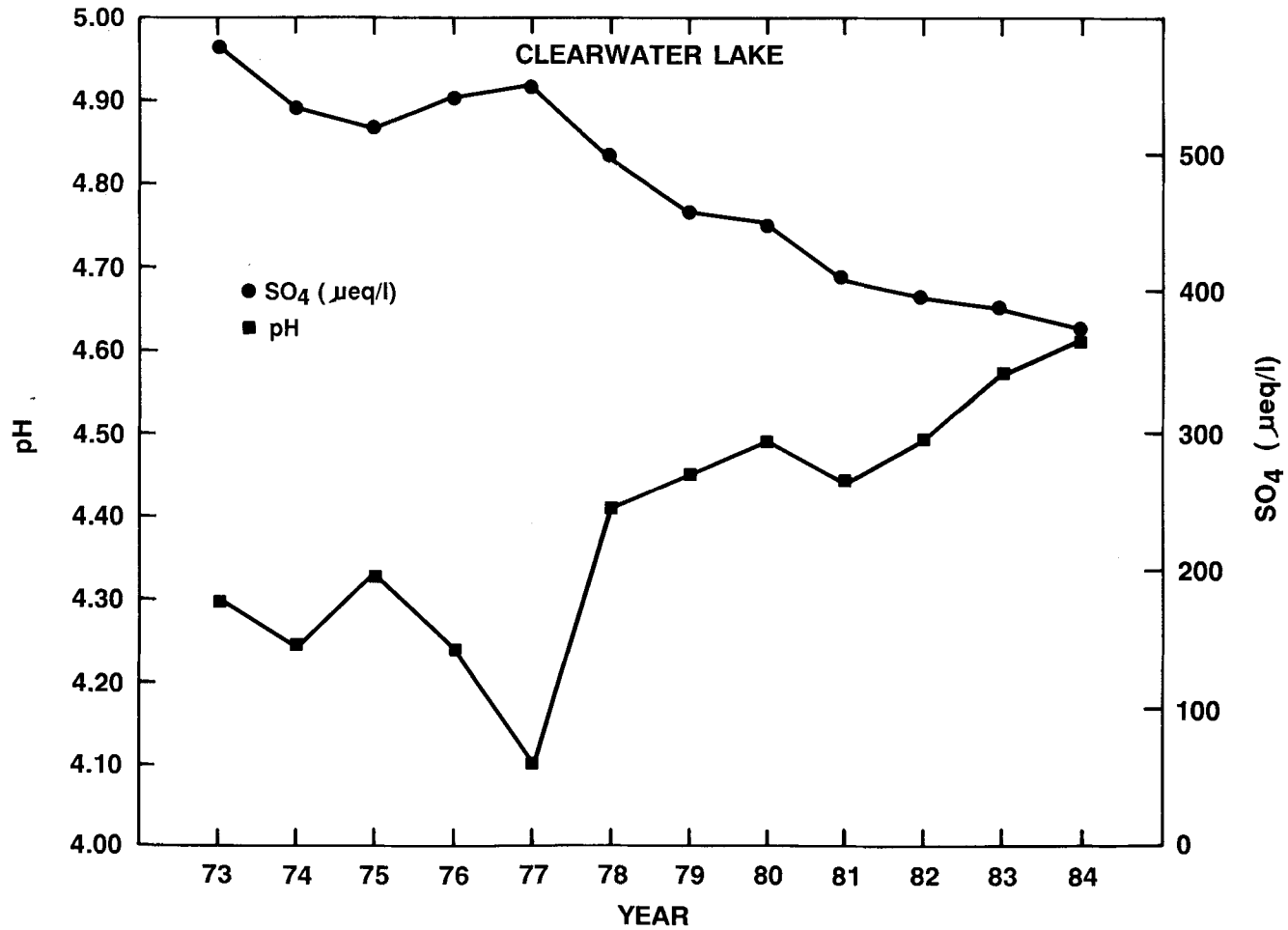


Fig. 3 Trends in sulphate and pH values for Clearwater Lake, Ontario

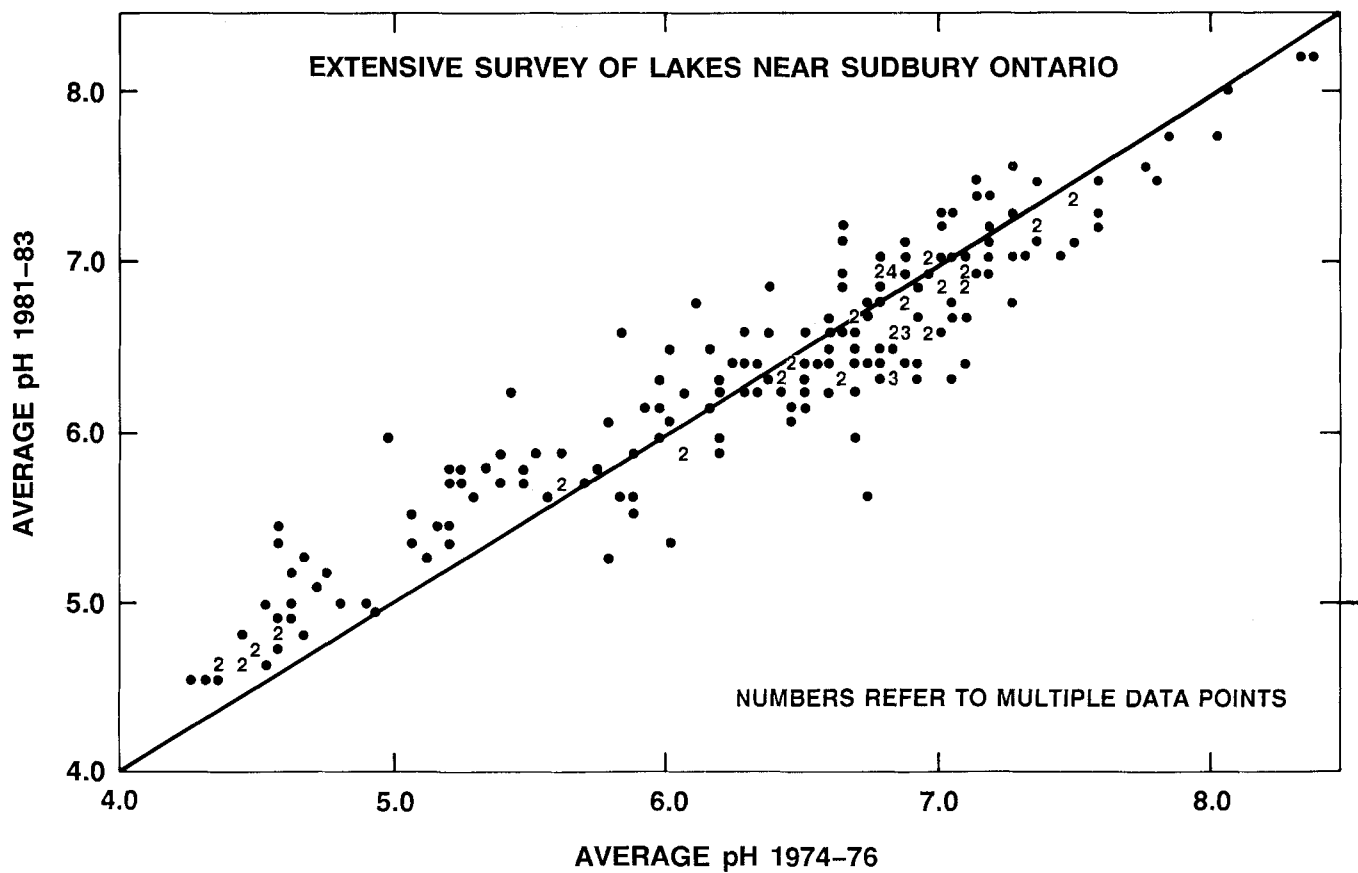


Fig. 4 Changes in the distribution of average pH of lakes in the Sudbury area between the periods 1974 - 1976 and 1981 - 1983

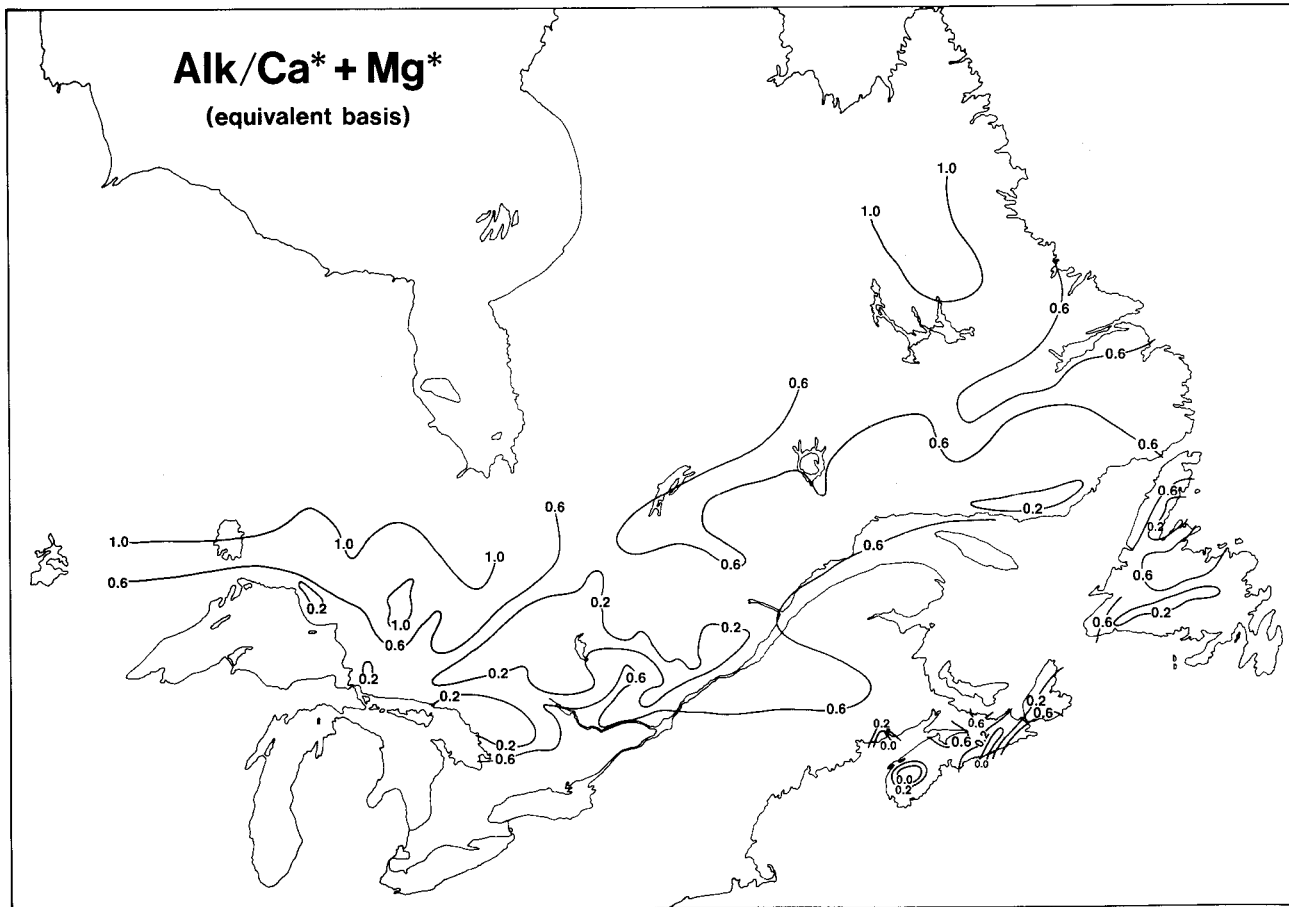


Fig. 5 The status of surface waters in eastern Canada as measured by the ratio of alkalinity to calcium plus magnesium. This map is based on approximately 8,000 sample points

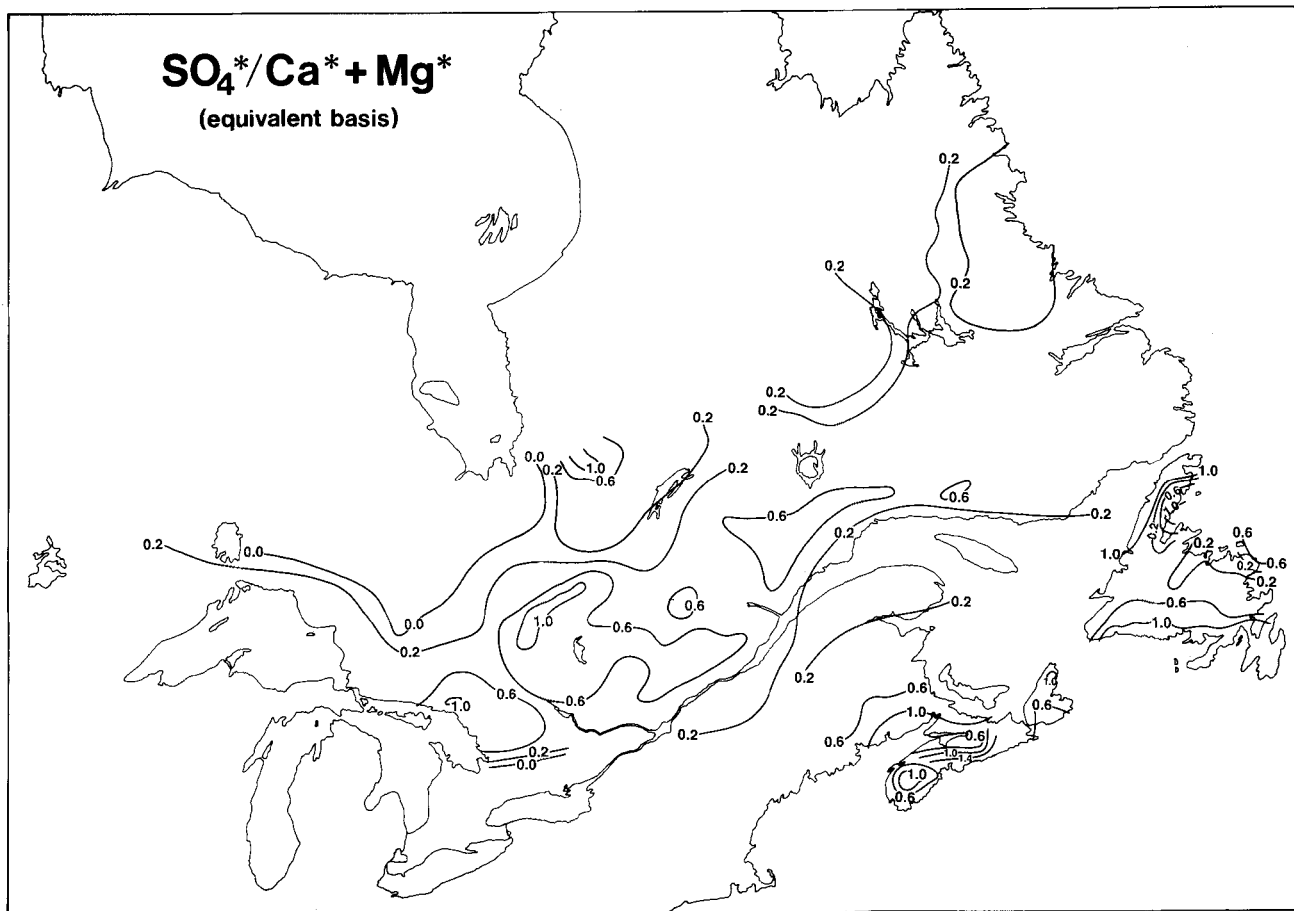


Fig. 6 Estimates for the ratio of sulphate to calcium plus magnesium for the same lakes documented in Fig. 5

GROUND WATER ANALYSIS AT 0.67m DEPTH AT TURKEY LAKE SAMPLE STATION

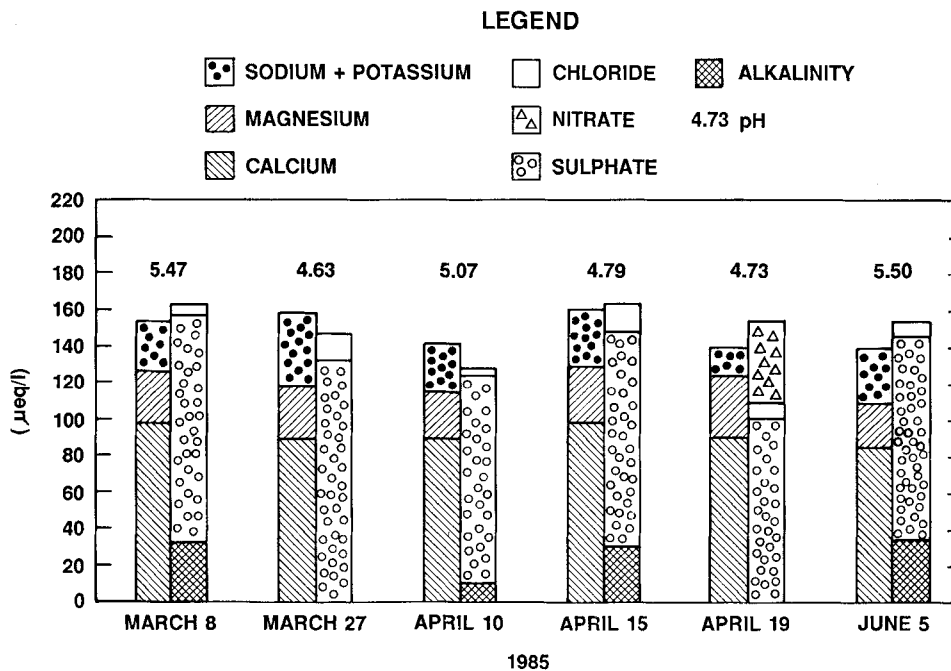


Fig. 7 The chemical composition of soil water during periods of heavy rain (March) and spring runoff (mid-April) for a watershed near Sault Ste. Marie, Ontario