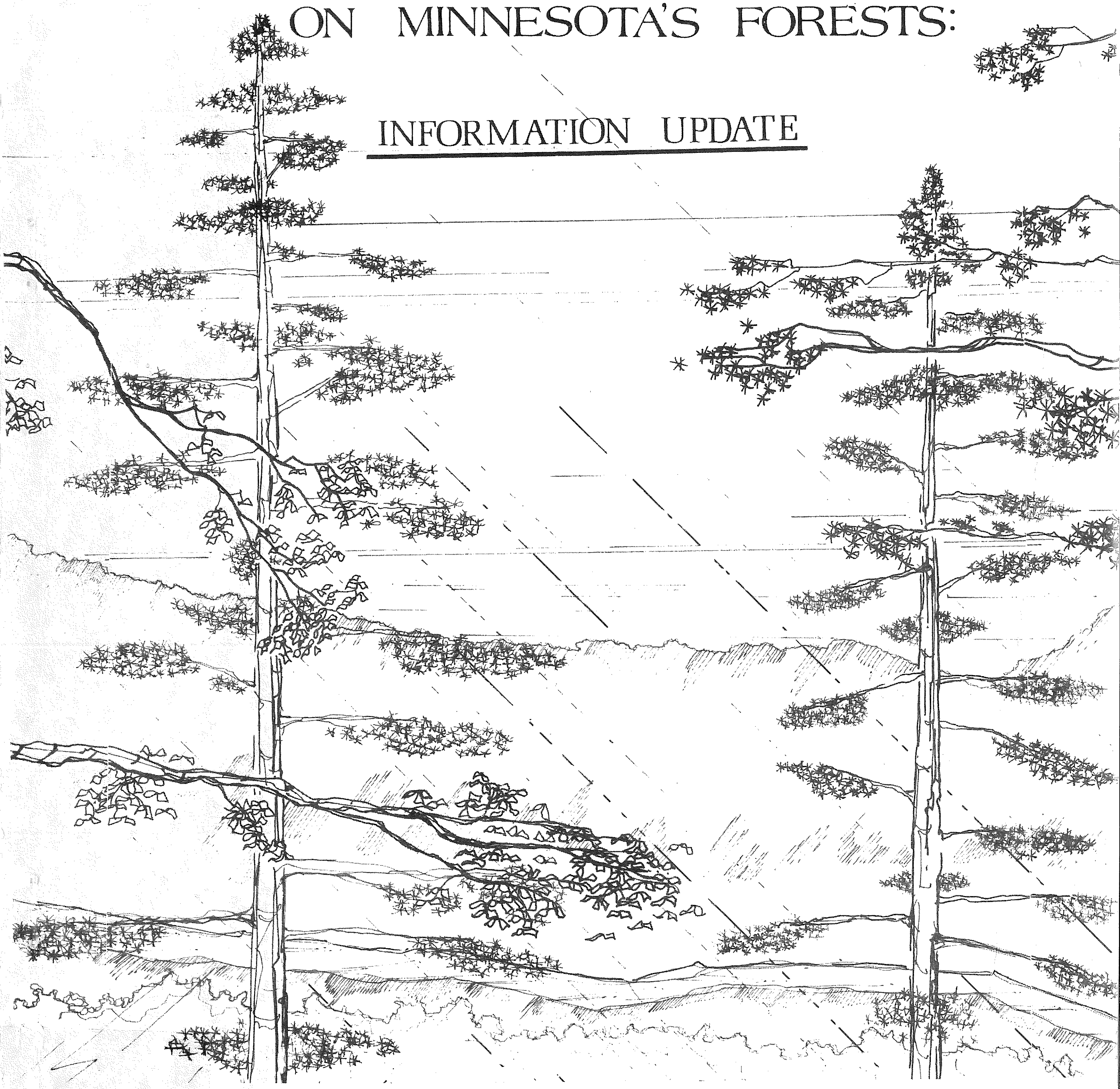
THE EFFECTS OF ACID DEPOSITION ON MINNESOTA'S FORESTS:

INFORMATION UPDATE



STATE of MINNESOTA
DEPARTMENT of NATURAL RESOURCES
DIVISION of FORESTRY

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The
Effects of Acid Deposition on Forest Ecosystems:
Minnesota's Response

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Literature Review
by
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ABSTRACT

This report assesses the direct and indirect effects of acidic atmospheric deposition (acid rain) on Minnesota's forests. A review of the present state of knowledge, research activities and information needs is also provided. Minnesota's response to acid rain is described, along with possible control options and mitigation techniques. A selected bibliography on the effects of acidic deposition on forest ecosystems is included.

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BACKGROUND[1]

Acid deposition[2] continues to be one of the most controversial energy/environment issues of the 1980's with potentially profound implications for environmental quality in the eastern United States, Canada and Central Europe. The issue may also significantly impact the economies of high sulfur coal producing regions in the eastern United States, as well as electric utility costs in areas where high-sulfur fuels are used extensively for electricity generation.

Acid deposition, often referred to as "acid rain," occurs when sulfur and nitrogen oxides emitted by coal-fueled power plants, smelters, vehicles and other sources, both man-made and natural, are transported in the atmosphere where they undergo a complex chemical transformation and return to earth as acid compounds. It is an issue requiring national attention because air pollutants are often transported in the atmosphere beyond the jurisdictions in which they are emitted, and contribute to acid deposition across state and even national boundaries (Figure 1).

Existing air pollution control policies under the Clean Air Act have been successful neither in resolving the interstate disputes over acid deposition nor in making it possible to reach agreement with Canada over how our two nations should deal with the exchange of acidifying air pollutants across our common border.

Acid deposition was first brought to prominent public attention by the Scandinavian countries, particularly Sweden, at the 1972 United Nations Conference on the Human Environment in Stockholm. This was done because

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[1] Adapted from "An Analysis of Issues Concerning 'Acid Rain'." Report to the Congress, U.S. General Accounting Office. GAO/RCED-85-13. December 1984.
185 p.

[2] The term "acid deposition" refers to the depositing of acid compounds from the atmosphere in both wet and dry forms. The terms "acid rain" and "acid precipitation" imply acid compounds deposited in wet form, omitting dry deposition of sulfur and nitrogen gases and particulates.

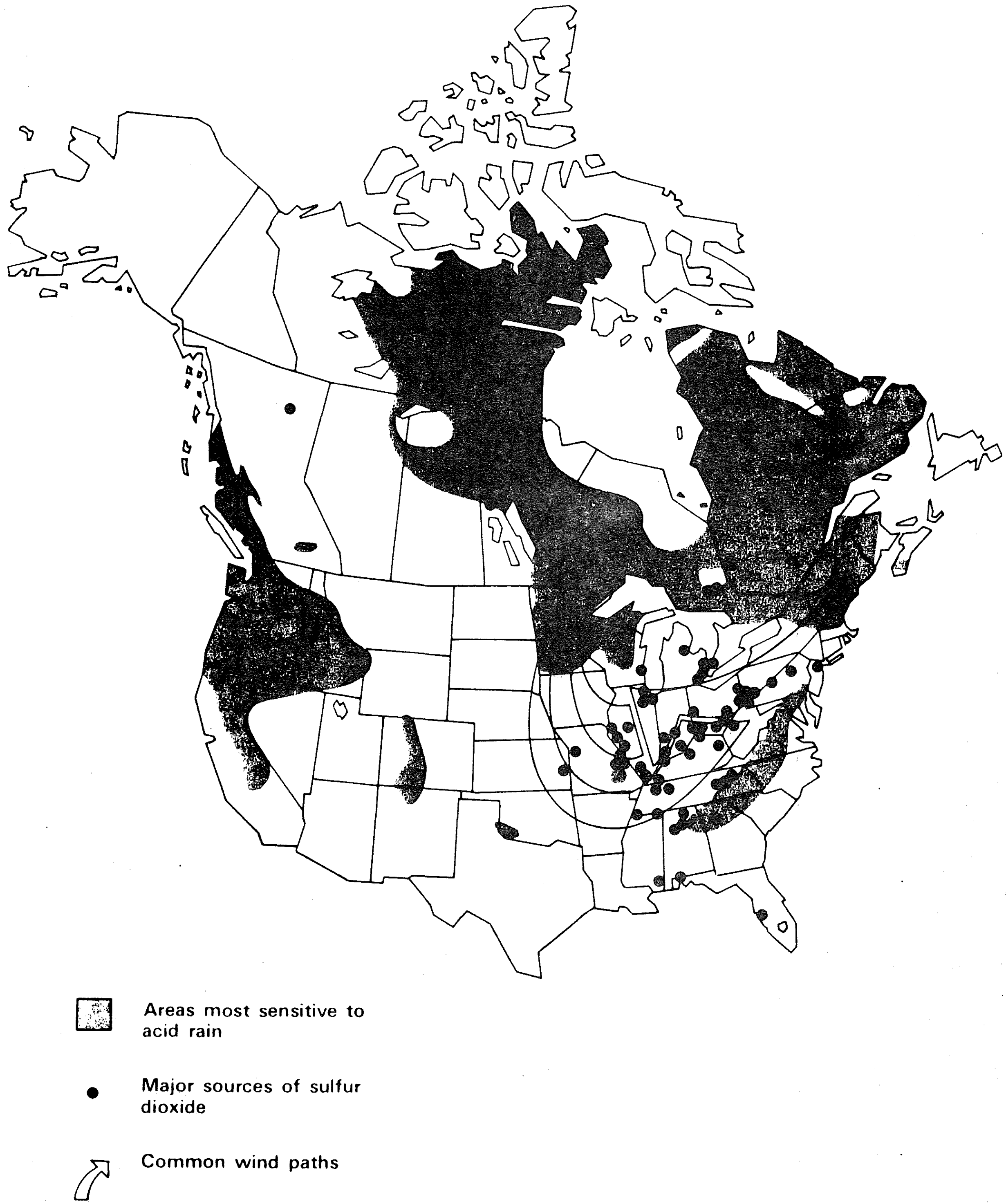


Figure 1. This map shows the major sources of sulfur dioxide emissions (more than 100 kilotons per year), common wind paths, and the areas of North America most sensitive to acid rain (after Galloway and Cowling, 1978).

Sweden and Norway had begun to recognize the effects of acid precipitation in their own countries, in the form of acidification of freshwater lakes and streams, and the decline or loss of fish populations in these waters.

The fact that the problem was first seen in Scandinavia turns out, in retrospect, to be largely due to a combination of three geographic factors. First, air movement patterns bring a good deal of the air pollution from industrialized areas in the northern part of Europe toward southern Sweden and Norway. Second, parts of the southern areas of these countries are at significant elevations above sea level and receive more precipitation than low-lying areas. Third, because these areas are at high elevation and high latitudes, they have been subject to quite severe climates, which make growing conditions for plants difficult. This has resulted in the formation of less soil there since the last ice age, compared with areas with more moderate climates. Hence, material deposited from the atmosphere has less chance of being absorbed by chemical or physical processes in these soils, and will pass on more readily to affect streams and lakes.

Intensive research in Sweden and Norway, work in other European countries, and joint European studies followed in the next few years. By 1977, this work led to recognition of the international nature of the problem--at least in the European context of relatively small countries--with a number of countries actually estimated to receive more of their acid precipitation from foreign than domestic sources.

Research focused on acid deposition in North America started in the middle 1970's although fishery losses had been observed earlier in lakes in the LaCloche Mountain area of Ontario. Because these lakes were located relatively near the site of the world's largest single sulfur-emitting source--a smelting complex at Sudbury--they did not necessarily give reason for concern about damage occurring because of emissions transported over long distances, as had been observed in Europe. Still, the amounts of the man-made pollutants, sulfur dioxide (SO_2) and oxides of nitrogen (NO_x), emitted in eastern North America were as large as or larger than those emitted in Europe so there was reason to search for similar effects here.

Acidification of lakes and associated losses of fisheries in about 180 of the higher altitude lakes in the Adirondack Mountains in northern New York were later detected, as was a correlation between water acidity and the decline of Atlantic salmon fisheries in some of the small rivers of Nova Scotia. In addition, studies were made to attempt to estimate the susceptibility to acidification of fresh waters in other areas of North America. These led to growing concern about the possibility of wider damage in a number of areas including northern Minnesota, much of New England, some mountain areas in the southern Appalachians, and large parts of southern Ontario and Quebec, Canada.

By 1978 the United States and Canada had established a Bilateral Research Consultation Group on the subject of trans-boundary air pollution. On July 26, 1979 the two governments released a joint statement announcing their intention to develop a cooperative air quality agreement, and in August 1980 a Memorandum of Intent (MOI) was signed to launch the process leading to negotiation of such an agreement. This process centered on establishing a set of joint Work Groups to assemble and analyze information and help propose measures for possible inclusion in an agreement.

At the same time, the U.S. government was establishing a coordinating body for acid precipitation research, first under presidential order in August 1979, and then through the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act of 1980, P.L. 96-294, June 30, 1980). This body, now known as the Interagency Task Force on Acid Precipitation, has issued annual reports for 1981-1985 and a National Acid Precipitation Assessment Plan in June 1982. Much of the work of the Task Force has been done in parallel with the work of the U.S. contributors in the U.S.-Canada Work Groups.

Intense political debate over the need for and cost of control actions, and how costs should be paid, have surrounded the acid deposition issue, tending to divide along geographic rather than party or ideological lines. This is because the areas experiencing or most vulnerable to damage are different from those areas from which the greatest share of man-made air pollutants are emitted. Leading examples of this controversy in Europe, for a decade or more, have seen Norway and Sweden seek reductions of utility and industrial emissions particularly from the United Kingdom, West Germany, France, the

Netherlands and several eastern European nations. Now, in more recent years, the eastern Canadian provinces and the northeastern states have been seeking similar action from major emission sources in the Midwest and Ohio River Valley.

Change on this front has not come easily because emission controls are expensive and the concept of long-range pollution is new and has been accepted slowly. Thus, while substantial emission reductions were made in the United States and Canada since SO_2 emissions reached their peaks two decades ago, these were generally done in response to policies aimed at protecting public health by meeting ambient air quality standards. Little further reduction is expected without further changes in emission policies. In fact, since the late 1970's the only important changes in emission control policies in nations involved in the acid deposition controversy have occurred in Canada and West Germany, which recognized that they themselves were at risk of or beginning to experience substantial damage to their own resources--particularly the large number of lakes at risk in eastern Canada and rapidly developing damage to forests in West Germany.

The major focus of concern on the part of those seeking emission reductions has been on sulfur compounds, mainly the oxide SO_2, which is the predominant form in which sulfur is emitted from combustion and other industrial processes. In most of western Europe a great deal of the SO_2 is emitted by combustion of heavy oils, with coal playing a lesser role than in the United States.

In the U.S. and Canada the call for reduction of SO_2 emissions is ironic because, as the 1970's ended, both countries had largely achieved the goals of SO_2 emission control programs that had started years earlier in response to concerns about health effects. As of 1980, total U.S. SO_2 emissions were estimated to be down 17 percent from their peak in 1973, and Canadian SO_2 emissions were down 28 percent from their peak, which occurred somewhat earlier, in about 1965.

According to projections made by the respective governmental air pollution control experts, however, these decreases are not expected to continue much longer in either country unless further controls are applied in response to new policies. In particular, by the year 2000, U.S. SO_2 emissions are projected to be more than 10 percent above 1980 levels, despite modest declines anticipated up to 1990. Western Canadian SO_2 emissions are projected to increase by one-quarter from 1980 to 1990 and by another 8 percent from then until 2000. It is only for eastern Canada, where policies to lessen acid deposition by reducing total SO_2 and NO_x emissions have recently been put into effect, that further reductions of SO_2 emissions are projected. The decrease is estimated to total 14 percent between 1980 and 2000, and the reduction could be significantly greater and could occur earlier if further emission reductions being planned by Canadian federal and provincial governments are actually ordered and implemented.

Canada has been making extensive efforts to urge the United States to join in carrying out major reductions of acidifying emissions, particularly of SO_2. The first formal Canadian emission reduction proposal made to the United States, in negotiations held in February 1982 under the MOI, was for the two nations each to lower their SO_2 emissions 50 percent below the 1980 levels. If such reductions were carried out, then United States and Canadian emissions would, in fact, drop about as much as the planned 1990 level in Sweden. To date, however, the nearest that any other nations have come to the Swedish plans occurred in a March 1984 meeting in Ottawa, where Canada and eight other European governments joined Sweden in agreeing to each reduce SO_2 emissions 30 percent below 1980 levels by 1993.

It is not clear whether emission reductions as severe as those now planned in Canada, or the even greater reductions planned in Sweden and proposed by Canada, will be necessary to prevent or sufficiently limit damage from acid deposition in North America. However, the scale of these actions does show how genuine and intense the concern about the problem is in countries that are experiencing acid deposition or are at risk of damage.

Recent Developments

It wasn't until the late 1970's that the issue of acid rain gained widespread public attention in the United States, even then it was an issue that focused on lakes and rivers. There was little evidence that acid deposition was substantially harming forests. More recently, however, a startling picture has begun to emerge, particularly in central Europe. Today, in West Germany, East Germany and Czechoslovakia, hundreds of thousands of acres of forest are in advanced stages of decline. Conifers such as fir, pine and spruce appear to be most susceptible. West German scientists have estimated that at least 30 percent of all forest areas are already damaged; trees are dead or severely stressed.

North American forests have not suffered such wholesale destruction, but in the Appalachians of Virginia and West Virginia, the Green Mountains of Vermont, and the White Mountains of New Hampshire, scientists have documented forest "dieback", especially among high-elevation red spruce. Pine forests in the New Jersey Pine Barrens have also been affected.

Finding it "plausible" that airborne pollutants coupled with secondary natural factors may be causing the decline, Dr. Robert Bruck of North Carolina State University's Plant Pathology Department has cited:

- Quantitative vegetation surveys in New York, Vermont and New Hampshire that show a 45 percent reduction in the basal area of living spruce trees over a 15-18 year period.
- A Virginia study showing an average of 82 percent of the red spruce exhibiting a five-fold decrease in annual growth increment between 1960 and 1965, as compared to growth increments between 1950 and 1960.
- A 20-30 percent growth decline in midland commercial pine forests of the Southern Piedmont area.
- Rapid deterioration in the physical appearance of southern Appalachian spruce-fir ecosystems caused by a complex disease syndrome involving ozone pollution, symbiotic root fungi, nitrate stresses, and high soil concentrations of lead, zinc, copper, nickel, manganese and aluminim.

Increasingly, attention is turning to the role of other pollutants in the atmosphere, either singly or acting in concert with acid deposition, to explain growth declines--especially the synergetic effects of ozone pollution and acid deposition. Thus, it appears we have a problem, if caused only in part by acid deposition. Debate is heated and more research is in order. Foresters have a great deal at stake due to the potential seriousness of acid depositon and its impacts on the forest environment. Foresters face a value judgment: support emission controls now or wait for research results and risk irreparable damage to our natural resources.

SUMMARY AND CONCLUSIONS

Forests are complex in structure, composition, ecology and in their response to agents acting upon them. These agents, in turn, are numerous and tend to act in combination rather than singly, and include many natural processes and events as well as stresses imposed by human activities.

Regional air pollutants, including but not limited to acid deposition, are among the most significant contemporary stresses that humans impose on temperate forest ecosystems. Gradual and subtle changes in forest metabolism, pest interactions, growth and species composition--over time and over wide areas--are the primary consequences to forests of regional air pollutants. These long-ranging and potentially widespread changes are more important than dramatic localized events, resulting in spectacular forest damage.

Perceived impacts of air pollutants on forests--such as alterations in growth rates or species composition--are obscured by the absence of easily observed or readily identifiable direct effects or symptoms. Consequently, it is difficult to assign responsibility for specific causes and effects.

Forest vegetation in Minnesota is unlikely to be affected directly by current levels of acid deposition. However, in the northeastern U.S., Canada and Central Europe forest vegetation is beginning to show significant effects from acid deposition due primarily to changes in soil chemistry. This may have implications for Minnesota forest soils.

Although adverse effects on Minnesota's forests resulting from acidic deposition have not been proven with existing evidence, one cannot conclude that acidic deposition is not having an adverse effect. Numerous legitimate hypotheses linking acid deposition with forest damage both here and abroad have been proposed and should be examined. It is critically important that research be conducted to provide greater understanding and perspective with which to reach management decisions and to frame public policy.

Sensitive and practical methods must be developed and implemented in order to monitor and predict forest health. For most foresters, however, there are essentially no practical options to counteract the subtle and unknown stresses imposed on forests by regional air pollutants. Indeed, foresters have a great deal at stake due to the potential seriousness of acid deposition and its impact on the forest environment.

Perhaps the most important thing to do is to work towards more adequate monitoring of forest resources. Wide scale monitoring involves two challenges. First, detection of forest stress does not suggest cause. The second challenge is to convince foresters that the time and costs associated with systematic monitoring of forest health is justified. Meanwhile, decisionmaking under uncertainty will test the forestry profession. The most logical step is to work for reductions in pollution emissions at their source.

ACIDIC ATMOSPHERIC DEPOSITION IN MINNESOTA: DIRECT AND INDIRECT FOREST EFFECTS

The effects of acid deposition on the terrestrial environment are likely to result from: 1) the direct and indirect effects of acids on exposed foliage, 2) the effects of acids on forest soils, and 3) effects on forest wildlife.

Injury to Vegetation

A number of studies identify potential mechanisms of direct injury to forest vegetation. In general, direct effects result when tree organs, such as leaves, limbs and roots contact acid deposition. Acidic deposition may also interact with abiotic stresses such as drought, low temperatures, pesticides, other air contaminants, or biotic stresses such as insect or disease pathogens. The distinction between direct and indirect effects can often be vague.

The biological response of forest trees is a function of the concentration of the deposition, the quantity deposited, frequency and duration of exposure, the intensity of rainfall, and susceptibility of vegetation. Development of foliar symptoms could also result from synergistic effects between photochemical oxidents, particulates, fluorides, and acid precipitation. Environmental and genetic variability, too, may influence foliar susceptibility.

Although acidic precipitation has not been shown to readily damage tree tissue at doses similar to those found under ambient conditions, the potential for damage cannot be dismissed (Evans and Curry, 1979). Individual precipitation events and cloud moisture are known to have pH values well below those for mean annual precipitation.

Potential direct effects of acid deposition include erosion of leaf surface waxes, interference with normal photosynthetic, metabolic and reproductive processes, leaf necrosis, premature senescence, poisoning of plant cells, and synergistic interaction with other environmental stress factors. Acidic precipitation may also directly influence trees by leaching substances from the tissues.

Indirect effects may include increased susceptibility to drought and other environmental stress factors, alteration of symbiotic associations of vegetation with mycorrhizae and nitrogen-fixing organisms, or alteration of host-parasite interactions. Little research has been conducted on the interaction of biotic and abiotic environmental stress factors. This interaction is highly variable and complex. The evidence of indirect effects does not support generalized statements concerning enhancement or restriction of abiotic or biotic stress factors by acid deposition.

Reproductive and Regenerative Effects

While direct effects from acidic deposition may not be manifest in mature trees, changes in the character of future forests could occur through changes in reproductive or regenerative phenomena of forest systems. Critical processes include pollen production, pollination, fertilization, fruit and seedling development, and juvenile growth. More research is needed in this area.

Ecosystem Productivity

The effects of acidic deposition on forest productivity can be either beneficial, neutral or detrimental to tree growth. Since nitrogen and sulfur are the primary acidic components in acidic deposition and are also essential plant nutrients, an increased growth rate due to a fertilizer effect can result. However, research also provides some evidence to suggest that acidic deposition can have detrimental effects including: 1) a loss of critical soil nutrients due to cation leaching or altered organic processes, and 2) toxic effects of elevated trace element levels (e.g., aluminum) in the soil solutions. Disruption of these important ecosystem processes can in turn influence structure, succession, production and regulation of the system.

Trends of declining growth during the past 20 to 25 years have been found in studies of beech, birch, and maple in the White Mountains of New Hampshire and the Catskill Mountains of New York, of red spruce in Vermont and the Smoky Mountains of Tennessee, and of pitch, shortleaf and loblolly pine in the Pine Barrens of New Jersey. Studies in Sweden, Norway and especially West Germany show similar, albeit much more severe, forest declines resulting from acid deposition. The hypothesis that acidic deposition can cause changes in tree species composition and ecosystem productivity is plausible. Direct scientific evidence, however, is not yet available.

The effects of acid precipitation on Minnesota's forests has been minimal up to the present time. It is unlikely that forest ecosystem productivity or timber productivity has been seriously affected (MPCA, 1985). It is also unlikely that ecosystem effects will occur in the near future as most of the rain falling on forest ecosystems is between pH 4.5 and 5.0, well above experimental levels shown to cause significant damage.

Effects on Soil Resources

Soils Sensitivity

Soil acidification is a natural process that occurs continuously in soils through which water percolates. Since soils acidify naturally, especially under coniferous vegetation, the real concern is whether acid precipitation will accelerate the process to a rate where vegetation growth, yield or establishment is impaired.

Forest soils in Minnesota are known to be more sensitive to acidification than agricultural soils. This is because 1) forested areas of the state are receiving more precipitation that is more acidic than agricultural areas, 2) forest soils of north-central and northeastern Minnesota are more extensively weathered, have less buffering capacity and are frequently shallow soils (less than 8 inches) over bedrock, and 3) unlike agricultural soils, forest soils are not commonly tilled, fertilized or cultivated.

In Minnesota, the majority of agricultural and prairie soils tend to have loam, silt loam, or clay loam textures, high buffering capacities, and tend to be found in drier climates with less precipitation of higher pH. Based on this, Minnesota's prairie and cultivated soils are not considered sensitive to acid deposition.

Susceptibility of a soil to acidification is closely associated with buffering capacity. A drop in pH will occur more rapidly in soils with a low buffering capacity and circumneutral pH than in soils having either high buffering capacity or low pH. Soils having low buffering capacity and low pH will not undergo appreciable change, however, any additional loss of bases may have detrimental effects on forest productivity (MPCA, 1985).

Sandy outwash soils in the eastern part of the state and shallow bedrock soils of the Arrowhead Region were originally thought to be the most sensitive to acid deposition. However, due to revised sensitivity criteria based on recent dose/response modeling results, and due to slower predicted rates of acidification, those soils previously classified as "sensitive" are now considered "potentially sensitive" to acid deposition. Soils reclassified as potentially sensitive are listed and briefly described in Table 1 and are shown in Figure 2.

Of the soils considered potentially sensitive a majority are soils derived from sandy outwash or sandy lacustrine sediments. Shallow bedrock soils are also represented, but to a lesser extent. The revised inventory contains an estimated 1,365,000 acres of potentially sensitive forest soils. The remaining soils in the state are considered nonsensitive to current levels of acid deposition.

Figure 2 illustrates areas of the state which contain potentially sensitive soils. Mapping at this scale, however, provides little detail and generally overestimates the areas in question. Potentially sensitive soils are far less homogeneous than illustrated. Areas mapped should be considered as an approximate location or boundary of areas containing potentially sensitive soils.

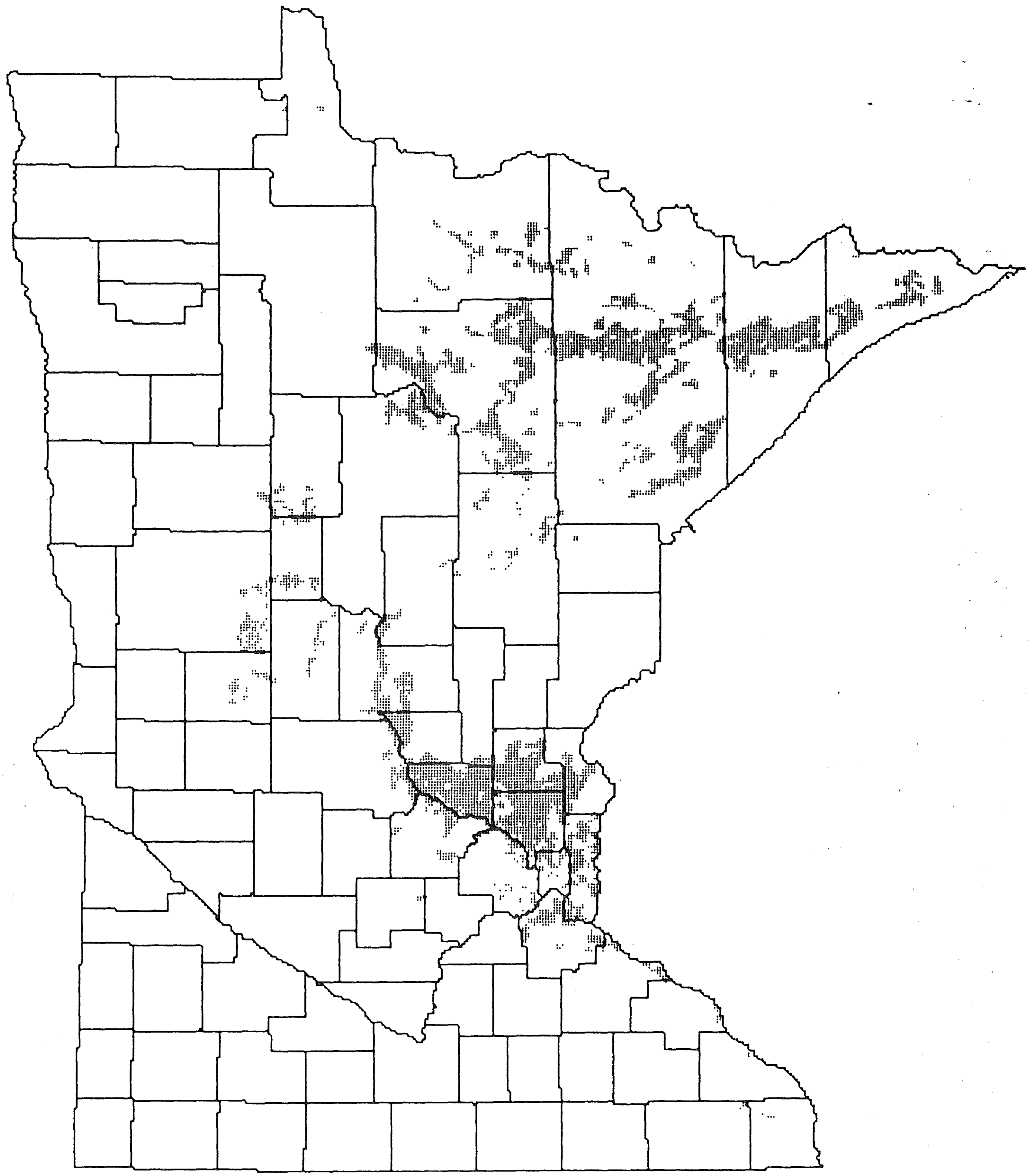
Northern portions of Cook, Lake, and St. Louis counties represents the approximate southern boundary of the Canadian Shield. Within this area are roughly 53,000 acres of shallow to bedrock soils mapped by the Superior National Forest as the Quetico series. Due to this soil's low initial buffering capacity and shallow depth to bedrock (less than 8 inches) it was classified as potentially sensitive. Remaining soils of the region were considered nonsensitive because of generally higher buffering capacities and greater soil depth. Due to mapping limitations, the Quetico series is not plotted on Figure 2.

Table 1. Soil Groups Classified as being Potentially Sensitive to Acid Deposition.

Soil	Description	Geomorphic Areas
SL-C	These soils formed in sandy lacustrine sediments, primarily in Glacial Lakes Upham and Aitkin. They include Aquic Udipsamments such as the Redby series. Areas occur in Itasca, Koochiching, St. Louis, and Cass counties. Approximately 469,600 acres.	Agassiz Lacustrine Plain Aitkin Lacustrine Plain Upham Lacustrine Plain Prairie River Outwash Plain
SL-NE	These soils formed in gravelly outwash, primarily of the Rainy Lobe. They include sandy skeletal Typic Udorthents and Typic Udipsamments, including the Toivola (Emmert) and Swatara soils. Areas occur in Cook, Lake, and St. Louis counties. Approximately 505,400 acres.	Toimi Drumlin Area Mesabi Range Big Rice Outwash Plain Sawbill Outwash Plain Brimson Outwash Plain Wahlsten Moraine Big Rice Moraine Vermilion Moraine
LTP-5	This landtype phase (LTP) occurs in bedrock controlled terrain in the Laurentian Shield that has a shallow mantle of till. Associated landform is ground moraine. Common landscape positions are ridgetops and upper sideslopes with frequent bedrock outcrops. They include Lithic Udorthents such as the Quetico series and to a lesser extent Lithic Dystrochrepts such as the Barto and Insula series. Areas occur in Cook, Lake, and St. Louis counties. Approximately 53,000 acres.	Tower-Ely Glacial Drift and bedrock Complex
SD-SC	These soils formed in outwash, primarily from the Des Moines Lobe, under prairie or savannah vegetation. They include Typic Udipsamments and sandy Udorthentic Haploborolls such as the Nymore and Hubbard series. Areas occur in Hubbard, Wadena, Becker, Otter Tail, Douglas, Todd, Morrison, Benton, Stearns, Sherburne, Mille Lacs, Wright, Hennipin, Isanti, Chisago, Anoka, Ramsey, Washigton, Dakota, Goodhue, and Winona counties. Approximately 207,120 acres.	Park Rapids-Staples Outwash Plain Anoka Sand Plain
ANOKA-2	Soils formed in outwash primarily from the Des Moines Lobe. They include Typic Udipsamments and Alfic Udipsamments. Zimmerman and Sartell are typical soils. Areas occur in Benton, Sherburne, Isanti, Chisago, Anoka, Washington, Ramsey, Hennipin, Dakota, Houston, and Filmore counties. Approximately 130,500 acres.	Anoka Sand Plain Mississippi Valley Outwash Twin Cities Formation

Source: MPCA, 1985.

Figure 2. Areas Containing Soils that are Considered Potentially Sensitive to Acid Deposition.



Source: MPCA, 1985.

Although soils in the western two-thirds of the state have buffering capacities and pH values similar to soils in the eastern one-third of the state, the western soils have not been weathered of their primary minerals. These minerals act as an additional buffer against acidification. The western soils also receive less acid deposition, have less available water to leach cations, and are generally less sensitive to acid deposition than the weathered eastern soils.

Soil Sensitivity Ratings

Soils having low buffering capacity are separated into sensitivity classes based on their buffering capacity, their present pH, and their general climate (Table 2). The sensitivity classes were developed for individual soil series. In mapping soils on a statewide basis, the Soils Atlas was used which has an accuracy down to 600 acres. Landscape units represented by one or more soil series were the smallest mapping units used. The sensitivity classes were applied to the landscape units and a rating assigned to the landscape unit based on the representative soil series or surface soil texture. Not all soils within a given landscape unit are considered sensitive or potentially sensitive. This stems from the fact that the landscape units were mapped on a minimum of 600 acres. When these landscape units occupy several thousand acres, the inclusions of other soil types also increases.

Table 2. Categories Used To Rate Forest Soil Sensitivity To Acid Deposition In Minnesota

The majority of soils in a landscape unit are considered to be:

	Mapping Symbol	Bases Surface 25cm Soil	pH	Rainfall
Sensitive 1	S1	200 keq/ha	4.5-7.0	27-30"
Sensitive 2	S2	200 keq/ha	4.5	27-30"
Sensitive 3	S3	Shallow soils over bedrock		
Potentially Sensitive 1	PS1	200-500 keq/ha	4.5-7.0	27-30"
Potentially Sensitive 2	PS2	200 keq/ha	4.5-7.0	21-27"
Potentially Sensitive 3	PS3	200-500 keq/ha	4.5-7.0	21-27"
Nonsensitive	NS	500 keq/ha as bases, clays, silts; carbonates in surface 25cm of soil; steep slopes, 12%; dark soils, Mollisols, high organic matter content; poorly drained or flooded soils.		

keq = kiloequivalents

Source: MPCA, 1985.

Considering the limited knowledge of the effects of acid deposition on soils, the generalized nature of the Minnesota Soils Atlas, the limited soils information available, and the time constraints imposed by the Acid Deposition Control Act of 1982 on the mapping of sensitive areas, the map presented is a reasonable approximation of sensitive soil areas in the state, based on MPCA data. It is anticipated that the map of sensitive soil areas will be revised as new information on soil sensitivity to acid deposition becomes available. There is, however, no conclusive evidence that acidic deposition has significantly increased the rate or occurrence of forest soil acidification in Minnesota over the past two decades.

Peatland Sensitivity

Peatlands are unique features upon the landscape and are most prevalent in north-central and northeastern Minnesota, occupying approximately 7.6 million acres of the state. The largest contiguous areas of peat were formed by paludification in the beds of Glacial Lakes Agassiz, Aitkin, and Upham. Peat also forms by natural succession in lake beds when plants die along the edges of a lake and gradually accumulate as a mat, filling in the lake.

Water chemistry plays an important role in determining peatland vegetation. Minerotrophic peatlands receive water from mineral soil areas that contains dissolved minerals and is either circumneutral in pH or slightly acidic. Swamps and fens are two types of minerotrophic peatlands, with swamps being wooded wetlands that contain trees and tall shrubs and fens being meadow-like areas characterized by the presence of sedges, reeds, and grass. Ombrotrophic peatlands receive their water solely from precipitation and are dominated by Sphagnum mosses, or by mosses and dwarf black spruce trees.

Peatlands were originally included in the listings of sensitive and potentially sensitive areas in Minnesota as a conservative measure. Researchers were most concerned with poor fen areas becoming acidified by acid deposition and changing to Sphagnum spp. bog areas. Poor fen areas generally consist of Carex spp. sedge meadows, with or without Sphagnum spp. moss carpets, and have surface water alkalinities of less than 40 ueq/l and pH's near 6.0. The poor fen peatland is minerotrophic, but the mineral and bicarbonate supply from soils is limited.

Poor fen areas become naturally acidified due to the hydrogen ion production of associated, or adjacent Sphagnum species. Acid deposition may cause these rare poor fen peatland communities to become acidified at a faster rate than normal.

In the past two years, research, and the general consensus from scientists has indicated that the poor fen areas are not as sensitive to acid deposition as was once thought. In fact, peatlands are more efficient sinks for sulfate, nitrate, and hydrogen ion than any terrestrial system studied. Anoxic conditions are common below the water table and this favors microbial reduction of sulfate.

Professor Urban (Department of Ecology and Behavioral Biology, University of Minnesota, 1984) estimated that approximately 40 to 48 Kg/ha/yr of anthropogenic sulfate deposition would be needed to overwhelm a bog's natural buffering capacity in the eastern United States. A deposition level of 40 to 48 Kg/ha/yr of anthropogenic sulfate is extremely high, and it is unlikely that Minnesota would ever experience deposition rates of such large proportions.

It is apparent that Minnesota peatlands would not be affected by acid deposition at the rates currently monitored in the state. Based on these arguments, peatlands are not considered sensitive to acid deposition at current rates of deposition, nor at expected rates of deposition, in the state of Minnesota.

Effects on Forest Wildlife

No evidence was found in the literature to suggest acute or chronic injury of forest wildlife by acid deposition. Although direct effects are unlikely, wildlife could potentially be affected through soil changes which cause changes in vegetative structure, density, composition, forage crop quality or nutritional value. Presently, it is assumed that wildlife populations are not under stress from the effects of acidic deposition in Minnesota. However, populations highly dependent on aquatic vegetation, particularly in the northeastern part of the state, may have reason for concern.

MINNESOTA'S RESPONSE TO ACID DEPOSITION

Minnesota produces less than 30 percent of its own acid precipitation, or about 1% of the annual U.S. emissions of sulfur and nitrogen oxides. The rest of the state's acid rain comes from Texas (up to 20 percent), Missouri, Iowa, Wisconsin, North Dakota, Illinois and from the Province of Alberta, Canada. Ours is not an Ohio Valley problem. Minnesota also "exports" some of its acid rain to other states and Canada. Because acid rain is largely a meteorological phenomenon which does not respect boundary lines, Minnesota must work in cooperation with other states and Canada to reduce SO_2 emissions at their source.

SO_2 Emissions in Minnesota

Minnesota's SO_2 emissions are among the lowest and cleanest in the nation. Currently, in-state sources emit approximately 230,000 to 240,000 tons per year of SO_2, down from 600,000 tons yearly during the early 1970's. Minnesota utilities also have among the lowest emission rates in the country, approximately 1.2 pounds of sulfur emitted per million BTU's of heat generated in the combustion process. Wisconsin utilities, in comparison, emit close to three times the total SO_2 as do Minnesota sources--at nearly three times the rate. Missouri sources, too, emit SO_2 at a much higher rate--about 10 pounds of sulfur emitted per million BTU's of heat generated. This is primarily because Wisconsin and Missouri are using high-sulfur eastern coal and they are burning it in older, less efficient generating plants not generally equipped with emission control devices. Still, Minnesota sources are the single most important sources in most areas of the state (Figure 3).

Sulfur dioxide accounts for about 2/3 of the acidity of rainfall in Minnesota. Natural sources (e.g., volcanoes) make up 5 percent of atmospheric SO_2 content, the remainder is attributable to the combustion of fossil fuels. Dry deposition of SO_2 in Minnesota is thought to comprise no more than 25 percent of total SO_2 deposition. NO_x is responsible for the remaining rainfall acidity. Minnesota is not a large emitter of nitrogen oxides, however NO_x has been implicated as a major culprit in forest damage, based on the European experience. NO_x is readily absorbed by terrestrial systems and is not re-released into aquatic systems. This can lead to over fertilization, the

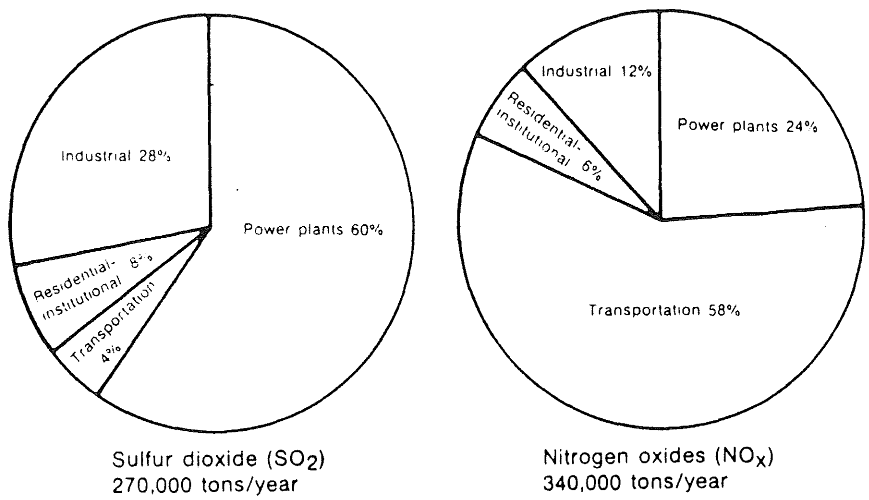


Figure 3. Sources of Sulfur Dioxide and Nitrogen Oxide Emissions in Minnesota.

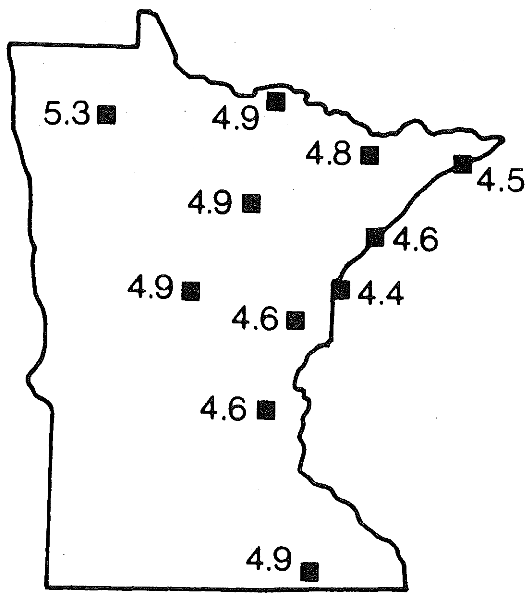
release of toxic metals in the soil, and damage of forest vegetation in temperate areas. Additional research on forest effects of NO_x deposition is needed.

Precipitation in Minnesota is most acidic in the northeast and least acidic in the western and southwestern portions of the state (Figure 4). The acidity of rain and the annual sulfate deposition rate in northeastern Minnesota is now at or above the levels that have caused lake acidification in Scandinavia, an area geologically similar to Minnesota.

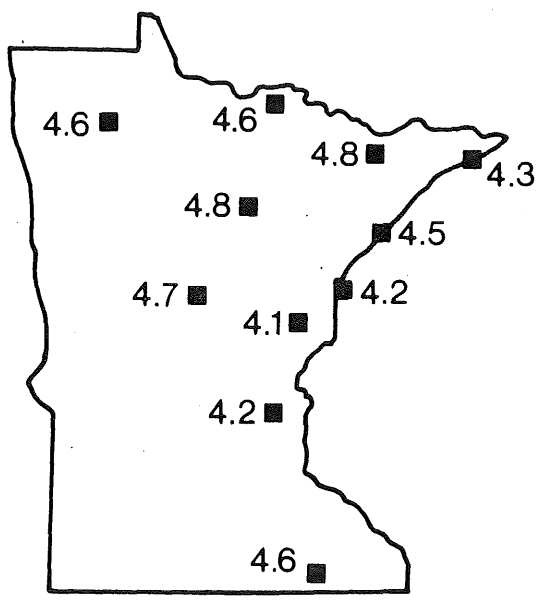
Rain is more acidic in Minnesota during the winter, since snowcover prevents soil particles from mixing with acids in the atmosphere. The eastern part of the state is also closer to areas emitting large quantities of SO_2 and contains more highly weathered soils with less inherent buffering capacity.

The resources most at risk are approximately 2,200 acid sensitive lakes in northeastern and north-central Minnesota (Itasca, Pine, Carlton and Lake counties). These are typically small, perched lakes adjacent to steep slopes, with thin soils over bedrock and with no inlets or outlets (headwater lakes). These lakes have little buffering capacity and may acidify over time even at current deposition levels. Of these, MPCA has identified about 200 critically sensitive Minnesota lakes, located primarily in Cook, St. Louis and Pine counties.

pH of Precipitation



(a) SUMMER (Apr. 84-Oct. 84)



(b) WINTER (Nov. 84-Mar. 85)

Figure 4. The average pH of precipitation (measured in the field) by season for 1984-1985. (Minnesota Pollution Control Agency Deposition Monitoring Network and the National Atmospheric Deposition Program.)

What Minnesota is Doing to Curb Acid Rain

Although Minnesota has stricter air pollution laws than many other areas, and its total sulfur dioxide emissions have been reduced significantly in recent years, acid rain remains a serious environmental problem for the state. In 1979 the Minnesota Pollution Control Agency (MPCA) formed a statewide task force to investigate acid rain. In 1980 the Minnesota Legislature passed the Acid Precipitation Act (Minnesota Laws, Chapter 490), mandating a one-year ($100,000) acid rain study to be conducted cooperatively by three state agencies: the MPCA, the Department of Natural Resources (DNR), and the Minnesota Department of Health (MDH) (Appendix A).

Under the one-year study, the three agencies collected existing information about acid rain, and conducted research and monitoring programs to determine the effects of acid rain on Minnesota resources. Early in 1982 the research compiled by the MPCA, the DNR and the MDH was published in a 350-page report, "Acid Precipitation in Minnesota."

The report to the LCMR affirms that northern Minnesota watersheds are geologically and chemically similar to those regions in which lakes have already become acidified. It also states that highly acidic precipitation is falling in northern Minnesota. There is no evidence, however, to indicate that any Minnesota lake has yet turned acidic, or has lost its buffering capacity. However, because of the glacially-originated thin soils and solid bedrock in the northeast, the capacity of the lakes in those regions to continue to buffer the acidic input is deteriorating.

There may be as many as 2,000 sensitive Minnesota lakes, 200 of which are critically sensitive. However, no lakes in Minnesota have been found to have been chemically altered. Such lakes do exist is Wisconsin and Michigan. Although some stop-gap measures, such as the liming of lakes, are currently being investigated, it appears that the only long-term solution to the acid rain problem is to reduce emissions of sulfur and nitrogen oxides.

In March, 1982 the Minnesota Legislature passed and Governor Quie signed the first comprehensive law in the United States for mitigating the problem of acid rain--the Minnesota Acid Deposition Control Act (Appendix B). By passing this important and timely law, the legislature recognized that acid deposition poses a present danger to certain ecological systems in Minnesota.

The Acid Deposition Control Act set forth a clear procedure for mitigating acid deposition in Minnesota by requiring the Minnesota Pollution Control Agency (MPCA) to:

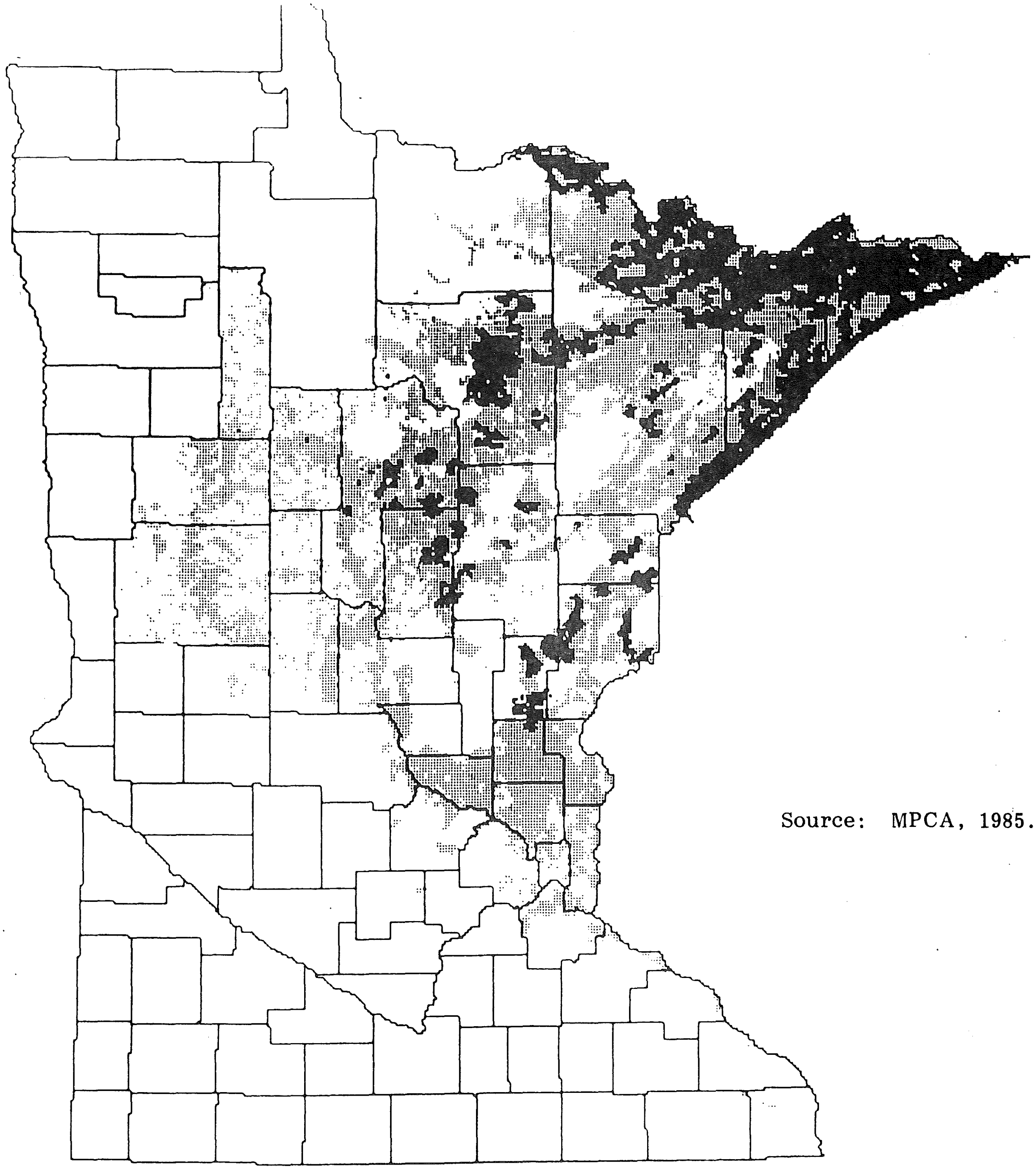
1) Prepare a preliminary list of resources sensitive to acid deposition by January 1, 1983
2) Conduct public meetings on the list by March 1, 1983
3) Publish a final list by May 1, 1983
4) Adopt an acid deposition standard (to be enforced in the sensitive areas) by January 1, 1985
5) Adopt a control plan, addressing both in-state and out-of-state sources, to attain and maintain the standard by January 1, 1986, and
6) Ensure that all Minnesota sources subject to the control plan are in compliance by January 1, 1990.

Because the activity of listing sensitive areas had never been accomplished anywhere else, the MPCA had to develop an approach and supplement the available data base for modelling. Additionally, application of soils information was determined to be important. Consequently, integration of the soils information into the model necessitated additional time which has delayed the implementation schedule by several months. The final acid sensitivity model, for both aquatic and terrestrial environments, is shown in Figure 5.

In addition to the legislatively ordered work, the PCA Task Force report recommended more study and evaluation. These recommendations called for more atmospheric monitoring and computer modeling, watershed studies, fish population, and fish mercury concentration research.

Proposed Acid Deposition Standard and Control Plan

After three years of intensive research, the MPCA staff says it is ready to propose a formal acid rain control strategy to protect the estimated 2,200 lakes and 1.4 million forest acres in Minnesota that are vulnerable to acid rain damage.



Source: MPCA, 1985.

Figure 5. Acid Rain Sensitivity - Final Model 8/21/1985
Aquatic and Terrestrial

Symbol	Count	Percent	Acres	Legend
	01150857	84.6	46,034,280	No Data
■	1 63279	4.7	2,531,160	Sensitive
░	2 145653	10.7	5,826,120	Potentially Sensitive

The proposed strategy includes a new acid precipitation standard and a stringent air pollution control plan to meet that standard, as required by the 1982 Minnesota Acid Deposition Control Act. Public hearings on the proposed strategy will begin in early 1986. The Pollution Control Board then would consider final approval, after reviewing the administrative law judge's recommendations.

The proposed control plan would tighten emission restrictions on sulfur dioxide (SO_2), which are already among the most stringent in the country, by freezing the allowable emissions of major SO_2 sources at 1984 levels. (There are 11 facilities considered major sources--emitting more than 5,000 tons per year SO_2.) Minnesota's total 1984 sulfur dioxide emissions were 165,000 tons, compared to 254,221 tons in 1980 and 713,444 tons allowed by present rules and permits. The control plan is designed to freeze allowable sulfur-dioxide emissions from the state's major sources at 194,000 tons a year by 1984, a reduction of 25 percent, or 60,000 tons, from 1980 levels.

MPCA officials emphasize that national acid rain reductions are needed to ensure long-term protection from acid rain damage. The agency estimates that about 60 percent of the acid rain that falls on Minnesota is caused by air pollution sources in other states and Canada, which are not subject to Minnesota's acid rain law.

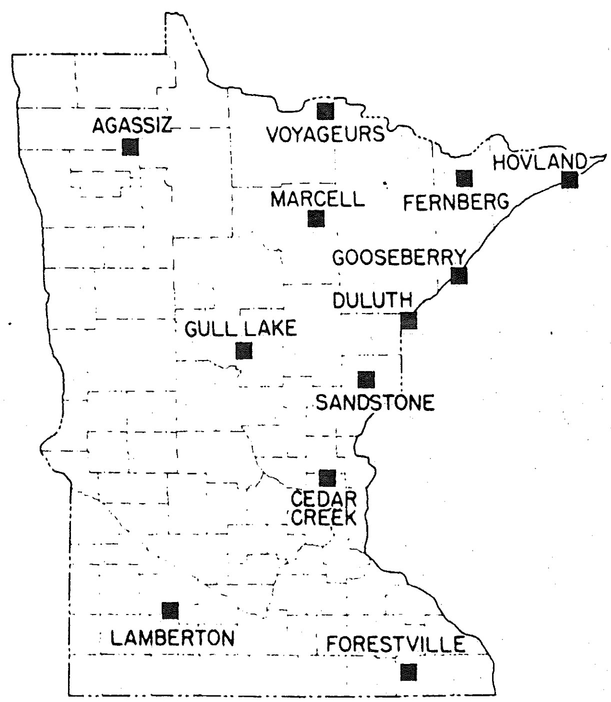
The proposed protection standard is 11 kilograms (kg) sulfate per hectare per year. This means that an acid sensitive area about 2.5 acres (1 hectare) in size cannot withstand more than about 24 lbs. (1 kg) of acidic fallout each year without serious risk of damage to a sensitive lake or forest. MPCA staff arrived at the proposed number after sampling hundreds of lakes and measuring rainfall acidity each week at a dozen collection sites, mostly in northeastern Minnesota, the most acid sensitive region of the state. The staff also studied weather patterns, and using sophisticated computer modeling, was able to determine which air pollution sources within Minnesota and out of state were contributing most to acid fallout in sensitive areas. Utilities and refineries are the largest in-state contributors to acid rain in Minnesota, according to the MPCA.

The MPCA will continue to press for national acid rain controls while further restricting in-state emissions.

Acid Deposition Monitoring

Currently, acid deposition is being monitored at a dozen sites in Minnesota (Figure 6). These monitoring stations indicate that most acid rain and snow are found in the northeastern part of the state (pH less than 5.0). The least acidic precipitation is found in the southwest (pH 5.0-5.5). Collections made along the North Shore in the fall of 1981 show that weekly rain pH values averaged 4.1 or 30 times more acidic than "normal" rain of pH 5.6. Figure 7 shows rainfall pH and ambient deposition levels at ten monitoring stations throughout Minnesota.

SITE NAME/LOCATION	ORGANIZATION
Fernberg/Ely, MN	NADP
	Minnesota Power/MPCA
	Minnesota/Wisconsin Power
	U.S. Environmental Protection Agency (EPA) — Duluth
	Ontario Ministry of the Environment
Hovland, MN	GLDP/MPCA
Gooseberry Falls, MN	GLDP/MPCA
Park Point/Duluth, MN	GLDP/MPCA
Gull Lake/Brainerd, MN	GLDP/MPCA
Lamberton, MN	NADP
Marcell, MN	NADP
Voyageurs Nat. Park	MPCA
Agassiz/Thief Riv Falls	MPCA
Sandstone, MN	MPCA
Forestville, MN	MPCA
Cedar Creek, MN	MPCA

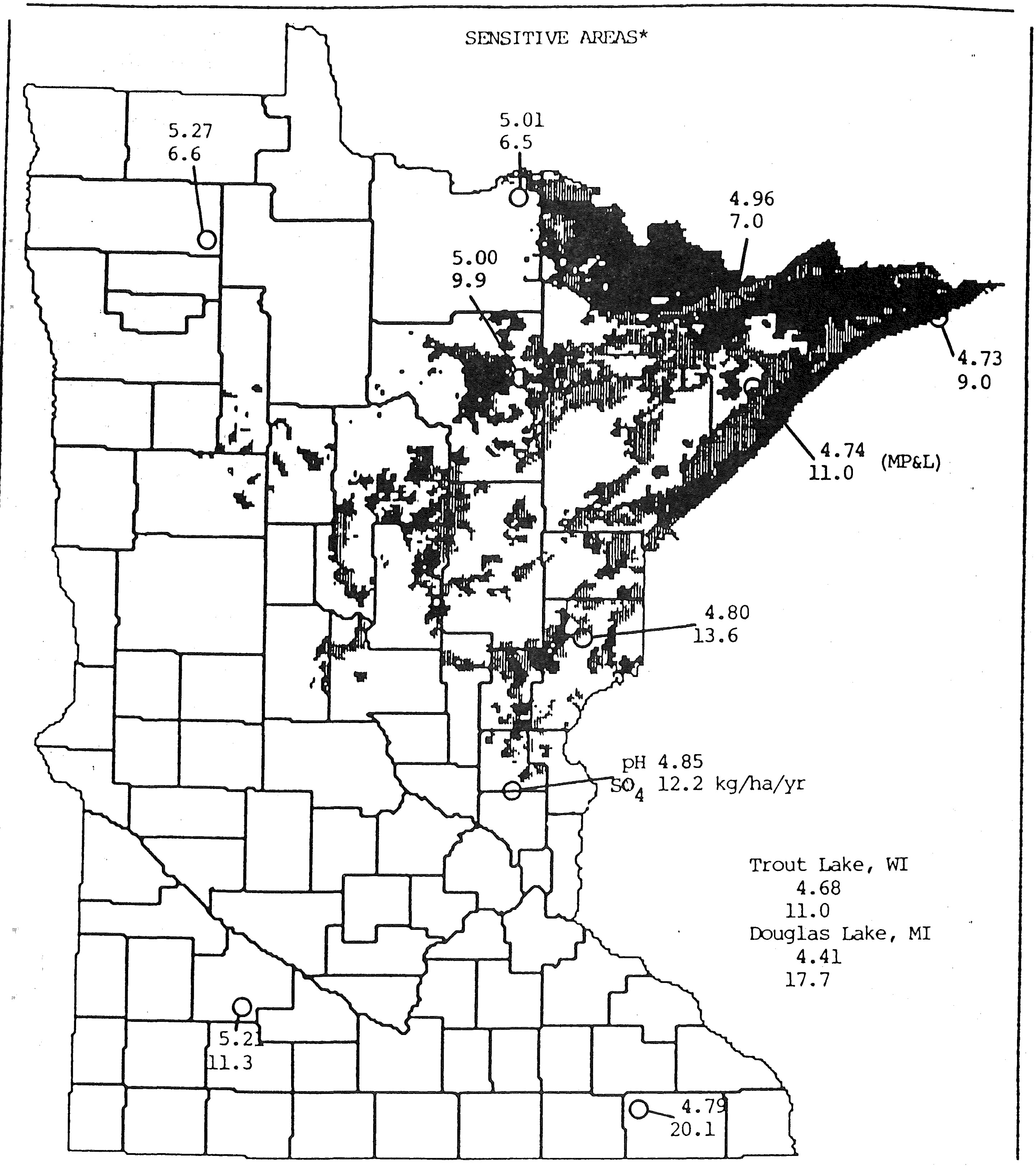


MPCA = Minnesota Pollution Control Agency

NADP = National Atmospheric Deposition Program

GLDP = Great Lakes Deposition Program

Figure 6. Acid Rain Monitoring Sites in Minnesota



* Map approximates the new sensitive areas map

Figure 7. Rainfall pH and Ambient Acidic Deposition Levels at Ten Monitoring Sites in Minnesota (1985).

Source: MPCA, 1985.

No losses or reductions in fish populations have yet been identified in Minnesota as a result of acid deposition. Damage to terrestrial ecosystems is less clear. Economists believe, however, that such losses, or the public's view of such losses, could have a marked effect on the economy of a region which depends on revenues from sport fishing or tourism.

International Cooperation

As the producer of only 15-20 percent of its own acid rain, Minnesota recognizes the need to work with other states and with Canada to control the problem. The Acid Deposition Control Act of 1982 clearly stated legislative intent to "support and encourage other states, the federal government, and the province of Ontario in recognizing the dangers of acid deposition and taking steps to mitigate or eliminate it within their jurisdictions." On August 5, 1983 the State of Minnesota and the Province of Ontario entered into a joint agreement to work cooperatively to reduce acid rain (Appendix C).

Although the Canadians do not have a formal national acid rain plan, they do coordinate research efforts through a national Research and Monitoring Coordinating Committee. Since 1981, this committee has been assembling current research findings, with the Canadian provinces sponsoring about 50% of the total acid rain research budget, and the remainder provided by the Canadian government. Canadians spend about $20 million a year on research, an amount similar to the U.S. On a per capita basis, however, this amounts to nearly 10 times what the U.S. has committed to federal acid rain research.

Canada recently announced plans to move ahead on a program to curb acid rain. The Canadian program will seek to reduce SO_2 emissions 50 percent by 1994. To achieve this goal Canada plans to spend $300 million in government and industry money for emission controls at smelters and more than $100 million for technological development, research, monitoring and establishment of an acid rain office to coordinate new policies.

Summary: What Deposition Rate Equals Resource Protection?

While adverse effects on Minnesota forests resulting from acidic deposition (or other air pollutants) have not been proven, we cannot conclude that acidic deposition is not having an adverse effect. Numerous legitimate hypotheses linking forest damage to acidic deposition have been proposed and merit further study. At present, science cannot provide a complete evaluation of the effects of regional air pollutants, including acidic deposition, on forest ecosystems. Likewise, present knowledge of the effects of acidic deposition on forest systems is insufficient to allow judgments concerning the need for or effectiveness of various mitigation and control measures.

INFORMATION NEEDS

Generalizations about ecosystem response to stress (all forms of air pollution, including acid deposition) are difficult because of the complexity and variability of forest systems. In nature, forests may be exposed to multiple and interactive air pollutants. It is, therefore, inappropriate to consider pollutants singly or in isolation.

Research Agenda

Because much uncertainty remains regarding the nature, causes and consequences of air pollutants on forest ecosystems, opportunities exist for better understanding of forest growth processes under natural as well as pollution-stressed environments. Some major areas of information needed with regard to acidic deposition and forest productivity are:

- Measuring and evaluating subtle changes in forest growth processes;
- Characterizing critical characteristics of gaseous pollution exposure dosages;
- Developing a better understanding of the dynamics of forest change and the role of pollutant-pollutant and pollutant-environment interactions;
- Determining the influence of acidic deposition on forest growth and long-term productivity, nutrient cycling, soil acidification, nutrient uptake and leaching, and soil chemistry;
- Examining mechanisms by which acidic deposition can adversely affect forest stand structure and productivity;
- Identification and development of key forest management alternatives influenced by acidic deposition considerations;
- Developing cost-effective mitigation techniques and control options;
- Development of analytical tools which can be used to assess the economic consequences of acidic deposition on forest productivity.
- Examining the impact of ozone, nitrogen compounds and volatile organic substances on terrestrial exosystems.

Research should include three components--field, modeling, and laboratory studies--of both a short and long-term nature. These efforts could be conducted concurrently, since each depends on the other. Careful monitoring will be needed in order to detect and evaluate the symptoms, extent, distribution and location of affected areas. Research must also be interdisciplinary in order to provide decisionmakers with greater perspective with which to reach management decisions and frame public policy.

Federal Acid Rain Research

The U.S. Interagency Task Force on Acid Precipitation has taken the lead to plan, implement and manage the federal government's acid rain research program--the National Acid Precipitation Assessment Program (NAPAP). Resulting from the Acid Precipitation Act of 1980, the program represents a nationwide research effort to improve our understanding of the causes, effects and possible answers to the acid rain problem. The program involves over 200 projects and hundreds of scientists in government, academia and the private sector.

Truly an interagency effort, NAPAP is chaired jointly by three federal agencies: the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA). In addition, nine other federal groups participate, each represented by the highest ranking researcher in that agency. These include the Departments of Commerce, Energy, Health and Human Services, Interior and State; the Council on Environmental Quality; NASA; the National Science Foundation; and the Tennessee Valley Authority.

These federal groups work in close cooperation with one another to integrate existing acid rain research, to assess current findings, and to plan and coordinate future efforts. The program also involves other groups with an interest in acid rain such as private industry, environmental groups, state and local government, universities, and even other countries.

Research Coordination

Of the twelve federal agencies and departments involved in the U.S. Interagency Task Force, five provide virtually all the program's core acid rain budget--$64.9 million for F.Y. 1985. These five are coordinating the research: EPA (53.2%), DOI (12.9%), USDA (14.0%), NOAA (6.4%), and DOE (13.5%).

To plan and implement an integrated research effort addressing the goals of the national program, the task force has established nine research categories. The percentage of the $65 million F.Y. 1985 budget spent on these nine categories is as follows: natural sources (1.8%), man-made sources (3.6%), atmospheric processes (21.6%), deposition monitoring (13.1%), aquatic effects (24.5%), terrestrial effects (25.2%), effects on materials and cultural resources (3.1%), and assessments and policy analysis (6.2%). The remaining research categories, control technologies and international cooperation comprise 1% of the total budget. Funds for the general development of SO_2 and NO_x control hardware are appropriated under preexisting programs. This task group coordinates its efforts with the assessment and research activities of the national program.

The national program has a 10-year authorization, after which time Congress will review the need for continuing the coordinated research effort. However, the task force is responsible for reporting annually to the president, Congress, and the nation on the program's progress, recent developments, and policy implications.

In all, the Forest Service, EPA and private industry are jointly spending about $6 million this year on NAPAP's "National Forest Effects and Forest Responses Program" for 1985, and beginning in 1986 this research program will be funded at over $13 million annually. Different parts of the cooperative program will examine spruce-fir forests in the east, commercial pine forests in the southeast, eastern mixed hardwoods and western coniferous forests. NAPAP's National Vegetation Survey will examine unexplained growth declines and visual symptoms of deterioration that may be related to atmospheric deposition on all U.S. forest lands east of the Mississippi.

In addition, the Forest Service's Rocky Mountain Research Station (Fort Collins, CO) is spending $1 million annually to examine acid deposition impacts on western alpine and sub-alpine forests. Another $500,000 annual research project is underway at the Pacific Southwest Station in California as is a $1.2 million watershed study commenced in 1982. Whether this research will turn up definitive answers on the links between air pollution and forest decline, however, is uncertain.

Other Studies

The Electric Power Research Institutes' (EPRI) environmental acid rain research program is second only to the federal government's, amounting to nearly $15 million per year. In fact, EPRI's involvement in acid rain research predates national efforts. Although EPRI, a national consortium of utility companies, takes a slightly different approach to specific research areas, their research program and the federal government's have produced both useful and complementary results. Program cooperation exists between EPRI and the national program on all levels: among researchers, scientists and reviewers.

EPRI recently funded research through the University of Minnesota's Departments of Forest Resources and Soil Science to determine how acid rain influences tree growth and survival. This multi-year, $332,000 project will examine the relationship between acid deposition and the release in the soil of toxic forms of aluminum. Researchers will also evaluate the influence of acid rain on nutrient and water uptake by roots. This research will contribute to development of an analytical model which is designed to predict forest response when acid deposition increases free aluminum and strips the soil of magnesium and calcium ions.

The State University of New York, College of Environmental Science and Forestry has received contracts totaling more than $1.3 million for two research projects on the effects of atmospheric deposition on northeastern forests. Funding for these projects was provided by the state and the utility industry.

The National Council of the Paper Industry for Air and Stream Improvement (NCASI) has also been actively involved in examining acidic deposition and its effects on forest productivity. Two technical reports have so far been produced reviewing the present state of knowledge, current research activities and continuing information needs. A formal position statement has also been developed.

Other major studies, each assessing different aspects of the acid rain phenomena, have been or are currently being conducted by various groups. The National Academy of Sciences (NAS) has completed two studies examining the effects of energy technologies on the atmosphere and assessing the current state of knowledge about atmospheric processes in order to better understand the relationship between acidic emissions and deposition. A third study is planned to examine long-term trends in precipitation and atmospheric chemistry.

The Office of Science and Technology Policy has commissioned a panel to analyze working group reports prepared under a bilateral agreement between the U.S. and Canada. Under this agreement, several reports were jointly produced by scientists from both countries. Other studies in progress include work by the Congress' Office of Technology Assessment on long-range transport of pollutants, and the Congressional Research Service's study of current and potential emission mitigation technologies. The U.S. General Accounting Office (GAO) also recently released a report (1984) providing an analysis of issues concerning "acid rain." The report focuses on the impacts, causes and possible controls for acid rain.

MITIGATION AND CONTROL STRATEGIES

Although science has largely determined the causes of acid deposition, there is uncertainty concerning the amount and timing of anticipated affects. Consequently, scientific information alone cannot determine whether it would be preferable to begin control actions now or wait until estimates of effects can be made more accurate. The issue must be approached by weighing the relative risks of alternative decisions--the risks of adverse economic impacts in some regions of the country, caused by immediate and costly control actions whose benefits cannot be accurately predicted, versus the risks of further, potentially avoidable, harm to the environment or public health in other regions of the U.S. and Canada if actions are delayed.

Agreement on an approach to the acid deposition problem is likely to be aided by separating the question of when and in which areas of the country control actions should occur, from the question of how the control actions will be financed. Cost/benefit analysis could also assist in identifying a range of economically efficient pollution control strategies, based on examination of expected benefits from proposed levels of acid deposition control.

Emission Controls

A number of control technologies currently exist to reduce emissions of SO_2 from utility and power generation processes. These methods can be grouped into those that are applied before, during or after the combustion process. Design of a cost-effective control strategy depends on the mix of control technologies available and their cost and performance characteristics. Control technologies may also be combined with non-hardware techniques to improve effectiveness and efficiency.

Control strategies aimed at reducing power plant emissions have shifted in the last decade from a focus on new plants to a concern over existing plants. The Clean Air Act of 1971 established tight federal standards on the combustion emissions of new plants with the assumption that as older plants were retired, their replacements would constitute a higher and higher percentage of utility generating capacity. However, with rising capital costs and a sharp reduction in historical load growth, plant turnover has stalled, sparking renewed legislative and regulatory efforts toward increased controls on pre-1971 plants.

This recent push introduces a fundamental choice of investment strategies for decisionmakers--whether to increase the investment on older, less-efficient plants where controls are not an integral part of the design or to reserve investment capital for systems now under development that combine superior environmental performance with improved energy and operational efficiency.

Proposed legislative and regulatory action has targeted coal-fired plants because of their large role in SO_2 emissions. Collectively, they exhaust about 14.4 million tons of SO_2 each year--91% of the total from utility plants of all kinds and about 60% of what comes from all man-made sources in the United States. Coal-fired plants are also a significant source of NO_x, although the greatest percentage comes from cars and trucks. The annual volume of 4.6 million tons from coal-fired plants is 82% of all utility NO_x and almost a quarter of the NO_x from all U.S. sources.

Whether or not widespread action is taken against coal-fired plant stack emissions, no single solution is expected to satisfy the widely varying fuel and design conditions of existing coal-fired plants. There are several basic control approaches and any number of technical variants under development or in use today. They encompass restricted plant operation; the use of different coals; altered firing practices, burners, and combustion conditions; and the introduction of reagents to inhibit or capture pollutants in combustion gases.

Other alternatives, such as coal switching and cleaning, modification of combustion process and equipment, and postcombustion exhaust treatment, turn to technologic advances to achieve their goal. But aside from differences in their development status, these options are not interchangeable in application.

A still longer-term view would include the approach of preserving capital to speed the development and transition to new coal generation systems that are inherently clean and more energy-efficient than current plants. New systems, such as fluidized-bed and gasification-combined cycle plants, represent the concept that the use of coal for power generation is not fundamentally in conflict with a clean environment, and thus they have strong appeal as an ultimate solution.

The actual steps that the utility industry takes toward emissions control, and when and how they come about, will flow from R&D success and from the form of policy regulation that may be adopted. Whatever the future holds, the industry has a wealth of research results to apply to the acid rain problem. A successful solution will involve continued research and judicious choices among the answers now at hand and within reach.

Forest Management Actions to Reduce Damage[3]

Forestry measures for reduction of damage may have three objectives: 1) mitigation of damages in the forests which are affected; 2) the prevention of damage in forests which are not yet affected; and 3) the establishment of new more resistant forests in areas which have been deforested. As forest damage occurs due to the interaction between manmade and natural stress, and since natural stress factors are largely uncontrollable, it is of primary importance to reduce the sources of manmade stress, i.e., emissions of relevant air pollutants, as far as present technology permits. The forest management regime must, on the other hand, use all such measures which may increase stand resistance against natural stress factors.

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[3] Adapted from: Scholz, Florian. "Report on effects of acidifying and other pollutants on forests." United Nations Economic Commission for Europe, Environment and Human Settlements Division, Air Pollution Unit. ISSN 0368-8798. 83 p.

The following measures could be applied for the presently growing damaged or not yet injured stands:

- Fertilizing, but only after careful analysis of the actual nutrient conditions, aiming to compensate a determined deficiency, but only with careful consideration of possible disadvantages.
- Other forestry measures that act to increase the resistance of a particular forest stand on a particular site.

The following measures may be applied primarily to avoid or reduce air pollution damage in presently growing stands:

- Silvicultural measures which aim to reduce the access by air pollutants, such as closing of the canopy as well as the borders of the stand.
- Measures aiming to reverse a harmful lowering of soil pH (liming). This measure is controversial and has not yet led to convincing results. Associated problems should be taken into account (accelerated decomposition of litter and sudden release of contained pollutants).
- Finally, such forestry measures should be taken, which aim to remove damaged trees at the right time to avoid secondary damage. Permanent observation plots where forestry activities are excluded should be established for monitoring damage progress.

For new establishment of forest stands and long-term protection of forests, the following measures are recommended, and the following cautions should be taken into account:

- Seed collection from suitable stands in order to ensure seeds as well as for establishing gene reserves. Seeds from more susceptible trees should be collected in order to obtain genetic diversity as broad as possible.
- Artificial reproduction of stands under cover where feasible.
- Protection of the natural reproduction by means of fencing and control of wildlife where necessary.
- Tree species should be selected which are well adapted to natural site conditions. In this respect, provenance should also be taken into account.

- Knowledge of the resistance of tree species toward classical pollution damage is not transferable to the acid deposition damage situation.
- Tree species, provenances and clones which on a particular site under its environmental conditions (still) show no injury, may not necessarily be recommended for other sites.
- Tree species which show damage later than others may then undergo a much quicker progress of damage. This fact makes alternate tree species recommendations difficult.

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APPENDIX A
LAWS OF MINNESOTA 1980, CHAPTER 490

An act relating to pollution; recognizing the extent and severity of the problem of acid precipitation; appropriating funds and designating state agencies and departments to conduct activities designed to identify, control and abate acid precipitation.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF MINNESOTA:

Section 1. **LEGISLATIVE FINDINGS: INTENT.** The legislature recognizes that acid precipitation resulting from the conduct of commercial and industrial operations both within and without the state poses a present and severe danger to the delicate balance of ecological systems within the state, and that the failure to act promptly and decisively to mitigate or eliminate this danger will soon result in untold and irreparable damage to the forest, agricluture, water, fish and wildlife resources of the state. It is therefore the intent of the legislature in enacting this act to commit the financial and technological resources of the state toward cooperative programs involving the state, adjoining jurisdictions and the federal government, which programs shall be designed to recognize the nature and extent of the problems of acid precipitation, identify the sources thereof, and develop the appropriate scientific and technological expertise essential to solving the problems and maintaining the balance of ecological systems.

Sec. 2. **APPROPRIATIONS.** The following sums are appropriated from the general fund to the agency and departments indicated for the purpose of conducting research and development projects, which may be in conjunction with appropriate authorities in the federal government, the state of Wisconsin and the province of Ontario, with the objective of identifying, controlling, and abating acid precipitation:

1. To the Minnesota pollution control agency-$52,283;
2. To the Minnesota department of natural resources-$24,287;
3. To the Minnesota department of health-$23,430.

The agency and departments are each authorized to increase their complement by one full-time position.

Funds appropriated by this section shall not lapse but shall remain available until expended.

The Minnesota pollution control agency is designated as the coordinating agency responsible for initiating contacts with other jurisdictions and coordinating research and development activities and projects. It is a condition of acceptance of the appropriations made by this section that each agency or department receiving an appropriation shall submit work programs and semi-annual progress reports in a form determined by the legislative commission on Minnesota resources. None of the moneys provided in this section may be expended unless the commission has approved the pertinent work program.

In addition, the agency shall consolidate and present to the legislature or appropriate interim committees thereof, recommendations for legislation deemed necessary to facilitate the control and abatement of acid precipitation.

Sec. 3. **PUBLIC EDUCATION ON ACID PRECIPITATION.** The Minnesota environmental education board shall conduct a program of public education on acid precipitation. The board shall report on the progress of the program to the respective chairmen of the house committee on environment and natural resources and the senate committee on agriculture and natural resources by January 15, 1981.

Sec. 4. This act is effective the day following final enactment.
Approved April 7, 1980
(NOTE: Section 3 has been codified in Minnesota Statutes 1982, Sec. 116E.035.)

APPENDIX B
LAWS OF MINNESOTA 1982, CHAPTER 482

An Act relating to the environment; limiting and reducing emissions of sulphur dioxide in the state; requiring adoption of an acid deposition control standard and plan by the pollution control agency; requiring reports; imposing an assessment on utilities; appropriating money; amending Minnesota Statutes 1981 Supplement, Section 116C.69, Subdivision 3; proposing new law coded in Minnesota Statutes, Chapter 116.

Section 1.
116.42. Acid deposition, legislative intent
The legislature recognizes that acid deposition substantially resulting from the conduct of commercial and industrial operations, both within and without the state, poses a present and severe danger to the delicate balance of ecological systems within the state, and that the failure to act promptly and decisively to mitigate or eliminate this danger will soon result in untold and irreparable damage to the agricultural, water, forest, fish, and wildlife resources of the state. It is therefore the intent of the legislature in enacting sections 116.42 to 116.45 to mitigate or eliminate the acid deposition problem by curbing sources of acid deposition within the state and to support and encourage other states, the federal government, and the province of Onatario in recognizing the dangers of acid deposition and taking steps to mitigate or eliminate it within their own jurisdictions.

Sec. 2.
116.43. Acid deposition defined
As used in sections 116.42 to 116.45, "acid deposition" means the wet or dry deposition from the atmosphere of chemical compounds, usually in the form of rain or snow, having the potential to form an aqueous compound with a pH level lower than the level considered normal under natural conditions, or lower than 5.6.

Sec. 3.
116.44. Sensitive areas; standards
Subdivision 1. List of areas. By January 1, 1983, the pollution control agency shall publish a preliminary list of counties determined to contain natural resources sensitive to the impacts of acid deposition. Sensitive areas shall be designated on the basis of:

(a) the presence of plants and animal species which are sensitive to acid deposition;

(b) geological information identifying those areas which have insoluble bedrock which is incapable of adequately neutralizing acid deposition; and

(c) existing acid deposition reports and data prepared by the pollution control agency and the federal environmental protection agency. The pollution control agency shall conduct public meetings on the preliminary list of acid deposition sensitive areas. Meetings shall be concluded by March 1, 1983, and a final list published by May 1, 1983. The list shall not be subject to the rulemaking or contested case provisions of chapter 15.

Subd. 2. Standards. (a) By January 1, 1985, the agency shall adopt an acid deposition standard for wet plus dry acid deposition in the acid deposition sensitive areas listed pursuant to subdivision 1.

(b) By January 1, 1986, the agency shall adopt an acid deposition control plan to attain and maintain the acid deposition standard adopted under clause (a), addressing sources both inside and outside of the state which emit more than 100 tons of sulphur dioxide per year. The plan shall include an analysis of the estimated compliance costs for facilities emitting sulphur dioxide. Any emission reductions required inside of the state shall be based on the contribution of sources inside of the state to acid deposition in excess of the standard.

(c) By January 1, 1990, sources located inside the state shall be in compliance with the provisions of the acid deposition control plan.

Sec. 4.
116.45. Reports to the legislature
By January 1, 1986, the agency shall submit its acid deposition control plan to the appropriate substantive committees of both houses of the legislature. By January 1, 1987, and each two years thereafter until January 1, 1991, the agency shall submit to the legislative committees a report detailing the reduction of sulphur dioxide needed to meet the requirements of section 116.44 and the progress which has been made to meet those requirements.

Sec. 5. Minnesota Statutes 1981 Supplement, Section 116C.69, Subdivision 3, is amended to read:
Subd. 3. Funding; assessment. The board shall finance its base line studies, general environmental studies, development of criteria, inventory preparation, monitoring of conditions placed on site certificates and construction permits, and all other work, other than specific site and route designation, from an assessment made quarterly, at least 30 days before the start of each quarter, by the board against all utilities. The assessment shall also include an amount sufficient to cover 60 percent of the costs to the pollution control agency of developing the acid deposition control plan required by sections 116.42 to 116.45; this amount shall be certified to the board by the executive director of the pollution control agency. Each share shall be determined as follows: (1) the ratio that the annual retail kilowatt-hour sales in the state of each utility bears to the annual total retail kilowatt-hour sales in the state of all such utilities, multiplied by 0.667, plus (2) the ratio that the annual gross revenue from retail kilowatt-hour sales in the state of each utility bears to the annual total gross revenues from retail kilowatt-hour sales in the state of all such utilities, multiplied by 0.333, as determined by the board. The assessment shall be credited to the general fund and shall be paid to the state treasury within 30 days after receipt of the bill, which shall constitute notice of said assessment and demand of payment thereof. The total amount which may be assessed to the several utilities under authority of this subdivision shall not exceed the sum of the annual budget of the board for carrying out the purposes of this subdivision plus 60 percent of the annual budget of the pollution control agency for developing the plan required by sections 116.42 to 116.45. The assessment for the second quarter of each fiscal year shall be adjusted to compensate for the amount by which actual expenditures by the board and the pollution control agency for the preceding fiscal year were more or less than the estimated expenditures previously assessed.

Sec. 6. **Appropriation.**
The sum of $81,455 is appropriated from the general fund to the agency for the purposes of this act; for fiscal year 1983, the assessment pursuant to section 5 shall not exceed this amount.

Sec. 7. **Effective date.**
Section 5 is effective June 1, 1982. Sections 1 to 4 are effective July 1, 1982.
Approved March 19, 1982.

(NOTE: Sections 1-4 have been codified in Minnesota Statutes 1982, Secs. 116.42-45.)

APPENDIX C
MEMORANDUM OF UNDERSTANDING

on co-operation in combatting acidification of the environment

BETWEEN

THE PROVINCE OF ONTARIO, represented for the purposes of this Memorandum of Understanding by Andrew S. Brandt, Minister of the Environment, and Thomas L. Wells, Minister of Intergovernmental Affairs, and hereafter designated as "Ontario",

AND

THE STATE of MINNESOTA, represented for the purposes of this Memorandum of Understanding by Sandra S. Gardebring, Executive Director of the Pollution Control Agency, and hereafter designated as "Minnesota".

SINCE Ontario and Minnesota share a deep concern about the present and future effects of transboundary air pollution, and in particular the serious and urgent problem of acid deposition;

SINCE the unique ecosystems of their respective adjacent territories are highly susceptible to the effects of acid deposition;

SINCE they share a common resolve to reduce and prevent transboundary air pollution in a cost-effective way and limit the damage it causes;

SINCE they are convinced that the best means to protect the environment from the effects of acid deposition is through the achievement of reductions in emissions of the pollutants that are its cause;

SINCE a significant amount of the acid deposition they receive has a common source and originates with emitters situated outside their respective territories;

SINCE they share a common resolve to improve the scientific understanding of the source, magnitude, and consequences of the problems of acid deposition;

SINCE they acknowledge the importance of mutual cooperation and collaboration to address this common problem;

THEREFORE: the Province of Ontario and the State of Minnesota agree on the following:

SECTION 1: PURPOSE OF THE MEMORANDUM

The purpose of this Memorandum is to ensure close cooperation and collaboration in the efforts of Ontario and Minnesota to improve the understanding of both the possible effects of acid deposition on their territories, and the steps necessary to reduce and prevent it.

To accomplish this goal, they agree to share scientific data and technical expertise, to collaborate on efforts to develop a better understanding of the causes and effects of acid deposition, and to collaborate on the establishment of integrated national action plans to reduce and prevent emissions, in a cost-effective manner, of the pollutants that are its cause.

SECTION 2: MUTUAL OBLIGATIONS OF THE PARTIES

2.1 Exchange of Information

The parties agree to provide, in a timely manner and when requested, data from acid deposition monitoring stations and related lakes studies, and any other requested information relating to the subject of acid deposition.

2.2 Emission Inventories

The parties agree to provide emission inventories of pollutants related to acid deposition from sources within their territories and to assist in obtaining emission inventories from other jurisdictions within their respective countries. Both parties will also provide projected future emissions when available.

2.3 Technical Expertise

Both parties agree to share technical expertise on subjects related to acid deposition. Such expertise may take the form of scientific review of work in progress and advice on future studies.

2.4 Joint Studies

The parties agree to work cooperatively on joint studies including but not limited to: i) the application of existing long-range transport and economic models for the purpose of developing regulatory strategies; ii) the development and application of an Acid Deposition and Oxidants Model for the purpose of developing regulatory strategies; iii) the refinements to dose/response data and models for the purpose of application to susceptible ecosystems in Ontario and Minnesota; iv) research studies to better understand the relationship between acid loadings and ecosystem response and the benefits provided by reducing acid loadings in affected regions.

SECTION 3: ABATEMENT STRATEGIES

3.1 National Strategies

The parties agree to work cooperatively in developing cost-effective national strategies to reduce and prevent the impacts of acid deposition. Such cooperation shall include identification of source regions and the development of emission reduction strategies, as required in 2.4 i), including an analysis of their socio-economic impacts, as well as encouragement and support on the national level to ensure the adoption of national strategies.

3.2 Alternative Strategies

In the absence of national action, the parties agree to collaborate on the development of alternative strategies that result in reductions in emissions of acid forming pollutants, attainable within existing legal and legislative framework.

SECTION 4: EFFECTIVE DATE

This Memorandum of Understanding will come into effect upon its signature by both parties, and will remain in effect until terminated upon six months notice given in writing by one of the parties to the other.

And the parties' duly authorized representatives have signed.

Signed on behalf of

THE PROVINCE OF ONTARIO

by [signature]

Andrew S. Brandt
Minister of the Environment.

date: August 5, 1983

by [signature: Thomas L. Wells]

Thomas L. Wells
Minister of Intergovernmental Affairs.

date: August 5, 1983

THE STATE OF MINNESOTA

by [signature: Sandra S. Gardebring]

Sandra S. Gardebring
Executive Director
Minnesota Pollution Control Agency.

date: August 5, 1983

Air Pollution Effects on Forests

- a selected bibliography -

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Jeanie Hartman, Librarian

NCSU ACID DEPOSITION PROGRAM

RALEIGH, NC

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