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AN ACID RAIN PERSPECTIVE

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AN ACID RAIN PERSPECTIVE

INTRODUCTION

The end of the 20th century brought to a close the first phase of one of North America's most significant environmental initiatives of the last two decades: the fight against acid rain.[1] Although this problem is still far from being completely neutralized, acid rain programs to date in Canada and the United States have been a significant success. In both countries, reductions in acidifying emissions have occurred faster than originally scheduled and at a lower cost to industry. However, the reductions achieved in the programs' first phase up to the year 2000, and even those contemplated in the next phase following 2000, will not be sufficient to completely protect the most sensitive regions of the continent from the damage caused by acid rain. That will take a still greater commitment.

ACID RAIN: CAUSES AND EFFECTS

A. Causes of Acid Rain

Acid rain is formed when sulphur dioxide (SO_2) and nitrogen oxides (NO_x)[2] react with oxygen and moisture in the atmosphere to form sulphuric and nitric acids.[3] Sulphur dioxide is released to the environment during the combustion of sulphur-containing fossil fuels and the smelting of sulphide ores. The composition of SO_2 sources is quite different in Canada

(1) Commonly called acid rain but more properly called acid precipitation.

(2) Unlike sulphur, which forms primarily only the dioxide, nitrogen forms a number of different oxides with varying ratios of oxygen to nitrogen.

(3) Acidity is commonly measured in units of pH. The pH of pure water is 7 and represents neutrality. Each unit decrease of pH corresponds to a ten-fold increase in acidity. One of the most acidic rainfalls yet recorded fell in Scotland in 1974 and was measured at 2.4 on the pH scale – roughly the pH of vinegar, over one thousand times as acidic as natural rain. In December 1982, a sample of fog taken at Corona del Mar in southern California had a pH of 1.69. This extremely high acidity developed after a two-day ground-level temperature inversion in the Los Angeles basin that prevented air pollution from dispersing.

and the United States. In Canada, 74% of SO_2 originates from industrial processes and 20% from electricity generation.[(4)] In the United States, the situation is almost the reverse, with 67% originating from electric utilities and 15% from industrial sources. Transportation and the combustion of fossil fuels account for relatively smaller amounts of SO_2 emissions in both countries.

Nitrogen oxides are formed by the oxidation of nitrogen from air during combustion processes. Transportation is largest source of NO_x and accounts for about 40%. Fossil-fuelled power generation is next, accounting for about 25%; other industrial, commercial and residential combustion processes produce the remainder.[(5)]

Sulphur dioxide emissions in both countries have a strongly regional character. About 80% of total emissions come from provinces east of the Manitoba-Saskatchewan border and from the 31 states east of the Mississippi River. Emissions of NO_x are more uniformly distributed than those of SO_2. Still, the eastern regions contribute more than 60% of emissions. Since these pollutants are transported for hundreds, or even thousands, of kilometres through the atmosphere, the effects may be felt a long way from the source. Because the prevailing weather patterns in North America tend to move in a northeasterly direction, emissions from the American industrial midwest and central Canada tend to be deposited in the northeastern United States and southeastern Canada.

B. Environmental Effects of Acid Rain

More is known about the effects of acid rain on some parts of the environment than on others. A good deal is known about the effects on aquatic ecosystems, which can be very vulnerable to acidic precipitation. The effects on terrestrial ecosystems, including agricultural crops and forests, are less well defined, but most authorities agree that a potential for damage exists. Acid rain can also damage buildings and other man-made structures.

Although acid rain is not believed to pose a direct risk to human health, there is growing evidence that the inhalation of acid aerosols can irritate the respiratory tract and aggravate respiratory ailments. The issue is made more complicated, however, by the fact that the effects of acidic pollutants are mixed in with those of other atmospheric pollutants such as

(4) Environment Canada, *acid rain and … the facts*, http://www.ec.gc.ca/acidrain/acidfact.html.

(5) *The State of Canada's Environment, 1996*, Environment Canada, Ottawa, 1996, p. 24-6.

ground-level ozone. Human health may potentially be harmed indirectly by toxic metals in drinking water and food, the levels of which can be elevated by acidification of surface waters.

1. Aquatic Ecosystems

Aquatic organisms vary greatly in their ability to tolerate acidification of their environment. As the pH of lakes, rivers and groundwaters begins to decrease, the least acid-tolerant species disappear first, followed by progressively less sensitive species as the pH continues to drop. Some insects, crustaceans, algae and zooplankton begin to disappear if the pH level is reduced even to 6.0. Some species of fish begin to decrease when the pH drops below 6.0. Lake trout is one of the more sensitive species, followed by brook trout and walleye, while perch is one of the more resistant species. Even though adult fish may tolerate higher levels of acidity, reproductive success may be reduced so that fish populations can be in difficulty before the problem becomes evident.

Other aquatic organisms are also affected by acidification. Algal communities in lakes become less diverse as the pH drops below 6.0 and the survival of rooted plants is generally diminished, while the growth of benthic (bottom-growing) mosses and attached algae is usually enhanced. As the pH falls, the number of invertebrates in the water column and in sediments decreases, organic matter decomposes more slowly, and fungi begin to replace bacteria as the dominant decomposer organisms. These changes can reduce nutrient cycling in a lake, leading to lower productivity. The loss of diversity with decreasing pH can make the ecosystem progressively more unstable. The clear, pristine water of an acidified lake may look beautiful, but the lake is essentially dead.

Surveys in the late 1980s estimated that approximately 14,000(6) Canadian lakes were acidified. Computer models predicted many more lakes in eastern Canada were at risk without a decrease in wet sulphate deposition in the most heavily affected regions.

Limited information now suggests that aquatic biological communities can recover fairly quickly from acidification (in years rather than decades) once the level of acid loading is reduced. The artificial "liming" of acidified waters has had some success in

(6) Federal/Provincial Research and Monitoring Co-ordination Committee (RMCC), *The 1990 Canadian Long-Range Transport of Air Pollutants and Acid Deposition Assessment Report, Part 1: Executive Summary*, 1990, pp. 1-17. (This number refers to lakes that are larger than one hectare in size. If smaller lakes are included, the number is much larger.)

decreasing acidification and re-establishing some fish populations. However, the procedure is expensive and liming does not precisely reverse the acidification process.

2. Terrestrial Ecosystems

The effects of acidic rain on terrestrial ecosystems are not as fully understood. Acid rain and particulates can damage the waxy protective coating of tree leaves. This decreases the tree's ability to deal with stresses such as drought, pests, disease and UV radiation. Acidification can also inhibit the germination of seeds and the growth of seedlings. Increased acidity may also leach nutrients from the soil.

The evidence to date suggests that forest decline in several parts of the world is due, at least in part, to air pollution, including acid rain. White birch stands in the Bay of Fundy in eastern Canada may have been damaged by acidic fogs. According to a 1988 survey, nearly all the trees were affected to some extent and 10% of the trees were already dead. A similar pattern of decline has been seen in stands of white birch on the shores of Lake Ontario, another area where acidic fogs occur.(7)

Through the late 1970s and the 1980s, sugar maples declined in northeastern North America. The phenomenon was most severe in Quebec, and acid rain was suspected as a factor. However, the North American Sugar Maple Decline Project showed that the health of sugar maples improved between 1988 and 1990, and it now seems likely that drought and insect defoliation, rather than acid rain, were the primary causes of the decline.

Acidic precipitation has not yet been shown to damage agricultural crops directly, but air pollution in general does inhibit the growth of some crops. The damaging effect of ground-level ozone, which is a major component of smog, on sensitive agricultural crops is now well documented.

3. Human Health

Although acid rain per se probably has little direct effect on human health, medical authorities now widely accept that acidic air pollution affects human health.

Extremely small particulates, formed in the atmosphere by the oxidation of SO_2, are capable of penetrating deeply into the lungs, where they can cause or increase susceptibility

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(7) *The State of Canada's Environment* (1996), p. 24-11.

to respiratory ailments. Evidence continues to accumulate that acid aerosols can have detrimental heath effects, particularly on children. For example, a paper by the Ontario Medical Association[8] reported on a study of respiratory health effects of exposure to acidic air pollution among 13,369 white children, aged eight to twelve years old, from 24 communities in the United States and Canada between 1988 and 199l. The study found that children living in the community with the highest levels of airborne acids were significantly more likely to report at least one episode of bronchitis in the past year compared to children living in the least-polluted community. It also found that reported bronchitis was associated with elevated levels of airborne acids for those children living in a non-urban environment. The paper concluded that chronic exposure to acid aerosol pollution may have observable negative consequences on children's health.

A study by Health Canada, Environment Canada, and Statistics Canada, published in 1994, showed statistically significant, positive associations between admissions to Ontario hospitals for respiratory ailments and atmospheric ozone and sulphate levels on the date of admission, and up to three days prior, although ozone was found to be a stronger predictor of admissions than sulphate. Of daily respiratory admissions in the months of May to August, 5% were associated with ozone and an additional 1% were associated with sulphate. All age groups were affected, but the largest impact of the ozone-sulphate mix (15% of admissions) was on infants up to one year old.[9]

A study by the U.S. Environmental Protection Agency estimated the monetary value of human health benefits from reducing sulphate particulates under Title IV of the *Clean Air Act Amendments* (CAAA). The model estimated that, by the year 2010, the benefits of the U.S. Acid Rain Program in the Windsor-Quebec corridor would fall within a range of US$291 million to US$1,868 million with a mean estimate of US$955 million, well in excess of C$1 billion a year (1994 dollars). For the eastern United States, the estimated range was from $12 to $88 billion with a mean of $40 billion.[10]

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(8) Ontario Medical Association, *Health Effects of Ground-level Ozone, Acid Aerosols & Particulate Matter*, 1998, http://www.oma.org/phealth/ground.htm.

(9) Richard T. Burnett *et al*., "Effects of Low Ambient Levels of Ozone and Sulphates on the Frequency of Respiratory Admissions to Ontario Hospitals," *Environmental Research*, Vol. 65, No. 2, May 1994, p. 172.

(10) United States Environmental Protection Agency, *Human Health Benefits from Sulphate Reduction under Title IV of the 1990 Clean Air Act Amendments*, Chapter 6, http://www.epa.gov/acidrain/effects/chap_6.pdf.

In a 1995 policy paper entitled "Clean Vehicles and Fuels for British Columbia," the British Columbia government estimated that the cost of atmospheric pollution to human health in the Lower Fraser Valley was $830 million in 1990 and would rise to $1.5 billion by 2005.[11]

The federal government estimates[12] that the health benefits to Canada of a 50% SO_2 reduction in both eastern Canada and the United States over and above the current commitments in the Eastern Canada Acid Rain Program and U.S. Acid Rain Program would include a reduction of:

- 550 premature deaths per year;
- 1,520 emergency room visits per year; and
- 210,070 asthma symptom days per year.

4. Man-made Structures and Materials

Acidic rain can accelerate the erosion and corrosion of building materials, metals, paints and other materials. To some extent, this simply adds to the ongoing cost of maintenance; but acidic pollution can also contribute to the destruction of irreplaceable objects of cultural importance such as monuments, sculptures and paintings.

C. Areas of Canada Susceptible to Acidic Precipitation

Some environments have the ability to neutralize or "buffer" acid rain, making it less harmful. Buffering capacity is usually related to the amount of calcareous minerals (such as limestone) in soils and rocks.

In parts of the country in which non-calcareous rock formations predominate, the environment has little buffering capacity and can consequently neutralize only limited amounts of acidic precipitation. For example, some lakes in the Haliburton-Muskoka region have lost 40 to 75% of their buffering capacity in less than a decade. Once that capacity has been eliminated, acidic precipitation can no longer be neutralized, the pH of the system drops rapidly, and the ecological effects noted earlier begin to appear.

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(11) British Columbia Ministry of Environment, Lands and Parks, "Clean Vehicles and Fuels for British Columbia," 1995.

(12) Environment Canada, *acid rain and … your health*, http://www.ec.gc.ca/acidrain/acidhealth.html.

A large portion of central and eastern Canada is based on granitic and silicious (i.e., non-calcareous) bedrock. Large areas of Nova Scotia and New Brunswick, almost all of Newfoundland, most of Quebec and large areas of Ontario are therefore especially susceptible to acid rain. Parts of the Northwest Territories, Manitoba and southern British Columbia may also be susceptible. In all, it has been estimated that some 43% of Canada's land area is sensitive to acid deposition.(13)

The areas of Canada that are likely to suffer the most damage are located in Ontario, Quebec and Labrador because of the generally prevailing westerly winds over most of eastern North America.

ACID RAIN PROGRAMS

A. Historical Background

Although some effects of acid rain were noted as early as the 17th century, modern recognition of acid rain as an environmental problem began in Scandinavia in the 1950s and 1960s, where observations were made of the increasing acidity of rainfall and of decreasing fish populations.

The Scandinavian observations prompted an OECD program to extend measurements over a wider area of Europe. The program, which ran from 1972 to 1977, confirmed the long-range transport of sulphur compounds and pointed to the need for international cooperation to combat the problem.

In Canada, abnormal acidity in precipitation and in Nova Scotia lakes was detected in the mid-1950s. It was hypothesized that the acidity was due to airborne pollution from distant sources. In the mid-1960s, losses of fish populations in lakes southwest of Sudbury, Ontario, were attributed to acidification caused by acid rain.

In 1978, the governments of the United States and Canada established the United States-Canada Research Consultation Group to study the problem of the long-range transport of air pollutants (LRTAP). The group was to study LRTAP and the related phenomenon of acidic precipitation and to aid in the coordination of research studies and the exchange of scientific information between the two countries. A preliminary report released by Environment Canada in October 1979 identified acidic precipitation as the problem of greatest common concern at that time.

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(13) RMCC (1990), pp. 1-17.

On 5 August 1980, Canada and the United States signed a "Memorandum of Intent Concerning Transboundary Air Pollution" as a preliminary step in the development of a bilateral agreement on air quality which would deal effectively with such pollution and, at the same time, combat acidic precipitation.

B. International and Bilateral Agreements

As concern mounted over the widespread damage caused by acid rain, major initiatives to decrease acid rain-causing emissions were introduced. In July 1985, 21 countries including Canada signed the Helsinki Protocol, which called for a 30% reduction of SO_2 emissions from 1980 levels as soon as possible and at the latest by 1993. The Canadian Acid Rain Control Program was introduced in the same year. Its objective was to reduce SO_2 emissions in eastern Canada by 50% from the 1980 level of 4.6 million tonnes.(14)

Progress in the United States was initially somewhat slower, but in 1990 the United States brought in the comprehensive *Clean Air Act Amendments*. Title IV of the Amendments committed the United States to cutting SO_2 emissions by 9.1 million tonnes (10 million tons)(15) by the year 2000.

On 13 March 1991, Canada and the United States signed a bilateral Air Quality Agreement, committing both countries to specific schedules for the reduction of acid-forming emissions. The significance of the Agreement was broader than acid rain, in that it established a framework for dealing with other transboundary air pollution problems such as ground-level ozone and particulates.

A second international protocol to reduce SO_2 emissions was signed in Oslo, Norway, on 14 June 1994. This protocol committed Canada to continue controlling its sulphur emissions in order to protect human health and the environment; to support the long-term aim of working toward achieving critical loads; to establish a Sulphur Oxide Management Area (SOMA) for southeastern Canada; and to support the establishment of a multinational Implementation Committee to review the implementation of the Protocol and compliance by the Parties.

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(14) Metric tonnes, which equal 1,000 kilograms.

(15) A short ton, which equals 0.91 metric tonnes.

Unlike the Helsinki Protocol, which committed all parties to an across-the-board 30% reduction of SO_2 emissions, the Oslo Protocol set out sulphur emissions ceilings that varied by country, with decreasing ceilings set for many countries for the years 2000, 2005, and 2010. Canada's national target was 3,200 kilotonnes for 2000 and beyond. The SOMA had a ceiling of 1,750 kilotonnes of SO_2 for 2000 and beyond. Canada ratified the Oslo Protocol in 1997.

In November 1988, Canada signed the first NO_x protocol.(16) Under this protocol, Canada committed itself to stabilizing NO_x emissions at 1987 levels by 1994.

1. Canada-U.S. Air Quality Agreement

On 13 March 1991, Prime Minister Brian Mulroney and President George H. Bush signed the Air Quality Agreement between Canada and the United States,(17) which addresses shared concerns about transboundary air pollution. The first air pollution issue addressed by the Agreement was acid rain. Under the Agreement, SO_2 emissions were to be permanently capped in both countries at approximately 13.3 million tonnes by 2010 in the United States and 3.2 million tonnes by 2000 in Canada. Precise commitments and schedules were specified in Annex 1 of the Agreement.

Other requirements included the scheduled reduction of NO_x emissions over the next 10 years, tighter emission standards for new motor vehicles, the monitoring of SO_2 and NO_x emissions, and specific actions to protect pristine wilderness areas in both countries from transboundary air pollution.

Annex 2 of the Agreement detailed the coordination of research and monitoring activities and the exchange of scientific and technical information to improve understanding of transboundary air pollution and the mechanisms to control it.

The Agreement also established a joint Air Quality Committee to assist with the implementation of the Agreement and to report on progress. The Air Quality Committee held its inaugural meeting on 26 November 1991 in Washington, D.C., and released its first progress report on 17 June 1992. Since then, the Air Quality Committee has issued reports at two-yearly intervals; the most recent was released in the fall of 2000.

(16) The 1988 United Nations Economic Commission for Europe Protocol to the 1979 Convention on Long-range Transboundary Air Pollution Concerning the Control of the Emission of Nitrogen Oxides or their Transboundary Fluxes.

(17) Agreement between the Government of Canada and the Government of the United States of America on Air Quality.

Under the Air Quality Agreement, Canada made a commitment to:

- reduce, as an interim measure, annual national emissions of NO_x from stationary sources by 100,000 tonnes below the forecast level of 970,000 tonnes by the year 2000;

- develop, by 1 January 1995, further emission reduction requirements for stationary sources to be achieved by 2000 and/or 2005; and

- implement a more stringent program for mobile sources of NO_x according to a schedule based on the class of vehicle.

C. The Canadian Acid Rain Control Program

In March 1985, Prime Minister Brian Mulroney announced the Canadian Acid Rain Control Program. This program was a cooperative undertaking by the federal and provincial governments and industry to reduce SO_2 emissions in eastern Canada by 50% by 1994 from an allowable base of 4.516 million tonnes in 1980. The goal of the program was to cap SO_2 emissions in eastern Canada at 2.3 million tonnes per year by 1994. That goal was met ahead of schedule in 1993.

Some of the original federal-provincial agreements lapsed in 1994. Renegotiated agreements with Nova Scotia, New Brunswick and Quebec were extended until the year 2000, when *The Canada-Wide Acid Rain Strategy for Post-2000* began; and Ontario has extended its 1994 agreement in perpetuity.

D. The Canadian Post-2000 Strategy

The Canada-Wide Acid Rain Strategy for Post-2000 was signed by the federal government and the provinces and territories at the Joint Meeting of Energy and Environment Ministers in Halifax, Nova Scotia, on 19 October 1998. *The Strategy* is based on the 1997 Report of the National Air Issues Coordinating Committee, *Towards a National Acid Rain Strategy*, and fulfils the commitment made in the ministers' 1994 Statement of Intent on Long-Term Acid Rain Management in Canada.

1. Goal of the Strategy

The primary long-term goal of *The Strategy* is to meet the environmental threshold of critical loads for acid deposition across Canada. In order to achieve this goal, *The Strategy* set out a number of steps:

- The federal government would aggressively pursue further SO_2 reduction commitments in key areas of the United States.

- Ontario, Quebec, New Brunswick and Nova Scotia would develop targets and schedules for further SO_2 reductions, along with targets and timelines for the southeastern Canada Sulphur Oxide Management Area (SOMA).

- Governments would take steps to minimize growth in emissions of SO_2 and NO_x in areas where acid deposition is below critical loads and would seek improvements where possible.

- Governments would ensure, to the extent possible, the use of processes, practices, materials, products and energy to avoid or minimize the creation of SO_2 and NO_x emissions from new sources and would apply, where appropriate, similar provisions to existing sources.

- The federal government would undertake an annual review of compliance with international commitments on SO_2 and NO_x emissions.

- The federal government would maintain an active role, in cooperation with the provinces and territories, in acid rain science and monitoring, and in assessing the role of nitrogen in acidification.

- The federal, provincial and territorial governments would review the adequacy of acid rain science and monitoring programs, and would report with recommendations to the Energy and Environment Ministers in 1999.

- Starting in 1999, annual reports on SO_2 and NO_x emissions and forecasts, and progress in implementing *The Strategy*, would be provided to the Energy and Environment Ministers.

2. Targets for the Strategy

Towards A National Acid Rain Strategy described the results of modelling different SO_2 emissions reduction scenarios at 25%, 50% and 75% reductions over and above existing emissions control programs for eastern Canada and the United States. Results showed that a) to meet critical loads in eastern Canada, the area where emissions must be reduced in Canada is the SOMA, and b) critical loads cannot be achieved without substantial parallel reductions in midwestern and northeastern U.S. states.(18)

Under the 25% (Canada and U.S.) reduction scenario, the area receiving harmful levels of acid precipitation would decrease by 34%, leaving aquatic systems within a 526,000 km^2 area in Ontario, Quebec, New Brunswick and Nova Scotia still vulnerable to the damaging effects of acid rain. At a 50% reduction in both countries, the aquatic systems

(18) Federal/Provincial/Territorial Ministers of Energy and Environment, *Supporting Document for The Canada-Wide Acid Rain Strategy for Post-2000*, Halifax, Nova Scotia, October 1998, p. 5.

receiving damaging levels of acid rain would be reduced to within an area of 220,000 km^2, entirely in Ontario and Quebec. With a 75% reduction in emissions in both countries, aquatic systems in virtually all of eastern Canada would be protected from acid rain.

Modelling also predicted substantial health benefits in terms of avoidance of premature deaths, emergency room visits and asthma symptom days. This exercise, however, was controversial and the Task Group did not reach consensus on the methodology or the implications of the results.(19)

Table 1:

Estimated Annual Health Benefits of SO_2 Emissions Reductions

Reduction Scenario	Premature Deaths Avoided	Emergency Room Visits Avoided	Asthma Symptom Days Avoided
25%	200	560	77,300
50%	550	1,530	210,070
75%	830	2,300	316,900

Source: *The Canada-Wide Acid Rain Strategy for Post-2000*.

Annual control costs were also estimated. These are summarized in Table 2.

Table 2:

Estimated Annual Control Costs (millions of dollars)

Province	25% Reduction	50% Reduction	75% Reduction
Ontario	$41-44	$378-450	$970-1,300
Quebec	$14-17	$78-128	$562-750
New Brunswick	$0	$1	$10-17
Nova Scotia	$16-20	$57-61	$130-193
TOTAL	$71-81	$514-641	$1,672-2,260

Source: *The Canada-Wide Acid Rain Strategy for Post-2000*.

(19) *Ibid.*, p. 6.

It is interesting to note that while the health benefits (with the exception of asthma symptom days avoided) are approximately proportionate to the reduction in SO_2 emissions, estimated costs escalate rapidly as the level of emissions reductions increases. At 75%, the estimated cost per tonne of reduced emissions is almost an order of magnitude greater than at 25%.

3. Eastern Canada Targets for Post-2000

Ontario, Quebec, New Brunswick and Nova Scotia have announced new targets for the post-2000 period. These are presented in Table 3.

Table 3:

SO_2 Reduction Targets for Ontario, Quebec, New Brunswick and Nova Scotia

	Eastern Canada Acid Rain Program Cap	**New Targets Under *The Canada-Wide Acid Rain Strategy***	**Timeline for New Targets**
Ontario	885 kt*	442.5 kt (50% reduction) announced in January 2000	2015
Quebec	500 kt	300 kt (40% reduction) announced in November 1997 250 kt (50% reduction) announced in April 2001	2002 2010
New Brunswick	175 kt	122.5 kt (30% reduction) 87.5 kt (50% reduction) announced in March 2001	2005 2010
Nova Scotia	189 kt	142 kt (25% reduction) 94.5 kt (50% reduction) announced December 2001	2005 2010

* kt = kilotonnes

Source: *2000 Annual Progress Report on The Canada-Wide Acid Rain Strategy for Post-2000.*

E. Transportation

Transportation is responsible for only a small portion of Canada's SO_2 emissions (approximately 4%.)[(20)] Federal government actions to limit SO_2 emissions from transportation sources and fuels are directed primarily to improving air quality. Nevertheless, measures limiting the amount of sulphur in fuels will help to reduce acid precipitation. Regulations limiting the amount of sulphur in gasoline to 150 ppm came into effect on 1 July 2002. The limit will be reduced to 30 ppm after 1 January 2005. Regulations will also limit the content of sulphur in on-road diesel to 500 ppm effective 1 January 2003, and to 15 ppm effective 1 June 2006.[(21)]

There are also plans to introduce regulatory limits for sulphur in off-road diesel fuel aligned with U.S. levels and timing, and to develop future standards for sulphur in fuel oils used in stationary facilities.

Limiting the sulphur content of fuels will reduce SO_2 emissions by an estimated 25 kilotonnes annually.[(22)] In terms of overall acid precipitation this is a relatively small reduction, but it should have a more significant effect on air quality, especially in urban areas.

F. The U.S. Acid Rain Program

On 15 November 1990, President George H. Bush signed Amendments to the *Clean Air Act*. Title IV of the Amendments authorized the Environmental Protection Agency (EPA) to establish an Acid Rain Program, the overall goal of which was to reduce SO_2 and NO_x emissions. The program primarily affects electric utilities, which account for 70% of SO_2 emissions and 30% of NO_x emissions in the United States. The legislation proposed cutting annual emissions of SO_2 and NO_x by 10 million tons and 2 million tons (9.1 and 1.8 million tonnes) respectively by the year 2000.

1. Sulphur Dioxide

The U.S. strategy to cut SO_2 emissions is being implemented in two phases. In Phase I, which lasted from 1995 through 1999, 263 of the highest-emitting units at 110 coal-burning electric power plants located in 21 eastern and midwestern states were regulated. In Phase II, which started in 2000, smaller and cleaner plants burning coal, oil or gas

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(20) Government of Canada, *Interim Plan 2001 on Particulate Matter and Ozone*, April 2001, p. 2.

(21) Sulphur in Diesel Fuel Regulations, SOR/2002-254, s. 3.

(22) *The Canada-Wide Acid Rain Strategy for Post-2000*, p. 5.

were regulated. All existing units with an output capacity of 25 or more megawatts are affected, and annual emissions limits on the large coal-burning plants are tightened.

Unlike the traditional "command and control" approach to regulation, a key element of the U.S. SO_2 program was an emissions allowance trading system. This enabled the federal government to set the overall limits for emissions but allowed the marketplace to find the most efficient means of meeting those limits through the economic incentive of tradeable allowances.

The EPA originally estimated that the market-based system would save industry \$1 billion compared to more traditional methods; however, the U.S. General Accounting Office has now estimated that the allowance trading program will save the Acid Rain Program \$2-3 billion annually. The program's success is also reflected in the cost of SO_2 allowances, which were estimated at US\$500-600/ton at the time the Act was passed. By 1996, allowances were trading below US\$100/ton. Since then, prices have risen again but generally remain below US\$200/ton.(23) Reasons for the costs being lower than expected include lower scrubber costs, better removal efficiencies, and increased use of low-sulphur coals.

2. Nitrogen Oxides

Under the *Clean Air Act Amendments*, the United States made a commitment to reduce total annual emissions of NO_x by approximately 2 million tons from 1980 emissions levels by the year 2000 by implementing a control program for electric utility boilers under Title IV and a mobile-source NO_x control program under Title II.(24)

The approach taken to controlling NO_x emissions from electric utilities was different from the SO_2 program. Instead of using tradeable allowances within an overall emissions cap, the Title IV NO_x program required the EPA to establish annual average emission limits for affected units in terms of pounds of NO_x per million British thermal units of fuel consumed (lb/mmBtu) for coal-fired electric utility units. The NO_x program was implemented in two phases, starting in 1996 and 2000.

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(23) U.S. Environmental Protection Agency, Monthly Average Price of Sulfur Dioxide Allowances, http://www.epa.gov/airmarkets/trading/so2market/prices.html.

(24) Agreement between the Government of Canada and the Government of the United States of America on Air Quality.

Under Phase I, NO_x emission limits were implemented for approximately 170 "Group 1" boilers. Group 1 includes two types of boiler: dry-bottom, wall-fired boilers, and tangentially fired boilers. These were the same boilers targeted for Phase 1 SO_2 reductions. Phase 1 NO_x reductions were projected to be approximately 400,000 tons per year.

3. Phase II SO_2 and NO_x Programs

Phase II, which began in the year 2000, set a permanent cap of 8.95 million allowances to utilities.(25) Annual SO_2 emissions limits imposed on the large, higher-emitting plants were tightened, and restrictions were imposed on smaller, cleaner plants fired by coal, oil, and gas. Over 2,000 units were affected, including all existing utility units serving generators with an output capacity of greater than 25 megawatts and all new utility units.

The final rule, which governs the Phase II portion of the NO_x program (which also began in 2000), was promulgated on 19 December 1996. The regulations set lower emission limits for approximately 600 additional Group 1 boilers that become subject to regulations in Phase II. In addition, the regulations establish initial NO_x emission limitations for Group 2 boilers. These include boilers applying cell-burner technology, cyclone boilers, wet-bottom boilers, and other types of coal-fired boilers.(26)

Phase II reductions, which affect virtually all coal-fired utility boilers, are expected to reduce NO_x emissions by a further 1.7 million tons (1.55 million tonnes) (0.77 million tons, Group 1; and 0.89 million tons, Group 2). Mandated total Phase II NO_x reductions for utility boilers amount to 2.1 million tons in 2000 and beyond.(27)

In addition, the EPA finalized a rule in September 1998 that requires 22 midwestern states and the District of Columbia to reduce NO_x emissions by an average of 28%. The rule, known as the NO_x State Implementation Plan (SIP) Call, requires emissions reduction measures to be in place by May 2004. Although the plan is primarily intended to decrease the transport of ozone across state boundaries in the eastern half of the United States, it is expected to reduce NO_x emissions by approximately 1 million tons by the summer of 2007

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(25) Each "allowance" permits a unit to emit one ton of SO_2 during or after a specified year. For each ton of SO_2 emitted in a given year, one allowance is retired, that is, it can no longer be used.

(26) Environmental Protection Agency, Acid Rain Program, Program Overview, http://www.epa.gov/acidrain/overview.html.

(27) U.S. Environmental Protection Agency, Nitrogen Oxides (NO_x) Reduction under Phase II of the Acid Rain Program, http://www.epa.gov/airmarkets/arp/nox/phase2.html.

beyond those achieved in the acid rain and mobile source programs. To help designated states to meet the ozone rule more cost-effectively, the final rule includes a NO_x emissions trading scheme.

In 1997, eight northeastern states filed petitions with the EPA under Section 126 of the CAAA, asking the EPA to find that utilities and other sources significantly contributed to ozone problems in the eight states. In January 2000, the EPA granted four of the petitions, as a result of which almost 400 facilities must reduce their annual NO_x emissions by about 500,000 tons from anticipated 2007 levels.(28)

4. Mobile Source Programs

In addition to regulating utilities, the EPA is implementing more stringent regulations to limit NO_x emissions from passenger cars and trucks, heavy-duty trucks, locomotives, aircraft and non-road vehicles. This includes programs such as the National Low Emission Vehicle (NLEV) Program. The new limits are being phased in at various times. Reductions under the NLEV Program began in May 1999 in the northeastern United States and in May 2001 for the rest of the country.

The U.S. *Clean Air Act* mandated initial tailpipe emissions standards (referred to as "Tier 1" standards) for cars and light trucks, and required the EPA to study whether further reductions in emissions standards for these vehicles were necessary. In February 2000, the EPA finalized new, more stringent "Tier 2" standards for all passenger vehicles, including sport utility vehicles (SUVs), minivans, light trucks up to 8,500 lb., and medium-duty passenger vehicles (8,500-10,000 lb.) that were previously not covered. The Tier 2 standards will be phased in by 2009, starting with the 2004 model year. The new standard is set at 0.07 grams NO_x per mile for all classes of vehicle, irrespective of the type of fuel used.(29),(30) The current Tier 1 standard for passenger vehicles is 0.6 grams NO_x per mile for passenger vehicles and 0.97 grams NO_x per

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(28) *United States-Canada Air Quality Agreement, 2000 Progress Report*, p. 4.

(29) U.S. Environmental Protection Agency, *Proposed "Tier 2" Emission Standards for Vehicles and Gasoline Sulphur Standards for Refineries*, http://www.epa.gov/otaq/consumer/f99010.htm.

(30) This standard refers to the amount of a pollutant a vehicle is allowed to emit after a "full useful life" of 120,000 miles (increased from 100,000 miles under Tier 1) and is applied to the fleet average for a manufacturer. More stringent standards apply to "intermediate useful life," set at 50,000 miles.

mile for light trucks greater than 3,750 lb.(31) (Many SUVs were classed in this latter category to avoid the more stringent standards for passenger vehicles.)

The Tier 2 standards will also limit sulphur in gasoline to a national average of 30 ppm in 2005, with a cap of 80 ppm in 2006.

G. The New England Governors/ Eastern Canadian Premiers Acid Rain Action Plan

In June 1998, the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) announced its *Acid Rain Action Plan*. The plan, which included 22 recommendations for specific actions, was motivated by the recognition that, because of a combination of sensitive ecosystems and high rates of deposition, the northeastern United States and eastern Canada had suffered more damage from acid rain than any other part of the continent.

The Action Plan included:

- a comprehensive and coordinated plan for further reductions of SO_2 and NO_x;
- a research and monitoring agenda targeted at improving science and increasing regional cooperation on sharing research and data; and
- a public education and outreach agenda to educate and mobilize the public toward the goal of protecting the natural environment.

The NEG/ECP Committee on Environment also appointed a steering committee to coordinate and prioritize the implementation of action items.

H. Trends in Emissions

1. Base Year

The year 1980 is used as the base against which commitments and progress are measured. In that year, Canadian emissions of SO_2 totalled some 4.6 million tonnes, with slightly less than 50% coming from the non-ferrous smelting sector. Emissions of SO_2 in the

(31) This is the Tier 1 standard for "full useful life." Tier 1 also set more stringent standards for an "intermediate useful life" of 50,000 miles.

United States amounted to 24 million tonnes,[32] of which thermal power generation contributed about two-thirds. On a per capita basis, Canada produced about twice as much SO_2 as the United States.

In 1980, NO_x emissions were 20 and 1.8 million tonnes in the United States and Canada, respectively.[33] At that time, the United States produced somewhat more NO_x on a per capita basis than Canada.

2. Canada

Reductions of SO_2 emissions in Canada have been substantial. In 1980, SO_2 emissions for the seven eastern provinces totalled 3.818 million tonnes. By 1995, this had been reduced to 1.702 million tonnes, 45% of the 1980 total and 26% below the eastern Canada cap of 2.3 million tonnes.[34] Smelters accounted for approximately 51% of emissions, while fossil-fuelled power plants accounted for about 16%. National emissions were 2.633 million tonnes, 18% under the year 2000 national cap of 3.2 million tonnes.

Reductions of NO_x emissions have been more modest and there appear to be some discrepancies in the numbers reported. According to the 1998 Canada-U.S. Air Quality Agreement Progress Report, NO_x emissions decreased from 2.1 million tonnes in 1990 to 2.0 million tonnes in 1995, largely as a result of industrial process changes, retrofitting of fossil-fuelled power plants, and provincial and federal programs targeting mobile sources.[35] The *2000 Annual Progress Report on The Canada-Wide Acid Rain Strategy for Post-2000* reports, however, that NO_x emissions totalled 2.226 million tonnes in 1995 and 2.186 million tonnes in 1999.

Under the Canada-U.S. Air Quality Agreement, Canada made a commitment to reduce NO_x emissions from stationary sources by 100 kilotonnes below forecast levels by 2000. The 2000 Canada-U.S. Air Quality Agreement Progress Report states that NO_x emissions from power plants, major combustion sources and metal smelting operations have been reduced below the forecast level of 970 kilotonnes by more than 100 kilotonnes, yet figures provided in the *2000 Annual Progress Report on The Canada-Wide Acid Rain Strategy* indicate that NO_x emissions from stationary sources in 1999 totalled 968 kilotonnes.

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(32) *The State of Canada's Environment* (1996), p. 24-11.

(33) *Ibid.*

(34) *2000 Annual Progress Report on The Canada-Wide Acid Rain Strategy for Post-2000*, Environment Canada, Ottawa, 2001, pp. 8-9.

(35) *Canada-United States Air Quality Agreement, 1998 Progress Report*, p. 3.

3. United States

In 1999, the last year of Phase I, SO_2 emissions for the original 263 designated units (electric utility boilers) were 4.35 million tons (3.95 million tonnes), almost 40% below the 7.0-million-ton (6.4-million-tonne) 1999 allowable level and down 50% from 1990 levels.(36) Total emissions for all Title IV sources (Phase I and Phase II) in 1999 were 12.45 million tons (11.32 million tonnes), down 21% from 1990 levels.(37) In 2000, the first year of Phase II of the program, total SO_2 emissions were 11.20 million tons (10.18 million tonnes). This represented a reduction of almost 29% compared to 1990 levels and 35% from 1980 levels. Emissions were, however, approximately 1.2 million tons above the allocation of 9.97 million tons (9.1 million tonnes). This was permitted because sources had been allowed to bank reductions beyond allocated levels during Phase I of the program. By 1999, the allowance bank amounted to 11.6 million tons; this reserve was drawn down by 1.2 million tons in 2000.

The U.S. EPA reports that total NO_x emissions in 2000 from all Title IV affected units were 3 million tons below what they would have been in the absence of the Acid Rain Program, easily surpassing the goal of a 2-million-ton reduction. Total NO_x emissions were 5.11 million tons – 1.55 million tons or 23% lower than 1990 NO_x emissions of 6.66 million tons. This was achieved at the same time that electrical production increased by 30%.

Despite the success in reducing emissions from electric utilities, overall NO_x emissions have so far remained relatively stable. This reflects the fact that although emission rates for both stationary and mobile sources are decreasing as a result of cleaner technology and regulation, gains are being offset by increased demand for electricity and increased vehicle use, and therefore fuel consumption. The U.S. EPA now expects that U.S. NO_x emissions may decline over the next several years as the NO_x SIP Call is implemented, and will then either remain stable or increase slowly as energy demand continues to grow and as new sources are built.(38)

I. Trends in Acid Deposition

In 1983, the Canadian Council of Resource and Environment Ministers established 20 kilograms per hectare per year (kg/ha/yr) of wet sulphate as a "target loading" for

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(36) *Ibid.*, p. 2.

(37) United States Environmental Protection Agency, *Acid Rain Program: Annual Progress Report, 2000*, p. 5.

(38) *Ibid.*, p. 21.

the Canadian SO_2 control strategy.[39] This was a maximum deposition level that would protect moderately sensitive aquatic ecosystems.[40]

In the early 1980s, a continuous area exceeding a deposition rate of 20 kg/ha/yr covered most of eastern North America from the states of Alabama and Georgia in the south to Missouri and Iowa in the west and virtually all of southern Ontario and southern Quebec in the north. A smaller but still substantial area, almost encircling lakes Erie and Ontario, covering most of southern Ontario and extending south of Lake Erie, and covering much of eastern Ohio, northern West Virginia, western Pennsylvania and some of northwestern New York, received deposition rates exceeding 30 kg/ha/yr. By the 1995 to 1998 period, the area of eastern North America exceeding 20 kg/ha/yr had shrunk significantly and areas receiving more than 30 kg/ha/year had virtually disappeared.[41]

Over the same period, however, the rate of wet nitrate deposition has remained largely unchanged. This is not unexpected, as total NO_x emissions in North America have so far decreased very modestly.

A curious observation is that the reduction in the rate of sulphate deposition does not appear to have been matched by a corresponding decline in the acidity of precipitation. The reason for this is not fully understood but seems to be related to reductions in the concentrations of alkaline and alkaline earth ions (potassium, calcium and magnesium) that would normally tend to neutralize acidity.[42]

In Ontario, long-term acid deposition has depleted soils that support maple-dominated hardwood forests of their alkaline ions, such as calcium, which are important nutrients. The loss of nutrients can lead to reduced growth and later to more severe damage, such as defoliation, and eventually to long-term declines in forest productivity.[43]

Moreover, soils that have lost their natural reserves of base ions can no longer buffer downstream lakes and rivers from acidification. Although lake monitoring has shown some improvement in the quality of surface waters – sulphate concentrations in most lakes in Ontario and Quebec have fallen, while they have remained stable in the Atlantic region – acidity levels remain high. The Acidifiying Emissions Task Group of the National Air Issues Coordinating Committee has stated that acidification of lakes poses a serious threat to

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(39) *The State of Canada's Environment* (1996), p. 24-18.

(40) RMCC (1990), pp. 1-3.

(41) *United States-Canada Air Quality Agreement, 2000 Progress Report*, p. 20.

(42) *Canada-United States Air Quality Agreement, 1998 Progress Report*, p. 16.

(43) *Canada-United States Air Quality Agreement, 1998 Progress Report*, p. 19.

biodiversity in eastern Canada and that nitrate deposition may, in time, undermine some of the benefits of controlling SO_2 emissions.(44)

J. What Next?

Despite undeniable progress in combating acid rain, there is still little room for complacency. In 1997, the Acidifiying Emissions Task Group of the National Air Issues Coordinating Committee stated that, even with full implementation of the Canadian and U.S. programs, an area of almost 800,000 km^2, equivalent to the combined land mass of the United Kingdom and France, would continue to receive harmful levels of acid rain (i.e., above the critical load for aquatic systems); as a result, 95,000 lakes in southeastern Canada would remain damaged by acid rain.(45) The Task Group also observed that continued nitrate deposition could undermine the benefits of controlling SO_2 emissions.

The key finding of Task Group, based on computer modelling, was that very large reductions in SO_2 emissions would still be required on both sides of the border to solve eastern Canada's acid rain problem. To reach a level of emissions that would protect virtually all of eastern Canada would require reductions of 75% beyond current caps for Ontario and Quebec and reductions of up to 30 and 50% for New Brunswick and Nova Scotia. It would also require reductions of 75% beyond current requirements under the U.S. *Clean Air Act* for the midwestern and eastern U.S. States. Without major reductions in U.S. emissions, Canada would not be able to protect sensitive areas from acidification.(46)

The post-2000 targets for Ontario, Quebec, New Brunswick and Nova Scotia have now been established at the 50% level in a timeframe that extends to 2015 for full implementation.

In July 2002, the Bush Administration sent new legislation to Congress to implement the President's "Clear Skies" initiative. The plan will cut power plant emissions of SO_2, NO_x and mercury by approximately 70% from current levels. If implemented, the plan will reduce emissions of these pollutants by 35 million tons in the next decade beyond the current provisions under the U.S. *Clean Air Act*.

"Clear Skies" would reduce power plant emissions of:

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(44) Acidifying Emissions Task Group, *Towards a National Acid Rain Strategy*, October 1997, p. iv.

(45) Acidifying Emissions Task Group, *Towards A National Acid Rain Strategy*, Report submitted to the National Air Issues Coordinating Committee, October 1997, p. iii.

(46) *Ibid*., p. v.

- SO_2 by 73% from the current level of 11 million tons, to a cap of 4.5 million tons in 2010 and 3 million tons in 2018;

- NO_x by 67% from the current level of 5 million tons, to a cap of 2.1 million tons in 2008 and 1.7 million tons in 2018;

- mercury by 69% from the current amount of 48 tons, to a cap of 26 tons in 2010 and 15 tons in 2018.(47)

The plan will implement the first-ever U.S. national cap on mercury. If fully implemented, the Administration's plan will go a long way to achieving critical loads over most of eastern North America.

CONCLUSION

Although initially slow to get started, acid rain programs in Canada and the United States have made undeniable progress in reducing SO_2 emissions. *The Canada-Wide Acid Rain Strategy for Post-2000* and Phase II of the U.S Acid Rain Program will build on the successes of the earlier programs to achieve further reductions over the next two decades. If passed, the U.S. "Clear Skies" initiative will bring about even more substantial reductions of acid emissions. Reductions of NO_x have been less substantial and are likely to remain so for the near future, although the "Clear Skies" initiative and new limits on emissions from transportation sources should help.

Although acid rain has been overtaken by ground-level ozone and global climate change in terms of prominent atmospheric environmental issues, it is important to appreciate that acid rain has not yet been eliminated. To do this will require both countries' commitment to follow through on existing programs and possibly, at a later date, to establish more stringent measures.

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(47) U.S. Environmental Protection Agency, News Release, "Clear Skies Legislation Introduced In Congress Proposal Will Improve Air Quality, Prevent Premature Deaths, Illnesses," 29 July 2002, http://www.epa.gov/epahome/headline_072902.htm.