

ACID PRECIPITATION IN CANADA

P. W. SUMMERS AND D. M. WHELPDALE, Environment Canada, Toronto, Ontario, Canada.

ABSTRACT

The total annual emissions of sulfur oxides and nitrogen oxides in Canada are estimated to be 7.2×10^6 tons and 1.4×10^6 tons, respectively. These figures represent 5% and 2%, respectively, of the estimated worldwide anthropogenic emissions. Nearly two-thirds of the Canadian SO_2 emissions come from primary smelters located in low population areas. The remainder originate from natural gas processing, pulp mills, fuel combustion and transportation in the more heavily populated areas. Transportation is the major source of oxides of nitrogen.

No co-ordinated precipitation sampling has been carried out on a national basis prior to the establishment of the World Meteorological Organization regional stations in 1974, but several local projects in problem areas have been conducted over the last 20 years. These data are reviewed with respect to sulphate and nitrate content, and when available, the pH.

The geographical distribution of acid rain in Canada is discussed in relation to main source areas of pollutants, prevailing meteorological conditions and precipitation type.

Finally, the extent of current and potential problems associated with acid rain is discussed, and current and recommended future monitoring and research programs are outlined.

1. INTRODUCTION

Acid rain has been identified as contributing to serious ecological effects in some parts of the world downwind of regions with large SO_2 emissions. Since Canada, with only half of 1% of the world's population, contributes 5% of the worldwide anthropogenic emission of SO_2 , and further, has the largest single source of SO_2 , this would suggest that acid rain may already be occurring on a significant scale in parts of the country. An attempt has been made to collect

all the information available on precipitation chemistry projects in Canada and also data from locations within the United States close to the border. These data are reviewed with respect to sulphate and nitrate content and, when available, the pH. The occurrence of acid rain (and rain with high sulphate and/or nitrate content) is discussed on a geographical basis by breaking the country down into five regions, and is then related to the main source areas of emissions, the meteorological conditions and precipitation type. The effects on the ecosystem depend on the chemical and biological characteristics of the receptors, but since this topic will be dealt with in other papers it will not be considered here. This paper will concern itself only with the chemical characteristics of the precipitation as it reaches the earth's surface. However, those regions where acid rain is already falling or where the acidity of the rain is expected to increase in the future are indicated, since these are areas of potential ecological problems.

2. AIR POLLUTION SOURCES

The two most common pollutants that cause lowering of the pH of precipitation below its equilibrium value of 5.7 are sulphur (either as sulphate particles or absorbed SO₂ gas) and nitrogen (in the form of nitrate). Generally speaking, the greater the concentrations of these compounds in precipitation the lower the pH, although the actual acidity is dependent on the amounts present in the strong acid form, which in turn depend on the amounts of neutralizing constituents present.

An inventory of emissions for the five major air pollutants in Canada was carried out for year 1970 (Environment Canada, 1973). Both sulphur oxides and nitrogen oxides were included in this survey. The total annual emissions of SO_x were estimated to be 7.2×10^6 tons (6.5×10^6 metric tons) distributed as shown in Figure 1. The only known new large source of SO₂ emissions not included is from the oil extraction plant in the Oil Sands region of northeastern Alberta where current emissions are approximately 0.1×10^6 tons per year. A breakdown of these emissions by broad categories is shown in Table I. The total annual emissions of NO_x were estimated to be 1.4×10^6 tons (1.3×10^6 metric tons) and the breakdown by source category is shown in Table I.

The significant features of the distribution patterns are as follows.

(i) A few very large primary smelting operations account for nearly two-thirds of the SO_x emissions in Canada. Generally speaking these are located in remote areas and, except for the associated company town, are in regions of low population density. The world's

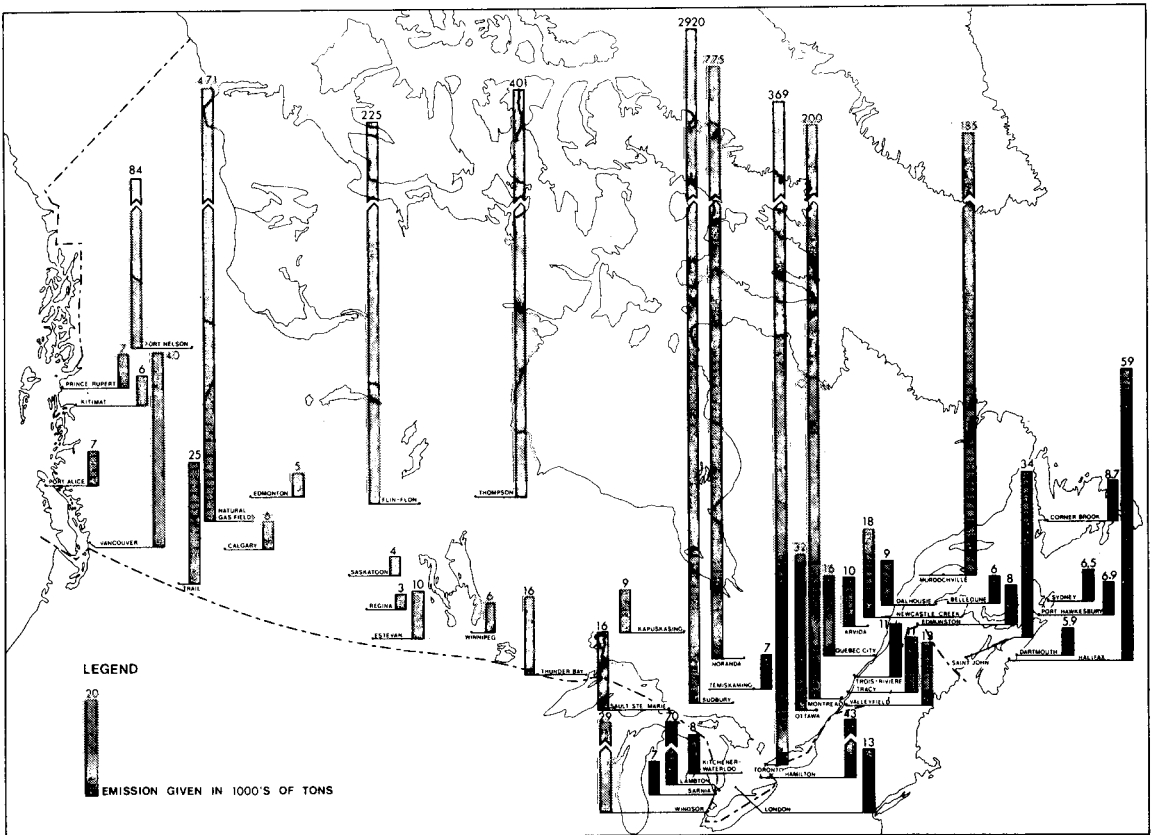


Figure 1. Distribution of major emissions of oxides of sulphur for 1970 (Environment Canada, 1973).

largest emissions of SO₂ (2.9 x 10⁶ tons per year) occur in the Sudbury area of northern Ontario. Approximately 85% of this is emitted from a single 380 m high stack, the world's tallest.

(ii) Most of the remaining SO_x emissions occur in, or near, urban areas as a result of combustion of fossil fuels for power generation, commercial and industrial activities and home heating. The extensive use of natural gas for these purposes in western Canada results in far less SO₂ being generated in western urban areas than in the east.

(iii) In sharp contrast to SO_x, nearly all of the NO_x emissions occur in urban areas with transportation responsible for nearly two-thirds of these emissions.

(iv) Total SO_x emissions are five times as great as NO_x emissions, and in all source categories except transportation the SO_x emissions are dominant.

Table I. Nationwide Emissions of Sulphur Oxides and Nitrogen Oxides for Canada - 1970 (Environment Canada, 1973)

Source Category	SO _x		NO _x	
	tong (×10 ³)	%	tong (×10 ³)	%
Primary Smelters	4,560	63	-	-
Industrial, Commercial and Private (mainly urban)	1,106	15	256	18
Natural gas, petroleum and chemical industry	680	9	15	1
Utilities and Power generation	479	7	176	13
Transportation	171	2	837	62
Pulp and Paper mills	165	2	-	-
Miscellaneous	49	1	75	6
TOTAL	7,210		1,359	

3. PRECIPITATION CHEMISTRY DATA SOURCES

An attempt was made to collect all published papers and reports on precipitation chemistry projects in Canada and in several cases additional material was received by private communication. Although data from over 30 projects were obtained some may still have been omitted, but this is not expected to change the general conclusions which follow. Quite clearly the data from all of these projects cannot be presented here, and thus they will be summarized and interpreted by region. The regions and the locations of the specific projects are shown in Figure 2. The WMO Regional Stations operated by the Atmospheric Environment Service of Environment Canada are also shown. These stations are carefully sited with standardized collection and analysis procedures and are thus generating a good base of quality-controlled data from which meaningful comparisons can be made in the future. In the other projects a very wide variety of collection, storage and analysis techniques were used. Thus caution should be exercised in comparing the results, and not too much emphasis should be placed on the precise reported values of pH or ion concentrations. The purpose here will be to look at broad regional differences.

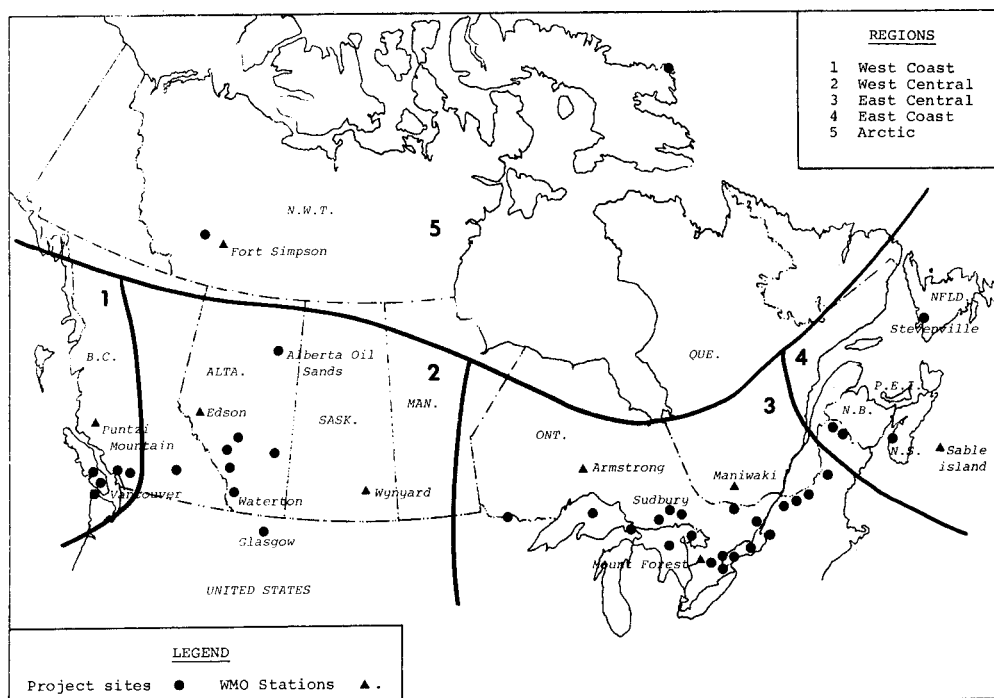


Figure 2. Geographical regions and project sites for acid precipitation study in Canada.

4. GEOGRAPHICAL DISTRIBUTION

4.1 WEST COAST

Concentrations are generally low for both sulphate (<2.0 ppm) and nitrate (<0.5 ppm), with pH values near neutral (5.0 - 6.5) except downwind of major sources in the Vancouver area, (e.g., Zeman and Nyborg, 1974).

4.2 WEST CENTRAL CANADA

The major source of SO_x in this region is the processing of natural gas in the foothills belt of Alberta between Waterton and Edson. In recent years concern about the possible effects on the soil in this important agricultural area has resulted in several studies. Downwind of this source concentrations of sulphate in event samples have been as high as 10 - 15 ppm with long term averages in rain running in the 2.0 - 3.0 ppm range, and the pH values slightly acid. In these same regions the concentrations in snow are very low (<0.5 ppm) even though the emissions remain essentially constant on a year round basis.

Sulphur budgets carried out on single sources (Summers and Hitchon, 1973; Nyborg et al., 1973) indicate that a large fraction of the emitted SO₂ is removed within 50 km of the source in summer by precipitation scavenging and direct up-take at the surface. Annual deposition rates of sulphur by precipitation have been estimated at between 2 and 10 lb/acre (2.2 and 11 kg/ha).

Elsewhere in this region concentrations of sulphate and nitrate are low and pH values are slightly basic, but no measurements are available near the two large smelters in northern Manitoba.

4.3 EAST CENTRAL CANADA

This region accounts for 60% of the Canadian emissions of SO_x and is the region where the most sampling has been carried out. Higher concentrations of sulphate occur at all sampling stations in southern Ontario and the Great Lakes basin -- even those well removed from known sources. Typical values in rain run between 2.0 and 7.0 ppm and near large sources run as high as 10 - 15 ppm. The general pH level is 4.0 to 5.0 and has been detected below 4.0.

The highest nitrate concentrations in Canada were measured in this region, ranging from 1.0 to 6.0 ppm, and could thus be a significant contributor to the acidity of the rain.

4.4 EAST COAST

Emissions of SO_x drop off again in this region with two urban areas and one smelter contributing the bulk. No recent precipitation chemistry data are available, but in the 1950's and 1960's sulphate concentrations of 2.0 to 4.0 ppm were reported with near neutral pH values. Concentrations of nitrate were between 0.25 and 1.00 ppm.

4.5 ARCTIC

No major pollution sources exist in this region of Canada and sulphate concentrations are generally <1.0 ppm with nitrates <0.7 ppm. The pH ranged from 5.0 to 7.0 in a very limited number of samples.

5. SECULAR TRENDS

The U.S. network operated by Junge (1958) in 1956 - 57 had several stations close to the Canadian border and one at a U.S. base (Steven-ville, Nfld.) in Canada. Unfortunately no recent measurements have been made close to these same locations. However, the one year's data

from Wynyard, Sask. appear to be yielding an annual average close to that reported by Junge for Glasgow, Montana.

Sulphate concentrations measured in bulk samples at several rural stations in northern New York State and Vermont in the mid to late 1960's (Pearson and Fisher, 1971) were in the 3.5 to 5.5 ppm range with pH values between 4 and 5. Although these ranges are very close to those currently being recorded in monthly precipitation - only samples at Mount Forest in rural southern Ontario, the data are not directly comparable.

While the above cases indicate no dramatic change in the regional characteristics of the precipitation chemistry, the data available are obviously inadequate for establishing any meaningful trends. After several years of operation, the WMO Regional network should be able to indicate such trends if they exist.

6. EFFECTS OF PRECIPITATION TYPE

Data from Alberta (Walker, 1969; Summers and Hitchon, 1973; Nyborg et al., 1973) all indicate much lower sulphate concentrations in snow compared to rain. Earlier data from Nova Scotia (Herman and Gorham, 1957) showed the sulphate concentrations in rain to be about 2.5 times that in snow. Since emissions from industrial sources remain essentially constant round the year, and the use of fossil fuels for heating and electric power generation increase in the winter, the total emissions are higher in winter than in the summer. The lower sulphate concentrations in snow are therefore attributed to the less efficient precipitation scavenging mechanism (Summers, 1975).

7. DISCUSSION

Three major air mass types dominate the weather in the populated belt across southern Canada. Arctic air which moves in from the NW or N, most frequently in winter, is very clean and thus precipitation (mainly snow) falling in such an air-mass tends to have very low sulphate and nitrate content.

Pacific air contains very little man-made pollution, although some sulphate associated with chloride and originating from sea spray is detected in precipitation on the west coast. Most of this is removed by the time the air reaches the interior of British Columbia and Alberta. The air mass remains essentially clean, except near the Alberta gas fields, as it moves east across Canada until it reaches the major source region in southern Ontario.

The third, and perhaps most important, air mass is the warm moist tropical air which moves north from the Gulf of Mexico across the major source regions in the eastern United States and makes frequent incursions into southern Ontario and eastern Canada, especially in the summer. It is within this air mass that the greatest potential for long range transport of pollutants into Canada exists. A study of haze in the Atlantic Provinces by Munn (1973) presents evidence for such transport. It is also within this air mass that much of the summer rainfall occurs, often in the form of convective storms, which appear to be the most efficient at scavenging pollutants (Summers, 1975) and hence giving the highest sulphate and nitrate concentrations and lowest pH values.

The configuration of pollution sources in Canada and the United States, and the major air mass flows, thus combine to make southern Ontario the main known receptor of acid rain in Canada on a regional basis. Although we are not aware of any recent precipitation chemistry data in the area east of Ontario, pH measurements in northern New England (Likens, 1972) and Munn's study suggest that southern Quebec and the Atlantic Provinces are probably receptor regions for acid rain also. The new WMO regional stations currently being set up at Maniwaki, Que. and Sable Island, off Nova Scotia, will soon provide additional data on this matter. Additional precipitation sampling stations are also being established in southern New Brunswick and southern Nova Scotia.

In southern Ontario the regional acid rain effect is strongly enhanced downwind of some of the major sources. For example pH values as low as 3.6 have been detected in rain falling through the plume near Sudbury (Wiebe and Whelpdale, 1975).

The potential for transboundary flow of pollutants contributing to acid rain is greatest in the east. With winds from the NW sector, pollutants from the major source area in southern Ontario could be transported into New England, although with these winds, rainfalls are not frequent or heavy. Snow often occurs in winter with winds from this sector, but in view of the lower scavenging efficiency probably does not contribute much to acidity of precipitation on an annual basis.

On the other hand, winds from the SW sector transport pollutants from the major sources in the eastern United States into southern Ontario, southern Quebec and the Atlantic Provinces, and the concentrations are further increased by the intense local sources. Most of the summer rainfall occurs with this flow and hence probably makes a major contribution to the acidity of precipitation on an annual basis. Quite clearly a major study of air mass motions, polluted parcel trajectories and an extensive precipitation monitoring program in the eastern U.S. and eastern Canada would be required to quantitatively define the extent of acid rain and the pollutant sources responsible as a result of long-range transport in general and transboundary transport in particular.

8. SUMMARY AND RECOMMENDATIONS

Two regions of Canada have been identified as currently being receptors for precipitation containing high sulphate and nitrate concentrations and/or with low pH values.

The first region is in central Alberta downwind of the natural gas processing plants. Although sulphate and nitrate concentrations are moderately high, the rain is only slightly acid. A potential future problem exists in northeastern Alberta where development of the Alberta Oil Sands over the next ten years could cause a dramatic increase in the sulphur dioxide emissions. A large inter-disciplinary environmental study of this region is now being initiated and will monitor present levels of pollutants and attempt to establish the pathways for both air and water pollutants and their likely effects on the ecosystem. This information will be used to establish appropriate control and land-use strategy in the area in order to minimize environmental damage.

The second region is southern Ontario (probably extending into southern Quebec, and the Atlantic Provinces) where slight to moderately acid precipitation appears to be falling over a large area. In this region, in addition to sulphate, nitrate appears to be making a significant contribution to the acidity. In general the rain is more acid than the snow. The effect is enhanced downwind of some of the major sources where extremely acid ($\text{pH} < 4.0$) precipitation has been detected.

Because of the "energy crisis", consideration is being given to a much greater use of coal for electric power generation in North America. This will undoubtedly lead to a sharp increase in emissions of both SO_x and NO_x especially if tall stacks are used, rather than best practical control technology, to satisfy the ambient air quality standards. Since many of these emissions will occur in the heavily populated and industrialized regions of eastern North America which are already experiencing acid rain this may result in a further lowering of the pH and an increase in the geographical extent of the affected areas. It is therefore recommended that the current extent of acid rain be better delineated by setting up a suitable monitoring network in Canada on a finer scale than the WMO network. This should comprise of the order of 100 stations, with maximum density in the eastern half of southern Canada and a few stations in the arctic. Such a network would enable the regional distribution of acid precipitation to be determined using standardized collection and analysis techniques. The establishment of such a network would not preclude the necessity for continuing more intensive sampling around known large sources. In fact it will make interpretation of results from these studies more definitive if the regional background levels are known more accurately.

Along with the operation of a Canadian precipitation chemistry network, further research effort needs to be devoted to gaining a better understanding of the precipitation scavenging mechanisms. This is particularly important because of the wide range of precipitation amounts and types that can occur in Canada. The relative importance of the wet and dry deposition processes is also a very critical aspect of assessing the environmental impact of new industrial developments.

Finally it is recommended that any large-scale Canadian effort in precipitation sampling and research devoted to acid rain should be closely co-ordinated with any similar activities in the United States.

ACKNOWLEDGEMENTS

The authors wish to thank those working on precipitation chemistry in Canada who provided the information used as the basis for this review, particularly the following, F. C. Elder, J. P. Kimmins, J. C. Scrivener, and B. Webber, who provided data from projects currently underway.

REFERENCES

- Environment Canada, 1973. A NATIONWIDE INVENTORY OF AIR POLLUTANT EMISSIONS - 1970. Report EPS 3-AP-73-2, Environmental Protection Service, 123p. Ottawa.
- Herman, F. A. and E. Gorham, 1957. Total mineral material, acidity, sulfur and nitrogen in rain and snow at Kentville, Nova Scotia, TELLUS 9: 180-183.
- Junge, C. E., 1958. The distribution of ammonia and nitrate in rain water over the United States. TRANS. AMER. GEOPHYS. UNION 39: 241-248.
- Likens, G. E., F. H. Bormann, N. M. Johnson, 1972. Acid Rain. ENVIRONMENT 14: 33-40.
- Munn, R. E. 1973. Secular increases in summer haziness in the Atlantic Provinces. ATMOSPHERE 11: 156-161.

- Nyborg, M. and McKinnon, Allen and Associates Ltd., 1973. ATMOSPHERIC SULPHUR DIOXIDE: EFFECTS ON THE pH AND SULPHUR CONTENT OF RAIN AND SNOW; ADDITION OF SULPHUR TO SURFACE WATERS, SOIL, AND CROPS; AND ACIDIFICATION OF SOILS. Proceedings of a Workshop on Sulphur Gas Research in Alberta (D. Hocking and D. Reiter, eds), Information Report NOR-X-72, Northern Forest Research Centre, 196 p. Edmonton, Alberta. December, 1973.
- Pearson, F. J. Jr., and D. W. Fisher, 1971. CHEMICAL COMPOSITION OF ATMOSPHERIC PRECIPITATION IN THE NORTHEASTERN UNITED STATES. Geological Survey Water-Supply Paper 1535-p, 23p. Washington, D.C.
- Summers, P. W., 1975. Note on SO₂ scavenging in relation to precipitation type. In PRECIPITATION SCAVENGING-1974. U.S.A. E.C. (in press).
- Summers, P. W., and B. Hitchon, 1973. Source and budget of sulphate in precipitation from central Alberta, Canada J. AIR. POLL. CONTR. ASSOC. 23: 194-199.
- Walker, D. R., 1969. Sulfur in precipitation in central Alberta, CAN. J. SOIL SCI., 49: 409-410.
- Wiebe, H. A., and D. M. Whelpdale, 1975. Precipitation scavenging from a tall-stack plume. In PRECIPITATION SCAVENGING-1974. U.S.A. E.C. (in press).
- Zeman, L. J., and E. O. Nyborg, 1974. Collection of chemical fallout from the atmosphere. CANADIAN AGRICULTURAL ENG. 16: 69-72.