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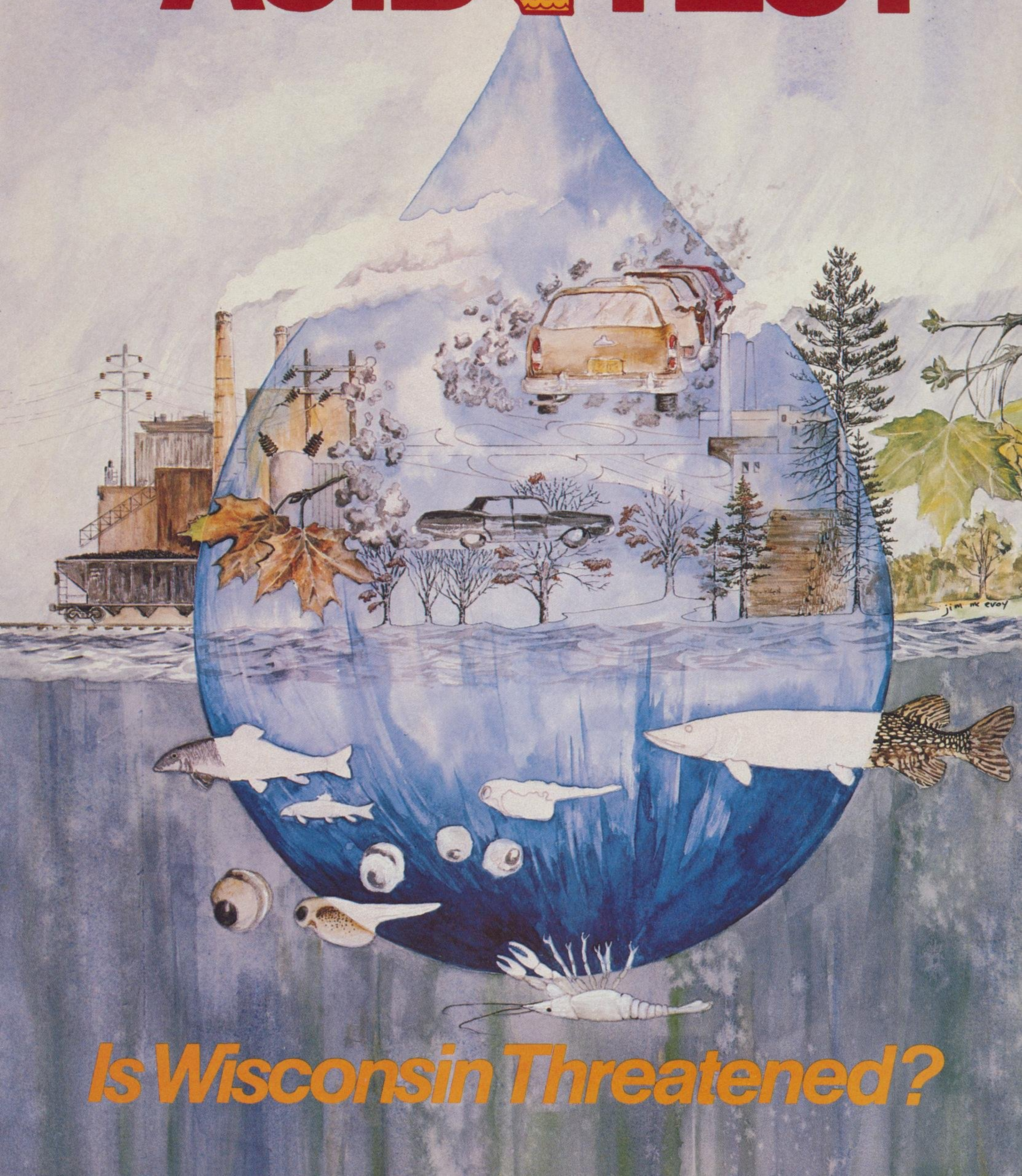
THE ACID TEST



Is Wisconsin Threatened?

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THE ACID TEST

Editor, J. Wolfred Taylor
Art Direction, Jill Kerttula
Issue Coordinator, Thomas Sheffy

Mildred Lake in Oneida County is one of 3,500 Wisconsin lakes that have low alkalinity and are susceptible to acidification. Photo by Katherine Webster

The Wisconsin cooperative acid deposition research program

THOMAS SHEFFY, DNR Acid Deposition Program Director, Madison

JERRY E. MENDL, Public Service Commission, Madison

RICHARD C. BRATCHER, Wisconsin Electric Power Company, Milwaukee

front cover—Painting by Artist Jim McEvoy

Joint fact finding research by government agencies and utilities, begun in 1981, is nearing completion. Results will help policy-makers deal with the acid rain issue in Wisconsin.

During the summer of 1979, DNR conducted a general water quality survey of 350 lakes in north central Wisconsin. Findings from that survey were so startling they eventually sparked a $2-million research program. The survey had found nearly half of sampled lakes to have relatively low alkalinities of 200 microequivalents per liter (ueq/l) or less. Alkalinity is a measurement of acid neutralizing capacity. The lower the alkalinity the less acid input a lake can tolerate without undergoing undesirable changes in water quality and aquatic life. About the same time, reports from Canada and Sweden had warned of acid rain damage to softwater lakes with alkalinities of 200 ueq/l or less. Concern heightened here during the fall of 1979, when rainfall samples collected at several locations in northern Wisconsin showed an average pH of 4.5, several times more acidic than unpolluted rain.

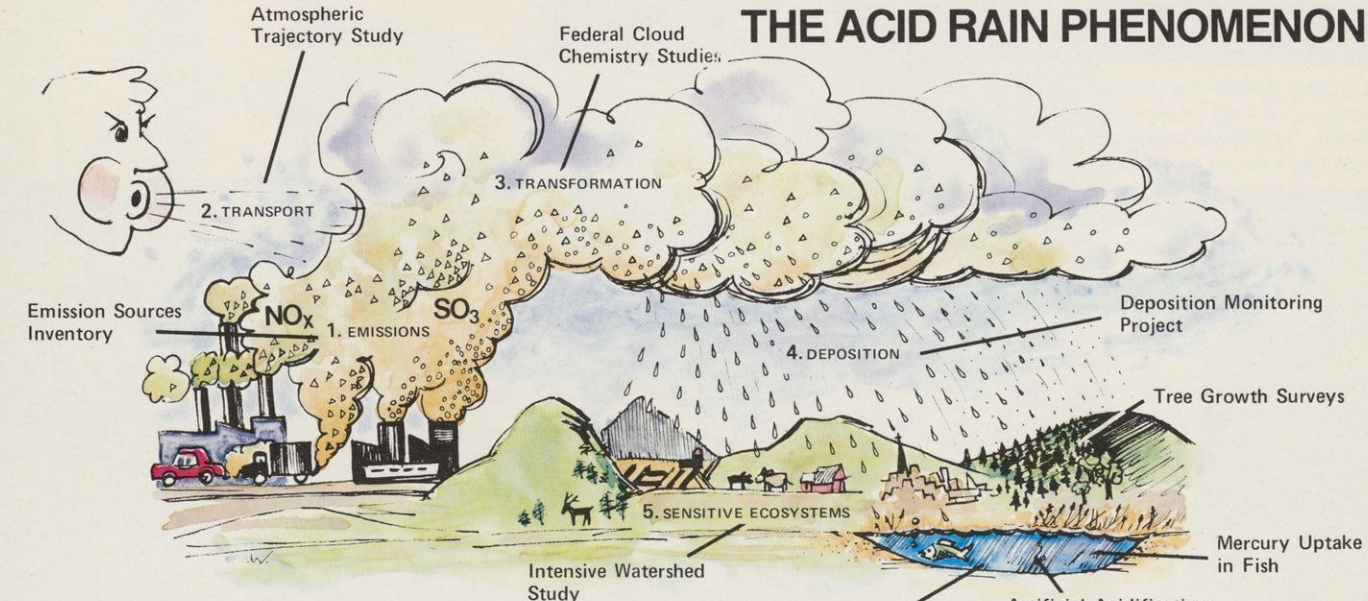
This preliminary information on lake susceptibility and acidic deposition generated concern because 80% of the state's nearly 15,000 lakes are found in 23 northern Wisconsin counties. Tourism and fishing are particularly important to their economy and directly linked to water resources. Any threat to the well-being of northern lakes might have dire economic consequences.

The response to this potential problem was a special DNR Acid Deposition Task Force to examine all available information. It published a report in June, 1980 entitled *A Review of Acid Deposition in Wisconsin: Recommendations for Studying and Solving the Problem*. When presented to the Wisconsin Public Service Commission (PSC) and a joint environmental committee of the State Legislature all agreed that further research was necessary.

The legislative committee directed DNR to seek research funds from Wisconsin utilities through the PSC and the utilities agreed to help develop and fund the research. Subsequently, representatives from DNR, the PSC and the Wisconsin Utilities Association formed a Joint Acid Deposition Technical Review Committee. The joint committee developed a research plan and began working on it in May of 1981.

This joint research, along with two other DNR projects, became the Wisconsin Acid Deposition Research Program. Cooperating in the effort are DNR, the Wisconsin Utilities Association, the PSC, the Wisconsin Geological Survey, University of Wisconsin, University of Minnesota, US Geological Survey, US Environmental Protection Agency, the Fish and Wildlife Service and the Electric Power Research Institute. Most elements of the program are due to be finished by the end of 1984.

THE ACID RAIN PHENOMENON



The "big picture" of acid rain includes the following sequence of events:
1) emissions, 2) atmospheric transport, 3) chemical transformation, 4) deposition and 5) effects on sensitive ecosystems. Wisconsin's Acid Deposition Research Program, and other federal research addresses each part of the acid deposition phenomenon.

Illustration by Artist Eric Weaver

Acid Deposition Research Projects

1. Deposition Monitoring

***Objective:* Characterize rainfall and dry deposition statewide.**

Method: *Add three new precipitation monitors to existing state network of eight.*

2. Deposition Data Integration and Quality Assurance

***Objective:* Establish and maintain a reliable data bank.**

Method: *Assemble historical precipitation data, implement quality assurance plan for existing monitors.*

3. Atmospheric Trajectory Study

***Objective:* Identify origin of air masses which deliver pollutants.**

Method: *Backtrack 31 weather systems which deposit acidic precipitation at monitors.*

4. Trajectory Quality Assurance

***Objective:* Ensure correct interpretation of trajectory analyses.**

Method: *Obtain independent review of trajectory plots.*

Most sulfur dioxide that causes acid rain comes out of smokestacks. They're also blamed, along with motor vehicles, for nitrogen oxides. Research on emissions has pinpointed sources both in-state and out-of-state.

Wet-dry collectors gather acid fallout for analyses as part of the deposition project. Special sensors move the lid back and forth in rainy or dry weather.

5. Emission Sources

***Objective:* Identify Wisconsin sources of sulfur dioxide and nitrogen oxide, and sources in surrounding states.**

Method: *Assemble detailed emission inventory for Wisconsin and surrounding states.*

6. Intensive Watershed Study at Round and East Eightmile Lakes

***Objective:* Determine manner and rate of response of sensitive lake systems.**

Method: *Measure interaction of acid deposition with vegetation, soil, groundwater, and lakes in two representative watersheds.*

7. Aquatic Resources Susceptibility

***Objectives:* Determine susceptibility, water quality changes; predict impacts.**

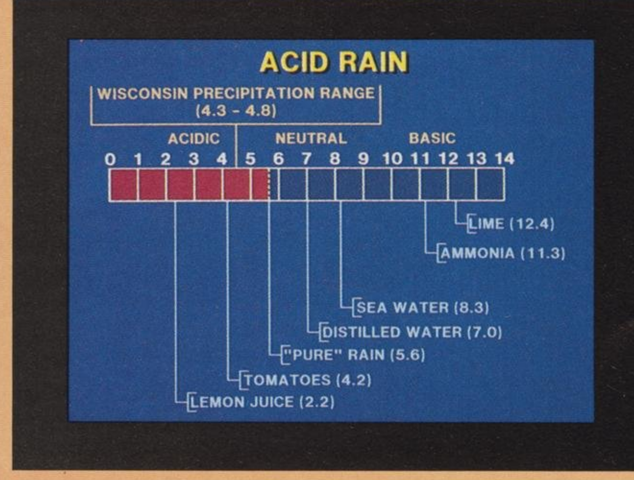
Method: *Measure water quality and biota of a large set of lakes, compare to historical data, intensively study two representative lakes.*

8. Artificial Acidification of Little Rock Lake

***Objective:* Determine the response of a warmwater community to artificial acidification.**

Method: *Separate two basins of the lake, acidify one, compare response of treated basin to control basin.*

THE ACID TEST



The studies have three broad objectives:

1. **To measure the acidity of precipitation in Wisconsin.**
2. **To determine where acid rain falling in Wisconsin comes from.**
3. **And to determine the effect of acid rain on Wisconsin's environment.**

Eight individual research projects were designed to help meet these objectives:

1. and 2.- Deposition monitoring and data base check—A network of three sites, in Douglas, Menominee and Walworth counties equipped with daily rainfall samplers measure 17 chemical parameters related to acid rain.

3. and 4.- Atmospheric trajectory and trajectory quality assurance—Computerized tracking of air parcels will help identify source regions of sulfur and nitrogen oxides that contribute to acid deposition in Wisconsin. The Trajectory Quality Assurance Project is an accuracy check.

5. Emission sources—A comprehensive source list of sulfur dioxide and nitrous oxides from Wisconsin, surrounding states and southeastern Canadian provinces. It covers entire areas including emission sources like highways and canals and specific point sources.

6. An intensive watershed study at Round and East Eight Mile lakes—Will generate a watershed data base of terrestrial, hydrological and limnological components, and predict the effects of acid loadings.

7. Aquatic resources susceptibility—Will determine susceptibility of northern Wisconsin lakes to acid deposition damage. To do this, researchers are assessing the current alkalinity of area lakes, detailing lake chemistry changes in comparison with historical data, and predicting future responses based on evaluation of these factors.

8. Artificial acidification of Little Rock Lake—A long-term study designed to document the aquatic effects of acidification on a small, soft water seepage lake. Little Rock Lake was selected because it is small (45 acres), poorly buffered and representative of an aquatic resource most sensitive to acid rain. By recording changes in the lake as acid is added, researchers hope to be able to predict the rate and effects of acidification which could occur in the future in hundreds of other soft water lakes in northern Wisconsin.

Taken together, these eight projects constitute the cooperative Wisconsin Acid Deposition Research Program. It will tell us how acid our rain is, where the acid comes from, whether it has caused damage yet and if not, when it might. Wisconsin was one of the first of only a half-dozen states to initiate acid rain studies. The US Interagency Task Force on Acid Precipitation has called the Wisconsin effort an "exemplary state program (which) reflects an integrated effort by state and private sector groups". And now, as the findings come in, they enhance Wisconsin's high national reputation for contributions to the understanding of acid rain. The main value of this cooperative effort, however, will be to provide policy-makers with a basis upon which to make rational regulatory decisions. Acid rain is an issue that must be addressed — and this is a start.

What is acid rain?

Acid precipitation — commonly called "acid rain" comes from burning fossil fuels, such as coal, gas and oil. Most fossil fuels contain sulfur compounds that react with oxygen when the fuels are burned to form sulfur dioxide. The largest sources of sulfur dioxide are power plants and other industries.

Nitrogen is a colorless, odorless gas that makes up about 80% of the air we breathe. But when fossil fuels are burned, nitrogen in the air reacts with the fuels to form nitrogen oxides. Most nitrogen oxides are produced by the combustion of fossil fuels in the engines of cars, trucks and other vehicles.

Sulfur dioxide and nitrogen oxides both are major air pollutants that can be harmful to human lungs — particularly for the very young, the elderly and for persons with respiratory diseases, such as asthma. Sulfur dioxide, by itself or in conjunction with other air pollutants, also can damage vegetation, buildings and structural materials.

But some sulfur dioxide and nitrogen oxides emitted into the air are changed chemically into acids. In this process, the sulfur dioxide and nitrogen oxide gases mix and react in the presence of sunlight with substances in the atmosphere, including oxygen, water, ozone (smog), ammonia and heavy metals, which are toxic in small amounts. Over a period of a few hours to a few days, the gases are changed through a complex chemical process, to form sulfuric and nitric acids.

These acid droplets then fall to earth with rain or with other forms of wet deposition, such as snow, hail, dew, fog or frost. This is what is generally referred to as "acid rain." However, some of the acids fall from the atmosphere as gases or particles, known as dry deposition.

No longer gaseous air pollutants, the sulfur and nitrogen in their new form as acids now display a different set of effects upon the environment. As acids, they can change the chemistry of precipitation, lakes and streams. As the chemistry of lakes and streams changes (pH declines) many species of aquatic life disappear. And, because the acid droplets can travel hundreds of miles with the wind, they can affect the environment far from their sources — even across international boundaries.

Uncontaminated rain is slightly acidic (pH 5.6). The acidity of a liquid, soil or other substance is measured on a pH scale that ranges from 0 — very acid — to 14 — very alkaline (or basic). A value of 7 is neutral. Distilled water is one of the few neutral substances. The pH scale is designed so every one-unit drop in pH represents a 10-fold increase in acidity. For example, pH 6 is 10 times more acid than pH 7; pH 5 is 100 times more acid than pH 7. Precipitation having a pH less than 5.6 — the theoretical pH of pure rainwater — may be referred to as "acid rain." Precipitation with a pH of 4.6 or less has caused damage to sensitive lakes and streams in Europe and North America.

Glossary

Acid bog lake — Normally a seepage lake in a region of non-calcareous soils which has undergone natural, successional changes over several centuries. All lakes are subject to this process, but it occurs very slowly, and normally results in a small, shallow, acidic lake (pH 4-5) having extremely low alkalinity and acid-tolerant biota (sphagnum-leather leaf-tamarack community; fish population often includes stunted panfish and small northern pike). These types of lakes are common in northern Wisconsin and existed long before the occurrence of acid rain. Because of their already low pH, acid bog lakes are extremely susceptible to further acid loading, but in these lake types it is often difficult, if not impossible, to separate acidification due to natural processes from acidification due to the more recent phenomenon of acid rain.

Acid deposition — Total process by which acids precipitate from the atmosphere onto land surface, physical objects or water.

Acid neutralizing capacity (ANC) — Amount of alkalinity — higher alkalinity means higher ANC and vise versa.

Acid loading — Quantification of acid deposition from all sources, both wet and dry.

Acid rain — Popularized phrase meaning any rain with a pH less than 5.6 (normal rain is thought to have a pH near 5.6).

Acid rain precursors — Sulfur dioxide, nitrogen oxides and other pollutants which are the initial air pollutants transformed into sulfuric and nitric acids.

Acid shock — Sudden surge of low pH water into an aquatic system. It can occur during the spring thaw when ice and snow that contain large amounts of acid deposition from the winter months melt in a short time and acid meltwater then gushes into lakes and streams. Acid shock can kill eggs, larvae and adult fish by creating a sudden pH decrease.

Alkalinity — A measurement of dissolved carbonates in water. These dissolved carbonates ($CaCO_3$ or $MgCO_3$) act to neutralize any acids that are added to aquatic systems.

Base — Any substance with a pH greater than 7 — often neutralizes acids.

Buffering capacity — Ability to neutralize acids. Water or soil with an alkalinity of 600 microequivalents per liter (ueq/l) provides a high buffering capacity; an alkalinity of 100 ueq/l provides very little buffering capacity.

Calcareous soil — Soil derived from dolomite with high concentrations of calcium ($CaCO_3$) and magnesium carbonate ($MgCO_3$) that can neutralize acids.

Carbonic acid (H_2CO_3) — A weak acid formed in normal unpolluted rainfall by the reaction of carbon dioxide (CO_2) and water (H_2O). It accounts for the slightly acidic nature of rain, which has a normal pH of about 5.6.

Dolomite — Mineral consisting of calcium magnesium carbonate ($CaCO_3$-$MgCO_3$), same as limestone, with a high capacity to neutralize acid precipitation.

Drainage lake — Lake with an inlet and outlet that usually provide a continual supply of buffering agents.

Dry deposition — Direct deposition of microscopic acid particles on land, water, plants and other surfaces.

Good Engineering Practice (GEP) stack height — Smokestacks about 2½ times taller than adjacent buildings; recommended to minimize local air pollution.

Granite — Hard igneous rock composed mainly of quartz, with low permeability to water and low chemical capacity to neutralize acid precipitation.

Granite bedrock — See Precambrian Shield.

Kilograms per hectare (kg/ha) — Metric measure of weight per unit area; one kg/ha is equal to .9 pounds per acre.

Lake liming — Treating a lake with powdered lime or limestone in an attempt to neutralize acid and raise pH.

Limestone — See dolomite.

Long-range transport — Process by which acid rain precursors are carried in air currents long distances from their sources.

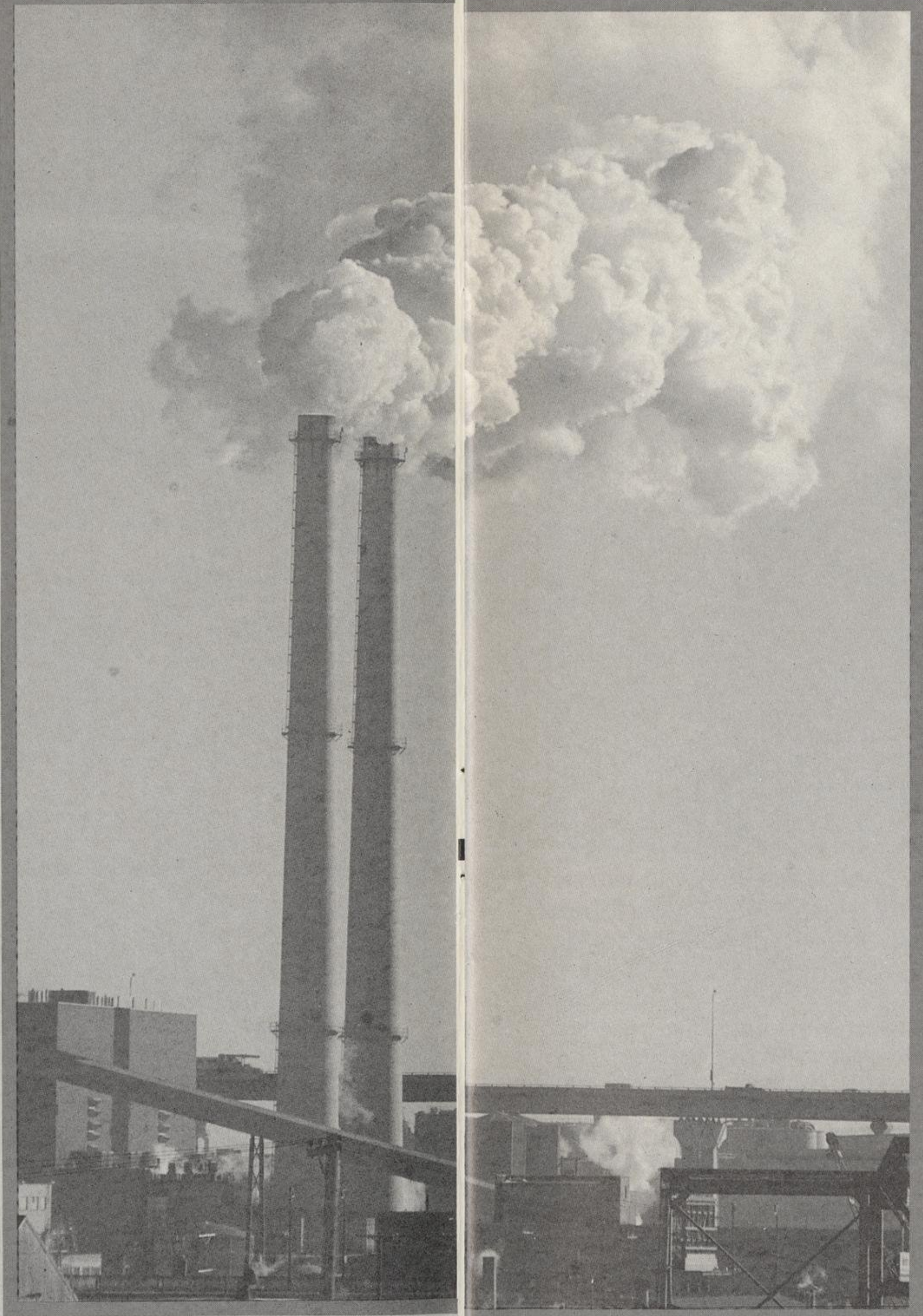
Microequivalents per liter (ueq/l) — Chemistry term to describe the amount of alkalinity in lake water. The lower the alkalinity, the more sensitive a lake is to acid rain because it can neutralize less acid.

Mobile source — Moving source of air pollution, such as an automobile.

National Atmospheric Deposition Program (NADP) — Establishes precipitation monitoring sites throughout the United States in an effort to document trends in acid deposition.

Nitric acid (HNO_3) — A strong acid that can greatly reduce the pH of rain. It results from the oxidation of nitrogen oxide pollutants in the atmosphere.

Normal rainfall — Rainfall with a pH near 5.6.



The Wisconsin Electric Power Company Valley Plant in Milwaukee. It is the seventh highest emitter of sulfur dioxide in Wisconsin and put out 40,691 tons in 1980. Photo by Dean Tvedt.

pH — Numerical scale to describe acidity and alkalinity. Values are derived from the hydrogen ion concentration of a solution. The pH scale ranges from 0 to 14 — pH 1 is very acidic (battery acid), pH 7 is neutral and pH 13 is very alkaline (lye).

Plume — Total downwind emissions cloud from a pollution source.

Parts per million (ppm) — Ratio to describe the concentration of one component in relation to another. It can be expressed as micrograms per gram (ug/g), milligrams per kilogram (mg/kg) or milligrams per liter (mg/l).

Precambrian Shield — Extensive layer of granite bedrock that lies very close to the earth's surface; sometimes exposed in much of northern Wisconsin, Minnesota and Upper Michigan. Granite bedrock is igneous rock with low permeability to water and low chemical capacity to neutralize acids. Lakes located on the Precambrian Shield are softwater lakes with relatively low pH and alkalinity. They are, therefore, very sensitive to further acid loading.

Precipitation event — A single precipitation occurrence. Several individual precipitation events may contribute to the total precipitation occurring in a week.

Residence time — Period of time an air pollutant remains suspended in the atmosphere before settling to the ground. Long residence times favor more acid formation from sulfur dioxide and nitrogen oxide.

Sandstone — Sedimentary rock composed mainly of quartz and silica, with low capacity to neutralize acid precipitation.

Scrubber — Device that uses lime or limestone slurry to remove sulfur dioxide from flue gas before emissions leave the smokestack.

Seepage lake — Lake with no inlet or outlet. It depends on surface runoff, precipitation and/or groundwater for recharge.

Stationary source — Fixed or "point" source of air pollutants, such as a coal-burning power plant.

Susceptibility — Vulnerability or sensitivity of a lake or stream to acid deposition. Many lakes in northern Wisconsin have high susceptibility to acidification because of several factors, such as low alkalinity and/or poorly buffered watersheds. Lakes with alkalinities of 200 ueq/l or less are considered sensitive to acid rain.

Sulfate (SO_4) — Intermediate form of sulfur that develops as sulfur dioxide (SO_2) and chemically converts to sulfuric acid (H_2SO_4).

Sulfate loading rate — Measure of sulfate ions deposited per unit area per year that scientists use to estimate the annual dose of acid an area receives. It is expressed in kilograms per hectare per year (kg/ha/yr) or pounds per acre per year (lbs /A/yr). A sulfate loading rate of more than 20 kg/ha/yr (17.6 lbs /A /yr) is known to damage sensitive lakes and streams.

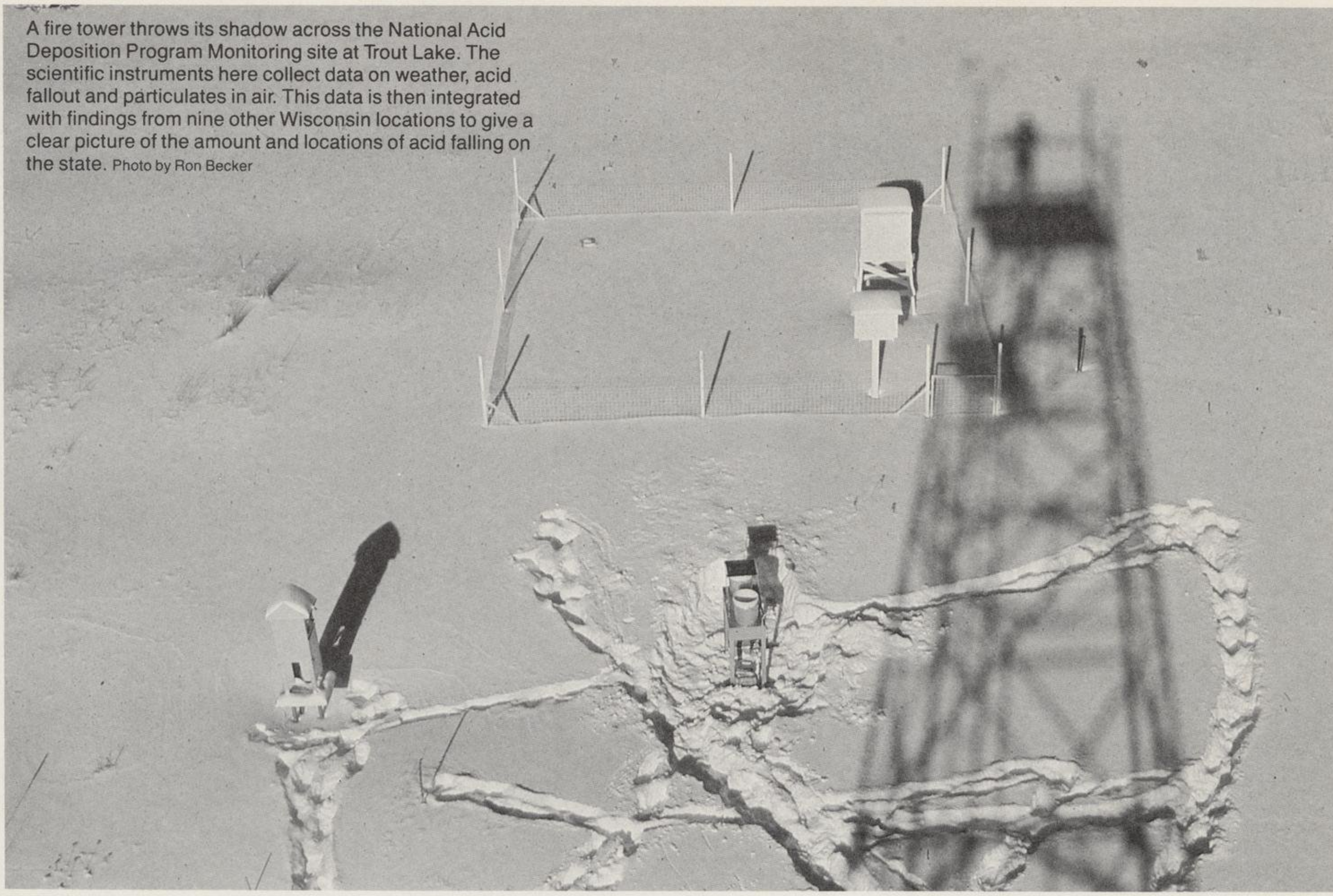
Sulfuric acid (H_2SO_4) — A strong acid that can greatly reduce the pH of rain. It results from the oxidation of sulfur dioxide (SO_2) pollutants in the atmosphere.

Tall stacks — Arbitrarily defined as smokestacks over 180 meters tall. Many stacks over 300 meters tall were recently built to reduce sulfur and nitrogen oxides at ground level near their emission sources. When oxides are injected higher into the atmosphere, air currents carry them further away.

Wet deposition — Precipitate deposition of dissolved acid particles in rain, snow, mist, dew or fog.

Wet/dry sampler — Device to measure the total amount of acid deposition — both liquid and particulate.

The DNR acid rain research team at Rhinelander Left to right, Ron Becker, Katherine Webster, Joe Eilers, Bob Martini, John Sullivan.



A fire tower throws its shadow across the National Acid Deposition Program Monitoring site at Trout Lake. The scientific instruments here collect data on weather, acid fallout and particulates in air. This data is then integrated with findings from nine other Wisconsin locations to give a clear picture of the amount and locations of acid falling on the state. Photo by Ron Becker

Precipitation monitoring

How acid is the rain?

ANDY MORTON & JULIAN CHAZIN, DNR Bureau of Air Management

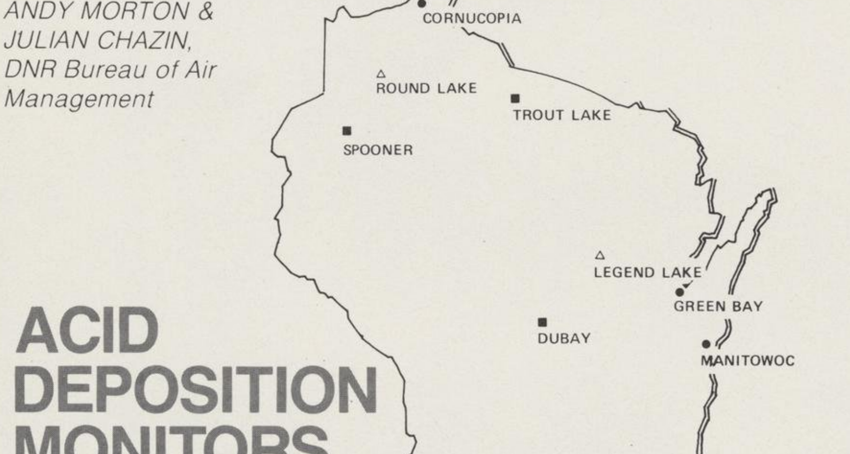


Illustration by Artist Eric Weaver

It's all acid, but the southeast is worse than the north — and that's better than the other way around considering where most of our lakes are.

You're ready to munch on a Sheboygan brat just cooked over your grill on a fine summer day, but the sky darkens, lightning flashes and your picnic is threatened with summer rain. No need to be too concerned, just run for cover — rain is a natural, everyday part of life. But don't count on it! This rain is different! Although it may not look or feel or even taste different from the rain that has been falling to earth since creation — it is. This rain is acid!

You might think acid rain just started to fall in the past few years. But Europe first noticed it in Norway around 1920. In North America the signs were discovered in the 1970s in Southern Ontario and in the Adirondacks when lakes were found to be dying there.

When acid rain was detected near Rhinelander in 1979 the state geared up to find out what was happening and why. DNR joined the National Atmospheric Deposition Program (NADP) in 1980 and became part of a nationwide monitoring network with stations at Spooner and Trout Lake. Four more stations were started in 1981 when EPA set up a system to monitor atmospheric inputs to the Great Lakes. In 1982 Wisconsin's Cooperative DNR-PSC-Utility research program put in three more sites and NADP installed an additional one operated by Consolidated Papers, Inc. All in all there are 10 monitoring sites in Wisconsin at Trout Lake, Spooner, Lake Geneva, Round Lake, Legend Lake, Lake Dubay, Green Bay, Cornucopia, Manitowoc and Milwaukee.

An important part of the DNR-PSC-Utility study brings together data collected by all these different monitoring networks and assesses their compatibility. Called the Data Integration and Quality Assurance Project, it also assesses the accuracy and precision of network data. An expert chemist has checked sites, equipment and operators, and artificial rainfall samples of known chemical composition were processed through all the networks to find out whether all the analysis results agreed with each other.

To determine rain's acidity and obtain reliable data is a little more complicated than just holding a piece of litmus paper out in a storm. Acidity in rain is sometimes so dilute that very sensitive equipment must be used to measure it accurately and precisely. The equipment must be reliable and checked often to make sure its measurements are consistent. Techniques used to analyze precipitation must also be of good quality and measurements between sites must be comparable with one another.

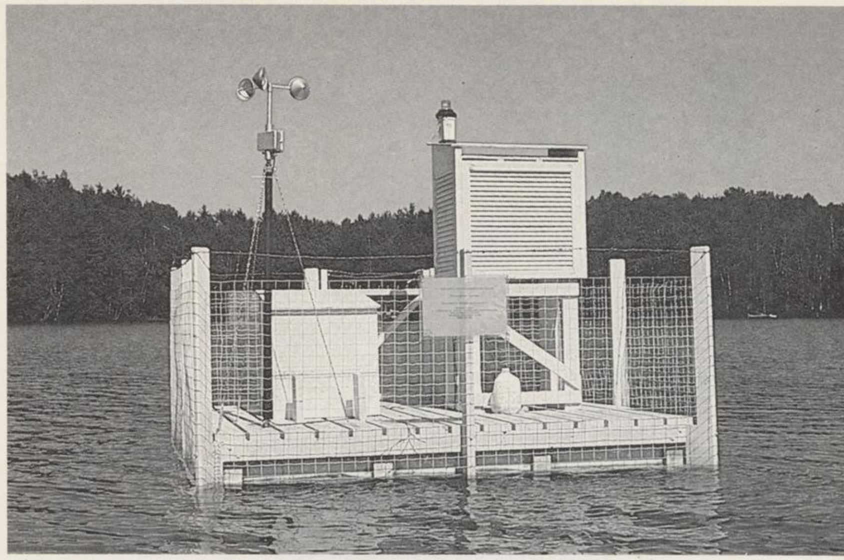
Acid rain monitoring sites need special wet/dry rain collectors, a rain gauge and very dedicated site operators. The wet/dry collector has a special lid which covers the rain collection bucket when it's not raining. When it rains a special sensor opens the wet collection bucket lid and covers the dry collection bucket. The rain gauge makes sure that the amount of rain sampled correlates with the amount that actually fell into the bucket. Most important of all, of course, are the site operators who collect samples, perform field measurements and rush samples to a large central laboratory for complete chemical analysis.

The concentration of acidity in rain water is measured by an electrical pH meter. Special handling techniques assure that the water is not contaminated. Readings are taken first in the field and then in the laboratory to be certain no changes have occurred during shipment and handling.

All the major components of rainfall in addition to acidity are measured: sulfate, nitrate, ammonium, calcium, magnesium, potassium, sodium, chloride and phosphate. In addition, some minor components are also measured and other tests performed which may help determine sources of acidity.

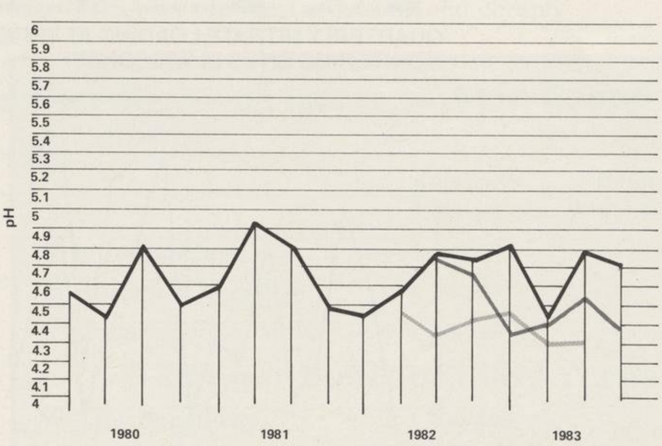
The acidity of rain can vary greatly from storm to storm and even within a storm. The most acid pH recorded in Wisconsin was 3.35 at Lake Geneva on August 8, 1982. The least was 7.16 at Spooner on October 7, 1980.

To reliably determine average acidity of rain for a given region, data on many rainfall events is needed. This can also help reveal trends. Researchers have found that acidity is greatest when the rain first starts and that light rain of short duration has higher acidity than long,

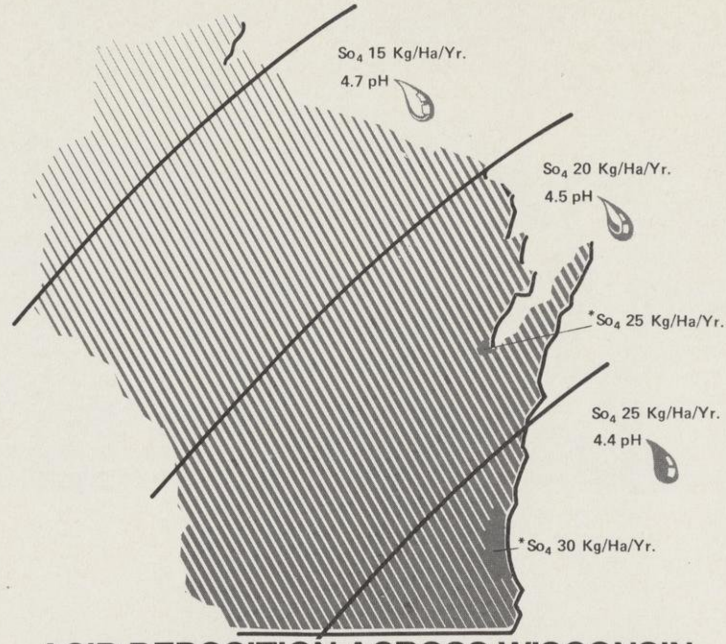


This floating weather station on Lake Clara measures evaporation rates as part of a water budget survey to find out where a lake's water comes from and where it goes.
Photo by Katherine Webster

Bags that contain deposition at Trout Lake are changed every 30 days and sent for analysis. Here Lisa Huberty and Nan Eckert of DNR's acid rain research team make the switch. Photo by Katherine Webster



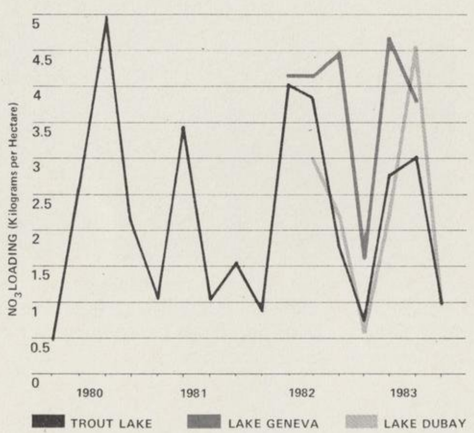
Precipitation is most acidic at the Lake Geneva monitor and least acidic at the Trout Lake monitor. Illustration by Artist Eric Weaver



ACID DEPOSITION ACROSS WISCONSIN

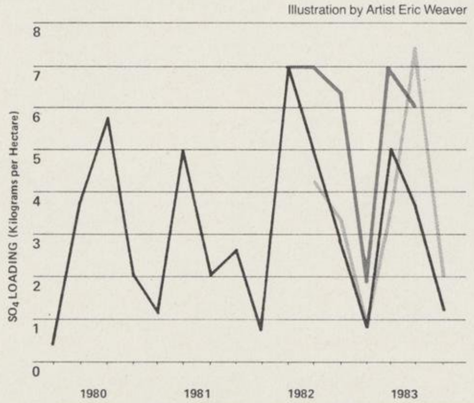
*Estimated values based on preliminary data.

Southeastern Wisconsin gets the most acidic deposition (dark portion of map –pH 4.4). The least is in northwestern Wisconsin (light portion of map –pH 4.7). Annual sulfate (SO_4)deposition is shown in kilograms per hectare per year (kg/ha/yr). Sensitive resources are considered at risk when the annual sulfate dose approaches 20 kg/ha/yr. Illustration by Artist Eric Weaver



QUARTERLY NITRATE LOADING AT THREE MONITORING SITES IN WISCONSIN

Illustration by Artist Eric Weaver



QUARTERLY SULFATE LOADING AT THREE MONITORING SITES IN WISCONSIN.

drawn out periods of rain. Because data has been collected only since 1980, there's no reliable fix on upward or downward trends. However, we do know how the acidity of rain varies spatially across Wisconsin. It is most acid in the southeast and least acid in the northwest with various gradations in between.

The pH at Lake Geneva where acidity is highest averages 4.4. Sulfate loadings there average 24.67 kilograms per hectare per year (kg/ha/yr). Loadings of over 20 kg/ha/yr have been known to damage aquatic ecosystems. The nitrate loading is 16.04 kg/ha/yr. The Milwaukee metropolitan area receives rain with a similar pH and slightly higher annual loadings.

A little further north, at the Lake Dubay monitor operated by Consolidated Papers, Inc., the pH averages 4.6, the sulfate loading is 17 kg/ha/yr and nitrate loading 10.05 kg/ha/yr. Relatively close by is Legend Lake (near Shawano) where pH is more acidic. There it averages 4.4, with a sulfate deposition of 21.3 kg/ha/yr and nitrate of 14.02 kg/ha/yr. In Green Bay the rainfall acidity and sulfate loadings are higher than at Legend Lake.

Rain at the cooperative project's three monitors up north is just about equal in acidity. Trout Lake, Spooner and Round Lake show an average pH of 4.6 to 4.8 while sulfate deposition ranges from 14.59 to 15.89 kg/ha/yr. Nitrates run from 9.72 to 12.07 kg/ha/yr.

The acid rain measurements for Wisconsin are similar to those found in the southeastern and extreme northeastern US and in the Maritime Provinces of Canada. Our rain is not quite as acidic as the rain in Scandinavia, northern Europe, the Adirondacks or southeastern Ontario where the average pH is below 4.4. However, sulfate loading here is comparable to other areas of the world being hard hit by acid deposition.

As mentioned earlier, where sulfate deposition is above 20 kg/ha/yr, sensitive lakes and streams have been acidified. While southeast Wisconsin is receiving greater than this amount, luckily the most sensitive aquatic resources aren't found there. Lakes and streams in the southeast have sufficient soil and water buffering capacity because of limestone to neutralize the acid rain. While the rest of the state gets slightly less than the critical 20 kg/ha/yr, one can't conclude that they're home free. At many Wisconsin monitoring stations measurements today are higher than 15 kg/ha/yr. We don't know what effect this dose has in Wisconsin, but in Scandinavia and Canada, researchers have found that sensitive lakes (those with zero alkalinity) have been damaged with deposition loadings of that amount. The exact effects of high loadings on human health, vegetation and building materials are being studied by the federal government and results are expected soon.

DNR will continue to monitor Wisconsin's precipitation to determine whether acidity is increasing or decreasing. In the future we look forward to enjoying that Sheboygan brat in fair or rainy weather without concern for whether or not the rain is acid.

DNR's first acid rain monitor was installed at Rhinelander in 1979 with borrowed equipment. Photo by Ron Becker

Experimental acidification of Little Rock Lake

Photo by Dennis Yockers

THOMAS SHEFFY and PAUL GARRISON, Wisconsin Department of Natural Resources

What will happen if Wisconsin lakes continue to be dosed with acid rain? Investigators will find out by adding acid to a representative lake and studying the response.

Gazing out from shore onto the 45 acres of Little Rock Lake, one can't help but marvel at the raw and simple beauty of this sparking jewel. Its gin-clear water reveals the bottom, often to depths of 10 feet or more. Here and there near shore a huge granite boulder protrudes from the surface. The only development is a beaver lodge on the northwest shore, the only summer guests a pair of loons. On sunny days, minnows flit about in the warm shallows. Come evening, largemouth bass break the surface, gathering the day's groceries. This peaceful setting is typical of several thousand small, soft water lakes in northern Wisconsin, Michigan and Minnesota. Abruptly this summer, the tranquillity at Little Rock Lake ended — so that the tranquillity of thousands of other lakes might be preserved.

The State of Wisconsin has begun a long-term cooperative study designed to document the aquatic effects of artificial acidification on a small, soft water seepage lake. Participants include the US Environmental Protection Agency (EPA), DNR, UW-Madison, UW-Superior, the University of Minnesota, the University of Minnesota-Duluth and the US Geological Survey. Special legislation was recently enacted to authorize the project.

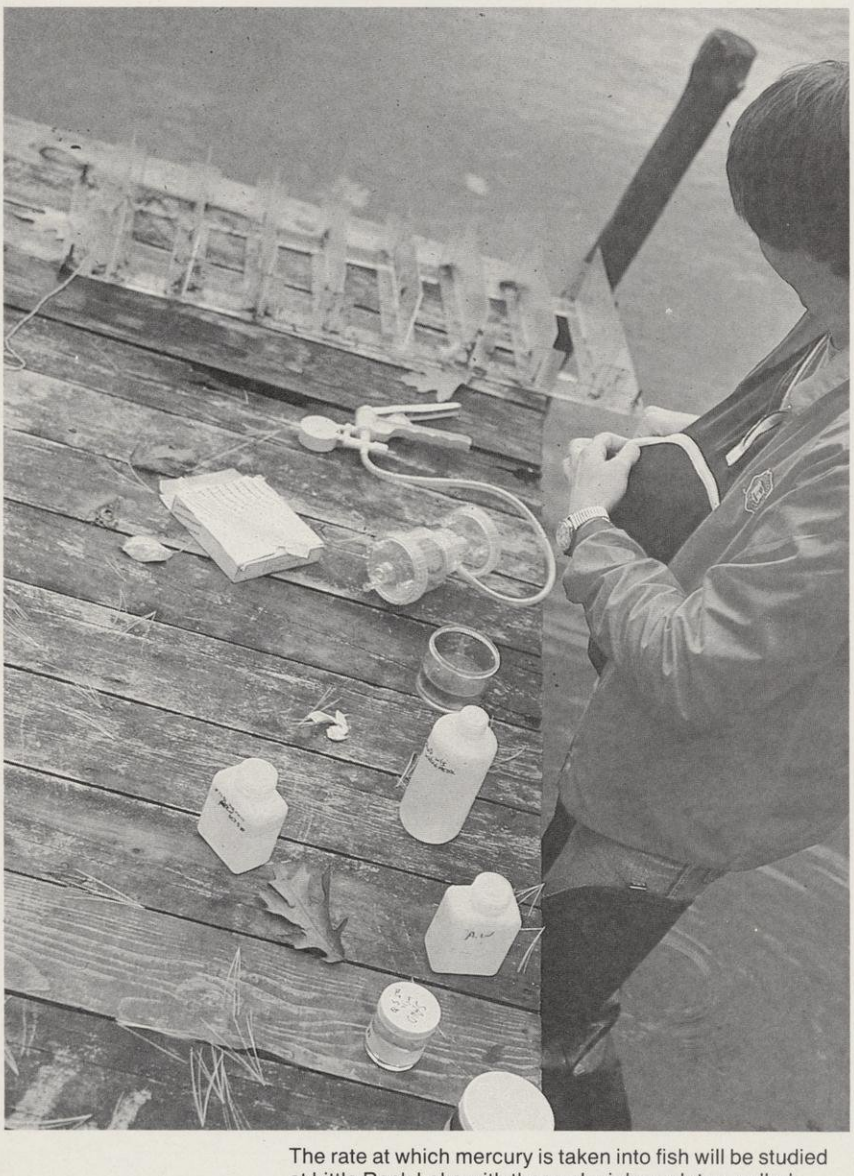
Little Rock, located seven miles north of Woodruff in Vilas County has been selected for study because it is small (45 acres), poorly buffered (only one milligram per liter of alkalinity), and representative of the state's aquatic resources considered most sensitive to acid rain. The lake's two basins are approximately equal in size and connected by a narrows. The surrounding watershed is entirely state-owned with no development and little public use.

The experiment will proceed in four phases. During Phase One which is already complete, extensive background information on the lake's current condition has been gathered. Researchers conducted detailed inventories of forest vegetation, lake water chemistry, lake biota and groundwater characteristics. This baseline data will be used for future comparisons.

During Phase Two, from the summer of 1984 until the spring of 1985, a dacron-fiber reinforced plastic barrier, sometimes called a "sea curtain," will be in place at the narrows between the two lobes of the lake, dividing it into two separate basins. Further background sampling will characterize any differences between the two basins caused by the barrier. A scenario of responses to be expected during the next phase will be formulated to test researchers' ability to predict acidification effects.

During Phase Three (July 1985) of the project, acid treatment will begin. One half of the lake will be gradually acidified with an artificial mixture of acids that would be similar to, but stronger, than those which currently are found in Wisconsin's precipitation. The other half of the lake will be left undisturbed to serve as a "control or reference" for drawing comparisons between the acidified basin and the untreated one.

Researchers will closely observe changes in the treated basin's aquatic life as the pH is gradually lowered from the current level of 6.0 to about 4.5 over a period of three to four years (1985-88). Specifically, changes in species diversity and abundance will be recorded for phytoplankton, zooplankton, benthic invertebrates, macrophytes and fish. The Little Rock Lake project will focus on understanding the changes in lake biota caused by acidification and will also compress the long-term process of manmade acidification into a period of about four years. Project investigators believe we cannot wait for several decades to test lakes in the Midwest to see how they will respond to acid rain. If we found that the lakes turned acid at the end of 10 to 50 years, it would be too late to do anything. We must determine, before it happens, how our lakes are likely to respond.



The rate at which mercury is taken into fish will be studied at Little Rock Lake with these plexiglass plates, called Stokes Samplers. Algae which colonize the plates are analyzed for mercury which correlates with amounts in certain species of fish. Photo by Joe Eilers

Restoration will take place in Phase Four after the acidification stage is complete. The lake will be monitored to see whether pH is naturally restored or whether artificial neutralization (liming) is required. This portion of the project has important management implications. Once the pH of the basin is returned to pretreatment condition, the barrier will be removed. Aquatic life from the untreated, control basin will be allowed to repopulate the other half of the lake, which will restore the entire lake to its original condition.

Scientists working on the acidification project will be able to document the effects of adding a known amount of acid to a lake which is representative of our most sensitive resources. This will clearly establish a link between cause and effect, something that has been difficult to accomplish in past surveys of lakes exhibiting a pH gradient.

The project will provide information previously unavailable about acid rain's effects on lakes with groundwater inflow. Canadian studies have addressed only bedrock basin lakes with different pH buffering capacities. Thus, comparisons to Wisconsin glacial-till conditions are not possible.

The total amount of acid required to produce "acidification" in Little Rock Lake can be used to estimate the time frame in which our lakes are likely to be affected. This can be done by dividing the total dose experimentally added, by the current annual dose now being received by Wisconsin lakes.

For the first time, scientists will be able to determine the response of a non-trout, warm water fish community to acidification.

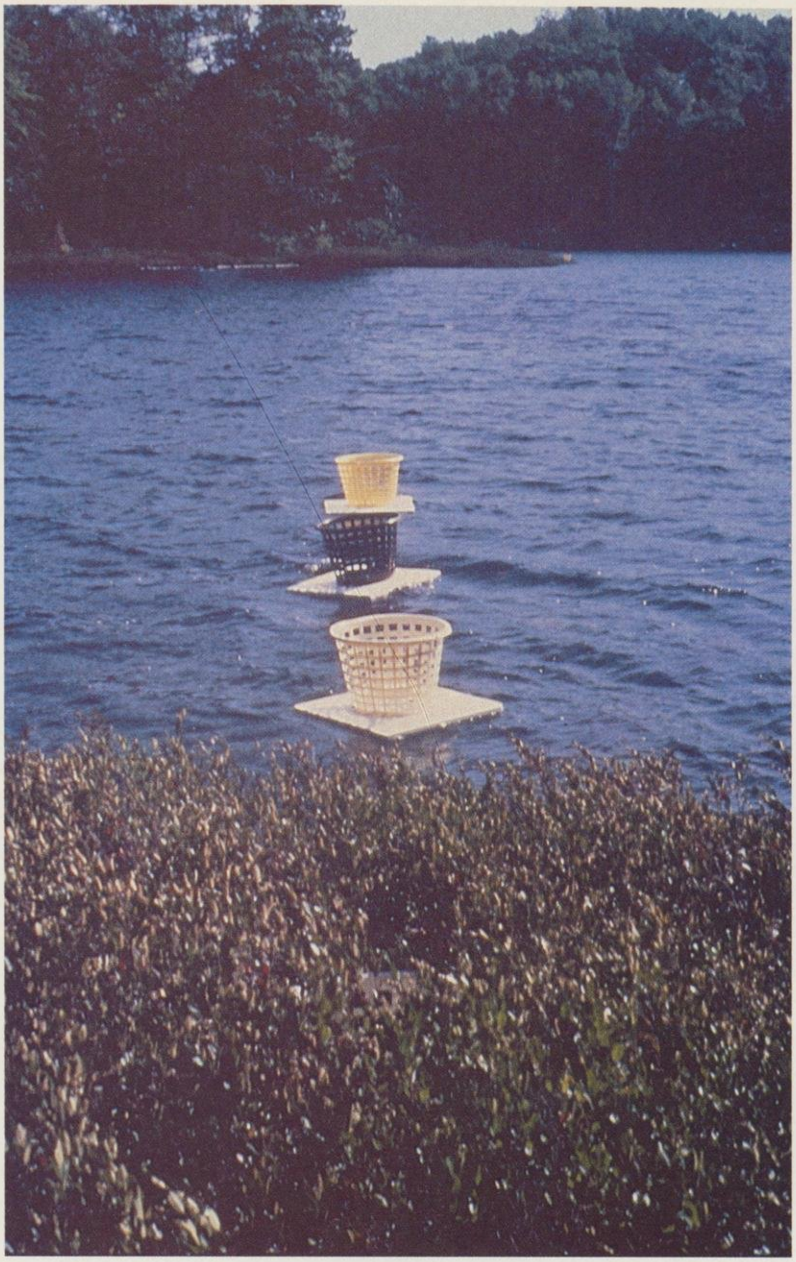
The observed effects on Little Rock Lake will be used as early warning signs and related to potential acid precipitation impacts on hundreds of other acid-sensitive lakes in the Upper Midwest. The research project will give Wisconsin a unique opportunity to make a major contribution to science and society. The project will bring to Wisconsin about $1.2-million in federal funds from the National Acid Precipitation Assessment Program over the next five years.

A similar project is underway in western Ontario, but in a very different geological and biological setting. The lake being acidified in Canada is not bi-lobed and no barrier is being used, so there is no "control" basin. The whole lake is being acidified. Furthermore, the lake has a granite

Installing the barrier at Little Rock Lake. One side will be gradually acidified and the other left intact as a control. Watching the effects on aquatic life will reveal the early warning signs of acidification. Photo by Dave Kunelius

An infra-red photo of the double-lobed lake helps identify vegetation on shore. Photo by Joe Eilers

Acid will be added to each compartment of these "limno-corrals" to determine how different amounts affect the biota. Photo by Dave Kunelius.



About 40 laundry baskets were floated on the lake to collect leaves and other material that falls into the water for analysis. Photo by Katherine Webster

basin and a cold water fish population, primarily a lake trout-dace minnow community. Wisconsin lakes are much different in hydrology and are warm water and cool water fish communities composed primarily of walleye, bass, northern pike, musky, yellow perch and other panfish. Information is needed on how Wisconsin fish populations respond to acidification.

Canadian scientists have been very supportive of our study and have worked closely with us in its design. The Canadians are especially interested in comparing their observations in a granite bedrock cold water lake to Wisconsin's warm water, glacial-till lake.

A few landowners in the vicinity have voiced concern about acids getting into the groundwater and then moving into other lakes and wells. If acid were to start moving out of Little Rock Lake and into the groundwater, the acid would be neutralized quickly as it moves through the soil. Pretreatment hydrology experiments show that groundwater movement away from Little Rock Lake is relatively slow, only a few feet per day, so there is ample time for neutralization of acid as the groundwater moves through the soil, and virtually no way the groundwater or other lakes in the area could be affected. Additionally, the 35 groundwater monitoring wells installed around Little Rock Lake will allow regular monitoring of the groundwater seeping from the lake.

It is natural that a plan to add acid to a pristine northern Wisconsin lake would cause a negative reaction when one first hears about the idea. But upon further and careful evaluation, most people agree that the scientific and social benefits greatly outweigh any drawbacks.

So, with a deep sense of responsibility, a reverence for our precious natural resources and a firm commitment to protect these resources for future generations, we are proceeding with the research. And hopefully our findings will insure that our children and grandchildren will also be able to gaze out from shore onto a small, crystal-clear lake in northern Wisconsin and marvel at its raw and simple beauty.

THE ACID TEST

"Everyone knows acid rain can kill lakes," said Representative Jim Holperin (D-Eagle River), "but we have very few hard facts about how long it takes, which organisms are affected first, and whether our lakes could ever fully recover from acid damage. The proposed study will help tell us all of these things. The public will be kept well informed of study findings, and public tours of the study site can be arranged by calling DNR."

SOX and NOX in Wisconsin

Natural or manmade?

What are the sources of sulfur dioxide and nitrogen oxides in the air over Wisconsin? Are they natural or manmade? Where are they located and how much sulfur dioxide and nitrogen oxides are emitted from them? The acid deposition emission source inventory is designed to answer these questions.

ERIC MOSHER,
DNR Air Quality Planner

The purpose of the project described here is to identify and characterize sulfur dioxide (SOX) and nitrogen oxide (NOX) emission sources which may contribute to acid deposition in Wisconsin and to quantify their emissions. Sulfur dioxide and nitrogen oxides were chosen because these chemicals react in the atmosphere to form sulfuric and nitric acids. The project took a comprehensive look at 1980 emissions in Wisconsin from all types of manmade and natural sources. In addition, manmade emissions were estimated for a large area surrounding Wisconsin. The project was conducted by DNR's Bureau of Air Management.

Are Wisconsin emissions of SOX and NOX natural or manmade? Precise data on natural sources are not available due to a lack of scientific research. However, best current estimates indicate natural sources give off relatively small amounts.

Natural sulfur compounds come from volcanic activity and related geothermal phenomena, sea spray and bacteria in soils. Soil bacteria, Wisconsin's only natural producers do not give off sulfur dioxide, but do emit organic sulfur compounds like hydrogen sulfide and carbon disulfide. Some of these are oxidized in the atmosphere to form sulfur dioxide and sulfates. Estimates are that anywhere from 5,000 to 25,000 tons of natural sulfur are emitted each year in Wisconsin. If all of it became sulfur dioxide, the amount from natural sources might be anywhere from 10,000 to 50,000 tons of SOX each year. The 50,000 tons would be only about 7% of the approximately 706,000 tons emitted by manmade sources in Wisconsin in 1980.

Lightning and soil bacteria are the only two natural sources of nitrogen oxides in the state.

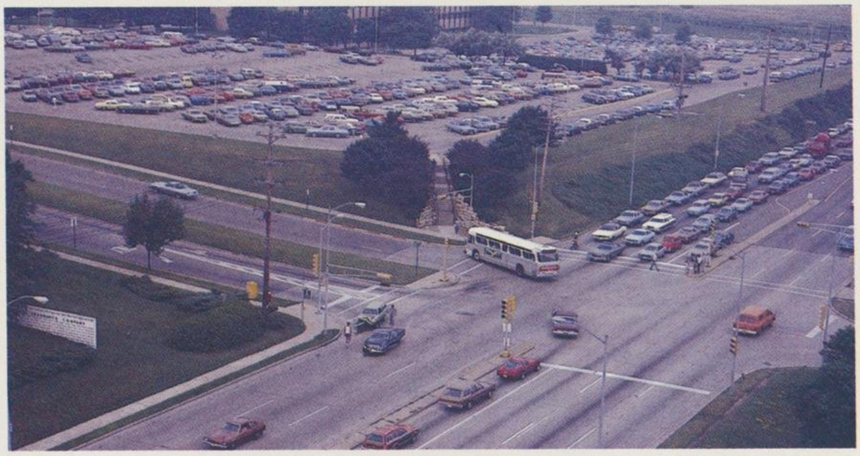
Electric utilities accounted for 70% (518,000 tons) of Wisconsin's sulfur dioxide emissions in 1980. They also release large quantities of nitrogen oxides. This is the biggest emitter in the state — the Wisconsin Electric Power Company's Oak Creek plant which sent 119,340 tons of sulfur dioxide and 23,028 tons of nitrogen oxides into the air.

Estimates are that soil bacteria may emit as much as 30,000 tons, and lightning another 5,000. These are rough estimates. The 35,000 tons would be about 8% of Wisconsin's total 1980 manmade NOX emissions of 447,000 tons.

Air quality investigators classify manmade pollutant sources into three broad categories: point sources, line sources and area sources. Point sources are smokestacks or other individual vents at industrial facilities. Line sources are motor vehicles operating on roadways. Area sources are small ones that are too difficult to be surveyed individually. Emissions from area sources are reported collectively for geographic areas such as cities, counties or states and include such things as residential heating, lawn mowing and snowmobiles.

Manmade SOX and NOX are produced primarily by fuel burning. Sulfur dioxide is also produced as a byproduct of certain industrial processes. In Wisconsin, process SO_2 emissions are primarily from pulp and paper mills.

SOX is produced when fuel containing sulfur is burned, thus causing the sulfur in the fuel to combine with atmospheric oxygen to form SO_2. Since sulfur is removed during the refining process, it is found in relatively unrefined fuels. Coal and residual oils contain quite large amounts (.5 to 5% by weight), distillate oils contain less (.3 to .5%), while gasoline and natural gas contain practically no sulfur. SOX is produced only when fuel containing sulfur is burned.



Motor vehicles are a major source of nitrogen oxide emissions.

Paper mills produced 10% (80,000 tons) of Wisconsin's sulfur dioxide emissions in 1980. The Proctor and Gamble mill at Green Bay put out the most — 24,032 tons. This is the mill at Mosinee where the study found 2,644 tons of sulfur dioxide released in 1980.

Nitrogen oxides, on the other hand, are produced when atmospheric nitrogen (and some fuel nitrogen) combines with atmospheric oxygen to form NOX. Thus, nitrogen oxides are produced when any fuel is burned, whether refined or unrefined.

The major SOX source in Wisconsin is coal burning in large electric utility and industrial boilers. This source alone accounted for some 80% (607,000 tons) of the approximately 756,000 tons of sulfur dioxide emitted in Wisconsin in 1980. All other sources are minor contributors.

Most of the sulfur dioxide from coal burning is produced by electric utility generating stations. These power plants emitted 70% (518,000 tons) of all 1980 sulfur dioxide in Wisconsin. Paper mill boilers produced an additional 10% (80,000 tons) and other industrial facilities contributed another 2 to 3%. Pulping and related processes at paper mills were responsible for only about 3% (22,000 tons) in 1980.

Motor vehicles put out very small amounts of sulfur dioxide --- only 1% (8,000 tons) of total 1980 emissions. Area sources accounted for 3% (22,000 tons).

Most SOX emissions in Wisconsin come from a small number of electric utility and industrial facilities. In 1980, 43 of them emitted 87% (656,000 tons) of all sulfur dioxide produced in Wisconsin. The 43 include 18 electric utility generating stations, 20 paper mills and five miscellaneous plants. These are the only Wisconsin facilities which emitted more than 1,000 tons each in 1980. Although responsible for most emissions, they represent only 8% of the 530 facilities which put out sulfur dioxide in Wisconsin.

Most SOX in Wisconsin comes from a few facilities concentrated in relatively small areas. Paper mills are clustered along the upper Wisconsin River and the lower Fox River. Many electric generating stations are located along Lake Michigan and the Mississippi River.

The picture is quite different for manmade nitrogen oxides. In this case there are two major sources, not one — coal burning by electric utilities and paper mills and gasoline and diesel fuel in motor vehicles: In 1980 these two accounted for about 173,000 tons of NOX each, or combined, about 72% of the total of 484,000 tons. Area sources contributed another 74,000 tons (15%). Other sources were minor contributors.

As with SOX, most NOX produced by coal burning in Wisconsin is emitted by a small number of industrial facilities. In 1980 only 24 plants emitted more than 1,000 tons each of nitrogen oxides. These 24 produced nearly 90% of the nitrogen oxides emitted from the 820 industrial and commercial sources in Wisconsin. The 24 include 15 electric generating stations and nine paper mills. These same sources also emitted most of Wisconsin's SOX in 1980.

The geographic distribution of SOX and NOX emissions in Wisconsin are similar. They tend to be concentrated in urban areas (motor vehicle traffic) and in areas where electric generating stations or paper mills are located.

To summarize, the majority of sulfur dioxide and nitrogen oxide emissions in Wisconsin are produced by fuel burning. SOX emissions come primarily from coal burning in electric utility and industrial boilers. NOX is produced primarily by use of gasoline and diesel fuel in motor vehicles and coal in electric utility and industrial boilers. All other sources, including natural ones produce only minor amounts of SOX and NOX in Wisconsin.

Sources outside Wisconsin

Since acid rain falls on Wisconsin from sources outside as well as inside Wisconsin, the study also took a look at other states. Emissions from a large area including the eastern two-thirds of the continental US and a large portion of Canada were inventoried. A grid system consisting of 80 by 80 kilometer squares was constructed to cover the area. The SOX and NOX emissions were determined for each grid square. Data were obtained from the US Environmental Protection Agency, the Canadian federal government, the Electric Power Research Institute and from various states. Only manmade sources were included.

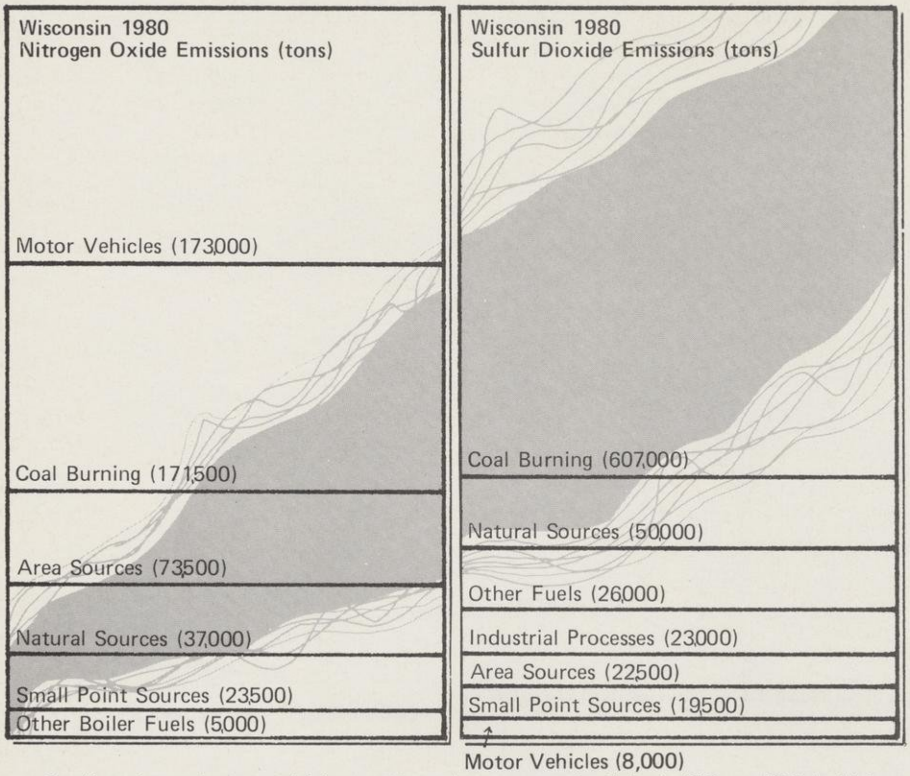
Top 20 Sulfur Dioxide Emitting States

Rank	State	1980 Sulfur Dioxide Emissions (1000's of tons)
1	Ohio	2,641
2	Pennsylvania	2,018
3	Indiana	2,004
4	Illinois	1,468
5	Missouri	1,298
6	Texas	1,274
7	Kentucky	1,118
8	Florida	1,093
9	West Virginia	1,086
10	Tennessee	1,074
11	New York	942
12	Michigan	905
13	Arizona	898
14	Georgia	838
15	Alabama	757
16	Wisconsin	636
17	North Carolina	601
18	California	446
19	Virginia	360
20	Massachusetts	344
	Total	21,801
	U.S. Total	26,501

Source: U.S./Canada Transboundary Air Pollution Study, Work Group 3B.

Fuel burning for heat in homes and businesses releases nitrogen oxides.

WISCONSIN SOURCES OF NITROGEN OXIDES AND SULFUR DIOXIDE



Coal burning and motor vehicles are the major sources of pollutants (NO_x and SO_2) which cause acid rain. Illustration by Artist Eric Weaver

How do Wisconsin's sulfur dioxide emissions compare with emissions from other states? According to data compiled for 1980 as part of the cooperative acid rain study between the US and Canada, Wisconsin ranked 16th in the US in total manmade sulfur dioxide emissions. According to that data, 636,000 tons* of sulfur dioxide were emitted by Wisconsin from manmade sources in 1980. That compares with 2,640,000 tons emitted in Ohio (ranked #1) and 6,800 tons emitted in Vermont (#50). Minnesota's sulfur dioxide emissions (260,000 tons) were less than half of Wisconsin's, while emissions in Illinois (1,467,500 tons) were more than twice the emissions in Wisconsin. About 905,000 tons came from Michigan.

The gridded emission inventories developed as part of the project will be used in conjunction with the meteorological trajectory study in an effort to determine potential source regions of acid deposition in Wisconsin. The trajectory study is discussed in another article. Together, these two studies should give a better idea of the sources of the acid falling on Wisconsin.

**The number of tons reported by the US/Canada cooperative study differs from the number reported by the Wisconsin study because the two used different data and methods to estimate emissions.*

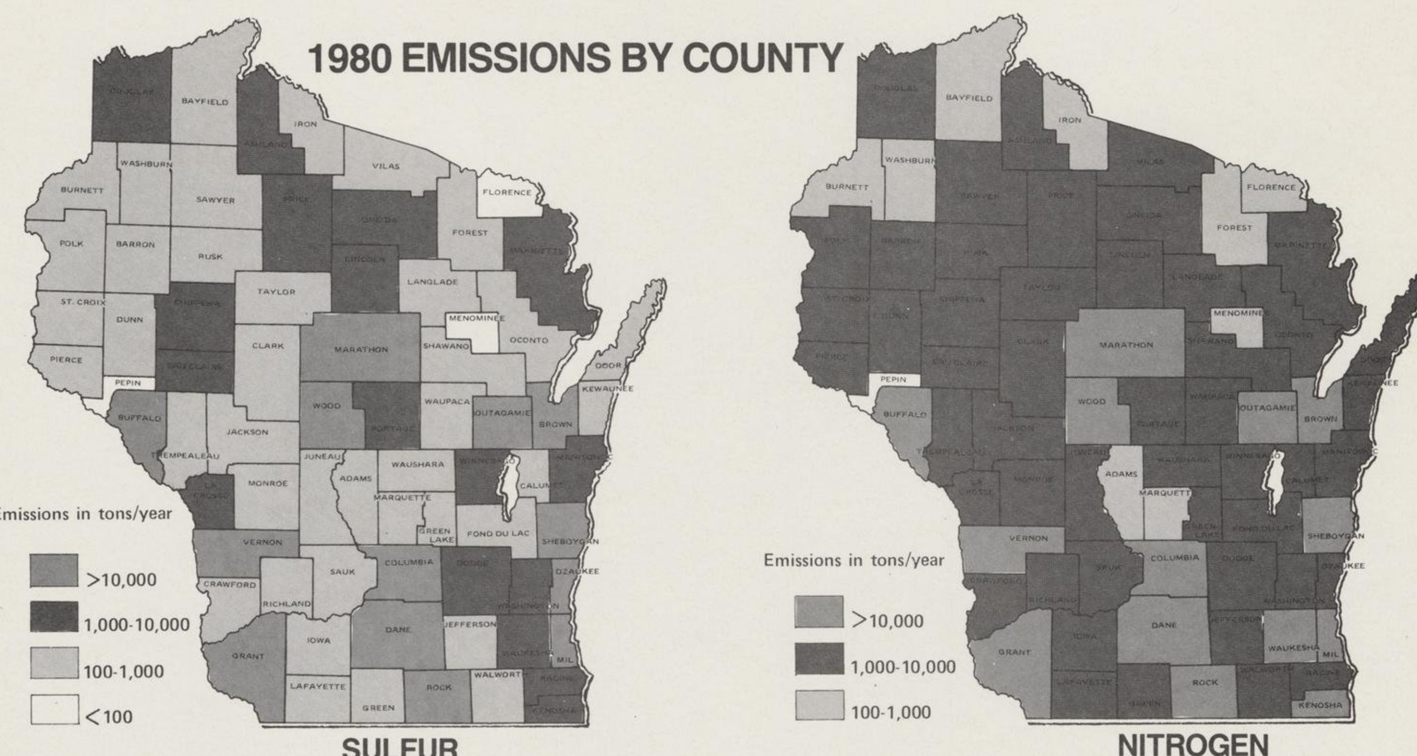
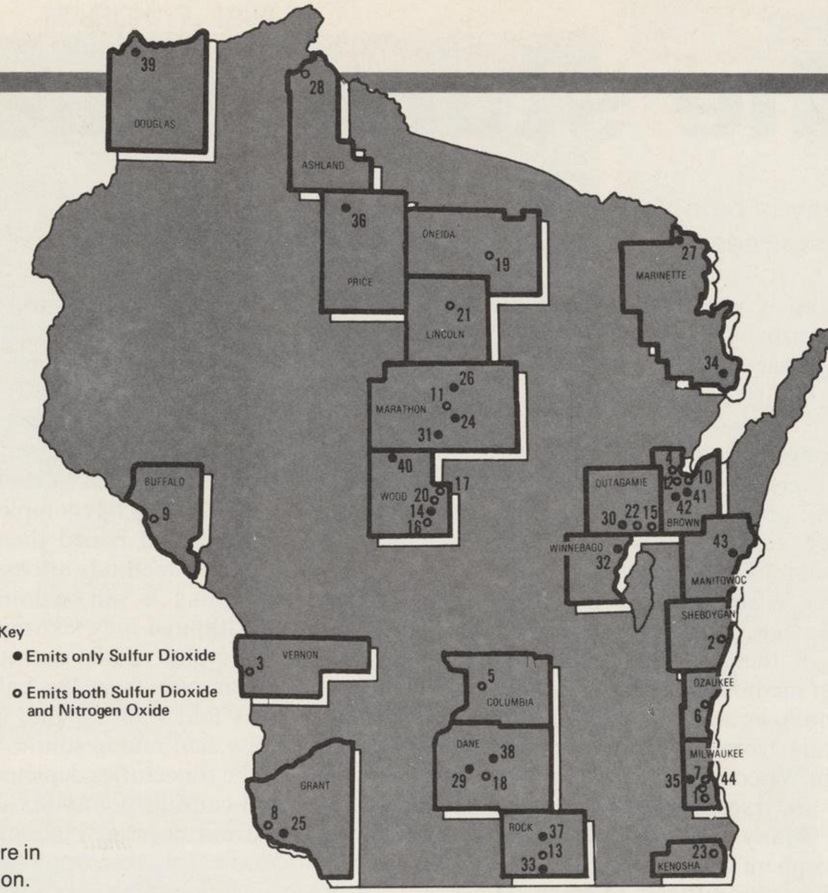


Illustration by Artist Eric Weaver



Areas of highest emissions are in places with the most population.

Illustration by Artist Eric Weaver

Wisconsin Point Source Facilities Which Emitted Over 1000 Tons Of Sulfur Dioxide and/or Nitrogen Oxides in 1980

Rank	Facility Name	Location	NO_x Emissions (Tons)	SO_2 Emissions (Tons)
1	**WEPCo Oak Creek**	Oak Creek	**23,028**	**119,340**
2	**WP&L Edgewater**	Sheboygan	**28,730**	**58,474**
3	**Dairyland Power**	Genoa	**8,240**	**46,364**
4	**WPSC Pulliam**	Green Bay	**7,181**	**45,828**
5	**WP&L Columbia**	Portage	**25,987**	**41,869**
6	**WEPCo Port Washington**	Port Washington	**6,152**	**41,211**
7	**WEPCo Valley Plant**	Milwaukee	**7,003**	**40,691**
8	**WP&L Nelson Dewey**	Cassville	**15,186**	**31,475**
9	**Dairyland Power**	Alma	**10,754**	**29,100**
10	**Proctor & Gamble Fox River Mill**	Green Bay	**2,042**	**24,032**
11	**WPSC Weston Plant**	Weston	**2,965**	**22,599**
12	**Fort Howard Paper Co.**	Green Bay	**6,196**	**17,908**
13	**WP&L Rock River**	Beloit/Janesville	**6,864**	**15,743**
14	**Nekoosa Papers, Inc.**	Port Edwards	—	**9,532**
15	**Thilmany Pulp & Paper**	Kaukauna	**3,966**	**8,733**
16	**Nekoosa Papers, Inc.**	Nekoosa	**1,239**	**8,715**
17	**Consolidated Papers, Inc.**	Biron	**2,649**	**8,572**
18	**Madison Gas & Electric**	Madison	**1,452**	**8,182**
19	**Rhinelander Paper Co.**	Rhinelander	**2,851**	**6,654**
20	**Consolidated Papers, Inc.**	Wisc. Rapids	**1,638**	**6,646**
21	**Owens-Illinois**	Tomahawk	**3,077**	**5,769**
22	**Midtec Paper Corp.**	Kimberly	**1,057**	**5,363**
23	**WEPCo Pleasant Prairie**	Kenosha	**5,235**	**5,307**
24	**Weyerhaeuser Company**	Rothschild	—	**4,679**
25	**Dairyland Power Stoneman Station**	Cassville	—	**4,661**
26	**Wausau Paper Mills**	Brokaw	—	**3,618**
27	**Niagara of Wisconsin**	Niagara	—	**3,472**
28	**Bay Front Generating Sta.**	Ashland	**2,190**	**2,988**
29	**University of Wisconsin**	Madison	—	**2,690**
30	**Consolidated Papers, Inc.**	Appleton	—	**2,651**
31	**Mosinee Paper Company**	Mosinee	—	**2,644**
32	**Menasha Corporation**	Menasha	—	**2,366**
33	**WP&L Blackhawk Station**	Beloit	—	**1,955**
34	**Badger Paper Mills, Inc**	Peshtigo	—	**1,872**
35	**Milwaukee Co. Institutions**	Wauwatosa	—	**1,822**
36	**Flambeau Paper Co.**	Park Falls	—	**1,775**
37	**General Motors**	Janesville	—	**1,749**
38	**Oscar Mayer & Co.**	Madison	—	**1,677**
39	**Murphy Oil Corp.**	Superior	—	**1,646**
40	**Marshfield Electric**	Marshfield	—	**1,608**
41	**Green Bay Packaging**	Green Bay	—	**1,396**
42	**Nicolet Paper Co.**	DePere	—	**1,306**
43	**Manitowoc Public Utilities**	Manitowoc	—	**1,302**
44	**WEPCo Lakeside Sta.**	Milwaukee	**1,153**	
	TOTAL		**176,835** ·	**655,984**

The storm-trackers

A way is being developed to pinpoint the sources of acid rain in Wisconsin.

LARRY BRUSS, DNR Air Quality Analyst,
PAUL KOZIAR, DNR Air Impact Analysis and Planning Chief

Who is responsible for acid precipitation in Wisconsin? This important question is currently being analyzed as part of the Cooperative DNR-PSC-Utility project. There had been some past efforts made in the US and Canada to identify responsibility for acid deposition in particular areas. However, results from them have not been widely accepted because important atmospheric processes were not considered or were oversimplified.

The Wisconsin Acid Deposition Joint Technical Review Committee recognized the shortcomings of these previous studies and proposed a better method. It is called back-trajectory analysis and follows an air parcel's path backward in time starting from the acid precipitation monitoring site in Wisconsin. As the air parcel's path and history are traced, pollutant sources can be identified. Many previous studies have ignored the atmosphere's vertical dimension because vertical motions are difficult to track. However, atmospheric vertical motion plays an important part in cloud formation, precipitation and in locating contributing air pollutant sources.

To do the study, the Cooperative DNR-PSC-Utility research program hired C.T. Main, an independent consulting firm.

Main's first step is to trace the path of pollutants before they are incorporated into precipitation. It is a complicated business. Twice daily the National Weather Service collects wind speed, wind direction, temperature, pressure and relative humidity data from weather balloons. Properly interpreted, these can be used to give each parcel of air that caused acid precipitation an individual identity. Scientists can then trace its path. Using the weather service data, meteorologists construct three dimensional pictures of the atmosphere and using wind vectors can trace vertical pollutant motions as well as horizontal motions.

Starting with a precipitating cloud, the consultants construct a "back-trajectory" that traces the pollutant's path back through the atmosphere. They can determine how much a source contributes to acid precipitation by accounting for such things as its distance from the precipitating cloud, the amount of pollution it emits and the time the parcel of air is located above the source.

Since trajectory construction is complex and tends to be subjective, DNR contracted for an independent assessment of Main's work to be conducted by Dr. Roger Pielke, an associate professor at Colorado State University. Together, Pielke and Main will iron out any rough spots in the analysis.

Back-trajectories will be constructed for 31 days on which precipitation occurred. The days will be picked on the basis of deposition amount and interesting chemistry or precipitation type: rain, sleet, snow, hail etc. Trajectories will be made for each monitoring site: Round Lake, Legend Lake and Lake Geneva.

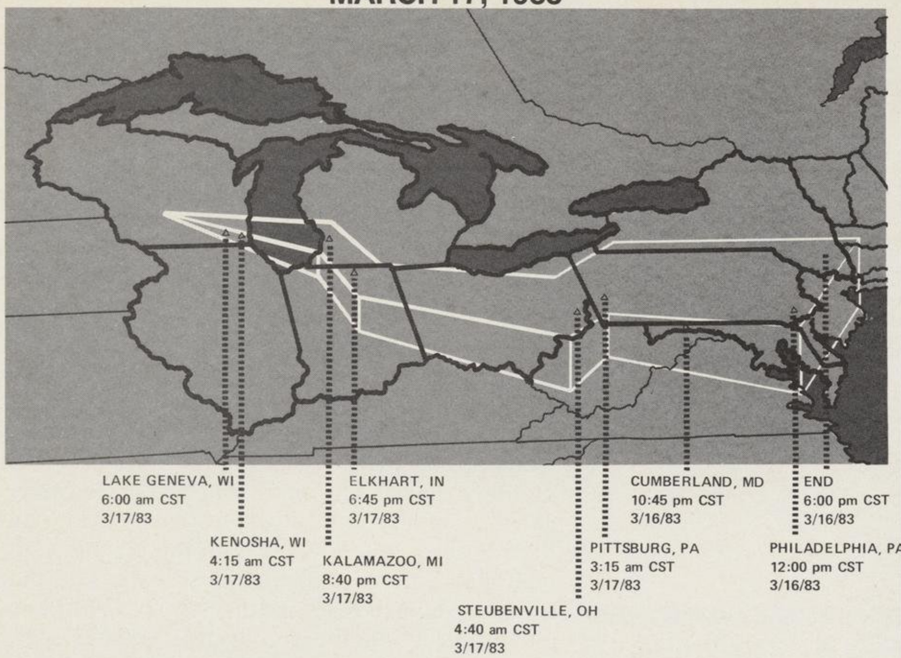
C. T. Main has completed the first six of the 31 analyses and issued them as a Phase I Report. After the methods are assessed and validated the remaining 25 will be done.

Although only six trajectories have been completed and results are still sketchy, preliminary information from the Lake Geneva monitor suggests that both in-state and out-of-state sources cause acid rain in southeastern Wisconsin. In one of the trajectories depicted, more than 50% of the acid-causing pollutants in rains from the north and northeast at Lake Geneva originate in Wisconsin. In rains from the south, southwest and southeast, depicted by the other trajectory plot, mostly out-of-state sources are the cause. We do not have sufficient information from Round and Legend lakes yet to perform in-state vs. out-of-state analysis. A final evaluation of in-state vs. out-of-state contributions to acid deposition in Wisconsin is expected by May, 1985.

In another part of the study, climatologists performed a statistical analysis of the several weather ingredients of acid precipitation: the month; surface wind direction and speed; amount and kind of precipitation; and weather type (such as cold front or warm front). As might be expected, this analysis showed that the greatest amount of acid generally occurred with the greatest amount of rain and that wind directions favoring the greatest amount of rain also generally favored the greatest amount of acid. One notable exception is Lake Geneva, which received most of its rain from the south and southeast, but most of its acid deposition from the north and northeast.

The climatology analyses along with back-trajectory studies hold the promise of locating acid rain sources. Final results will not be in until study methods are ironed out and the remaining 25 trajectories completed. Once these are done all concerned will have a better idea where to concentrate efforts at abatement.

BACKTRACK OF A STORM AT LAKE GENEVA MARCH 17, 1983

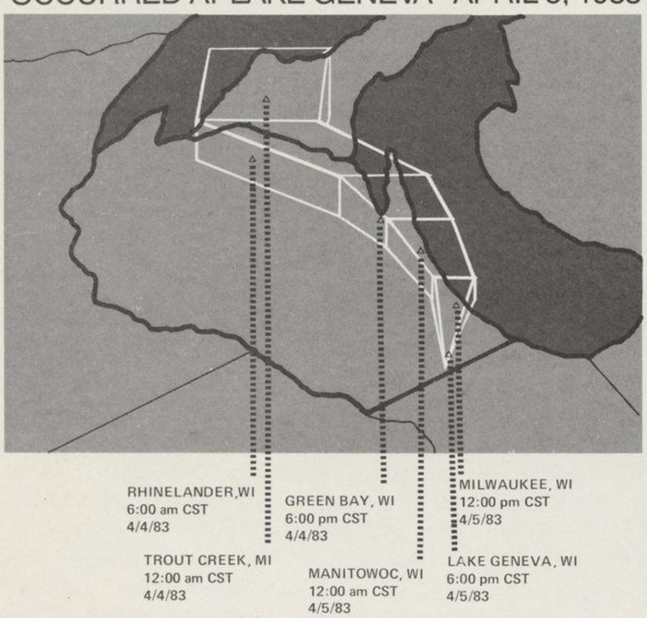


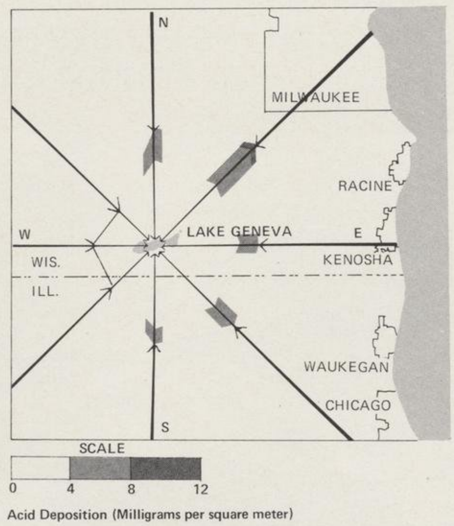
◀ In this back trajectory most pollutants contributing to acid deposition at Lake Geneva originated out-of-state as far away as Philadelphia.
Illustration by Artist Eric Weaver

Arrows indicate surface wind direction. Bar length indicates amount of acid deposition. Most acid deposition at Lake Geneva occurs with northeast and north surface winds.
Illustration by Artist Eric Weaver
▼

In this back trajectory most pollutants contributing to acid
▼ deposition at Lake Geneva originated in Wisconsin.
Illustration by Artist Eric Weaver

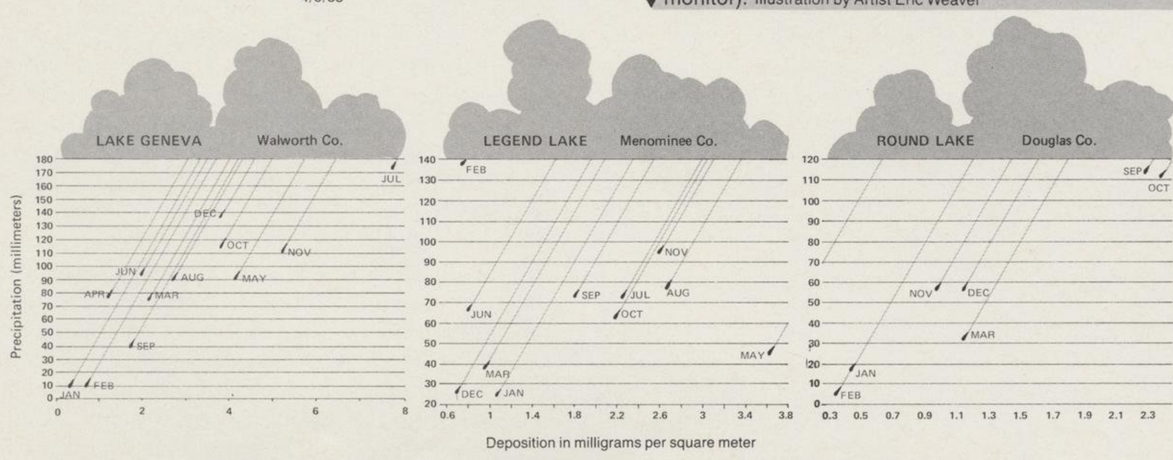
BACKTRACK OF A STORM WHICH OCCURRED AT LAKE GENEVA - APRIL 5, 1983





ANNUAL ACID DEPOSITION BY WIND DIRECTION, LAKE GENEVA

The good correlation between total monthly precipitation and acid deposition simply means that when it rains a lot, there's a lot of acid deposition. Heaviest acid deposition occurs in southeastern Wisconsin (Lake Geneva monitor) while the least is in northwestern Wisconsin (Round Lake
▼ monitor). Illustration by Artist Eric Weaver

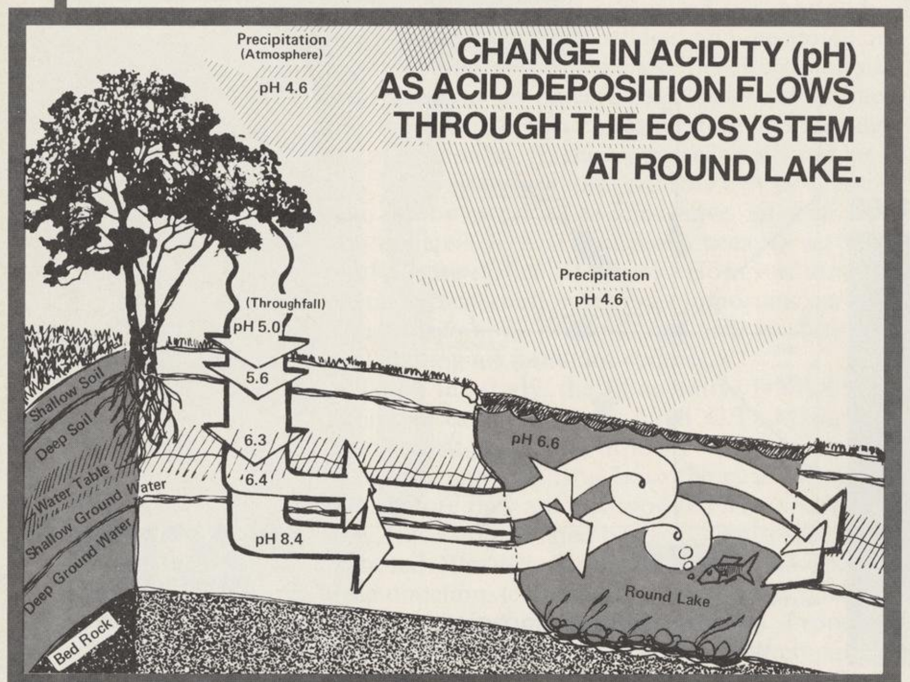


TOTAL MONTHLY ACID DEPOSITION AND PRECIPITATION

Intensive watershed study: Round & East Eightmile Lakes

Soil, trees and in-lake processes help buffer the effects of acid rain. Study findings will be fed into a mathematical model to help managers predict what will happen when a lake is hit by acid rain.

DOUG KNAUER AND STEFANIE BROUWER
Water Resources Research, DNR



Round and East Eightmile lakes have moderate to low sensitivity. In these groundwater flow-through seepage lakes, the trees and soils in the watershed neutralize some of the acid rain. Groundwater flowing through the lake brings with it sufficient alkalinity to neutralize present acid loading. Illustration by Artist Eric Weaver

The first alarms about the damaging effects of acid rain on the environment were sounded several decades ago. Since then, understanding of the problem and processes involved has deepened. It's known that emissions of sulfur and nitrogen oxides from coal-fired power production, automobile exhausts and industrial processes can be changed in the atmosphere to cause acid rain. Studies show that lakes in both the US and Canada have become more acidic recently and that acidification decreases the diversity of fish species and results in simplified ecosystems. What we lack is reliable information on how terrestrial soil, groundwater and aquatic processes operate normally, as well as how they operate under the influence of acid rain. We need to understand ecosystems before we can assess how they will be affected by acid rain.

Ecosystem damage may occur because acid rain can disrupt the delicate balance between the physical, chemical and biological components of the environment. These components are closely linked, performing essential functions. To address the link between acid rain and the interaction between watersheds and lakes, the Electric Power Research Institute (EPRI) has funded several extensive studies. The original study was conducted between 1977 and 1981 in three forested watersheds of the Adirondack region of New York state. This study was based on the recognition that rainfall follows various pathways through the terrestrial system before reaching a lake. It was also based on the assumption that a lake's vulnerability to acidification can only be understood by studying the biology, chemistry, geology and hydrology of the entire watershed. As part of this study, a mathematical model was designed to describe in a quantitative way the acidification processes. The model defines the processes occurring along the pathways that rainfall follows through forest canopies, soils, groundwater, streams and lakes.

In 1981, the EPRI project expanded to two sites in northwestern Wisconsin; Round Lake in Douglas County and East Eightmile lake in Bayfield County. These lakes are different from the Adirondack study lakes in surface elevations, soil depth to bedrock and hydraulic residence time (the amount of time it takes water to flow through the lake). The project is being managed by DNR's Bureau of Research. The complexity of the study requires that detailed measurements be made within the different components of the ecosystem: forest, soils, groundwater and lakes.

An interdisciplinary team of scientists has been assembled to work on each phase, including a forest soils expert (Dr. James Bockheim, U.W.-Madison), a hydrogeologist/water chemist (Dennis Wentz, U.S. Geological Survey), a forest pathologist (Allen Prey, DNR) and a limnologist (Paul Garrison, DNR). Mathematical modelers are using the information collected by the Wisconsin researchers to modify the model designed during the Adirondack study.

The Wisconsin study lakes are seepage lakes with no channelized surface inlets or outlets. While not the most vulnerable in Wisconsin to acid rain, they include soils and vegetation types common to northern Wisconsin and hydraulics similar to other Wisconsin seepage lakes. Groundwater and rainfall are the controlling factors of the water budgets of both lakes. The project objectives are:

To develop water budgets for the lake basins.

To determine the chemical composition of rainfall and dry fall, such as dust, and how the chemistry is modified as rainfall passes through the forest canopy, soils and groundwater.

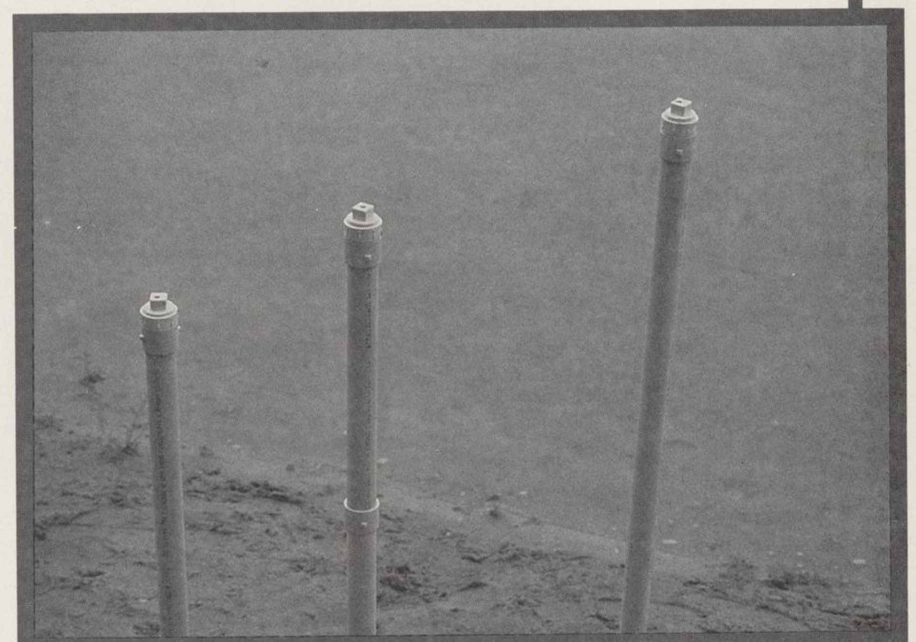
To predict the effects of acid rain on the two Wisconsin lakes using the Adirondack model.

To test the effectiveness of the Adirondack model in a different geographic region.

Findings to date show that:

a. The pH of rain at the two sites is 4.6.
b. Trees help neutralize acidity.
c. Soils are more effective than trees in mitigating the effects of acid rain.
d. Neither Round nor East Eightmile lakes experience a depression of pH during early spring because the soils in the area do not freeze and much of the meltwater associated with heavy snow cover infiltrates the soils.
e. In-lake processes, such as bacterial action in sediments and bottom waters, can help buffer the effects of acid rain.

These results are being applied to the mathematical model developed for the Adirondack study. If the model can be validated for Wisconsin, it will become a valuable tool for resource managers. The last glacier left Wisconsin with about 15,000 lakes of which 7,000 are estimated to be seepage lakes. An understanding of the effect acid rain has on the environment will help DNR formulate plans to mitigate potential damage before it is too late.



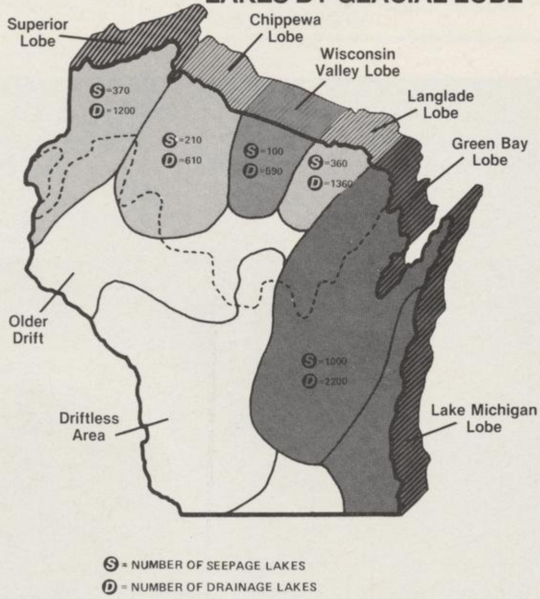
A series of wells help determine groundwater's contribution to lake water budgets.

How sensitive are Wisconsin's aquatic resources?

KATHERINE WEBSTER, BOB MARTINI, & JOSEPH EILERS, Water Quality Planning, DNR North Central District

The water chemistry of about 3,500 Wisconsin lakes makes them sensitive to damage by acid rain.

AVERAGE ALKALINITY (IN MICROEQUIVALENTS PER LITER) OF SEEPAGE (S) AND DRAINAGE (D) LAKES BY GLACIAL LOBE

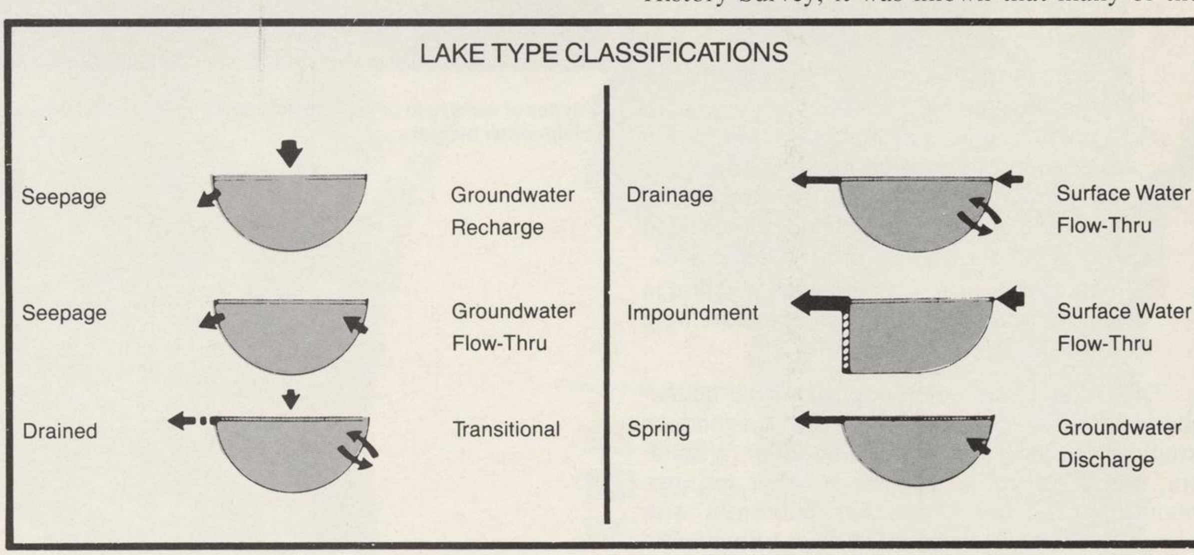


The makeup of soils left by various glaciers influences the sensitivity of lakes. The Wisconsin Valley Lobe left behind till containing very few acid-neutralizing substances. Lakes in this area are most sensitive. The average alkalinity of seepage lakes (100) and drainage lakes (590) influenced by this lobe is lower than other parts of the state. Illustration by Artist Eric Weaver.

North central Wisconsin contains one of the highest concentrations of lakes in the world. In Vilas and Oneida counties alone, there are nearly 2,500 lakes covering 13% of the total surface area. Each year thousands of people use them for fishing, swimming and other recreation. They are a valuable economic base for the region.

Since June 1979, DNR's North Central District Water Quality Planning Section in cooperation with several organizations, has conducted research to evaluate the sensitivity of northern Wisconsin's aquatic ecosystems to damage by acid deposition. The studies have also measured the acid loading rate from the atmosphere. Support from over a dozen sources helped finance a wide variety of research projects including one to estimate the quantity and type of aquatic resources at risk.

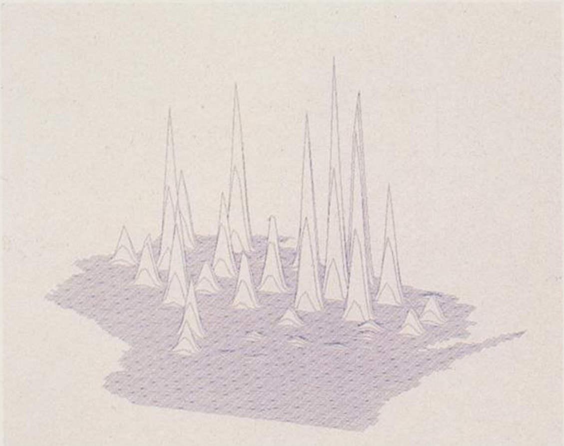
Based on pioneering limnological research in the 1930s by Dr. Edward Birge and Chancey Juday of the Wisconsin Geological and Natural History Survey, it was known that many of the



Clara Lake in Lincoln County is a typical sensitive, precipitation-dominated lake with low alkalinity. One study here will look at the availability of mercury to various kinds of aquatic life. Photo by Bob Martini ▶

Inset: A flume records the cubic feet per second of surface water entering Clara Lake as part of a water budget study. Photo by Joe Eilers ▶

Water samples taken year-round are tested for buffering capacity, pH and other chemical components. Photo by Joe Eilers



Distribution of softwater lakes in Wisconsin.

In 1979 an EPA helicopter from the laboratory at Duluth landed on several Wisconsin lakes to take water samples for alkalinity and other tests. Photo by Dave Kunelius

region's lakes were of the soft water type. In contrast to hard water systems, soft water lakes contain low concentrations of the dissolved compounds (primarily carbonates) which maintain lakes at stable acidity or pH levels. Measured as alkalinity, these compounds comprise the acid neutralizing capacity (ANC) of a lake. When the input of acidic compounds from atmospheric deposition exceeds the ANC, acidification results.

The first step in the project was to collect high quality water chemistry data. In cooperation with the EPA Environmental Research Laboratory at Duluth, a survey of 275 lakes in the Upper Wisconsin River Basin was conducted. This would answer two important questions. First, what proportion of lakes in the region are sensitive to damage by acidic deposition? Secondly, are there physical characteristics of sensitive lakes which can be used for broader evaluations of resources at risk? Researchers in other regions of North America have related lake sensitivity to variables such as bedrock type, soil type and surface geology. This study would test the importance of these factors in north central Wisconsin.

Results showed 44% of the study lakes to be sensitive with an alkalinity of less than 200 microequivalents per liter (ueq/l) and 23% to be extremely sensitive with an alkalinity of less than 40 ueq/l. Some lakes (4%) have no alkalinity and thus, possess little or no ability to neutralize incoming acids.

Although such a large proportion of the study lakes are sensitive, a slightly larger number are not. There is a broad range both in pH (4.6 to 9.2) and alkalinity (-25 to 1111 ueq/l). Lakes of widely varying chemistry are often found only a short distance from each other. For example, the acid neutralization capacity ranged from below zero (ultra-sensitive) for McGrath lake (pH 5.3) to 860 ueq/l (not sensitive) for Little Tomahawk Lake (pH near 8.0). Yet, the two lakes are separated only by a narrow ridge.

How can lakes so close to one another be so different? The answer lies in a lake's major source of recharge water and buffering materials. Lakes receive their recharge water from three basic sources: (1) precipitation, (2) groundwater inflow and (3) surface water inflow (streams). Lakes which receive most of their recharge water from precipitation represent our most sensitive water bodies. Lakes influenced by groundwater and/or surface water are generally less sensitive to acid deposition.

McGrath Lake is an example of our most sensitive lake type, because its main source of water is precipitation. Its lake water chemistry is strongly influenced by precipitation — hence, this type of lake is said to be "precipitation-dominated." In this kind of system, lakewater seeps out of the lake into the groundwater aquifer. The lake's major source of water (precipitation) provides essentially no alkalinity to the lake.

Other kinds of lakes are less sensitive because groundwater flows through the system bringing with it a renewed supply of akalinity. Groundwater obtains its alkalinity as it moves through the soil, dissolving the buffering materials.

Precipitation-dominated and groundwater flow-through lakes are generally seepage lakes, without inlet or outlet streams. Lakes with inlet and outlet streams, termed drainage lakes, are generally less sensitive than seepage lakes, because inflowing streams usually provide a replenishing supply of alkalinity.

Our least sensitive lake type is called a spring-lake. Spring-fed lakes like Little Tomahawk receive an abundant and continuous supply of acid-neutralizing groundwater.

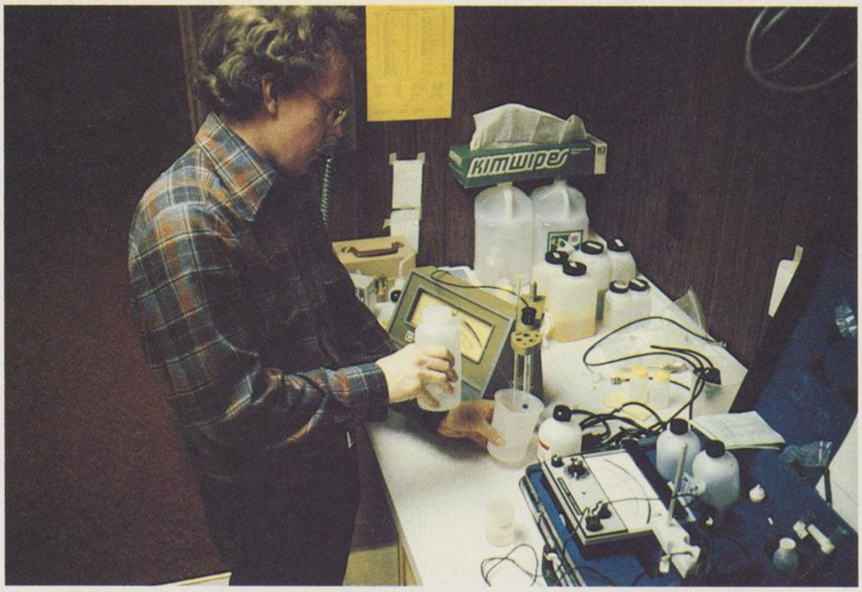
There is a continuum of of lake types which fall within the three major categories described above.

Most lakes receive some input from groundwater and from streams, but it is the relative contributions (quantity and quality) from these two sources and from precipitation that determine lake chemistry. Studies on lakes Clara and Vandercook in north central Wisconsin have demonstrated that precipitation is indeed the dominant source of water to these sensitive seepage lakes. The amounts of groundwater and surface water they receive are small.

North central Wisconsin is not the only region in the state with sensitive aquatic resources. Analysis of data collected by DNR as part of a statewide lake survey in the 1960 to 70s indicates nearly 3,500 of the state's 14,947 lakes are sensitive, while 8% are extremely sensitive. Although many of the sensitive lakes are small in size, there are still 1,750 larger than 10 acres, totalling over 28,000 acres.

A majority of Wisconsin's lakes are located in the northern one-third of the state. They were created 8,000 to 10,000 years ago when a series of glaciers advanced into the area. An evaluation of lake alkalinity in the major glacial lobes suggests that the makeup of the glacial till influences the acid neutralization capacity of particular lake types. Considering seepage lakes only, the mean alkalinity of lakes within the Wisconsin Valley lobe, which covered the region containing the study lakes, is lower than that of any other lobe. This suggests the glacial till left behind by that particular glacial advance contains very little carbonate, while other lobes deposited material richer in acid neutralizing substances. Seepage lakes are lower in acid neutralizing capacity than drainage lakes across all glacial lobes.

What can we project for the future of Wisconsin's sensitive lakes? If precipitation is the dominant source of water, sustained high acid loadings from the atmosphere could increase the acidity of our most sensitive systems. Those lakes contain little or no buffering substances with which to combat additional pollutants. The Water Quality Planning Section is closely monitoring a cluster of these very soft water lakes as part of a nationwide study designed to detect long term changes in lake water chemistry. Through this and other research in the region, an understanding of the complicated interactions between acid rain and the lakes which receive it will emerge. This will provide the basis for sound decisions to protect Wisconsin's precious aquatic resources.



Researcher Ron Becker tests the pH of precipitation at the DNR laboratory at Rhinelander.


Depth and direction of groundwater flow are determined from observation wells. Using a tape measure to record depth are Nan Eckert and Lisa Huberty of the DNR acid rain research team. Photo by Katherine Webster


STOP
ACID
RAIN

Interpreting acid rain research findings in Wisconsin

What does it all mean?

Rhetoric, speculation, bias and fear have confused the acid rain issue. Let's take a hard look at the data and see what's revealed.

THOMAS B. SHEFFY,
DNR, Acid Deposition Program Director
Wisconsin Department of Natural Resources

The main purpose of acid rain research in Wisconsin is to provide a factual base from which DNR resource managers and state policy makers can make decisions regarding controls. This is a two-step process: the scientist has to collect reliable data, then interpret and explain it.

The first question research set out to answer was "How acid is the rain in Wisconsin?" Four years of data from 10 rainfall collectors throughout the state provide a clear answer. Wisconsin is presently receiving acidic deposition with an average pH of 4.4 in the southeastern third of the state, 4.6 in the midstate region and 4.8 in the northwestern part of the state. The acidity of precipitation in Wisconsin comes mainly from sulfuric and nitric acids. Of these two, sulfuric predominates.

What do these pH values and the presence of sulfuric and nitric acid in the rain mean? Unpolluted rainfall is slightly acidic because some carbon dioxide from the atmosphere dissolves in rain, producing a weak solution of carbonic acid. Scientists commonly use a pH of 5.6 as a reference point for unpolluted rain because pure (distilled) water in equilibrium with atmospheric carbon dioxide has a pH of 5.6. The validity of this reference point is a subject of current debate. However, precipitation with a pH consistently below 5.0 caused primarily by sulfuric and nitric acids is considered unnaturally acidic and the result of manmade emissions. Additionally, we know that environmental damage has occurred in Scandinavia, Canada and New England in areas where the pH of rain is 4.6 or less.

Geographically, Wisconsin lies on the western fringe of the acid deposition impact region of northeastern United States. Precipitation is near normal at points west of our state. Starting at about the Minnesota-Wisconsin border and moving eastward, the acidity of rain gets progressively stronger to a pH of 4.2 in a core area covering parts of Ohio, Kentucky, Pennsylvania and New York.

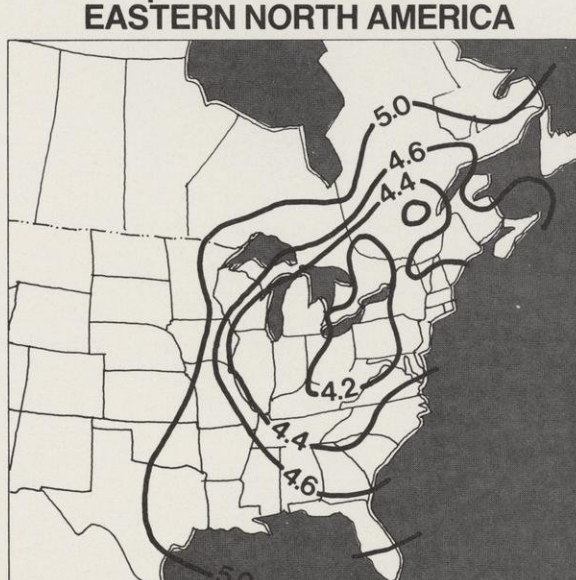
Another way of evaluating the acidity of rainfall is to calculate the total wet dose of acid falling on a standard unit of area in one year. This is called an "annual loading rate." In regions of the world where 20 kg/ha/yr (about 17 pounds per acre) have been deposited, acidification of surface waters has occurred. Therefore, scientists sometimes use the annual rate of 20 kg/ha/yr as the "danger threshold for acid loading." The use of this standard in Wisconsin is presently being evaluated.

The southeastern half of Wisconsin is receiving an annual acid loading rate that equals or exceeds the danger threshold of 20 kg/ha/yr. So whether you look at the pH of rainfall or the annual acid loading rate, a significant portion of our state is receiving precipitation with an acidity equal to or greater than that which has caused damage in other parts of the world.

The second question we set out to answer was "Where does the acid rain falling in Wisconsin come from?" To answer this question we have done two things. First, we have identified all major sources of the two acid rainmaking pollutants, sulfur dioxide and nitrogen oxides in Wisconsin and surrounding states. Second, we have tried to determine what proportion of the acid rain falling in Wisconsin is due to in-state sources of pollutants and what proportion is due to out-of-state sources. Here's what we've found:

The majority of sulfur dioxide and nitrogen oxide emissions in Wisconsin are produced by fuel burning. Over 87% of Wisconsin's sulfur dioxide emissions come from 43 point sources — primarily coal-fired power plants and paper mills. Nearly 72% of Wisconsin's total emissions of nitrogen

pH OF ACID RAIN IN EASTERN NORTH AMERICA



Wisconsin lies on the western fringe of the acid rain belt with precipitation as acidic as pH 4.4. A core area covering parts of New York, Ohio, Pennsylvania, Kentucky and southern Canada has an even greater problem, with pH as low as 4.2.
Illustration by Artist Eric Weaver

◀ Lisa Huberty of the acid rain research team makes a point.
Photo by Katherine Webster

oxides come from motor vehicles and 24 point sources—again electrical utilities and paper mills. In Wisconsin and in the rest of the eastern US, natural sources of sulfur dioxide and nitrogen oxide are considered negligible.

Although the Atmospheric Trajectory Project is not completed, information gathered to date on in-state versus out-of-state contributions to acid rain gives us some insights. For example, preliminary data from the Lake Geneva monitor shows that a significant in-state source contribution, about 50%, can occur with north and northeast winds. When acid rainfall comes with southerly winds, the in-state contribution observed is less than 50%. However, most acid deposition at Lake Geneva in 1982-83 occurred when winds were northerly. Although the data are scant, and our interpretations are at best tentative, it is reasonable to believe that in-state sources may account for a significant portion of the acid rain falling in southeastern Wisconsin.

The third research question was "Has acid rain caused any damage in Wisconsin to date? If not, is future damage likely?" To cause damage, the rain must fall on resources which are sensitive to acids. One sensitive resource looked at is the northern soft-water seepage lakes. More than 80% of the state's 15,000 lakes are found in 23 northern counties. These lakes provide a recreational base for much of Wisconsin's $7-billion tourism industry and any threat is also a threat to a main part of the state's economy.

Soft-water lakes contain very low concentrations of dissolved chemicals called carbonates. Carbonates are mother nature's alka seltzer, in that they tend to neutralize acids. The amount of carbonate in a lake is measured as alkalinity. Alkalinity levels, which are expressed in microequivalents per liter (ueq/l) measure the acid neutralizing capacity of lakes. The higher the alkalinity in a lake, the higher the acid neutralizing capacity and the less susceptible a lake is to acid rain. On the other hand, low alkalinity means high susceptibility to acid rain.

It is generally accepted by scientists that acid-sensitive (susceptible) lakes are those which have alkalinities of 200 ueq/l or less.

This "danger susceptibility threshold" of 200 ueq/l has been used to estimate how many lakes in Wisconsin are sensitive to acid rain. Various inventories of Wisconsin lakes indicate that approximately 2,000 in the northern third of the state (and about 3,500 statewide) have alkalinities of 200 ueq/l or less.

Of greater concern is the fact that of the 2,000 susceptible lakes in northern Wisconsin, about 500 are extremely sensitive and have alkalinities of only 40 ueq/l or less. And of these 500 extremely sensitive lakes, about 100 have alkalinities at or below zero.

This group of 100 or so "super-sensitive" lakes cause most concern. The reason can be found in the dynamic relationship between lake susceptibility and acid loading. As stated previously, the general rule is that the acid loading rate to a susceptible lake (200 ueq/l alkalinity or less) should not exceed 20 kg/ha/yr or damage may result. However, this relationship is quite variable. For example, some less susceptible lakes in southern Wisconsin with alkalinity higher than 500 ueq/l can probably neutralize annual acid loading rates above 20 kg/ha/yr. On the other hand, "super-sensitive" lakes with near-zero alkalinity may not be able to neutralize annual acid loading rates well below 20 kg/ha/yr. In fact, Canadian, Swedish and American scientists suggest an annual loading rate of no more than 9 to 15 kg/ha/yr must be established to protect our most sensitive lakes. (The 1982 Stockholm Conference on Acidification of the Environment) Under this criterion, the present loading rates of 14 to 18 kg/ha/yr in north central Wisconsin would be too much for some of the state's zero-alkalinity lakes.

Heightened concern for this group of 100 or so "super-sensitive" lakes has led to more intense study. A comparison of water chemistry measurements taken between 1925 and 1941 with present-day water chemistry, taken between 1979 and 1982, shows that eight of these near-zero lakes have decreased in pH. In addition, some walleye and bass from eight lakes in northern Wisconsin show mercury contamination above the safe limit of 1.0 part per million (ppm). There is a general correlation between low pH waters and elevated mercury burdens in fish. Acidic water has been shown to increase the accumulation of mercury in fish tissue.

Since there is no historical data on mercury levels in these lakes an increase cannot be proven. However, it is safe to conclude that if acidification lowers the pH of other lakes in northern Wisconsin, a greater concentration of mercury in gamefish can be expected, if indeed, the basic biological integrity of the lakes and their fisheries can even be sustained. The decreased pH values in eight near-zero alkalinity lakes and elevated levels of mercury are consistent with a working hypothesis that these lakes may be showing the first signs of acidification.

Although some of our near-zero alkalinity lakes are showing signs which suggest acid rain stress, the majority of Wisconsin lakes are not in this low-alkalinity category. Round and East Eightmile Lakes, which have alkalinities of 180 and 475 ueq/l respectively, provide us with valuable information about lakes with moderate to low sensitivity. In these kinds of seepage lakes, the trees and soil in the watershed neutralize some of the acid rain. The groundwater seeping into the lakes brings with it sufficient alkalinity to neutralize present acid loading. These kinds of groundwater flow-through systems do not appear to be immediately threatened by acid rain. Unfortunately, the same cannot be said for our near-zero alkalinity lakes, which receive very little alkalinity from groundwater and whose chemistry is strongly influenced by precipitation.

The difficult question facing policy-makers is whether to pass tough pollution control measures which would protect a minority of ultra-sensitive, precipitation dominated lakes, or to pass more modest control measures which would protect a majority of less sensitive lakes. Some would argue that we should protect even our most sensitive lakes, since they are an integral part of a larger Wisconsin ecoystem. As Aldo Leopold said. "intelligent tinkering requires saving all the parts," so it can be argued that these most sensitive lake systems provide an important home for many species. It may not be possible to quantify, document, or even to foresee the benefits of protecting such resources, but would that make it wrong to protect them?

Summarized, the findings of the various studies show the following:

- Since 1979, Wisconsin has recorded rain and snow that are up to 10 times more acidic than normal. This level of precipitation acidity has caused environmental damage elsewhere in North America.

- The annual acid loading rate in portions of Wisconsin exceeds the critical level that has caused lake damage elsewhere. Continued deposition at the present rate in our highly sensitive northern lakes threatens fish and other aquatic life.

- Preliminary data from the Lake Geneva monitoring site suggests that a significant portion of the acid rain falling at this site can come from local in-state sources of air pollution.

- Of Wisconsin's nearly 15,000 lakes, 2,000 in the northern third of the state, and 3,500 statewide, are susceptible to acid deposition. Of these 3500, about 1200 have alkalinities so low that damage from acid rain is likely if the present rate of acid deposition continues.

- Although no biological damage has been documented to date in Wisconsin's lakes, a few highly sensitive precipitation-dominated lakes in northern Wisconsin have shown decreases in pH. Further analysis is required, but one of the working hypotheses is that these lakes may be showing the first signs of acidification.

- Gamefish in several acidic lakes in northern Wisconsin contain mercury levels higher than the US Food and Drug administration's safe limit of one part per million. Mercury is toxic to people who eat such fish. Acidic water dissolves mercury from rocks and sediment and converts it into a form that aquatic organisms readily accumulate in tissue. If acid rain lowers the pH of other lakes in northern Wisconsin, more widespread mercury contamination in gamefish can be expected.

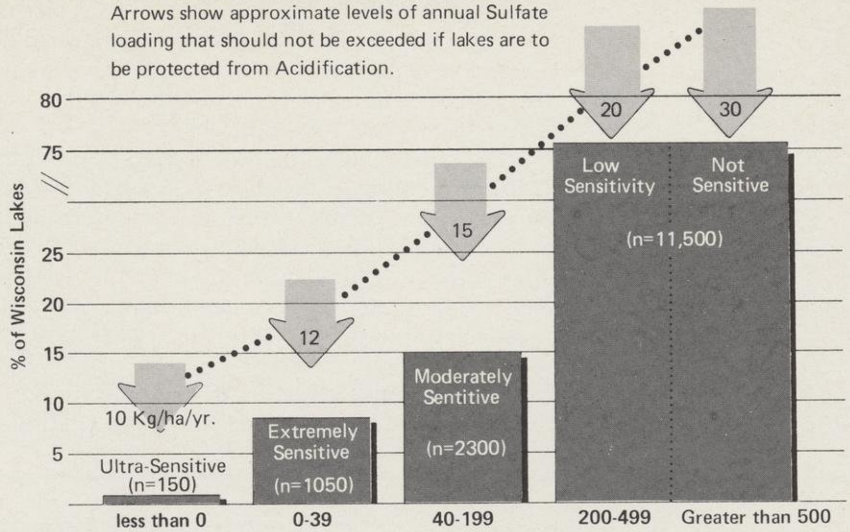
- Lakes with moderate to low sensitivity are protected by buffering mechanisms in the watershed and a renewed supply of alkalinity from groundwater entering the lake.

Research in Wisconsin and other parts of the world describes the problem with considerable clarity and reveals a basic consensus: acid rain is derived primarily from manmade emissions of sulfur dioxide and nitrogen oxides. It has caused significant damage to the environment in parts of Scandinavia, Europe, Canada and the New England states. Wisconsin resources face a threat of similar damage. A reduction in sulfur dioxide and nitrogen oxide emissions before they enter the atmosphere would reduce the threat of damage in Wisconsin and other sensitive areas.

- In response to these findings, two important laws were recently enacted in Wisconsin to address the acid rain problem. First, a maximum annual limit — sometimes called a "cap" — of 500,000 tons of sulfur dioxide was placed on the total emissions from the five major utilities in the state. This holding action will prevent sulfur dioxide emissions from these major sources from increasing in the future. To allow uncontrolled increases would be irresponsible.

- The second law calls for a two year study on how Wisconsin can most efficiently and cheaply

DISTRIBUTION OF WISCONSIN LAKES BY SENSITIVITY CATEGORY



Alkalinity range (ueq/1) of lake sensitivity categories:
n is the estimated number of Wisconsin lakes in each category.

The more sensitive a lake is, the less sulfate (acid) loading it can sustain. Acid loadings limited to no more than 10 to 12 kg/ha/yr may be required to protect Wisconsin's most sensitive lakes. Current loading rates in Wisconsin range from 15 to 30 kg/ha/yr.

Illustration by Artist Eric Weaver

Sensitivity of Lakes to Acid Based on Alkalinity

Class	Alkalinity (ueq/l)	Estimated # of Wis. Lakes in Class
I Ultra-Sensitive	0	150
II Extremely Sensitive	0-39	1050
III Moderately Sensitive	40-199	2300
------- Danger Susceptibility Threshold ------		
IV Low Sensitivity	200-499	11,500
V Not Sensitive	500	
		TOTAL 15,000

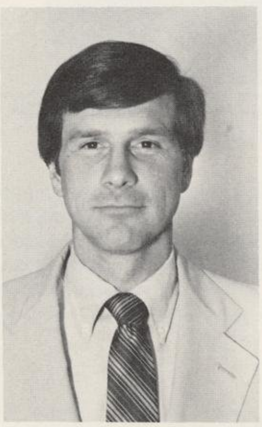
reduce sulfur dioxide (SO_2) emissions if necessary. This "SO_2 reduction cost study" is being done in anticipation of national legislation calling for significant SO_2 reductions in the continental United States. Wisconsin will be one step ahead of the game if it has an SO_2 reduction strategy in place when federal rules are passed.

- The law creating the cost study also directs DNR to develop statewide rules which would limit emissions of sulfur dioxide and ensure that ambient air quality health standards are met in all areas of the state. Besides improving air quality in Wisconsin, these health related limits will no doubt have spin-off benefits with regard to acid rain.

- DNR has also created a new Acid Rain Section to evaluate several things: new research findings, the effectiveness of the "cap" law, ways to most effectively reduce emissions, the effects of proposed federal legislation, and the need for further state legislation related to acid rain.

These first and logical steps of holding emissions to historic levels, determining the best way to go about reducing emissions, developing rules for attaining health standards and careful research will not solve the acid rain problem. The real solution is for the US Congress to pass a law which results in meaningful emission reductions nationwide. The advantage of a national approach is that the law (and the attendant cost burden on industrial sources) could apply equally to all states, and all states would share the cost of the cleanup. Wisconsin will continue to press for such a national solution.

Environmental and industrial views of the acid rain debate.



The viewpoints

LYMAN F. WIBLE, Administrator, Division of Environmental Standards

In the past few years, the public understanding of the acid rain phenomenon has sometimes been hampered by premature interpretation of facts, partial reports, side issues, misinterpretations and overstatements by various interest groups. Consequently, public opinion on the issue of acid rain has been in a constant state of turmoil.

More recently, public opinion has converged to a point where many people believe that acid rain poses a substantial risk to our resources. Although the costs of reducing emissions which cause acid rain are also substantial, many individuals and groups point to the risk of irreversible damage to resources and call for more stringent federal pollution controls. Others, emphasizing scientific uncertainties about transport and interaction of air pollutants may draw different conclusions about how to balance risks against costs. These interests claim that further pollution controls are premature, may waste money and would impose unreasonable burdens on industry and the public.

The DNR articles printed in this publication present a statement on the risks and research surrounding acid rain. Future studies will examine the costs of alternative controls in Wisconsin. DNR will report on these costs which are so important in the development of pollution control decisions. The following environmental and industrial viewpoints provide an interesting discussion of acid rain policy options as they are perceived today. Do we act now to control acid rain or wait for results from ongoing research? If so, how long should we wait?

Both courses involve risks. Delaying controls for five to 10 years will allow emissions and, presumably, acid rain to remain high for a decade or two with the risk of more environmental damage. Acting now involves the risk that controls may be less cost effective or efficient than controls designed 10 years from now. At the same time, advances in scientific understanding (of the problem or of pollution control measures) over this time period are by no means assured.

By considering the two editorials which follow, the reader has an opportunity to weigh 1) the risks of resource damage or loss, against 2) the risks of unwarranted or misdirected control expenditures. This evaluation or tradeoff is the decision which the state must eventually face, and DNR's role is central to this process.

THE ACID TEST

THE ENVIRONMENTAL VIEW

Acid rain: A clear and present danger

SHELLEY MOORE, Citizens For A Better Environment

Acid rain is so dangerous, protective action must be taken now. Environmentalists say the state cannot afford to wait for a federal law and that DNR rules need change.

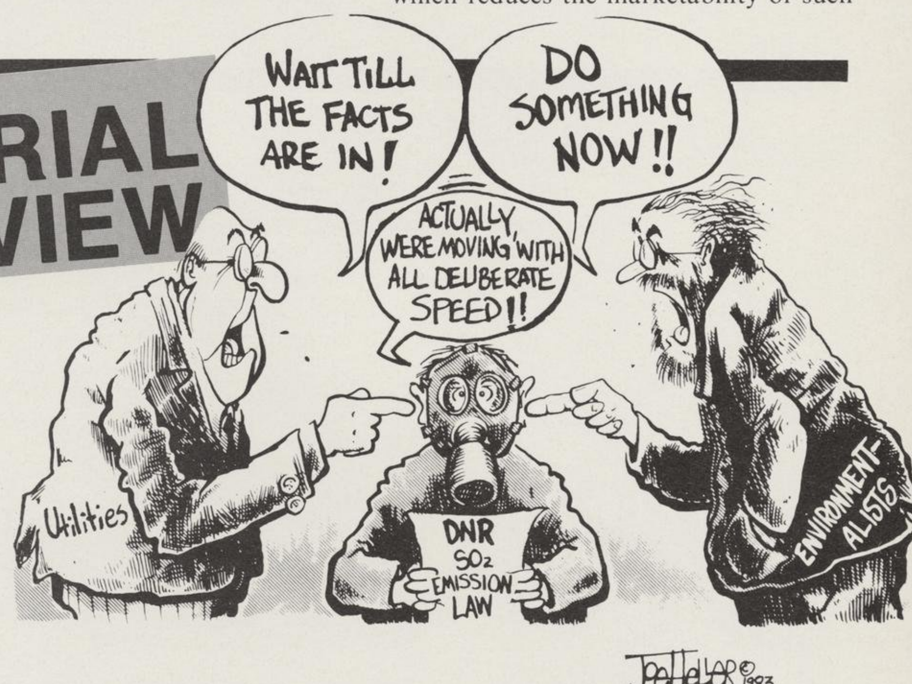
Acid rain poses a very real threat to the health and welfare of Wisconsin citizens. Along with environmental contamination from toxics, acid rain looms as the most critical environmental problem of the decade, indeed, possibly of the century. Both acid rain and toxics threaten the economic livelihood of many Wisconsin industries such as fishing, tourism, agriculture and forestry. Both pose a threat to the health of present and future Wisconsin residents. This threat is unparalleled in scope and degree of potential devastation, which would, in all likelihood be permanent and irreversible. Is this position supported by data or is it just alarmist rhetoric?

Acid rain has already caused extensive damage in Scandinavia, eastern Canada and the northeastern United States. Thousands of lakes and streams have been acidified to the point where fish are no longer able to survive. In the Adirondacks, 212 lakes can no longer maintain a fish population. The Office of Technology Assessment (OTA) estimates that more than 9,000 lakes and 60,000 miles of streams in the eastern US are threatened by acid rain. In Ontario, 4,000 lakes have already succumbed and the Canadian government estimates another 48,000 to be threatened. In Minnesota, about 3,000 are threatened.

Acidified lakes show aluminum concentrations which subsequently have a toxic effect on fish. Increased uptake of mercury in predator fish has also been documented. The National Academy of Science warned in 1981 that unless acid rain is controlled, the number of effected lakes will double by 1990.

In addition to aquatic effects, acid rain and its precursors damage such materials as stone, textiles, paint, paper and leather. It can also reduce yield and marketability of important crops. Field-grown soybeans showed yield decreases of 11 to 23% when exposed to simulated acid rain. Every 1% reduction in yield represents a \$50-million annual loss. Acid rain can also cause necrotic spotting which reduces the marketability of such

THE INDUSTRIAL VIEW



Look before you leap

RICHARD C. BRATCHER, Chairman, Wisconsin Utilities Acid Deposition Task Force

No immediate action is needed on acid rain. Wait for the facts.

While much remains to be learned about acid deposition, there is one thing we do know: no crisis exists in Wisconsin.

This finding is among the preliminary results of the Wisconsin Acid Deposition Research Program being conducted jointly by state and federal agencies and Wisconsin's utility companies. Over the next two years, research to be completed under this program will go a long way toward answering these important questions:

- Will Wisconsin's environment be affected by acid deposition in the future? If so, how quickly?
- If acid deposition is expected to have adverse effects, what is the best way of

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crops as apples, tomatoes, lettuce, radishes and other produce.

Acid deposition is also believed to be a major cause of decline and death of certain forest stands in Germany, Poland and Czechoslovakia. West German scientists estimate that 30% of the forests in that country are effected. Certain forests in New York, Vermont and New Hampshire also show severe stress symptoms including dieback and subsequent invasion by parasites. On both continents, the foliage of declining trees contains 10% more sulfur than that of healthy trees. Scientists hypothesize that a combination of environmental stresses, including acid deposition and drought, are damaging these forests.

Acid rain also poses a potential human health threat. The precursors to acid rain — sulfur and nitrogen oxides — have long been known to directly damage human health when inhaled. Exposure to sulfur oxides in combination with particulate matter has been associated with increased mortality during episodes of heavy air pollution and with aggravated symptoms in persons with heart and lung disease. Studies show that sulfur oxides can obstruct breathing, particularly when present in combination with other air pollutants. Recent research indicates that people with asthma may develop intense constriction of the airways at levels of sulfur oxide much lower than previously believed. Its gases are associated with the aggravation or development of bronchitis and emphysema. Exposure increases acute respiratory disease and depresses lung function in children. Both children and the elderly are particularly sensitive to the effects of air pollution. High concentrations of nitrogen oxides can be fatal. At lower levels, nitrogen oxides can increase susceptibility to viral infections such as influenza, irritate the lungs, and cause bronchitis and pneumonia. Thus, it is important to note that the substances that cause acid rain also cause direct human health damage. This is especially important in Wisconsin, since many areas of the state do not meet the national health-based ambient air quality standards.

In addition to direct damage to human health, acid rain precursors may also have indirect effects. Water supplies which are acidified can dissolve copper and lead out of pipes. While treatment facilities can adjust acidity to combat this problem, it is not so easily dealt with in individual water systems. Wells and groundwater have been found to be acidified in some regions in Sweden, a possibility which could be of some concern in the US.

The Threat To Wisconsin

We now know that about 3,500 Wisconsin lakes are vulnerable. The acid rain falling here has a weighted annual mean pH of about 4.4 in the southeastern part of the state, 4.6 in north central Wisconsin and 4.8 in the northwest. This range is similar to that which caused environmental damage in Scandinavia, Canada and New England. Major sources of sulfur oxides and nitrogen oxides have been identified in Wisconsin. Over 87% of Wisconsin's sulfur dioxide emissions come from 43 point sources — primarily coal-fired power plants and pulp and paper mills.

Based on what's been learned in Scandinavia, Canada and New England, it is believed that Wisconsin's sensitive surface waters will become acidified if sulfate found in deposition exceeds a loading rate of 17.6 pounds of sulfate per acre per year for an extended period. Loading rates in half the state now exceed that amount. Several hundred vulnerable Wisconsin lakes have alkalinities near zero with a loading rate of between 12.3 and 15 pounds per acre per year. An unresolved question is whether acid rain has already created a Wisconsin lake obituary. As of now DNR researchers have not definitely stated whether eight northeast Wisconsin lakes which showed a decline in pH over the past 30 to 50 years are actually acid rain casualties. Nevertheless, the Wisconsin Interpretive Assessment Document on Acid Deposition states that acidification is likely to occur if present conditions in these lakes continue.

Wisconsin research has also shown that walleye, largemouth and smallmouth bass over five years old in several northern Wisconsin lakes with naturally occurring low pH exceed the FDA safe limit for mercury. The conclusion reached by Wisconsin researchers is that if acidification does occur in northern Wisconsin lakes, we can expect to see more mercury contamination in gamefish.

Taken together, these study results, conclusions and possibilities support the premise that acid rain will eventually cause damage in Wisconsin, if it hasn't already occurred. Must we wait for dead lakes, lost forests, or worse yet, humar health problems?

It is our belief that the magnitude o harm posed to the quality of life in Wisconsin mandates protective action now. Environmentalists are not the only ones to express such views:

"Congress should require a significant reduction by 1990 in the current level of sulfur dioxide emissions in the eastern United States." *The National Commission on Air Quality: March, 1981.*

"It is the Committee's opinion, based on the evidence we have examined, that the picture is disturbing enough to merit prompt tightening of restrictions on atmospheric emissions from fossil fuels and other large sources such as metal smelters and cement manufacture.

"Of the options presently available only the control of emissions of sulfur and nitrogen oxides can significantly reduce the rate of deterioration of sensitive freshwater ecosystems." *The National Academy of Sciences: September, 1981.*

"Members of the Work Group propose that present deposition of sulphate in precipitation be reduced to less than 20 kg/ha/yr [50% reduction over wide areas of the eastern US] in order to protect all but the most sensitive aquatic ecosystems." *US - Canadian Memorandum of Intent on Transboundary Air Pollution: January, 1983 Effects Work Group (Canadian Summary).*

"The Conference considered that the establishment and implementation of the concerted programmes for the reduction of sulphur emissions to be a matter of urgency.

"The acidification problem is serious and, even if deposition remains stable, deterioration of soil and water will continue and may increase unless additional control measures are implemented and existing control policies are strengthened." *The Stockholm 1982 Conference on Acidification of the Environment.*

"We recommend that additional steps should be taken now which will result in meaningful reductions in the emissions of sulfur compounds into the atmosphere beginning with those steps which are most cost effective in reducing total deposition.

"If we take the conservative point of view that we must wait until the scientific knowledge is definitive, the accumulated deposition and damaged environment may reach the point of 'irreversibility'." *White House Office of Science and Technology Policy panel on acid rain: June 27, 1983.*

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preventing or mitigating the effects?

- Are local sources of sulfur dioxide and nitrous oxides significant contributors to acid deposition in Wisconsin?
- Would a reasonable benefit be gained by further reducing emissions in Wisconsin?

The Wisconsin Power and Light Edgewater Plant at Sheboygan. In 1980 it was the second highest emitter in the state of both sulfur dioxide and nitrogen oxides with 58,474 and 28,730 tons respectively. Photo by Ron Becker.

Wisconsin's major utilities welcome the opportunity to participate in the Wisconsin Acid Deposition Research Program and to work cooperatively with the Department of Natural Resources and the Public Service Commission. This research will help us define the nature and significance of acid deposition in Wisconsin. Then, the state legislature, regulatory agencies, and utility managers together will be able to make reasonable judgements about the issue.

The researchers already have made a number of important findings. We know that Wisconsin's lakes have not been damaged. We know that Wisconsin's lakes are less susceptible than those in areas such as the Adirondack Mountains. We know that potentially vulnerable areas of northern Wisconsin receive only about 21% as much acidity in rainfall as does the northeastern US. And, we know that any changes that might take place in Wisconsin would probably not occur quickly, but rather over a period of several decades. All of these facts, developed through the cooperative research program, lead to the conclusion in the program's First Annual Report that we are not facing a crisis in Wisconsin.

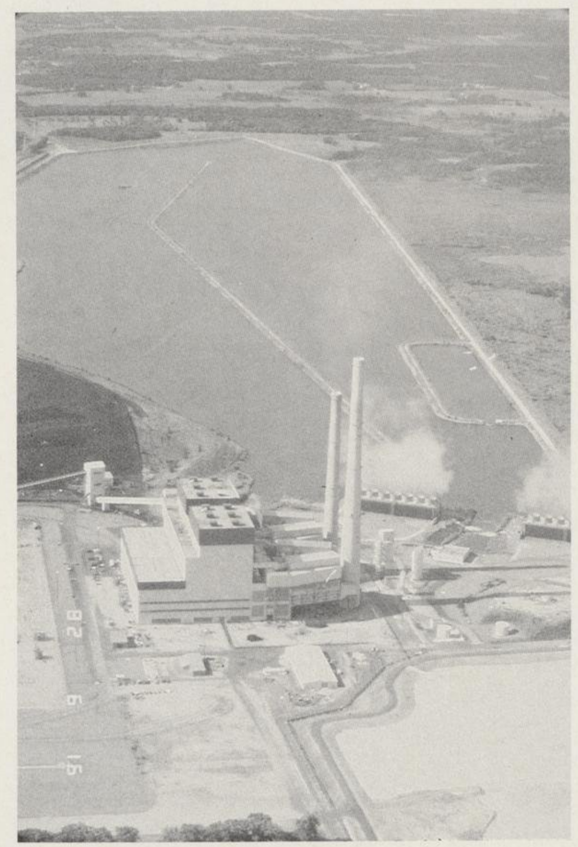
While these findings are reassuring, the utilities, state agencies, and other interested parties still need to know what long-term risks may exist and what cost-effective measures could minimize those risks.

Answers to those questions are already being developed. The research program is gaining the ability to predict changes in lake water quality that could result from changing acid deposition. Since water quality is influenced not only by precipitation falling directly on a lake but also by interactions of precipitation with vegetation, soils and groundwater in the surrounding watershed, the relationship is much more complex than previously thought. Completion of needed research over the next two years will significantly improve our ability to predict the relationship between changes in acid deposition and lake water quality.

Similarly, by the middle of 1985 we will have a much better understanding of the contribution of Wisconsin's emission sources to acid deposition in Wisconsin. With this information in hand, policymakers will have a clearer picture of whether reducing these emissions would significantly reduce acid deposition in Wisconsin.

Both of these important pieces of the puzzle will help Wisconsin's legislators and regulators decide whether — and if so, what — actions should be taken. Without this essential information about causes and effects of acid deposition in Wisconsin, these decisions can only be based on guesswork.

Another piece of the puzzle will be answered in 1985 by a joint DNR/Utility study of the costs of significantly reducing emissions of sulfur dioxide. Requested by the Wisconsin legislature, this study will help determine the costs of reducing sulfur dioxide emissions by 30 to 70%. Control techniques to be examined include coal cleaning,



A new Wisconsin law places a cap of 500,000 tons per year on sulfur dioxide emissions from the state's five major utilities. This new power plant in Columbia County was especially designed to burn low sulfur coal. Photo by Dennis Yockers

THE ACID TEST

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Federal Government Failure To Act

Acid rain is a local, state, national and international problem. Many Americans had great hopes that Congress would pass an acid rain bill, along with reauthorization of the Clean Air Act, in the last session. This did not happen. Nevertheless, it is useful to review the most important provisions under discussion because they will most certainly be considered at the next politically opportune moment.

The Waxman-Sikorski Bill (H.R. 3400) was the most important of the numerous acid rain bills because it was the most comprehensive in scope and also had the most co-sponsors. Introduced by Representatives Henry Waxman (D-CA), Gerry Sikorski (D-MN) and Judd Gregg (D-NH), H.R. 3400 would have sought emission reductions through an innovative approach. [The only Wisconsin co-sponsors were Aspin (D-1st District), Kastenmeier (D-2nd District) and Obey (D-7th District)]. The first phase of the bill would require the 50 largest and dirtiest utility plants across the country to install scrubbers, thus reducing total annual emissions by seven million tons. The only Wisconsin plant on this list is the Wisconsin Electric Power Company (WEPCO) Oak Creek Generating Station, which would have to reduce annual sulfur dioxide emissions by 66,300 tons. Phase two would require an additional three million ton reduction across the 48 states. An allocation formula determines the amount of each state's reduction. A state may choose any method it deems appropriate to meet the reduction goal. Wisconsin's target emission reduction would be 342,600 tons. Thus, an additional 276,300 ton reduction would have to be found from other sources. The reductions would have to be achieved within 10 years.

H.R. 3400 would also create what has been termed an "acid rain superfund." It would be raised by a one mil per kilowatt surcharge on all non-nuclear electricity generated in the 48 states. This fund would pay for 90% of the controls on the 50 largest utility sources, and the remainder of the funds would be apportioned among the other sources which must make reductions. The Office of Technology Assessment has estimated an average increase of $2.19 per month on an average Wisconsin residential electric bill. Industry-generated cost estimates are considerably higher. There is no provision for offsetting of increased emissions from future sources.

H.R. 3400 has two provisions for nitrogen oxides. It would establish tougher standards for new coal-burning plants, setting an annual reduction in nitrogen oxide emissions of 1.5-million tons. It also sets tighter nitrogen oxide emission standards for large trucks, thereby achieving a two to three million ton reduction.

Both DNR and Governor Tony Earl had endorsed H.R. 3400 in concept (reservations have been expressed regarding the mandatory scrubber requirement and the adequacy of the funding mechanism). Passage of this legislation is the most critical element in development of a national solution to the problem.

Given the political uncertainties regarding the prospect of federal legislation, and the growing certainties documenting the threat to Wisconsin, the Wisconsin legislature and DNR have taken the position that some state action is indeed justified now. However, actions taken by both the legislature and DNR form a public policy whose elements are both irreconcilable and contradictory and do not go far enough.

The Wisconsin legislature has recently passed three bills pertaining to acid rain. The most notable of these would "cap" major electric utility emissions at 500,000 tons per year, beginning in 1985. This bill also sets a goal of 675,000 tons in annual sulfur dioxide emissions for all Wisconsin sources. The cap bill has been roundly criticized for not covering all major sulfur dioxide sources (the pulp and paper industry was originally to be included), and for setting a "cap" which is not actually constraining.

Another Wisconsin bill directs DNR to study the cost of 30, 40 and 50% reductions in emissions of sulfur dioxide from all sources. Finally, the Little Rock Lake research project was also authorized. This project will study effects of acidification on warm water fish communities, and will allow development of a list of diagnostic symptoms of lakes undergoing acidification.

These actions are of course laudable in intent, but weak in terms of substantively addressing the problem of acid rain — although they were admittedly never designed to do so. Wisconsin cannot be content to impose a quasi-cap, and merely support further research. The State of New York recently took the landmark step of passing legislation mandating emission reductions within state boundaries. The bill calls for an emission rollback of 12% by 1988, and a 30% reduction by 1991, or soon thereafter. Massachusetts and other states may also follow the New York example. Unfortunately, New York had to sustain widespread damage before it adopted this bill. Wisconsin must not hesitate until the damage is done, but must take preventative steps and adopt rollback legislation now.

Although DNR has, of course, supported the three Wisconsin acid rain bills which passed, it has continued to adhere to an archaic position through its regulation of sulfur dioxide as an ambient health problem. Environmental groups threatened litigation to obtain development of statewide sulfur dioxide rules. Wisconsin is one of only three states in the nation without such rules. Thus, several areas of the state are currently in violation of the national ambient air quality standards. Rules* must be developed and implemented which ensure attainment and maintenance of the standards through use of reasonably available control technology.

*Passed by the Natural Resources Board 9/26/84.

However, DNR must change its position on allowing stack-height increases as a primary method of pollution control. By increasing stack height, emissions are dispersed over a greater area. This not only avoids emission reduction, it may even allow them to actually increase — without subsequent violation of the ambient standards at ground level.

In the past, DNR has allowed sources to raise stacks to a height defined as good engineering practice (GEP). A GEP stack can be as high as 2½ times the height of a building adjacent to the source of emissions as defined by the US Environmental Protection Agency. The conditions under which sources are allowed to take advantage of increases in stack heights up to GEP have been the subject of national controversy. Recently a federal court rejected the US Environmental Protection Agency's definitions of GEP stack height.

Unfortunately, the DNR has continued to allow sources to take full advantage of EPA's definition of GEP, even though DNR has the authority to impose stack height regulations which are more stringent than the federal EPA regulations.

The most notorious example occurred in Green Bay. Even though DNR

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blending of different sulfur content coals, switching to lower sulfur coal, installation of flue gas desulfurization equipment, early retirement of older plants, increased energy conservation and other measures.

By examining such a range of options and associated costs, policy-makers will be in a better position to respond to federal legislative proposals or to understand the cost implications of initiatives that might be proposed at the state level. Wisconsin's utilities feel this is an important issue to our customers - the citizens of Wisconsin - since some proposed federal legislation could raise electric rates by 25% or more.

In the meantime, the legislature has also enacted a bill which limits major utility sulfur dioxide emissions while research is conducted to determine whether further reductions are needed.

As a result of foresight and cooperation between state government and utilities, Wisconsin is in the unique position of having established a decision-oriented acid deposition research program. Over the next two years, this research will provide the information policy-makers need to make rational judgements about the issue. The largest threat to Wisconsin's overall well-being comes not from deferring action, but from acting before the facts are in. We have the time and the ability to make a rational decision. Let's use them wisely.

Stack heights are the subject of a national controversy. Photo by Dennis Yockers

Ninety-five acre Vandercook Lake in Vilas County
The amount of acid loading from the atmosphere is critical to a sensitive lake like this one. Studies here analyze the water and chemical budgets as well as the biota. Photo by Katherine Webster

imposed a "cap", taller stacks there will allow a potential 64% increase in emissions over 1982 levels, and a 41% increase over average annual emissions from 1979 to 1981. DNR also recently allowed GEP stacks in Peshtigo, Rhinelander and Rothschild. Both the states of Michigan and Minnesota have joined Wisconsin environmentalists in protesting these approvals.

Although DNR has allowed stack height increases up to GEP, it did testify before the Public Service Commission to prevent a major utility from constructing a stack above GEP. Fortunately, recent court decisions will force EPA to promulgate more stringent stack rules. These new rules will force DNR to re-examine and probably re-write control strategies for many areas across the state.

Finally, the Wisconsin research effort must be broadened to include areas currently being ignored. According to the first annual report, research is needed to determine effects of acid rain on Wisconsin farmland and crops; on manmade materials such as buildings, highways, bridges, culverts and statuary; on mammals, birds, amphibians and reptiles; on the economy; and on control strategies for sources. Of these, research on forestry and materials damage would be of highest priority. Research on materials damage is especially needed in southeast Wisconsin, which is receiving the highest acid loading in the state, and which has the greatest population density and concentration of sensitive materials.

Wisconsin has a legal and moral obligation to give the fullest protection possible to our priceless resources. Delaying state action and waiting for a federal law is a gamble which risks the Wisconsin ecosystem. Environmental treasures could be lost before a national consensus on control is achieved. For the sake of current and future generations, the Wisconsin legislature and DNR must refuse such a dangerous gamble.

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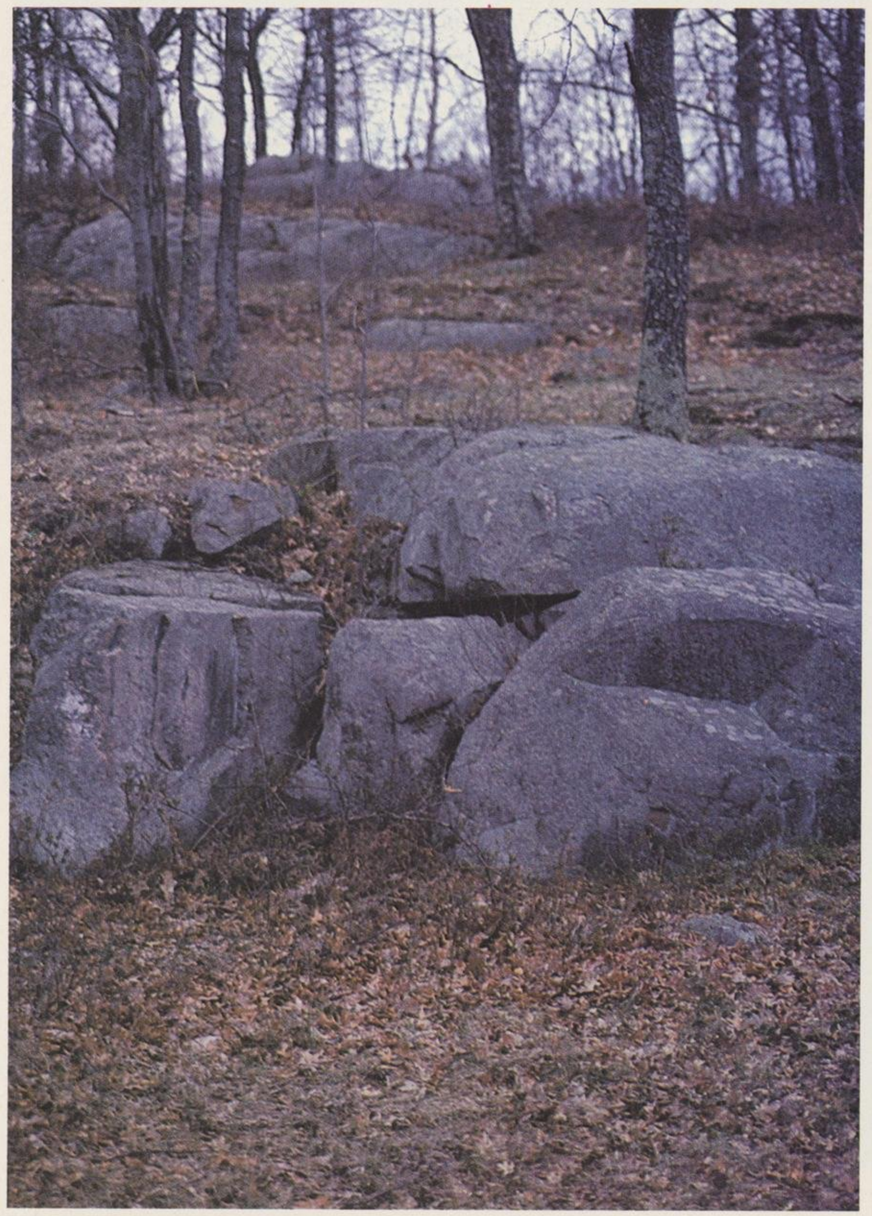


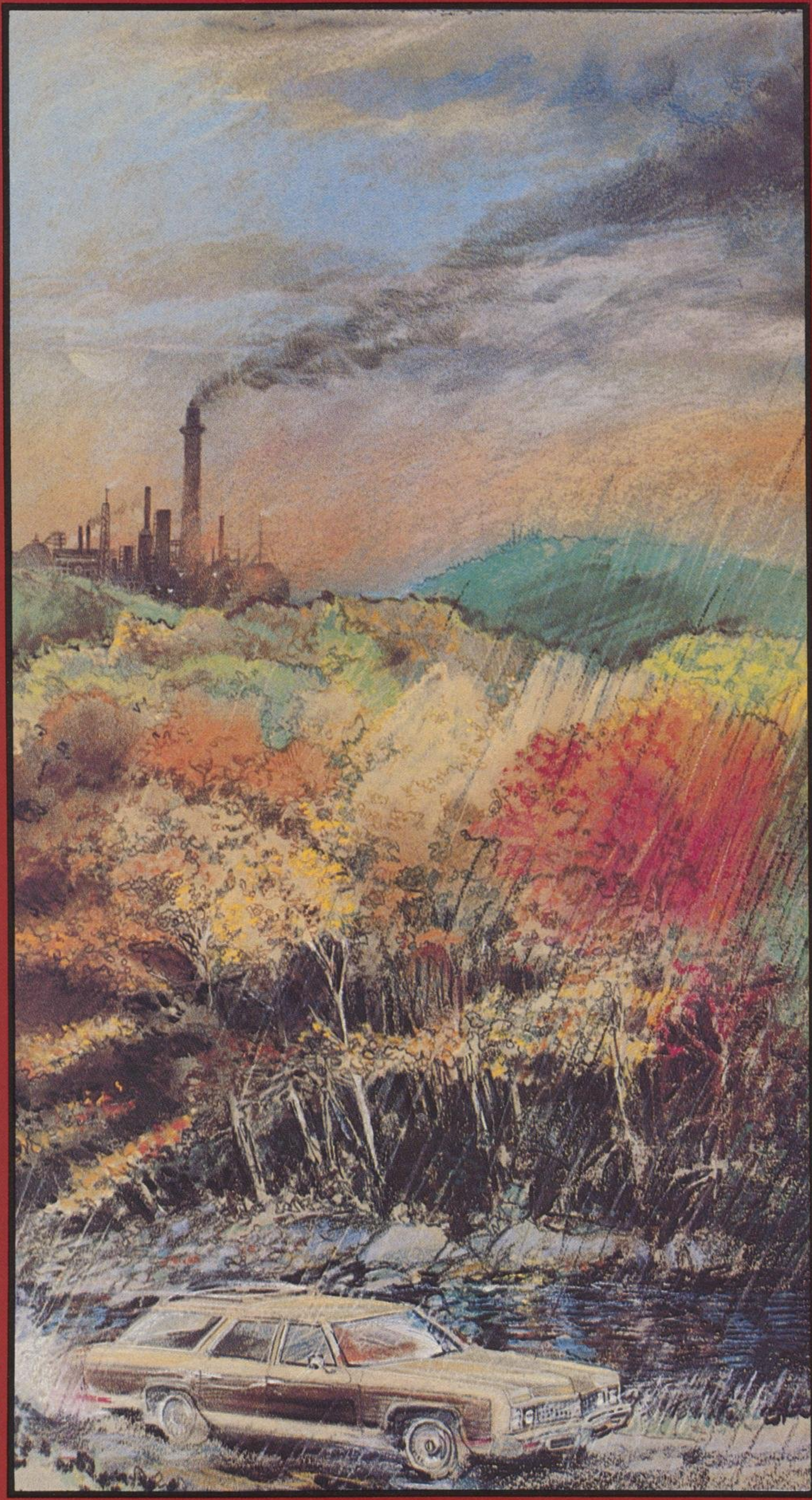
Areas of the state with granite bedrock offer little buffering capacity to lakes. Photo by Pete Flaherty

Wisconsin has a legal and moral obligation to protect our priceless resources for the sake of current and future generations. Photo by Dean Tvedt

Large walleyes like this seven pounder can be contaminated with mercury when caught from acidic lakes. Photo by Thomas Sheffy

In the Adirondacks and in Scandinavia acid rain has wiped out certain species of fish and other aquatic life. Art courtesy of the National Wildlife Federation.

back cover—Art courtesy of the National Wildlife Federation



"Evidence of our concern about acid rain is seen in the $2-million dollars that has been invested in Wisconsin acid rain research in the last five years. What we have learned from this research has heightened our concern and convinced us that action is needed now at both the state and federal level. This includes continued research, an immediate halt to increases in emissions and a federal program that will require emission reductions."