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REPORT BY THE

# Comptroller General

OF THE UNITED STATES

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## The Debate Over Acid Precipitation: --Opposing Views --Status Of Research

The use of coal as a substitute for imported oil is raising concern over the possible impact of acid precipitation on the environment and human health. Precipitation can become acidified when sulfur and nitrogen oxides emitted by fossil-fueled powerplants, vehicles, and other man-made or natural sources are chemically changed in the atmosphere and return to earth as acid compounds.



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Environmental organizations and some agencies and interest groups contend that more stringent emission controls are needed immediately. On the other hand, some agencies and many industries, particularly in the coal and utility sectors, argue that much more research is needed to determine if achievable emissions reductions could significantly diminish the extent of acid precipitation, and if the benefits of such regulations would be worth their potentially high cost.

Although there is significant disagreement between advocates on opposing sides of the issue, misleading and inaccurate statements have added greatly to the confusion of the debate. This interim report on a more comprehensive GAO study seeks to clarify areas of agreement and disagreement between parties in the debate, summarize the state of scientific understanding, and report on ongoing research which will aid in making informed decisions on possible Government action.



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COMPTROLLER GENERAL OF THE UNITED STATES  
WASHINGTON D.C. 20548

B-204447

The Honorable Wendell Ford  
United States Senate

Dear Senator Ford:

This responds to a request by your office for an interim report, as part of a more extensive study on acid precipitation.

In an October 8, 1980, letter, you asked GAO to undertake "an objective and balanced analysis of the acid rain phenomenon. This analysis should address the question of whether it is appropriate to take regulatory action now to deal with acid rain or to wait until better scientific information is available."

Specifically, you asked us to examine

- the current state of knowledge on the subject;
- when we can expect to have better information resulting from scientific work in progress, and what type of information we can expect; and
- what would be the likely consequences for energy development, the environment, and economic development of taking action now versus waiting until more information is available.

At a subsequent meeting, on February 5, 1981, your office requested us to prepare a preliminary report to clarify the often confusing range of viewpoints on the main technical and regulatory issues and the status of scientific research on key issues, determining what is presently known and what is uncertain. The following pages address this request.

ACID PRECIPITATION--AN ISSUE INVOLVING  
CONTROVERSY, COMPLEXITY, AND HIGH STAKES

Acid precipitation may be one of the most polarizing yet least understood energy/environment issues of the 1980s. Its implications for environmental quality and national energy policy, particularly regarding increased coal use as a substitute for imported oil, may be profound.

According to the Environmental Protection Agency (EPA), a number of environmental organizations, and some researchers, precipitation becomes acidified when sulfur and nitrogen oxides emitted by fossil-fueled powerplants, vehicles, and other sources, both natural and manmade, are chemically changed in the atmosphere and return to earth as acid compounds. They contend that this acidity is causing a wide range of damage to the environment and may indirectly damage human health. They cite evidence that it kills freshwater fish, disrupts other parts of aquatic ecosystems, and may injure forests, reduce crop yields, and damage manmade materials including buildings, statuary, finishes, and metals. According to this view, acid precipitation will continue and, indeed, could surge with greater coal use. This assertion has led many in government, environmental organizations and the academic community, as well as individuals and groups in affected regions, to call for immediate adoption of more stringent emissions controls--especially for older, coal-fired powerplants which generally have higher emission levels than new plants.

Assertions about acid precipitation's causes and effects, and the need to stiffen emissions regulations, have not gone unchallenged. The coal and utility industries, some researchers, and recently DOE have claimed that there is little or no scientific basis to substantiate these alleged causes and effects. Importantly, many advocates of this position do not deny that acid precipitation is a problem; but they contend that years of research are needed to determine if emissions reductions could significantly diminish the extent of acid precipitation, and if it is a problem worthy of additional expensive regulation of coal-burning facilities.

THE ACID PRECIPITATION DEBATE IS UNNECESSARILY  
CONFUSED BY INACCURATE AND MISLEADING STATEMENTS

Significant disagreement exists even between the most restrained advocates on opposing sides of the issue. Unfortunately, misleading and inaccurate statements have only added further confusion to the debate. This has inhibited the search for consensus among the participants in the debate, obscured findings of important ongoing scientific research, and led to confusion among the general public.

For example, the International Atlantic Salmon Foundation claimed, in a cover letter accompanying a periodic publication,

--48,000 lakes in North America doomed to destruction...

--\$8 billion estimated lost from the American economy...

--thousands of individuals are physically affected, some fatally...

.....all because of ACID RAIN

Without question, acid rain is the most serious and deadly environmental problem that man has ever faced. Acid rain knows no boundaries and its effects are catastrophic."

Such statements attract public attention, but either do not reflect the current state of knowledge or exaggerate available evidence. The claim, for example, that some individuals are affected fatally by acid precipitation is not substantiated by scientific research to date (see pp. 11-13).

The extreme view on the other side holds that acid precipitation is a non-issue that has been blown out of proportion by anti-growth environmental extremists seeking a rationalization for a continuing attack on emissions. Supporters of this view assert that no damage from acid precipitation has been demonstrated, and that no proven relationship exists between acidity in precipitation and man-made emission sources such as coal-fired powerplants. Control measures are therefore completely unwarranted, given scant and unconvincing data on the subject.

Other advocates on each side of the question, as well as scientists researching the subject, fall between these extremes. Their disagreements are often confined to interpretation of scientific data and the relevance of alternative research methods. Indeed, in some areas, general agreement exists on key issues. These facts are often overshadowed by less-informed rhetoric from some interest groups and media representatives. Accordingly, this information report seeks to clarify the acid precipitation debate by

- identifying, for each of the component technical questions of the debate, the positions of interest groups on each side of the issue;
- identifying areas of agreement on important issues;
- describing the findings of the scientific community including areas of agreement and major points of uncertainty; and
- indicating the status of ongoing research which will aid in making informed decisions on government action.

These are difficult tasks involving a degree of interpretation and judgment on arguments and studies put forward by many individuals and groups. We have attempted to be as balanced as possible, but undoubtedly some will disagree with our characterization of aspects of the issue. Acid precipitation is a complex phenomenon about which reputable scientists disagree. Even those scientists expressing general agreement have disagreed on specific points. Furthermore, as might be expected on such a disputed subject, some arguments on each side are confusing the issue by trying to prove a case rather than seek the facts.

SUMMARY OF FINDINGS

We have grouped the key issues of the debate into the following areas, which are discussed in detail in the appendices to this letter:

- What do we know about the impacts of acid precipitation? (Appendix I, pp. 1 to 13).
- What causes the problem? (Appendix II, pp. 14 to 31).
- What is the range of views on how to deal with acid precipitation? (Appendix III, pp. 32 to 44).

Although the complexity of the acid precipitation phenomenon precludes our making sweeping generalizations about the level of understanding and agreement on these broad issues, we believe that characterizations can be usefully made about many of the specific questions within them.

What do we know about the environmental impacts of acid precipitation?

Major questions concerning acid precipitation's alleged environmental impacts relate to effects on aquatic and terrestrial ecosystems, man-made materials such as statuary, metal and finishes, and human health. Damage to aquatic ecosystems is one of the areas of highest consensus among interest groups debating the phenomenon. Acid precipitation's environmental impacts in the other areas are less understood and quantifiable. Among the specific issues being discussed and studied:

- Broad agreement exists that low alkalinity or buffering capacity in and around lakes in certain areas, especially in the Northeast U.S. and Southeast Canada, make them particularly vulnerable to acidification.
- Most advocates agree that some lakes and streams in these areas are becoming increasingly acidic. Those favoring regulations attribute this acidification to acid precipitation. Opponents of further regulations suggest that other factors may also be responsible. There is substantial consensus among scientists, although not unanimity, that acid precipitation is the primary cause of this condition.
- Present levels of aquatic damage are widely disputed. Many urging regulations say that extensive damage (e.g., destruction of fisheries) has already taken place, although others emphasize potential effects if present trends continue. Opponents of regulation have charged that reports of damage tend to be highly exaggerated. Scientists acknowledge that acidification of lakes and streams has thus far caused some damage to aquatic life in the U.S. and Canada, and are presently estimating future damage rates.

- Broad agreement exists that damage to terrestrial ecosystems-- forests, crops, and soils--is far less documented than damage to aquatic ecosystems. While some advocates of regulations say that proof of terrestrial damage exists, others concede that these effects are harder to understand and quantify. Most scientific work in this area is limited, having taken place only in laboratories or under highly controlled circumstances.
- Although most acknowledge that acid precipitation can damage man-made materials such as buildings, statuary, metals, and surface finishes, scientific work in this area thus far is largely only qualitative. Most work to date has not separated the effects of acid precipitation from those of other pollutants, so that acid precipitation's contribution to the damage could be estimated. Detailed assessments of the effects of acid precipitation alone are just getting underway.
- Advocates of regulation contend that acid precipitation may indirectly affect human health by causing heavy metal contamination of drinking water and edible fish. Opponents of regulation have been firm in denying any evidence of health effects from acid deposition. Field data in this area thus far shows some evidence of contamination, but no firm evidence of harm to health.

Do we know the causes  
of acid precipitation?

The debate over the effects of acid precipitation has been paralleled by an often heated debate over its causes. Advocates of further regulation claim that convincing evidence shows that man-made sources, particularly older coal-fired powerplants in the Midwest, cause acid precipitation in the Northeast and Canada. Opponents of regulation contend that there is insufficient proof that this is the case. We have found that the debate over causation, and the scientific research aimed at resolving the debate, has focused on a series of key questions following the chain of steps which trace from results back to alleged causes. Key issues include the following:

- General agreement exists that much of the northeastern U.S. and southeastern Canada are receiving acid deposition at rates many times in excess of that expected from a "pure" atmosphere. Most of the acid is sulfuric acid, with one-quarter to one-third nitric acid. In areas of the West experiencing acid precipitation, the proportions are different, with the majority of the acidity often being nitric acid.
- Participants in the debate disagree on whether the acidity of precipitation has been increasing. Data allegedly showing increases in the amount and geographic extent of acid precipitation between the 1950s and 1970s, both in North America and

Europe, has been widely circulated for several years. In the past year, however, coal and utility industry sources have challenged the data as not proving the conclusion.

- Most advocates agree that long-range transport and chemical transformations of SO<sub>2</sub> and NO<sub>x</sub> occur in the atmosphere. They disagree, however, whether sufficient detailed knowledge exists to link emissions from the Midwest to acid deposition in the Northeast U.S. and Southeast Canada. Scientists tend to see a link, but believe further understanding is necessary to be sure whether, or how much, deposition would be affected by emissions reductions.
- There is agreement that sulfur compounds in the atmosphere of the Northeast U.S. and Southeast Canada come predominantly from man-made sources. The man-made NO<sub>x</sub> emissions in the U.S. are quite substantial--almost as large as SO<sub>2</sub> emissions. However, good estimates of NO<sub>x</sub> emissions by natural sources are not available, so the relative shares of natural and man-made NO<sub>x</sub> are not clear.
- Wide disagreement exists over the extent to which local versus distant sources are responsible for acid precipitation. Most research to date has focused on long-range transport of sulfur compounds from coal-fired powerplants. Some recent reports, however, argue that local combustion, particularly of residual and home heating oil and fuel for mobile sources, could be major contributors. Scientific work suggests that both contribute, but has not firmly established the shares from each.
- Most participants in the debate acknowledge shortcomings of present models used to describe transport and transformation processes. These models cannot accurately estimate the contribution of an individual source to acid precipitation in downwind, "receptor" regions. Scientists, however, are developing models that can estimate the effects of a region's emissions on receptor areas.

Views on proposed strategies  
to abate acid precipitation

The debate on whether regulatory measures, beyond those already in the Clean Air Act, are needed to control acid precipitation has centered around two questions: (1) Is current regulation of emissions under the Act sufficient to address acid precipitation concerns, given our current state of knowledge about the phenomenon? and (2) How effective would additional proposed regulatory strategies be in alleviating acid precipitation, and what would their economic, environmental and other impacts be? Regarding the status of the debate on these issues:

- Participants in the debate are polarized over the adequacy of the Clean Air Act in addressing acid precipitation concerns.



Opponents of further regulation contend that, given our present lack of knowledge about acid precipitation's causes and effects, the Act is actually too burdensome. Supporters of further regulation say that the Act allows unacceptably high SO<sub>2</sub> emissions levels from older powerplants and ineffectively addresses transport and transformation problems.

- Proposed strategies to deal with acid precipitation vary widely in their economic, energy, and environmental impacts. Relatively inexpensive strategies, such as liming waters and coal washing, have limited environmental benefits. Comprehensive strategies, such as scrubbing existing powerplants, can significantly reduce SO<sub>2</sub> emissions but are more costly. Furthermore, the extent of their environmental benefits is disputed.
- EPA, DOE, and other agencies and organizations are presently studying the impacts of intermediate strategies designed to abate acid precipitation. Most of them focus on reducing SO<sub>2</sub> emissions from electric utilities, with particular emphasis on coal-burning powerplants. The coal and utility industries, and even DOE, however, cite studies suggesting that targeting coal-fired powerplants in the Midwest may not be effective in reducing acid precipitation in the Northeast, and that more attention needs to be paid to effects of NO<sub>x</sub> as well as SO<sub>2</sub> emissions.
- In addition to its economic, energy, and environmental impacts, the United States' decision on whether and how to implement control strategies could have international implications. Canadian officials consider transboundary air pollution, which they assert causes acid precipitation in eastern Canada, to be a serious bilateral issue with the United States. U.S. decisions on whether and how to address the problem therefore could affect relations between the two countries.

OBSERVATIONS--HOW  
WE VIEW THE DEBATE

Summing up the evidence on the acid precipitation debate, even the most conciliatory representatives of the opposite sides arrive at different conclusions.

Those most concerned with the additional costs and problems expected from further emissions controls argue from the point that there is no firm proof that reductions of emissions would result in lessening acid deposition. Therefore, they conclude, it is inappropriate to take any additional control actions at this time, because the controls would be certain to involve costs but would stand a risk of producing no benefits.

On the other side, those most concerned with the present and anticipated damage due to acid precipitation start from the point

that the oxide precursors of deposited acids, particularly SO2, come predominantly from man-made emissions. From this they conclude that reducing oxide emissions upwind from threatened areas is most likely to prevent or reduce damage, so they urge that at least moderate steps in this direction should be started promptly. They view as inequitable the present situation, in which they see all costs and risks being borne by the regions suffering damage, contending that the emitting regions should also take some share of risks and costs.

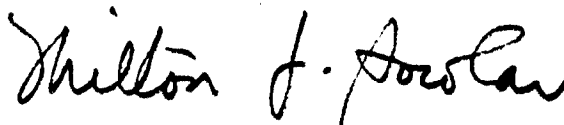
Our future work, which will result in a final report next year, will take into account the costs and equity issues raised by the participants in the debate. In that work, we will seek estimates of the time required to resolve uncertainties about the technical questions discussed in this report. In addition, we will look more closely at the impacts of regulating--as well as the impacts of not regulating. We will also assess the time required to develop and implement new or modified regulatory programs, should such programs be warranted. Our findings in these areas will serve as the basis for our views on whether to "regulate now" or "wait and see."

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In our work to date, we have obtained information from scientists and officials of the Departments of Energy and State, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and consular officials from Canada and several European Nations. In addition, we interviewed Federal officials associated with the U.S. Interagency Task Force on Acid Precipitation. This Task Force was established under Title VII of the Energy Security Act of 1980 (P.L. 96-294) to develop and implement a coordinated National Acid Precipitation Assessment Program. We also reviewed and analyzed a wide range of studies by researchers in government, industry and academia (from foreign Nations and the United States), as well as testimony, statements, and papers arguing a wide spectrum of viewpoints in the acid precipitation controversy. This information was supplemented with individual interviews and conference presentations and discussions. At your request, we have not obtained agency comments on this report.

As requested by your office, we plan to restrict further distribution of this report for four days after issuance, unless its contents are released by your office before that time.

Sincerely yours,



Acting Comptroller General  
of the United States

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WHAT DO WE KNOW ABOUT THE ENVIRONMENTAL  
IMPACTS OF ACID PRECIPITATION?

Those who claim that acid precipitation is a demonstrated environmental problem for the U.S. assert that significant damage already has occurred, and that firm evidence shows that far more damage will occur unless regulatory action is taken. Among the alleged effects of acid precipitation are:

- acidification of lakes, streams, and groundwaters resulting in damage to fish and other aquatic life;
- reduced forest productivity and damage to agricultural crops;
- deterioration of man-made materials such as buildings, statuary, finishes and metal structures; and
- indirect effects on human health arising from contamination of drinking water by metals being released from soils and pipes and from contamination of edible fish by toxic metals, particularly mercury.

Some difference of opinion exists within this group over the extent to which current evidence substantiates each of these claims. Some say that proof exists to verify all of them. Others claim that damage to lakes and aquatic life has been sufficiently documented, but that more documentation is needed to verify and assess acid precipitation's effects on soils, vegetation, man-made materials, drinking water, and edible fish. All agree, however, that certain areas in the Northeastern U.S. and Southeastern Canada are highly vulnerable to these kinds of damages. These hard-rock areas tend to provide little of the natural buffering materials in their lakes and soils that are found in areas of calcium-bearing rock (e.g., limestone, marble, or dolomite) which can absorb or neutralize acids.

Those asserting that acid precipitation is not a sufficiently documented environmental problem acknowledge the vulnerability of these regions to acidification, but dispute most of the claims of "proven" damage. This is especially true for terrestrial impacts such as those on vegetation and soils, where complex biogeochemical linkages are involved. Only aquatic impacts are acknowledged by some in this group as proven--and even in this case they question whether acid precipitation is the only cause.

Scientific research thus far presents a blurred picture of acid precipitation's impacts. Convincing data does suggest damage to aquatic systems, but data on other impacts is far less conclusive. Important ongoing research aims to clarify the extent of present damage, the tolerance levels of different ecosystems to acidification, and the rate of damage to which these ecosystems are being subjected.

AQUATIC IMPACTS

Damage to aquatic ecosystems is the area of highest consensus among interest groups debating the acid precipitation phenomenon. Environmental groups and others calling for immediate regulation cite a formidable body of scientific literature which documents the problem. Spokesmen for the utility and coal industries acknowledge that acidic conditions have damaged aquatic ecosystems in some areas, although some of them say that acid precipitation may be only one of several causes.

Among the major contentions about the aquatic impacts of acid precipitation:

- the alkalinity or buffering capacity, and eventually the pH of lakes and streams in affected areas, is being lowered by the accumulation of acids from precipitation. 1/
- fish populations are being affected through various types of interference with their reproductive cycles and through outright fish kills; and
- other aquatic organisms, including plants and micro-organisms and some amphibians, are also being harmed.

Low buffering capacity makes some lakes vulnerable to acidification

Participants in the acid precipitation debate agree that the low buffering capacities in and around lakes in certain areas of the Northeast U.S. and Southeast Canada make them particularly vulnerable to acidification. These lakes tend to be surrounded by hard insoluble bedrock with thin, sandy, infertile soil. A map showing roughly the areas of concern for North America is shown in figure 1. More detailed inventories of the conditions of lakes in these and other areas are now underway and are being reported.

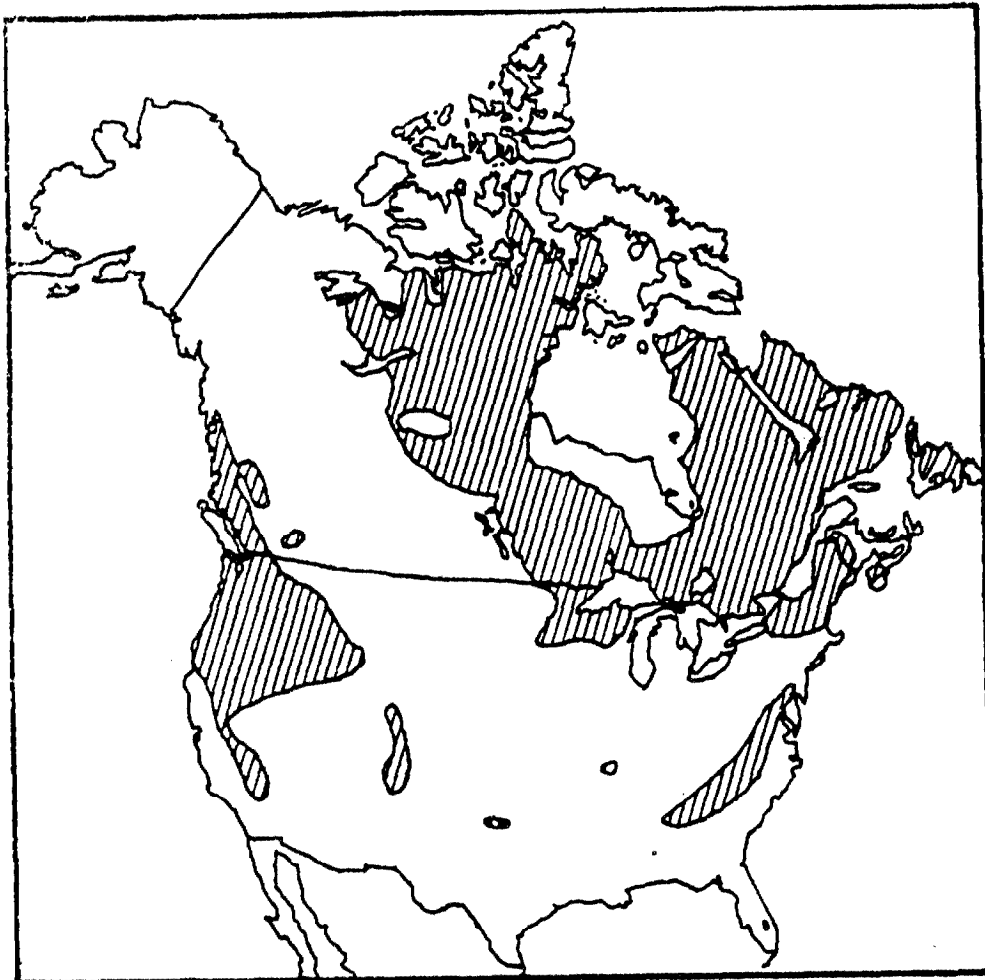
According to EPA, "The extent of change in acidity of a lake or stream is determined mainly by the buffering capacity of the

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1/pH is the scientific measure of acidity. It decreases as acidity increases. In a neutral solution--neither acidic or alkaline--the pH=7. The pH scale is logarithmic, so that a change of one unit of pH means a ten-fold change in acidity. Rain from a pure atmosphere would be slightly acidic, pH=5.6, due to absorption of carbon dioxide from the atmosphere, so precipitation is usually called acidic only if it has a pH below 5.6. Rain with pH=4.6 has ten times as much acid as normal, while rain at pH=4.0 is forty times as acidic as normal. For comparison, vinegar has a pH about 3.0.

Figure 1

North American Areas Containing Lakes that  
Are Sensitive to Acidification by Acid Precipitation



Source: "The LRTAP Problem in  
North America: A Preliminary  
Overview," prepared by the  
United States-Canada Research  
Consultation Group on the Long-  
Range Transport of Air Pollu-  
tants, 1979

surrounding soil and the composition and size of the watershed in which the water resides. If the watershed soil is alkaline--containing limestone or bicarbonate to neutralize incoming acids--the lakes and streams will be acidified less rapidly and the aquatic community will be far less susceptible to harm." 1/ Unfortunately, in affected regions of the Northeastern U.S. and Southeastern Canada, soils provide little alkalinity, or capacity to neutralize acids as they enter the surface waters. As acid deposition continues, it is argued that this limited alkalinity will be further reduced and then the lakes' pHs will drop sharply, adversely affecting aquatic life.

Alleged effects on fish  
and other aquatic life

Advocates of further regulation cite evidence that acidification of lakes and streams is already reducing populations of fish and other aquatic life in Eastern North American as it has dramatically in Scandinavia. Some assert that fish kills result from melting of acidified snow. According to one scientist who has worked in acid precipitation research for over 10 years,

"acids and other soluble substances contained in polluted snow are released as contaminated meltwater during warm periods in winter or early spring. The resulting release of pollutants can cause major and rapid changes in the acidity and other chemical properties of streams and lake waters. Fish kills are a dramatic consequence of such episodic inputs into aquatic ecosystems." 2/

EPA supported this view in a 1980 publication, noting that "In lakes subject to highly acidic spring thaws, where acids are released in sudden, intense bursts, the already-stressed fish tend to die in large numbers." 3/ EPA also asserted that additional fish deaths were caused by leaching of metals from soils--especially aluminum and possibly mercury--during periods of acid precipitation. According to EPA, these metals become mobile and soluble in soil after an acidic rain. Runoff and leaching subsequently transfer the metals to the water in sufficient amounts to cause fish to die.

It is asserted that, while direct fish kills are more dramatic, the most common cause of decline of fish populations in

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1/U.S. Environmental Protection Agency, "Acid Rain" EPA-600/9-79-036, July 1980. p. 14.

2/Ellis Cowling, "Acid Precipitation and its Ecological Consequences", North Carolina State University, Raleigh, 1980.

3/U.S. Environmental Protection Agency, "Acid Rain" EPA-600/9-79-036, July 1980, p. 16.



acidified lakes is failure in the reproductive cycle. Acidity inhibits development of reproductive organs in some fish, and reduces egg production. Even if eggs are successfully hatched, the young do not develop normally. The situation is complicated further by the effects on reproduction of the metals released into acidified lakes. According to a university scientist, whose view was agreed to by an acid precipitation specialist from the Electric Power Research Institute (EPRI),--a research institute supported by the electric utility industry--

"Interference with normal reproductive processes is induced not only by acidity itself but also by increased concentrations of certain cations--notably aluminum--in acidified lake and stream waters." 1/

In addition to fish, other aquatic life is also asserted to be adversely affected by acid precipitation. Populations of frogs, salamanders, and other amphibians are dwindling, allegedly because acid precipitation is interfering with their reproductive processes. Aquatic plants (i.e., algae) and microorganisms which are vital elements of the food chain for other animals are also affected.

#### Responses by opponents of regulation

Most industry spokesmen, and others who propose a "wait and see" attitude about acid precipitation, acknowledge that acidification of lakes and streams has probably caused many of the aquatic impacts discussed above. According to a National Coal Association spokesman on the subject, "The most credible allegation of environmental damage appears to be that of a possible contribution to the acidification of certain lakes in very limited areas of the northeastern United States and Canada." 2/ While asserting that the extent to which acid precipitation contributes to this acidification is unknown, he acknowledged that "acidic rain could be contributing to the acidification of the lakes." Another proponent of the "wait and see" attitude, the former Director of Ohio's Environmental Protection Agency, confirmed a relationship between acid precipitation and damage to aquatic ecosystems, stating that while many alleged effects of acid precipitation have not been substantiated, "exhaustive research from the Scandinavian countries have shown only a proven effect on aquatic life." 3/

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1/Ellis Cowling, op. cit.

2/William Poundstone, Testimony before the Senate Energy and Natural Resources Committee, May 28, 1980.

3/James F. McAvoy, Testimony before the Subcommittee on Oversight and Investigations of the House Committee on Interstate and Foreign Commerce, Feb. 26, 1980.

Thus, many supporting a "wait and see" attitude concede that acidification of lakes and streams is causing damage to aquatic ecosystems. However, this concession is qualified by the following points:

(1) Media reports of aquatic damage, they assert, are often exaggerated. Our review substantiates this claim. For example, the media have reported that distant U.S. emissions have caused fish kills and "dead" lakes in Ontario. According to a Canadian Embassy official, however, the Canadian government attributes these occurrences to the local effects of smelters located in Ontario. The Canadian government's concern over U.S. emissions relates more to anticipated damage to aquatic ecosystems in the future if acid deposition continues at the current rate.

(2) It is unclear to what extent acid precipitation leads to acidification of lakes and streams. Coal industry spokesmen, for example, have told us that there is no simplistic correlation between the acidity of rain and the acidity of these lakes--many factors must be considered such as local acid-forming bogs or swamps, forest fires, and forestry and agricultural practices.

(3) Even if it has been established that acid precipitation causes aquatic damage, it may be that man-made emissions from nearby sources cause the acid precipitation rather than the distant man-made sources that are targeted by environmentalists and others for emissions reduction. This contention relates more directly to the general question, "Do we know the causes of acid precipitation?", which will be discussed in appendix II.

#### Status of scientific research on aquatic impacts

We have found general agreement in the scientific community, through interviews and an inspection of the literature, that lakes and streams in the Northeast U.S. and Southeast Canada are becoming increasingly acidic, and that this acidification is already causing damage to some aquatic ecosystems. There is substantial consensus, although not complete unanimity, that acid precipitation is the primary cause of this condition.

The available scientific data presents a more convincing case for aquatic impacts than for other types of effects. It is better understood by the scientific community and more easily quantified. Among the areas of substantial agreement:

- the pHs of many lakes and streams in affected areas have dropped, in a number of cases with concurrent increases in sulfate concentrations, and stress placed on limited buffering capacities.
- fish populations in Nova Scotia rivers and Adirondack lakes have already been affected by this acidification,

and other areas in eastern North America are threatened by acidification. Most scientists agree that fish are affected most during their reproductive and embryonic stages. Somewhat less agreement exists, although still a consensus, that some mature fish are dying from acidification or its consequences.

--substantial consensus exists that acidification adversely affects amphibians, as well as other components of the aquatic ecosystem such as aquatic plants and microorganisms.

--aquatic damage is caused directly by higher acidity, and indirectly by acidification triggering the release of toxic metals such as aluminum and mercury into affected waters.

Importantly, we have found some consensus in the scientific community, although not universal, that acid precipitation is the primary cause of acidification of lakes and streams. For example, EPRI's Program Manager for Ecological Effects reported that:

"the consensus of the participants in an International Workshop on the Ecological Effects of Acid Precipitation held in Galloway, Scotland, in September 1978, was that regional acidification of surface waters has been identified in several areas of North America and Europe and that the cause is primarily acid precipitation. However, not all are in agreement." 1/

While there have been some suggestions by scientists that forestry or agricultural practices may contribute to acidified conditions of lakes and streams, our examination of the scientific literature and discussions with individual researchers indicate consensus that acid precipitation is the major cause of lake acidification. However, whether distant or nearby man-made sources or natural sources cause acid precipitation is another question--one which we address in appendix II.

Ongoing scientific research is attempting to clarify the relationship between quantities of acid deposition and their effects on aquatic ecosystems. Several models currently being tested are estimating the amount of degradation to lakes caused by various levels of pollutant loadings. Scientists say that these techniques will help them to predict quantitatively how much damage to aquatic ecosystems can be expected in the future from acid deposition or, alternatively, to estimate thresholds or tolerance levels of acid deposition, below which no damage, or limited damage, could be expected.

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1/Robert Brocksen, Testimony before the National Commission on Air Quality, October 5, 1979.

ACID PRECIPITATION'S IMPACTS ON TERRESTRIAL ECOSYSTEMS,  
MAN-MADE MATERIALS AND HUMAN HEALTH ARE LESS UNDERSTOOD

Acid precipitation's environmental impacts are, at present, less certain and less quantifiable in areas other than aquatic ecosystems. Although the subjects discussed below have been and are presently being researched, the results are preliminary and not easily quantified. As a result, the acid precipitation debate in these areas is particularly confusing. Unproven hypotheses have been reported as fact in the news media and elsewhere. On some occasions, overly ambitious conclusions have been inappropriately drawn from incomplete data.

Below, we attempt to clarify the arguments expressed by participants on each side of this debate, and to report the findings and the status of ongoing scientific research. We discuss acid precipitation's alleged impacts on:

- Terrestrial ecosystems;
- Man-made materials; and
- Human health.

Effects on terrestrial ecosystems (forests, crops, and soils)

Advocates of regulation have made claims about acid precipitations's effects on forests, crops, and soils with varying levels of intensity. Some assert that sufficient proof of terrestrial damage exists to strengthen the case for government action to control acid precipitation. Among the alleged terrestrial impacts are:

- damage to plant tissues and interference with photosynthesis;
- stunted forest growth;
- reduced yields of tomatoes, beans, and other agricultural crops; and
- interference with the process by which nutrients in soil are regenerated and retained.

Some advocates of regulation acknowledge, however, that terrestrial effects are much more difficult to quantify because of the vast number of species of plants and animals, the long time-scales of change in many ecosystems, and the complex inter-relationships among and between organisms and their environment. EPA and some interest groups contend that although these impacts are possible, further research is needed to prove that they are happening. EPA literature on these impacts has qualified many assertions with "cans" and "mays". For example, EPA reported in

one publication that acid precipitation "may affect young growing tissues and the process of photosynthesis," and that "acids in rain may affect the storage function of soils." 1/ (Emphasis added)

Opponents of regulation express stronger skepticism about alleged terrestrial impacts. It is reflected in testimony, cited earlier, before the Senate Committee on Energy and Natural Resources:

"As to whether acid rain causes severe ecological harm to plant life, the available evidence is too limited to make a determination...much more work remains to be done in this area before we have concrete evidence of the effect of acid rain on plant life." 2/

The Edison Electric Institute (EEI), the electric utility trade association, supports this view, noting in a recent report that "no measurable vegetation symptoms have been found in the field which are attributable to acidic rain. Furthermore, no claim of crop loss or damage attributable to acidic rain has been confirmed in the field." 3/ EEI supports its claim by citing an EPA report 4/ which states,

"Though various specific biological effects of simulated acidic rain have been demonstrated in controlled field and laboratory experiments, reliable evidence of economic damage to agricultural crops, forests, and other natural vegetation and to biological processes in soil by naturally occurring acidic precipitation has been reported very rarely."

Our review of the literature confirms the assertion that, to date, most reports of adverse terrestrial impacts of acid precipitation are studies based on laboratory exposure to simulated acid precipitation. Some of these studies have demonstrated, under controlled conditions:

--increased mortality of pine seedlings;

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1/U.S. Environment Protection Agency, "Acid Rain," EPA-600/9-79-036, July 1980, pp. 19 and 20.

2/William Poundstone, op. cit.

3/Edison Electric Institute, "Before the Rainbow: What We Know About Acid Rain," Washington, D.C., 1980, p. 59.

4/U.S. Environmental Protection Agency, "Air Quality Criteria for Particulate Matter and Sulphur Oxides," External Review Draft #1, April 1980, Washington, D.C., p. 3-8.

- loss of nutrients due to leaching from leaf organs;
- in certain cases, nitrogen and/or sulfur in precipitation can be beneficial nutrients and accelerate growth.

Occasional field data has begun to appear from recent and ongoing studies. One report on 15 years of field studies in west Germany indicates major changes in soil chemistry affecting forests located on poorly buffered soil. These changes are attributed to acid deposition causing aluminum release into soils that results in the death of small roots. As a result, the trees are in "a highly stressed condition involving less foliage, dry and brittle crowns, etc." leading to a view that "The condition of the trees is such that their ultimate survival is unlikely..." 1/

This report avoids claiming that the German findings will apply directly to North American forests but rather urges that work be launched promptly to examine this possibility. The point made here, as with earlier Scandinavian evidence of aquatic damage, is that European experience can provide a warning of problems we may face in the future.

Overall, most scientists say that more research is needed before we have an adequate understanding of the effects of acid deposition on terrestrial ecosystems. This contrasts with the general agreement among scientists that oxides of sulfur and nitrogen, ozone, and certain other gases do cause damage to vegetation, including economic damage to crops, when present in sufficient concentrations.

#### Effects on man-made materials

Detailed assessments of the effects of acid rain on man-made materials such as buildings, statues, metals and paints, separated from the effects of other pollutants, appear to be just getting underway. To date, the literature we have seen is largely anecdotal--for example, an EPA publication, speaking of German sculptures not deteriorated noticeably between 1702 and 1908, and then substantially eroded by 1969, says:

"The interactions between the statuary and air pollution (SO<sub>x</sub>, NO<sub>x</sub>, acid rain and dry deposition) are thought to be chiefly responsible." 2/

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1/G.H. Tomlinson, "Acid Rain and the Forest--the Effect of Aluminum and the German Experience," Research Centre, Senneville, Quebec, Feb. 1981.

2/U.S. Environmental Protection Agency, "Acid Rain," EPA-600/9-79-036, July 1980, p. 22.

Later the document says:

"A link between corrosive damage to steel and SO<sub>2</sub> has also been exposed." 1/

Similar examples of major deterioration of buildings and statues, of corrosion of metal objects and damage to finishes are also cited frequently, but usually in circumstances where the result is the total effect of an industrial-age atmosphere rather than the effect of acid rain alone.

The interim report of the joint U.S.-Canadian Impact Assessment Work Group recognizes this explicitly in discussing "several complicating factors" that must be taken into consideration in any assessment:

"To date, there have been virtually no studies which provide estimates of the relationship between degrees of deterioration and atmospheric deposition, the so-called dose-response relationship."

"A further complicating feature...is the confounding impact of local pollution sources."

"It should be noted, in addition, that local corrosive effects of the primary pollutants (e.g., SO<sub>2</sub>) are fairly well documented, while the role of acidic precipitation in corrosion processes is not well understood." 2/

While most of the literature we have seen on effects of acid deposition on materials does indicate a belief that damage is occurring, there appears to be wide, if not complete, agreement that a good deal of research will be needed to get measures of the dose-response relationship and, based on that, estimates of the location and cost of the damage and the possible savings from reduced acid deposition.

#### Effects on human health

There were few claims of direct effects on human health in the literature we surveyed, and they tended to be attributed to other pollutants rather than to acid deposition itself. Opponents of regulation were quite firm in denying any evidence of health effects from acid deposition.

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1/Ibid., p. 23.

2/U.S. Canada work Group 1, "Impact Assessment, Interim Report," prepared in accordance with Memorandum of Intent on Transboundary Air Pollution, Feb. 1981, p. 6-3.

In its own assessment of the issue, the joint U.S.-Canadian Work Group on Impact Assessment reported:

"Available information gives little cause for concern over direct health effects from acid deposition. The pH of acidic precipitation is generally well within the range normally tolerated by the skin and gastrointestinal tract." 1/

As with several other types of effects, we have encountered assertions that other products arising from transformation of SO<sub>2</sub> and/or NO<sub>x</sub> emissions, particularly respirable sulfate particles, were responsible for health effects at distant locations. However, these are controversial both because of disputes about the methods used in the studies and because of the complicating effect of mixtures of pollutants.

Attention has been focused, in the health area, on what are called indirect health effects. There are two such effects often discussed, both involving the metals which can be dissolved and carried by water of greater than usual acidity. These are contamination of edible fish with mercury, and contamination of drinking water by heavy metals such as lead leached either from watersheds or from water storage and distribution systems. A Department of Energy paper acknowledges that these are potential impacts, but says that they have not yet been well-analyzed or demonstrated. 2/

The joint U.S.-Canadian Impact Assessment Work Group's interim report indicated "no clear evidence of health effects from drinking these contaminated waters" 3/ in a number of cases they cited where metal levels were apparently elevated due to acid deposition. Similarly, the Work Group Report said there was no clear evidence of health effects from mercury-contaminated fish, but noted that fish from some poorly buffered lakes contained elevated mercury levels, some in excess of Canadian or U.S. action levels. In this area, the work group acknowledged that the mechanisms by which acidification of lakes could lead to elevated mercury content in fish were, as yet, unknown.

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1/U.S. Canada Work Group 1, "Impact Assessment, Interim Report," prepared in accordance with Memorandum of Intent on Transboundary Air Pollution, Feb. 1981, p. 5-1.

2/Office of Environmental Assessments, Department of Energy, "Acid Rain: How Real an Issue?", Dec. 30, 1980.

3/U.S. Canada Work Group 1, "Impact Assessment, Interim Report," prepared in accordance with Memorandum of Intent on Transboundary Air Pollution, Feb. 1981, p. 1-4.



Research being planned in the health field will examine the two areas of indirect effects to determine their extent and, if necessary, to examine mitigation measures.

DO WE KNOW THE CAUSES OF ACID PRECIPITATION?

We have seen that there is at least partial agreement on some of the effects of acid deposition and on the need for further research to estimate effects in other areas. The question to examine next is whether the causes of acid deposition are known.

In this appendix we will first state the general arguments given from opposing positions on this question, then look sequentially at the three subquestions:

- Is acid really being deposited from the atmosphere?
- If so, how does the atmosphere become acidic?
- Where does the acid originate?

THE ARGUMENTSThe charges

Those viewing acid precipitation as a problem requiring legislative attention assert:

- That it results in large part from man-made emissions of oxides of sulfur and nitrogen;
- That these emissions are transformed in the atmosphere to sulfuric and nitric acids, and can be transported great distances; and
- That these acids are then deposited where they harm vegetation, soils, surface water, and materials.

Furthermore, this view goes beyond acid deposition alone, to a broader contention: that other secondary products, also generated by transformations of sulfur and nitrogen oxides, are responsible for substantial shares of certain recognized major pollutants in areas distant from the emitting sources. Specifically, much particulate pollution, in the form of sulfate particles, is attributed to atmospheric transformations of transported SO<sub>2</sub>, and the production of oxidant pollution (ozone and related substances) is attributed to transformations involving transported nitrogen oxides.

In addition to this qualitative explanation of acid precipitation and related phenomena, there has been a quantitative assertion often made: that measurements show a strong trend toward more acidic precipitation over eastern North America and southern and southwestern Scandinavia in the period between the mid-1950s and the present. The trend in North America is asserted to involve a great spreading of the area receiving highly

acidic precipitation, accompanied by decreases of average precipitation pH in the affected region by 0.5 or more units, corresponding to a three-fold or greater multiplication of the amount of acidity in precipitation.

### The rebuttals

In response to these views, those who do not believe that acid precipitation merits governmental action at this time offer a number of alternative explanations for the reported phenomena, and dispute much of the supposed explanation as unproved:

- They contend that in areas such as southern Sweden and southwestern Norway, where evidence of acidification was first reported, the problem is likely caused by changes in agricultural or forestry practices rather than by deposition of acidic material from the atmosphere.
- The assertion that the acidity of precipitation has been increasing over the past two or more decades has been called unproved by analysts re-examining the data which supposedly proved the point.
- Attribution of acid precipitation to long-range transport of pollutants from major complexes of industry and powerplants has been answered by arguments that, in areas with high rates of acid deposition, natural sources or local sources of pollutants, particularly from burning fuel oils, may have the leading role as causes, with distant sources having little responsibility.
- Even if long-range transport and atmospheric transformation of pollutants are acknowledged to occur, there are contentions that complex events in the atmosphere, both physico-chemical and meteorological, determine whether, where, and how much deposition occurs. Because of these, it is claimed that it is not possible to quantitatively describe the relation between emissions from any single source or source region and deposition in another location. Therefore, according to this view, we do not know whether, or how much, deposition in any location would be reduced by a lowering of emissions in another area.

### Is there any agreement?

Going through the chain of events asserted to be involved in acid precipitation--emissions, transport and transformation, deposition and damage--we have found varying levels of agreement on how well matters are understood. Some of this agreement can be explicit, but it also can be shown tacitly, by silence or by partial acknowledgement that an allegation appears credible.

Furthermore, in our examination of the literature on the subject, we have found that some movement is apparently occurring in the debate, as attention in newer publications turns from theoretical assertions toward the production and discussion of actual data to answer specific questions.

### IS PRECIPITATION REALLY ACIDIC?

There have been many reports of acidity in rain recently, and they are not seriously contested. Thus, in a 1980 booklet by the Edison Electric Institute, the Director of Environmental Assessments of the Electric Power Research Institute explains utility support for large-scale research on the subject as follows:

"Simply, we recognize: (1) that acid rain is falling, (2) that such rain can cause serious ecological damage, and (3) that atmospheric emissions from utility plants may play a role in the occurrence of acid rain." 1/

In this area, then, there is agreement that acid deposition is occurring now.

### How acid is the rain?

An estimate of the mean amount and distribution of acid precipitation in North America for 1976-1979 is shown in figure 2. 2/ In this figure the lines connect places with the same level of acidity in precipitation. The lines are marked in terms of acid deposition in milligrams per square meter per year. The line marked 10 corresponds to an average precipitation pH of about 5.0, 20 corresponds to an average pH of 4.7, 50 corresponds to about pH 4.3, and 100 corresponds to about pH 4.0.

For comparison, the theoretical value for precipitation from a "normal" atmosphere containing carbon dioxide as its only acid would be about pH 5.6, which would correspond to an acid deposition of 2.5 in the units in the figure. This means that the entire area enclosed by the 20 line is receiving at least 8 times as much acid in precipitation as it would from "normal" rain, and the area enclosed by the 50 line is receiving at least 20 times as much acid in precipitation as would be expected from unacidified rain.

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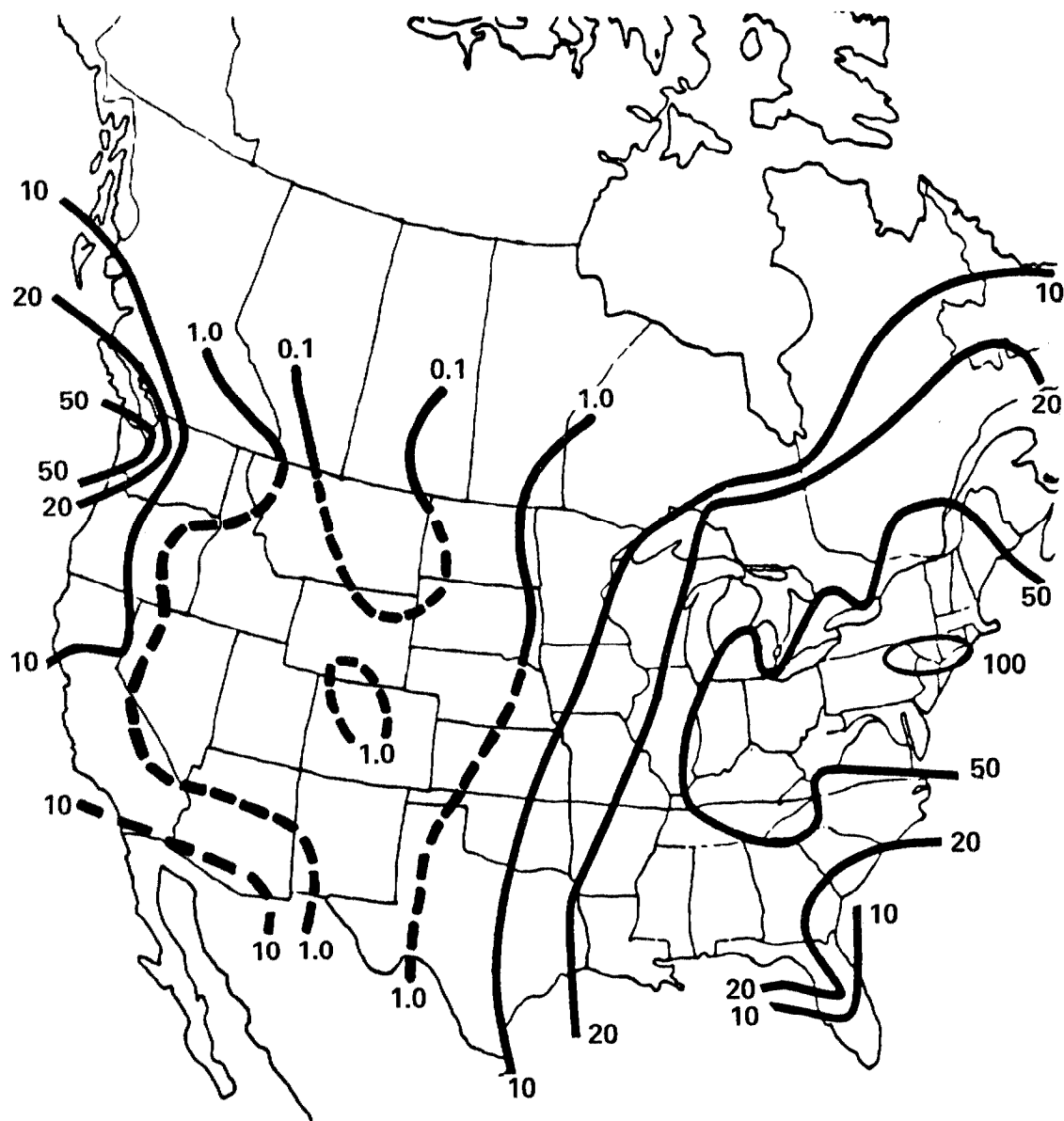
1/Ralph Perhac in, "Before the Rainbow: What We Know About Acid Rain", Edison Electric Institute, Wash., D.C., 1980, p. 17.

2/Taken from February 1981 Interim Reports by Work Groups under U.S.-Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 1, p. 3-9, and Work Group 2, p. 6-4.

Figure 2

Mean Annual Acid Deposition in  
Precipitation for Period 1976-1979

(Deposition values are  
derived from mean pH and  
mean annual precipitation)



Source: February 1981 Interim Reports by Work Groups under U.S.-Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 1, p. 3-9, and Work Group 2, p. 6-4.

The map shows a large area of the northeastern U.S. and part of southeastern Canada receiving precipitation twenty times as acidic as "normal", and a smaller core area centered near New York City receiving precipitation forty times more acidic than normal. Smaller areas on the West Coast also experience acidic precipitation. The mid-continent area, however, shows much lower acidity with some areas experiencing precipitation more alkaline (less acidic) than expected from normal rain.

The report from which this map was reproduced estimates that there were possible errors of up to  $\pm 50$  percent in the acid deposition measurements on which the map was based. <sup>1/</sup> These are explained as arising from differences in methods and quality assurance between different monitoring networks whose results were combined to develop the map. While there may be disagreements about the level of accuracy of this map, it does not differ in major ways regarding the acidity of precipitation from measurements in Pennsylvania and New York cited as examples by EPRI. In any event, major efforts are now underway, by both governments and industry, to expand the number of stations monitoring deposition and to improve their accuracy, consistency and intercomparability. We can surely expect close scrutiny, and possibly some debate again, as more monitoring results on acid and other components of precipitation are gathered and compared.

What kind of acid is  
found in precipitation?

Besides its distribution, there is relatively well-accepted information about the relative proportions of the different types of acid found in precipitation. These proportions are important in regard to the question of which emission changes might affect future acid deposition.

Measurements made in several watersheds in eastern North America are described by EPA as showing a majority of sulfuric acid (up to 65 or 70 percent) with nitric acid ranging from  $1/3$  to  $1/2$  the amount of sulfuric acid, and other acids present in smaller amounts. Another source shows similar results--62 percent of acidity as sulfuric acid, 32 percent as nitric acid, and 6 percent as hydrochloric acid. Measurements near the ocean tend to have higher levels of chloride but this is usually regarded as having come as salt from sea spray, rather than as hydrochloric acid.

The proportions of acids in precipitation in eastern North America differ with the season, with sulfuric acid much higher in summer, but nitric acid not changing much seasonally. Also, the

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<sup>1/</sup>The logarithmic nature of the pH scale means that large changes in acid concentrations correspond to relatively small changes in pH. As an example, this  $\pm 50$  percent uncertainty in acidity is equal to less than  $\pm 0.2$  in pH.

portion of total acidity represented by nitric acid appears to have been increasing somewhat in measurements running a decade or more. Proportions of acids also differ geographically, with Western U.S. measurements showing nitric acid often about equal to sulfuric acid and, in occasional cases, nitric acid contributing as much as 80 percent of total acidity. In contrast, measurements in remote areas of the oceans tend to show most acidity as sulfuric acid with only about one-tenth as much nitric acid.

The acids are usually not pure in rain, but rather are partly neutralized by alkaline materials such as ammonia or windblown soil dust. <sup>1/</sup> Acid deposition measurements generally report the net acidity left, excluding that already neutralized. More complete analyses also show the other ions besides acid.

#### Is acid found only in rain?

Acidity is known to be found in snow as well as rain. In addition, there is evidence that acid is deposited in the form of gases, solids, and with fogs, haze and mists, collectively called dry deposition. All of these contributions are counted in acid deposition.

There is significant uncertainty about the relative proportions of acid contributed by precipitation and by dry deposition. Some rough estimates suggest the split is about even, but there is uncertainty which is less a matter of disagreement than of scarcity of knowledge. The measurement of dry deposition is just in its infancy. To date, estimates of dry acid deposition are much less accurate than estimates for precipitation acidity, tending to be based on models, or on a few calibrated watersheds where wet deposition is measured, total deposition is estimated at the outlet from the watershed, and then the dry component is approximated by difference. It is generally agreed that development of methods to obtain good routine monitoring data on dry deposition is desirable.

#### Has precipitation become more acidic recently?

The general question of what the history of acid deposition has been remains hotly contested. This is understandable, since most parties in the debate recognize that knowing past trends could help confirm the cause of acid deposition by showing what other trends may be correlated with it.

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<sup>1/</sup>Alkaline dust from the plains and desert areas is often cited to explain the fact that much of the West-Central portion of the U.S. does not experience acidic precipitation.

Assertions that records of rainfall pH showed substantial increases in the amount and geographic extent of precipitation acidity between the 1950s and 1970s, both in North America and Europe, were widely circulated for several years. In the past year, however, coal and utility industry sources have given equally wide distribution to a critique of the data and analysis that supported this assertion, contending that the data does not support the conclusion. For example, in an EEI book on acid rain, all five articles separately present this argument. <sup>1/</sup> Currently, the assertion is no longer being presented in the same form in recent compilations on precipitation acidity, apparently a tacit acknowledgement that the critique is valid.

Still, the belief that acid deposition has developed and grown in recent decades, and certainly since the Industrial Revolution of the 18th and 19th centuries, remains strong with many who see acid rain as a pressing problem. They are convinced that acid rain at the current level is much more acidic than existing ecosystems are accustomed to coping with. Therefore, they continue to pay much attention to the search for evidence to prove this view. Conversely, there is an understandable skepticism of such proofs from utility and other interests involved in the use of fossil fuels, and particularly coal. Types of evidence being examined, and argued about, include old precipitation preserved as glacier ice, and old lake sediments which can show records of the conditions of the lake waters in earlier times.

There are additional arguments on the issue of historic trends in acid deposition which make it difficult to reconcile views. One is that overall U.S. coal use did not grow but indeed fell in the 1950s, and in its growth after that only went back up toward levels it had been at in the 1910s, 1920s, and 1940s. Furthermore, it is pointed out, industrial and utility oil use only began their major growth in the late 1960s, also too late to explain the asserted growth of precipitation acidity from the 1950s. Another argument that has been made is that total amounts of acid substances in precipitation have not increased, but rather that the net acidity has risen because there have been decreases in the amounts of alkaline particulate materials emitted, which used to balance or neutralize that acidity. This decrease in particulates is attributed to the vast growth, since 1950, in the use of precipitators to remove particulate emissions from stack gases, thus presenting a possible case where a partial solution to the overall emission problem exacerbated another facet of the problem.

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<sup>1/</sup>Carolyn Curtis, Ed., "Before the Rainbow: What We Know About Acid Rain," Edison Electric Institute, Wash., D.C. 1980.



In summary, to date the question of the historic trend in acid deposition still seems strongly disputed. However, it is agreed that wet and dry acid deposition are now occurring, and monitoring is being expanded rapidly to obtain detailed measurements of it.

HOW DOES THE ATMOSPHERE BECOME ACIDIC?--TRANSPORT AND TRANSFORMATION

"Winds blow from Ohio, carry a killer eastward" is a recent newspaper headline on an acid rain story. This firm declaration is an example of the strong and simplified tone of some explanations of acid rain. In response to this rhetoric there are assertions, from some affiliated with major pollutant emitting areas or industries, that "...this can come from a multitude of sources such as exceptionally severe winters and unusual rainfalls due to tropical storm activity," and that "...case studies were made that show that the amount of sulfate from large sulfate emitting sources can rarely be recognized at distances beyond 200 miles."

The occurrence of acid deposition has been agreed to, at least in part, and the amounts, sources, and locations of a major share of emissions are relatively well characterized. However, the question of the linkage between the two seems to show the greatest extent of uncertainty, and the most frequent appearance of irrelevant or oversimplified assertions.

The central phenomena that are involved in the asserted link between emissions and deposition are the transport of emitted pollutants up to many hundreds of miles through the movement of air masses, and the chemical reactions that the oxide pollutants can undergo during this time, which can result in their transformation into other polluting products including sulfuric and nitric acids.

There is agreement on general principles

There is not serious disagreement that transport and transformation do occur. For example, regarding transport, an engineer from the Central Electricity Generating Board of England (whose tall stacks have been accused of being the source of much acid rain in Scandinavia) said, in 1980:

"There has never been any reasonable doubt that industrial air pollutants may travel many hundreds of kilometers since this has frequently been observed with natural pollutants...". 1/

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1/G.W. Barrett, Station Engineer, Central Electricity Generating Board, Statement at Allegheny County State Implementation Plan Hearing, Pittsburgh, Pa., March 25, 1980.

Similarly, regarding transformations, a spokesman for the Environmental Assessment Department of EPRI has said, of the SO<sub>2</sub> transported from powerplant emissions:

"During that transport a number of things happen: (1) the SO<sub>2</sub> is diluted by surrounding air, (2) the SO<sub>2</sub>, in part, settles to the ground. (3) SO<sub>2</sub> oxidizes to sulfate compounds, and (4) sulfates are deposited on the ground surface." 1/

There is disagreement on the important details

While there is agreement that these transport and transformation phenomena occur, there is a good deal of room for disagreement on the quantitative details about actual paths that pollutants follow in specific situations. These factors include:

- the relative rates and timing of transport, transformation, and deposition. These will determine how much of a pollutant will fall, in which form, near its emission site, how much will fall on more distant, possibly sensitive areas, how much will carry beyond the continent to fall in the sea where it is likely to be neutralized, and how much, if any, remains in the atmosphere.
- the rates at which transformations occur, including relative rates for different possible transformation pathways. For example, SO<sub>2</sub> may be converted to sulfuric acid or sulfate in the air, then absorbed in a cloud; it may be absorbed as SO<sub>2</sub> and then converted; it may be deposited dry and converted in the leaf canopy of trees, or it may reach the ground as SO<sub>2</sub>.

Those urging further regulation of emissions sometimes acknowledge these complexities, but argue that the overall picture is clear enough to set general policies. On the other hand, those opposed to further controls point to these uncertainties to support their arguments that controls would be premature at this time.

Scientists studying these processes generally indicate that, while it appears clear that acid deposition comes from oxide emissions, the proper course of action to take is not yet clear, because we lack the necessary understanding of how the sequence

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1/Ralph M. Perhac, Testimony before Subcommittee on Environmental Pollution of Senate Committee on Environment and Public Works, March 19, 1980.

of events operates. Explaining this point at a recent public meeting, an atmospheric scientist from Brookhaven National Laboratory said:

"...since we have not identified the rate-limiting step in the incorporation of SO<sub>2</sub> into rain water, if that rate-limiting step is a catalyst (for example, carbon or a transition metal) then we might not reduce the amount of sulfate in the rainwater by simply reducing the amount of SO<sub>2</sub> in the air." 1/

#### Can Modeling be Used to Explain These Processes?

Mathematical models to describe transport have been employed for some time in regulatory activities. However, their accuracy has been relatively limited. One critic from an analytic firm said that:

"...any attempt to estimate the contribution of a given source to the acidity of rain hundreds of kilometers downwind is very likely to be inaccurate by a factor of 10, and may well be wrong by a factor of 100." 2/

In recent testimony, we noted that indeed models are often of poor accuracy, have limited ranges for describing the effect of individual sources, and are hampered by unknowns about transformation rates. 3/

However, another approach to modeling is being attempted by a number of research groups. Rather than trying to trace the emissions of individual sources, this approach, called long-range transport (LRT) modeling, combines the emissions from all large and small sources in each region and treats the transport and transformation of the combined emissions using actual meteorological data and simplified parameters to describe transformation and deposition. A main idea in this approach is that fitting these models to actual emission and deposition data, by adjusting the parameter values in the

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1/L. Newman, in "Acid Rain and the Atlantic Salmon," Proceedings of a Conference, Nov. 22-23, 1980, sponsored by the International Atlantic Salmon Foundation., p. 35.

2/Maynard E. Smith, in "National Symposium on Acid Rain," Proceedings of a Conference, Sept. 23-24, 1980, sponsored by Greater Pittsburgh Chamber of Commerce.

3/U.S. General Accounting Office, Testimony before Senate Committee on Environment and Public Works, June 30, 1981.

model, can be used as a way to estimate the correct values of the parameters.

The state-of-the-art of LRT modeling is being surveyed by the joint U.S.-Canada Atmospheric Modeling Work Group. In their February 1981 interim report, this Work Group reported preliminary results for a number of LRT regional models being used to try to link emissions and deposition over the entire geographic area of eastern North America. The results are discussed in terms of "transfer matrices" which would show, for each pollutant, the contributions reaching a set of receptor areas from a series of source regions.

These models are still under development, though, since they currently treat only sulfur compounds, not nitrogen compounds or acidity, and are currently being focused on annual averaging rather than more short-term descriptions. Furthermore, such models require validation by comparison with monitoring data from field networks, which the report says is only now becoming good for wet deposition and is not yet possible for dry deposition. Thus, the potential of the models as tools to estimate transformation rates, a main advantage they are supposed to offer, appears likely to accompany continuing development of the models themselves and the accumulation of more of the monitoring data to which their results are to be compared.

In summary, it is generally agreed that long-distance transport and transformation of sulfur and nitrogen oxides could explain acid formation in the atmosphere. However, there is also at least moderate agreement that it is not yet known clearly how these processes work in the kind of detail needed to make accurate quantitative connections between source regions and receptor areas, or to be certain what effect on deposition would come from partial changes in emissions.

#### WHERE DOES THE ACID ORIGINATE? -- EMISSIONS

Sulfur and nitrogen oxides are not usually thought of as part of the atmosphere so, if they are indeed the sources from which acids are formed, we must examine the issues of how and where they are produced.

The questions which must be answered are:

--are sulfur and nitrogen oxide emissions predominantly natural or man-made?

--which sources emit the man-made pollutants?

--can deposition in affected areas be explained by local pollutants, or are transported pollutants responsible?

Are sulfur and nitrogen oxide emissions man-made or natural?

Experts on both sides of the acid precipitation debate agree that sulfur and nitrogen oxides originate from both man-made and natural sources. In the eastern half of the United States and Canada, however, the areas allegedly most affected by acid precipitation, emissions (particularly sulfur oxides) appear to be predominantly man-made.

Some natural sources emit precursors of sulfur dioxide, such as organic sulfides. Some scientists suggest that oceanic sources of these sulfides may explain acid precipitation detected in remote regions such as Hawaii and Amsterdam Island in the Indian Ocean. Volcanoes can directly emit large amounts of sulfur dioxide. Lightning can form nitrogen oxides from the nitrogen and oxygen in the air. Other natural sources, such as wildfire, decomposing organic matter, and plant life, release significant amounts of both sulfur and nitrogen compounds which can be converted to oxides in the atmosphere. Man-made sources include stationary sources such as fossil-fueled electric utilities and industrial plants, mobile sources using gasoline and other fossil fuels, and commercial and residential heating. Man-made non-energy sources also contribute sulfur compounds from metal smelters and nitrogen compounds from wind-blown agricultural fertilizers.

According to the U.S. Interagency Task Force on Acid Precipitation, the Electric Power Research Institute, and other scientific research organizations, the relative contributions by natural and man-made sources to global atmospheric loadings of these oxides are uncertain. There is considerable agreement, however, that emissions of sulfur pollutants in acidic areas of Eastern North America are overwhelmingly man-made. Indeed, a recent EPRI report summarizes its results:

"...field data conclusively show...the total annual biogenic sulfur emissions are less than one percent of the man-made sulfur emissions from utilities and other industries in the SURE region." [most of the eastern U.S. north of the Gulf Coast] 1/

Thus, sulfur emissions in the Northeastern U.S. are essentially all man-made. There remains some uncertainty, however, about the possibility that natural sulfur emissions from further south could contribute to the total atmospheric loading in the region. The EPRI report just cited estimates that 1 to 2.5

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1/Electric Power Research Institute, "Biogenic Sulfur Emissions in the SURE Region," EPRI Report EA-1516, Palo Alto, Calif., Sept. 1980, pp. v-vi.

percent of sulfur in the SURE region atmosphere might come from natural emissions from land farther south, but does not estimate contributions from waters such as the Gulf of Mexico. An atmospheric scientist from NOAA, working in the U.S. Interagency Task Force on Acid Precipitation, told us that measurements have been reported of sulfur compounds in air moving into the Tennessee area from the south which appeared to show that such sources might make a noticeable contribution to total atmospheric sulfur further north--estimated as possibly as much as 10 percent or more, but certainly nowhere near half. Thus, even taking account of such "imports," it appears clear that atmospheric sulfur in the northeastern U.S. and southeastern Canada is predominantly of man-made origin.

Turning to nitrogen oxides, the picture is less clear. While amounts of man-made NOx emissions in the U.S. are quite large--about the same as those of SO2--scientists told us that sources of nitrogen oxides of natural origin have not yet been measured well enough to be sure of the relative proportions of natural and man-made contributions to total atmospheric NOx.

#### Relative importance of sulfur and nitrogen oxides

Both nitrogen and sulfur oxides can be precursors of acids deposited from the atmosphere. To date, most scientific attention has been focused on sulfur oxides, for two main reasons:

- in the areas of eastern North America where acid deposition has been argued to be the greatest threat, the annual proportion of sulfuric to nitric acid in precipitation has averaged 2:1 or greater.
- studies of the impacts of acid deposition have tended to show that nitric acid is more often absorbed and used as a nutrient by plants, so it is less likely to pass on and cause adverse impacts on aquatic or terrestrial ecosystems than sulfuric acid.

Recently, however, coal and utility industry sources have argued that greater attention should be focused on nitric acid deposition, and its nitrogen oxide precursors, contending that:

- nitric and sulfuric acid deposition are about equal in winter, and so they make about equal contributions to the large acid pulse released in spring snow melting which can be particularly harmful to aquatic systems. Moreover, absorption of nitrate by plants reportedly occurs much less from snowmelt, because the snow pack and frozen ground keeps the meltwater from percolating through the ground to plant roots.

--in contrast to the Northeast, other areas of the U.S., particularly in the West, have a predominance of nitric acid in acidic rain, and

--nitric acid in rain has been increasing in recent years, while sulfuric acid apparently has not. This roughly parallels changes in NOx compared to SOx emissions. Most projections also show substantial expected increases in NOx, but not in SOx, emissions in the coming years.

Scientific views at this time still tend to focus more on sulfur than on nitrogen oxides and acids, but this is not a universal view and some scientific attention is now being paid to NOx and nitric acid as well as the sulfur compounds.

Which sources emit the man-made pollutants?

Table 1 shows a breakdown of man-made SO2 and NOx emissions in the U.S. for 1978. There are two major points which are often made about this data, concerning the electric utility share of emissions and particularly the contribution of utility coal-burning.

The table shows that electric utilities contribute the majority of U.S. SO2 emissions, and are a significant contributor of nitrogen oxides. In particular,

--electric utilities account for over 65 percent of all U.S. SO2 emissions. Nonferrous smelters, by comparison, which are a major source of Canadian SO2 emissions (42 percent), contribute only 7 percent to total U.S. SO2 emissions, and that occurs further west than the areas which are of maximum concern in present acid deposition.

--electric utilities emit 31 percent of total man-made nitrogen oxide emissions, second only to transportation sources which contribute 40 percent.

The table also shows the dominant impact of coal-burning on total utility sector emissions. Coal-burning accounts for 90 percent of the utility industry's sulfur emissions and 71 percent of its NOx emissions. Moreover, EPA data shows that a disproportionately large share of these emissions is concentrated in the Ohio River Valley area, which includes all of Kentucky, most of West Virginia, and major portions of Illinois, Indiana, Ohio and Pennsylvania. According to EPA's Ohio River Basin Energy

TABLE I

1978 Emissions from Energy Sources in the United States  
(thousand of tons per year) (note a)

<u>Source Category and Fuel</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>
<u>Electric Utilities</u>		
Coal	17,490	5,632
Fuel oil	1,892	1,353
Natural gas	0	946
Total	19,382	7,931
<u>Industrial</u>		
Coal	2,079	671
Fuel oil	1,265	363
Natural gas	0	3,949
Other fuels	165	429
Total	3,509	5,412
<u>Commercial</u>		
Coal	44	11
Fuel oil	990	297
Natural gas	0	154
Total	1,034	462
<u>Residential</u>		
Coal	66	0
Fuel oil	286	154
Natural gas	0	231
Total	352	385
<u>Subtotal</u>		
Stationary Sources	24,310	14,190
<u>Transportation</u>		
Highway Vehicles	440	7,370
Other	440	2,970
Total	880	10,340
<u>Total</u>		
All Sectors	25,190	24,530
<u>TOTAL</u>		
All Emissions (note b)	29,700	25,630
Energy Source Share	85%	95%

a/Total may differ slightly from the sum of the source category totals because of independent rounding of data.

b/Includes energy sources but excludes natural sources.

SOURCE: National Commission on Air Quality.



Study, 1/ 72.7 gigawatts of coal-fired powerplant capacity in this six state region, producing about 18 percent of total U.S. electricity, accounted for nearly 47 percent of total U.S. electric utility SO<sub>2</sub> emissions in the mid-1970s, and for 32 percent of total U.S. SO<sub>2</sub> emissions from all sources. It should be noted that these are plants whose emissions are regulated much less stringently than those of newer plants which began construction after August 1971, and which must meet "New Source Performance Standards" under the Clean Air Act.

Recent reports prepared for the Department of Energy, however, point out situations where sources other than coal-burning powerplants,--e.g., residual oil-fired facilities or motor vehicles--can be major contributors to acid precipitation. 2/3/ These areas have acidic precipitation which would appear to have to be caused by other sources than coal-burning ones, because of their low level of coal use.

One case is Florida, where only 4 out of 56 powerplants are reported to burn coal. In contrast, the State is ranked third in the Nation in consumption of residual oil, which the reports cite as second only to coal as a source of sulfur oxide emissions.

Another case is California, which apparently has no coal-burning utilities or smelters, either in the State or close upwind, that could make significant contributions of acid precipitation's oxide precursors. California, the reports note, ranks second in the Nation in oil consumption and is responsible for 13 percent of all U.S. use of residual oil. In addition, the State has very large motor vehicle NO<sub>x</sub> emissions which, the reports suggest, correlates with the dominant role of nitric acid in most areas of California that have acid precipitation.

Can local emissions explain acid deposition,  
or are transported pollutants responsible?

Besides the question of which fuels contribute emissions that may result in acid deposition, there is also debate about the relative roles of nearby and distant sources.

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1/U.S. Environmental Protection Agency, Ohio River Basin Energy Study, "Selected Impacts of Electric Utility Operations in the Ohio River Basin (1976-2000)," Washington, D.C., Sept. 1980.

2/M.P. Esposito, M.F. Szabo, T.W. Devitt and P. Spaite, "Acid Rain: The Impact of Local Sources," prepared for DOE Morgantown Energy Technology Center, Nov. 24, 1980.

3/Pedco Environmental Inc., & P.W. Spaite, Co., "Fuel use Patterns and Acid Rain," prepared for DOE Morgantown Energy Technology Center, April 1981.

The DOE reports just cited argue that local combustion, particularly of residual and home heating oil, may be an important contributor of primary emissions of sulfates, as well as of potential catalysts such as vanadium which could speed the transformation of SO<sub>2</sub> into sulfates. This was suggested to explain the presence of sulfates, and therefore of sulfuric acid deposition, in places such as the Adirondack Mountains in New York. One report asserted that, using a simplified model, it was possible to explain from 29 to 34 percent of sulfate deposition in this area as arising from local sources. Further, by making the assumption that between one-fourth and three-fourths of local sulfur emissions were transformed by atmospheric catalysts and deposited locally as sulfate, the report said it was possible to show that local sources could explain 36 to 70 percent of measured local sulfate deposition.

Other modeling studies have been done using the LRT regional models previously discussed. In a review by a group of U.S. and Canadian researchers 1/ models of deposition in the Adirondacks are described as indicating that:

"...while there is a significant contribution from local sources in the same region, the larger contribution to wet deposition comes from sources up to a thousand or more kilometers away in adjacent regions."

There is also some field data which is interpreted to argue against the view that local sources could have a dominant role in acid deposition in New York State. A report from the New York State Department of Environmental Conservation, Division of Air, 2/ indicates that New York has been concerned with sulfate particles in its atmosphere since the early 1970s, explaining that:

"This concern was prompted by observations that ambient atmospheric sulfate concentrations had not decreased very much despite a several fold statewide reduction in sulfur emissions."

The report then shows that high sulfate concentrations in rural areas of New York, away from large emissions sources,

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1/U.S.-Canada Research Consultation Group, "Second Report on the Long-Range Transport of Air Pollutants," A.P. Altshuller and G.A. McBean, Co-chairman, Nov. 1980, p. 10.

2/Peter E. Coffee, "Long-Range Transport of Acidic Pollutants to New York," in Proceedings of National Symposium on Acid Rain, Sept. 23-24, 1980, sponsored by Greater Pittsburgh Chamber of Commerce, Pittsburgh, PA.

occurred when the areas were covered with air masses that had previously moved over the industrial Midwest, especially when those air masses had moved slowly or stagnated while over the Midwest. In contrast, the report showed sulfate concentrations were much lower under air masses that had not been over industrialized regions in the last 600 miles before reaching New York. The report noted that the combined SO<sub>2</sub> emissions from eight midwestern states, often upwind from New York, are almost 50 times as great as the total in New York State, and concluded that particulate sulfate in New York was predominantly a result of their emissions.

Overall, these reports seem to indicate agreement that acid rain is produced from a combination of precursor compounds originating in both local and distant regions, but there remains disagreement about the relative shares contributed by local and distant sources respectively. The validity of the assumptions in the reports discussed, and quantitative examination of their detailed arguments and conclusions, are questions which we hope to examine in our ongoing work on acid precipitation.

VIEWS ON PROPOSED STRATEGIES TO ABATE ACID PRECIPITATION

The need for further regulatory actions to reduce acid precipitation, beyond emissions limits already required by the Clean Air Act, has been a subject of intense debate. Opponents of tighter regulation argue that current emissions controls are already too stringent and extremely costly--and that there is no proof that tighter controls will alleviate acid precipitation. Supporters argue that existing clean air law does not effectively address the problem of long range transport of air pollutants, which they assert causes acid precipitation.

Our position on this issue will depend on our assessment of what is known about the causes and effects of acid precipitation, and the prospects of alternative control measures to significantly reduce the problem. Equally important, however, is an assessment of the consequences of taking such actions. Alternative regulatory strategies would have different economic, energy, and environmental impacts.

The coal and utility industries argue that comprehensive emissions controls on all major stationary oxide emitters would cost billions of dollars and could reduce the Nation's ability to substitute domestic coal for imported fuels--with as yet no guarantee that the problem would be alleviated. Others, however, respond that delay or inaction will carry costs as well, by prolonging damage to sensitive ecosystems. Moreover, it may adversely affect our relations with Canada since that country attributes its acid precipitation problem in substantial part to emissions originating in the United States.

The question of whether existing controls should be strengthened to reduce acid precipitation is discussed below as follows:

--Current regulation of emissions under the Clean Air Act--  
DOE, industry and other opponents of further regulation argue that, given our limited knowledge about the subject, the current law is more than adequate in addressing acid precipitation concerns. Environmental groups and other supporters of further regulation say that the CAA, as it is now structured, actually contributes to the problem and must be strengthened.

--Proposed regulatory strategies to mitigate acid precipitation--DOE, EPA and other organizations are studying the impacts of alternative regulatory options to further reduce oxide emissions. These options are discussed in this report, although the findings of these and other studies and GAO's own analysis will be presented in our final report.

DO EXISTING CONTROLS UNDER THE CLEAN AIR  
ACT ADEQUATELY ADDRESS ACID PRECIPITATION?

The Clean Air Act established a complex set of programs to control air pollution in the United States. Many of them relate to atmospheric discharge of utility emissions which have been alleged to cause acid precipitation. There is widespread disagreement, however, on whether they effectively address the problem. Opponents of further regulation assert that unless utility emissions can be directly linked to acid precipitation and environmental damages, present controls under the CAA must be considered sufficient. Supporters of further regulation argue that this link has already been established, and that the relevant provisions of the CAA do not address the problem. These provisions, discussed below, include:

- provisions which are intended to limit emissions of sulfur and nitrogen oxides.
- provisions which attempt to limit long-range transport of air pollutants (including sulfur and nitrogen oxides).

Provisions intended to limit emissions  
of sulfur and nitrogen oxides

Several key provisions of the Act--notably the National Ambient Air Quality Standards (NAAQS), New Source Performance Standards (NSPS), Prevention of Significant Deterioration Program (PSD), and the Nonattainment Program--already focus on limiting sulfur and nitrogen oxide emissions.

NAAQS are standards for maximum allowable ambient concentrations of pollutants. Standards already exist for nitrogen and sulfur oxides. For older facilities--those which began construction before August 17, 1971--the standards are enforced through emissions limitations set in EPA-approved State Implementation Plans (SIPs). The Edison Electric Institute contends that SIP limits restrict emissions from existing powerplants "in a manner which will ensure attainment and maintenance of the NAAQS." <sup>1/</sup> Supporters of further regulation, however, argue that two drawbacks with the NAAQS make them unable to control acid precipitation:

- The SIP emissions limits are too lenient, allowing states to release large amounts of pollutants and still remain in compliance with NAAQS.
- Concentration limits in the NAAQS can be met without regard for the total amounts of pollutants released

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<sup>1/</sup>Carolyn Curtis, Ed., "Before the Rainbow: What We Know About Acid Rain", Edison Electric Institute, Wash., D.C. 1980, p. 80.

by facilities, since the pollutants may be transported away from the local area and so not affect ambient concentrations in their immediate vicinity.

We treated these issues in recent testimony noting first that "Several Midwestern states have higher sulfur dioxide emissions limits than other states, to allow sources to burn locally available high sulfur coal without controls or with minimal controls." 1/ We also cited contentions by air quality officials in Northeast states that these heavily emitting facilities in the Midwest, many of which are old powerplants, are polluting their air. They contend that prevailing winds carry the emissions out of the host state, allowing that state to emit more pollutants without affecting their compliance with the NAAQS. It is downwind states, however, which they assert absorb much of these emissions --emissions which some say cause acid precipitation.

The National Commission on Air Quality's recent report on the CAA supported the view that the NAAQS process does not effectively address the acid precipitation issue, and recommended that "Congress should require a significant reduction by 1990 in the current level of sulfur dioxide emissions in the eastern United States." 2/

New Source Performance Standards (NSPS) have been developed under the 1970 and 1977 amendments to the Act. They require new coal-fired powerplants to comply with strict limitations on allowable sulfur emissions and reduce the previous emissions limits for nitrogen oxides. As older units are retired, a growing proportion of coal-fired powerplant capacity will come under the tighter NSPS requirements. According to industry spokesmen, these stringent standards will lead to significant emissions reductions. Supporters of further regulation agree that the NSPS are strong enough to lead to substantial emission reductions over time. However, they assert that the older, heavily polluting plants will not be retired early enough for the NSPS to offer a near-term reduction of the acid precipitation problem.

Prevention of Significant Deterioration (PSD) provisions require that new coal-fired powerplants in areas with relatively clean air must use the Best Available Control Technology (BACT). BACT requirements must be equal to or more stringent than NSPS

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1/U.S. General Accounting Office, Testimony before the Senate Committee on Environment and Public Works, on Interstate Transport of Sulfur Dioxide and Total Suspended Particulates, June 30, 1981.

2/National Commission on Air Quality, "To Breathe Clean Air," March 1981, p. 2.2-20

limits. The PSD program also established air quality levels (Classes I, II, and III) which may not be exceeded in areas subject to PSD. Since these levels are substantially below the NAAQS, industry contends that they provide additional protection against emissions which allegedly lead to acid precipitation. Supporters of the PSD program concede that its standards are rigorous, but believe that they do not alleviate the acid precipitation problem. They assert that PSD regulates the oxides a powerplant emits--not the sulphates and nitrates that are blamed for acidification. According to one environmental attorney,

"the air quality concerns addressed by the PSD program do not encompass all forms of air quality deterioration. They involve only SO<sub>2</sub> and particulates, not sulfates and nitrates, the secondary products being deposited by acids. Even after the program is expanded to cover the other "criteria" pollutants, the presence of sulfuric or nitric acids in PSD areas will be a violation of the spirit, but not the letter, of the PSD requirements." 1/

EPA's nonattainment provisions apply in poor air quality areas where the NAAQS are exceeded. Proposed powerplants or other facilities must restrict emissions to the "lowest achievable emission rate" as determined by EPA. Furthermore, sponsors of the new facility must obtain local "offsets" which ensure that net emissions of the pollutant in the locality will not increase. Industry argues that these provisions ensure that total emissions of sulfur and nitrogen oxides from nonattainment areas will decrease. EPA scientists and environmental groups in the past have stated, however, that regulation of nonattainment sources has frequently addressed only local air quality effects--not long-range transport of acid-causing emissions. The results, they assert, would be to aggravate the acid precipitation problem while still complying with the Act.

Provisions which attempt to limit long-range transport of sulfur and nitrogen oxides

While the CAA programs discussed above are geared toward emissions limitations, Congress enacted several amendments in 1977 to abate the interstate transport of sulfur and nitrogen oxides and other pollutants. These amendments, which have had limited effectiveness, include: (1) limits on the height of smokestacks and (2) requirements that one state's air emissions not adversely affect the air quality of another (Sections 110(a)(2)e and 126).

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1/G. Wetstone, "Air Pollution Control Laws in North America and The Problem of Acid Rain and Snow", Environmental Law Reporter, ELR, 5009, Jan. 1980.

Some powerplants in the past have reduced local air quality effects by increasing the height of their smokestacks. Many environmentalists argued that this practice increased both total pollutant emissions and long-range transport of acid-causing sulfates and nitrates. Congress sought to discourage tall stacks in 1977 by requiring EPA to limit their use. Industry contends that EPA regulations provide strong incentives to limit stack heights (even though in their view no one has proved that tall stacks contribute to acid precipitation). Environmentalists have argued that EPA's tall stacks regulations are too lenient, and that the agency has historically allowed the use of tall stacks to reduce local pollution problems. One group cited a 1979 EPA study which reported that since the 1970 Clean Air Act amendments, more than 175 smokestacks over 500 feet high have been constructed, all but eight belonging to electric powerplants. 1/

One area of agreement among industry, environmentalists and State and Federal regulators is the inability of pollution control officials to regulate, or even measure, interstate transport of air pollutants--pollutants which some allege cause acid precipitation in downwind states. The Clean Air Act Amendments of 1977 attempted to address this problem by requiring that emissions allowed under one state's SIP cannot inhibit another state's ability to meet its own ambient standards. However, as we noted in recent testimony, three problems have hampered the effectiveness of these provisions:

- limitations in the models used to identify the impact of pollution generated in one state upon the air quality of another state,
- problems applying the broad language of the amendments to the circumstances of specific disputes, and
- the lack of EPA regulations to clarify the language of the amendments. 2/

The modeling limitations most directly inhibit the effectiveness of these provisions to abate acid precipitation. First, available EPA approved models can only estimate pollutant concentrations with moderate accuracy even close to the source. Moreover, the models become much less accurate concerning long-range transport--such as between the Midwest and the Northeast.

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1/U.S. Environmental Protection Agency, "Identifying and Assessing Technical Bases for Stack Height for the EPR Regulatory Analysis," Preliminary Report #69-023323, Sept. 1979.

2/U.S. General Accounting Office, Testimony before the Senate Committee on Environment and Public Works, June 30, 1981.



Finally, presently approved models are not capable of dealing with acid precipitation, because they are not equipped to model transformations such as the conversion of SO<sub>2</sub> to sulfate.

PROPOSED REGULATORY STRATEGIES  
TO CONTROL ACID PRECIPITATION

There is debate on where  
controls should be focused

A wide range of strategies has been proposed for controlling acid precipitation, almost all of them aimed at reducing oxide emissions which are asserted to be precursors of the acids in precipitation. These strategies focus primarily on the electric utility sector, with particular emphasis on older coal-burning plants. This emphasis has occurred because these plants are major emitters and because many of them are located in the Midwest, upwind of areas of the northeastern U.S. and southeastern Canada which are regarded as most vulnerable to acidification.

However, recent reports prepared for the Department of Energy have suggested that the focusing of control strategies on coal-burning utility plants in the Midwest may not be a very effective approach to reducing acid precipitation in the Northeast. 1/2/ To follow this argument, we must look back at the emission data in appendix II.

Using data from table I in appendix II we see that coal-fired utility plants accounted for about 59 percent of total U.S. SO<sub>2</sub> emissions in 1978, and 22 percent of all NO<sub>x</sub>. However, further examination of the data shows that these emissions totaled only about 42 percent of combined U.S. sulfur and nitrogen oxide emissions. Moreover, the data show that the coal-fired utility share of NO<sub>x</sub> emissions was much less than the 40 percent contribution from transportation sources, and was also exceeded by the 24 percent contributed by non-utility stationary energy uses.

The DOE reports look further at emissions data, and emphasize the fact that a disproportionate share of U.S. oil consumption occurs in the northeastern states. They then combine three arguments to point attention to other sources than the midwestern coal-fired utility plants. One argument is that, because they are released nearby, local emissions can have a greater effect in a

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1/M.P. Esposito, M.F. Szabo, T.W. Devitt, and P. Spaite, "Acid Rain: The Impact of Local Sources," prepared for DOE Morgantown Energy Technology Center, Nov. 24, 1980.

2/Pedco Environmental Inc., and P.W. Spaite Co., "Fuel Use Patterns and Acid Rain," prepared for DOE Morgantown Energy Technology Center, April 1981.

region than the pollutants transported from larger but more distant sources. The second argument is that local oil-burning in the Northeast, both in utility oil plants and in smaller commercial and residential units, releases a much greater share of its sulfur already oxidized to sulfates, or accompanied by catalysts that can rapidly oxidize it, than is true for coal-burning facilities. Finally, it is argued that the production of acid rain precursors by transportation sources in some parts of the Northeast is greater than production by any other local source.

These arguments show that there is not full agreement on where to focus the control strategies being considered to reduce acid precipitation.

#### Proposed control strategies vary widely in benefits and impacts

Control strategies proposed to deal with acid precipitation vary substantially in their costs, energy implications, and ability to reduce emissions. As one might expect, the least expensive regulatory strategies--such as liming lakes and streams or coal washing--offer the smallest potential for reducing impacts, while the most expensive strategies--such as retrofitting scrubbers onto older existing powerplants--reduce emissions the most. These three strategies are discussed here to illustrate this wide variance. An overview of "intermediate" strategies, such as those evaluated in studies co-sponsored by DOE and EPA, follows.

#### Liming

Many in industry, government, and the scientific community have suggested that the lake acidification problem can be alleviated through "liming". Liming is the use of limestone (calcium carbonate) or other alkaline materials to neutralize the excess acid in lakes, streams, or ponds. Unlike many other control methods, it would deal with all sorts of acids rather than sulfuric acid only. According to EPA, studies have shown that liming can have beneficial effects on plant life and fish survival in affected areas. Ontario's Ministry of Environment reports having successfully restored the pH of four acidified lakes near the Province's Sudbury smelters to normal, at a cost of about \$50 per acre. Advanced techniques for injecting neutralizing substances are also being developed which will increase the effectiveness of the treatments.

Liming, however, cannot solve all problems related to lake and stream acidification. Its effects are temporary--usually three to four years, according to Ontario's Ministry of the Environment. Furthermore, many government agencies which have experimented with liming say that it can only be applied to a fraction of affected waters. One Pennsylvania researcher contends that it can only be applied in about one percent of the cases for

economic and logistic reasons. The Canadian Embassy's Environmental Counselor reinforced the point at a recent symposium on acid precipitation:

"It's one thing to dump lime in an acid creek beside a coal mine. But how is that to be transposed into effective mitigating action regarding tens of thousands of lakes in northern Ontario, Quebec and elsewhere, spread out over more than one million square miles and often far from the nearest road?" 1/

Our discussions with other experts in industry, government, and the scientific community show consensus that, while liming can provide at least temporary relief from some damage caused by acidification, it cannot be used in all instances.

#### Coal washing

Coal washing is viewed by experts on both sides of the acid precipitation debate as a relatively inexpensive technique to make moderate reductions in SO<sub>2</sub> emissions. It is a process that removes pyritic sulfur from coal before it is burned, and is most effective when used with high sulfur coals such as those in northern Appalachia and the Midwest. A study done for EPA reported that coal washing can reduce sulfur content of Pennsylvania and Illinois coals, for example, by over 30 percent. 2/ Regarding cost, the study estimated that, for eight eastern and midwestern coal states, cleaning all coals would increase the average delivered cost of raw coal by only 10 to 20 percent--a low price compared with other SO<sub>2</sub> control strategies. 3/ A report prepared for the National Commission on Air Quality estimates capital and annual operating costs of a 200 million tons per year coal washing program at \$3 billion and \$1 billion, respectively. These estimates do not take into account the potential economic benefits of coal washing--reduced transportation, storage and handling costs, improved thermal efficiency and boiler operation, lower maintenance costs, and reduced disposal costs for ash. 4/

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1/George Rejhon, in "National Symposium on Acid Rain," proceedings of a conference, Sept. 23-24, 1980, sponsored by the Greater Pittsburgh Chamber of Commerce.

2/Teknekron Research, Inc., "Coal Resources and Sulfur Emissions Regulations. A Summary of Eight Eastern and Midwestern States," March 1981, Berkeley, Calif.

3/Ibid., p. 2-3.

4/Environmental Law Institute, "Institutional Aspects of Transported Pollutants," Feb. 1981, Washington, D.C.

Coal washing's major drawback is its limited potential for sulfur removal. If 10 to 30 percent sulfur removal is deemed sufficient to mitigate acid precipitation, then it might be a cost-effective strategy--and one that has the support of many from the coal and utility industries. If, however, greater SO<sub>2</sub> reductions are warranted, coal washing's benefits would be limited.

#### Scrubbing existing powerplants

Retrofitting existing coal-fired powerplants with "wet scrubbers" can achieve up to a 90 percent reduction of SO<sub>2</sub> emissions compared to uncontrolled operation on high sulfur coal. Such a control strategy could substantially reduce total atmospheric SO<sub>2</sub> loadings because a relatively small number of large powerplants is responsible for much of the emissions in the eastern half of the United States. A report prepared for the National Commission on Air Quality suggests that retrofitting the 50 largest coal-fired powerplants in the eastern U.S. could reduce SO<sub>2</sub> emissions by 6 to 8.5 million tons per year. 1/

Although it may be an effective way to reduce SO<sub>2</sub> emissions, it is clearly one of the most expensive. The report just cited estimates that retrofitting the 50 largest utility SO<sub>2</sub> emitters would cost \$7 to \$14 billion for capital costs. 2/ DOE's Morgantown Energy Technology Center's estimates are even higher--\$14.8 billion for capital costs and \$4.2 billion for annual operating costs. 3/ These enormous costs are the major reason that the coal and utility industries vigorously oppose such a strategy before a more conclusive link is established between SO<sub>2</sub> emissions and acid precipitation.

#### Economic, energy, and emissions impacts of other regulatory options estimated by DOE/EPA modeling studies

While calling for significant reductions in SO<sub>2</sub> emissions by 1990, the National Commission on Air Quality recommended to Congress that:

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1/Environmental Law Institute, "Institutional Aspects of Transported Air Pollutants: An Examination of Strategies for Addressing Long-Range Air Pollution Problems," Washington, D.C., Feb. 18, 1981, p. 32. (The report bases these figures on the EPA-sponsored study, "Interim Report Phase I: Acid Rain Mitigation Study, Selected Results for FGD Retrofit Strategies and Historical Operating Characteristics of Fossil-Fired Units," R-009EPA-80, July 1980.)

2/Ibid, p. 34.

3/Figures supplied by DOE's Morgantown Energy Technology Center, West Virginia.

"[t]he actual level of the significant reduction to be required and the measures to be required to bring about that reduction should be determined after Congress reviews results from the joint studies by DOE and EPA, expected in mid-1981, on the costs and other effects of various methods of reducing sulfur dioxide emissions." 1/

Although a broad range of studies have been and are being performed to estimate costs of alternative emissions control strategies, these two studies, (performed under contract by Teknekron Research, Inc. (TRI) and ICF, Inc.) have received considerable attention. The studies use complex models to estimate the impacts of a broad range of regulatory strategies. Among the strategies evaluated by the models are:

- A benchmark "base case" to use as a comparison of the impacts of the other regulatory options. The base case assumes compliance by existing powerplants with current SIP emissions regulations, and, for newer plants, compliance with New Source Performance Standards. (Both ICF and TRI models.)
- Coal washing for powerplants complying with SIP emissions limits. Two scenarios are simulated, one requiring all powerplants to use washed coal, and the other requiring only high sulfur coal (greater than 1.5 percent sulfur) to be washed (TRI model only).
- Stricter SO<sub>2</sub> emissions caps for existing powerplants than currently required by State Implementation Plans. Caps of four and two pounds of SO<sub>2</sub> per million Btu's are examined. (Both ICF and TRI models).
- Rollback of SIP emissions limits for all powerplants equal to or greater than 100 megawatts. These plants would be required to reduce their emissions by a specified percentage of their present SIP limit. (TRI model only, using 50 percent and 30 percent SIP rollbacks).
- Early retirement of older, heavily polluting powerplants. A maximum 35-year lifetime is simulated for all fossil fuel-fired powerplants (TRI model only).
- Least emissions dispatching. Cleanest powerplant units are required to be used most by electric utilities in preference to more heavily polluting

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1/National Commission on Air Quality, "To Breathe Clean Air," March 1981, Washington, D.C. p. 2.2-20.

ones. Most utilities presently use least cost dispatching, where the most cost effective units are used first. (TRI model only).

Results of the ICF and TRI studies have recently been released in draft form. They estimate, to the year 2000, the impacts of alternative regulatory strategies on a number of environmental, economic and energy variables such as emissions reductions, types and costs of control actions, utility revenues, electricity generation and costs, and national and regional coal production.

This type of cost and impact data will make an important contribution to a determination of which control strategies are justified, if such action is necessary. We believe that an understanding of the costs and benefits of alternative strategies is essential for developing sound regulatory policy in this area. In our final report, we will examine this and other data from the Electric Power Research Institute, the Environmental Law Institute, additional DOE work, and similar studies by other public and private organizations.

#### POTENTIAL INTERNATIONAL POLICY IMPACTS OF U.S. ACTIONS ON CONTROL STRATEGIES

In addition to its economic, energy and environmental impacts, the United States' decision on whether and how to implement control strategies could have international implications. The Canadian Government asserts that thousands of lakes and streams in its Eastern Provinces are being acidified, in substantial part because of U.S. emissions. <sup>1/</sup> At a November 1980 conference on acid precipitation in Portland, Maine, the Parliamentary Secretary of the Canadian Ministry of the Environment made his Government's position clear:

"The official position of the Government of Canada is that we cannot wait for a perfect understanding of the acid precipitation phenomenon before moving to control it."

Canada's Minister of the Environment echoed this concern at a January 1981 meeting of the American Association for the Advancement of Science, calling for a bilateral effort to resolve the problem:

"I can only hope for the necessary ingredients of political will which can allow an international resolution of this difficulty...May I stress once again that the urgency is extreme."

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<sup>1/</sup>Canadian officials acknowledge that Canadian emissions, to a lesser extent, may be affecting U.S. territory.

A Canadian Embassy official acknowledged to us that current negotiations on the issue could take time, citing a similar process which took six years before an agreement was signed. <sup>1/</sup> However, he underscored the importance to the Canadian Government of continued progress toward an agreement with the U.S. on acid precipitation.

Congress called for such negotiations in the Foreign Relations Authorization Act of 1979 (P.L. 95-426), urging the President to "make every effort to negotiate a cooperative agreement with the Government of Canada aimed at preserving the mutual airshed of the United States and Canada..." and to "take whatever diplomatic actions appear necessary to reduce or eliminate any undesirable impact upon the United States and Canada resulting from air pollution from any source."

Bilateral negotiations on acid precipitation formally began in July 1979, when the U.S. and Canadian Governments released a joint statement noting their growing shared concern about the actual and potential effects of transboundary air pollution (TAP) and their common determination to reduce or prevent TAP which injures health or property across the boundary. The statement also agreed on principles and practices to address in developing a bilateral agreement.

The process was carried forward in August 1980 by a Memorandum of Intent (MOI) stating the intention of the two Governments to begin negotiation of a cooperative agreement on TAP. In the MOI the two Governments also agreed on interim actions to:

"promote vigorous enforcement of existing laws and regulations as they require limitation of emissions from new, substantially modified and existing facilities in a way which is responsive to the problems of transboundary air pollution."

The MOI also created five joint Work Groups to assist the negotiations by assembling and analyzing information and by identifying measures for possible inclusion in an agreement. These groups produced a first set of interim (Phase I) reports in February 1981 that focused on acid precipitation.

In recent months, however, Canadian officials have expressed concerns that Work Group activity and the overall negotiation process have slowed substantially with the change of U.S. administrations. Of even greater concern is what they view as present attempts to weaken existing U.S. sulfur and nitrogen oxide emissions controls under the Clean Air Act, rather than

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<sup>1/</sup>This negotiation process culminated in the Great Lakes Water Quality Agreement in 1972.

strengthen them. One Canadian Embassy official told us that Canada

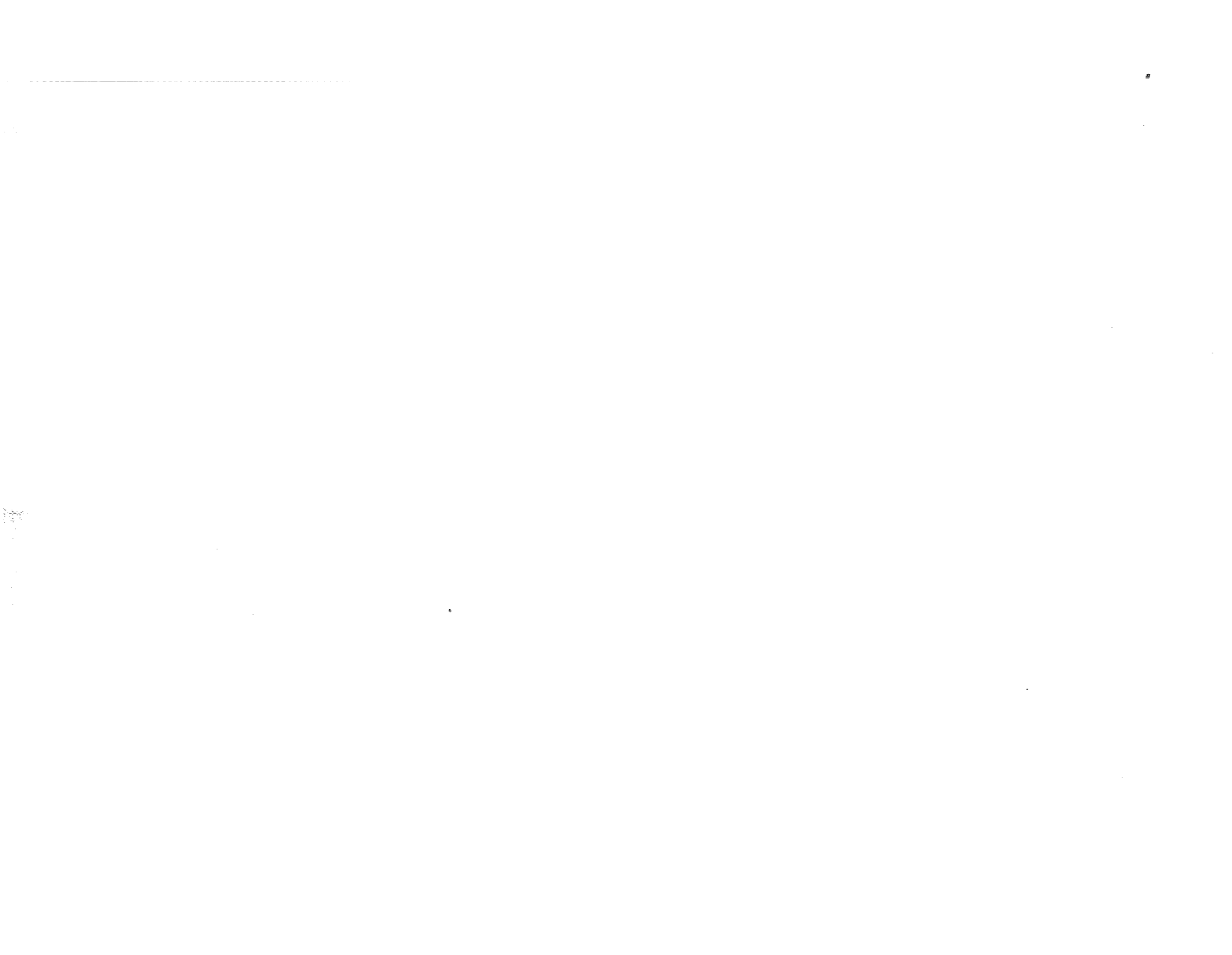
"cannot allow the current Clean Air Act debate in the United States to be conducted as a domestic exercise... it has extra-territorial reach and is therefore a matter of foreign policy."

The Province of Ontario underlined this sentiment in March by filing a legal intervention that requested EPA to reject proposals from six states to relax SIP emissions limits governing 18 powerplants.

These factors point to potential impacts on U.S.-Canadian relations if there is inaction on strategies to deal with acid precipitation.

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