

# ACID RAIN

Sources and Effects in Connecticut  
Report of the Acid Rain Task Force



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## Sources and Effects in Connecticut Report of the Acid Rain Task Force

Rain in Connecticut and the Northeast is generally more acid than that found in other areas of the United States. Opinions regarding the danger posed by acid rain range from no danger at all, to perceptions of dying fish and vegetation, corroding statues, crumbling buildings, and threats to human health.

Given this background of concern, the Connecticut General Assembly created an Acid Rain Task Force with the passage of Special Act 81-44 "An Act Concerning the Study of Acid Rain." This act charged the Task Force with studying the sources and effects of acid rain in Connecticut, and specified that the Task Force should work in cooperation with The Connecticut Agricultural Experiment Station. The act also required that the Task Force submit a final report of its findings and recommendations to the Governor and to the General Assembly on or before January 1, 1983. This document is the final report of the Acid Rain Task Force.

The members of the Task Force and the organizations that they represent are listed on the facing page. In addition to examining the nature and sources of acid rain, the Task Force examined the effects of acid rain according to the following categories: effects on soil

and water, effects on fish, effects on vegetation, effects on structures, and effects on human health. Speakers addressed the Task Force on these various topics and they are listed in Attachment I, as well as others providing information to the Task Force. A brief bibliography of reference materials provided by the speakers, as well as other documents examined by the members of the Task Force are shown in Attachment II. Published materials are available from the authors. Copies of other materials may be seen in the offices of the Environment Committee.

The Task Force realized that undertaking research on acid rain was beyond its charge. As with other environmental concerns, significant disagreement exists between advocates on opposing sides of the issue, with the consequence that the public is confused. Thus, the Task Force sought out informed opinion amongst knowledgeable people, relying heavily on the considerable expertise available within Connecticut's borders. Our report indicates where a consensus of opinion was reached, as well as areas that require further investigation.

## NATURE OF ACID RAIN

Simply stated, acid rain is produced by reaction of moisture with oxides of carbon, sulfur and nitrogen in the atmosphere to produce a mixture of carbonic, sulfuric and nitric acids. The principal oxide of carbon is carbon dioxide, or  $\text{CO}_2$ , which is present in normal air at a relatively constant concentration of about 0.03%. Reaction of  $\text{CO}_2$  with moisture then produces "normal" rain with pH about 5.6. Rain with a pH lower than 5.6 is considered to have been acidified.

The principal oxide of sulfur is sulfur dioxide, or  $\text{SO}_2$ , which is produced by biological oxidation of

sulfur-containing compounds and by the combustion of fossil fuels. On a world-wide basis, natural production of  $\text{SO}_2$  far exceeds man-made sources. However, in the industrialized nations, sulfur oxides generated by man often far exceed natural production of  $\text{SO}_2$ . When coal and wood were major fuels, much of the acidity produced by combustion was neutralized by smoke and fly ash. Although early studies of the acid content of rain are sparse, it is reasonable to conclude that tall smokestacks and particle precipitators converted local soot problems into regional acid rain sometime after World

War II. A portion of the sulfur compounds in air are oxidized to sulfate ( $\text{SO}_4^{2-}$ ) and react with other materials to form fine particulate aerosols. The most common form appears to be ammonium sulfate, with the ammonia presumably derived from volatilization from biological materials.

The oxides of nitrogen in air are complex and usually referred to as  $\text{NO}_x$ . The principal source of nitrogen oxides is high temperature combustion, where nitrogen and oxygen naturally present in the air combine to form  $\text{NO}_x$ . As with  $\text{SO}_2$ , natural emissions of  $\text{NO}_x$  on a global basis far exceed man's contributions, but automobiles and other combustion processes overwhelm these sources in industrial areas. At present, sulfur oxides in air generally exceed nitrogen oxides, but

increased emissions of  $\text{NO}_x$  are expected to increase the nitric acid component in rain.

Thus, in reality acid rain is a mixture of acids dissolved in water, reactive gaseous oxides, and fine particulate sulfate and nitrate aerosols. In addition, air contains other pollutants such as ozone, hydrocarbons and heavy metals which may interact in synergistic fashion with various components in acid rain. Consequently, acid rain must be considered as only a part of the larger problem of air pollution in Connecticut. Where possible, we shall discuss the specific sources and effects of the various constituents of acid rain, as well as indicating possible interactions with other air pollutants.

## SOURCES OF AIR POLLUTANTS

It is convenient to divide sources of air pollutants into two groups, local and long range. Local sources are those whose effects occur within 20-25 miles, while long range pollutants persist for 50 miles or more. Table 1 from Yocum (1981) describes some of the characteristics of long range and local air pollutants and reveals the importance of specifying the particular pollutant of concern. For example, if damage is caused largely by gaseous  $\text{SO}_2$ , local sources are likely to be relatively more important. Conversely, ozone damage is often produced from more distant sources except under particular meteorological conditions. Acid rain itself can arise from both local and long range sources.

Although New England lies generally downwind from sources of air pollutants to the west, prompting Bormann (1981) to label us "the garbage can of the United States," it is difficult to determine the relative amounts of any particular pollutant transported into Connecticut in comparison with the amounts generated within our borders. The Connecticut Department of Environmental Protection has studied the transport of ozone, sulfur dioxide, nitrogen dioxide, and total suspended particulates in some detail and their findings are discussed below.

### Sources of Ozone

Ozone is produced by the reaction of sunlight with hydrocarbons and  $\text{NO}_x$  precursors in the atmosphere. Analysis of the June 10, 1974 "smog" episode in Connecticut by Rubino, Bruckman and Magyar (1976) showed that peak ozone levels occurring in Connecticut in late afternoon of that day were probably transported into Connecticut with the prevailing southwesterly wind. Continued monitoring of ozone levels in Connecticut has shown high concentrations in summer months (Connecticut Air Quality Summary, 1979). It has been estimated that transport of ozone from the New York-northern New Jersey urban complex can account for up to 70% of the concentrations measured in Connecticut on certain days in the summer (Bruckman, 1982). However, a report by the Connecticut Academy of Science and Engineering (CASE, 1979) points out that appreciable amounts of ozone may be

transported into New York City from outside its borders. While the Connecticut Academy of Science and Engineering is presently re-examining the issue, their 1979 report indicated that reliable estimates of the contributions of pollutants from the New York-New Jersey area could not be made. Thus, although ozone levels in Connecticut are among the highest in the country, the precise source areas cannot be specified at present. The long range nature of ozone transport (Table 1), however, suggests that additional source areas exist outside of the immediate New York-New Jersey metropolitan area. This is particularly important in devising control strategies, since there have been significant decreases in amounts of most other air pollutants in Connecticut during the past seven years, with ozone remaining high (Connecticut Air Quality Summary, 1979; CASE, 1979).

### Sources of Sulfur Dioxide

Sulfur dioxide is produced largely by combustion of fossil fuel and has a relatively short residence time as a gaseous pollutant in the air (Table 1). Emissions of sulfur dioxide east of the Mississippi River are shown in Fig. 1. Measurements of sulfur dioxide concentrations in the air in Connecticut showed no episodes exceeding air quality standards in 1979 (Connecticut Air Quality Summary, 1979), confirming a gradual reduction in concentration of  $\text{SO}_2$  during the 1970s. Unlike ozone, concentrations of  $\text{SO}_2$  tend to be higher in the winter, presumably due to increased burning of fuel. Measurements of  $\text{SO}_2$  concentrations during persistent SW winds indicates that 15% to 57% of "typical" daily  $\text{SO}_2$  levels can be attributed to transport from the New York-New Jersey metropolitan area (Bruckman, 1978). On an annual average basis,  $\text{SO}_2$  transport from the SW is estimated to contribute 1% to 11% to the observed concentration in the air in Connecticut (Bruckman, 1978). The attainment of  $\text{SO}_2$  standards for Connecticut is attributed to restrictions on sulfur content of fuels (Connecticut Air Quality Summary, 1979). As with ozone, however, the CASE (1979) report questions whether reliable estimates of sources of  $\text{SO}_2$  outside Connecticut can be determined from present

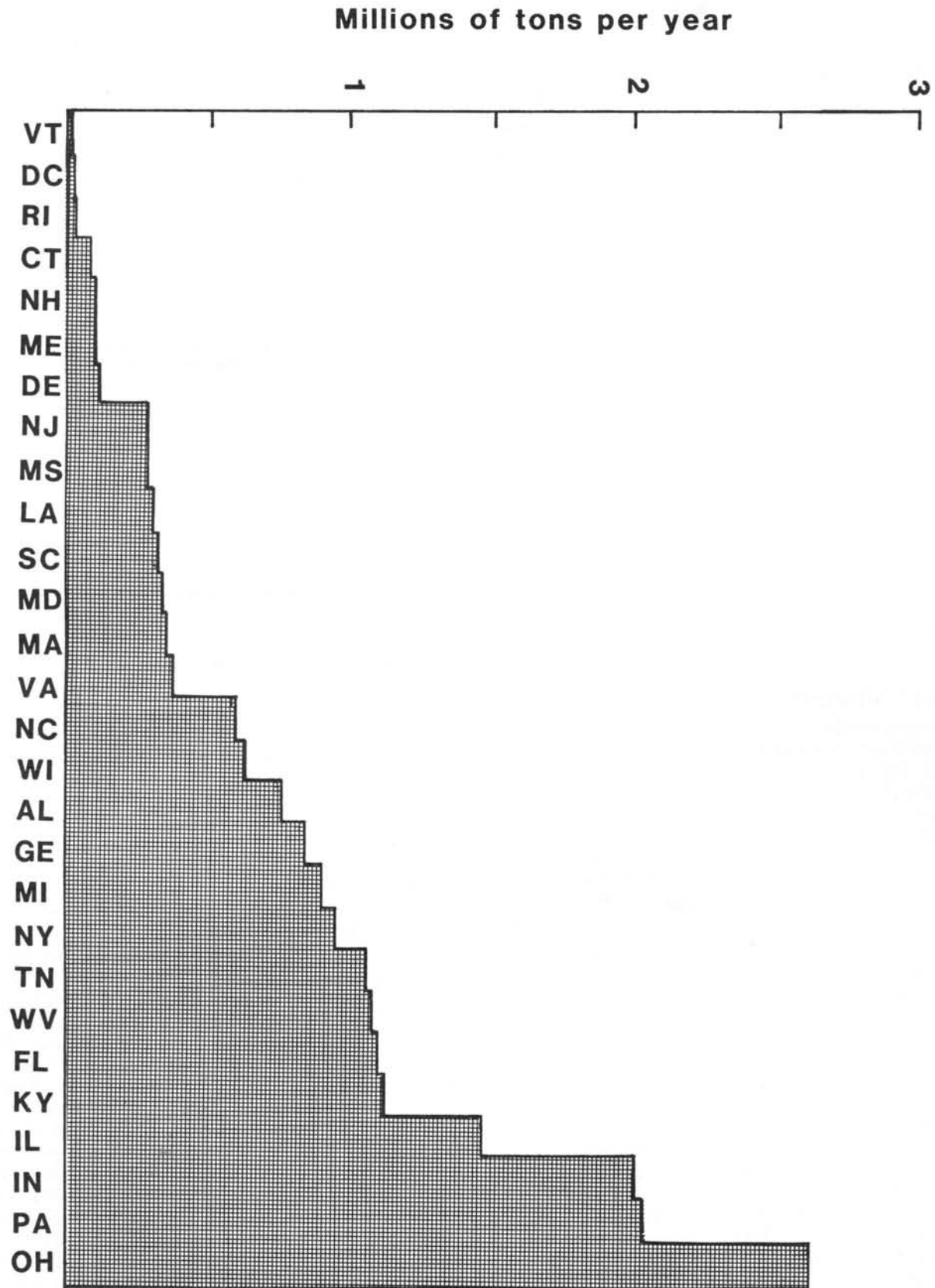


Figure 1. Estimated annual emissions of sulfur dioxide in 1980 east of the Mississippi River (Data from New England Interstate Water Pollution Control Commission).

**Table 1. Characteristics of Long Range and Local Air Pollution (Yocum, 1981).**

Pollutant	Long Range	Local
Ozone and Other Oxidants	Ozone and other oxidants are produced over moderate to long range transport in presence of sunlight from hydrocarbon and NO <sub>x</sub> precursors.	Ozone and other oxidants formation are likely only under low winds and sunlight if precursors are present.
Sulfur Oxides	SO <sub>2</sub> tends to be oxidized to particulate sulfates.	Exists primarily as SO <sub>2</sub> ; however under stable conditions conversion to particulate sulfate can occur.
Nitrogen Oxides	Significant conversion to particulate nitrates.	Exist primarily as NO and NO <sub>2</sub> , but under low wind speed, stable conditions and sunlight, conversions to nitrate particulates and organic nitrates are possible.
Particulate Matter	Only the smallest primary particle sizes persist. Large component of material converted from gases and vapors to particulates such as sulfates.	Exists in wide range of sizes which may be bimodal. Particles are capable of producing surface soiling.
Dry Acidic Deposition	Dry deposition of acidic particulates. (e.g., sulfates are possible.)	Dry deposition of acidic particulates is possible, especially under stable conditions, often enhanced by moist surfaces.
Acid Rain	Acidic rain mechanisms may be predominantly through droplet condensation around acidic particles.	Acidic rain mechanisms may be predominantly through rain washout of acidic particles and pollutant gases.

data. It seems important to continue to monitor SO<sub>2</sub> concentrations to determine effects of possible changes in allowable sulfur content of fuels in Connecticut and elsewhere.

### Sources of Nitrogen Oxides

Nitrogen dioxide in the air has been measured by the Connecticut Department of Environmental Protection since 1973. During this time, concentrations of NO<sub>2</sub> have declined somewhat, with no episodes in 1979 exceeding air quality standards. About 60% of the NO<sub>2</sub> in Connecticut is estimated to come from automobiles (Connecticut Air Quality Summary, 1979). Levels of NO<sub>2</sub> tend to be somewhat higher in the winter months and are less dependent on wind direction than with some other pollutants.

### Sources of Total Suspended Particulates

Total suspended particulates (TSP) are a complex mixture of dust, soot, aerosols, and even liquid droplets small enough to remain suspended in the air. More than half of the particulate emissions in Connecticut are attributed to fuel combustion and creation of road dust by automobiles. Identification of the sources of particulates is complicated by the fact that particle size decreases with increasing distance from the source, but particle sizes are not routinely measured. Particulates have been measured in Connecticut since 1957, but frequency of sampling and other changes in procedures make interpretation difficult. As with ozone and sulfur dioxide, increased TSP concentrations have been associated with southwesterly winds (Bruckman, 1977). In view of the characteristics of particulate matter (Table 1), it seems difficult at this time to attribute

any particulate fraction to specific locations upwind from Connecticut.

### Sources of Acid Rain

Given the difficulty of determining the geographic sources of specific pollutants such as ozone, sulfur dioxide or nitrogen oxides, it is clear that determining the specific sources of Connecticut's acid rain will be at least as difficult. Nevertheless, a clear association has been found between the sulfuric acid component of acid rain and emissions of sulfur dioxide. Therefore, regions where emissions of sulfur dioxide are high and that are upwind of Connecticut are undoubtedly contributing to the acidity of our rain. Table 1 suggests that mechanisms exist for transport of acid rain from both local and long range sources.

Figure 2 shows the mean annual pH of rain in the United States and Canada for the period 1979-1980 (National Research Council, 1981). Although there are relatively few data points in New England (and none in Connecticut), it appears that the region of most highly acidified rain lies considerably to the west of Connecticut. Data summarized in the Northeast Damage Report (1981) show that the concentrations of NO<sub>3</sub> and SO<sub>4</sub> in rain were also greater to the west of Connecticut during 1978-1979. The U.S. Geological Survey in cooperation with other agencies has monitored rainfall at nine stations in New York since late 1964. A recent summary of the data for 1965-1978 by Barnes et al. (1981) shows that the average sulfate concentration in rain has decreased steadily at about 2% per year. The largest decreases (up to 5% per year) were observed at Albany and at two stations on Long Island. Nitrate concentrations have increased 6% to 12% per year, while hydrogen

ion concentrations increased in the western part of the state and decreased in eastern portions. These observations, coupled with a decrease in  $\text{SO}_2$  and  $\text{NO}_x$  concentrations in the air in Connecticut, run counter to the opinion held by some that acid rain is steadily worsening in Connecticut.

### Trajectory Uncertainties

One of the major issues raised by Canada and the northeastern United States is how to reduce local acid deposition, with particular emphasis on sulfur oxides and particulate sulfates. Several models to calculate the transport, dispersion, chemical reaction, and deposition of sulfates have been proposed. These models have been used to identify specific source areas, and even sources, as being responsible for specific episodes of high sulfate concentration. Bowne described the uncertainties that are inherent in trajectories calculated by using these models, which are typically 30% to 50% of the distance from the source. Thus, if the source is 300 miles away, the predicted distance of transport can have uncertainties of the order of plus or minus 150

miles. In addition, trajectories often have angular uncertainties of 20 degrees or more. Using the example above of a source located 300 miles upwind, an angular uncertainty of 20 degrees corresponds to an uncertainty of 100 miles to the right or the left of the predicted trajectory.

Similar uncertainty in the use of models was reported by Hans Martin, senior advisor to the Environment Canada Atmospheric Research Program. However, a study in Ontario using wind records in which the location of an air mass was traced back day by day to its source seemed to promise greater reliability. The United States and Canada, under the Memorandum of Intent on Transboundary Air Pollution, are also examining several potential computer models.

Thus, there is no question that sulfate particulates may be transported far from the emission point. Bowne concluded that attempts to apportion local measurements of sulfates among distant point sources by modeling of chemistry and especially the determination of trajectories have large uncertainties, but that regions and perhaps even states can be identified as source areas.

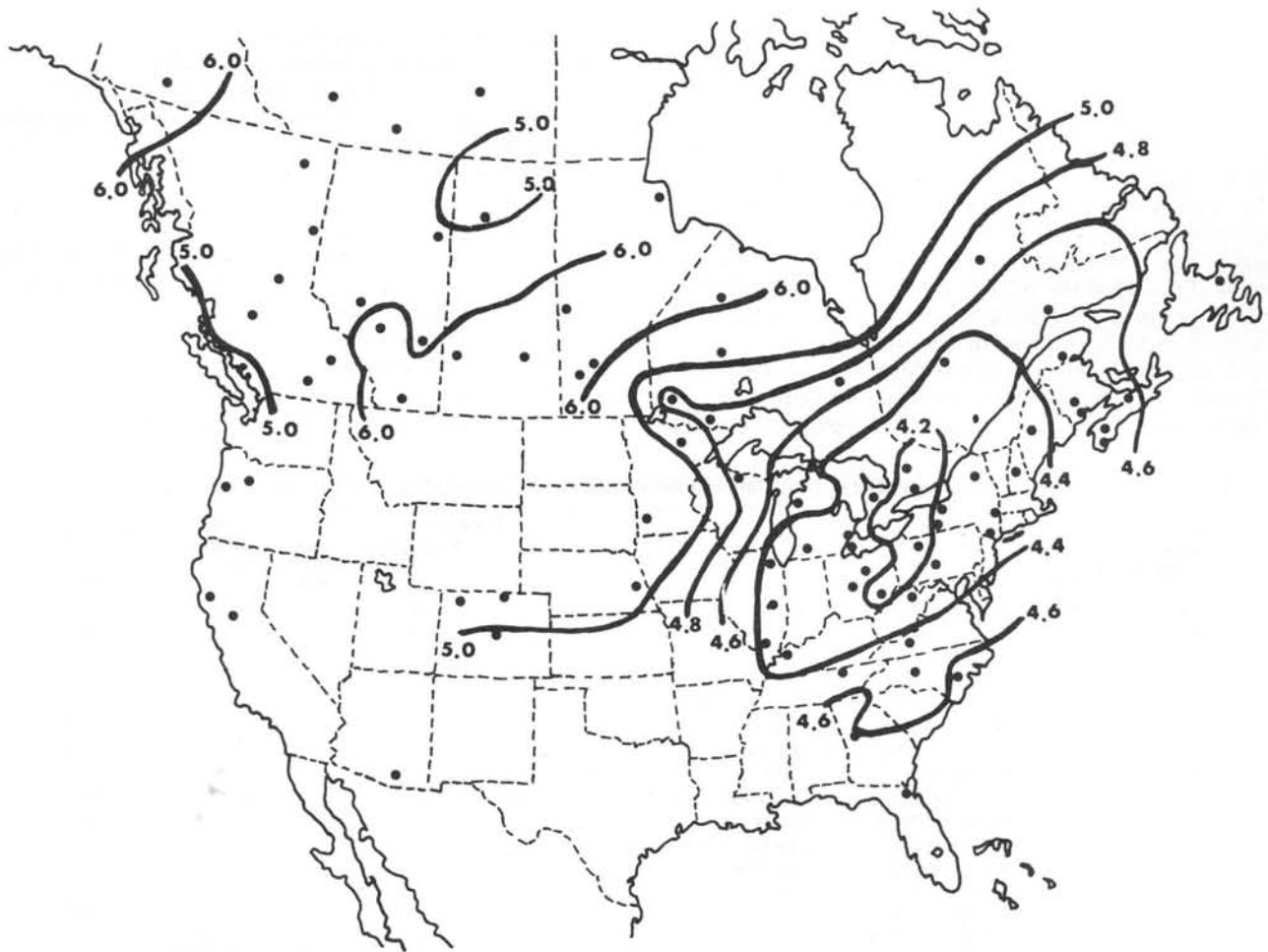


Figure 2. Mean annual pH of rain, 1979-1981 (National Research Council, 1981).

# EFFECTS OF ACID RAIN

## Effects on Soil and Water

In an invitational paper presented at the First International Symposium on Acid Rain, Frink and Voigt (1976) pointed out that, from its very inception, soil formation is an acidifying process. Because the amounts of acid in a year's worth of "acid rain" at pH 4.2 can be neutralized by about 50 lbs of limestone per acre per year, they concluded that the impact on managed agricultural soils would be negligible in comparison with the thousands of pounds of limestone regularly added to the soils in New England to neutralize acidity from fertilizers and biological decay of plant material.

Although early research on acid rain generally recognized that agricultural soil would not be affected, acid rain is thought to be causing severe acidification in mountainous landscapes in humid temperate climates with organic-rich, thin mineral soils developed from highly siliceous bedrock under coniferous forests and heaths. Acidification of these soils in the Adirondacks, northern New England, southeastern Canada, and Scandinavia is said to be an early warning of eventual acidification of lowland watersheds with deeper soils of greater buffering capacity as in Connecticut.

Krug and Frink (1983) have reviewed much of the literature on the effects of acid rain on soil and water, and in testimony to the Task Force stated that much of the acidification that has been observed in lakes can be attributed to the acidity produced by the formation of podzols and associated peaty soils under aggrading forests. The pH of the humus and upper mineral horizons (if present) is typically less than pH 4 and can acidify runoff regardless of the pH of the rain. Acid forest soils typically contain a reservoir of hydrogen ions that is 10,000 times greater than the hydrogen ions in acid rain. Since soil cannot distinguish between

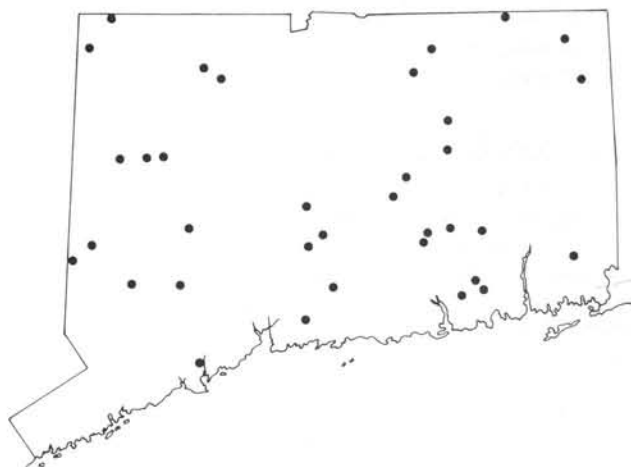


Figure 3. Locations of 35 lakes in Connecticut tested for alkalinity (The Connecticut Agricultural Experiment Station).

hydrogen ions from acid rain and hydrogen ions from all other sources. Krug and Frink conclude that significant acidification of forest soils by acid rain is unlikely. However, Krug and Frink (1983) also note that land use, soils and acid rain need to be examined on a watershed-by-watershed basis in order to determine the relative effects of these sources of acidity on lakes and streams.

Similar conclusions are contained in the recently published Proceedings of the Acid Precipitation Research Needs Conference in New York (1982): "Acidification of Adirondack lakes may be related to long-term natural trends accelerated by acid rain. There is a need to quantify and differentiate between these two acidification processes."

The final report of the SNSF-project in Norway (Overrein et al., 1980) acknowledges that runoff from

Table 2. Connecticut Ponds Included in U.S. Fish and Wildlife Service study of New England lakes.

Size Acres	Code	Pond	Town	Present <sup>1</sup>		Historical <sup>2</sup>		Year
				pH	Alkalinity	pH	Alkalinity	
17.5	1147	Bigelow Pond	Union	6.24	84	6.4	—	1955
55	1148	Blue Pond	No. Stonington	6.64	152	—	—	—
85	1149	Burr Pond	Torrington	6.50	126	6.0	424	1940
2.5	1150	Darling Pond	Chaplin	6.02	94	—	—	—
7.5	1151	Emmons Pond	Hartland	4.60	6	6.0	—	1963
40	1152	Griggs Pond	Woodstock	6.37	128	—	—	—
72.5	1154	Holbrook Pond	Hebron	6.78	264	6.6	—	1954
17.5	1153	Howells Pond	Hartland	5.48	43	6.8	82	1953
32.5	1155	Millers Pond	Durham	5.56	30	—	—	—
15	1101	Mohawk Pond	Cornwall, Goshen	6.50	122	6.6	82	1953
27.5	1156	Norwich Pond	Lyme	6.76	244	7.1	—	1973
17.5	1157	Potters Pond	Woodstock	6.14	90	—	—	—
7.5	1158	Spring Pond	Granby	7.10	408	—	—	—
0.5	1102	Straits Pond	Warren	6.58	120	—	—	—
70	1159	Uncas Pond	Lyme	6.82	154	6.6	—	1954
25	1160	Whitmans Pond	Thompson	5.02	25	—	—	—

<sup>1</sup> Mean of two samples of surface water, October-December, 1980. Alkalinity in  $\mu\text{eq/l}$ . Data of Haines (1982).

<sup>2</sup> Data files, Connecticut Department of Environmental Protection. Measurements were generally made during summer months when the pH may be high, making direct comparison difficult.



acid soils will be acid and can affect the pH of lakes and streams. The report also notes that acidification of lakes and streams predates acid rain, and that acidification of soils due to changes in land use can contribute to acidification of fresh waters.

In Connecticut, a comparison of alkalinity of 20 lakes measured in 1937-1939 and again in 1973-1974 does not show significant changes in alkalinity (Norvell and Frink, 1975). This study has been expanded to include some 70 lakes, with earlier data available for 35. The locations of the lakes are shown in Fig. 3. The results do not show significant decreases in alkalinity (Fig. 4). The one lake where the alkalinity appears to have decreased from about 2.4 to 1.6 meq/l is actually a run-of-the-river impoundment (Lake Housatonic) where the alkalinity is affected by flow and waste water discharges. A number of lakes with low alkalinities (less than 0.5 meq/l) appear to show decreases, but this is probably within experimental error.

Haines presented testimony concerning the pH of a number of small lakes in Connecticut with relatively undisturbed watersheds (Table 2). For the eight lakes with historical data on acidity (1940-1973), five showed a decrease in pH. For three lakes with alkalinities measured between 1940-1953, one showed an increase and two showed a decrease. The pronounced acidification of Emmons Pond is puzzling and may be due in part to natural processes of acidification in the watershed (Haines, personal communication to C.R. Frink, November 1, 1982).

### Effects on Vegetation

In describing the effects of air pollutants on vegetation, Smith (1981) suggested that the complex interactions could be divided into three classes:

- Class I. Low dose. Vegetation and soils serve both as sources and sinks for air pollutants. Depending on the pollutant, the impact may be undetectable (innocuous effect) or stimulatory (fertilizing effect).
- Class II. Intermediate dose. Individual species of trees and other vegetation may be subtly but adversely affected. These effects could include reduced productivity, changes in species composition, and increased damage from insects or disease.
- Class III. High dose. Acute morbidity or mortality of specific trees and consequent impacts on erosion, climate and other changes in the ecosystem.

As with others providing information to the Task Force, Smith stressed that acid rain is not a synonym for air pollution. He stated that sulfur dioxide, oxidants (ozone) and trace metals have particular importance in Connecticut, and that Connecticut is also within a zone of high acid deposition. The impact of present levels of air pollutants on forests and agricultural crops in Connecticut was described by Smith as Class II or subtle stress. The interaction of acid deposition with microbial plant pathogens and insect pests is

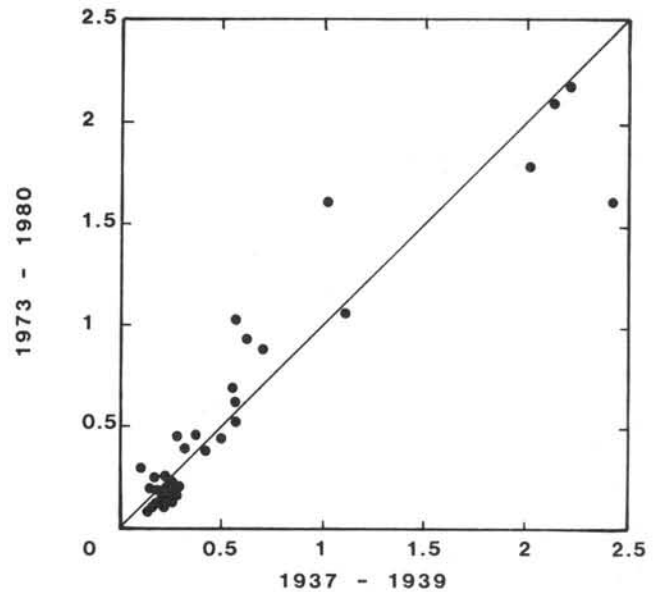


Figure 4. Alkalinity in meq/l for 35 Connecticut lakes (The Connecticut Agricultural Experiment Station).

likely to be one of the most important Class II effects (Smith et al., 1982).

Bormann discussed impacts of air pollution on the New England landscape with the Task Force, also emphasizing that acid rain is only one of many air pollutants that interact with other substances to damage the environment. Bormann indicated that it was possible to damage plants with acid rain in laboratory experiments, but that such damage was difficult to detect in the field. He expressed concern, however, that "large-scale genetic, biological, and ecosystem changes are probably occurring under current levels of air pollution stress."

### Effects on Fish

According to Haines (1981) and Haines and Schofield (1980), continued exposure to low pH is not likely to kill adult fish in acidified lakes. Sudden exposure caused by acidified spring runoff seems to kill fish at higher pH values than chronic exposure to gradual increase in acidity. More likely symptoms are reduced growth, skeletal deformities, and especially reproductive failure. This in turn may lead to reduced species diversity or outright extinction of susceptible species.

The mechanism of toxicity to fish in acidified waters is not clear. The effects may be due to the hydrogen ion itself, or to aluminum and other metals leached from acid soils, or to synergistic interaction between acid and metals. Different strains of fish, particularly trout, differ in their tolerance of acidity and perhaps can provide resistant strains that will survive and grow in acidified waters (Haines, 1981).

To date, there are no reports of damage to fish in lakes in Connecticut. In testimony before the Task Force, Haines indicated that the greatest threats to Connecticut lakes are eutrophication and chemical

pollution. The increased eutrophication of Connecticut's lakes is well documented (Norvell and Frink, 1975), as is the pollution of the lakes on the Housatonic River with PCBs (Frink, et al., 1982).

### Effects on Structures

Yocum (1981) summarized the types of damage to materials that can be caused by air pollution as shown in Table 3. In testimony to the Task Force, Yocum indicated that acid rain itself has little effect on material damage. Most damage is caused by dry deposition or sorption of gases, particularly  $\text{SO}_2$  and  $\text{NO}_x$ , which then react with dew or other moisture. Other environmental factors contributing to damage are sunlight, temperature, freezing and thawing, microorganisms and salt.

Damage to buildings and statues that is visible today is likely due to events 30 years earlier, according to Yocum. He also indicated that damage to materials has declined somewhat in the past few years.

Because of the relatively short residence time of  $\text{SO}_2$  and  $\text{NO}_x$  in the atmosphere, damage to structures is more likely to be caused by local rather than long range sources (Yocum, 1981).

### Effects on Health

Human exposure to acid rain takes three forms: breathing of air which contains aerosols and particles,

consumption of drinking water, and direct contact with rain. Health effects have been studied in many ways. The principal methods reviewed here are the response of humans to specific levels of pollutants in laboratories, statistical analysis of the correlations between pollution levels and health records (morbidity and/or mortality), and analysis of death and sickness rates during episodes of very high pollution levels.

The episodes of fog in London in 1952 and Donora, Pennsylvania in 1948 dramatically show the effects of very high levels of air pollution. In these two episodes, high levels of sulfur oxides and particles coupled with atmospheric stagnation caused thousands of people to become ill with respiratory ailments and significantly raised the death rate for a short period of time. As a result of these episodes, steps were taken to regulate emissions and this magnitude of air pollution and effects on health is no longer likely.

There have been a large number of statistical studies of the correlations between levels of specific pollutants and public health. These studies are usually very complicated and the results only show correlation which does not prove cause and effect. We summarize the results of four of these statistical studies below.

A London study (Douglas and Waller, 1966) followed four thousand children from birth to age fifteen. The study showed that lower respiratory infections were consistently related to pollution and the severity of the

**Table 3. Air Pollution Damage to Materials (Yocum, 1981).**

Materials	Type of Damage	Principal Air Pollutants	Other Environmental Factors	Methods of Measurements	Mitigation Measures
Metals	Corrosion, tarnishing	Sulfur oxides and other acid gases	Moisture, air, salt	Weight loss after removal of corrosion products. Reduced physical strength, change in surface conductivity.	Surface plating or coating. Replacement with corrosion resistant material.
Building Stone	Surface erosion, discoloration	Sulfur oxides and other acid gases, particulate matter	Moisture, temperature fluctuations, salt, vibration, microorganisms, $\text{CO}_2$	Surface reflectivity, measurement of dimensions.	Cleaning and sand blasting. Impregnation with resins, replacement.
Paint	Surface erosion, discoloration	Sulfur oxides, hydrogen sulfide, ozone, particulate matter	Moisture, sunlight, microorganisms	Weight loss of painted panels, surface reflectivity.	Repainting, replacement with more resistant paint.
Textiles	Reduced tensile strength, soiling	Sulfur oxides, nitrogen oxides, particulate matter	Moisture, sunlight, physical wear	Reduced tensile strength, reduced fluidity (cotton), surface reflectivity.	Replacement
Textile Dyes	Fading, color change	Nitrogen oxides, ozone	Sunlight	Reflectance and color value measurements.	Replacement
Paper	Embrittlement	Sulfur oxides	Moisture, physical wear	Decreased folding resistance.	Synthetic coatings, storing indoors in pollutant-free atmosphere.
Rubber	Cracking	Ozone	Sunlight, physical wear	Loss in elasticity and strength, measurement of each frequency and depth.	Add antioxidant to formulation. Replace with more resistant materials.
Leather	Weakening, powdered surface	Sulfur oxides	Physical wear	Loss in strength.	Store in indoor pollutant-free environment, replace.
Ceramics	Changed surface appearance	Acid gases, HF	Moisture	Loss in surface reflectivity.	Protective coating, replace with more resistant material.

illness increased with the level of pollution. The socioeconomic status of the children was not important.

In 1970, Hodgson found that mortality from respiratory and heart disease in New York City correlated with air pollution levels (Hodgson, 1970).

In 1977, Lave and Seskin showed that in the largest United States cities (not Hartford), there is a close relationship between mortality rate and pollution levels of sulfates, sulfur dioxide, suspended particles, and possibly nitrous oxide. There was no consistently significant relationship for levels of nitrate, nitrogen dioxide, carbon monoxide, and hydrocarbons (Lave and Seskin, 1977).

In 1979, Mendelsohn and Orcutt studied two million death certificates from 1970 and found "Some pollutants, especially sulfates, are closely associated with many deaths, whereas other pollutants, especially ozone and nitrogen dioxide have no apparent effect on expected lifetimes." Quoting further: "The dose-response curves, even for relatively low measurement levels in the sample, appear to be linear. For all practical purposes, there is no evidence of a lower threshold effect for any of the pollutants." If the results of this study are extrapolated to the entire country, the authors predict that a total of 140,000 deaths a year, which is 9% of all fatalities, are attributable to air pollution. The study reported that mortality due to air pollution in New England is about twice that in the rest of the country. The maximum damage was found to occur in eastern Ohio where sulfate concentrations were also close to a maximum.

Many studies have linked sulfate levels to respiratory problems. Recently, breathing sulfuric acid aerosols has been found to alter mucociliary clearance rates in healthy non-smoking adults (Lippman, et al., 1981). Sulfate levels above  $6-10 \mu\text{g}/\text{m}^3$  cause increased asthma attacks (EPA, 1974). Higher sulfate levels have been linked to daily mortality increases, acute lower respiratory diseases in children, and aggravated heart and lung diseases in the elderly (EPA, 1974). Levels cited in these studies are exceeded in the Northeastern U.S.

The most serious effects of air pollution on health are due to the presence of respirable particles approximately 1 micron in size which can lodge in the lung. Some of these particles are sulfate aerosols produced by the reaction of  $\text{SO}_2$  in water to form  $\text{H}_2\text{SO}_4$ , which is then neutralized in part by ammonia in the atmosphere (Tanner et al., 1981). Levels of respirable particles are not controlled by existing federal particulate standards, which are based on total particulate levels with no size distinction. Emission control technologies have therefore focused on removal of large particles to achieve total particulate standards, leaving respirable particles relatively unaffected.

In terms of direct external human contact, concentrations of acids in acid rain are sufficiently low that burns and rashes are not observed. The long term effects of direct contact with low levels of acid precipitation, if any, are not known at the present time.

Potential indirect effects of acid rain include consumption of acidified drinking water and consumption of fish from acidified water bodies. Acid water has been shown to dissolve lead and copper from water pipes. However, proper pH control of community water supplies would normally prevent this from occurring (Northeast Damage Report, 1981, p. 51). It is suspected that acidic water is partially responsible for dissolving mercury and lead minerals which accumulate in fish. This has been observed in New York (Fuhs, 1979), but should not occur in Connecticut lakes which are less acidic.

In summary, there can be adverse health effects from the pollutants which accompany and make up acid rain. The magnitude of the effect depends on the amount of exposure, i.e., dose. Respirable particles, sulfur oxide aerosols, and toxic heavy metals are the species of highest concern. The air and water quality standards in Connecticut offer some degree of protection by limiting the amount of sulfur dioxide, total suspended particles and heavy metals in air and water. In most cases these standards do not completely address the control of those species which most directly concern health.

## STUDIES OF ACID RAIN IN CONNECTICUT

### Atmospheric Deposition Monitoring

The Connecticut Department of Environmental Protection and the US Geological Survey initiated a cooperative atmospheric deposition monitoring program in 1981 to assess the chemistry and distribution patterns of "acid rain" in Connecticut. Objectives of the program are to determine differences across the state, to determine relationships between atmospheric deposition and air mass movements, and to provide baseline data to determine trends and estimate loads. Monitoring site locations, collection methods, and analytical methods are consistent with criteria established by the National Atmospheric Deposition Program.

Three monitoring sites have been selected—Quine-

baug fish hatchery near Wauregan; Salmon River State Forest near Leesville; and Morris Reservoir near Thomaston. The Wauregan site was activated in October 1981, and the other two sites became operable in October 1982. The program is designed for collection of wet deposition during selected storms and collection of dry deposition samples every two months. Samples will be analyzed for pH, specific conductance, major anions and cations, major nutrients and selected heavy metals. As of October 1982, 13 samples had been collected and analyzed for pH and conductance, and four samples had been collected and analyzed for chemical constituents. Data will be reported in the annual US Geological Survey report series and an interpretative report will be published in late FY 84.

### Effects of Precipitation and Snowmelt on Surface Water Quality

The Connecticut office of the US Geological Survey has developed a proposal to study the Salmon River watershed to determine whether precipitation and snowmelt alters the water quality characteristics of the Salmon River, Blackledge River, and Dickinson Creek. The study would involve simultaneous sampling of surface water, precipitation and snow cores. The proposal was submitted for consideration for federal research funds.

### Effects of Acid Rain on Drinking Water Supplies

The New England Water Works Association and the Environmental Protection Agency are presently conducting a cooperative study of the effects of acid rain on water supplies in New England. Objectives of this study are to determine if changes in water supply quality occurred with the advent and increase in acid rain; to evaluate trends with respect to corrosion, dissolution of metals and asbestos, bacteriological quality, and taste and odor organisms; and to estimate the economic impact of acid rain on public water supplies. The study involves a review of historical data and records as well as collecting samples of raw and finished water. Approximately 25 Connecticut water supplies are included in this study. A report of this study is due in 1982.

### Effects of Acid Rain on Lakes

The US Fish and Wildlife Service Research Laboratory in Orono, Maine is presently conducting a water quality study of acid-sensitive lakes in New England. Lakes selected for the study were those likely to be susceptible to acidification due to watershed size, geological conditions, and land use. The study involves sample collection and analysis in 1980 and 1981, and a review of historical data. Sixteen ponds in Connecticut are included in the study (Table 2). The results to date were discussed earlier.

### Effects of Acid Rain on Soil and Water

The Connecticut Agricultural Experiment Station in New Haven has studied changes in Connecticut's forests in plots established in 1927. These studies will be expanded to include changes in soil properties that have occurred as the forest matures. Additional studies will be made of lakes in upland landscapes with highly coniferous watersheds where the greatest acidification of soils has been observed.

### Effects of Acid Precipitation on Amphibians

Pierce of Connecticut College is presently completing a research project on the effects of acid rain on the wood frog, *Rana Sylvatica*. One objective is to examine the acid tolerance of three life states—embryo, larva, and metamorphosing larva. Another part of the project is a study of the spatial and seasonal variations of pH in a pond where wood frogs breed. The project also is examining relationships between pH of rain and pH of the breeding pond. A report is scheduled to be completed by the end of 1982.

### Air Quality Monitoring

The Connecticut Department of Environmental Protection Air Compliance Unit maintains an ambient air quality monitoring network which routinely measures many parameters associated with acid rain. Greatest emphasis is placed on six pollutants for which Environmental Protection Agency standards have been set—total suspended particulates, sulfur dioxide, ozone, nitrogen dioxide, carbon monoxide, and lead. Approximately 40 stations are monitored throughout the state. Sulfur dioxide and nitrogen dioxide are measured continuously, and total particulates are measured once a week. In addition, nitrate, sulfate, chromium, and 10 metals are measured on a quarterly basis.

The Department of Environmental Protection has also participated in the Environmental Protection Agency Inhalable Particulate Network in recent years. Under this program, the Department of Environmental Protection has collected samples from stations in Connecticut and has sent samples to the national laboratory for measurement of respirable particles.

### Effects of Acid Rain on Surface Water Quality

Historical and recent Connecticut surface water quality data is being used by the aquatic effects research program of the Federal Interagency Task Force on Acid Precipitation. A primary objective of this study is to quantify the extent of acidification and sensitivity of lakes, streams, and groundwaters of the United States. This will include a determination of trends in the acidification of surface waters, and an assessment of future acidification. Principal participants are the Environmental Protection Agency and Brookhaven National Laboratory. This program has produced a national map of surface water sensitivity based on total alkalinity.

## CURRENT REGULATION OF ACID RAIN

### The Federal Program

As now constituted, the federal Clean Air Act does not address the acid rain issue. The control of acid rain which now exists is indirect, a byproduct of pollution abatement strategies designed to deal with other pol-

lution problems. Failure to deal with acid rain and long range transport of pollution in general primarily results from the fact that long range transport of pollution has only come to be a subject of public debate since the Clean Air Act was last amended in 1977. Whether

these issues will be addressed in the current revision of the Act remains a subject of some controversy.

The pollution abatement programs established under the federal Clean Air Act were intended to deal with localized air quality problems close to sources of pollution. To this end, the Environmental Protection Agency has established National Ambient Air Quality Standards (NAAQS) for seven major pollutants including sulfur and nitrogen oxides. NAAQS are the basis for most of the nation's air pollution control program. The inadequacy of these localized pollution standards to deal with acid rain was noted by the National Commission on Air Quality which pointed out that the key factor associated with acid rain is "not ambient pollutant concentration but rather total pollutant loading which is only indirectly linked to ambient concentration." This approach means that large amounts of pollutants may be generated in certain localities without violation of ambient air standards if there is sufficient dispersion. Thus, even a stringent local program of control may still result in long range pollution problems. In fact, some commentators have pointed out that strategies to disperse local pollution, such as tall stacks, have contributed to the acid rain problem. The existing NAAQS have also been cited as problematical in dealing with acid rain because standards exist only for sulfur dioxide and nitrogen dioxide gases, whereas sulfates and nitrates, the derivative particulate compounds of these gases which apparently react with water vapor in the formation of acid rain are only indirectly regulated.

In accordance with the Clean Air Act's focus on local ambient pollution concentrations, states are required to prepare individual State Implementation Plans (SIP) to demonstrate how the NAAQS will be met in each state. Because the SIP process concentrates on control of sources within a state to meet federal standards, pollutants transported beyond state boundaries may escape regulation. According to the report of the National Commission on Air Quality, sections of the Clean Air Act that address interstate pollution have proved ineffective. Section 110(a)(2)(E) of the law requires that the Environmental Protection Agency not approve any SIP that allows pollution which would "prevent attainment or maintenance" of ambient air standards in another state. However, the report notes, no regulations have been issued to clarify the legislation and therefore there is no guidance on the relative responsibilities of polluting and receiving states. Section 126 of the Act permits state or local governments to petition the Environmental Protection Agency to enforce Section 110. However, due to the technical and political complexity of these cases, no petition has been granted and some have been awaiting a decision for years.

Despite the inadequacies of the Clean Air Act, several existing control strategies may indirectly address acid rain by reducing local pollution or preventing

further deterioration. These include the non-attainment program, which requires reduction of emissions in an area which does not meet the NAAQS. In addition, the Prevention of Significant Deterioration (PSD) program which seeks to protect air in areas that meet federal standards by requiring more stringent standards for new or modified pollution sources, and the new source performance standards which impose stricter controls on certain categories of polluters, will reduce the future growth of acid rain pollutants although they will not reduce current levels.

### Connecticut's Program

Connecticut's air pollution program is largely a response to the federal Clean Air Act. Although emissions of sulfur and nitrogen oxides in Connecticut will probably not cause acid rain in Connecticut, long range transport of these pollutants adds to overall atmospheric loading which may result in acid rain elsewhere. For many years, Connecticut had by far the toughest statewide sulfur-in-fuel requirement in the nation. No fuel could be burned in the state that had more than 0.5% sulfur. This put Connecticut in compliance with the sulfur NAAQS by a wide margin. This standard was recently altered to permit burning of fuel containing 1% sulfur by business and industry. According to the Department of Environmental Protection, this change in the standard will increase sulfur oxide emissions from about 73,000 tons per year to somewhat over 123,000 tons per year. For purposes of perspective the Department of Environmental Protection notes that emissions of sulfur oxides from just the Port Jefferson and Northport power plants on Long Island produce over 150,000 tons per year, more than all Connecticut sources combined. Another recent development concerning sulfur dioxide was the repeal of Connecticut's stricter property related (secondary) sulfur dioxide standard which will cause some additional deterioration of air quality. Connecticut was one of the few states to have such a standard. Since Connecticut remains in attainment for sulfur dioxide, certain major new air pollution sources must also obtain a PSD permit which will subject them to stricter review.

Connecticut has attained the NAAQS for oxides of nitrogen. Although localities of the state exceeded these standards in the early 1970s, controls on the stationary sources have caused the state to reach attainment. In the future, new large sources will have to obtain PSD permits. In addition to stationary sources, motor vehicles also emit oxides of nitrogen. Connecticut has chosen to leave control of such emissions to the Federal Motor Vehicle Emission Control Program which requires manufacturers to produce vehicles emitting less nitrogen oxides. Connecticut has not chosen to regulate nitrogen oxides under the Automobile Inspection/Maintenance Program since the state is at attainment.

# STATUS OF FEDERAL LEGISLATION ON ACID RAIN

## Background

Congressional action addressing the acid rain problem must be examined in the context of the debate over reauthorization of the federal Clean Air Act. Final action to reauthorize the Act has not been taken by either the full House or Senate, but significant provisions directed at mitigation of acid rain have emerged from the Senate Environment and Public Works Committee. For example, the Senate bill requires a substantial reduction in sulfur dioxide emissions in a 31-state region. The Senate Committee voted 15-1 on August 19, 1982 to report its Clean Air Act amendments to the full Senate for consideration. However, the Senate has yet to take up this new bill.

The House bill on the Clean Air Act issue differs substantively from the Senate version and does not recommend a regulatory control approach to acid rain. The House version, currently in a markup phase in the House Energy and Commerce Committee, basically adopts a continued research approach to the issue of acid rain.

## Senate Bill Status

The bill reported out by the Senate Environment and Public Works Committee is an amended version of S-1706, originally introduced by Senator Mitchell of Maine. It would require an 8 million ton reduction below 1980 levels in existing sources of sulfur dioxide emissions within a 31-state eastern acid rain mitigation region. States included are Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, West Virginia, and Wisconsin, as well as the District of Columbia. These states would be given 12 years to achieve the required reductions in sulfur dioxide emissions (The original S-1706 established a 10 year timetable). State Implementation Plans (SIP) required

under the Clean Air Act would have to be revised to contain enforceable emission reduction steps and approved by EPA within four years. If states failed to reach agreement within 18 months on the allocation of SO<sub>2</sub> reductions, EPA would make the decision. States would also be allowed to trade emission reductions under the bill.

Acid rain research would continue under the bill with the Inter-agency Task Force required to submit annual progress reports to Congress, plus two comprehensive reports that include recommendations for reducing acid rain. The Senate bill also recommends a five-year authorization of the Clean Air Act.

## House Bill Status

House activity on the Clean Air Act and the related issue of acid rain centers in the House Energy and Commerce Committee. The House proposal (HR-5252) accelerates research efforts established under the Energy Security Act of 1980 from ten years to five years. That federal law (P.L. 96-294(1980)) established a comprehensive acid precipitation program and carbon dioxide study to be carried out by an Acid Precipitation Task Force, jointly chaired by the Secretary of Agriculture and the administrators of the Environmental Protection Agency and the National Oceanic and Atmospheric Administration.

The House bill also requires the Environmental Protection Agency to report on alternative control strategies for addressing the acid rain situation. This includes precombustion fuel treatment and inherently low-polluting combustion technologies such as atmospheric fluidized bed combustion. (These control strategies, as well as the accelerated research approach, were originally offered in HR-5055).

The House Energy and Commerce Committee has taken no action on HR-5252 since mid-August. It is unlikely that a House bill will contain regulatory measures directed specifically at acid rain.

## CONCLUSIONS

### Nature and Sources of Acid Rain

There is little doubt that rain in Connecticut and elsewhere in the Northeast has been acidified by increased emissions of sulfur dioxide and nitrogen oxides. The increased emissions of sulfur dioxide can be attributed largely to increased combustion of fossil fuels. Nitrogen oxides are produced during high temperature combustion regardless of the composition of the fuel and the observed increases can be attributed largely to automobiles as well as stationary combustion sources.

In addition to acidifying rain, the gaseous oxides of nitrogen and sulfur may react directly with materials they contact, or they may react with other substances to produce particulate aerosols. Thus, acid rain is a mixture of acids dissolved in water, reactive gaseous oxides, and fine particulate sulfate and nitrate aerosols. In addition, air contains other pollutants such as ozone, hydrocarbons and heavy metals that also may be harmful. Unfortunately, these various pollutants are often grouped together under the heading of "acid rain," which has become a subject of national and even international environmental concern.

The sources of acid rain and other air pollutants in Connecticut are not readily quantified. This is due in part to the varied components of acid rain: if damage is caused largely by gaseous  $\text{SO}_2$ , for example, its relatively short residence time in the atmosphere suggests that local sources are important. Fine particulate aerosols, on the other hand, can be transported over longer distances. The more distant the source, the more difficult it becomes to specify that source. Present models that attempt to estimate the trajectory of polluted parcels of air have errors of the order of 50% of the distance involved. However, it is clear that regions and perhaps even states can be identified as source areas.

Rain in Connecticut has an average pH of about 4.3-4.4, which is highly acidic compared to unpolluted rain with pH 5.6. The area of most highly acidified rain (pH~4.2) lies to the west of Connecticut, covering the general area of western Pennsylvania, western New York, eastern Ohio, and southeastern Ontario. Measurements of sulfate and nitrate deposition confirm

that this area is the center of acid deposition. Because large amounts of sulfur dioxide and nitrogen oxides are produced in the 28 states east of the Mississippi, it is reasonable to conclude that, once again, man has fouled his own nest.

### Effects of Acid Rain

To date, the effects of acid rain on the environment of Connecticut can be summarized as subtle. The soils of Connecticut are generally well buffered and show no evidence of acidification by acid rain. Measurements of the alkalinity of 35 lakes in Connecticut show little or no change since earlier measurements in 1937-1939. Similarly, there is no evidence that fish in our lakes have been affected by acid rain, but there are 1000 lakes in Connecticut large enough to have names and some changes may have gone undetected. There is no evidence of damage to agricultural crops, and little or no reason to believe that our forests have been adversely affected to date. However, concern has been expressed that current levels of air pollution may cause genetic, biological and ecosystem changes that have yet to be identified.

The effects of acid rain on structures in Connecticut are evident in the weathering of some statues and other building stone. The damage is caused largely by the sorption of gaseous oxides, particularly sulfur dioxide, which then dissolves in dew or other moisture to produce sulfuric acid.

There is little evidence of any direct effect of acid rain—i.e. increased acidity of rainfall—on human health. The notion that acid rain will burn skin or dissolve one's clothing has no basis in fact. However, there is no question that some forms of air pollution are harmful to health. Specifically, fine particulate aerosols can lodge in the lung and cause respiratory problems. A portion of these aerosols are acidic due to the presence of sulfur oxides. The association between these air pollutants and human health is statistical, rather than clinical, with one published study indicating an increase in mortality in New England due to air pollution. The precise role of sulfate aerosols in this complex air pollution problem is not known.

## RECOMMENDATIONS

The Task Force finds that there is a serious need for increased public understanding of the sources and effects of acid rain in Connecticut. In addition, the Task Force has identified areas where there are significant gaps in our knowledge. Finally, the Task Force recommends some regulatory activities that may aid in controlling acid rain.

**Public Awareness.** The Task Force recommends that the Department of Environmental Protection, Department of Health Services, and other appropriate agencies undertake educational programs that will inform the public of the facts concerning acid rain.

**Increased Knowledge.** The Task Force recommends that further studies of acid rain in Connecticut should include the following in order of priority:

- Methods for monitoring total suspended particulates should be improved so that sulfates and particle size can be measured. As satisfactory methods are developed, the frequency of sampling should be increased. This will assist further epidemiological studies that are needed to determine the health effects of size and acidity of respirable particulate matter.
- Monitoring of pH of rainfall should be expanded to include pH of rivers and streams, particularly during spring runoff into head water streams. Special attention should be given to sensitive areas such as salmon spawning and stocking locations.

- Studies of lakes should focus on those in highly forested watersheds where acidification seems most likely. These studies should include effects of acidification on growth of forests where possible.
- Monitoring of sulfur dioxide should continue to determine if recent changes in allowable sulfur contents of fuel have resulted in changes in concentrations of sulfur dioxide in the air.
- Transport models should be developed with sufficient accuracy to predict movement of air pollutants so that effects of regulatory changes can be determined.

**Regulatory Action.** The Task Force recognizes that Connecticut is a national leader in regulating emissions of sulfur dioxide. The Task Force also realizes that many of the regulatory actions needed to reduce the effects of acid rain in Connecticut are federal as well as state. However, significant amounts of sulfur oxides are produced in Connecticut by burning of fossil fuels, and significant amounts of nitrogen oxides are produced in Connecticut from automobiles. Changes in current regulations on sulfur content of fuels or on emissions from automobiles should be carefully evaluated in terms of effects that may be expected.

The Task Force recommends that the General Assembly memorialize Congress to strengthen the Clean Air Act with particular reference to regulation of particle size of total suspended particulates, and to address the problem of regional transport of pollutants into Connecticut.



## ATTACHMENT I

**Persons Providing Information to the Task Force**

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- Mr. Norman E. Bowne, Vice President and Chief Scientist, TRC Environmental Consultants, Inc., East Hartford, CT.
- Mr. Leonard Bruckman, Director, Air Compliance Unit, Connecticut Department of Environmental Protection, Hartford, CT.
- Dr. Erskine Crossley, Staff Scientist, Office of Legislative Research, Connecticut General Assembly, Hartford, CT.
- Mr. Charles G. Fredette, Senior Sanitary Engineer, Connecticut Department of Environmental Protection, Hartford, CT.
- Dr. Terry A. Haines, Leader U.S. Fish and Wildlife Service, Columbia National Fisheries Research Laboratory Field Research Station—Orono, University of Maine, Orono, ME.
- Mr. John Kasprak, Research Attorney, Office of Legislative Research, Connecticut General Assembly, Hartford, CT.
- Mr. Edward Kluck, Housatonic Fly Fishermen's Association, Hamden, CT.
- Dr. Edward C. Krug, Assistant Soil Chemist, Connecticut Agricultural Experiment Station, New Haven, CT.
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- Dr. Hans C. Martin, Senior Advisor, Federal Long Range Transport of Air Pollutants, Liaison Office, Atmospheric Environment Service, Environment Canada, Downsview, Ontario, Canada.
- Dr. William H. Smith, Professor of Forest Pathology, School of Forestry and Environmental Studies, Yale University, New Haven, CT.
- Dr. Jan A. J. Stolwijk, Associate Director, John B. Pierce Foundation Laboratory and Professor of Epidemiology, Yale University, New Haven, CT.
- Mr. John E. Yocum, Vice President and Chief Consulting Engineer, TRC Environmental Consultants, Inc., East Hartford, CT.

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