# ACID RAIN IN NORTH AMERICA

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# I. INTRODUCTION

Nitrogen oxide and sulphur dioxide when released into the atmosphere, are carried on prevailing winds, combined with water make sulphuric ($H_2S0_4$) and nitric acids ($HNO_3$), returned to the earth, sometimes hundred of miles away in the form of rain, snow, sleet, hail or fog and are known as ACID RAIN. Acid rain not only has a destructive effect on human health and the environment, it is also the source of a host of social and transborder problems, and has been a major issue in Canada and the U.S. for more than a decade.

Approaches to controlling acid rain and to distribute fairly the economic impacts of such control between governments and industries have been proposed and implemented. Past actions seem to have created more problems and issues than solutions. Besides the complexity of the issue, the widespread awareness of acid rain is fairly recent and research in the field is very sporadic and often focused on a specific and local issue. A global study is required to further the understanding of the causes and effects of acid rain, so that workable economic solutions can be developed.

In this paper, acid rain issues, including past and current studies on the subject, and related economic theories are presented. This paper is regarded as a small contribution to the initial process of building a solid base from which to combat the devastating effects of acid rain. The second chapter of this paper provides a background analysis of acid rain in the U.S. and Canada as well as the assimilative capacity of the environment. In the third chapter the emission trends in North America are identified, followed by a discussion of the impact of acid rain on the environment (including water, soil, health, and infrastructural damage) in the fourth chapter.

Major clean air programs in North America are described in the fifth chapter. The last chapter is devoted to an in-depth theoretical analysis of the different methods of controlling acid rain emissions. Different viewpoints on acid rain, and recommendations for further works are found in the conclusions.

# II. BACKGROUND ANALYSIS

Acid rain or acid precipitation is not a new phenomenon, the term "Acid Rain" was actually first used, almost a century ago, by Robert Angus Smith. In his book entitled "Air & Rain: The Beginnings of a Chemical Climatology" (1872), Smith introduced many concepts that we now consider as part of the acid precipitation problem [1].

## 2.1- BACKGROUND

Over a decade before Smith, Evelyn (1861) and Graunt (1862), both English authors, recognized the local problem of industrial emissions on human health and plants, and the transboundary problem of pollutants between England and France. To eliminate the local problem they suggested that industries be built out-of-town and that taller chimneys be used to transport smoke to a further distance [1]. However, these remedial measures further aggravated the transboundary problem.

Although earlier awareness of the impact of industrial emissions on public and environmental health was noted in the 1860's, extensive research and studies were not done until a century later, in the 1960's and 1970's in Scandinavia when the issue of a potentially major environmental problem, acid rain, was raised. Oden, a Swedish author (1967 & 1968), demonstrated that acidity in Scandinavia was attributed largely to sulphur emissions in Great Britain and Central Europe. He hypothesized that the "...probable ecological consequences of acid precipitation would be changes in surface water chemistry, decline of fish populations, leaking of toxic metals from soils into surface waters, decreased forest growth, increased plant diseases, and accelerated damage to materials"[1].

North American awareness of acid precipitation developed in the early 1970's. Both Canada and the United States engaged in a long term program for the chemical analysis of precipitation. The data showed that approximately two-thirds of the total land of North America received acid precipitation [1]. In 1978, Canada and the U.S. established a Bilateral Research Consultation Group on the long range transport of airborne pollutants to facilitate the exchange of scientific information and to coordinate the research between the two countries on the acid rain problem [4]. The evidence provided by this group indicated that the disproportionate flow of air pollutants in the eastern part of North America contained 11 times more nitrogen oxides and two to four times more sulphur oxides transported from the U.S. to Canada than the opposite direction [3]. As a result, Canada and the U.S. government signed a Memorandum of Intent in August 1980. This resolution called for a cooperative agreement on transboundary air pollution and an establishment of the Work Group to investigate the scientific and technical aspects of the acid rain issue in order to preserve and protect mutual air resources [2].

An extensive infrastructure exists in both countries to research and monitor the atmospheric and biological aspects of acid precipitation. The National Atmospheric Deposition program was organized to monitor the chemistry and to research the effects of acid rain. The National Acid Precipitation Assessment program - a ten year program of research on the causes and effects of acid precipitation - was established to develop a firmer scientific basis for environmental and energy policy decisions regarding acid precipitation [1]. The program cost about $18 million in the 1982 fiscal year and $22 million in 1983. Fifty percent of this amount was spent on monitoring and tracking emissions, with 40% devoted to estimating effects. There were also many other projects funded by both private and state authorities. The Canadian federal and provincial governments in 1983 funded approximately 350 projects researching into acidification of the environment, with an annual cost of about $25 million. Three hundred full-time scientists, technicians and supporting staff were employed, of which 40% were engaged in atmospheric processes, 40% in aquatic effects and 20% in terrestrial damages (mainly forestry)[3].

In 1982 Ellis B. Cowling in his study about acid rain focused on "the effects of sulphur dioxide exposure and associated acid precipitation and heavy metal deposits in the vicinity of metal smelting operations, especially those near Sudbury, Ontario"[1]; and he indicated that "declining fish populations were discovered in more and more lakes of southern Ontario and Nova Scotia" [1]. More evidence of environmental effects in the Adirondack Mountains and other regions in the north east were provided by researchers in the United States. It is important to define the effects of acid rain pollution, but for that we must first look at the sources of acid rain.

## 2.2- SOURCES OF ACID RAIN

"Wet deposition" is the process by which acids are deposited in rain or snow and it generally occurs far away from the source. Acid fog is also a form of wet deposition that may occur either near or far from sources. Another process is called "dry deposition" which develops close to emission sources. In this process particles such as fly ash, sulphate and nitrates, and gases such as sulphur dioxides and nitric oxide are deposited on surfaces. Once these dry particles or gases come into contact with water it will become acidic.

Most $SO_2$ emissions come from non-ferrous smelting, fossil fuel fired power generation and vehicular transportation. Natural sources such as volcanoes and mud flats emit sulphur dioxide into the atmosphere, but their contribution is small. Natural sources of $SO_2$ generally consist of seaspray decomposition of organic matter, reduction of sulphate in oxygen-depleted waters and soils, volcanoes, and forest fires [4].

Terrestrial and marine biospheres are the two important sources of sulphur compounds. While human-made sources account for over 90% of the total emissions in eastern North America, natural emissions account for approximately 4% of the total, and the remainder comes from the outside region (see Table 1). The exact magnitude of the natural sources of sulphur dioxide and nitrogen oxide related nitrogen compounds inventories is uncertain due to the difficulties in determining the method for estimating their actual amounts. However, we do know that those sources are not yet playing a significant role in total emissions in North America.

**2.2.1- Canadian and U.S. infrastructures with $SO_2$ emission:**

There are 6 important copper, zinc, and nickel smelting plants, an iron ore sintering plant and three thermal-electric power plants in Canada [5]. In the U.S, there are a total of 15 copper smelters, 5 lead and 5 zinc smelters. The major non-ferrous smelting capacity is located in the western U.S with the largest concentration in the Arizona-New Mexico region. In Canada, 59% of sulphur dioxide emissions come from copper and nickel smelters which are located in Manitoba, Ontario and Quebec and 16% come from electrical utilities. The reverse situation holds true for the U.S. where thermal power generation is the main source for $SO_2$ emissions. Electrical utilities account for 74% of $SO_2$ emissions. It should be noted, however, that smelting is a far less significant source of $SO_2$ since smelters account for only 1% of the total emissions (see Table 2) [6]. In 1990, annual $SO_2$ emissions in Canada were estimated at 3.7 million tonnes. That year the U.S had 21.2 million tonnes and on a per-capita basis, Canada produced about twice as much $SO_2$ as the U.S.[7]. Three companies - Inco, Falconbrige and Noranda mines - are the largest sources of sulphur dioxides. Lesser amounts are emitted at other smelter operations including Hudson Bay mining and the smelting plant at Flin Flon, Manitoba and the Algoma Steel sintering plant in Wawa, Ontario.

The United States relies heavily on high sulphur coal for energy generation, with many of these power plants located mainly in midwestern states - Virginia, Pennsylvania, Kentucky, Indiana and Ohio. Therefore, approximately 80% of total emissions come from provinces east of Manitoba-Saskatchewan border and from the 31 states east of the Mississippi river. Thus the $SO_2$ emissions indicate a similar regional pattern for both countries.

**2.2.2- Canadian and U.S. infrastructures with $NO_X$ emissions:**

$NO_X$ is considered to be the sum of two individual gases, nitric oxide (NO) and nitrogen dioxide ($NO_2$). $NO_2$ forms only 5% to 10% of the volume of total $NO_X$ from combustion sources. It is, however, formed in the atmosphere by a reaction between ozone ($O_3$) and nitric oxide [15]. The main source of $NO_X$ emissions are vehicular transportation. $NO_X$ emissions account for approximately one-third of the air precipitation in North America. In eastern Canada mobile sources, which account for two-thirds (69%) of emissions, play a major role in nitrogen oxide; another one-third (31%) comes from power plants and other sources. Therefore, emissions standards for motor vehicles are a vital part in controlling the $NO_X$ emission problem. In the U.S., utilities account for one-third of nitrogen oxide and mobile sources account for about half (44%) of all $NO_X$ emissions (see Table 2). In 1990 the emissions of nitrogen oxide were estimated at 1.9 and 19.6 million tonnes in Canada and in the United States, respectively; therefore, on a per-capita basis, the U.S. produced more $NO_X$ than Canada [7].

Because of the prevailing winds within and between the two countries, the $NO_X$ and $SO_2$

produced in Canada and the U.S. created the transboundary problem. However, due to the combination of the variability of winds and the multiplicity of sources, there exists difficulties in estimating the total transboundary movements of pollutants. The transboundary flow of sulphur dioxide between the two countries has been estimated in Table 1A:[8]

**TABLE 1A. Sulphur dioxide emissions in the U.S. and Canada**

| | 1970 | 1980 | 1986 | 1995 |
|---|---|---|---|---|
| United States to Canada | 5.1 | 3.8 | 3.2 | 3.5-4.2 |
| Canada to the U.S. | 2.1 | 1.5 | 1.0 | 0.7* |

Source: Environment Canada, Acid Rain - The Fact, 1988.
* based on forecasts in millions of tonnes

The prevailing winds in North America generally blow from west to east but this also varies according to season. Once the sulphur dioxide is released from the coal-fired plants of the Ohio Valley, the air pollutants will cool down and condense to acid rain once they have reached the Appalachian and Adirondack mountains. Towards the northeast more rain and acid fall as this air mass joins the cooler northern air over Ontario, Quebec and the Atlantic coast. Loaded with dioxide emissions from Ontario and Quebec, the air pollutants will travel south and east into the U.S. which, combined with warmer air condense into rain, and therefore, acid rain [9]. More than half of the acid precipitation falling in Canada is believed to originate from the U.S.; and Canada is responsible for approximately 15% to 25% of the acidity in the eastern U.S.[8]. Table 3 shows that two-thirds of North America's shaded area are vulnerable to acid precipitation and this fact clearly demonstrates to us why both countries must put more time and effort to combat acid rain problems.

The impact of acidity on the environment may vary depending on the assimilative capacity of which is the topic of the next section.

## 2.3- ASSIMILATIVE CAPACITY

The buffering capacity, or assimilative capacity, of an ecosystem is the ability of an ecosystem to absorb potentially harmful inputs [4]. The impact of acidity on the environment varies across the region since the buffering capacities of various ecosystems are fairly fixed: some can withstand acid inputs for long periods of time, others for shorter timespans. For example, acidity can be neutralized naturally in the environment if soils are supplied with a strong base - such as lime and lakes with bicarbonate buffer (hard water)[4]. The Canadian Shield and the mountains of New York state, for example, have a limited buffering capacity to neutralize the levels of acid deposition.

Soil and bedrock characteristics are used as indicators for the assessment of aquatic sensitivity in North America. Bedrock such as limestone, dolomite and other carbonate - rich rocks and deep clay and/or carbonate-rich soils has higher alkalinities and therefore increasing buffering capacities, as shown by the unshaded area in Table 3. The shaded area shows the regions containing bedrock with a low potential to reduce acidity, e.g rocks having a high silica content such as granite and quartzose sandstone and loamy and/or carbonate-poor soils, which have low alkalinities and hence low assimilative capacities [10].

Table 4 shows us that the provinces or territories most susceptible to acidic precipitation are: Quebec (82%), Newfoundland (56%), and Nova Scotia (54%), and the total area of land is approximately 46% of the country. Most of the province of Quebec is highly sensitive to acidic precipitation. In Nova Scotia there are an estimated 9400 lakes many of which have a poor buffering capacity. Much of the province of Newfoundland is sensitive to the effects of acid rain due to its rock formation which is granitic and lacks a buffering chemical. Twenty-one percent of Canada known to be moderately sensitive ecosystems consist of the Gaspe Peninsula, New Brunswick, British Columbia, Prince Edward Island and the western part of Northwest Territories. About one-third of the surface waters in New Brunswick are located in the zones of poorly buffered soils. The lower mainland and southern coastal regions of British Columbia are sensitive to acid rain because the geological structure of the area lacks a buffering assimilation. Although the surface waters of P.E.I have a potential capability for neutralizing acidity because of substances leached from the soil, provincial governments worry that once this renewable but limited buffering capacity is depleted, the acidity would impose a major threat to the ecosystem. The northern environment is believed to be extremely sensitive to pollution of all kinds. Soils are very thin and large areas of regions are covered by sensitive bedrock. Endowed with well-buffered soils, another 23% of Canada is not considered to be sensitive to acid deposition. This statistic represents the St. Lawrence lowlands, the central and southern portions of Ontario and Quebec, and the Prairies [16]. In Manitoba, at least half of the province is potentially sensitive to acid rain. Its lakes are very low in buffering capacity. Soils and water bodies in both Saskatchewan and Alberta are well buffered against acid precipitation although the Canadian shield covers the northern part of Alberta.

Table 5 shows us that most of the American states are very sensitive to acid rain due to their bedrock formation and thin soil characteristics. All states having 10-20 kg/hectare year of sulphate deposition are vulnerable to acid precipitation. Florida is one of the few which has a high potential to reduce acidity. It estimates its potential at 73%, Minnesota sets it at 77% and

Wisconsin at 70%. From Table 6 we observe that for 20-40 kg/hectare year of sulphate deposition Louisiana has a 88% potential for reducing acidity, North Carolina a 85% and South Carolina a 76%. These states are classified as being areas less sensitive to acid rain because of their well-buffered assimilation. While other states contain insignificant capacity for buffering, the Dist. of Columbia has a 53% potential, Pennsylvania a 54% and Georgia a 55%, and are considered to have a moderate potential to reduce acidity. Table 7 indicates that all regions having deposits of over 40kg/hectare year of sulphate are defenceless against the effects of acid rain because of a geological deficiency in buffering chemicals.

The buffering capacity of areas could be considered as a variable in policy formulation in addition to emission inventories. Acid rain policy should be set to reflect the fact that some areas have a better buffering capacity than others; especially in the process of determining emission targets. Emission targets could depend on the particular nature and the assimilative capacity of the environment surrounding the firm in question, thus varying with, for instance, the geographic location of the firm.

# III. EMISSION TRENDS IN NORTH AMERICA

Current emission inventories play an essential role in strengthening policy analysis, and together with historical emission inventories, give us a baseline from which projected emissions can be made. In the following section, we present some of the results from retrospective studies on emissions of common contaminants (such as sulphur dioxide and nitrogen oxide) from human-made sources, and we discuss the significant roles that acid precipitation sources play in both Canada and the U.S..

## 3.1- ACID RAIN IN CANADA

The concentration and volumes of $SO_2$ and $NO_X$ emissions are produced largely by industrial production in North America. In addition to examining the main emitters in Canada by region, we will examine two of Canada's largest sources of acid rain - the International Nickel Company (Inco) and Ontario Hydro. These two industries are important not only because of the magnitude of their pollution but also because of their characteristics and activities as main contributors to acid rain. Both Inco and Ontario Hydro account for 70% of the province's total emissions, even though they are subject to tougher standards called for by Environment Canada. For example, as we will see later, Inco was required to bring its emissions down from 3600 tonnes as calculated in 1980 to its 1950 tonnes/day level by 1983. Ontario Hydro was required to reduce its $SO_2$ and $NO_X$ emissions by 43% before 1990.

From Table 8 we notice that the Inco Limited smelter at Copper Cliff is the largest emitter of $SO_2$ in Canada with 572,000 tonnes in 1991. Much of this pollution travels over long distances to produce acid rain in other regions of Canada and in the U.S.. Other major sources causing acid rain include Ontario Hydro's electric power generations (167,000 tonnes), the Algoma Steel Corporation Ltd. iron ore sintering plant in Wawa (53,000 tonnes) and the Falconbridge Nickel Mines Ltd. smelter in Sudbury (70,000 tonnes). Altogether these main sources of sulphur dioxide make Ontario the largest emitting province.

The copper smelter at Noranda Quebec is Canada's second largest source of $SO_2$ emissions. The two non-ferrous smelters operated by Noranda Mines Ltd. emit a total of 210,000 tonnes in 1991. The smelter at Horne emits 165,000 tonnes annually with no control technology, and the Murdochville smelter produces 45,000 tonnes. Recently the Quebec government ordered Noranda to reduce its emission by 50% in 1990, of which the cost will be between $80 and $100 million. Noranda plans to achieve these reductions by reducing the rate of sulphur dioxide per tonne of ore smelter from the current rate of 0.6 to 0.36 of ore smelted. In order to achieve the abatement targets, Noranda mines built a new sulphuric plant at Rouyn-Noranda that will reduce the emissions by 96% [11]. The progress report on Canada-U.S. Air Quality Agreement indicates that the construction of this acid plant was completed in 1989 and it has been operating at full capacity to capture sulphur efficiently. The smelter has performed well and announced that its emission target of 55,000 tonnes will be reached by the year 2000 [7].

Moving now to the west, Manitoba has two major point sources of $SO_2$ emissions (see Table 8). In 1991, the Hudson Bay Mining and Smelting Company at Flin Flon emits 293,000 tonnes and the Inco Ltd. nickel smelter in Thompson produces 250,000 tonnes. The provincial environment ministry has ordered the companies to study appropriate technology since their smelters are not equipped with any sulphur containment technology [11]. The Hudson Bay Mining and Smelting Company at Flin Flon has been modernized to operate more efficiently.

This project has cost \$187 million and it is estimated that $SO_2$ emissions will be further reduced by 25% to meet its emission limit by 1994 since these two major $SO_2$ sources are required to reduce their annual emission to below 220 kilotonnes in 1994 as part of the Eastern Canada air control program [7].

The major source of $SO_2$ in Alberta is the natural gas processing plants with annual emissions of 343,000 tonnes. Special concern about this rate of emission has been raised since it could impose pollution upon northern Saskatchewan areas as a result of long range transport. Alberta is believed to be responsible for approximately 95% of pollution in North West region [13].

As we observed earlier, Inco is the largest industrial source of sulphur dioxide in Ontario and elsewhere in North America. In 1970 Inco was ordered to cut emissions immediately from 5200 tonnes per day to 3600 tonnes by the end of 1976, and 750 tonnes by 1979. The order included a requirement for a 1250 foot smoke stack to replace the existing chimneys at Copper Cliff [14]. By 1973 and three years ahead of schedule, Inco had cut emissions to 3600 tonnes per day largely with the contribution of a new mill that separates sulphur from the nickel ore before it goes into the smelter and up the stack as sulphur dioxide. The new mill created improved nickel production and reduced air pollution. Although Inco was making progress in reducing emissions, the company failed to get below 3600 tonnes and claimed to the Ontario Ministry of the Environment that economically and technologically Inco could not reduce its emissions of 750 tonnes per day. Therefore, in order to deal with the acid rain problem, Ontario set a new limit for Inco in 1980 which the company is trying to achieve by cutting its emissions by a further 60% by 1994 and by spending over \$50 million on research since 1981 to develop better methods of sulphur containment [14]. Since the signing of the Air Quality Agreement in 1991, additional progress has been made at the Inco smelter with the complete building of an ore processing mill in Sudbury, which will remove concentrated sulphur from the ore before smelting [7].

The second largest source of $SO_2$ and $NO_X$ in Canada is Ontario Hydro from its fossil-fuelled generating stations. Ontario Hydro's fossil-fuelled generating program began in 1953. Much of the fuel at Hydro's coal fired plants was imported from the U.S.. About 497,000 tonnes of sulphur dioxide and nitrogen oxide were released in 1980 and therefore in 1981 the Ontario government required Ontario Hydro to reduce its emissions by 43% by the year 1990. Ontario Hydro was in full compliance with its emissions (see Table 8). The government established the emission cap for which Ontario Hydro will select the most appropriate technology. Higher smoke stacks seem to be the only immediate remedy for meeting local concerns. In the long run, a cost-recovery factor will have to be imposed in other regions if one wants to reduce the emissions further.

Assuming that coal, water and nuclear plants were being equally used to produce electricity by Ontario Hydro, if they were to reduce their consumption of coal, the company would have had to build more nuclear plants to generate electricity to meet the demands of energy in the near future. It was estimated that by the mid 1990's there would be an increased demand for electricity. This means that fossil-fuel plants will have to be brought back into use hence increasing the use of coal after all [15]. To meet the restriction on emissions, Ontario Hydro, among other things, bought up to $400 million of Appalachian washed coal from the U.S.. This reduced the sulphur content by 20% but led to an increased cost of about $3 to $4 per ton. The company has also blended U.S. coal with low sulphur coal from western Canada for the Nanticoke plant. This blending will cut down $SO_2$ emissions by about 15% but increases the coal costs by approximately $50 million. Ontario Hydro is in the process of testing technologies that would result in the most effective way of reducing emissions by using wet and dry scrubbing [14]. The company is building two flue-gas desulphurization scrubbers at the existing coal-burning Lambton source, with which 90% of the $SO_2$ emissions will be captured and the scrubbers are expected to operate early in 1994 [16].

The question we ask ourselves is what can be done more quickly, effectively and economically at present to reduce $SO_2$ emission from coal burning power plants. For many, intensive research into the problem is not enough, an immediate control of plant emissions must be implemented before further damage occurs.

## 3.2- ACID RAIN IN THE U.S.

Acid rain control has always been an economic and political issue. Choosing a strategy to curb emissions forces political complications. Some argue that clean up costs should be borne by the utilities emitting the most pollution, hence putting the burden on their customers. Others have suggested that the costs should be shared by utility users nationwide.

With all available technologies, switching to low sulphur coal appears to be cheaper than adopting the scrubber method. But West Virginia, Ohio, Indiana and Illinois states with high sulphur coal production have the concern that this could cost jobs for miners and hurt their economies. From Table 9 we see that 55% of the top 20 coal-fired power plants are concentrated in the midwestern area and the remainder are scattering in other parts of the U.S..

In the United States the key issue of the debate has been who should pay the costs of reducing sulphur dioxide emissions from coal burning power plants. The answer to this question has not been settled because of the on-going battle between the states which consider themselves "victims" of acid rain against the ones accused of being the "perpetrators" of the acid rain problem. In order to have a better understanding about this issue, we will later examine studies which have been able to clarify somewhat the problem of acid rain in the United States.

The northeastern states that regard themselves as victims have claimed achievements in cleaning up $SO_2$ emissions in the 1970s and in paying the cost of that clean up. Their ecosystems are now in danger because of the emissions generated elsewhere- mainly by the states in the midwest, the perpetrators. On the other hand, the perpetrator states say that they have also reduced $SO_2$ emissions and paid the costs. They further argue that if the proposed cut in emissions and the increase in costs were imposed only on the perpetrator states, then this would lead to severe economic hardship. Instead they propose that the costs of emission reduction should be shared nationally.

Because the northeastern states lie generally downwind from the midwestern states, major sulphur dioxide emissions from coal-burning power plants have occurred. In 1980, for example, $SO_2$ emissions from just five midwestern states contributed about one-third of all $SO_2$ pollution nationwide [17]. Despite the lack of evidence to ascertain the relationship between mid-western $SO_2$ emissions and acidic rainfall in the northeast, some studies suggest that at least half the acid rainfall in the north-east is coming from pollution in the mid-west. A study at the University of Rhode Island indicated that 80% of the northeast's acid rain problem comes from midwestern power plant emissions [17]. Midwestern states fully recognize that their coal-burning plants are major sources of sulphur dioxide emissions in the U.S.. As seen in Table 10, the top ten states play a significant role in pollution emissions. Although they agree that their $SO_2$ emissions are substantial and troublesome, midwesterners are worrying about controlling costs under the proposed national acid rain program.

A study has been completed by the U.S. Congressional Budget Office (CBO) on the analysis of the economic impact of acid rain control associated with an eight million ton reduction program. The "polluter must pay" principle is incorporated into the study and the conclusion indicates that the average annual cost for the five midwestern states between 1986 and the year 2015 will be $685 million, or about 36% of the total projected annual cost nationwide [17]. Producers in the Midwestern states with high sulphur coal consumption could face a double economic burden in reducing $SO_2$ emissions. Not only would electricity rates increase, but job losses would also occur. An estimate of 10,551 mining jobs would be eliminated in Pennsylvania and Ohio alone [17].

James Cannon argued that the issue of who is responsible for the acid rain problem and who should pay for the controlling costs should be assessed with a new perspective. That is, focus should be given to an alternative way of assigning responsibility and allocating costs. This would be done by identifying the users - e.g, the beneficiaries of such power, - rather than applying the "polluter must pay" principle which focuses on confining responsibility and hence costs for acid rain to the generators of high sulphur coal-fired power [17].

The CBO study has shown that northern states, traditionally viewed as victims, play a significant role in power importing. Measured by percentage of total in-state sales in 1984, the top 15 states (see Table 11) imported at least five percent of power for their consumers from other states - Rhode Island (89%), New Jersey (50%), Maine (10%). For power exporting states, as measured by total volume of exports, West Virginia ranked first followed by Pennsylvania. Kentucky and Indiana ranked sixth and seventh, respectively. Comparing these figures to the $SO_2$ emissions associated with power exports (see Table 12), they show that West Virginia emitted 677,077 tons in 1984, Pennsylvania (326,293 tons), Kentucky (300,600 tons), and Indiana (320,371 tons).

It is evident that one must examine the magnitude of coal-fired power imports and exports to complete the acid rain debate so that an equitable implementation of any acid rain program can take place. For example, if acid rain is a national problem, then all the states should share the cleanup costs. The result of this change in attitude might affect the acid rain victim states economically as well as some acid rain bystander states that are not directly required to make sizable pollution reductions on their own. Another problem is that electric utilities are the largest consumers of coal in the U.S. and are projected to account for over 70% of the market in 1995. From Table 13 it is clear that the midwestern states are heavily dependent on coal power - Ohio by 95%, Indiana 99%, West Virginia 99%, Kentucky 94%, Missouri 95%. Hence any major shift of demand in this sector would result in a heavy economic impact on the coal industry. The United Mine Workers of America studied the effect of acid rain legislation on Appalachian and midwestern coal mining employment. They showed that 80,000 job losses would occur if all utilities switched to the lower sulphur coal method in order to achieve target emission reductions. It is estimated that the annual total economic cost would be $3 billion to $6 billion provided that not all utilities choose the fuel switching alternative. Therefore, to avoid further severe unemployment, it was suggested that alternate methods, such as scrubbers, could reduce $SO_2$ emissions and could prevent job losses. For many states, switching to low sulphur coal is more profitable to producers than choosing the scrubber method. While the increased cost of switching can be passed on to the electricity consumers through fuel adjustment clauses, the capital expenditures for the building of scrubbers would take a longer time to be recovered since the increased rate has to be approved by the public utility commission during public hearings.

## 3.3- TRENDS IN THE U.S $SO_2$ AND $NO_X$ EMISSIONS

Coal was the predominant fuel from 1900 until 1940 when oil and gas were considered as an attractive alternative for fuel consumption in the U.S.. The emissions of $SO_2$ seem to be directly related to fuel type, from which coal combustion has been the governing factor in the rise and fall of emission rates [18]. Table 14 gives us the estimates of historical emissions of sulphur dioxide throughout the U.S. since 1940. For the period 1940 to 1980, the $SO_2$ emissions increased between 29% and 34% once all studies have been reviewed. However the emissions decreased in the range of 14% to 18% within the 1970-1980 period. The trend continued to decline by 8% reflecting the recent emissions data for 1970-1984.

There are several explanations for the reduction of $SO_2$ emissions. Firstly, this reduction resulted from federal and state regulations - having forced the closure of 10 smelters. Secondly, there was a decrease in the average sulphur content of the coal from 1.63% in 1980 to 1.44% in 1984 and the percentage of coal-fired emissions from utility station with flue gas desulphurization systems increased from 12.85% in 1980 to 20.26% in 1984. Finally, the significant reduction of emissions was attributable to the continued operation of old plants as opposed to new plants based upon regional shifts in power demand [18]. The United States is committed to achieving a permanent national cap of 895 million tons of $SO_2$ per year for electric utilities by the year 2010. In addition, another 5.6 million tons of emission cap is placed upon industrial sources to ensure that they will comply with regulation under the Clean Air Act [19].

Estimates given by Knudson (see Table 15) showed that American nitrogen oxides emissions have increased significantly from about 9 million tonnes in 1950 to 21 million tonnes in 1980 [20]. There have been fluctuations over the past 10 years. After reaching its peak in 1978 nitrogen oxide emissions declined about 10% in 1983. The decline was explained by the increased emission controls of automobiles and a decline in industrial fuel use. Nevertheless, the trend increased slightly during the 1983-1985 period. Power plant emissions of $NO_X$ increased by 33% for the 1975-1985 period.

Total U.S. nitrogen oxide emissions are projected to increase from about 19 million tonnes in 1980 to 24 million tonnes by the end of the century. $NO_X$ emissions from power generating stations are projected to increase about 50% by the year 2000 and in the transportation sector the emissions are projected to increase from 8.5 million tonnes in 1980 to about 10 million tonnes by the year 2000. All the emission projections are estimated from the baseline presumption of economic and energy growth and that there are no changes in current environmental regulations [7].

## 3.4- CANADIAN $SO_2$ AND $NO_X$ EMISSION TRENDS

Canadian sulphur dioxide emissions decreased from 6.9 million tonnes in 1970 to 4.6 million tonnes in 1980 or about 41%. During the same period, emissions in eastern Canada decreased from 5.6 million tonnes to 3.8 million tonnes, or approximately 44%. Western Canada, including Saskatchewan, Alberta and British Columbia, contributed only one-fifth of the total emissions. Eastern Canada, on the other hand, has large smelters and therefore, is a major emitting region. However, sulphur dioxide emissions from these smelters have decreased about

45% during 1970-1980 period. In other words, after peaking in 1970, human-made $SO_2$ emissions in Canada have declined dramatically in recent years [16].

Due to growing public awareness about environmental issues, legislation such as the "Clean air act" and "Motor vehicle safety act" were introduced. Process improvement through the adoption of pollution abatement technologies resulted in the reduction of emission releases. Also, production cutbacks and smelter closures led further to the decline of emissions [18]. As a result of these improvements, total emissions of $SO_2$ in Canada are expected to decrease from 3.7 million tonnes in 1990 to 3.2 million tonnes by the year 2000. Eastern Canada provinces are obliged to reduce $SO_2$ emission to 2.3 million tonnes by 1994 [16].

In Canada, estimated nitrogen oxide emissions increased steadily from 1955-1980 due to an increase of fuel combustion and transportation activity, and annual $NO_X$ emissions varied from 0.6 million metric tons to 1.3 million metric tons during the 1955-1970 period. By 1980, as a 1986 report from Environment Canada has noted, emissions amounted to 1.7 million metric tons as a result of a 17% increase from fuel combustion and a 36% increase in emission from transportation activity. Between 1981 and 1984 the preliminary data for eastern Canada has shown a slight decrease in total nitrogen oxide resulting from a cutback of emissions from power plants and motor vehicles [20]. In 1990, Canadian $NO_X$ emissions increased to 1.9 million tonnes, of which approximately 63% were coming from mobile sources.

Projected nitrogen oxide emissions will increase from about 1.8 million tonnes in 1980 to 2.4 million tonnes by the year 2000. In the absence of further control action, $NO_X$ emissions in transportation sector are expected to decrease from 1.18 million tonnes in 1985 to 960,000 million tonnes by the end of the century [7]. We must therefore, conclude that Canadian nitrogen oxide emissions are generally low compared to the U.S.. We will now see the impact of acid rain on the Canadian and the American environments, including the affects on nature, human populations and building infrastructures.

# IV. IMPACT OF ACID RAIN ON THE ENVIRONMENT

The major consequences of acid precipitation on the environment are characterized as: the acidification of lakes and streams with their potential damage to aquatic fish and plant life; the depletion of soil nutrients and diminished forest productivity; the accelerated deterioration of metals, stone, and other materials; toxic metal contamination of edible fish and drinking water; and direct and indirect effects on human health. Among these consequences, reliable evidence for aquatic acidification, fish mortality and some soil effect are well documented. Although the documentation detailing the impacts on crop damage is limited, researchers are still investigating terrestrial ecosystem effects.

The conclusions reached on the effects to human health is a controversial issue because of inconsistencies among statistical measurements. Material damages are estimated from different assumptions; and even though the results do not correctly reflect the damage costs, those figures show us that acid rain is slowly deteriorating resources.

In this section, we will be studying the effects of acid rain on the aquatic ecosystem and the terrestrial ecosystem; the effects it has on human health, and its effects on human-made structures.

## 4.1- AQUATIC ECOSYSTEM EFFECTS

The acidity of precipitation is measured by the pH scales, the lower the pH number the more acidity the substance [4]. Streams and lakes have shown signs of acidification before it becomes apparent in soils, plants and forests. The decline and possible loss of populations of fish and other species from acidified lakes, rivers and reservoirs are among the damages caused by the acid rain problem. Since surface waters are affected in ways that are not always noticeable or easily perceived, the fish deaths are considered as merely the tip of the "acid iceberg". The decline of fish populations is important both from a biological and economical standpoint because they have sporting and commercial implications. Between 1970-1978 sports fishing catch rates in Quebec's Laurentian park fell by one-third and this was claimed to have been caused by acidified lakes [21].

Surveys have indicated that approximately 31,000 Canadian lakes are acidified, and it is predicted a further 10,000 to 40,000 lakes will be acidified in eastern Canada if wet sulphate deposition concentrated on the affected areas is not reduced. Loss of the Atlantic salmon populations in several rivers in southwestern Nova Scotia has been recorded and fish population losses and declines have been noticed in Ontario [27]. In addition, extensive surveys in eastern Canada confirmed that species diversity and richness is lessened in acidified surface waters emphasizing the potential effects of acid rain on aquatic resources.

A total of 4,016 lakes in Ontario were under survey by the Ministry of the Environment to study the impact of the acidity level. The following results were documented:[3]

| | |
|---|---|
| - 4% acidified | : 155 lakes can support few or no fish |
| - 13% extreme sensitivity | : 522 lakes; |
| - 41% moderate sensitivity | : 1647 lakes; |
| - 18% low sensitivity | : 727 lakes; |
| - 24% not sensitivity | : 965 lakes. |

The Canadian Environment Protection Agency and the National Acid Precipitation Assessment Program have concluded studies on national surface water in order to project the population and distribution of lakes and streams at different levels of pH and acid neutralizing capacities. A total of 1620 lakes in the most potentially sensitive areas in the eastern U.S. were statistically selected for the survey. The results have shown that approximately 260 lakes (4% of the total area) have a pH lower than 5.0, and 1,360 lakes (19% of the total) are estimated to have neutralizing capacities [23]. This data indicates that although the current number of acidic lakes is relatively small, the number of potentially sensitive lakes is relatively large. It is documented that 8% of the lakes in the Adirondack mountain range, which are located in eastern U.S. zone receiving high acidic deposition, had a pH of less than 5.0 and a 10% reduction in fish in 1930s. And in the 1970s the number of acidic lakes increased to 48% and fish losses rose to 52% [12].

The Menz and Mullen (1984) study has attempted to estimate the economic significance of damages due to increased acidity in Adirondack recreational fishery. They suggested that the results should be considered as low-bound estimates because different underlying assumptions were used for empirical and conceptual purposes and because only a limited portion of the Adirondack recreational fishery was observed. The estimated net economic value and net loss for Adirondack fishery are summarized in Table 16. The findings show that the net economic value of interfishery substitution is estimated at $38 million, whereas an economy without interfishery substitution has a net economic value of $55 million. These figures are derived from the values of ponded (coldwater and lakes) and stream fisheries. Due to an increased acidity in the aquatic system, $1.7 million is expected to be lost per year in angler economic value if substitution between ponded fishery types is considered in estimating the fishery's economic value. Greater losses of $2.0 million are expected when interfishery substitution is considered. They argued further that since it was possible that economic losses from acidification damage were greater than currently known, another estimate of losses was performed assuming the loss of twice critical average. The findings for the net losses increased substantially from \$1.7 million to \$2.7 million for interfishery substitution and from \$2.0 million to \$3.2 million in case where there was no interfishery substitution [24].

## 4.2- TERRESTRIAL ECOSYSTEM EFFECTS

Researchers and experts agree that studying the effects of acid rain on soils, trees and plants is more difficult than on lakes and rivers. The reason is that there are a large number of possible interactions between the atmosphere, the terrestrial ecosystem and the waiting period (response time to acid stress) to observe the effects on soils and trees. It is difficult to quantify those effects since we have no original areas with which we could compare today's forests with pre-pollution levels. It is also difficult to separate the effects of acid deposition and related air pollutants from the environmental stresses which might affect the forest ecosystem. The effects on crops also have important economic and agricultural implications, but those on trees resulting in forest damage is also an area of major concern. This is why intensive research is being carried out by both American and Canadian scientists.

There is a growing concern over the possible acidification of soils in recent years since soils supply nutrition to plants and animals that provide us with food, fibres, and timber products. The concern is that once the biological damage on soils has reached the critical point, where fertility rate decreases hence causing a decline of productivity, acidification damage may be irreversible [21]. While research efforts have not provided any conclusive data, the potential loss of forest productivity is extremely threatening. For example, the forest industry in Eastern Canada contributes \$14 billion per year to the gross national product. Experts have noticed a decline in sugar maple trees in Quebec and Ontario regions having high loadings of atmospheric pollutants.

This will surely affect the Quebec region where the maple syrup industry contributes $40 million annually to its economy [8]. The reason for this decline was due to environmental stresses and acid rain has been considered as the major factor in certain location [43]. The red and white spruce, and red and white jack pine were tested by the Canadian forestry service in New Brunswick. The results indicated that under acid rain conditions, those trees grew poorly compared to the ones growing under normal conditions. Characteristics of these trees ranged from fewer and smaller needles, retarded germination rate, to reduced seedling productivity.

In 1963, another report studied the serious damage to vegetation documenting the downwind effects from an iron sintering plant in Wawa, Ontario. This plant had been operating since 1939 and emitted about 100,000 tons of $SO_2$ per year. Four levels of damage were documented:[26]

| | |
|---|---|
| - very serious (barren) | : up to 6.5 kilometres |
| - serious (most trees dead) | : 6.5-19.0 kilometres |
| - considerable ( few living spruce and birch trees left; most of the canopy dead) | : 19.0-27.0 kilometres |
| - moderate (some damage) | : 27.0-38.0 kilometres |

Ten years later it was reported that regions of "total kill", "heavy damage", and "light damage" were extended to 29, 40 and 60 kilometres respectively [26].

By using a relative pollutant exposure index, McClenahen (1983) demonstrated that both white ash and northern red oak reduced height growth significantly in the vicinity of urban and downwind areas of Ohio, compared to the upwind regions. The study concluded that the decline was related to pollutant exposure [27]. Camel's Hump- a peak forested with red spruce and balsam firs in the Green mountains of Vermont- was being researched by scientists from the University of Vermont. The result of their studies indicated that between 1965 and 1981 half of the spruce trees had died. In addition seedling production, tree density and tree growth rates had dropped by nearly a half. After 1965, wood volume declined substantially and Vogelman (1982) concluded that "if such losses in only a few years are representative of a general decline in forest productivity, the economic consequences for the lumber industry will be staggering" [28]. In the eastern U.S., the most widespread forest decline developed in spruce fir forests. Foliage damage and increased tree mortality were concluded as being the results of air pollution. These forests are located at high elevations in the White mountains (New Hampshire), Adirondack (New York), Green mountain (Vermont), and southern Appalachians (Virginia, Tennessee, North Carolina) [20].

Although it is difficult to quantify the growth decline in economic terms, all agreed that its magnitude is tremendous. There are a great number of variables that can exaggerate or nullify the effects of pollution on growth, including gypsy moth defoliation and drought. In addition to timber supply, forests give us many more amenities such as erosion control, wildlife habitat ecosystem stability and aesthetics which are even more difficult to quantify [3].

## 4.3- HUMAN HEALTH EFFECTS

It is documented in both field and laboratory studies that air pollution has an adverse effect on human health. The effects of acid deposition range from mere nuisance - such as bad smells, reduced visibility, irritation of the eyes, nose and throat - to fatality. While direct effects of acid rain on human health have not yet been proven, the indirect effects that relate to humans by contact with acidified materials substances (for example, food and water supplies), have been and should be studied carefully before any further conclusions can be made [21].

Researchers attempted to explain the relationship between acid rain and human health by using eight years of air pollution data from the southwestern Ontario region. The study showed that there was an association between the ambient level of sulphate, ozone and temperature and the increase in hospital admissions for respiratory illnesses [29].

Another study compared the respiratory effects of exposure to long range transport of air pollution in two rural communities. School children in Tillsonburg, Ontario, which has a high level acidic air pollution, and in Portage la Prairie, Manitoba, which has little transported air pollution, were examined through a lung function test and a respiratory health questionnaire. The result indicated that the children in Tillsonburg had 2 percent lower lung function measurements than those in Portage la Prairie, and had a higher incident of respiratory problems [29]. These findings suggested that there are the potential effects of transported air pollution on human health. Researchers continue to study the cause-and-effect relationship of this occurrence.

Although it is widely accepted that a reduction in sulphur dioxide would generate substantial human health benefits, no study has attempted to put a value on these benefits or to define them in terms of reductions in premature deaths. Health benefits from acid deposition controls can be derived from the modelled reductions in ambient sulphates from an acid deposition control program. The modelling was accomplished by examining an acid rain control program that would reduce 12 million tons of emission in 31 states. The results indicated that there would be a 36% reduction of human sulphate exposure [3].

The study released by the American Lung Association reported that air pollution from automobiles (consisting of carbon monoxide and nitrogen oxide), caused an estimated 50,000 to 120,000 "excess deaths" in the U.S.. The health care expenses have amounted to roughly $40 billion for the entire population because of automobile pollution. This dollar estimate is based on 12 recent studies completed by the Association [30].

The recent growing concern is on the acidification and possible contamination of groundwater. Acidic water, as noted by Environment Canada, may increase the concentration of lead and copper through plumbing. The problem is that drinking water in rural areas may be affected by acid rain. This argument has been put forth by research which requires experts to study potential affected zones and to determine the levels of contaminants in drinking water [29].

## 4.4- HUMAN-MADE STRUCTURE EFFECTS

To some extent, most of the literature agrees that sulphur dioxides have a direct effect on buildings and materials made of stone and metals that exposed to atmosphere. The extent to which various materials are affected is still largely undetermined. The problem of quantifying the damage that would link cause to effect as well as the amount of material exposed, is yet to be resolved. What we know is that air pollution speeds up the natural chemical weathering and corrosion of exposed materials in a variety of ways. For example, iron or steel-based structures are seriously affected by acid deposition, followed by extensive economic losses. On the other hand, non-ferrous metal structures which have layers of oxides and sulphates on the surface, protect the metal below [21].

Although it is argued that economic damage of acid deposition upon materials and structures can be measured in different ways such as replacement costs, costs of avoidance or prevention, and aesthetic costs; the magnitude of its damage has been exceedingly difficult to assess and document. Despite these limitations, a number of different studies have attempted to quantify the damages to materials from $SO_2$.

The process of material erosion have been accumulating through time due to acidic deposition. Buildings, roads, sculptures and other human-made structures can be aesthetically and functionally damaged. Although damage costs to the urban and rural environment are difficult to calculate; in 1985 it has been estimated that the value of Canadian construction amounted to $61 billion and out of this total, about $11 billion was for repairs and maintenance as a direct result of acid rain effects [12].

Tolba's experimental tests show that materials in polluted urban and in industrial air with high concentration of sulphur dioxides erode faster than they do in the countryside. The range of corrosion rates is at between two and ten times faster. Stankunas and his colleagues in 1981 estimated that the annual damage to the painted surfaces in the Metropolitan Boston area from $SO_2$ varied between $830,000 to $31,300,000 depending on the different damage functions being used to calculate. Thus the air pollution damage to paint was considered economically significant [31].

It is difficult to estimate the damage function for most materials. Some studies attempted to express damage estimates in terms of economic value, the results still being of questionable values. Fink et. al.(1971) estimated about $3.3 billion exterior metal damage costs, which is said to be undervalued. Salmon provided an estimate of $9.1 billion for material damages in 1971. However, he did not include protective coatings, an element which would reduce deterioration costs and as a result, the study, it is said, probably overstated the damages from acid deposition [3]. Nevertheless, all the evidence demonstrates that the scope of potential damage from acid deposition is considerably high.

To put more emphasis on the efforts that governments are putting into finding some solutions to the four areas we have discussed above; namely the effects of acid rain on the aquatic and terrestrial ecosystems, its effects on human health and on human-made structure, we will now concentrate on the "Clean Air" program in North America.

# V. CLEAN AIR PROGRAM IN NORTH AMERICA

The Canadian provincial governments believe that acid rain has caused extensive damage to aquatic and the terrestrial ecosystem in eastern areas. Thousands of lakes in Ontario, Quebec and Nova Scotia are under what is called "acid stress", meaning that hundreds of lakes in Ontario alone are fishless because of acid rain. The Ontario government estimates that the loss of 6,000 jobs and approximately $28 million in annual revenue from tourism and fisheries are attributable to acid deposition. Damage to timber industry may cause directly or indirectly one million jobs and an estimated cost of about $20 billion in revenue; furthermore, repairs to Canadian buildings have cost approximately $1 billion annually. Approximately 2.6 million square kilometres of eastern Canada area are endangered by acid rain, which had been the main cause for the damage on fishery, tourism, agriculture and forestry [32].

## 5.1- Clean Air Act in Canada

In Canada the 1971 Clean Air Act (CAA) is the primary legislative mechanism for controlling air pollution. Provincial and federal governments are working in harmony to ensure the effectiveness of control programs. Under the CAA, the ministry of the environment is "empowered to establish a national system of air quality monitoring stations, commission air pollution research, formulate comprehensive plans for air pollution control, and publish and distribute information to the public"[32]. Furthermore, the Minister of Environment is authorized to submit objectives, emission guidelines and standards for the national air quality. Alberta, Ontario, Saskatchewan, Manitoba, Quebec and New Brunswick have followed ambient air quality standards for sulphur dioxide and nitrogen oxide emissions under federal guidance. The national ambient air quality objectives concentrate on three ranges of air quality: tolerable, acceptable and desirable.

> "The tolerable range indicates a level where there is a danger to the public health; this is roughly equivalent to the primary air quality standard of the U.S. Clean Air Act. Acceptable range indicates a level where 'welfare' effects may occur, such as damage to the vegetation, water, soil, or to the general public's comfort; this is comparable to the secondary standard of the U.S. Clean Air Act. The desirable range indicates a long range air pollution control goal"[32].

The problem is that these objectives are based on ambient concentrations of the pollutant rather than on total emissions. In Canada, legislation sets strict emission targets and penalties for non-compliance and it does not depict how pollution sources should reduce their emissions. However, industry is free to select the most efficient and effective ways to achieve emission reduction targets. Instead of reducing their total emissions, polluters try to dilute the concentrations by dissipating the pollutants into the atmosphere by means of tall smokestacks.

Since there are no restrictions on the height of smokestacks, the Canadian industries by using this technique will achieve provincial government standards that are based on the above objectives. Therefore polluters are benefitting at the expense of other regions through long range transport of acid rain. For example, according to the 1985-1986 Environment Canada reports, it estimated that 44% of sulphur dioxide emissions have been reduced during the 1970-1984 period in Manitoba, Ontario, Quebec and the Atlantic provinces. $NO_x$ emissions in these provinces, however, increased between 1970-1978 but slightly decreased since 1980 [33].

In 1985, the federal government announced that Canada would implement a comprehensive new acid rain control program that would substantially reduce Canada's own acid rain and the amount it exported to the U.S.. Based on the outcomes of international scientific research, Canada will decrease its total sulphur dioxide emissions to 2.3 million tonnes (50% from 1980 level) by 1994 from eastern Saskatchewan and Manitoba border sources.

Under specific emission reduction requirements and the period of ten years, the programs give industrial emitters time to develop and test new technologies and to adjust their controls on target emission levels. The programs are estimated to have a cost of $500 million per year once under way [8]. Between 1987 and 1994, major emitters invest about $1.7 billion in capital projects to reduce their $SO_2$ emissions [7].

Specifically, the province of Quebec has commissioned extensive studies on all aspects of acid rain research, especially on the issue of forest decline. In 1985 the Quebec government announced to cut its $SO_2$ emissions by 45% (more than 400,000 tonnes) by 1990 which is 4 years earlier than the 1994 deadline. All new smelting operations in the province are required to manage at least 95% of the sulphur dioxide emissions [34]. In 1991, Quebec emits 378,000 tonnes of emissions which are well below the provincial objective for the 1990-1993 period of 600,000 tonnes [16].

Ontario's "count down acid rain" program, announced in 1985, would reduce the total emissions by 60% by 1994. The government commanded the four major $SO_2$ emitting industries to report their activities twice a year to ensure the achievement of this target [34]. In 1991, these four companies were in full compliance with their emission limits.

## 5.2- Clean Air Act in the U.S.

The Clean Air Act of 1970 in the U.S. is the nation's major guidance for an air quality control program. Although this act has been amended several times, it is normally viewed as being unable to improve the current acid rain problem. The Act provides the authority for the states and localities to develop and to implement all air pollution control activities. Environment Protection Agency and the states join their forces to direct overall mandatory program [35]. While the former establishes a national ambient air quality goal and set guidelines for air quality standards, the latter are responsible for developing and implementing control measures to meet federal requirements. In the U.S., the State Implementation Plan (SIP) process and the National Ambient Quality Standard (NAAQS) are the key mechanisms for emission regulations. However, the two mechanisms are incapable of correcting spill-overs of sulphur dioxide and nitrogen oxide activated via tall smokestacks [32]. The costs for air quality regulations are projected at approximately $230 billion during the period 1977-1986. Capital investment expenditures for equipments are amounted to $80 billion and air pollution control costs are about $15 billion. Those projected costs of the Act not only impose direct effects on firms, but also affect the economy as a whole [35].

Based on all the available current research and the options for its management, the U.S. government concluded in 1983 that although it was clear acid rain was a serious concern both in the U.S. and Canada, the problem lacked the information needed to make further decisions on the design of additional emission controls. In June of 1989, the U.S. government proposed to cut its acid rain emissions in half by the year 2000. Under the new plan, sulphur dioxide emissions will be reduce by 10 million tonnes annually in 11 years and nitrogen oxide emissions by 2 million tonnes from the projected levels in the same year [36]. In August of 1989, a study confirmed that the planned cuts in pollutants would improve lakes over the next 50 years in New York, New England and Pennsylvania. Moreover, the improvements in the U.S. environment which was projected in the report would also apply to Canada because industrial emission sources in the American mid-west contribute approximately 50% of acid rain on Canadian lakes, streams and forests [37].

On March, 1991 the Prime Minister of Canada and the President of the United States signed the Canada-U.S. Air Quality Agreement. This symbolizes the will of the two countries to fight against acid rain. Canadian government is committed to the agreement by introducing the Green plan which provides $30 million, 6-year extension to the research and monitoring and control efforts on air pollution [19].

The aspect for continued air quality improvement is unpredictable due to, among other things, the economic costs and the controversy of the goals of domestic energy independence and clean air. Therefore, the question we ask ourselves is whether the price we pay for the benefits of the Clean Air Act is justifiable.

Having looked at the various effects of acid rain on the environment, the human factor and finally, which infrastructures are to blamed, how do we explain human inaction toward this problem. In a final chapter we follow with a theoretical analysis which will hope to create some discussion as to what actions should be undertaken.

# VI) THEORETICAL ANALYSIS

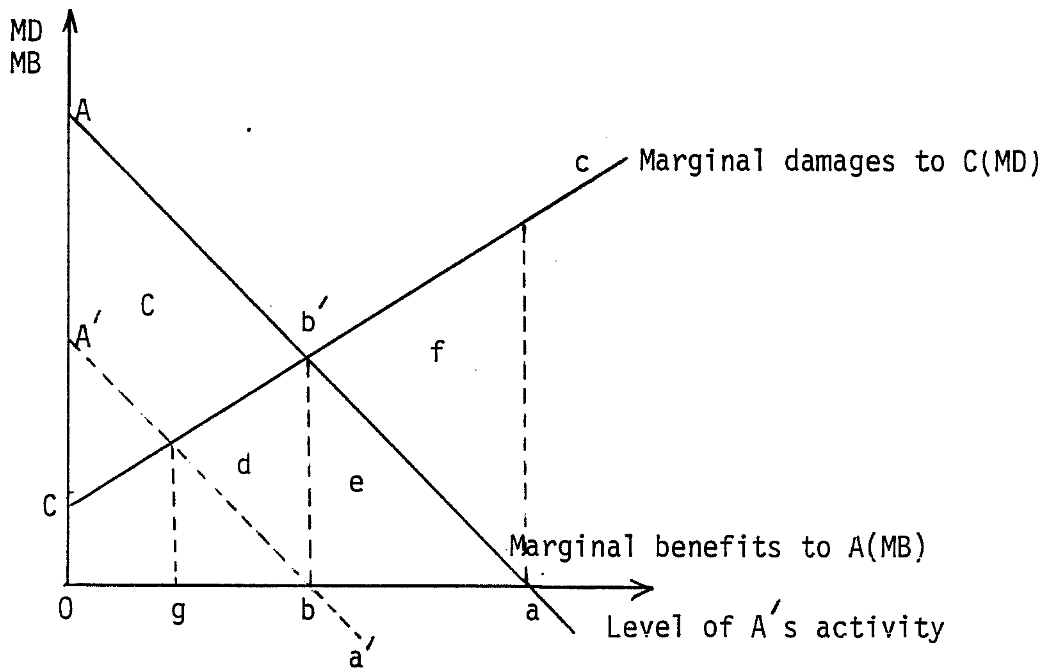
The causes and effects of acid rain having been described in the previous chapters, indicate that an assessment of the economic impacts and the distribution of the associated costs will not be a simple, straight forward process. For this, a comprehensive economic model must be developed. Several economists and organizations have put forward theoretical frameworks which form the basis for government decision making. Summaries of such theoretical frameworks are presented in this chapter.

In 1931 Jacob Viner introduced the concept of "technological external diseconomy" in which one firm imposed costs on another producer by physical action, as opposed to pecuniary external diseconomy where one firm imposed costs on another producer through the market system [38]. Keeping this in mind, the problem of environmental quality is a product of the use and misuse of limited natural resources. Pollution is well known in economics as an "externality" and the concept of externality recognizes the problem of social costs and social benefits resulting from the private use of resource [39]. Air pollution arises because in its natural state air is considered as "free", with a price of zero. In order to have a market for this public good, property rights over resources have to be defined and enforceable and air quality standards have to be clarified [39].

R.H. Coase, in his famous article "The problem of social costs", analyzed how externalities could be internalized through voluntary exchange or the market mechanism [40]. Could this approach be applied to the air pollution problem or are there other economic instruments that can be considered as qualified policy to alleviate further the already damaged environment? The following sections of this chapter will review the major economic instruments and various studies that identify the use of taxes, subsidies, quotas, government regulations, and marketable permits. The purpose will be to find out whether any one of these are relevant to the acid rain problem.

## 6.1- Coase Theorem

Ralph Turvey illustrated the concept of externality based on Coase's theorem with a diagram [41].




Consider the case of an American coal-fired utility (A) whose emissions fall on Canadian forests and woodlands (C) that lie downwind from the emitting source. From the diagram the area under the Aa curve shows the marginal benefits that polluter A will obtain. The area under the Cc curve represents the marginal damages to C. Suppose the right to pollute is given to A and bargaining power is not taken into consideration, the polluting activity will reach up to Oa, thus A will reap all the benefits of the polluting activity. With bargaining, C will be willing to pay up to **e+f** to secure a reduction of A's emissions to **b**, and the American polluter will be willing to accept anything over **e**. Suppose now the Canadian forester has the right to clean air, A will be willing to pay up to **c+d**, and C will be willing to accept at least **d** to allow A's activity to reach **b.**

Following this example, we have established that the allocation of resources will be the same no matter which party receives the property right. The value of production, in other words, will be maximized without government intervention. As there exists no property rights to clean air, the government can now decide to impose a tax on the American producer equal to a price at which the marginal benefit is equal to the marginal damage at the optimal output **Ob**. From the diagram, we observe that A's marginal benefit curve has shifted to the left (A'a') due to each **b'b** unit of tax imposed on the firm's activity. The socially optimal output will again be at **Ob** if there is no negotiation. But what if in spite of taxes, the Canadian forester realizes that a new equilibrium could be reached, leading to a further decrease in pollution. That is, American firm A would accept bribes and reduce its level of activity to **Og**. This result will lead to distortions of resource allocation since A's activity is now below the efficient level.

After observing these possible outcomes, Coase concluded and later Turvey also agreed, that taxes do not necessarily provide optimal conditions through a voluntary exchange market approach [41]. There are no boundaries for acid rain since once air pollution occurs in one country it will travel long distances and will pollute the air of other countries. The question is, therefore, can some proposals of international law lead the economy to an optimal allocation of resources? The Coase theorem suggested that under proper conditions market forces could provide an effective outcome [40]. However, others argue that this suggestion would not apply to the international pollution situation since Coase examined cases in which one firm would impose an external diseconomy on another firm, concluding that when the property rights are well defined and when the transaction costs are negligible, a socially optimal allocation of resources will be achieved [42]. The reality is that the number of individuals involved in the transboundary pollution is large, and the fact that transaction costs have to be sufficiently small no longer applies. It takes more time for negotiations to be settled prior to an agreement, thereby increasing the time costs of achieving the optimal outcome, where the problem lies with the existence of multi-party externalities [43].

There are several criticisms on the applicability of the Coase theorem to the air pollution problem. Firstly, Coase examined two-party situations where pollution was conceived as an immediate threat to the revenue of the affected firm [44]. In case of air pollution the problem will have to be settled not only between the two individuals, but the spill-over effects also spread to other individuals in the economy as a whole. These indirect effects are reflected through indicators such as consumers' declined commercial and recreational activities and poor health [45]. In practice, as we discussed earlier, since air pollution generates multi-party externalities it would create tremendous transaction costs to the affected individuals, if they were forced to negotiate bribes. Secondly, a misallocation of resources will arise in situations where the polluter could impose a threat to the victim by increasing the production of the optimal level so that the bribe would be higher. The polluter will generate higher revenues due to the incentive of the victim to negotiate a payment [46].

After examining all the above circumstances we come to the conclusion that the conditions for the Coase theorem will not apply to our problem in dealing with the issue of acid rain.

## 6.2- The Polluter-Pays Principle (PPP)

Although Coase provided a thorough explanation of the mutual relationship between externalities and pollution, it is widely recognized that the focus of the acid rain problem is on the American producers and users of electricity, the coal-deposit firms and their employees, and on the Canadian owners of smelters and fossil-fuel generating stations. Since the main focus is on the polluting agents of these harmful emissions, we will now examine the Polluter-Pays Principle (PPP)- its definitions and its proposals- in order to verify whether it can be considered as a possible way of controlling the already damaged environment and a way to further curtail the emission rates, thereby achieving an efficient allocation of resources.

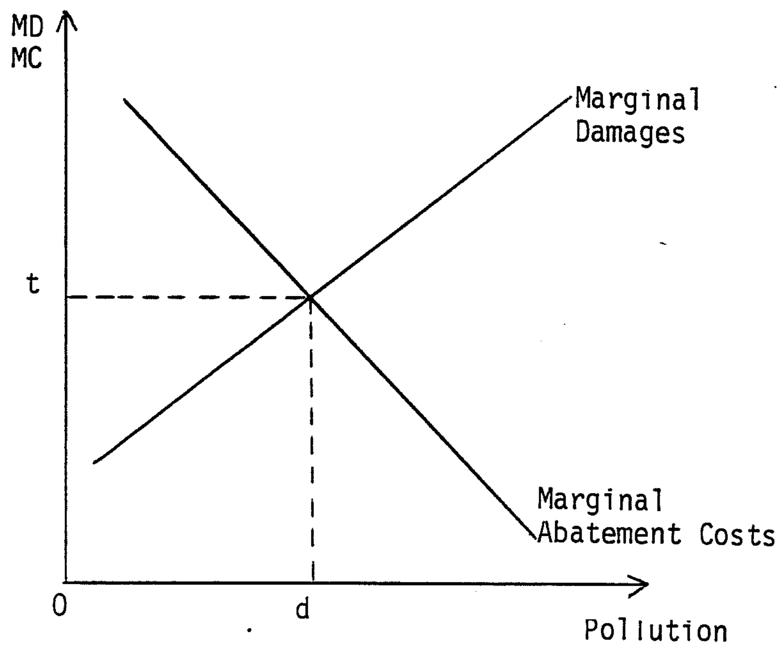
In 1972 the Organization for Economic Co-operation and Development (OECD) introduced the PPP to its members and suggested that the PPP should become a part of their national environmental policies. In addition, member countries were urged to move away from assisting the polluters in bearing the cost of pollution control through subsidies or tax allowances [47]. Recognizing the significant role of the PPP proposal, extensive studies have been carried out, resulting in an OECD 1974 implementation of the guidelines for the PPP. The Polluter-Pays Principle is basically a "non-subsidy" principle; nevertheless, exceptions to the general rule are allowed if certain conditions were met [48]. For example, to qualify for assistance it is required that industries, regions, or plants have severe difficulties and furthermore the assistance must not be likely to create any distortions to international trade. The ultimate goal of the Polluter-Pays

Principle is to ensure an acceptable level of quality of the environment [47]. The PPP believes that due to scarcity and the over-use of resources, it is necessary for the public authorities to establish a price for environmental goods and to assign the responsibility to the polluter. As the name suggests the polluter has to pay for the damages it produces; that is, regardless of how these costs are incurred, it is obligated to cover all costs associated with pollution controls [48]. Therefore, the main concerns of the principle are how to internalize the external effects of pollution and how to fix charges for polluting activities. With an effort to coordinate efficiency and equity with available economic instruments for environmental policies, the principle further recommends that it is not always the polluter who has to bear all the expenses; consumer in many cases should also play a role in contributing to pollution control costs [48]. Also, it is not practical for the polluter to pay all the costs associated with pollution prevention and control measures; for example, parts of the administrative costs should be passed onto the taxpayers since it is not equitable to charge the cost only to the polluting party. Finally, whether the polluter can pass totally or partially some of its costs on the consumer, depending on the market structure and on the elasticity of demand.

In 1981, the OECD Environment Committee reviewed the PPP principle and clarified some ambiguities relating to proposals such as the notion of "an acceptable state of environment", the length of the transitional period, the inclusion of administrative costs, etc. [48]. Specific recommendations have been suggested to the members to ensure a more effective use of policy instruments. Among the reviewed economic instruments within the PPP, three main instruments are defined, they are: air pollution taxes, subsidies to producers, and pollution rights.

## 6.2.1- Taxes versus Subsidies; Pollution Rights

In his paper on the Polluter-Pays Principle, Beckerman discussed these three approaches and concluded that in the short run the effects of resource allocation are the same regardless of which methods are applied [65]. This conclusion is illustrated with the following diagram.




From the graph we see that the desirable level of pollution is at **Od** where the marginal cost of pollution is equal to the marginal damage from pollution. This optimum amount of pollution can be obtained if a pollution tax or subsidy is fixed at **Ot.** The producer will pay **$Ot** per unit of pollution or he is paid **$Ot** for every unit of reduced pollution. The equilibrium point is the same in both cases; in the former case, to the right of **d** since **$Od** of tax is greater than the amount of marginal costs, the producer will reduce pollution up to the point where the cost of further reductions would exceed the tax (points to the left of **d**). In the latter case, there would be reduction up to the point where the cost of further reduction would exceed the bribe he would receive for agreeing to a further reduction. The producer therefore has the same incentive to reduce pollution emission by the same amount with either method. Nevertheless, in the long run the subsidy approach would lead to a resource distortion since it provides an incentive for new firms to enter the market [50]. Thus, in order to distract new entrants it is important to specify the existing and the remaining level of pollution for the proposed method of air quality control.

The question is whether taxes or subsidy schemes would lead to the same optimal solution if abatement technologies are suggested by the emission reduction program? Hartwick and Olewiler suggested that subsidies would bring more firms into the industry causing more pollution if we assume that the abatement capital installed and pollution emitted are the same for each firm. The reverse case would apply to taxes where firms would invest in technologies that minimize their pollution control costs; but depending on the tax rate firms will decide to adopt new technologies or not [50]. Compare the two cases, Hartwick and Olewiler conclude that taxes are preferable to subsidies as an economic instrument that would minimize the costs of meeting some environmental targets of controlling the pollution and to obtain an efficient use of resources. Firms would avoid paying taxes for the excess amount of emissions, if there are any, and firms would have an incentive to invest capital in a more efficient and least cost emissions-control technology.

Assuming that the tax scheme is now considered as a policy to control the pollution problem, what we must face now is the technical aspect of collecting accurate data to estimate the marginal damage and marginal benefit curves. However, we are not certain about the shape of those curves. Thus, if an appropriate tax rate is set under these conditions then an improvement of social welfare in general is questionable. Given this information, it is unlikely that the government could implement an optimal tax since it is too costly to obtain all the facts about the environmental benefits and damages [50].

Another possible price mechanism method for achieving the optimal amount of pollution, as Beckerman discussed, is to confer pollution rights. The optimum amount of pollution is **Od** (see above diagram) where marginal social damage from pollution intersects the marginal costs of abatement. The government then issues the "rights" to that amount and allows the equilibrium price to be settled on the market. The equilibrium price of the permit is **$Ot** and firms are obliged to bid for the rights to the point where the price of pollution rights is just equal to the costs of polluting without a permit. The three instruments that he discussed lead to the same conclusion that all polluters equate their marginal costs of using pollution as an input into their production process to the optimum price of pollution [65]. That is to say, the objective of Polluter-Pays Principle is achieved since the externality imposed on the society has been internalized and the marginal conditions for optimization of resource allocation are satisfied. Although the three methods theoretically provide us with the same optimal solution, the choice between different instruments remains debatable. It is not only the problem of reconciling environmental goals with other economic policy objectives but also the problem of how the public reacts to the involved institutions and instruments e.g. taxes and market rights.

The economic objectives of the Polluter-Pays Principle is to resolve the market failure of acid rain; however, that concept has not fully been implemented to the extent where, instead of control costs, residual damages have to be paid. The impasse of acid rain is the problems associated with the transfrontier pollution among the nations where property rights of air are not established and estimated damages and benefits are difficult to quantify. In his paper, The Economics of Transnational Pollution, Larry E. Ruff expressed that the transboundary problem in principle could be settled among the nations once the governments initiated institutional arrangements and mechanisms of environmental rights [66]. The suggestions seem to be simple and well-defined but still the governments are hesitant to negotiate environmental rights since they are uncertain how to manage these rights once they are established. The complexity and diversity of acid rain problems indicate clearly to us that pure economic considerations cannot resolve transboundary pollution [66]. The PPP principle, therefore, is unlikely to provide an optimal solution among nations because of different values and different opportunity costs in different countries. In the past the PPP principle was simply accepted, and governments attempted to coordinate its implementation into their environmental policy of controlling air pollution. However, it is difficult to enforce "polluter pays" since firms will partially or fully pass the costs of complying with regulations onto the consumers; furthermore, political and economic arguments overlap and will lead to a time lag between policy legislation and policy application, e.g. the cases of Northeast and Midwest states in the U.S and the Inco firm of Canada as we discussed above.

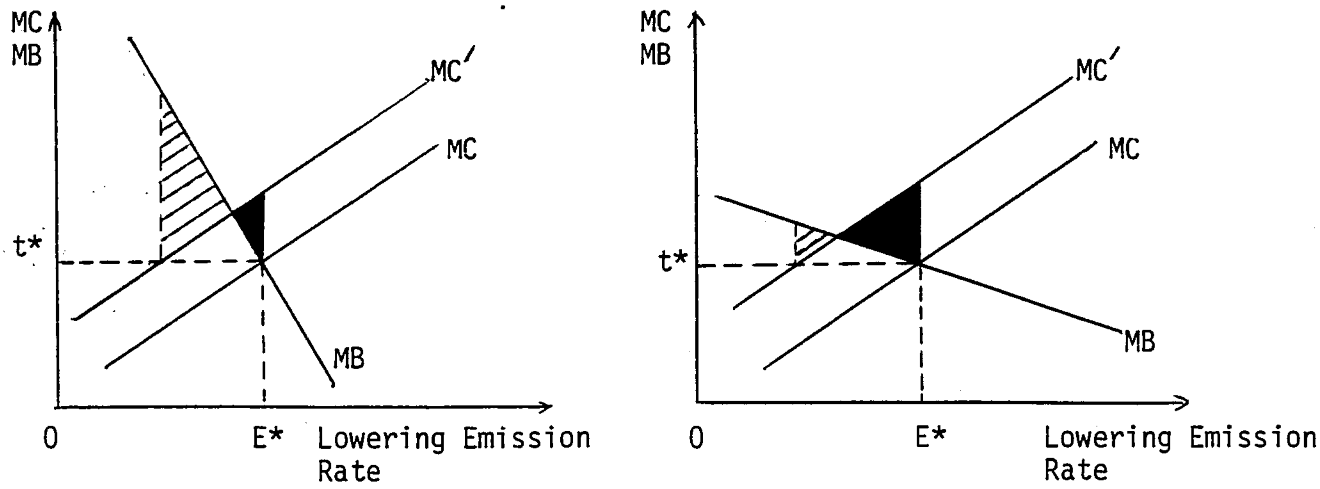
Canada's air quality and our environment are valuable assets of natural resources and once they are used up, the effects may not be reversible. The acid rain problem is unique and the magnitude of uncertainties further complicates the matter.

## 6.3- Uncertainty and Acid Rain

The main focus of environmental policy decisions concerning acid rain involve uncertainties. For example, the former Reagan administration's acid rain policy communicated that more information is needed before taking any further action to deal with the problem of acid deposition; and how much more information needed is also uncertain. Lack of knowledge about the environmental effect of policies, and the effects of acid rain on health and forest productivity confound the problem. The social optimal level of emission reduction is unknown due to incomplete data on damages caused by air pollution. In addition, the inability to place a precise dollar estimate on social costs or aesthetic values, such as the cost of resettling coal miners if firms decide to switch production to low sulphur coal, accentuates the uncertainty in economic evaluation models. This uncertainty makes firms' decision makers and pollution control agencies go through their marginal cost functions [51].

Adar, Griffin, and Fishelson (A-G-F) examined how uncertainty triggers the choice of the optimal policy instrument between effluent taxes and standards for achieving maximum expected economic efficiency of pollution control despite the incomplete information about the marginal damage and marginal benefit functions. They showed us that what determines the choice of an optimal policy is the slope of the marginal benefit and marginal cost curves.

One can conclude that when the marginal benefit of improving air quality is steeper than that of the marginal cost function, a lower expected social cost with the standard approach is preferable to a tax. Conversely, when the slope of the marginal cost curve is steeper, a tax is preferable to a quota [67]. The underlying assumptions are a linear marginal benefit and marginal cost functions, a deterministic marginal benefit function of emission reduction and stochastic marginal cost functions. These arguments can be illustrated with the following diagram.



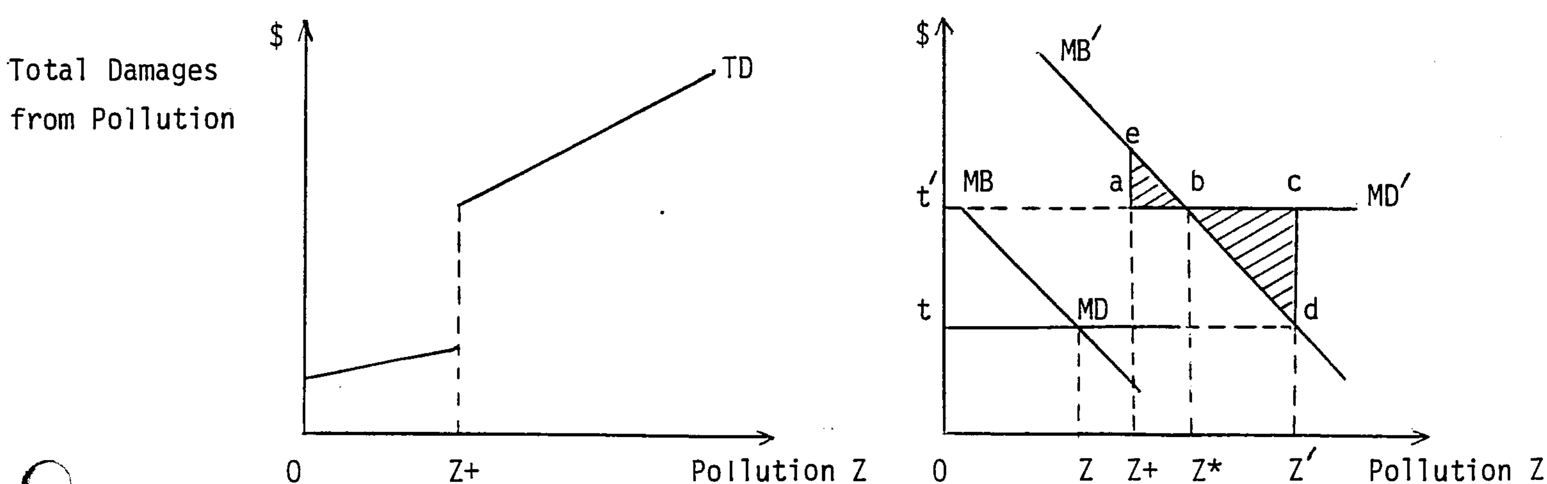

Taxes
Standards

Expected social cost under standards < Expected social cost under taxes

Taxes
Standards

Expected social cost under standards > Expected social cost under taxes

The model we examine here above is the one in which all the functions are linear and continuous, marginal cost functions are well defined. However, what happens to the optimal policy if these functions are discontinuous? Hartwick and Olewiler investigated the possible combination of control instruments that minimize expected efficiency losses under uncertainty. Their proposal is demonstrated with the following diagrams.




( a ) ( b )

Let us assume that the marginal damage function (MD) is known and discontinuous while the marginal benefit function (MB) is uncertain. From the graph we can see that total damages due to air pollution are increasing monotonically from **O** to **Z+** in (a) and the marginal damage is increasing at a constant rate in (b). The threshold level is at **Z+** where there is a big jump between the two segments of the MD function. The shapes and positions of these MD and MB curves play a vital role in policy decisions [50].

Optimal policy is shown through the suggested combination of standards and taxes. To prove this we will first examine how the standards and tax policy alone affects social losses, comparing this result with the one under the combined policy. Suppose the government has estimated the marginal benefit and follows the optimal path where MD intersects MB to set a fixed tax rate at **Ot** and the pollution is as a result at **Z**. Assuming further that due to errors in quantifying the actual benefit, the actual MB curve is above the estimated one. If the tax rate is **Ot** then social losses would be **bcd** and an excess amount of pollution emissions at **Z'**. An alternative for the government is to impose a standard at the threshold level **Z+**. Another problem arises if the marginal benefit is underestimated, because the pollution now is too little compared to **Z***. An extreme case would result if a higher tax rate is set at **Ot'** and the estimated marginal benefit is MB. A larger amount of efficiency losses would occur if MB' is overestimated, since the actual MB leads to smaller amounts of pollution. As Hartwick and Olewiler pointed out, the combination of a standard at the threshold level **Z+** and a tax rate of **Ot** would ensure the optimal amount of pollution. They suggested that even if the government does not have information about either the MB and MD curve, the combined policy would still be the best proposal to neutralize the excessive pollution emission. In other words, in the presence of uncertainty it is unlikely that the optimal results will be attained under either a tax or a standard policy [50].

The study of Watson and Ridker (W-R) was stimulated by Adar and Griffin's (A-G) suggestion that different expected social losses would occur if the marginal costs are uncertain and if effluent charges and emission quotas are used as policy instruments to control air pollution [53]. Although the empirical results agree with A-G's proposal, the underlying assumptions in W-R's analysis do not strictly follow A-G's theoretical framework, W-R have derived nonlinear marginal benefit and marginal cost functions [53]. As we discussed earlier, A-G emphasized the determinant in choosing the optimal policy was the relative slopes of the marginal benefit and marginal cost curves. On the contrary, under W-R's assumptions the different estimated expected social losses for both tax and standard instruments would be the leading indicators in policy making. They assume that a Federal control agency would impose uniformly a tax or an emission quota on all firms, and the purpose of their study is to find out which policy will lead to a minimum expected social loss. In W-R's empirical analysis, both tax and standard instruments are estimated for the period 1975 to 2025, under a strict and a relaxed policy, as well as an optimal policy. Under a strict policy, current Federal regulations are incorporated into the model and further air pollution restrictions are considered in the future. Contrast to a strict policy, a relaxed policy allows flexibility in both stringency and timing of strict regulations. The optimal policy is the one that will minimize the sum of control and damage costs [53].

One of the assumptions that Watson and Ridker emphasized is the high level of aggregation for sources or industries. Their empirical results, therefore, need not be considered as an absolute indication in choosing the optimal policy since the results may apply to aggregated sources but may not apply to specific components within the aggregates. Another point is that the analysis is performed under the assumption of high economic growth rates and high population growth rates [53]. As a result, the considered value has led to a relatively steep marginal cost curve and therefore it tends to select the effluent charges as an optimal policy instrument. Overall the decision to choose the optimal policy is based on the lower expected costs of either the simulated tax or standard instruments, depending on whether the government decides to implement this expected cost-minimizing control policy or to consider the two non-optimal strict and relaxed policies we have discussed above.

Watson and Ridker's findings in Table III [53] show us that for nitrogen oxides emissions approximately 80% of the results are in favour of a quota as the policy instrument. The expected costs range from $66 million under a strict policy for electric utilities to $28 billion under a relaxed policy for mobile sources. There are only two cases under a strict policy where effluent charges are preferred to quotas. Their expected costs are estimated at $463 million and $3 billion for electric utilities and vehicular transportation, respectively [53].

In the case of sulphur oxide emissions existing under a strict policy, the expected costs would be smaller for industrial sources if a tax is applied. If quotas are used to control the emissions the expected costs for electric utilities, residential and commercial sources and transportation sources would be $3 billion, $34 billion and $2 billion, respectively. Nevertheless, under a relaxed policy, effluent charges provide electric utilities, industrial and transportation sources with smaller expected costs of $42 billion, $48 billion and $421 million, respectively. Finally under a cost-minimizing policy a reduction of expected costs range from $1 billion if quotas are considered as the optimal policy instrument for industrial, residential and commercial, and transportation sources. The reverse case would apply to electric utility where tax would lead to a saving of $1 billion [53].

Watson and Ridker's analyses have suggested that the application of a tax would lead to an efficiency gain with relatively high control levels, finding which basically supports the theoretical analysis of Adar and Griffin. Another suggestion is a possible combination of a tax and a quota, of which the switching from one policy to another should be considered when timing is permittable and the transaction costs of doing so are feasible. For example, they find that during the period from 1975 to 1990 under a strict and a cost-minimizing policy, the expected costs would be smaller if a quota is used, whereas in later years the effluent charges would lead to lower expected costs. In other words, the decision to choose one policy instrument over another should be studied and examined carefully before adopting it [53].

So far we have examined the role of taxes and standards in dealing with environmental problems. They are utilized to correct the distortions in the market where the price of a "bad", namely acid rain, is not established. The argument for a choice between taxes or standards as an environmental instrument is based on costs. Should we be concerned with the costs imposed on the polluters who are the cause of the emissions that damage the environment, or should we be further concerned about costs to the society as a whole? Is society better off if environmental taxes or standards are put in place? In Canada and in the United States, standards have been used extensively under command-and-control legislation. While all agree that the quality of the environment has been somewhat improved, the question as to what extent it has improved remains controversial. In the following section we are going to observe whether the regulatory approach is applied efficiently and effectively as policy for controlling the acid rain problem.

## 6.4- The traditional regulatory approach

Air pollution has been considered as an externality and when the public became concerned about the irreversible effects of acid rain on the environmental quality, government intervention played a central role to control the damage to the environment. Direct controls enforce the polluting activity to comply with regulations by means of legal measures and therefore this approach bypasses the potential of economic mechanisms [54]. The traditional regulatory approach seemed to be a practical solution to curtail undesirable emission. This method is based on the "best available" and "best practicable" technologies, where a maximum level of emission is set for the firms by regulators. The firms will either have the right to choose the best suited technology to comply with emission limits, or a specific type of emission-control technology will be imposed on them. While the former is referred to as a "performance standard", the latter is referred to as a "design standard". These policies are considered under the "command-and-control" approach. Firms which do not meet the standard would face regulatory penalties. The responsibilities of the government, therefore, is to set standards and to monitor the firm's degree of compliance throughout its period of adjustment [54].

In his study about the performance and design standards of environmental regulation, Benoit Laplante suggested that, firstly, it is difficult for the regulator to set "acceptable" emission limits at the level where an adequate enforcement of environmental policies becomes effective due to imperfect information. Facing this dilemma, Canadian and U.S regulators could apply the "best available" and "best practicable" technologies. Secondly, the Ontario Ministry of Environment confirms that firms are more likely to minimize their costs under a performance standard to comply with the targets. Laplante's results indicate that under a design standard the social cost of an emission abatement program will be lower compared to a performance standard [55]. He calculates the private costs and social costs and compares the results under the performance and design standard. From his results, the findings show that the private costs are smaller if a performance standard is imposed on the polluter and, on the contrary, consumers' losses and social costs are higher.

Between the two policies, society is better off with a design standard which has a relatively lower social cost. Clearly from his study we observe that under a design standard social welfare is higher and this indicates the important position of private costs and social costs in policy making. In Canada, most of the industry is under a performance standard while in the U.S. environmental regulators often use a design standard [55]. Since the indicators suggest to us that the social cost of complying with the target is smaller under a design standard, the government should not ignore the possible combination of the two policies that could lead to a more efficient and effective use of resources.

At first, the traditional regulatory approach is quite simple to adopt since needed improvements in environmental quality can be achieved under government regulation. But due to a lack of information, the question of the efficiency of this technological approach is debatable. The concepts of cost and benefit are indiscernible although regulators have acquired technological and engineering data, compliance costs and other socioeconomic factors in order to achieve the emission target [55]. It seems that this approach provides no incentives for the firm to develop better emission-control technology, and the goal of obtaining a minimum cost is not feasible.

Bruce Doern discusses that there is a further possible reduction of emission, even below the initial target, with market-oriented emission-control policy such as emissions taxation or marketable permits [56]. The reason is that the firms will equate their marginal cost and marginal benefit functions and will avoid not paying the emission tax above that equilibrium point or they would sell the permits of the unused emissions. Furthermore, firms would have an incentive to invest into research and development for a more efficient and least cost emission-control technology.

In the next section we are going to examine whether market-oriented approaches can be considered as better alternatives to the current traditional regulations.

### 6.5- Marketable permits

Economists have long argued that the traditional regulatory approach is inefficient in controlling the pollution problem and suggested that the government could internalize the externality by organizing a marketable permit system, such as emissions trading. Early advocates studied the use of the market as a way to lead to an optimal price for air pollution [57]. The government will set a target level of environmental quality or quantity of emissions, then it will establish permits that grant the owner the property right to pollute a specified amount. Montgomery, proved that the optimal amount of pollution is achievable with low costs as long as the tradable-permit market is competitive and firms minimize their costs of compliance [58]. Tientenberg analyzed the impact of implementing the current air regulation with the tradeable permit system. His study shows that in the short run the potential cost savings would be significant once the emission trading program is undertaken [59]. While in Canada emission trading has not been applied into the existing air-pollution control regulation, the U.S. has been gaining experiences by using emission trading. We are now going to examine the concept of emission trading that grants firms the right to trade the permits for emitting air pollutants. The performance of these activities are also analyzed, when possible, to evaluate the impact of the program in order to find out whether this approach could be exercised efficiently as an alternative to the traditional regulations in Canada.

When the Environment Protection Agency (EPA) compared their existing command-and-control approach with the emission trading they realized the potential for cost savings in the billions of dollars annually. Since 1974 the EPA has experimented, developed and implemented policies for more effective and efficient air pollutant control [60]. This emission trading program is, therefore, considered as an extension of the Clean Air Act, in which greater flexibility allows firms to trade emission rights both internally and externally within and among industries. The EPA initially establishes environmental goals and two types of standards are introduced: the ambient-based system (ABS) and the emissions-based system (EBS) [60].

**The ambient-based system (ABS)**

Under the ABS, receptor areas must be determined so that total projected emissions would be compatible with the ambient air quality standards. Once it is agreed upon, a number of permits that would sum up to this total amount of emissions is issued. The regulators will decide whether these permits can be granted to the existing polluters or be auctioned through the market. The sole task of the regulator now is monitoring and enforcing polluting activities to ensure the market operates efficiently. It is argued that one of the ABS advantages is that sufficient information about the marginal costs of the firms or any calculation of marginal damages and marginal benefits of pollution are not required to determine the optimal tax for the target level of emission [50]. Furthermore, the permit system would allow firms to attain pollution limits at a minimum cost. This will result in incentives for firms to invest their capital in abatement technology that could reduce substantially the cost of controlling air pollution. Nevertheless, polluters would find compliance with ambient standards too costly. The reason is that once the receptor areas are defined, firms have to obtain all the permits in a large number of markets where their pollution is transported to and, therefore, the polluters have to incur tremendous transaction costs. This also shows that its administration will be complex for the control authority to monitor [50].

**The emission-based system (EBS)**

Under the emission-based system (EBS), the rate of emission will be specified for a particular type of source. Permit markets are narrowed down to one market where firms can now eliminate the problem of multiple markets that is faced under the ABS. The advantage of emission standards is that since firms are not allowed to trade across regions, they try to operate efficiently in this single market [50]. The major concern about this approach is the "hot spots" problem where an excessive amount of pollution is concentrated within one area. This particular problem could be resolved by creating thinner markets within an assigned zone. However, then it comes close to the ambient-standards multiple market problem. Another concern involves the spillover effects of air pollution. In this case it is difficult for the firms to comply with the standards since the EBS policy is designed without a market that can deal with significant transaction costs of the transboundary pollution [50]. This scheme is therefore suitable for specific pollutants that have confined impacts or quick dispersion characteristics and a global market with no spillovers or hot spots. For example, chlorofluorocarbons (CFCs)- which are transpired from aerosol sprays and refrigerants once they are released into the environment- are dispersed quickly into the upper atmosphere and deplete the ozone layer. This leads to the irreversible effects such as the global warming effects, skin cancers, and agricultural yield reduction [50]. When compared to the ABS, emission standards require more data and information to determine the number of permits that can be given to each region. This requisition involves the issue of how effective the ABS and EBS are; since time and resources have been unable to obtain essential information that guides policy makers to plan efficient strategies for air quality control [60].

We have just discussed the theoretical advantages and disadvantages of the two alternative policies: the ambient standards and the emission standards. We will now examine the empirical study of Atkinson and Tietenberg that tries to compare and evaluate the performance of different marketable permits based on its operating control costs. The simulation in this study is by a linear programming model, where the data consist of the 27 largest plants that emit about 80% of total particulate emissions in the St. Louis Air Quality Control Region of the United States [61]. In this study, Atkinson and Tietenberg compare six types of marketable permits. The six models include: 1) the ambient-based system, as we discussed earlier; 2) an emission-based system with a rollback version in which a specified percentage of emission reduction is assumed for the worse air quality zone; 3) the highest ambient permit (HAP) as a simplified form of the ABS, where the difference between the HAP and the ABS is the permit market, where under the HAP there is only one permit market and these permits are defined in terms of the most polluted region; and, 4-6) three other types of multiple-zone modified emission permit systems [61].

The simulated findings have shown that the ABS is the most cost-effective method with the lowest abatement costs because the standards are less stringent than other schemes we have considered. But when standards vary, the prices of the permits are quite volatile. The compliance costs of the HAP scheme are very close to that of the ABS. This result indicates that although the problem of multiple permit market is restrained within a single market, there is not a big difference in abatement costs between these two methods [61]. The most expensive method is the emission-based system, or its modified versions, with significant increases in the controlling cost of achieving a given air-quality level. In addition to a tremendous compliance cost of the emission-based method, permit expenditures induce a larger share of total expenditures which sum up the control cost and permit expenditures [61]. The problem under the EBS is that the regulators have to put more stringent tactics to fulfil the desired level of air quality. This requirement is reflected with very costly permit prices in the simulation where the ratio between permit expenditures and the total of permit expenditures and control costs is quite high. However, the ratio slightly decreases for all six types of permit systems as the degree of control is more severe due to a faster escalating control costs when comparing it to permit expenditures [61].

If one is to consider the effectiveness of these methods, emissions have increased under the ABS and HAP strategies since these two systems are designed to reduce only the emissions at the sources that generate a massive pollution impact on the region but not at distant minor sources where emissions increase substantially. Overall, total emissions increase because distant sources emit more than the emission reduction at the proximate sources. Nevertheless, the ABS is the only scheme that guarantees ex-ante and ex-post air quality standards since the regulators have a complete control over environment standards [61]. Finally, based on this finding the authors suggest that the regulator should implement policies according to the aspect of pollutants that have local and/or long distance impact, such as the acid rain problem [61]. This means that the cost savings from using differentiated permit schemes have to be reviewed carefully in dealing with the long-range pollutant transport issue. Among the examined six permit schemes, Atkinson and Tietenberg come to the conclusion that the HAP system seems to be a feasible policy since it is simpler to administer and to monitor polluting sources, and furthermore, the assumption of single market would save tremendous transaction costs incurred by firms [61]. Although the HAP scheme is considered as a plausible policy, it can be applied only to pollutants that have the global distribution characteristic as we discussed earlier in the ambient-based system. This leads us to the conclusion that air-quality improvement under this policy will be questionable when dealing with the acid rain problem. Finally, all of the permit systems discussed have the hot spot problem where increased emissions exceed the desired standards, except the ABS. Therefore, to ensure an acceptable level of pollution it is necessary for the control authority to set up a threshold level for the polluters to comply with [61].

So far we have observed some economic implications of the ABS and EBS marketable pollution right systems to achieve ambient air quality standards. Could they be employed to curb the acid rain problem? Another study by Scott Atkinson deals with the question of acid rain and marketable permits. In his study, Atkinson uses a programming model similar to that of Atkinson and Tietenberg to examine the impact of an emissions permit system in the Cleverland region of the Ohio River Basin [62]. The data include the twenty-five largest plants that emit about 95% of total sulphur dioxide emissions in the region and these sources come from industrial operations, coal and oil fired electric utilities. The significant amount of pollution in the region is presumably one of the contributors to acid deposits in Canada and the north-east United States. The simulation is analyzed with the comparison of the three systems against each other: the current State Implementation Plans (SIP), the ambient discharge permits (ADP) and the emission discharge permits (EDP) [62].

The programming model shows that local ADP is the least-cost method to attain ambient standards with an approximate total annual cost of $82.9 million compared to $123.4 million of the local SIP strategy. This is due to the different assigned allocation of control responsibility of the two strategies [62]. While the ADP system is taken into account the lowest marginal cost for each individual operation, the SIP system is controlled with a uniform rate of liability for all sources. Overall, the ADP and the SIP strategies are less are less costly than the EDP strategy which is about $158.2 million and this cost differential is due to a more stringent policy under the EDP system [62]. The findings also shows that the local ADP is an effective strategy to remove sulphur dioxide emissions in comparison with the SIP and EDP strategies. This significant total amount of emission degradation is a result of, firstly, the local ADP being a cost-effective method which is reflected in its low total annual costs and permit prices; secondly, local ADP system being required to reduce its emissions at ambient ground-level and higher smokestack as a solution to transporting pollution to farther distances [62].

Assuming now that the long-range transport of pollutants is constrained to the model, we see from the results that total emission control for the three strategies are increased and at the same level. Under the SIP and ADP strategies, total sulphur dioxide emissions are elevated similarly and their total annual costs are increased from $82.9 million to $112.8 million for the ADP and from $123.4 million to $144.3 million for the SIP system. The global ADP method is no longer considered as a cost-advantage method because of its substantial increase in annual costs [62].

After examining the two studies, we can agree that the ABS system seems to be a potential candidate to attain compliance with local ambient standards. The decision to use the ABS system is based on its local cost of control which is found to be less than or equal to that under any other system. The cost of saving under the ABS system would lead to a local significant reduction of emissions but at the expense of an increase in sulphur dioxide in other regions due to its long-range acid deposition from high smokestacks. To alleviate this long-range effect Atkinson suggests global restrictions on the transmission of sulphur dioxide out of the regions by imposing an acid rain transport constraint [62]. From the simulated findings, this suggestion reduces the saving costs of the ABS system relative to the SIP and EBS strategies. It is therefore questionable whether the global ABS method is well-suited for the acid rain problem. One becomes unsure about these strategies when we take into account the global effects of acid rain: should the cost saving differential of the local ABS system be adequate to compensate for additional transaction costs and administrative costs of the global ABS system or should the global SIP system be implemented despite its relatively high total annual costs? The answer is still unclear, depending on the multitude of sufficient collecting data and on the sufficient information providing by potential traders [62].

Krupnick et al. suggest an offset scheme that combines certain properties of the ABS and EBS systems. Their proposal is that the tradable permit, instead of being defined in terms of pollutant concentrations at each receptor point or in terms of emission levels, is specified in terms of emissions which are allowed to be transferred amongst polluters [63]. It is shown theoretically that the sum of transaction and abatement costs could be achieved to meet ambient air-quality standards. Although the suggested model is designed to overcome some problems arising from the ABS and EBS systems, it is quite difficult to avoid an increase in administration costs once its air diffusion model is used to resolve the impact of new emission trends. The government has to incur the cost increase since it is important to have sufficient information on trade patterns in order to issue and approve trade permits so that the aggregate effects of any changes in the standards will be observed for future study [63].

So far we have discussed possible concepts and methods in dealing with the problem of pollution control. Although they are differ greatly in the distribution of costs and benefits among polluters and the regulators, they all tend to direct us to strive for cost-effective allocations of air improvement targets. In the following part we are going to review the U.S. experience with trading that has been applied primarily in air pollution control [64].

### 6.5.1- The U.S. experience with emission trading

Emission trading has long been introduced to the U.S. environmental policies during 1970s to increase flexibility to the firms and also to control a number of air pollutants. It defined the four activities that firms may employ to meet the target level. These activities include netting, offsets, bubbles and banking [57].

Netting allows major firm to increase its emissions if existing emissions elsewhere in the same firm decrease to the level where net increase is negligible. Table 17 summarizes estimates of the numbers of transactions, estimated cost savings and environmental quality impact that had resulted through 1985. Examining these findings we see that netting is the most widely used activity which involves 5000 to 12,000 transactions internally. The tremendous estimated cost savings of the program vary from $525 million to $12,000 million, reflecting uncertainty about the number of trade and cost savings. And finally, environmental quality impact is slightly negative due to the overall increase in emissions. Despite its popular application, netting is considered as a hindrance which encourages emission-credit markets since firms will save their emission reduction and not sell their excess amount of emissions to other firms [60].

The offset program allows new firm to enter an area where ambient air quality standard does not achieve the target level. It requires the existing firm to reduce the emissions that less than or equate to the same type of emissions from the new firm [60]. The significant result of this activity is that economic growth has been stimulated in those non-attainment areas. It is estimated that about ten percent of the 2000 offset transactions have occurred during this period [57]. The firm's willingness to pay for the offsets means that there is economic gain, but the magnitude of this benefit cannot be evaluated and as a result there is no estimated cost savings for this program. The impact of offsets on the environmental quality has been neutral or will lead to a decrease of emissions due to relatively small number of trades and a more stringent regulation on new sources [57].

Bubbles allows an existing firm to increase its emissions if another firm in the same region reduces its amount of emissions. Although the number of trades is quite small compared to netting and offsets, cost savings for bubble program are estimated about $435 million, of which $300 million results from federal approval and another $135 from state approval. It is uncertain for air quality as a result of an incomplete information about data collection; however, preliminary reports showed that the aggregate impact of bubbles might be slightly positive [57].

Banking allows the firm to save its emission reductions as an asset for future use or sale. It is the less common use of the emission trading program since it offers no incentive for the firms to bank its emission credit. Firms are concerned about the uncertainty of regulations imposed on these credits, such as confiscation or time limits on the validity of banked emission credits [64]. Cost savings of banking cannot be calculated; even so they are suggested to be insignificant given a small number of transactions. The aggregate effect of this activity may be slightly positive since banked credits implies a reduction of emissions that will be saved to offset future emission increases. Yet, its potential impact on air quality is regarded irrelevant because few firms are accumulating emission credits for their asset value.

From the findings and the evaluation of emission trading market performance it is suggested that an increase in transaction costs and a decrease in trades are affected by one or all of the following factors: many restrictions are regulated on new and modified sources; complicated administrative requirements and liable information are imposed on firms; and finally, effective allocation of property rights depends on the monitoring aspect and if this aspect is burdensome, stricter trading permits are likely to be issued [57].

Although the estimated cost savings from emission trading range from $135 million to $12 billion, the performance evaluation of these activities are far less than expected [64]. Since the substantial savings indicate that firms would be more cost-effective in meeting emission limits because trading permits among firms enable them to equate their marginal abatement costs; and since the aggregate environmental impact of emission trading is not significantly improved, it appears that there is a tradeoff between the goal of reducing costs and improving air quality. The U.S. experience proposes that we should not ignore potential cost savings of emission trading and moreover the goal of cost reduction and air quality improvement can be compromised by a careful design for each mechanism of the trading program.

Economists have long supported tradeable permit scheme for its potential cost-effectiveness and its capability to stimulate economic growth and achieve environmental standards simultaneously. Should marketable permits be freely traded if they are considered as an alternative to the traditional regulatory approach? Observing the experience in the United States we realize that despite the flexibility, which is designed to offer firms to achieve emission target at a lower cost advantage as it is claimed, the actual cost savings are not as large as they are expected. This is due to tight regulations on trades and procedural requirements and they are regarded as barriers to trading. For the trading market to be effective, it is important to avoid a thin market where fewer operating firms are likely to exercise their power to hoard permits. That is to say a trading zone has to be designed properly to ensure that each zone would include a sufficient number of pollutant receptors to perform actively in the permit trading market [19]. Problems may occur if the assigned area includes so many small plants which will finally contribute a further increase in administrative costs. It is suggested that for trading programs to be more realistic and cost-effective it should comprise all major pollutant sources and leave small sources to other economic instruments or regulatory standards [19].

Therefore, the answer to the question of whether marketable permits should be freely traded has to be reexamined. Many factors are taken into account in designing economic instruments and implementing regulations. Potential impacts of the chosen policy such as economic, income and regional distribution effects have to be fully investigated before the government implements the economic instruments in Canada.

## VII. CONCLUSIONS

Acid rain has been recognized as a major threat to the environment. We have shown that it is a major cause of damage to forestry, agriculture, tourism, the aquatic ecosystem and historic buildings and monuments.

Since 1970 intensive research on the effects and control of acid rain has been conducted in Canada and in the United States and is still on-going. Both countries have taken action to deal with the problem of acidic deposition. More significantly, the Canada-U.S. Air Quality Agreement has been signed to renew their commitment to fight against transboundary airborne pollution.

Acid rain is considered as an economic externality to the environment. While attractive in theory, there are many difficulties involved in implementing environmental policies. Traditional regulatory approach has been applied to both Canada and the U.S.; however, the Americans have had more experience with the use of economic instruments to achieve socially desirable environmental goals. As discussed in Chapter VI., economic instruments offer a number of potential advantages over the regulatory approach. They will not only give decision makers the flexibility to choose the most cost effective method, but also to provide economic incentive for the firms to reduce pollution and to invest capital in a more efficient and less costly emission control technology.

The ultimate goal of regulators and firms is cost minimization. Nevertheless, this objective is difficult to obtain since there is a significant scope for the use of a variety of economic instruments in dealing with the acid rain problem. While in some cases regulatory approval is preferable, in others it is more cost effective if regulators and market incentives are combined to achieve emission target levels.

In Canada, experience with the use of economic instruments has been limited; nevertheless, we should consider the potential cost savings of the U.S.'s emission trading programs. Since acid rain is an international or at least a transborder problem, it seems reasonable to suggest that a comprehensive economic model is mandatory and can only be achieved with support, co-operation, and compromises from all levels of governments and related industries.

As acid rain continues its destruction, the expense of pollution is borne by the population in the form of social and environmental costs. Therefore, understanding the cause and effect of acid rain and the reduction in its emission is not only crucial but must be made mandatory for all countries. Most of all what is important is that the choice for action exists and can only be made by an increased awareness about the seriousness of acidification, not just among governments and industries but also to end users, the public.

# TABLE 1

## ATMOSPHERIC SULFUR INPUTS FOR EASTERN NORTH AMERICA

| Term | Magnitude ($Tg\ S\ yr^{-1}$) for Eastern: Canada | | U.S.A. | | North America | |
|---|---|---|---|---|---|---|
| Man-made emissions | 2.1 | (47)[b] | 14 | (91) | 16 | (93) |
| Natural emissions, | | | | | | |
| sea spray, internal | 0.06 | (1) | -[c] | | 0.06 | (-) |
| terrestrial biogenic | 0.06 | (1) | 0.04 | (-) | 0.1 | (1) |
| marine biogenic | 0.2 | (4) | 0.4 | (2) | 0.6 | (3) |
| Inflow from oceans | 0.04 | (1) | 0.02 | (-) | 0.06 | (-) |
| Inflow from west | 0.1 | (2) | 0.4 | (2) | 0.5 | (3) |
| Inflow to U.S. from Canada | - | | 0.7 | (5) | - | |
| Inflow to Canada from U.S. | 2.0 | (44) | - | | - | |
| TOTAL | 4.6 | (100) | 15.6 | (100) | 17.4 | (100) |

[a]Area includes Ontario, Quebec, the Atlantic Provinces, the Gulf of St. Lawrence, approximately one-half of the Hudson Bay, and in the United States all area east of 92°W (approximately east of the Mississippi River).

[b]Numbers in parenthesis indicate percent of total emissions (natural and man-made).

[c]Dashes indicate negligible contribution.

SOURCE: Record, Frank A., et al., Acid rain information book 1982

# TABLE 2

## EASTERN CANADIAN AND EASTERN U.S. SULPHUR DIOXIDE AND NITROGEN OXIDE EMISSIONS IN 1980

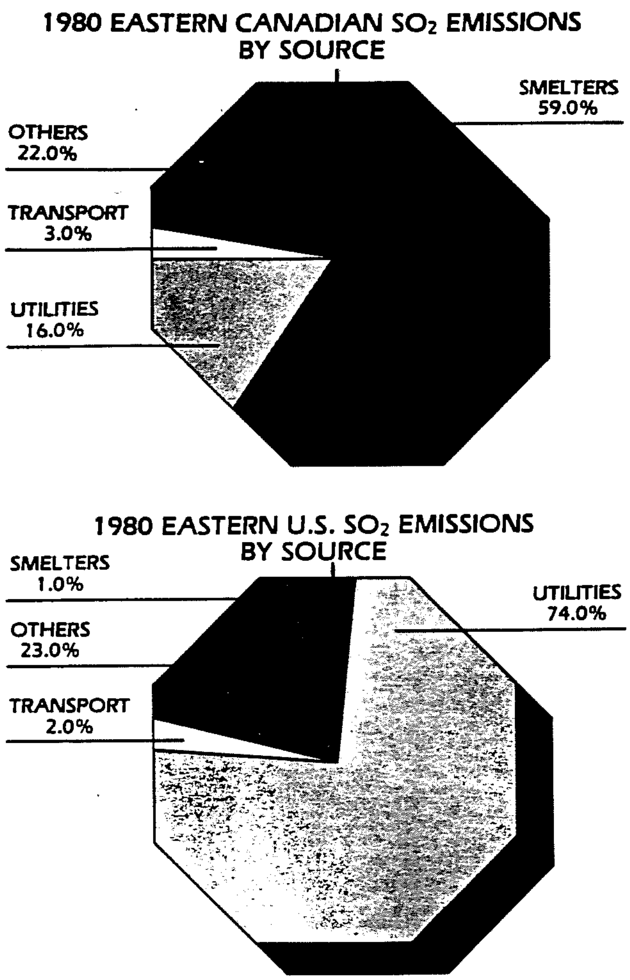
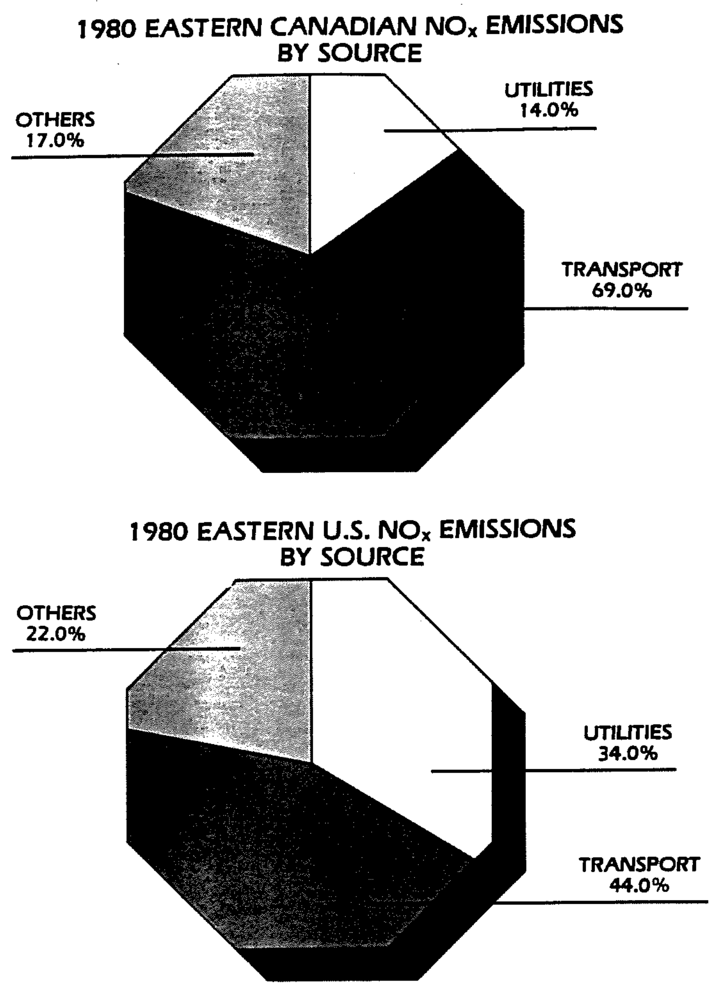



Figure 1 – 1980 Eastern Canadian and Eastern U.S. $SO_2$ Emissions



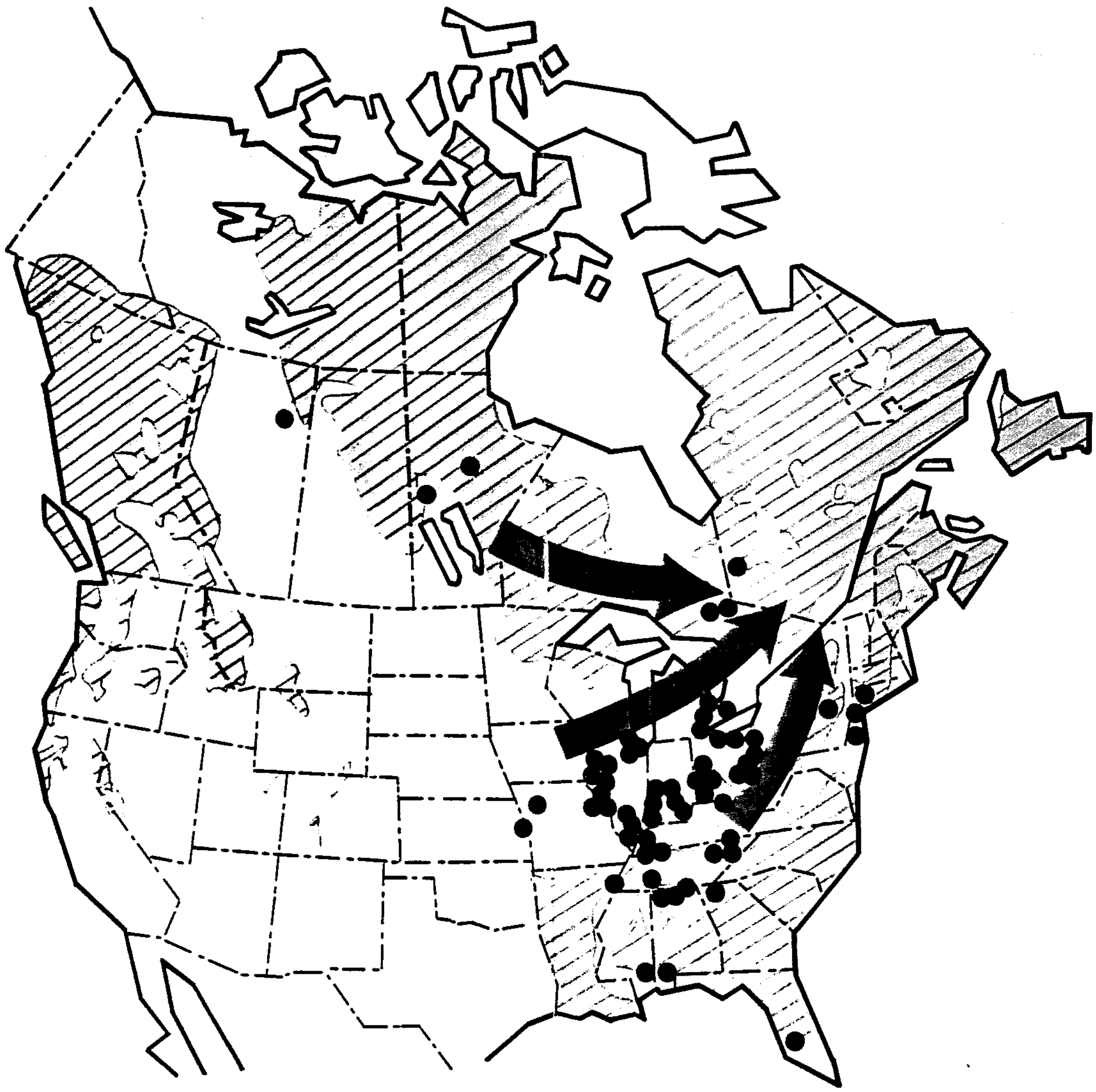

**Note:** The $NO_x$ emission total for eastern Canada reflects a change in methodology for estimating road vehicle emissions. Consequently, it should not be directly compared to previously reported estimates.

Figure 2 – 1980 Eastern Canadian and Eastern U.S. $NO_x$ Emissions

SOURCE: Environment Canada, Clean air programs in Canada and the United States, 1988

TABLE 3

LOCATION OF MAJOR SOURCES OF SULPHUR DIOXIDE EMISSIONS IN NORTH AMERICA AND PREVAILING WIND PATTERNS



● Areas having $SO_2$ emissions greater than 100 kilotonnes per year.

Areas most sensitive to acid precipitation.

Important storm paths.

SOURCE: Environment Canada, Acid rain - The fact, 1988

TABLE 4

# PERCENT DISTRIBUTION OF AQUATIC SENSITIVITY CLASSES ACROSS CANADA

| PROVINCE/TERRITORY | AQUATIC SENSITIVITY CLASSES* | | | | |
|---|---|---|---|---|---|
| | HIGH | MODERATE | LOW | UNRATED (ICE) | UNRATED (ORGANIC) |
| British Columbia | 32 | 44 | 18 | 3 | 3 |
| Alberta | 6 | 11 | 70 | <1 | 13 |
| Saskatchewan | 37 | 3 | 56 | 0 | 4 |
| Manitoba | 30 | 2 | 38 | 0 | 30 |
| Ontario | 34 | 20 | 20 | 0 | 26 |
| Quebec | 82 | 8 | 7 | 0 | 3 |
| New Brunswick | 31 | 49 | 12 | 0 | 8 |
| Nova Scotia | 54 | 33 | 13 | 0 | <1 |
| Prince Edward Island | 46 | 54 | <1 | 0 | <1 |
| Newfoundland | 56 | 30 | 4 | 0 | 10 |
| Northwest Territories | 48 | 25 | 18 | 6 | 3 |
| Yukon Territory | 43 | 35 | 17 | 3 | 2 |
| Canada | 46 | 21 | 23 | 2 | 8 |

* Aquatic sensitivity is interpreted from the potential of soils and bedrock to reduce acidity.

SOURCE: Environment Canada, A national sensitivity assessment, 1988

TABLE 5

## U.S. AQUATIC RESOURCES BY STATE AND ACID SENSITIVITY CATEGORY (km ) 10-20 kg/ha.yr SULPHATE DEPOSITION (USDA 1971, 1978)

| | Low Potential to Reduce Acidity | Moderate Potential to Reduce Acidity | High Potential to Reduce Acidity | Total Surface Water Area in the State |
|---|---|---|---|---|
| REGION III | | | | |
| Virginia - | 10 | 20 | 40 | 2,950 |
| West Virginia | 10 | 0 | 0 | 480 |
| REGION IV | | | | |
| Florida | 0 | 100 | 9,560 | 13,130 |
| Georgia | 280 | 210 | 180 | 3,000 |
| REGION V | | | | |
| Illinois[a] | 0 | 0 | 0 | 2,110 |
| Michigan | 1,350 | 0 | 190 | 4,180 |
| Minnesota | 1,460 | 8,440 | 890 | 13,810 |
| Wisconsin | 2,310 | 1,240 | 240 | 5,420 |
| REGION VI | | | | |
| Oklahoma | 0 | 0 | 1,170 | 4,440 |
| Texas | 0 | 0 | 1,060 | 15;260 |
| REGION VII | | | | |
| Iowa[a] | 0 | 0 | 0 | 990 |
| Kansas | 0 | 0 | 1,000 | 3,140 |
| Missouri[a] | 0 | 0 | 0 | 2,770 |
| Nebraska[a] | 0 | 0 | 0 | 2,330 |
| REGION VIII | | | | |
| North Dakota | 0 | 620 | 200 | 4,540 |
| South Dakota | 0 | 410 | 1,210 | 4,240 |
| TOTAL | 5,420 | 11,040 | 15,740 | 82,790 |

[a] These states are included, even though they do not have surface water area in counties falling into one of the three sensitivity categories, because they have surface water area falling into the urban/agricultural category receiving 10-20 kg sulphate/ha.yr.

SOURCE: U.S.- Canada Memorandum of intent on transboundary air pollution, 1983

## TABLE 6

### U.S. AQUATIC RESOURCES BY STATE AND ACID SENSITIVITY CATEGORY (km ) 20-40 kg/ha.yr SULPHATE DEPOSITION (USDA 1971, 1978)

| | Low Potential to Reduce Acidity | Moderate Potential to Reduce Acidity | High Potential to Reduce Acidity | Total Surface Water Area in the State |
|---|---|---|---|---|
| REGION I | | | | |
| Connecticut | 340 | 0 | 0 | 500 |
| Maine | 6,010 | 0 | 0 | 6,010 |
| Massachusetts | 970 | 0 | 0 | 1,100 |
| New Hampshire | 860 | 0 | 0 | 860 |
| Rhode Island | 340 | 0 | 0 | 460 |
| Vermont | 720 | 0 | 0 | 1,000 |
| REGION II | | | | |
| New Jersey | 150 | 660 | 10 | 920 |
| New York | 1,930 | 1,050 | 520 | 5,260 |
| REGION III | | | | |
| Delaware | 0 | 0 | 0 | 330 |
| Dist. of Columbia[b] | 0 | 0 | 0 | 0 |
| Maryland | 0 | 1,020 | 80 | 1,900 |
| Pennsylvania | 40 | 300 | 400 | 1,620 |
| Virginia | 70 | 1,600 | 840 | 2,950 |
| W. Virginia | 110 | 20 | 120 | 480 |
| REGION IV | | | | |
| Alabama | 10 | 1,280 | 1,590 | 3,040 |
| Florida | 0 | 410 | 960 | 13,130 |
| Georgia | 250 | 1,660 | 560 | 3,000 |
| Kentucky | 30 | 140 | 410 | 2,320 |
| Mississippi | 60 | 970 | 620 | 2,470 |
| North Carolina | 310 | 9,010 | 1,110 | 10,480 |
| South Carolina | 0 | 640 | 2,100 | 2,750 |
| REGION V | | | | |
| Illinois | 0 | 0 | 90 | 2,110 |
| Indiana | 0 | 40 | 150 | 930 |
| Michigan | 1,650 | 0 | 140 | 4,180 |
| Ohio | 0 | 0 | 20 | 970 |
| Wisconsin[b] | 0 | 0 | 0 | 5,420 |
| Tennessee | 90 | 100 | 1,440 | 3,140 |
| REGION VI | | | | |
| Arkansas | 0 | 180 | 500 | 3,670 |
| Louisiana | 0 | 0 | 10,050 | 11,390 |
| Oklahoma | 0 | 880 | 1,330 | 4,440 |
| Texas | 0 | 10 | 3,040 | 15,260 |

## TABLE 6

## CONTINUED

| | Low Potential to Reduce Acidity | Moderate Potential to Reduce Acidity | High Potential to Reduce Acidity | Total Surface Water Area in the State |
|---|---|---|---|---|
| REGION VII | | | | |
| Iowa[b] | 0 | 0 | 0 | 990 |
| Kansas[b] | 0 | 0 | 0 | 3,140 |
| Missouri | 0 | 0 | 1,320 | 2,770 |
| TOTAL | 13,940 | 19,970 | 27,400 | 107,890 |

[a] The states of Minnesota (13,810 $km^2$), Nebraska (2,330 $km^2$), North Dakota (4,540 $km^2$) and South Dakota (4,240 $km^2$) received less than 20 kg/ha.yr sulphate deposition in 1979-80.

[b] These states are included, even though they do not have surface water area in counties falling into one of the three sensitivity categories because they have surface water area falling into the urban/ agricultural category receiving 20-40 kg sulphate/ha.yr.

SOURCE: U.S.- Canada Memorandum of intent on transboundary air pollution, 1983

# TABLE 7

U.S. AQUATIC RESOURCES BY STATE AND ACID SENSITIVITY CATEGORY (km ) FOR GREATER THAN 40 kg/ha.yr SULPHATE DEPOSITION (USDA 1971,1978)

| | Low Potential to Reduce Acidity | Moderate Potential to Reduce Acidity | High Potential to Reduce Acidity | Total Surface Water Area in the State |
|---|---|---|---|---|
| REGION II | | | | |
| New York | 0 | 200 | 0 | 5,260 |
| REGION III | | | | |
| Maryland | 20 | 0 | 0 | 1,900 |
| Pennsylvania | 0 | 250 | 220 | 1,620 |
| W. Virginia | 10 | 0 | 210 | 480 |
| REGION IV | | | | |
| Kentucky | 0 | 260 | 480 | 2,320 |
| Mississippi | 0 | 90 | 10 | 2,470 |
| Tennessee | 0 | 10 | 640 | 3,140 |
| REGION V | | | | |
| Illinois | 0 | 0 | 80 | 2,110 |
| Indiana | 10 | 0 | 0 | 930 |
| Michigan | 40 | 0 | 40 | 4,180 |
| Ohio | 0 | 0 | 360 | 970 |
| REGION VI | | | | |
| Arkansas | 130 | 1,170 | 400 | 3,670 |
| Louisiana | 0 | 0 | 1,050 | 11,390 |
| Oklahoma | 0 | 210 | 0 | 4,440 |
| Texas | 0 | 0 | 4,050 | 15,260 |
| REGION VII | | | | |
| Missouri | 0 | 0 | 80 | 2,770 |
| TOTAL | 210 | 2,190 | 7,620 | 62,910 |

SOURCE: U.S.- Canada Memorandum of intent on transboundary air pollution, 1983

TABLE 8

A) MINERAL EXTRACTION—MAJOR $SO_2$ SOURCES (KILOTONNES)

| | 1980 | 1988 | 1989 | 1990 | 1991 | 1994 |
|---|---|---|---|---|---|---|
| | (Actual) | | | | | (Emissions limits) |
| **MANITOBA** | | | | | | |
| Inco Ltd. (Thompson) | 215 | 284 | 250 | 247 | 250 | 220 |
| Hudson Bay Mining and Smelting Co. (Flin Flon) | 248 | 266 | 249 | 253 | 293 | 220 |
| **ONTARIO** | | | | | | |
| Inco Ltd. (Copper Cliff) | 812 | 658 | 637 | 617 | 572 | 265 |
| Falconbridge (Sudbury) | 123 | 60 | 68 | 70 | 70 | 100 |
| Algoma (Wawa) | 161 | 80 | 71 | 43 | 53 | 125 |
| **QUEBEC** | | | | | | |
| Noranda (Horne) | 552 | 425 | 292 | 146 | 165 | 166 |
| Noranda (Murdochville) | 91 | 58 | 49 | 43 | 45 | 65 |
| **NEW BRUNSWICK** | | | | | | |
| Noranda (Belledune) | 15 | 23 | 23 | 6 | 8 | — |

B) ELECTRIC POWER GENERATION—MAJOR $SO_2$ SOURCES (KILOTONNES)

| | 1980 | 1988 | 1989 | 1990 | 1991 | 1994 |
|---|---|---|---|---|---|---|
| | (Actual) | | | | | (Emissions limits) |
| Ontario Hydro | 396 | 321 | 305 | 195 | 167 | 175 |
| New Brunswick Power | 123 | 158 | 177 | 141 | 130 | 123 |
| Nova Scotia Power | 125 | 147 | 146 | 143 | 144 | 145 |

SOURCE: Annual report on the Federal-Provincial Agreements for the Easten Canada Acid Rain Program , Canada's Green Plan P.4,1991

## TABLE 9

TOP 20 COAL FIRED POWER PLANTS IN THE U.S.A RANKED ACCORDING TO TOTAL SULPHUR DIOXIDE EMISSIONS IN 1979

| Rank | Plant | State | Estimated sulphur dioxide emissions Thousands of tonnes/year |
|---|---|---|---|
| 1 | Paradise | Kentucky | 372.5 |
| 2 | Muskingum | Ohio | 340.2 |
| 3 | Gavin | Ohio | 339.5 |
| 4 | Cumberland | Tennessee | 289.7 |
| 5 | Monroe | Michigan | 264.9 |
| 6 | Clifty Creek | Indiana | 263.7 |
| 7 | Gibson | Indiana | 261.1 |
| 8 | Baldwin | Illinois | 257.9 |
| 9 | Labldie | Missouri | 224.0 |
| 10 | Kyger Creek | Ohio | 205.5 |
| 11 | Bowen | Georgia | 202.6 |
| 12 | Conesville | Ohio | 186.8 |
| 13 | Mitchell | West Virginia | 186.2 |
| 14 | Hartfields | Pennsylvania | 167.2 |
| 15 | New Madrid | Missouri | 164.0 |
| 16 | Sammis | Ohio | 160.7 |
| 17 | Wansley | Georgia | 159.7 |
| 18 | Homer City | Pennsylvania | 159.1 |
| 19 | Johnsonville | Tennessee | 157.9 |
| 20 | Gaston EC | Alabama | 154.8 |

SOURCE: Irwin, Ronald et al., Still waters: The chilling reality of acid rain, 1981

TABLE 10

TOP 10 STATES: 1980 SO2 EMISSIONS FROM UTILITY AND NONUTILITY SOURCES

| STATE | 1980 SO2 EMISSIONS (TONS) | PER CAPITA SO2 EMISSIONS (LBS/PERSON) |
|---|---|---|
| OHIO | 2,647,000 | 493 |
| PENNSYLVANIA | 2,022,000 | 340 |
| INDIANA | 2,008,000 | 733 |
| Illinois | 1,471,000 | 256 |
| Missouri | 1,301,000 | 523 |
| Texas | 1,277,000 | 162 |
| KENTUCKY | 1,121,000 | 604 |
| Florida | 1,095,000 | 205 |
| WEST VIRGINIA | 1,088,000 | 1,107 |
| Tennessee | 1,077,000 | 459 |
| 10 STATE TOTAL | 15,107,000 | 488 |
| NATIONAL TOTAL | 26,480,000 | 226 |

TABLE 11

TOP 15 POWER IMPORTING STATES (MEASURED BY % OF END USER SALES)

| STATE | 1984 POWER IMPORTS AS % OF IN-STATE SALES |
|---|---|
| RHODE ISLAND | 89% |
| NEW JERSEY | 50% |
| Mississippi | 39% |
| Louisiana | 34% |
| Virginia | 31% |
| California | 31% |
| Minnesota | 26% |
| Maryland/DC | 23% |
| Idaho | 20% |
| Iowa | 17% |
| MASSACHUSETTS | 14% |
| Ohio | 10% |
| MAINE | 9% |
| Florida | 7% |
| NEW HAMPSHIRE | 5% |

**SOURCE:** James S. Cannon, Controlling acid rain - A new view of responsibility, 1987

## TABLE 12

| SO2 EMISSIONS ASSOCIATED WITH POWER EXPORTS TOP 15 POWER EXPORTING STATES | |
|---|---|
| STATE | 1984 TONS SO2 EMISSIONS |
| WEST VIRGINIA | 677,077 |
| PENNSYLVANIA | 326,293 |
| Alabama | 193,395 |
| Wyoming | 88,793 |
| New Mexico | 55,907 |
| KENTUCKY | 300,600 |
| INDIANA | 320,371 |
| Georgia | 165,106 |
| Oregon | 908 |
| Arizona | 29,880 |
| North Dakota | 58,599 |
| Washington | 8,593 |
| Texas | 13,776 |
| Nevada | 17,843 |
| North Carolina | 46,876 |
| 15 STATE TOTAL | 2,304,017 |
| NATIONWIDE POWER PLANT EMISSIONS | 17,331,000 |

## TABLE 13

| TOP 10 STATES: 1984 POWER GENERATED FROM COAL | | |
|---|---|---|
| STATE | COAL POWER GENERATION (GIGAWATT-HOURS) | % DEPENDENCE ON COAL POWER |
| OHIO | 103,263 | 95% |
| PENNSYLVANIA | 98,132 | 75% |
| Texas | 91,901 | 42% |
| INDIANA | 80,246 | 99% |
| WEST VIRGINIA | 77,166 | 99% |
| Georgia | 63,821 | 87% |
| Illinois | 63,233 | 63% |
| Michigan | 55,629 | 77% |
| KENTUCKY | 55,072 | 94% |
| Missouri | 53,241 | 95% |

SOURCE: James S. Cannon, Controlling acid rain - A new view of responsibility, 1987

## TABLE 14

### NATIONAL EMISSION TRENDS FOR SULFUR DIOXIDE (ALL SOURCES - ANTHROPOGENIC) (10 Short Tons)

| | EPA | Gschwandtner | Knudson | OTA |
|---|---|---|---|---|
| | 1985 | 1985 | 1986 | 1984 |
| 1940 | 19.6 | 20.5 | | 19.1 |
| 1950 | 22.4 | 21.2 | | 18.1 - 21.6 |
| 1960 | 22.0 | 22.3 | | 21.2 - 22.2 |
| 1970 | 31.1 | 31.9 | | 28.7 - 30.8 |
| 1971 | 29.5 | 31.3 | | |
| 1972 | 30.2 | 30.7 | | |
| 1973 | 31.6 | 30.3 | | |
| 1974 | 29.7 | 29.9 | | |
| 1975 | 28.2 | 29.5 | 28.4 | 27.3 - 28.2 |
| 1976 | 28.9 | 28.6 | 29.2 | |
| 1977 | 29.0 | 28.6 | 29.3 | |
| 1978 | 27.0 | 27.2 | 27.4 | |
| 1979 | 27.0 | 27.7 | 27.4 | |
| 1980 | 25.6 | 27.2 | 26.0 | 25.2 - 26.1 |
| 1981 | 24.6 | | 25.6 | |
| 1982 | 23.5 | | 23.8 | |
| 1983 | 22.7 | | 23.3 | |
| 1984 | 23.8 | | 23.9 | |
| Change 1940-1980 | +29% | +33% | +31%* | +34% |
| Change 1970-1980 | -18% | -15% | -16%* | -14% |
| Change 1980-1984 | -8% | | -8% | |

* Used EPA based case estimate

**SOURCE:** Frederick B. Pope III- An overview of sulfur dioxide emission trends for the U.S. and Canada, Environment Protection Agency, 1988.

<u>TABLE 15</u>

**ESTIMATED OF MAN-MADE NITROGEN OXIDE EMISSIONS FROM VARIOUS SOURCE CATEGORIES IN THE UNITED STATES: 1975-1985**
(million metric tons/yr of nitrogen oxide)

| YEAR | SOURCE CATEGORY | | | | |
|---|---|---|---|---|---|
| | HIGHWAY VEHICLES | POWER PLANTS | INDUSTRIAL FUEL COMBUSTION[a] | OTHER[a,b] | TOTAL[a] |
| 1975 | 7.1 | 4.8 | 3.5 | 3.2 | 18.6 |
| 1976 | 7.4 | 5.1 | 3.7 | 3.3 | 19.5 |
| 1977 | 7.6 | 5.4 | 3.7 | 3.5 | 20.2 |
| 1978 | 7.6 | 5.4 | 3.7 | 3.6 | 20.3 |
| 1979 | 7.3 | 5.5 | 3.6 | 3.6 | 20.0 |
| 1980 | 7.2 | 5.8 | 3.0 | 3.3 | 19.3 |
| 1981 | 7.3 | 5.9 | 3.0 | 3.2 | 19.4 |
| 1982 | 7.0 | 5.6 | 3.1 | 3.0 | 18.7 |
| 1983 | 6.8 | 5.8 | 2.7 | 2.9 | 18.2 |
| 1984 | 6.8 | 5.8 | 2.9 | 3.1 | 18.6 |
| 1985[c] | 7.1 | 6.3 | 2.9 | 3.0 | 19.3 |

[a] Emissions from industrial combustion and other sources from Knudson appear to be low compared with estimates from the 1980 NAPAP Emissions Inventory (Wagner et al., 1986). Therefore, the totals presented may be low by approximately 1.2 million metric tons/yr.

[b] The category "other" includes residential and commercial fuel use, industrial processes, aircraft, railroads, vessels, and off-highway vehicles. It does not include emissions from forest fires and other burning.

[c] An estimate for 1985 emissions from power plants was calculated using the same methodology as in Knudson, 1986. The 1985 value for total emissions was obtained by adding the 1985 power-plant estimate to 1985 values for other categories of sources from the U.S Environmental Protection Agency 1987.

Source: Knudson, 1986

SOURCE: NAPAP Interim assessment - Emissions of acidic deposition precursors, 1988

TABLE 16

**ESTIMATED ECONOMIC VALUE AND NET LOSS FOR ADIRONDACK FISHERY (1982$)**

| | With Interfishery substitution | Without Interfishery substitution |
|---|---|---|
| Net economic value (without acidification) | 38,319,595 | 55,068,556 |
| Loss in net economic value (with acidification) | 1,660,954 | 1,964,040 |
| Loss in net economic value (assuming loss of twice critical average) | 2,611,148 | 3,201,961 |

**SOURCE:** Fredric C. Menz and John K. Mullen, Acidification impact on fisheries: Substitution and the valuation of recreation sources; in Thomas D. Crocker edition, Economic perspectives on acid deposition control, 1984.

## TABLE 17

SUMMARY OF EMISSION TRADING PERFORMANCE.

| Activity | Cost Savings (US$ million) | Environmental Quality Impact | Number of Trades |
|---|---|---|---|
| Netting | $525-12,000 | Slightly Negative | 5000-12,000 |
| Offsets | Not Applicable | Neutral | 2000 |
| Bubbles | $435 | Neutral | 132 |
| Banking | Very Small | Very Slightly Positive | 100 |

Source: Robert W. Hahn and Gordon L. Hester, "Marketable permits: Lessons for Theory and Practice," Ecology Law Quarterly, vol. 16:36, p.374, 1984

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