



# THE ACID RAIN PRIMER



**POLLUTION PROBE** is a non-profit charitable organization that works in partnership with all sectors of society to protect health by promoting clean air and clean water. Pollution Probe was established in 1969 following a gathering of 240 students and professors at the University of Toronto campus to discuss a series of disquieting pesticide-related stories that had appeared in the media. Early issues tackled by Pollution Probe included urging the Canadian government to ban DDT for almost all uses and campaigning for the clean-up of the Don River in Toronto. We encouraged curbside recycling in 140 Ontario communities and supported the development of the Blue Box programme. Pollution Probe has published several books, including *Profit from Pollution Prevention*, *The Canadian Green Consumer Guide* (of which more than 225,000 copies were sold across Canada) and *Additive Alert!*

In the 1990s, Pollution Probe focused its programmes on issues related to air pollution, water pollution, climate change and human health, including a major programme to remove human sources of mercury from the environment. Pollution Probe's scope has since expanded to include new concerns, such as the unique risks that environmental contaminants pose to children, the health risks related to exposures within indoor environments, and the development of innovative tools for promoting responsible environmental behaviour.

Since 1993, as part of our ongoing commitment to improving air quality, Pollution Probe has held an annual Clean Air Campaign during the month of June to raise awareness of the inter-relationships among vehicle emissions, smog, climate change and human respiratory problems. The Clean Air Campaign helped the Ontario Ministry of the Environment develop a mandatory vehicle emissions testing programme, called Drive Clean.

Pollution Probe offers innovative and practical solutions to environmental issues pertaining to air and water pollution. In defining environmental problems and advocating practical solutions, we draw upon sound science and technology, mobilize scientists and other experts, and build partnerships with industry, governments and communities.

OCTOBER 2006

Pollution Probe is pleased to publish this second edition of the Acid Rain Primer. The first edition was published in 2000. This edition contains a more in-depth description of the science of acid rain and the policy and regulatory history of this fascinating environmental and health issue.

Great progress has been made by Canada in reducing acidifying emissions. Credit is due to the dedicated individuals, government officials and politicians who worked hard to achieve this progress. Unfortunately, the acid rain story is still unfolding, with new science telling us that greater reductions of sulphur dioxide and nitrogen oxides are required to save lakes and forest ecosystems. Recent policy and regulatory decisions will result in significant reductions in sulphur dioxide emissions by 2015. More must be done, however, to reduce nitrogen oxide emissions, which are also a major source of acidification and ecosystem damage.

Pollution Probe is grateful to the Ontario Ministry of the Environment, Environment Canada and Inco Limited for their financial and technical support to update and expand the Acid Rain Primer. We consulted extensively with a range of expert reviewers who are acknowledged as contributing to this work. It is our hope that the rich and instructive story of acid rain can be turned into an educational resource for both schools and non-formal educational venues so that both the science of acid rain and the story of environmental policy leadership can motivate progress on other pressing environmental issues.

A handwritten signature in black ink on a light yellow background. The signature reads "K. B. Ogilvie" in a cursive, slightly slanted script.

Ken Ogilvie  
Executive Director  
Pollution Probe

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Pollution Probe is solely responsible for the contents of this publication.

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# CHAPTER ONE: INTRODUCTION TO ACID RAIN

**D**uring the late 1970s and early 1980s the issue of acid rain came to the forefront of the political and social agendas in Canada. As a result, numerous domestic and international clean air commitments were put into place aimed at reducing emissions of the pollutants that cause acid rain. Over the past three decades, huge progress has been made in this regard and signs of recovery have been seen in lakes that were previously highly polluted.

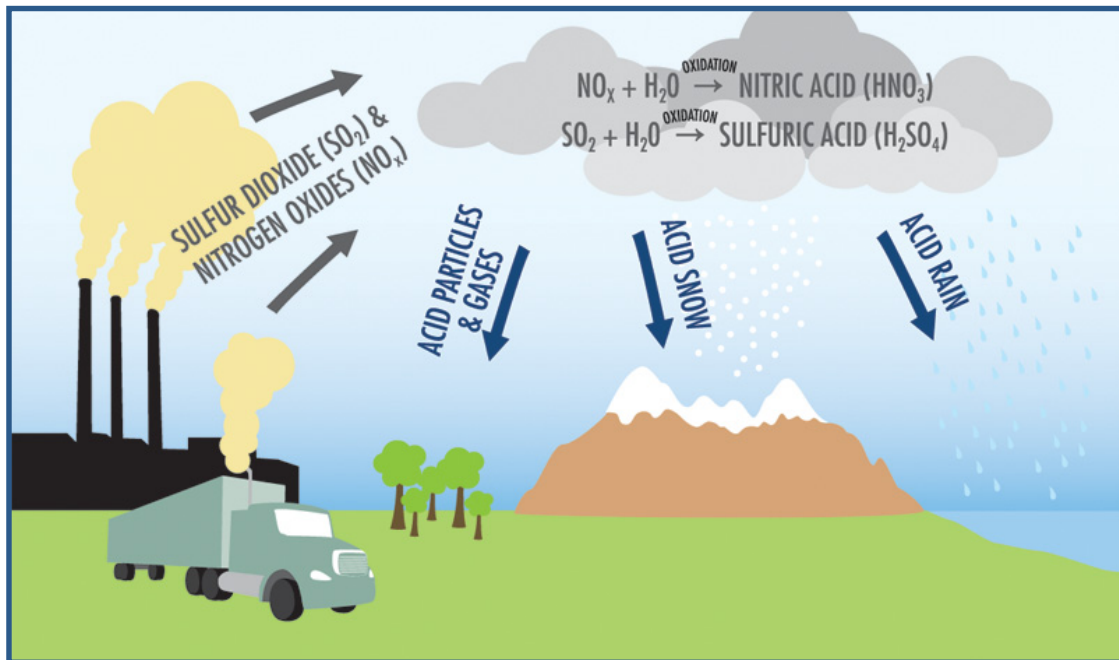
However, there is a general misconception that the issue has been solved entirely. Unfortunately, this is not the case. Acid rain is still a problem in many parts of the world and is a major concern in North America, particularly eastern Canada. In fact, new research indicates that the problem could remain for another 60 years or more.

# What is Acid Rain and How is it Formed?

Rain is formed as part of the hydrologic cycle. In that cycle, water evaporates from the land and sea into the atmosphere. This moisture-rich warm air then cools and condenses to form clouds. Clouds are transported around the world until they release the water back to the Earth as rain, snow or fog. When water droplets form and fall to the Earth they pick up particles and chemicals that float in the air. Even unpolluted air has particles, such as dust

or pollen, as well as naturally occurring gases, such as carbon dioxide (CO<sub>2</sub>). As rain forms and falls it dissolves the CO<sub>2</sub> that is in the atmosphere. The CO<sub>2</sub> reacts with the rain water, forming a very weak solution of carbonic acid. This makes the rain slightly acidic by the time it falls to the Earth. This mildly acidic rain doesn't cause any harm to the environment or people. In fact, it is essential to an ecosystem's health; it dissolves minerals and weathers rocks very

**Figure 1-1: How Acid Rain is Formed**



Source: [www.dec.state.ny.us/website/dar/ood/aciddep.html](http://www.dec.state.ny.us/website/dar/ood/aciddep.html)



slowly, thereby releasing to the environment elements that are essential for the growth of trees and many other organisms. It is only when rain becomes more than mildly acidic that it becomes “acid” rain.

Rain becomes excessively acidic because of pollutants that humans (and some natural processes) have released into the air. Two pollutants in particular are the main cause of acid rain: sulphur dioxide ( $\text{SO}_2$ ) and oxides of nitrogen ( $\text{NO}_x$ ). In the air, and in the presence of water vapour,  $\text{SO}_2$  chemically changes into sulphuric acid and  $\text{NO}_x$  changes into nitric acid. Sunlight can increase the speed of these reactions. As more and more  $\text{SO}_2$  and  $\text{NO}_x$  are emitted into the air, more of these acids are formed. These acids are then dissolved in the water that forms rain. The rain becomes so acidic that it damages the environment when it falls to the Earth.

Acid rain also includes fog, hail, sleet and snow, any of which can be acidic. Moreover, not all acid deposits are associated with precipitation. Acids in the air can take the form of gases and particles that are deposited dry onto the Earth. Dry deposits cause the same environmental damage as do wet deposits. Furthermore, when these dry deposits are washed from surfaces by rainstorms, the acidic runoff water combines with the falling rain, making an even more acidic solution. Therefore, scientists prefer “acid deposition” as a more accurate term than acid rain.

## A SCIENCE-DRIVEN, LONG-TERM PROJECT

The acid rain issue is a good example of the many steps and varied participants involved in successfully resolving a large-scale, international pollution problem. Hundreds of scientists studying the atmosphere, vegetation, surface waters, building materials and economics have worked together to define the ecological nature of acid rain; to design cost and environmentally effective control programs; and to demonstrate the environmental benefits of emission controls. These achievements were made in spite of substantial scientific controversy, frequently generated by industries facing emission controls.

Scientists and NGOs worked hard to explain the causes and effects of acid rain to the public via video documentaries, brochures, lectures and media interviews. The informed public pressed for action by politicians, who, in turn, accepted the recommendations of the scientific community and issued the required control orders. By giving industries specific emission targets, reasonable time frames to reach compliance and the option to choose the appropriate technology, emission controls were achieved at acceptable costs.

Substantial environmental recovery attests to the success of the immense effort. However, getting from the point of defining the problem scientifically and sharing information with the public to instituting emission controls and revisions and documenting the environmental benefits has taken nearly four decades. Even now, there is still a long way to go.

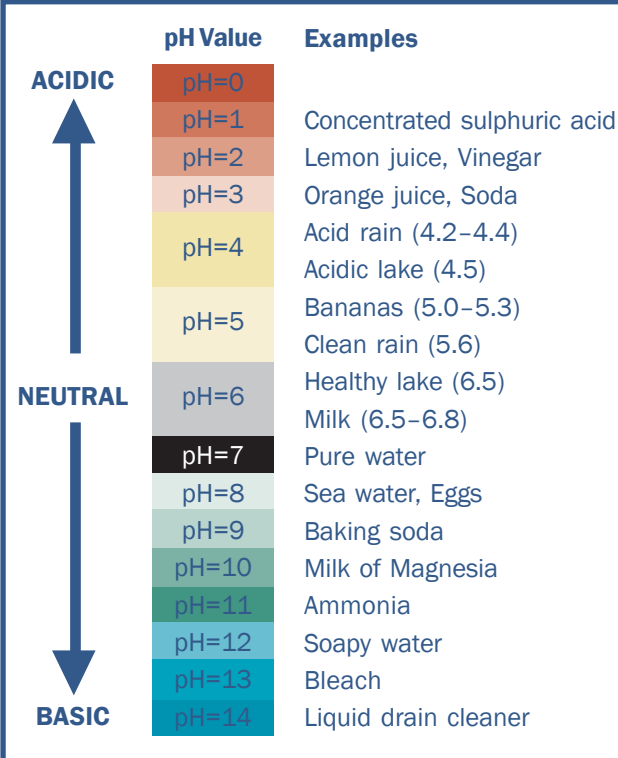
# How is Acid Rain Measured?

Since acids release hydrogen ions, the acid content of a substance is determined by measuring the amount of hydrogen ions. This is expressed as its pH (potential of Hydrogen) level. The pH scale (Figure 1-2) ranges from 0 (extremely acidic) to 14 (extremely alkaline or basic, meaning not at all acidic). A pH level of 7.0 means that the substance is neutral – neither acidic nor alkaline. The lower the pH value of a substance, the more acidic it is.

Small number changes on the pH scale actually mean large changes in acidity. The difference from one level to the next is a ten-fold increase or decrease in hydrogen ion concentration. This is called a logarithmic scale. Since acidity increases the lower we go on the scale, a pH level of 6 is 10 times more acidic than a pH level of 7. A pH level of 5 is 100 times (10x10) more acidic than a pH level of 7.

Clean rain typically has a pH of 5.6 because of the carbonic acid. Rain measuring less than 5.6 on the pH scale is more acidic and is therefore called “acid rain.”

Figure 1-2: The pH Scale



	pH Value	Examples
ACIDIC ↑	pH=0	
	pH=1	Concentrated sulphuric acid
	pH=2	Lemon juice, Vinegar
	pH=3	Orange juice, Soda
	pH=4	Acid rain (4.2–4.4) Acidic lake (4.5)
	pH=5	Bananas (5.0–5.3) Clean rain (5.6)
NEUTRAL	pH=6	Healthy lake (6.5) Milk (6.5–6.8)
	pH=7	Pure water
	pH=8	Sea water, Eggs
	pH=9	Baking soda
	pH=10	Milk of Magnesia
	pH=11	Ammonia
	pH=12	Soapy water
	pH=13	Bleach
BASIC ↓	pH=14	Liquid drain cleaner

Source: Adapted from [www.epa.gov/acidrain/site\\_students/phscale.html](http://www.epa.gov/acidrain/site_students/phscale.html)

# Sources of Acid Rain

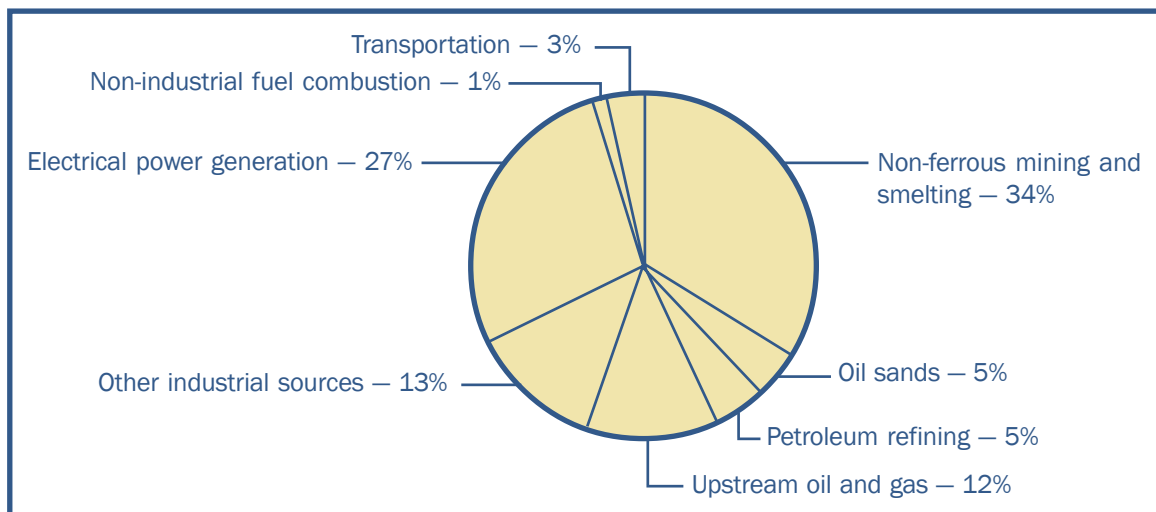
Although there are naturally occurring emissions of  $\text{SO}_2$  (e.g., volcanoes) and  $\text{NO}_x$  (e.g., forest fires, soil and lightning), human activities are responsible for the majority of the emissions put into the air. Globally, half of all  $\text{SO}_2$  and most  $\text{NO}_x$  emissions are produced as a result of burning fossil fuels, such as coal, oil and gas. Fossil fuels are made up of layers of once living organisms that have accumulated over thousands of years. The bodies of these organisms contain chemical elements, such as carbon (C), hydrocarbons (HC), sulphur (S) and nitrogen (N). When we burn fossil fuels, these elements are released into the atmosphere as

waste products. Oxygen, present in the air, combines with the sulphur and nitrogen in the fuel to form many different compounds of sulphur and nitrogen, including sulphates and nitrates, sulphuric and nitric acids, and the two nitrogen compounds that comprise  $\text{NO}_x$  (nitrogen oxide (NO) and nitrogen dioxide ( $\text{NO}_2$ )).

In Canada, the major sources of  $\text{SO}_2$  (Figure 1-3) are smelting metals (taking metal out of raw ore by melting the ore), burning coal for electrical power generation, industrial emissions (e.g., pulp and paper, petroleum and aluminum industry), and oil and gas extraction and

**Figure 1-3: Canadian Sources of  $\text{SO}_2$  (2002 Criteria Air Contaminants Emissions)**

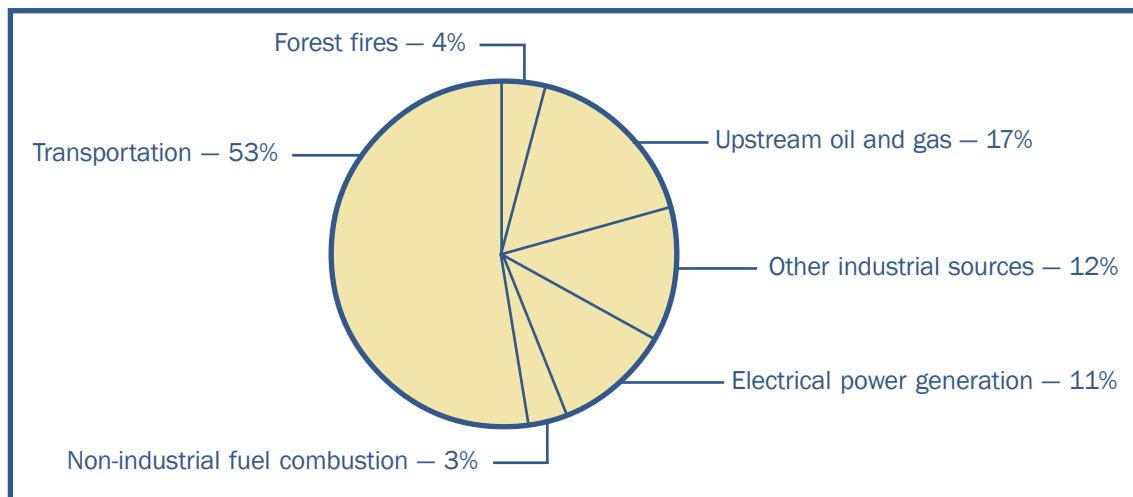
Total: 2.2 million tonnes



Source: [www.ec.gc.ca/pdb/cac/Emissions1990-2015/canada\\_SOx\\_e.cfm](http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/canada_SOx_e.cfm)

**Figure 1-4: Canadian Sources of NO<sub>x</sub> (2002 Criteria Air Contaminants Emissions)**

Total: 2.2 million tonnes



Source: [www.ec.gc.ca/pdb/cac/Emissions1990-2015/canada\\_NOx\\_e.cfm](http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/canada_NOx_e.cfm).

refining. These same sources may also emit NO<sub>x</sub>. In Canada, however, the largest source of NO<sub>x</sub> is the burning of fossil fuels by the transportation sector (Figure 1-4).

In the eastern US, the largest source of SO<sub>2</sub> emissions is coal-burning electric power generation in the Ohio Valley region. In the western states, however, acid rain is primarily a result of NO<sub>x</sub> emitted from car exhaust.

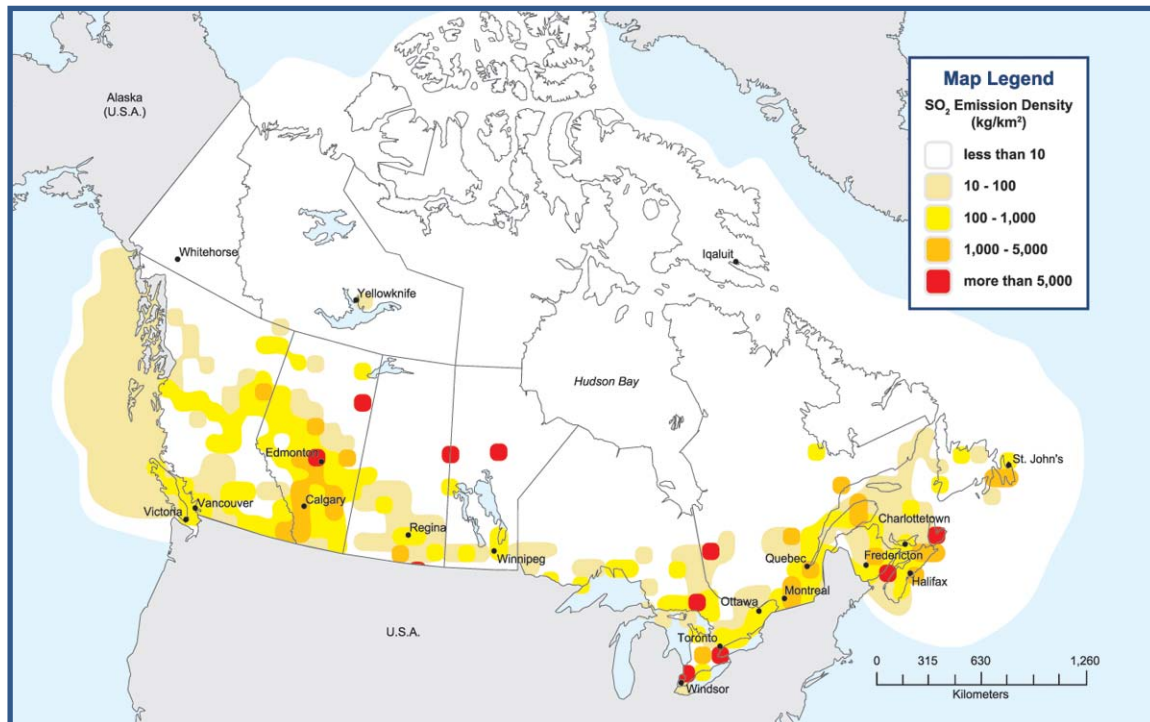
# Geographic Distribution of Acid Rain Sources

The geographic distributions of  $\text{SO}_2$  and  $\text{NO}_x$  emissions are quite similar to one another (i.e., in the most populous regions of the country). In eastern Canada,  $\text{SO}_2$  and  $\text{NO}_x$  emissions are concentrated along the Windsor-Quebec City corridor, with hotspots in other regions that are home to electric power generating stations, non-

ferrous mining and smelting, and industries such as pulp and paper production.

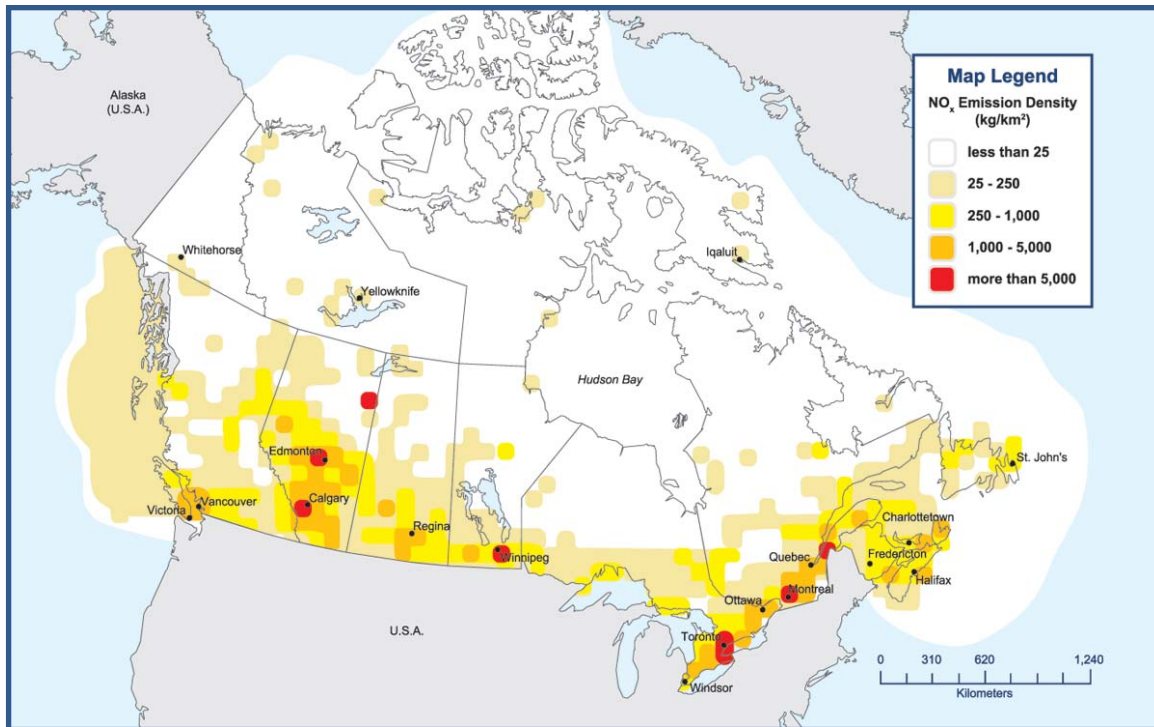
In western Canada, high levels of  $\text{SO}_2$  emissions can be found in Alberta, primarily from upstream oil and gas production, thermal electric power generation and oil sands

**Figure 1-5: Sulphur Dioxide ( $\text{SO}_2$ ) Emissions in Canada for 2000**



Source: Environment Canada. 2004.

**Figure 1-6: Nitrogen Oxide (NO<sub>x</sub>) Emissions in Canada for 2000**



Source: Environment Canada. 2004.

operations. Sources in Saskatchewan and Manitoba include thermal electric power generation and non-ferrous mining and smelting industries, respectively.

Figures 1-5 and 1-6 spatially illustrate the major SO<sub>2</sub> and NO<sub>x</sub> emission sources in Canada. Note that there are high levels of SO<sub>2</sub> and NO<sub>x</sub> all along the western coast – it is thought that emissions from ship traffic play an appreciable role in overall air pollution in that region.

# Transboundary Pollution

Once acid-causing pollutants are released into the atmosphere, they may be transported by prevailing winds a long distance from their point of origin, sometimes up to several thousand kilometres, before falling to the Earth again as acid rain. In eastern North America, weather systems generally move from southwest to northeast. Because eastern Canada lies downwind of major eastern US power generation and transportation sources, an estimated 45–75 per cent of acid rain in this region comes from emission sources in the eastern US.

From 1996–2000, eastern North American sources emitted an average of 7.7 million tonnes of sulphur per year, with 92 per cent of these emissions originating from US sources. Examining where this sulphur was deposited clearly illustrates the enormous impact that US emissions of pollutants have on Canada. Of an estimated total 2.32 million tonnes of sulphur deposited in eastern North America each year, much of it produced in the US, 28 per cent, or 0.64 million tonnes, falls in the eastern provinces of Canada. It should be noted that transboundary air pollution also flows from Canada and across the border to the US.

## “SUPERSTACKS”

The use of tall smokestacks by industry and power plants may appear to lessen pollution locally, but the reality is that they serve to disperse pollution over a larger area, thereby worsening the problem of transboundary pollution. Decades ago, when smokestacks were only a few stories high, pollution usually stayed near the ground and settled on land nearby, causing damage to surrounding plants and animals. To reduce this localized pollution, industry started constructing very tall smokestacks, so-called “superstacks” — some over 300 metres. Opponents argued that the stacks would not remove the pollutants from the air; rather, they would only lift the pollutants into the prevailing winds and increase the time the pollution stayed in the air. They argued that the longer the pollution was in the air, the greater the chances that acid rain would form, thus turning a local pollution problem into a regional one.

In 1972, a 381-metre-high superstack was commissioned at the Inco Ltd. plant in Sudbury, Ontario, and became the world’s tallest stack. Shortly after this, the growing understanding that superstacks were not the answer to pollution brought about an end to their construction in Canada. Unfortunately, from 1970–1979, an estimated 429 stacks greater than 60 metres (200 feet) high were constructed in the US. From 1972 to 1978, the average height of stacks at power plants burning fossil fuels in the US increased from 122 to 183 metres (400 to 600 feet). For example, by 1980, the Tennessee Valley Authority had built several stacks 305 metres (1,000 feet) in height, all designed to improve local air quality.



Source: [http://en.wikipedia.org/wiki/Inco\\_Superstack](http://en.wikipedia.org/wiki/Inco_Superstack)

## CHAPTER TWO: ACID RAIN IN CANADA



**N**ot all areas of Canada are affected equally by acid rain. This is because areas differ in their ability to offset or neutralize acidity. This is largely determined by the type and rate of weathering of the soils and bedrock in the region.

A region's underlying bedrock (the geologic deposit from which a soil is derived by weathering) is the most important factor on how sensitive an area will be to acid rain. Alkaline substances, such as calcium, magnesium and potassium (known as "base cations"), are found in the Earth's bedrock and soil. In essence, when an acid and a base combine, they cancel each other out, producing a neutral substance. When the rain is only mildly acidic, there are enough alkaline substances to balance the acidity and neutralize the effects on the soil and water. However, when the rain is highly acidic,

these acid-buffering substances can become depleted. There may not be enough of them to continually offset the acid effect of the rain. When nature can no longer buffer the effect, the balance is lost. This is what has been slowly happening for the past 100 years in the natural environment due to acid rain.

The areas most affected by acid rain are those with shallow soil cover on slowly weathering bedrock (since beneficial alkaline substances are released as the bedrock is weathered by incoming rain). For example, igneous bedrock (e.g., the granite bedrock of the Canadian Shield that covers almost half of Canada) has a very low alkaline content and, therefore, can't buffer the effects of acid rain. On the other hand, regions that are formed on limestone or sedimentary bedrock (e.g., southern Ontario and parts of western Canada), which contain high levels of calcium, can tolerate fairly high acidic deposits over long periods of time. Limestone is very alkaline, and so it can maintain an acceptable balance despite increased acidity.

Figure 2-1 shows North American areas containing lakes that are sensitive to acid rain. The shaded sensitive area on the map in Canada corresponds with the same area covered by the Canadian Shield.

**Figure 2-1: North American Areas Containing Lakes Sensitive to Acid Precipitation**



Source: Ontario Ministry of the Environment. 1980.

# Problem Areas in Canada

## Eastern Canada

The problem areas of Canada are primarily in the eastern provinces that lie on the Canadian Shield and, therefore, lack natural buffers. Ontario, Quebec, New Brunswick and Nova Scotia are the most significantly damaged by acid rain. Most of the emissions that impact eastern Canada are produced at the large metal smelters in central Ontario and Quebec.

Emissions from the US also affect Canada's eastern region. In the US, the greatest amount of emissions comes from a high density of coal-fired power plants in the eastern states. Weather systems carry these pollutants from the upper midwestern US states across southern Ontario, southern Quebec and into the northeastern US. Pollutants also travel up the northeast corridor of the US into the Atlantic Provinces.



## Western Canada

Major emissions sources that impact western Canada are located in Alberta (from upstream oil and gas production and oil sands), southern Saskatchewan (from electric power generation) and northern Manitoba (from mining and smelting). However, there is currently not enough information to tell us how acid rain is affecting these ecosystems. Historically, western Canada has experienced less industrialization than eastern Canada. This factor, combined with eastwardly moving weather patterns and acid resistant soils, has so far protected much of western Canada from the damage of acid rain.

Not all areas in western Canada are naturally protected. Some lakes and soils rest on granitic bedrock, such as is found in areas of the Canadian Shield, in northeastern Alberta, northern Saskatchewan and Manitoba, parts of western British Columbia, and the Northwest Territories (see Figure 2-1). Ecosystems in these areas are as vulnerable to acid rain as those found in northern Ontario. Acid rain may also become a regional problem downwind of the Alberta oil sands projects, where rapid expansion of bitumen extraction industries is expected to cause large increases in emissions of  $\text{SO}_2$  and  $\text{NO}_x$  in the next 20 years. A big concern to scientists is that if  $\text{SO}_2$  and  $\text{NO}_x$  emissions continue to increase in western Canada, the same sort of acid rain damage that has happened in eastern Canada could occur in the west.

## CHAPTER THREE: THE EFFECTS OF ACID RAIN

**A**s noted earlier, normal rain is mildly acidic to begin with (pH of 5.6). Nature has a way of balancing this acidity in rain by offsetting it with other alkaline minerals, such as calcium, magnesium and potassium, that are found in the Earth's bedrock, air, soil and lakes. Weathering of the bedrock by the carbonic acid found in "clean" rain also releases bicarbonates into the soil and surface waters, which helps to neutralize stronger acid inputs.

Each natural ecosystem has an upper limit in its ability to withstand the effects of acid rain. This threshold level is referred to as the ecosystem's "critical load." The critical load is the highest level of acid rain that an ecosystem can receive over the long-term that won't result in harmful effects to the environment. In other words, if the threshold is

exceeded, then the flora and fauna will suffer damage. Knowing the critical load for a region is very important because it tells us how much  $\text{SO}_2$  and  $\text{NO}_x$  can be put into the environment without causing damage to lakes, fish and plants.

Regions across Canada have different critical loads. Scientists have defined the critical load for aquatic ecosystems as the amount of wet sulphate deposition that protects at least 95 per cent of lakes from acidifying to a pH level of less than 6.0. Research has shown that, in general, lakes with a pH of 6.0 or more support a wide variety of wildlife, such as the loon and the other aquatic organisms on which it depends. Conversely, lakes with a pH

of less than 6.0 have fewer species of fish and other aquatic organisms. Estimates of critical loads in aquatic ecosystems in eastern Canada range from more than 20 kg of sulphate per hectare per year in the more tolerant areas to less than 8 kg per hectare per year in the most sensitive regions. These highly sensitive areas are found mainly in the Canadian Shield areas of central Ontario, eastern Quebec and the Atlantic provinces.

When the environment can no longer neutralize the acid deposition – that is, when the critical load is exceeded – severe damage to an area can occur. Acid rain has negative impacts on lakes and aquatic ecosystems, forests and soils, human-made structures and materials, human health and visibility.



Photo: Marie-Aude Bodin. [www.wateryear2003.org](http://www.wateryear2003.org).

# Lakes and Aquatic Ecosystems

The effects of acid rain can most clearly be seen in aquatic ecosystems. Lakes and the animals that live in and around them are directly affected by higher acidity. Acid rain causes a range of effects that harm or kill individual fish, reduce fish populations, completely eliminate fish species from an affected body of water, and decrease the number of species of plants and animals. It should be noted that, while sulphate deposition is the primary cause of acidified aquatic systems in Canada, there are instances of lakes being acidified naturally by organic acids. This has occurred in all provinces, particularly Nova Scotia, Newfoundland and eastern Quebec. This section of the primer, however, focuses only on the effects of sulphate deposition on lakes and aquatic ecosystems.

Acidic compounds can get into the water in a number of ways. They can fall directly into lakes as dry deposits from the atmosphere in the form of gases and particles, or they can enter the water as wet deposits in the form of rain, snow, sleet, hail, dew or fog.

Acidic chemicals can also enter lakes through runoff from the land. Rain that falls on land comes in contact with rock and soil before entering the lakes. Rain that is acidic releases or “mobilizes” toxic metals from the soil, and then carries them into the water.

In each of these cases, the pH level of the water decreases gradually. There are other times when the pH level of the water can drop quickly, such as during the spring snow melt. As rising temperatures cause the snow to melt, the acids and other chemicals in the snow are released rapidly into the runoff. The melted snow then runs off into streams and rivers and from there into lakes. The large amount of acids and chemicals suddenly entering the water causes a drastic change to the pH of the lakes. This is sometimes referred to as “spring acid shock” or “episodic acidification.” When this happens, the aquatic life has no time to adjust to the sudden change. Whole populations of fish may be killed off as a result. Since many amphibians, fish and insects lay their eggs in the water to hatch during the spring, it is a particularly vulnerable time for them. Sudden pH changes can cause deformities in the young or even kill them.

Acidity in lakes can affect aquatic organisms both directly and indirectly. Airborne  $\text{SO}_2$  dissolved in lake water results in weak solutions of sulphuric acid, making it difficult for fish to take in oxygen to breath. The sulphuric acid also causes metals, such as aluminium, to be released into the lake. This “mobilized” aluminium causes mucus to form on the gills of the fish and prevents them from absorbing oxygen. If the mucus continues to build up, the fish will suffocate. The ability to absorb calcium for the development of bones and shells is reduced in acidic water, leading to

the extinction of some species in affected lakes. The eggs of fish and amphibians may be brittle or weak and fail to hatch. The embryos of amphibians can be too tough for the young to break through at the proper time so they grow too large before becoming free swimming and their spines become deformed.

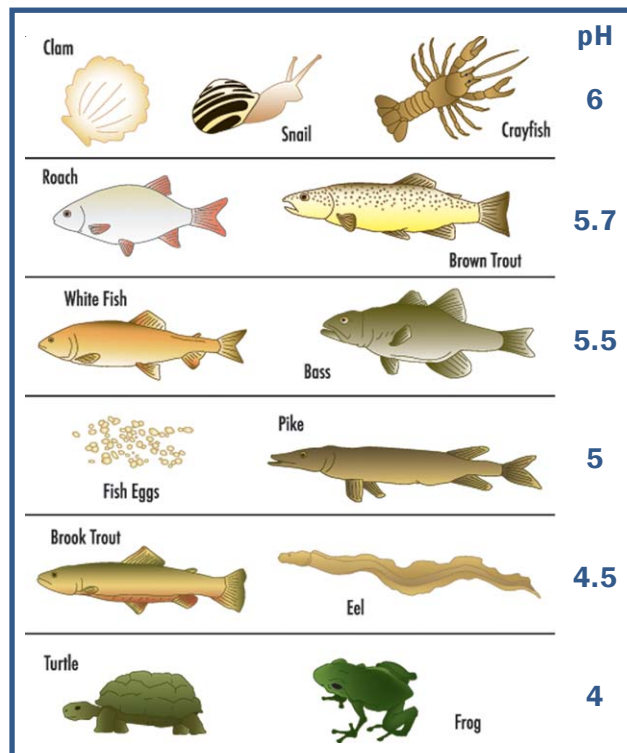
The different species that live in lakes, rivers and wetlands vary in their sensitivity to acid levels. Low concentrations of acidity will affect only those plants and animals that are very sensitive. However, as acidity increases, more and more plants and animals will be harmed. Figure 3-1 and Table 3-1 show the sensitivity of various aquatic organisms to lowered pH levels.

Animals can be indirectly affected by acid rain through a disruption to their food supply. Frogs, for example, can survive in waters that are fairly acidic – as low as pH 4.0. However, some of the food they eat, such as insects, cannot survive at low pH levels. Mayflies, which are a source of food for frogs, cannot tolerate acidity lower than pH 5.5.

Not all plants and animals are negatively affected by acid rain. Some populations actually thrive as acidity increases. As waters become more acidic, certain species of mosses and plankton begin to grow and take over the lakes, making it difficult for other water plants to survive. Plants that grow on the bottom of lakes tend to increase with acidification.

Ironically, acidified lakes look crystal clear, giving the false impression that they are free of

**Figure 3-1: Lowest pH Levels at which Aquatic Organisms Can Survive**



Source: Pollution Probe. 2000.

pollutants. However, this clarity is a result of a lack of plant life, which enables light to reach the bottom of the lake, making the lake look transparent. Acidification also kills many of the bacteria or decomposers that normally break down dead plant and animal material. Hence, decomposition is very slow in acidified lakes. These materials eventually sink to the bottom instead of going through the natural process of decomposition, making the water look clear.



**Table 3-1: Effects of Acid Rain on Water Ecosystems**

As water becomes more acidic and its pH approaches	Effects of acid rain on water ecosystems
6.0	Crustaceans, insects and some plankton species begin to disappear.
5.0	Major changes in the make-up of the plankton community occur. Less desirable species of mosses and plankton may begin to invade. The progressive loss of some fish populations is likely.
Less than 5.0	The water is largely devoid of fish. The bottom is covered with undecayed material. The nearshore areas may be dominated by mosses. Terrestrial animals, dependent on aquatic ecosystems, are affected. Waterfowl, for example, depend on aquatic organisms for nourishment and nutrients. As these food sources are reduced or eliminated, the sustainability quality of habitat declines and the reproductive success of birds is affected.

Source: [www.ec.gc.ca/acidrain/acidwater.html](http://www.ec.gc.ca/acidrain/acidwater.html)

Nova Scotia has been one of the hardest hit provinces in Canada in terms of fish habitat damaged by acid rain. Of the 65 rivers in the province's southern upland region that have Atlantic salmon, 14 of them now have a pH of less than 4.7 and salmon have completely disappeared from these rivers.

### Waterbirds

Acid rain poses a threat to waterbirds that depend for their survival on food sources within aquatic ecosystems. The effect of declining pH

levels on these birds can depend on several factors, including the habitat (wetland, small lake or large lake), feeding habits of the birds and the severity of acidification. Common duck species, such as the Common Goldeneye, Hooded Merganser, Ring-necked Duck and American Black Duck, nest and breed in small water bodies that are threatened by lowered pH levels. Fish-eating species, such as the Common Loon and Common Merganser, prefer large lakes and river systems and are equally at risk from the effects of acid rain on their food source. Other fish-eating species, such as the Kingfisher, Heron and Bittern, as well as river

## ACID RAIN ADAPTATION IN NOVA SCOTIA

Wild Atlantic salmon are an endangered species. It is estimated that, in less than 300 years, the population has decreased by 90 per cent. The Nova Scotia Salmon Association is an organization focused on the preservation of wild Atlantic salmon in rivers in Nova Scotia. In September 2005, they were successful in using a Norwegian technology to add powdered limestone to the West River in Sheet Harbour, just outside Halifax, to regulate its pH level. It is the first river in North America where this technology has been utilized.

The technology, called “lime dosing,” has proven to be a success in Norway to revitalize acid rain damaged rivers in that country. In the past, powdered limestone was spread on acid rain impacted lakes and rivers manually, usually during the winter freeze-up. Lime dosing involves an automated system that draws in river water, combines it with metered doses of powdered limestone, and then releases it further downstream. The system is programmed to provide a consistent pH of 5.5, ideal for salmon habitat.

(or riparian) species, such as the Tree Swallow, are affected as a result of disruptions in the aquatic food chain.

The quality and quantity of many of the important food sources for loons (e.g., fish and crayfish) are reduced in lakes below pH 6.0. For example, two adult loons require up to 180 kilograms of fish during the summer to rear one chick; therefore, their breeding success is lower on acidified lakes where young may starve from lack of food. The Canadian Lakes Loon Survey (CLLS) – a volunteer-based program – monitors the breeding success of loons on over 1,000 lakes annually across Canada. These surveys have shown that, between 1981 and 1997, the proportion of successful pairs that raised at least one large young declined, and that the rate of decline was more extreme on lakes with high acid levels than on well-buffered lakes.

Reproduction rates in loons can be affected by mercury levels in the environment. As levels of acidity in surface waters rise, the rate of conversion of inorganic mercury into toxic methylmercury increases (methylmercury is the most biologically toxic of the chemical species of mercury in the environment). In turn, fish accumulate higher concentrations of methylmercury in lakes with lower pH levels. As a result, fish-eating birds are most at risk from mercury exposure when they consume these fish. Methylmercury is highly toxic to the developing embryos of the loon. Declines in loon reproduction have been associated with elevated mercury levels in fish.

## Forests and Soils

Forests and soils are also affected by acid rain. Trees and other plants need soil nutrients and minerals, such as calcium, magnesium and potassium, to grow. When sulphuric and nitric acids fall onto the Earth in any form of precipitation – rain, snow, mist, sleet or fog – they dissolve these nutrients and minerals and wash them away so they are no longer available for the trees and plants. Without adequate food, trees grow more slowly, to lose their leaves and

needles, become weak and eventually die. Scientists took measurements from one forest in the Muskoka–Haliburton region of Ontario in 1983 and 1999. Their results showed large losses of calcium from the soil over the 17-year time period.

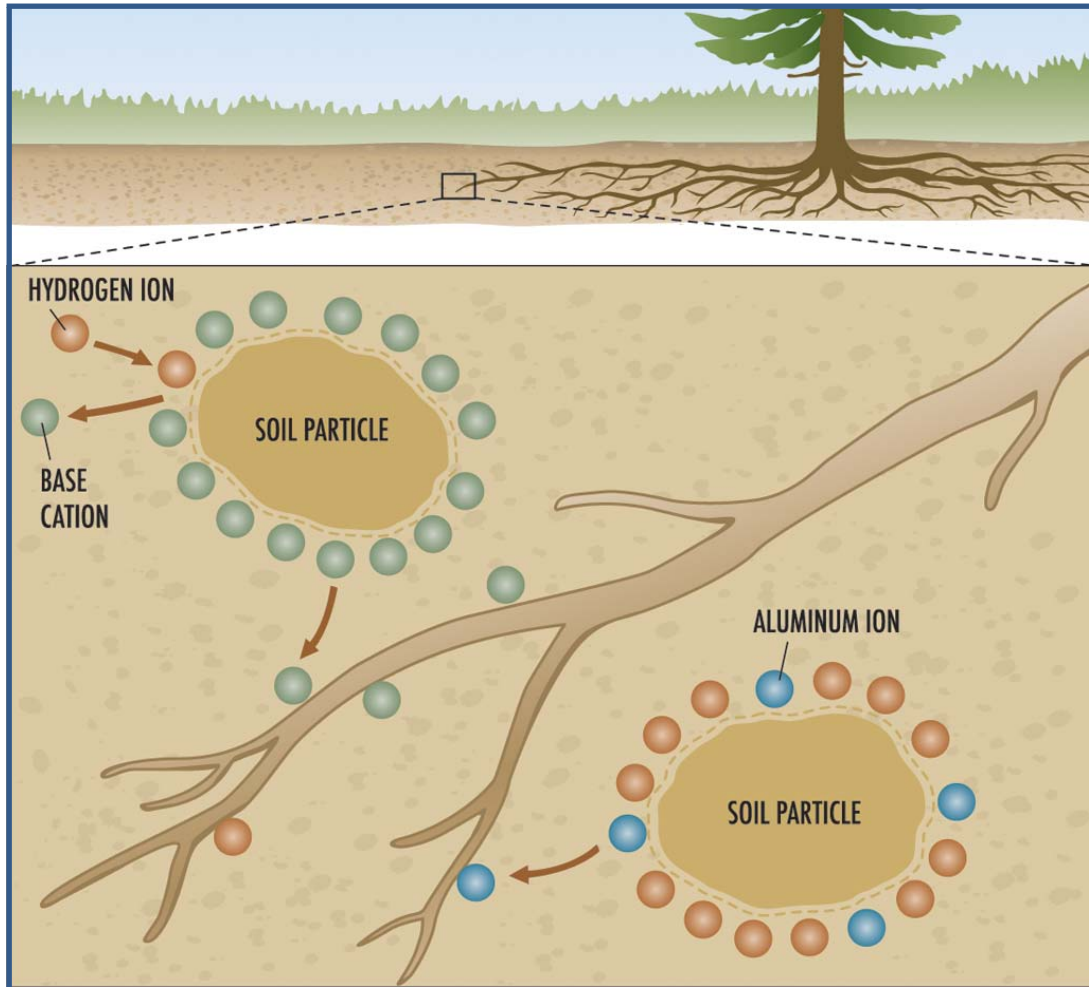
Even when acid deposition levels fall below critical loads, after having been high, soils may not be able to support healthy forests for many

**Figure 3-2: Forest Dieback as a Result of Acid Rain**



Photo: Tom Brydges

**Figure 3-3: Effect of Acid Rain on Soils**



Base cations (green) in soil provide nutrients for plants, which absorb the chemicals through their roots. Typically, base cations attach themselves to particles of humus or clay (left). But when acid rain falls on the soil, hydrogen ions (red) from the rain displace the base cations, which are then washed away. Over time, the hydrogen ions, together with aluminium ions (blue) released from the soil as a result of acid rain, can build up on particles (right). Not only do hydrogen and aluminium displace essential nutrients, they also interfere with the plant's biochemistry; aluminium in particular can be toxic.

Source: Hedin, L. 1996.

years. This is because the weathering process that restores nutrient base cations (depleted from acid deposition) is very slow (see Figure 3-3).

Acid rain also releases metals that are very harmful to trees and plants. Aluminum, for example, once freed up in the soil, can be absorbed by the roots of trees. When this happens, it becomes difficult for the trees to absorb needed nutrients, such as calcium and magnesium (Figure 3-3).

When tree leaves and needles are in frequent contact with acidity, the thin waxy coating that protects them, called the cuticle, can erode. As a result the leaves become damaged and covered in brown spots. Vegetation in high mountain regions, or along some coastal areas, can receive prolonged acid exposure because it is frequently surrounded by acidic clouds and fog. These clouds and fog can be more acidic than rainfall. It is not unusual for acidic fogs to have a pH of less than 5.0. Acid fogs have been known to cause extensive damage to white birch along the Bay of Fundy coast in New Brunswick (see Figure 3-4).

The chemistry of summer marine fogs is a good indicator of regional atmospheric quality and changes due to emission controls. On the west coast of the Bay of Fundy, lower annual concentrations of sulphate and acidity were detected for the period of 1996–1999 as compared to the earlier period of 1987–1989. There was no significant difference detected in nitrate concentration between the two data sampling periods. These observations are

**Figure 3-4: Damage to Birch as a Result of Acidic Fog in the Bay of Fundy, New Brunswick**



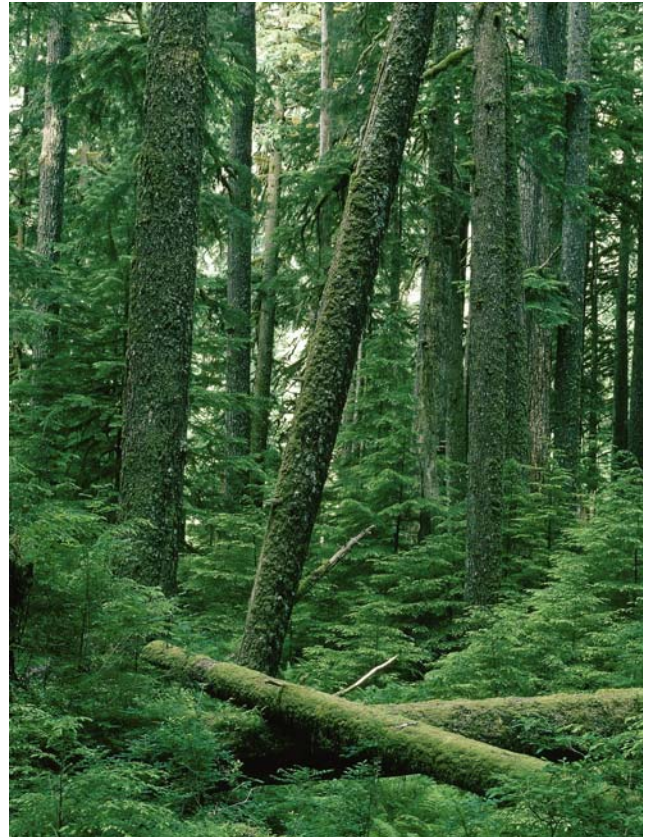
Source: [www.atl.cfs.nrcan.gc.ca/index-e/what-e/science-e/forestconditions-e/arnews-e/birch-e.html](http://www.atl.cfs.nrcan.gc.ca/index-e/what-e/science-e/forestconditions-e/arnews-e/birch-e.html)

consistent with pollution control efforts at the upwind high emission sources.

The foliar browning of coastal birches adjacent to the Bay of Fundy was particularly evident prior to 1987. Limited observations during the period of 1996–1999 indicated a slight reduction in browning symptoms for that period while casual observations since 2005 have suggested some recovery of the birch.

When trees are already weakened from acid rain damage, they are more susceptible to damage from other causes. Trees that are already weak may become more easily injured by periods of drought or very cold weather. Sulphur dioxide in the air may also combine with other chemicals, such as ammonia. The result is ammonium sulphate, which forms on the surface of trees. When the ammonium sulphate goes into the soil, it reacts to form sulphuric acid. These conditions encourage the growth of fungi that can kill the tree. When trees are under such stress, they are vulnerable to diseases and pests that may end up killing them.

Nitrogen compounds, the other component of acid rain, affect trees somewhat differently than sulphuric acid. Nitrogen encourages the growth of plants, and trees are no exception. In the case of acid rain, the weak nitric acid solution may encourage the trees to grow, even though there are not enough other nutrients available in the soil. Nitrogen compounds may also force trees to grow too late into the fall when they should be using their energy to prepare for the cold of winter. The trees then become more vulnerable to frost damage.



As with lakes and aquatic organisms, acid rain not only affects individual trees, but also the whole balance of the forest ecosystem. Acid rain changes the composition of the forest. Trees and plants that are sensitive to acidity are damaged and die off, while those that are more tolerant thrive and take over. This has an impact on the survival of the animals that feed or depend on the various tree species.

# Human-made Structures and Materials

Living organisms are not the only things affected by acid rain. Almost anything that is exposed to acid rain over a long period of time ends up damaged or changed in some way. This includes buildings, sculptures, paint, metal, glass, paper, leather, fabrics and rubber. Most human-made materials will deteriorate over time, even when they come in contact with unpolluted “clean” rain. But, when the rain is acidic, the damage to the materials happens more quickly. For example, there are historic buildings and monuments that have been around for hundreds of years. Over most of that time they have decayed very slowly. However, since acid rain has become a problem, these structures have deteriorated more quickly.

## Stone

Some types of stone are especially vulnerable to acid deposition. Sandstone, limestone and marble contain calcium carbonate so they break down more easily in reaction to acidity than many other materials. This is significant because many of the historic monuments and buildings around the world are made of these materials. When particles that contain  $\text{SO}_2$  react with the calcium carbonate, a material called gypsum is formed. Gypsum dissolves easily in water and is washed off the stone’s surface by rain. The result is that the finely carved details of architecture and sculpture are worn away.

Repairing damage to houses, buildings and monuments costs billions of dollars.

Historic structures all over the world have been affected by  $\text{SO}_2$  pollution (see Figure 3-5). They include the Taj Mahal in India, the Acropolis in Athens, palaces in Venice, and cathedrals in West Germany and the United Kingdom. In Canada, the parliament buildings in Ottawa have suffered severe damage as a result of acid deposition.

**Figure 3-5: The Effects of Twentieth-century Air Pollution**



A sandstone figure on an early-eighteenth-century building in Germany shows the effects of twentieth-century air pollution. The photograph on the left was taken in 1908 and the one on the right in 1969.

Source: Westfälisches Amt für Denkmalpflege, Münster, Germany.

## Metals

Zinc, iron, steel, copper, bronze, silver and gold are all affected by acid rain. Some metal statues have had to be replaced with copies made of acid-resilient plastic materials. The sound coming from affected bells has changed as a result of corrosion by acid rain. Bridges are corroding more quickly as a result of acid rain. Paint on vehicles is also damaged by acidity in the atmosphere. Water pipes and underground storage tanks, electrical devices and industrial equipment are all susceptible to deterioration due to acid pollution.

## Fabrics and Paper

Flags exposed to the elements are also being eaten away by acidity in the atmosphere. Chemicals in tanned leather react with sulphur pollutants and form acids that cause the leather to crack and crumble. In some places, even things that are indoors are damaged by acid pollution. For example, the ventilation systems of some libraries and museums are not designed to keep out acidic particles in the air. The particles get into the buildings and begin to destroy the materials inside, such as ancient books and pieces of art. Paper absorbs acidic pollutants and becomes very brittle. Modern paper is even more fragile than old paper when it comes to acidity. This is because newer paper often contains metals that speed up the deterioration process.

## Glass

Old stain glass windows may also be affected by acidic precipitation. In Europe, it has been estimated that some 100,000 stained glass windows are at risk of damage. Some have already been damaged. In France, for example, the intense blue colour of the stained glass windows in Chartres Cathedral has faded and many of the images have been worn away to such an extent that they are no longer recognizable.





## Human Health

Acid precipitation doesn't hurt people directly. For instance, walking in acid rain, playing in acid snow or swimming in an acid lake is no more dangerous to people than doing these same things in unpolluted rain, snow or water (although breathing in acid fog can irritate the lungs). However, when  $\text{SO}_2$  or  $\text{NO}_x$  combine with other chemicals in the air, even when the levels of  $\text{SO}_2$  and  $\text{NO}_x$  are quite low, it can cause harmful effects to the cardiac and respiratory systems.

In particular,  $\text{SO}_2$  and  $\text{NO}_x$  can react with water vapour and other chemicals in the air to form tiny particles that end up floating in the air. These particles are so small that it is very easy for us to breathe them into our lungs without even noticing. When we breathe in larger particles, such as dust in a room or stirred up dust on a road, the particles are big enough that they make us cough, which prevents the particles from getting into our lungs. But the tiny particles formed from  $\text{SO}_2$

or  $\text{NO}_x$  emissions are so small that they can penetrate deep into the lungs when inhaled and can trigger respiratory problems, such as asthma, dry coughs, headaches, and eye, nose and throat irritations. These pollutants can even cause long-term respiratory damage.

Studies have found a small, but significant, association between rising particle levels in the air and an increase in the number of respiratory symptoms, hospital admissions and people that die prematurely from heart and respiratory problems. Studies have not found a level that is completely safe for people and at which no health effects are seen. Elderly people, people with heart disease, and people with respiratory problems, such as asthma, are at greatest risk from short-term exposure to acid particles.

For more information on the harmful health effects of these pollutants, see Pollution Probe's *Smog Primer* at [www.pollutionprobe.org/Publications/Primers.htm](http://www.pollutionprobe.org/Publications/Primers.htm).

## CO-BENEFITS OF REDUCING SO<sub>2</sub> AND NO<sub>x</sub>

There are linkages between the pollutants that cause acid rain and other environmental problems. Some actions that reduce emissions of SO<sub>2</sub> and NO<sub>x</sub> would not only lessen acid deposition, but could also have additional benefits by reducing other pollutants in the atmosphere, such as particulate matter, ozone, mercury and greenhouse gases. In other words, by controlling one problem, another sometimes equally troubling problem can be controlled.

**Particulate matter** is often composed of nitrate and sulphate particles. By reducing airborne emissions of SO<sub>2</sub> and NO<sub>x</sub>, the nitrate and sulphate components of particulate matter will also decrease, leading to less airborne particulate matter.

**Carbon dioxide** is a major greenhouse gas that, as with SO<sub>2</sub> and NO<sub>x</sub>, is emitted from the burning of fossil fuels. Therefore, reducing the burning of fossil fuels will also reduce the emissions of a major greenhouse gas.

Acid deposition and **ground-level ozone** both have the pollutant NO<sub>x</sub> in their formation. Once again, reducing emissions of NO<sub>x</sub> through an acid rain program will lead to reductions in concentrations of ozone.

The combustion of fossil fuels also releases **mercury** to the atmosphere. Mercury contamination in lakes is enhanced under acidified conditions. In addition, as levels of acidity in surface waters increase, the rate of conversion of mercury into toxic methylmercury, which is harmful to fish and wildlife, also increases. Studies have shown that significant declines in acid deposition and mercury result in declines of mercury levels in fish and fish-consuming wildlife, such as the Common Loon.

# Visibility

In many areas of Canada and the US, magnificent vistas are obscured by an acidic haze (see Figure 3-6). The chemical reactions that sulphur dioxide and oxides of nitrogen undergo in the atmosphere lead to the formation of particles that can reduce the clarity of what we see in the distance. This is a major problem in three areas of Canada – the lower

Fraser Valley in British Columbia where the surrounding mountains trap pollutants; the Windsor-Quebec corridor where pollutants are present from local sources and from the US; and in the southern Arctic and northern prairie provinces where, because of prevailing wind patterns from sources in Europe and Asia, sulphate haze can be a visibility issue.

**Figure 3-6: Glacier National Park, Montana on a Clear Day (left) and a Low-visibility Day (right)**



Source: [www.epa.gov/air/visibility/parks/glacier.html](http://www.epa.gov/air/visibility/parks/glacier.html)

## CHAPTER FOUR: ACID RAIN POLICY IN CANADA

## History of the Acid Rain Issue

The United Nations Conference on the Human Environment, held in Stockholm in June 1972, marked one of the most significant milestones in the acid rain story. It was there that a Swedish acid rain case study, presented by soil scientist Svante Oden, scientifically demonstrated three facts:

1. Acid rain was a large-scale regional phenomenon in much of Europe.
2. Both precipitation and surface waters were becoming more acidic.
3. Long-distance airborne transport of both  $\text{SO}_2$  and  $\text{NO}_x$  was taking place among European nations.

Oden also predicted the ecological consequences of acid rain, including declining fish populations, acidification of soil systems and decreased growth of forest trees.

By 1977, the Canadian media had turned its attention to the issue of acid rain, with the following headlines appearing in newspapers and magazines:

- “Acid in Snow, Rain Eats Away at Houses – And it’s Getting Worse,” *Globe & Mail*, February 28, 1977.
- “Burning in the Rain,” *MacLean’s Magazine*, July 11, 1977.
- “Acid Rain from US Battering Canada,” *Toronto Star*, October 23, 1977.
- “Acid Rain Could be Serious Problem for Haliburton Lakes,” *The Highlands Express*, November 23, 1977.
- “What is Being Done about Mercury and Acid Pollution,” *The Echo and Recorder*, November 30, 1977.

Media and public interest in acid rain increased very slowly during the 1970s, but increased rapidly after a 1978 *Toronto Star* article was printed entitled “Rain of Pollution Killing Our Resort Lakes.” The article revealed that the entire Muskoka-Haliburton resort area was “suffering a devastating fall of acid rain caused by chemical air pollution which is destroying lakes.” The article also stated that “Ontario’s acid rain is already as serious as that in any other area of the world known to be suffering similar damage.”



In 1982, Canadian scientists proposed to reduce the deposition of sulphates by rain and snow to no more than 20 kilograms per hectare per year. This “target load” was intended to protect “all but the most sensitive surface waters.” That same year, the environment ministers of the seven eastern provinces and the federal government accepted this target load and agreed to reduce emissions by 50 per cent. This target was dependent upon comparable action from the US. This began a long road of commitments, both international and domestic, to reduce emissions of sulphur dioxide. Some of these commitments, which are profiled throughout this chapter, continue today.

## The Eastern Canada Acid Rain Program

In 1984, the Canadian federal and provincial environment ministers agreed to launch a “Made in Canada” plan independent of US actions to reduce sulphur emissions in Eastern Canada by 50 per cent. This supported the later commitment by the United Nations Economic Commission for Europe (UN-ECE) to reduce total national emissions by 30 per cent over the next ten years.

In 1985, Canada and the seven eastern provinces (Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland) launched the Eastern Canada Acid Rain Program. This comprehensive program focused on the east where acid rain had traditionally been more of a problem. The goal of the program was to limit wet sulphate deposition to no more than 20 kilograms per hectare per year, from levels as high as 40 kilograms per hectare per year. This target of 20 kilograms was predicted to protect moderately sensitive ecosystems. The provinces agreed to cap SO<sub>2</sub> emissions from all seven provinces at 2.3 million tonnes per year (this number was based upon calculations that determined how many tonnes of SO<sub>2</sub> could be emitted in order to achieve the critical load). They negotiated the cap to be met by 1994.

**Progress Report:** Canada succeeded in reaching its overall target. All of the provinces successfully met their individual SO<sub>2</sub> targets by 1994. Collectively they emitted 1.7 million tonnes of SO<sub>2</sub>, significantly below the 2.3 million tonne cap, and achieved a 56 per cent reduction from 1980 levels.

## First Sulphur Protocol (1985)

In 1979, the Convention on Long-Range Transboundary Air Pollution (LRTAP) was signed under the auspices of the UN-ECE (see the last section of this chapter for a summary of conventions and protocols and how they are used to protect the environment). It was the first international agreement to connect the acid rain problem with the transboundary flow of air pollutants.

The 1979 Convention resulted in the development of a number of protocols that contain concrete measures to control transboundary emissions of air pollutants. The first protocol dealing directly with the reduction of SO<sub>2</sub> was appropriately titled the 1985 First Sulphur Protocol. Twenty-two UN-ECE countries, including Canada, were part of this protocol. The parties committed to reducing the 1980 SO<sub>2</sub> emission levels by at least 30 per cent by the 1993 target year. Canada’s reduction target of SO<sub>2</sub> for the whole country was 3.2 million tonnes by 1993.

**Progress Report:** Joint action under the Convention resulted in a major reduction of transboundary flow of pollution. Both individually, and as a whole, the 21 nations that signed the 1985 Sulphur Protocol reduced sulphur emissions by more than 50 per cent from 1980 levels by 1993. Eleven nations achieved reductions of at least 60 per cent. Canada exceeded its 50 per cent reduction target for Eastern Canada and met its national 30 per cent reduction target in 1992, with national emissions totalling 3.1 million tonnes.

### Canada-US Air Quality Agreement (1991)

Depending on geographic location, between 45 and 75 per cent of the sulphur and nitrogen deposition in eastern Canada comes from sources in the US through transboundary pollution. Therefore, it was essential to have the cooperation of the US in solving this problem.

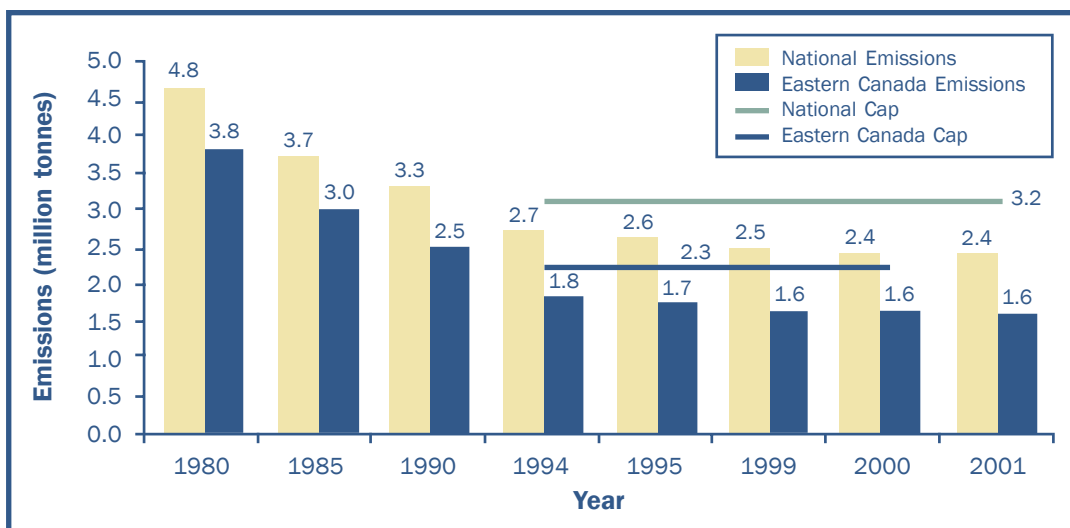
In March 1991, both countries signed the Canada-US Air Quality Agreement. While the agreement provided a framework to address many issues of air pollution, the initial focus was on acid rain. Under this agreement, Canada repeated the commitments it had already made under the first two agreements discussed above. As per the Eastern Canada Acid Rain Program commitments, Canada agreed to extend both the emissions cap of 2.3 million tonnes from 1994 to 1999, and the national emissions cap of 3.2 million tonnes to the year 2000 and beyond.

The US agreed that it would reduce SO<sub>2</sub> emissions from the whole country by 10 million tonnes from 1980 levels by 2000, and would introduce a permanent national emission cap of 8.95 million tonnes of sulphur dioxide per year for electric utilities by 2010.

**Progress Report:** Canada has been successful in reducing domestic SO<sub>2</sub> emissions. In 2003, SO<sub>2</sub> emissions in the seven easternmost provinces were almost 30 per cent below the eastern Canada cap of 2.3 million tonnes per year, even though the cap expired in December 1999. Canada's national SO<sub>2</sub> emissions decreased about 50 per cent from 1980 to 2003, which is 25 per cent below the national cap (see Figure 4-1). The US progress has been slower, but steady, with the highest level of reduction achieved by the electric power sector. By 2004, electric power sources in the US reduced SO<sub>2</sub> emissions by about 34 per cent, a decrease of over five million tonnes from 1990 levels, and more than 40 per cent compared to 1980 levels. It is expected that, by 2010, US SO<sub>2</sub> emissions will be reduced by the targeted 40 per cent.



**Figure 4-1: Canadian SO<sub>2</sub> Emissions from Acid Rain Sources\* (1980–2001)**



\* Total SO<sub>2</sub> emissions

Source: International Joint Commission. 2004.

## Second Sulphur Protocol (1994)

In 1993, the UN-ECE updated the First Sulphur Protocol. The Second Sulphur Protocol (also known as the 1994 Oslo Protocol or the Protocol on Further Reduction of Sulphur Emissions) was adopted in 1994, ratified by Canada in 1997, and came into force in 1998. To date, 26 countries have ratified this protocol.

As a country, Canada was still required to cap its emissions of SO<sub>2</sub> at 3.2 million tonnes by 1993 and beyond. What was new about this protocol was that it took into account the principles of critical loads, which considered cause and effect as criteria for identifying areas for further

managing SO<sub>2</sub> emissions. Therefore, Canada proposed to the UN-ECE that emission reductions be geographically targeted in areas where emissions are or could cause a transboundary acidification problem. This targeted area in Canada is known as the Sulphur Oxide Management Area or SOMA (shown in Figure 4-2) and measures one million square kilometres. This area includes only those source regions found to be contributing to acidification in Canada and the US. Five provinces in Canada are part of the SOMA – Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Island. Canada agreed to cap SO<sub>2</sub> emissions in the SOMA at 1.75 million tonnes a year, starting in the year 2000.

**Figure 4-2: Canada's Sulphur Oxide Management Area (SOMA)**



Source: Federal/Provincial/Territorial Ministers of Energy and Environment. 1998.

In 1994, Canada and the provinces began working with stakeholders to develop a new national strategy to fulfill its obligations under the Second Sulphur Protocol and to protect acid-sensitive areas, human health and visibility.

**Progress Report:** Canada met its Protocol commitment in the SOMA region, with 2001 SO<sub>2</sub> emissions equal to approximately 1.1 million tonnes, or 38 per cent below the cap.

## Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (1999 Gothenburg Protocol)

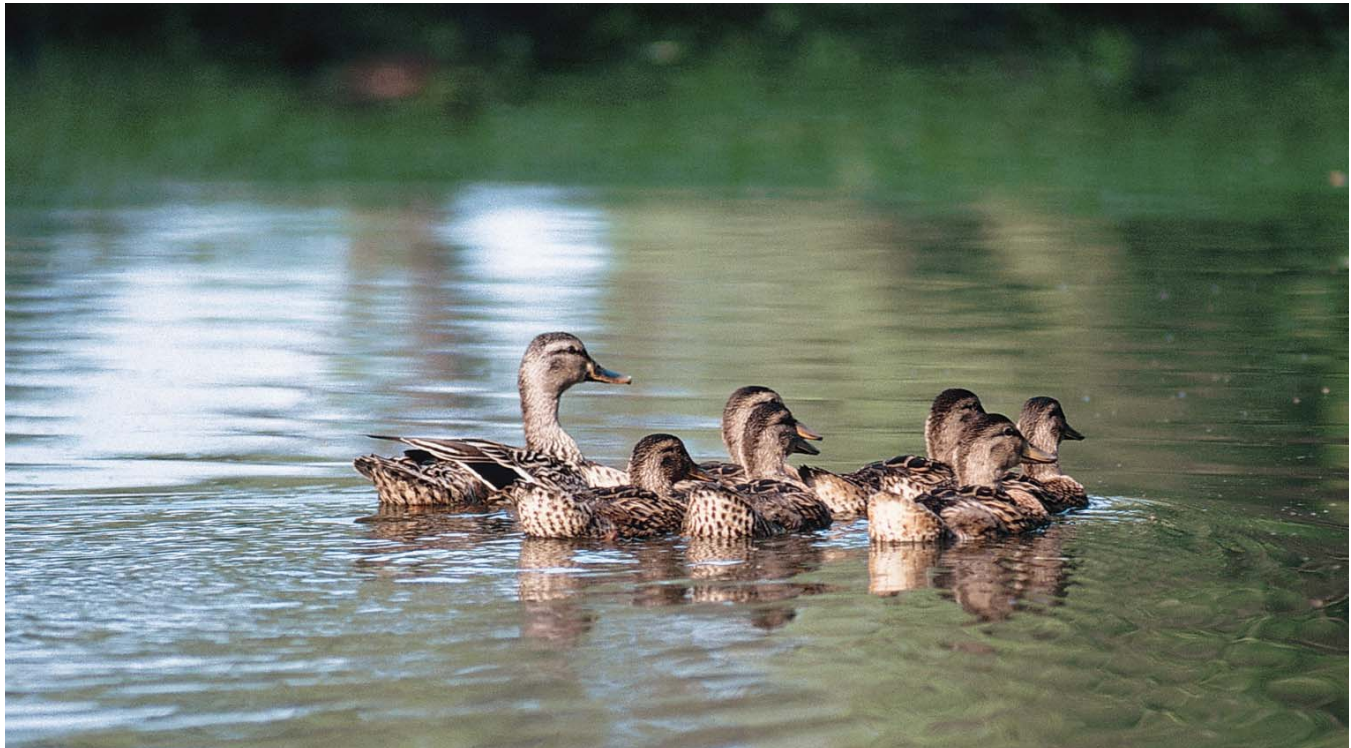
More recently, the Gothenburg Protocol has been negotiated. To date, 31 countries have signed the Protocol, including Canada, and 20 countries have ratified it. This multi-pollutant, multi-effect protocol sets emission reduction targets for SO<sub>2</sub>, NO<sub>x</sub> and other pollutants beyond commitments made in earlier protocols. By mid-2006, Canada had not ratified the Protocol. When, and if, Canada does ratify, the level of emission reductions required will be determined at that time.

## The Canada-wide Acid Rain Strategy for Post-2000

In October 1998, federal, provincial and territorial energy and environment ministers signed the Canada-wide Acid Rain Strategy for Post-2000. The primary long-term goal of the Strategy is to achieve critical loads for acid rain across Canada, while ensuring that areas not currently known to be affected by acid rain continue to be protected (i.e., British Columbia, Alberta, Saskatchewan, Nunavut, Northwest Territories, Manitoba, Newfoundland and Labrador, Prince Edward Island, and northern Ontario and Quebec). One element of the Strategy is to identify new emission reduction caps in eastern Canada. The Strategy builds on

the work of the “Acidifying Emissions Task Group.” The Task Group was composed of representatives from federal and provincial governments, industry, and environmental and health groups. Their report, *Towards a National Acid Rain Strategy*, was released in October 1997. It found that there is one area in Canada where most of the reductions need to be made in order to stay below the critical loads in eastern Canada. That area is the southeast Canada SOMA, excluding PEI (which does not contribute very much to the acid rain problem). In the US, emission reductions in the mid-western and northeastern regions are also very important to achieving critical loads in Canada.

Under the Strategy, Ontario, Quebec, New Brunswick and Nova Scotia have announced additional SO<sub>2</sub> emission cuts beyond established caps set out under the Eastern Canada Acid Rain Program. Ontario announced a target of 50 per cent reduction by 2015; Quebec targeted a reduction of 40 per cent by 2002 and 50 per cent by 2010; New Brunswick targeted a 30 per cent reduction by 2005 and 50 per cent reduction by 2010; and Nova Scotia’s aim was for a 25 per cent reduction by 2005 and up to 50 per cent reduction by 2010. Jurisdictions are now developing plans to achieve these reductions in addition to the other elements of the Strategy.



# Recent Policy and Regulatory Advances in Canada

## Pollution Prevention Plans for Base Metal Smelters, Refineries and Zinc Plants

In April 2006, the federal government issued a notice requiring the preparation and implementation of pollution prevention plans by base metal smelters, refineries and zinc plants across Canada that release to the environment one or more of the substances covered by the plan (which includes sulphur dioxide).

Facilities will be asked to consider in their plans the “application of best available techniques for pollution prevention and control to avoid

or minimize the creation and release of pollutants and waste and to reduce the overall risk to the environment or human health.” They will also be asked to develop and implement a Community Air Quality Protection Program (CAPP) to ensure air quality objectives are met. As well, a Smelter Emissions Reduction Program (SERP) should be developed and implemented to prevent and control emissions, taking into account the annual limit targets for air releases of various substances. Table 4-1 outlines the annual limit targets for sulphur dioxide at certain base metal facilities.

**Table 4-1: Annual Air Release Limit Targets for Sulphur Dioxide**

Company	2008 Targets (tonnes per year)	2015 Targets (tonnes per year)
Teck Cominco – Trail Operation	3,400	3,400
Hudson Bay Mining and Smelting Company Ltd. – Flin Flon	187,000	33,500
Inco – Thompson	187,000	22,800
Inco – Sudbury	175,000	66,000
Falconbridge – Kidd/Timmins	7,525	7,525
Falconbridge – Sudbury	66,000	25,000
Falconbridge – Horne	45,000	43,500
Falconbridge – Brunswick	12,700	11,000
Falconbridge – CEZ	6,900	6,900

## Ontario's Industry Emissions Reduction Plan

In May 2005, the Ontario Ministry of the Environment announced its "Industry Emissions – Nitrogen Oxides and Sulphur Dioxide" regulation. This regulation applies new NO<sub>x</sub> and SO<sub>2</sub> emission limits to thirty facilities in seven industrial sectors starting in 2006 and is designed to make these limits even stricter in the future. This regulation will help ensure that Ontario meets the *Canada-Wide Standards for Particulate Matter and Ozone*.



## INTERNATIONAL CONVENTIONS AND PROTOCOLS TO PROTECT THE ENVIRONMENT

Over the years, international environmental problems have been addressed using a procedure called conventions and protocols. This process involves negotiating a multi-step series of agreements on the nature of an issue, devising solutions (conventions) and implementing control actions (protocols).

The basic elements of conventions and protocols can be found in the Canada/USA Boundary Waters Treaty of 1909, which is one of the oldest international environmental agreements in the world. While the treaty mainly relates to issues and disputes over waters along the Canada-US boundary, one article allows for other issues, such as transboundary air pollution, to be addressed. Although the terminology has changed over the years, the treaty contains all of the elements of the conventions and protocols process that is still applied today in dealing with multi-national pollution problems.

The first step in the international agreement process is the establishment of a written agreement, referred to as the convention. Conventions usually deal with one major issue and are frequently negotiated under the United Nations Environment Programme. There are currently more than 260 international conventions and agreements that deal with environmental issues.

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## INTERNATIONAL CONVENTIONS AND PROTOCOLS TO PROTECT THE ENVIRONMENT (*continued*)

International conventions have a common set of features:

1. The convention is intended to build international consensus that a particular ecological, wildlife or pollution problem exists that requires international control action. The convention is worded in general terms to encourage countries to sign the convention, thereby agreeing that there is a problem. Specific control action requirements are usually not included so that countries can take part in the scientific discussions without agreeing to control measures.
2. The convention establishes a process of regular meetings of high-level representatives of the countries, often called the Conference of the Parties (COP).
3. The convention commits countries to conduct further research and monitor the issue, and frequently there is an agreement to prepare scientific assessments. This allows more information to be gathered, which leads to improved consensus on the issue. Governments are then in a stronger position to establish domestic policies for control actions.
4. The convention commits countries to various reporting requirements, including submission of regular reports on what they have done to enforce the convention.
5. The convention sets up a secretariat to manage the overall process.
6. The conventions include agreements to negotiate protocols for specific control or other management actions needed to resolve the problem. Countries may choose not to sign a protocol, while continuing to participate in the convention activities.

Once conventions and protocols are written, country representatives sign on to indicate the intention of their governments to ratify (or approve and confirm) them and to implement agreed upon actions. Conventions and protocols each contain an agreement on how many countries must ratify the document before it enters into force and becomes a legal obligation for all signatories. Until the required number of countries ratify an agreement to bring it into force, it does not become a binding obligation on the part of any country.

The strength of the protocol process lies in the highly flexible ability to reach agreement on smaller issues within a much larger problem. The small components may be less controversial and more amenable to action. Single issues can be addressed, leaving the more difficult or less important ones until later. Success comes from the cumulative effect of many small actions. For example, the Convention on Long-Range Transboundary Air Pollution has eight protocols, which deal with many specific pollutants, including SO<sub>2</sub>, NO<sub>x</sub>, volatile organic compounds, persistent organic compounds and heavy metals. While these pollutants have many common sources and effects, it would not have been possible to deal with them all at once. The protocol process allows for them to be dealt with on a manageable piecemeal basis.

Source: Adapted from Brydges, T. 2004(b).



CHAPTER FIVE: ARE ECOSYSTEMS RECOVERING  
FROM ACID RAIN?



**W**hile it is encouraging to learn that Canada has so far met all of its domestic and international commitments to reduce  $\text{SO}_2$  and  $\text{NO}_x$  emissions, the question remains as to whether these cuts have translated into sufficient decreases in acid deposition, and, in turn, ecosystem recovery. Changes in acid deposition are tracked from a network of federal and provincial monitoring stations located throughout Canada. The question of whether ecosystems are recovering lies in exhaustive scientific research that has been undertaken in acid-sensitive regions over the past two decades.

# Monitoring Acid Rain

As awareness of the dangers of acid rain grew, scientists began to organize a network of monitoring systems. The Canadian Network for Sampling Precipitation (CANSAP) started to operate in 1977, with 48 monitoring sites across the country. CANSAP evolved into a federal/provincial network, called Canadian Air and Precipitation Monitoring Network (CAPMoN), which began operating in 1983.

In the US, wet deposition monitoring has been carried out since 1978 by the National Atmospheric Deposition Program (NADP), as well as by state and industrial networks.

Monitoring stations, located in acid-sensitive areas of the country, tell us whether there is acid rain in an area, how much there is, and if reductions in emissions have led to reductions in acid rain. The information that is collected from these monitoring stations is stored in the National Atmospheric Chemistry (NAtChem) Data Base and Analysis Facility that is run by Environment Canada. NAtChem is the only place in North America that has data on the acid rain situation in both Canada and the US.

Wet deposition measurements in the networks are made by analyzing precipitation samples gathered from acid rain collectors. The Nova Scotia networks collect samples on a daily basis, while most other networks in Canada collect samples on a weekly basis. In the US, the

National Trends Network (NTN) collects samples on a weekly basis, while the Atmospheric Integrated Research Monitoring Network (AIRMoN) collects samples daily.

**Figure 5-1: An Environment Canada Acid Precipitation Collector**



A rain sensor, sticking up on the right side, activates a motor that moves the cover off the collection vessel on the left. When the rain stops, the cover moves back over the collector.

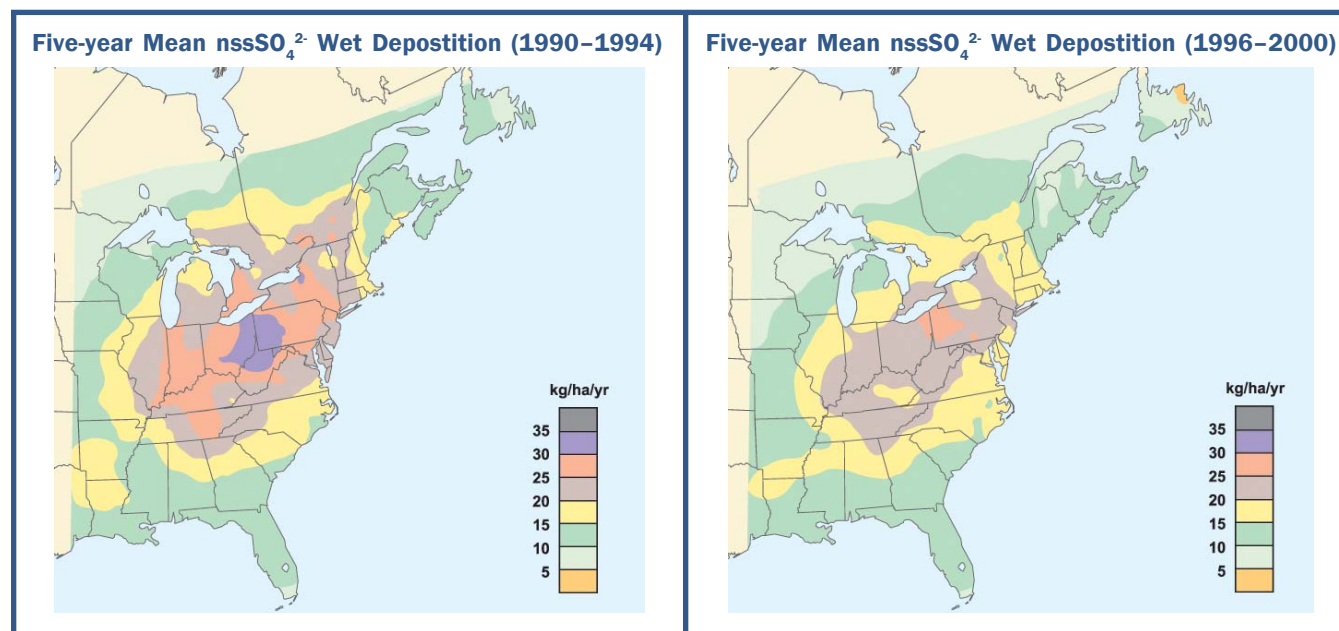
Source: [www.atl.ec.gc.ca/msc/as/as\\_acid.html](http://www.atl.ec.gc.ca/msc/as/as_acid.html)

# Atmospheric Response to Reductions in Acid-causing Emissions

The NAtChem data have shown, as expected, that the reductions of SO<sub>2</sub> emissions over the past two decades have resulted in reductions of sulphates in air and precipitation. According to Environment Canada, although levels of acid deposition have declined in eastern Canada

over the past several decades (see Figure 5-2), approximately 21–75 per cent of eastern Canada (approximately 0.5–1.8 million km<sup>2</sup>) continues to receive levels of acid deposition in excess of critical loads, based on best and worst case scenarios.

**Figure 5-2: Pattern of Sulphate Wet Deposition in Eastern North America from the Early to Late 1990s**

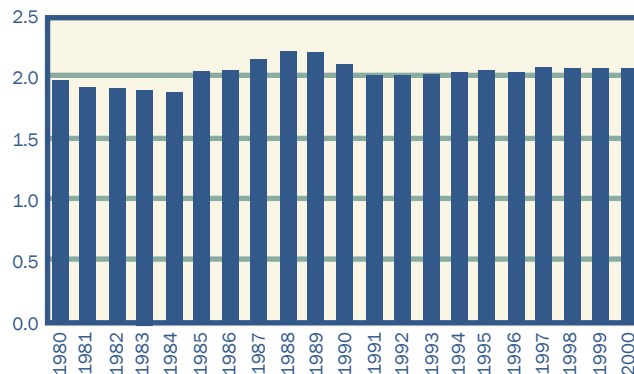


The map on the left shows the five-year mean wet deposition pattern for the period 1990–1994. The map on the right shows the five-year mean pattern for the period 1996–2000. A significant decrease in the area receiving deposition in excess of 20 kg/ha/yr has occurred in response to decreases in SO<sub>2</sub> emissions.

Source: Environment Canada. 2004.

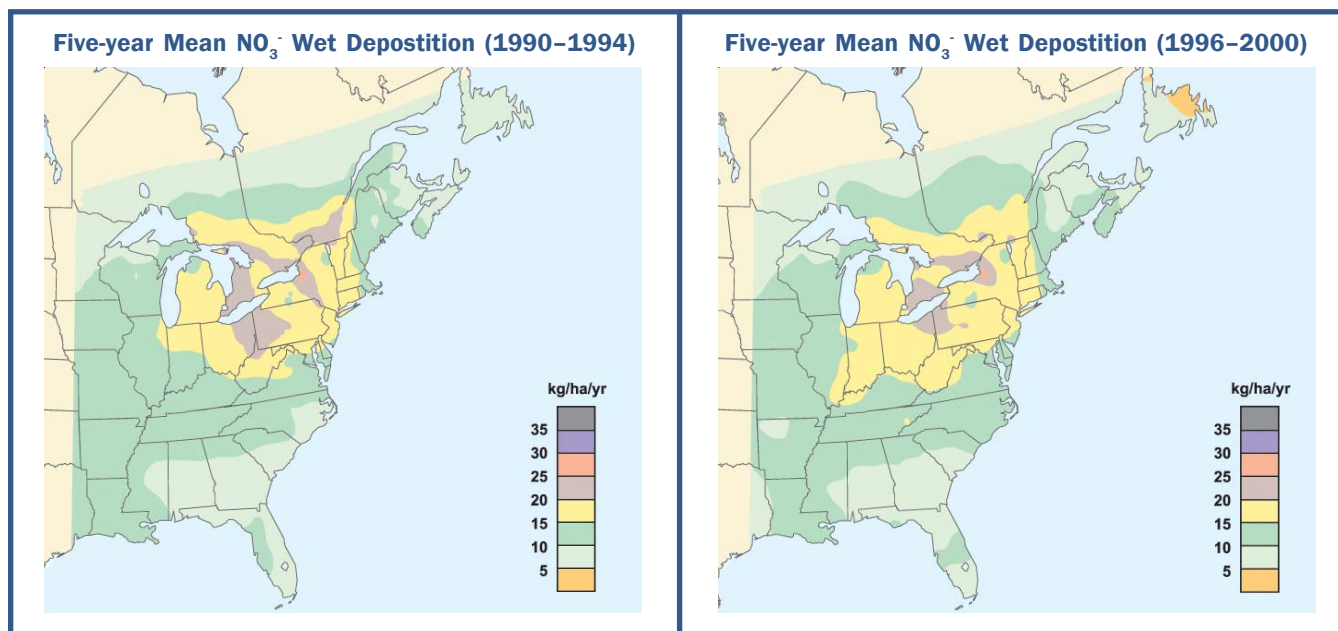
In contrast to SO<sub>2</sub> levels, up to the year 2000, nitrate levels in the atmosphere and in precipitation did not decrease; rather, they increased slightly from the early 1980s (see Figure 5-3). Therefore, the pattern of nitrate wet deposition over eastern North America has showed no major change between 1990–1994 and 1996–2000 (see Figure 5-4). Researchers are concerned that nitrate deposition may eventually weaken some of the benefits achieved from reduced SO<sub>2</sub> emissions.

**Figure 5-3: Nitrogen Oxides Emissions in Canada (million tonnes)**



Source: [www.ec.gc.ca/soer-ree/English/Indicator\\_series/new\\_issues.cfm?issue\\_id=3&tech\\_id=10#bio\\_pic](http://www.ec.gc.ca/soer-ree/English/Indicator_series/new_issues.cfm?issue_id=3&tech_id=10#bio_pic)

**Figure 5-4: Pattern of Nitrate Wet Deposition in Eastern North America from the Early to Late 1990s**



Source: Environment Canada. 2004.

# Ecosystem Recovery

Ecosystem recovery, the reversal of damaged chemical and biological conditions, is a slow process accomplished in several phases. The start of an ecosystem's recovery from acid rain begins when acid emissions in the atmosphere decrease, which in turn leads to reductions of acid deposition and allows for the first phase – chemical recovery – to take place.

**Chemical recovery** is characterized by increasing alkalinity (i.e., increasing pH of the lakes), as well as decreased concentrations of sulphate, nitrate and metals (aluminum, nickel and copper) in soils and surface waters. If adequate, these reductions will eventually lead to healthier pH levels and larger “acid neutralizing capacity” – a process that will likely take several decades.

As chemical conditions improve, the second phase of ecosystem recovery, **biological recovery** (i.e., an increase in individual species of plants and animals, communities and habitats) becomes possible. It is important to note, however, that recovery of an ecosystem should not be defined as returning to a pre-disturbed state. Ecosystems experience natural changes over time, which are influenced by both internal and external (e.g., acid deposition or climate change) factors.

## WHAT IS ACID NEUTRALIZING CAPACITY?

Acid Neutralizing Capacity (ANC) is the ability of lake or stream water to neutralize or “buffer” incoming acidity. ANC is an important measure of the impact of acid deposition, as well as an indicator of chemical recovery from acid deposition. ANC values are reported in micro- or milli-equivalents per litre. Surface waters with ANC values below 0 micro-equivalents per litre ( $\mu\text{eq/L}$ ) are considered chronically acidic. Waters with ANC values ranging from 0–50  $\mu\text{eq/L}$  are considered “susceptible to episodic acidification”. Waters with ANC values greater than 50  $\mu\text{eq/L}$  are less sensitive to acid deposition. The ability of a watershed to neutralize acid and resist the effects of acid deposition depends on many factors, including climate, soil conditions, surface and bedrock geology, and land-use history.

# Are Ecosystems Recovering?

## Aquatic Ecosystems

In natural ecosystems, lakes and rivers are usually the first to provide observable responses to decreases in SO<sub>2</sub> emissions. The first expected response is a decrease in the water's sulphate levels, which ideally would be followed by an increase in pH levels. According to Environment Canada's *2004 Canadian Acid Deposition Science Assessment* report, "At present, full scale chemical and biological recovery has not been observed in any ecosystem, but there are encouraging signs of improvement." According to the report, some Canadian lakes have not recovered as quickly as might be expected. Several factors, described below, have diminished the impact of decreased acid deposition.

## Lake Chemistry

A total of 766 lakes in Ontario, Quebec, Nova Scotia and Newfoundland have been monitored to detect changes. From 1990 to 2001 (latest data reported), the expected trends were predominant as sulphate concentrations decreased in 85 per cent of the lakes, while alkalinity and pH increased in 64 and 74 per cent, respectively. Many of the lakes that recorded unexpected trends were in Nova Scotia and Newfoundland, and scientists noted that these lakes were still in a state of

disequilibrium with respect to the changing atmospheric deposition. It can be expected that, over time, chemical recovery will be observed in more lakes.

Lakes have also recovered in Europe in response to emission reductions under the UN-ECE sulphur protocols. In southern Norway, where the geology is similar to Eastern Canada, significant improvements in the distribution and absence of acid-sensitive invertebrate species have been reported and some formerly acidified watersheds have returned to levels where damage is now negligible.

## Forest Ecosystems

In addition to a healthy looking canopy, a forest ecosystem's health is largely judged by the soil levels of base cations and tree nutrients, such as calcium, magnesium, potassium and sodium. Evidence of lake recovery discussed earlier suggests that soil chemistry in forest ecosystems may also be recovering. This is because the water quality of a lake is largely controlled by the runoff from the surrounding soil; hence, healthier waters are a result of healthier soils.

Scientific evidence on whether forest systems are showing signs of recovery is mixed. According to the *2004 Canadian Acid Deposition Science Assessment*, further

## THE SUDBURY SUCCESS STORY

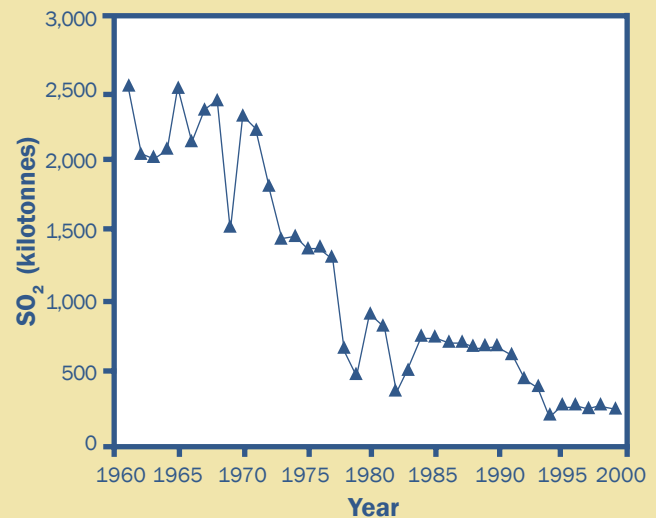
The ore-rich deposits found in the bedrock surrounding Sudbury, Ontario, make the region one of the world's largest suppliers of nickel and copper ore. When nickel-copper ore is smelted, sulphur dioxide is released into the environment. In the 1960s, the Sudbury metal smelters were among the largest sources of sulphur emissions in the world, contributing about four per cent of global sulphur emissions. More than a century of smelting in the region took a heavy toll on the environment. For example, from 1961 to 1971, the pH level in Lumsden Lake in Killarney Park near Sudbury went from 6.8 to 4.4 — an increase in acidity of more than 200 times. Sulphur dioxide emissions acidified an estimated 7,000 lakes in a zone of about 17,000 square kilometres of pristine wilderness. The lakes most severely damaged were those located roughly 20 to 30 kilometres downwind of the smelters. Local plant and water life was devastated by deposits of sulphur dioxide, as well as copper and nickel metal. Dying lakes were surrounded by eroded and exposed bedrock that had a charred and pitted appearance. This so-called “moonscape” appearance can partially be attributed to earlier harvesting of surrounding forests by a dominant logging industry that operated in the region from 1872 to 1927. Clearcutting was also used to facilitate “open roast yards,” now long abandoned.

The documentation of fish losses from Sudbury area lakes was one of the key turning points that alerted North Americans to the dangers of acidic pollutants. In the late 1970s, private, public and commercial interests combined to establish an unprecedented “re-greening” effort. Acid-neutralizing lime was spread over charred soil of the Sudbury region by hand and by aircraft. Seeds of wild grasses and other vegetation were also spread. In twenty years, more than three million trees were planted. Between 1978 and 1993, 3,070 hectares of barren land were limed, fertilized and

seeded. Combined with this re-greening effort was a significant cut in the region's smelter emissions of SO<sub>2</sub> to meet government regulations.

During the 1960s, the region's two major producers of smelter emissions, Inco and Falconbridge, emitted more than 2.5 million tonnes of SO<sub>2</sub> into the atmosphere each year. By 1999, emissions at the smelters were reduced by about 90 per cent from 1960 figures (Figure A). As a result of these efforts, acidity of the lakes in this region dramatically decreased. A remarkable example is Clearwater Lake, located 13 km from Sudbury where the pH level increased from 4.3 in 1973 to 6.2 in 1999.

**Figure A: Total SO<sub>2</sub> Emissions from Sudbury Smelters** (Inco Ltd. and Falconbridge Ltd. combined, 1960–1999)



Source: Kellar, W, J Heneberry and S Dixit. 2003.

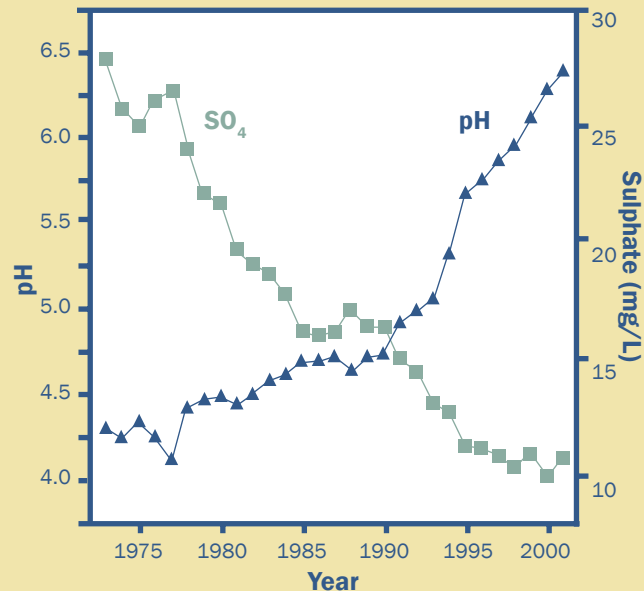
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## THE SUDBURY SUCCESS STORY *(continued)*

Figure B shows the relationship between decreasing acid deposition and increasing pH levels in Clearwater Lake during this time period. Figure C shows the long-term historical trend (1840–2000) of the pH levels in Sudbury’s George Lake, which showed a similar recovery to Clearwater.

In lakes where chemical recovery is occurring, the early stages of biological recovery are evident as well. Some species, such as the acid-sensitive mayfly species, increased from 1998–2002. Clams, crayfish and fish are also present in some lakes again. The populations of water birds, including loons and hooded mergansers that eat fish, are on the rise again. However, the recovery of insects and other animals in acidified lakes

**Figure B: Trends in pH Values at Clearwater Lake**  
(near Sudbury, Ontario)

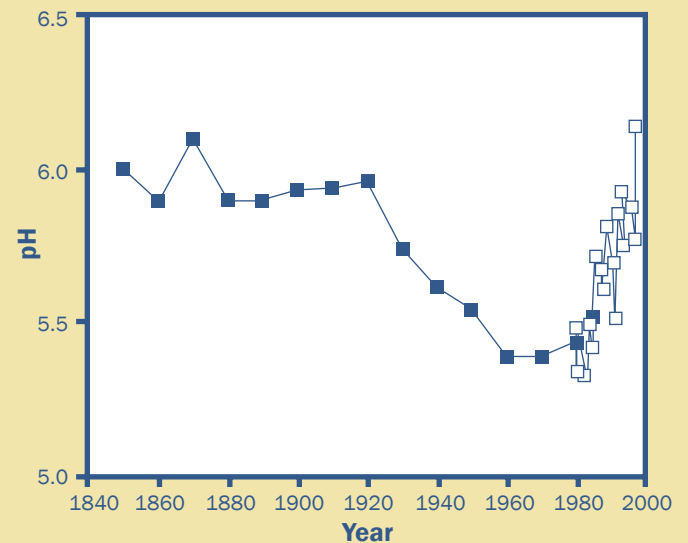


Source: Gunn J and W Keller. 2005.

will require re-colonization and successful repopulation of those sites.

Although some of Sudbury’s lakes remain acidified and ecosystem recovery is still considered in its early stages, scientists believe the rejuvenation of Sudbury’s lakes is one of the most convincing case studies of the natural environment’s response to reduced acid rain.

**Figure C: Trends in pH Values at George Lake**  
(near Sudbury, Ontario)



Mines in the area had been operating for more than 30 years before George Lake started to show signs of acid deposition from the neighbouring smelters. Note: values prior to 1985 (closed squares) were inferred from studying lake fossils (diatoms), which can provide information on past environmental conditions. Measured values are given for the period 1981 to 1998 (open squares).

Source: Brydges, T. 2004(a).



reductions in acid deposition are needed to meet critical loads, which would prevent the continued loss of base cations and restore the health of the forest. Research in Quebec showed that between the 1970s and the 1990s, forest sites located in areas where critical loads were being exceeded had a growth rate 30 per cent lower than forest sites located in areas with no exceedances. On the other hand, the Ontario Hardwood Forest Health Survey, a long-term program established by the Ontario government, determined that, over the time period 1986–1998, 84 per cent of the studied forest plots had improved, 12 per cent had not changed, and only four per cent had become worse. According to this study, “hardwood forest health in the province appears to be quite good; severe decline is limited and very site-specific.” Forest harvesting also plays a role in the depletion of calcium and other base cations by permanently removing quantities stored in the tissues of trees. Recent critical load calculations do not account for harvesting, which means the calculations are overestimated.

## ROAST YARDS (1888–1929)

Back in the early years of Sudbury’s mining history, “roasting” was used as the first step in the processing of the area’s sulfide ore. The sulfide was removed from the copper-nickel ore through burning in an “open roast yard,” which was a mound of ore and wood. The ore was heated to a high enough temperature to oxidize the sulfide, which then burned off as  $\text{SO}_2$ . This burned for two months or more before the residue was loaded onto trains and into a furnace for smelting. It was estimated that more than 3.3 million cubic metres of wood was burned and 10 million tonnes of  $\text{SO}_2$  was released in the 11 years that roast yards were in use. This process not only stripped the surrounding land of its woody vegetation for use as fuel wood, but also killed plants and acidified soils in the immediate vicinity of the roast yards.

## LIMING

Soils with high acid-neutralizing capability usually have an alkaline substance, such as limestone, present. If a soil is lacking base alkaline substances, then buffers can be added to neutralize the acids. This process is called “liming.” Pulverized limestone (calcium carbonate) is most commonly used. When calcium carbonate dissolves, it releases both calcium ions and carbonate ions. The calcium ions are beneficial for aquatic life. The carbonate ions react to neutralize the acid. This reaction also produces some bicarbonate ions, which, in turn, improve the pH and cause any aluminium present in the water or soil to convert to its non-toxic form.

In 1973, a liming pilot study was started in Sudbury, Ontario, as a short-term remedy to counter the damage by acid deposition, until the effects of emission controls became evident. The first lake liming experiments treated four acidic, metal-contaminated lakes. About 40–80 tonnes of calcium oxide were added to each of the test lakes. In all cases, lake water pH immediately returned to a healthy value and the water clarity decreased due to the re-introduction of a more functional food chain.

Past liming efforts have been of particular benefit to the Aurora Trout, which is native to only two lakes (Whitepine and Whirligig) in the entire world, both of which are located in the Sudbury region. The wild population of the trout disappeared in the 1960s due to the acidification of the lakes; however, their re-introduction to the native lakes was attempted in the 1990s following lake liming to improve water pH. This liming proved successful and stabilized Aurora Trout populations.

Limestone can also be added directly to the soil in a watershed. The acid rain is thereby neutralized by the lime as it washes across the forest floor and into nearby lakes and streams. In 1974, a limestone treatment detoxified metal- and acid-contaminated soils in Sudbury. Grasses and trees flourished on the treated land, and insects, birds and small mammal populations increased in the limed areas.

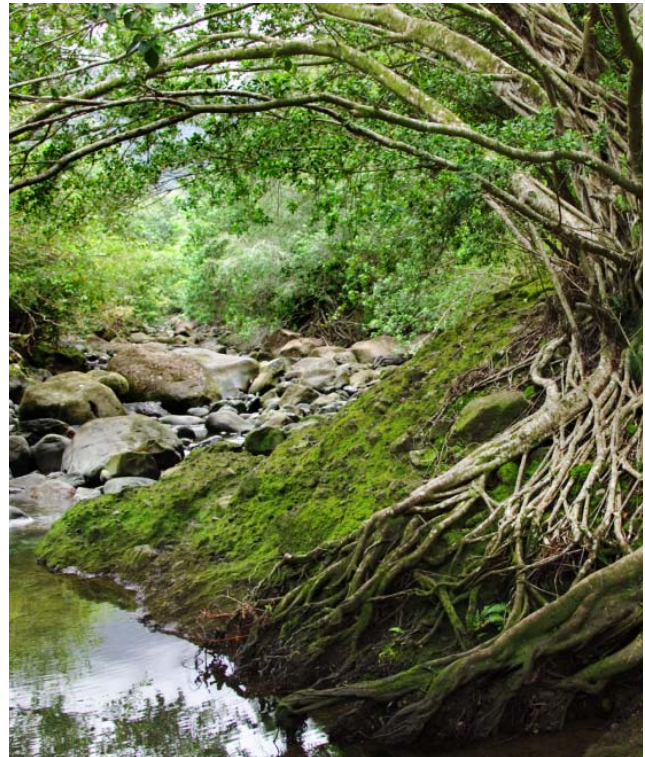
Liming tends to be costly, particularly if used on large lakes, and has to be done repeatedly (as long as acid rain continues) in order to keep the water from returning to its acidic condition. As a result, liming is no longer utilized in Ontario as a means of restoring acidified lakes. Instead, a preventative approach is used, with acid rain regulations limiting emissions at the source before damage can be done.

# Challenges Affecting Ecosystem Recovery

Despite the fact that sulphur emissions have decreased significantly over the past 25 years in North America, research has shown the actual progress of ecosystem recovery to be less dramatic. Although many lakes are responding chemically to the reductions in emissions, research has shown that several somewhat complex factors are delaying or weakening the chemical recovery of some lakes and the biological recovery of others.

**Drought and dry weather:** Wetland soils are typically “anaerobic” (i.e., lacking in oxygen) due to the water-logged state of the soil. Under this condition, sulphate deposited by acid rain is changed to the sulphide form (a chemical process called “reduction”) and stored stably in the soil. However, during dry periods when water levels fall, oxygen penetrates into the previously water-logged soil. This addition of oxygen oxidizes the sulphide to sulphate, which is then released into surface waters. This release of sulphate causes lakes to acidify in the same way as acid rain does. This process, known as “drought-induced acidification,” raises wetland watershed sulphate levels and limits the expected recovery. Global climate models project increased incidences of drought in Canada, under various climate change scenarios. If these projections are correct, drought-induced acidification episodes will become more frequent in wetland watersheds.

**Decrease of base cations in precipitation:** Acid rain trends show that while precipitation sulphate levels have been decreasing, acidity levels of rain haven’t changed as much. This finding may be related to the fact that base cation levels in precipitation, which buffer some of the acidity, have also decreased. Just as there are substances in rock and soil that are alkaline and serve to neutralize acid in the precipitation, these same base cations are also normally present in the air, mostly found in airborne



particles referred to as atmospheric dust. For reasons not yet fully understood, there are now fewer of these neutralizing substances in the air than there were in the past. So even though there is less SO<sub>2</sub> going into the air, the rain is still more acidic than expected because the bases aren't there to help neutralize the rain before it falls to the ground.

**Release of sulphate previously stored in soil:**

Reductions in acid emissions have resulted in a decrease in acid deposition to soils. Unfortunately, due to an equilibrium that exists between sulphate inputs from the atmosphere and releases from the soil, this decrease is expected to cause the release of sulphates previously stored in soils, essentially delaying the effects of SO<sub>2</sub> emission reductions. The amount of sulphate stored in soils and available for release is dependent on the characteristics of the soil and the concentration of sulphate in deposition. Today, the release of sulphate into surface waters exceeds the amount of sulphate received via acid deposition in most eastern Canadian forested watersheds. For example, the stored sulphate in Plastic Lake in the Muskoka-Haliburton region of Ontario is predicted to be released into surface waters for up to several decades. The original source of much of this soil-bound sulphur was past inputs from acid deposition.

**Mineralization and immobilization of sulphur/sulphates:** There are two forms of sulphur in the soil – organic and inorganic. Sulphur can be chemically transformed from one form to another via two processes – mineralization, which is the transformation of organic sulphur into inorganic sulphate (which can then be leached from the soil) and immobilization, which is the transformation of inorganic sulphate into organic sulphur (which stays in the soil). Both of these processes occur at the same time within the soil. Research has shown that mineralization may be a source of sulphate to drainage waters if the amount of sulphate released from mineralization exceeds the rate of sulphate immobilization. The rates at which mineralization and immobilization occur are influenced by several outside factors, including sulphur content of the soil, soil temperature, soil moisture, presence or absence of plants, and soil pH. A number of studies have suggested that mineralization is responsible for additional sulphate releases from watershed soils in Canada.



## CHAPTER SIX: WHAT STILL NEEDS TO BE DONE?

In 1982, when the original targets for reducing SO<sub>2</sub> were set, the effects of acid rain on lakes and other ecosystems were not fully understood. The 20 kilograms per hectare per year target loading that drove the Eastern Canadian Acid Rain Program and influenced the Canada-US Air Quality Accord emission limits was defined as protecting all but the most sensitive lakes. In subsequent years, the science was greatly improved, and the 1997 Canadian Acid Rain Assessment included a detailed set of critical acid deposition loading values that would protect all surface waters. The critical loads were even adjusted for specific areas, with lower values for the most sensitive areas, such as southern Nova Scotia.

## WHAT YOU CAN DO TO HELP REDUCE ACID RAIN

Electric power generation is the second largest source of acid rain pollutants in Canada.

Individuals can make a difference by cutting down on their energy use. There are a number of simple things you can do:

- Turn off lights, computers, radios and other appliances when you are not using them.
- Use energy efficient appliances and light bulbs.
- In the winter, keep your thermostat at 20°C during the daytime (and 17°C when sleeping). In the summer keep it set at 26°C.
- Insulate your home from drafts. Use weather-stripping around doors and windows.

Reducing the use of your vehicle also helps to decrease acid rain pollutants. Try to take the following actions:

- Carpool, take public transit, walk, run or cycle.
- Have your car's emission control system checked regularly and keep the tires properly inflated.
- Consider fuel efficiency when purchasing your next vehicle.

Involve yourself in the issue. Knowing more about the problem and pushing for solutions is another way that individuals can combat acid rain. Read up on the subject of acid rain and become educated about the problem. Write to your government representative about enacting suitable legislation.

Understanding the important contribution that scientific research has made to acid rain policy is important. Let your elected representatives know that good science leads to good policy. Tell them that acid rain scientific research must continue in order for the acid rain problem to be solved.

Governments responded to the need for further reductions in emissions of SO<sub>2</sub>. The provinces of Ontario, Quebec, New Brunswick and Nova Scotia committed to reductions of 50 per cent from their caps in the Eastern Canadian Acid Rain Program. Quebec, New Brunswick and Nova Scotia are committed to a 50 per cent reduction by 2010 and Ontario is committed to this reduction by 2015 (although Ontario has a proposal to consult on advancing its target deadline from 2015 to 2010). When these controls are in place, comparing the expected deposition values with the 1997 Canadian Acid Rain Assessment calculations indicates that the lakes will be fully protected in less sensitive areas, such as around Sudbury, Ontario. In very sensitive areas, such as southern Nova Scotia, 80 to 85 per cent of the lakes will be fully protected while 15 to 20 per cent will improve in quality, but will not likely return to their pristine conditions. It will take until 2020 to 2030 to determine how effective the new emission controls actually are. However, it is thought that by that time, the effects of climate change on a host of variables (such as precipitation, runoff, weathering rates, vegetation growth, organic matter decomposition, etc.) may mask any effects of acid deposition.



## Future Concerns

The latest scientific assessment of the acid rain issues in Canada (*Canadian Acid Deposition Science Assessment 2004*) affirms that full recovery of forests and lakes has not been observed yet. Parts of eastern Canada are still receiving damaging levels of acid rain, and even some areas where emissions have been substantially reduced are not rebounding back to health as quickly as predicted. Meanwhile, there is growing concern that areas of western Canada, previously spared from acid rain, may begin to show damage as pollutant levels rise along with rapid economic development. There are also concerns that rising emissions of  $\text{NO}_x$  and  $\text{SO}_2$  from western Canada could adversely affect ecosystems downwind in eastern Canada. These findings demonstrate that it is important to reduce emissions beyond current targets, while continually improving science and monitoring activities to track and assess ecosystem responses.

Scientists have focused on the following two major concerns with regards to a rationale for further controls on acid emissions – loss of base cations from forested watersheds, and nitrogen deposition and saturation. These two factors are limiting the level of recovery that may be possible in eastern Canada. It is thought that with increased emission reductions beyond current commitments, these two concerns may be overcome.

### Loss of Base Cations from Forested Watersheds

As noted earlier, a healthy supply of base cations (e.g., calcium, magnesium and potassium) is needed in soils to neutralize the effects of acid inputs. The gradual loss of these buffers from an area can occur naturally from weathering and soil processes. However, for the past 50–60 years, human-caused acid deposition has accelerated the loss of base cations, particularly calcium, from soils in already acid-sensitive areas. This loss of base cations decreases the ability of soils to neutralize future acid inputs, making the area more sensitive to acid deposition. There are a few cases where lakes with declining sulphate deposition continue to acidify, in part because the rate of base cation decline exceeds the rate of sulphate decline.

In addition, if acidic rain does not become neutralized in the soil, it will eventually enter nearby lakes and streams, thereby damaging the aquatic life within. Depletion occurs when base cations are displaced from the soil by acid deposition at a rate faster than they can be replenished by the slow breakdown of rocks or the deposition of base cations from the atmosphere (base cations can be emitted to the atmosphere as particles from both natural processes, such as soil erosion or sea salt, and human activities, such as industrial processes and combustion of fuel). This depletion of base



cations hinders the capacity of sensitive soils to recover. Hence, while the acidity of deposition is itself decreasing, the capacity of watersheds to neutralize acid deposition is also declining.

Loss of base cations, particularly calcium, from forested watersheds in eastern Canada and the US is widespread. This problem threatens the long-term sustainability of forests and slows down the recovery of lakes and rivers. In order to achieve recovery of ecosystems, the level of acid deposition would need to decline to the point at which inputs of base cations to soils from weathering of bedrock and deposition equals or exceeds the loss of base cations by acid leaching or other processes (i.e., thus not exceeding the soil critical load).

### Nitrogen Deposition and Saturation

Forests are typically capable of taking up more nitrogen for growth than is available in the soil. Several recent studies suggest, however, that in some areas nitrate deposition is causing nitrogen levels in the soil to go beyond the amount that the forest can absorb (as noted earlier, nitrogen emissions have not decreased substantially nationwide and have actually increased in some areas). When this “nitrogen saturation” occurs, the nitrogen, in the form of nitrates, can leach out and acidify nearby surface waters. An increase in nitrate leaching will also increase the rate of base cation leaching, which counteracts the benefits of reduced  $\text{SO}_2$  emissions.

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## Pollution Probe's Primer Series

Pollution Probe has prepared a series of educational Primers on environmental topics. The goal of the Primers is to inform Canadians about current environmental issues by setting out the scientific basis for concern, potential solutions and the policy tools available. Each Primer focuses on what is being done, and what more can be done, by governments, businesses and individuals on these issues. The Primers are researched and written under the direction of Pollution Probe's Executive Director. Before publication they are reviewed by scientists, non-governmental organizations, industry experts, policy makers and others who have technical expertise on the issue to ensure that they are factually correct and reflect current thinking on the topic.

For more information, or to see the Primers on-line, visit our website at  
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**TORONTO OFFICE:**

625 Church Street  
Suite 402  
Toronto, Ontario  
Canada M4Y 2G1

tel. 416-926-1907  
fax 416-926-1601

**OTTAWA OFFICE:**

63 Sparks Street  
Suite 101  
Ottawa, Ontario  
Canada K1P 5A6

tel. 613-237-8666  
fax 613-237-6111

[www.pollutionprobe.org](http://www.pollutionprobe.org)