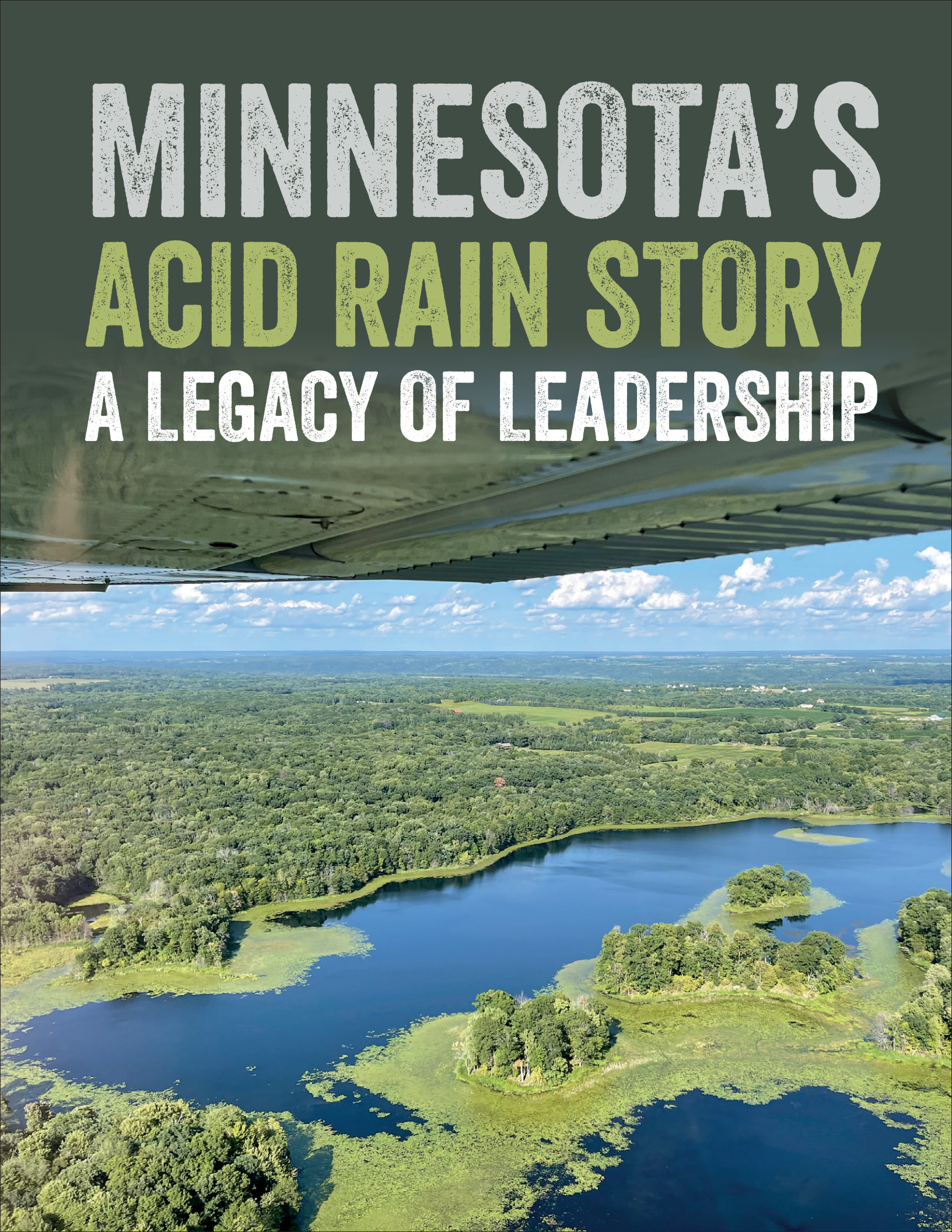
MINNESOTA'S ACID RAIN STORY

A LEGACY OF LEADERSHIP



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In 1982, the Minnesota Legislature passed, and Governor Al Quie signed, the Minnesota Acid Deposition Control Act, the first acid rain regulation in the United States at a time when it was arguably the hottest environmental issue. The act directed the Minnesota Pollution Control Agency to develop an acid deposition standard and control plan. In 1986, despite resistance from coal and energy interests, the agency promulgated rules fulfilling the statutory requirement.[1]

The scientific groundwork that set the stage for Minnesota's action involved two internationally renowned scientists: a Canadian who emigrated to Minnesota, where he spent a career conducting groundbreaking research on aquatic systems, and a Minnesotan who emigrated a short distance across the border into nearby Ontario to conduct seminal work on watersheds affected by pollution. Their holistic approaches drew on nuclear weapons testing, pollution of lakes by detergents, and the complex relationships between the atmosphere and the aquatic systems. Their work helped drive public concern about acid rain and the eventual passage of the Minnesota law.

THE ENVIRONMENTAL SCENE, 1960–1980

Environmental consciousness was on the upswing in the 1960s and 1970s. Rachel Carson's influential book *Silent Spring* was published in 1962. Oil shortages drew attention to the limits of natural resources. Environmental catastrophes such as Ohio's Cuyahoga River fire (1969) and Pennsylvania's Three Mile Island partial nuclear meltdown (1979) created an awareness that human activities were fundamentally damaging the planet. More and more Americans, and others around the world, were recognizing that something was amiss in humans' relationship to the earth. The zeitgeist of this era was characterized by British astronomer Sir Fred Hoyle's 1948 prediction: "Once a photograph of the Earth, taken from outside, is available . . . a new idea as powerful as any other in history will be let loose."

Eighteen years later, on August 23, 1966, NASA's Lunar Orbiter took the first photos of Earth from the moon's orbit. Many observers have noted the impact this image had on the human psyche. The growing environmental awareness led to the celebration of the first Earth Day (1970) and the passage of pivotal legislation, including the National Environmental Policy Act (NEPA, 1970), the Clean Air Act (1970), and the Clean Water Act (1972). The Environmental Protection Agency was established in 1970, and President Richard Nixon appointed highly regarded William Ruckelshaus as its first administrator.[2]

As pollution became more blatant in the 1960s and 1970s, times were ripe for new environmental regulations. Public support was high for improvements in clean air and water. A politically active generation building on earlier social and antiwar movements expanded public awareness that corporations were "getting away with murder." In addition, increasing affluence in the US economy made it possible to pay for these regulations. Caught off guard, the business community was unable to mount sufficiently strong opposition. These landmark pieces of legislation embodied the mindset that environmental problems could be solved locally by controlling big polluters.

Aerial photo of Terrapin Lake in Washington County, Minnesota, in 2021.

The directives in the laws are known in the parlance of environmental regulation as "command and control," because they mandate emissions limits at individual industrial plants.[3]

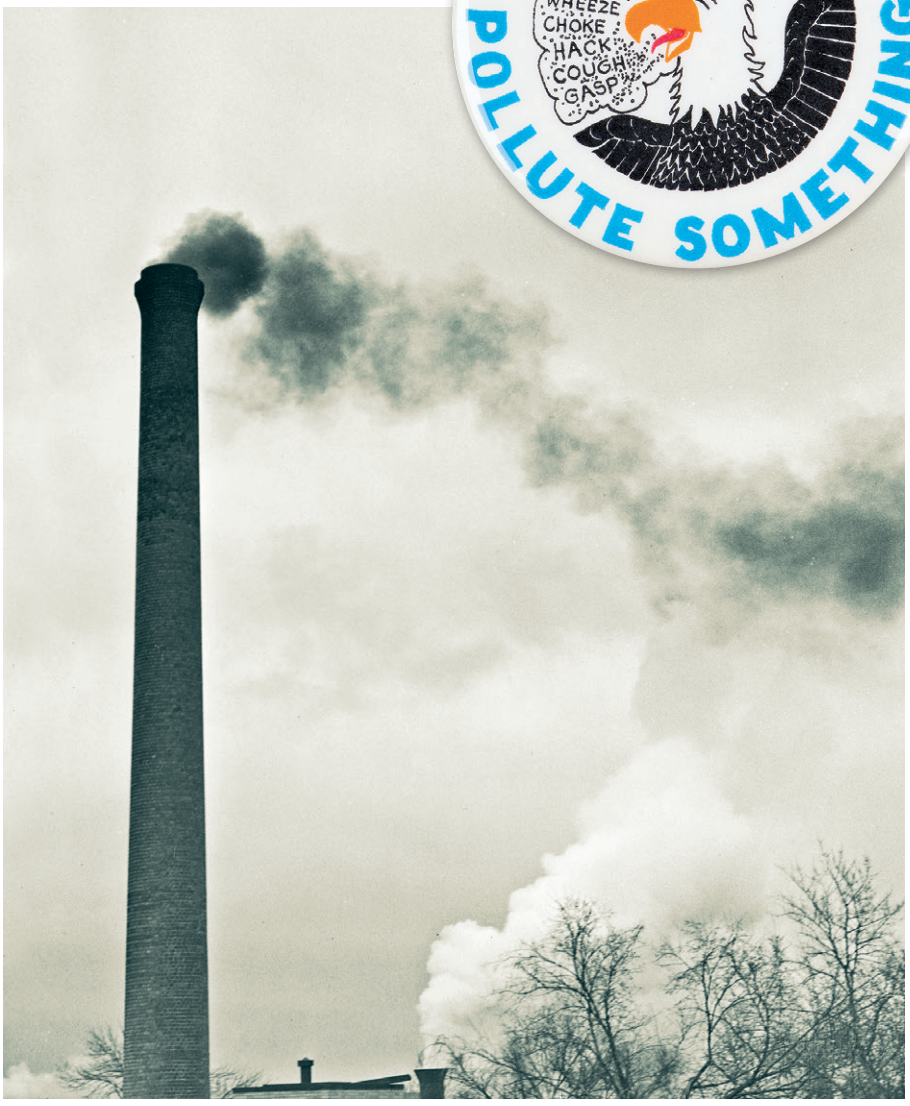
Even as these new laws were passed, many scientists and government officials began to recognize that environmental impacts cross political boundaries; that effects can be subtle and move from one compartment in the environment, such as the air, to another compartment, such as water; and that solving these problems might require multijurisdictional and even multinational efforts. In the 1960s and 1970s, however, this holistic consciousness was in its infancy. Ironically, one of the unforeseen consequences of the 1970 Clean Air Act was that many polluters, rather than reduce emissions, raised the heights of their smokestacks to disperse the pollution more widely, thus reducing local impacts but exacerbating acid deposition downwind.

Acidic deposition has existed since coal burning became widespread during the Industrial Revolution. The term "acid rain" was coined in 1872 by Robert Angus Smith, who first observed the acidity of precipitation in 1852 in Manchester, England. His observations were largely ignored or forgotten. Modern awareness of acid rain dates to 1955 and is attributed to Earl Barrett and Gunnar Brodin, working in Sweden; and to Eville Gorham, who began his acid rain work in England's rural Lake District before coming to Minnesota. These scientists showed that acidic precipitation, fog, and clouds containing acidified water from urban and industrial sources dispersed far downwind. This was something new that we really hadn't known about clouds.[4]

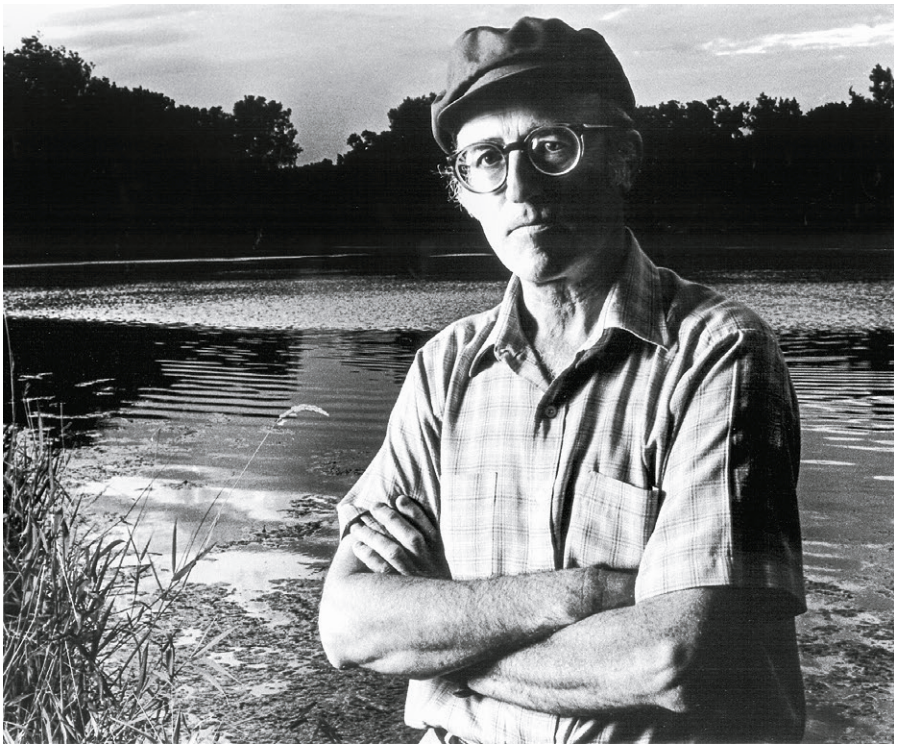
TWO SCIENTISTS WITH MINNESOTA CONNECTIONS AT THE FOREFRONT

Two internationally preeminent scientists with Minnesota connections, professors Eville Gorham and David Schindler, were at the forefront of the work that formed the basis for environmental regulations addressing acid rain. Born in Halifax, Nova Scotia, Gorham earned his doctorate at University College, London, studying the chemistry of bog wetlands and rainfall in England's Lake District. Serendipitously, as he describes it, in 1957 he discovered high levels of radiation in the hillside vegetation in Westmorland, England.

> Then, as if a light bulb flashed on in my head, I suddenly realized that the local hillsides contained their own ion-exchangers in the form of Sphagnum moss. . . . Next morning . . . I gathered some moss, brought it back to the lab, burned it, and placed the ash in the Geiger



Industrial pollution had gone largely unchecked in the United States for decades. By the 1970s and '80s, environmentalists were becoming more organized and outspoken in their demands for regulations.



Eville Gorham of Halifax, Nova Scotia, photographed at an unidentified Minnesota lake in 1984.

> counter. When I switched on the counter it began chattering . . . so rapidly that I rushed down to [colleague and radiation expert] Don Swift's office shouting "Don, come quick, something's gone wrong with the counter." He . . . accused me of contaminating the machine . . . that these count rates were impossible. . . . I began testing the ashes of all sorts of plants: mosses, lichens, ferns, herbs, grasses, tree leaves and garden plants, and found that mosses and lichens were far higher than the others in their fallout content. This was because mosses and lichens—lacking roots in the soil—derive their mineral supplies mostly from rain and snow.[5]

Soon afterward, Gorham chanced to read an obscure Norwegian Defense Research Ministry report on radiation levels in Norway, which were presumably resulting from nuclear testing in the atmosphere in remote areas of the Pacific Ocean. The report indicated that the bones of reindeer were much richer in radioactive strontium than the bones of sheep. Gorham immediately realized that this was because lichens are a large part of the reindeer diet, and that led him to predict that reindeer herders would also have high levels of radiation in their bodies. That prediction was later substantiated by scientists in Finland, Alaska, and elsewhere. The studies flowing from this remarkable insight provided evidence to support the Nuclear Test Ban Treaty of 1963. Gorham's experience with radioactive fallout also informed his ongoing work on nutrient cycling in wetlands. He observed that elevated levels of acidity in England's rural lakes correlated with the acidity of rainfall; the highest acidity occurred downwind from industrial areas.[6]

In 1962, an attractive job offer brought Gorham to the University of Minnesota, where he spent the rest of his career pursuing his many interests in ecology—especially the effects of atmospheric deposition on wetlands—and earning many awards. Upon his death in 2020, the *Minneapolis Star Tribune* featured him in an article entitled, "World-Renowned Ecologist Was 'Grandfather of Acid Rain Research.'"[7]

The finding that radioactive substances could travel long distances in the air and cause harmful effects far from the source was an eye-opener for scientists and the public. The parallels with acid rain soon began to multiply, especially in the northeastern United States, in adjacent Canada, and in northern Europe, places where lake acidification was being observed. The issue gained notable traction in Scandinavia due to the work of Svante Odén, who was commissioned by the Swedish government to prepare a report on acid rain. To the consternation of his superiors, he went outside normal scientific channels and sent a preliminary version to the Stockholm newspaper *Dagens Nyheter*, where it was published in 1967, garnering much more attention than the 1955 work by Barrett and Brodin published in a Swedish scientific journal. In 1968, the Swedish National Research Council published Odén's report, "The Acidification of Air and Precipitation and Its Consequences in the Natural Environment."[8]

Many early US acid rain studies were done in New England and the Appalachian Mountains, both downwind from the sulfur dioxide–emitting power plants in the Ohio River valley. In 1955, researchers began a large-scale ecosystem study at Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. Gene Likens, F. Herbert Bormann, and colleagues found the rainfall there to be nearly 100 times more acidic than they expected. They also found that lakes and streams in New England were acidifying and losing fish, similar to conditions in Scandinavia. James Galloway and

coworkers at the University of Virginia studied the damage to Appalachian forests by acid deposition.[9]

Meanwhile, in the Midwest, scientists in Minnesota and neighboring Wisconsin and Ontario began studying acid rain as well. Among them was David Schindler, who had grown up near Barnesville, Minnesota. He attended the University of Minnesota and North Dakota State University. While a Rhodes scholar at Oxford University, he read Eville Gorham's work on acid rain. After graduating in 1966, Schindler accepted a position at Trent University in Ontario, but he was soon lured away to a new, unique project called the Experimental Lakes Area (ELA), which lies just north of Minnesota near Lake of the Woods.[10]

Schindler and coworkers began measuring lake chemistry and acidity in 1968, and they later started large-scale experiments manipulating entire lakes. The first ELA study involved placing a plastic curtain through the middle of Lake 226 (each lake is numbered) and adding phosphorus to one side. An algal bloom developed on the phosphorus side. Arizona State University biologist James Elser described the aerial photo of the experiment as "the single most powerful image in the history of limnology," and the experiment led to phosphorus bans in detergents. Other ELA experiments involved dosing lakes with mercury, estrogen, or oil.

Faced with budget cuts, and on the advice of Gorham and others, Schindler refocused ELA work on acid rain. From 1976 to 1993, he and ELA staff added sulfuric acid to Lake 223 and began taking copious measurements on the effects of this addition. The most dramatic thing they found was that "lake trout stopped reproducing not because they were toxified by the acid, but because they were starving to death." The acid was killing the smaller organisms in their food web. Photographs of starving fish drew widespread public attention.[11]

Acid rain studies began to generate extensive publicity. Gene Likens said that his phone didn't stop ringing for months, recalling, "It was that media exposure that really put acid rain on the map in North America." On December 14, 1978, for example, the ABC *Evening News* reported,

> In the Adirondack Mountains of New York the lakes are so clear they mirror the forest around them. One might think pollution could never taint this mountain paradise, but it has. The fish have died in this lake. The rain has turned the water acid. Scientists say particles of sulfur are carried by these clouds and when it rains it pours a mild sulfuric acid into lakes like this one. The experts say power plants discharge most of the sulfur into the air. And what goes up these smokestacks, must come down.[12]

Based on the work of Gorham and others, blame for acid rain pointed to emissions from distant coal-burning power plants; however, the existing command-and-control regulatory framework did not allow for such a scenario to be adequately addressed. Long-range atmospheric transport and deposition of air pollution was a new field, and a definitive cause-and-effect relationship between sulfur dioxide emissions and distant acid rain was not yet confirmed to everyone's satisfaction. "There were lots of deniers of acid rain," noted Likens.[13]

Professor David Schindler speaking at a symposium honoring the fiftieth anniversary of the Experimental Lakes Area project.

In 1978, the National Atmospheric Deposition Program began monitoring acid rain. Two years later, the National Acid Precipitation Assessment Program began studying the causes of acidification. In addition, the US National Research Council had established a panel of experts in the late 1970s to look into the issue. David Schindler was asked to lead the panel, and Eville Gorham and Svante Odén were key members. Schindler and Gorham had first met in 1970 and found that they shared professional interests and enjoyed one another's company. They became the driving force behind the panel's finding of "overwhelming" evidence that emissions from fossil-fuel power plants were causing acid rain. The panel's work was politically sensitive and gained notoriety as "the Canadian Conspiracy," since Gorham was a Canadian working in Minnesota and Schindler was a Minnesotan working in Canada. As Schindler recalled,

Schindler and coworkers began measuring lake chemistry and acidity in 1968, and they later started large-scale experiments manipulating entire lakes.

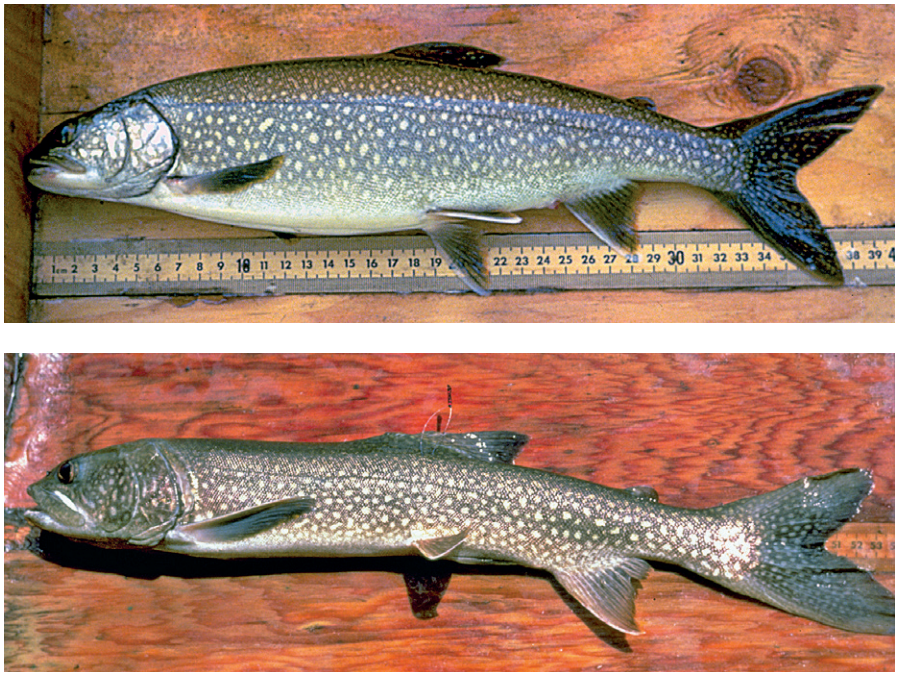
> The official US position was that only a few small lakes in the Adirondacks were harmed, and they did not like our showing that there were thousands of more sensitive lakes in Canada, acidified by American emissions. Of course, that is when Canadian bureaucrats became interested, bragging about how foresighted they had been to begin the ELA work that they had earlier refused to fund.[14]

The members of the National Research Council's expert panel were asked to testify before Congress about the report. Schindler was forbidden by his Canadian superiors to communicate with the chairman of the US House of Representatives' Energy and Commerce Committee, John Dingell (Michigan Democrat), because the negotiations between the US and Canadian governments on how to address acid rain were sensitive, and Schindler was known to speak openly about his conclusions without regard to the possible political implications. Schindler's bosses also threatened to dismiss him if he traveled to the United States to testify. He did so anyway, traveling on vacation time and as an American citizen. "It was a bad time for an introvert, but I survived and later even got awards for some of the same things I had been reprimanded for a decade earlier!"[15]

A plastic curtain was placed across a narrows in Lake 226 in the Experimental Lakes Area, and phosphorus (then commonly used in detergents) was added to one side of the lake. The algal bloom that developed on the phosphorus side (bottom of photo) provided dramatic evidence of the effects of pollutants on our lakes and waterways.

Controversy about whether to regulate emissions arose among US states. Those that mined and burned coal generally did not have vulnerable resources like low-alkalinity lakes and forests on soils with little buffering capacity, while economies in New England and states like Minnesota that had vulnerable lakes and forests were not reliant on coal. The northeastern states with the best documented damages called for a national plan to control emissions, but support was tepid in much of the rest of the country. The Ohio Valley states with many large coal-burning power plants and the eastern coal-mining states were adamantly opposed to emissions limits. The automobile, steel, and rubber industries of the Rust Belt states were in decline, and those states also opposed regulations. Coal and electric-power interests believed that addressing acid rain would result in increased electricity costs, further hurting these industries. At the national level, for the time being, economics trumped environmental concerns, and action was put off.

The 1980 election of President Ronald Reagan solidified a pro-business, anti-environment approach to federal regulations. On the campaign trail, Reagan claimed, "approximately 80 percent of our air pollution stems from hydrocarbons released by vegetation, so let's not go overboard in setting and enforcing tough emission standards from man-made sources." Reagan's appointees to head the Environmental Protection Agency and the Department of the Interior (Anne Gorsuch Burford and James Watt, respectively) opposed regulation and worked to undo existing rules. With powerful interests opposing action, political leaders took the more politically palatable approach of endorsing further study.[16]



Lake trout before and after acidification eliminated key food species from Lake 223 in the Experimental Lakes Area during the lake acidification study.

Meanwhile, back in Minnesota, politicians from both sides of the aisle followed a different path. Minnesota stood alone in taking the moral high ground by enacting measures to limit emissions from state sources despite the fact that the bulk of deposition in the state originated elsewhere. Even the highly impacted New England states did not act independently but chose to support a national approach.[17]

MINNESOTA—AN ENVIRONMENTAL LEADER

The State of Minnesota is often recognized for its environmental progressiveness. Perhaps the rich and varied landscape, the traditions of the indigenous Native American tribes, and the large numbers of conservation-minded hunters and fishers fostered a heritage of environmental protection and an attitude of respect and preservation. The Minnesota Pollution Control Agency (MPCA) was established in 1967, three years before the US Environmental Protection Agency. Minnesota was an early adopter of a state environmental policy act, passed in 1973, requiring review of projects for potential environmental impacts. The state has also been a trailblazer in many other efforts to legislate and regulate for environmental protection.[18]

These policy efforts included a long battle to preserve the Boundary Waters Canoe Area Wilderness (BWCAW). Following hotly contested debates, Congress passed and President Jimmy Carter signed the 1978 act establishing the wilderness. The National Association of Property Owners, the State of Minnesota, and other nearby property owners challenged the law in court, but a broad coalition of state and national environmental groups worked to preserve the wilderness designation, which was upheld by the US Supreme Court in an 8–1 decision on March 8, 1982.[19]

This highly mobilized and motivated environmental coalition was sensitive to other threats to the

A Union Pacific freight train carrying car after car of western coal through the Thunder Basin National Grassland in Wyoming.

A pro-BWCA button from 1978.

state's natural resources. Collectively, these activists were well positioned to respond to the new threats of acid rain. They also were aided by Eville Gorham from the University of Minnesota, by a progressive state legislature willing to act, and by the relatively inexpensive solution of switching to low-sulfur western coal. These conditions enabled Minnesota to act ahead of the nation and alone among states.[20]

Preliminary acid rain research by the MPCA in the 1970s suggested that approximately 1,000 of the state's lakes were threatened, and an additional 3,500 could be threatened if emissions continued unchecked. The thin humic soils and coniferous forests of northeastern Minnesota were also vulnerable. At a US House subcommittee meeting in 1980, Gorham testified, "In Minnesota, the data we now have suggests that rain is approaching the acidity levels which have caused distinct damage in Scandinavia." These concerns proved powerful in the political arena and convinced Minnesota lawmakers to act.[21]

During the 1970s, progressives dominated the state political scene. The Democratic-Farmer-Labor Party (DFL) held majorities in both houses of the state legislature for most of the decade. By the late 1970s, the party held as many as 49 out of 67 seats in the state senate. The house of representatives was more volatile; the DFL held as many as 104 out of 134 house seats in the late 1970s, but by the early 1980s the body was more evenly divided. DFL governors held office for 26 of the 36 years between 1955 and 1991.[22]

In 1982, state representative Arlene Lehto noted that Minnesota should take steps to limit its own emissions before asking other states to make reductions, saying, "I believe it will lay a foundation for us to go after the other states who are causing 70 percent of our problem."

Despite differences on other issues, the two main political parties broadly supported environmental causes.

These arguments carried the day in Minnesota despite lobbying from the electric utilities, the taconite mining industry, and out-of-state coal mining interests. The opponents argued that, in acting alone, Minnesota would put the state's industries at a competitive disadvantage. They further feared that emissions reductions achieved ahead of federal action might not be credited under a later national plan, forcing Minnesota's industries to make reductions twice over.[23]

Despite differences on other issues, the two main political parties broadly supported environmental causes. The house authors of the acid rain bill included DFL representatives Arlene Lehto (St. Louis County), Willard Munger (Duluth), and Lee Greenfield (Minneapolis); and Republicans Gary Laidig (Stillwater area) and William Dean (Minneapolis). The bill passed the house with only four opposing votes. The senate author was DFLer Gerald Willet. The final senate vote was 56 in favor and 3 opposed. The bill was then sent to Governor Al Quie (Independent Republican) for his signature, securing the first acid rain regulation in the United States.[24]

The act directed the MPCA to develop an acid deposition standard and a control plan to ensure that the standard was attained and maintained. One indicator of the strength of support for action on acid rain is that while Governor Quie signed the Acid Deposition Act, he was not on record as a staunch environmental advocate, and that same year he vetoed another significant piece of environmental regulation, the Minnesota Superfund law. A sum of $81,455 was appropriated from the general fund to conduct the mandated work in the first year (1983), and an assessment on electric utilities was established for future funding.[25]

The statute did not call for specific controls, due in part to the lack of detailed knowledge about the sensitivity of resources in Minnesota and exactly what was needed to protect them. Instead authority was delegated to the executive branch, i.e., the MPCA, to conduct studies and promulgate rules. Although numerous acidified lakes had been identified in New England and Canada, along with a handful as near as Michigan and Wisconsin, no acidified lakes had been found in Minnesota. The view across the political spectrum was that the MPCA could be trusted to conduct a serious analysis and propose a reasonable solution.

SHOW US THE DATA

One of the MPCA's first steps was to determine the extent to which resources in Minnesota were at risk from acidic inputs. Beginning in the late 1970s and early 1980s, field workers from the MPCA, the US

Environmental Protection Agency Duluth Laboratory, the US Forest Service, and the Minnesota Department of Natural Resources sampled 1,842 lakes and found that 474 of them were sensitive to acid rain. Most of the sensitive lakes were small, averaging about 240 acres, but many were valuable fishing and recreational lakes. Extrapolating from this sample, the MPCA estimated that as many as 2,200 lakes in Minnesota could be affected. Approximately 200 lakes were considered highly sensitive, primarily in Itasca, Lake, Pine, and St. Louis Counties.[26]

Monitoring of other ecosystems showed that they were not as sensitive to acidic inputs as the poorly buffered lakes. Sandy outwash soils of eastern Minnesota and shallow bedrock soils of the Arrowhead Region, encompassing 1,365,600 acres, were classified as potentially sensitive to acidic deposition. No evidence was found for damage to forests or peatlands at the existing levels of deposition. These findings suggested that if lakes were protected, then less-sensitive resources like soils and forests would also be protected. The MPCA found no lakes in Minnesota with significant damage to aquatic life; however, such lakes were known in nearby Wisconsin, Michigan, and Ontario.

In December 1982, the MPCA compiled a report entitled "Aquatic, Terrestrial, and Peatland Ecosystems in Minnesota Considered Sensitive or Potentially Sensitive to Acid Deposition." It was presented to a technical review committee, and after comments and discussion, the MPCA Citizens' Board approved the report in April 1983. The MPCA continued to update the sensitive areas listing as new information became available.[27]

As a prelude to rulemaking, the MPCA had established a technical review committee with representatives from the forest, tourist, utility, and mining industries, as well as environmental advocates and state agencies. The committee was charged with discussing specific issues and, if possible, resolving some of them prior to the formal rulemaking process. The meetings were open to the public and were sometimes attended by dozens of interested parties. The committee narrowed the focus to the most controversial issues, and unsurprisingly given the divergent interests attending the meetings, little progress was made in resolving them. Most attendees favored controls on acid rain; however, those opposed to regulations were well funded and brought teams of attorneys and consultants. The MPCA realized early on that consensus would be difficult. Nevertheless, taking into account the review committee inputs, the agency proceeded to develop rules pursuant to the statutory directive.

Acidified lakes were often treated by adding lime from a boat or by helicopter, as in this demonstration during a 1990 conference in Gävle, Sweden.

The Minnesota Administrative Procedures Act prescribes a rigorous process to ensure that interested parties can comment on proposed rules. In October 1984, the MPCA published a Notice of Intent to Solicit Outside Opinion. In November 1985, the MPCA Citizens' Board authorized formal rulemaking, and the agency filed documents with the chief administrative law judge indicating the intent to hold hearings. In December 1985, MPCA director Thomas Kalitowski issued a Notice of Hearing; eight days later Northern States Power Company (NSP; now Xcel Energy) filed a procedural objection. Several procedural filings ensued, but the process moved forward.[28]

Rule promulgation requires development of a Statement of Need and Reasonableness describing the statutory authority, the reason for the rule, and why the specific features of the proposed rule are reasonable. After the statement is registered, a 30-day public comment period follows. If 25 or more persons request an administrative hearing, an administrative law judge must take testimony. Agencies are required to demonstrate a rational basis for a rule, but they do not need to demonstrate that it is the "best" rule.[29]

The MPCA Statement of Need and Reasonableness was lengthy and technically detailed. It was also unusual. Rather than relying exclusively on existing evidence, the MPCA conducted original research and contracted with university scientists in Minne-

sota and elsewhere for additional research. Collectively, they concurred that rainfall with a pH of 4.7 or lower (i.e., more acidic) would harm Minnesota's most sensitive lakes. Polluters, however, do not emit pH directly. The pollutants they emit—mainly sulfur dioxide—react in the atmosphere to form acids. MPCA scientists needed to correlate the level of sulfur that corresponds to a pH of 4.7. That critical analysis allowed the MPCA to link acidification back to specific polluters. The MPCA analysis showed that a limit on sulfur deposition of 11 kilograms per hectare per year (equivalent to 9.8 pounds per acre in the form of sulfate) would protect Minnesota's sensitive lakes. The proposed rule set the standard at that level and was applicable only in areas of the state with sensitive resources. Monitoring data in 1985 showed that the standard was met at all MPCA monitoring stations with the exception of a site near Sandstone. This finding was good news. Minnesota lakes were mostly in pretty good shape, and limiting acidic deposition would prevent the type of degradation that was seen in New England and Scandinavia.[30]

Atmospheric scientists used air transport models to trace sulfate deposition back to the sources of sulfur emissions and identify the responsible entities.

Another piece of information needed for the rulemaking was identifying where the acidic deposition was coming from. Atmospheric scientists used air transport models to trace sulfate deposition back to the sources of sulfur emissions and identify the responsible entities. MPCA modelers worked with national experts to select and implement two transport models. The models showed that Minnesota emissions contributed between 6 percent and 30 percent of the deposition at sensitive sites in the state. Other states and Canadian provinces contributed the remaining 70–94 percent. Surprisingly, Texas was the biggest contributor to Minnesota's sulfate deposition, at 9–18 percent. Emissions from the Texas petrochemical industry were huge (more than 1.6 million tons per year of sulfur dioxide); a large proportion of precipitation in the Upper Midwest originates from the Gulf of Mexico. The two biggest contributors within Minnesota—NSP's Sherco and Minnesota Power's Clay Boswell power plants—were responsible for 1–12 percent of the deposition at locations around the state.

A Minnesota rule could not control emissions coming from other states and provinces, and federal regulations did not account for long-range interstate transport of pollutants. Reducing Minnesota's sulfur dioxide emissions to zero would not result in attainment of the standard. The MPCA concluded that a national approach was necessary and therefore proposed a control plan that would accomplish Minnesota's reductions if a national plan were enacted. The provisions of the plan included a cap on sulfur dioxide emissions from Minnesota's two largest utilities (NSP and Minnesota Power); a limit on statewide emissions of 194,000 tons per year (a reduction of 60,000 tons per year from 1980 levels); a requirement for large power plants without efficient controls to install Reasonably Available Control Technology (i.e., a 50 percent reduction at NSP's Allen S. King and a 20 percent reduction at Minnesota Power's Clay Boswell plant); and a two-year study period (1990–92) to evaluate the need for a second round of reductions. The requirements were achievable by switching from high-sulfur eastern to low-sulfur western coal, which was ramping up production at the time.

This two-bucket type of rain sampler began to be used widely in Minnesota and around the country in the 1970s. The precipitation detector on the front triggers the cover to move across to the second bucket, allowing precipitation to be collected in the bucket on the right.

MPCA estimated the control costs at $40.9 million per year for NSP and $4.7 million per year for Minnesota Power. Benefits were difficult to monetize because most of the socio-economic value of natural resources (such as environmental amenities associated with pristine aquatic ecosystems) are external to markets. A large percentage of Minnesotans in the Land of 10,000 Lakes participate in fishing, boating, and other activities on the state's waters. The MPCA hired Bemidji State University economist Patrick Welle to conduct a contingent valuation survey of Minnesota citizens. The study revealed that Minnesotans were willing to pay between $1 million and $89.4 million per year to protect sensitive lakes; the midpoint was higher than the estimated costs. Clearly, Minnesotans placed a high value on lakes and were willing to pay to protect them.

SHOWDOWN IN THE HEARING ROOM

To support its case during the administrative hearings, the MPCA tapped the expertise of 11 state scientists and 14 other scientists from the University of Minnesota, the University of Wisconsin, Bemidji State University, the US Environmental Protection Agency, the US Forest Service, the Wisconsin Department of Natural Resources, the Ontario Ministry of the Environment, and others. A coalition of environmental groups also participated, bringing their own attorneys and witnesses. NSP and Minnesota Power—the main opponents—were supported by coal (particularly eastern) and taconite mining interests, the Electric Power Research Institute, consulting firms, and university scientists.

Between January 22 and May 1, 1986, Administrative Law Judge Allan Klein began hearing testimony. On 35 evenings, at hearings in Roseville, Duluth, Hibbing, and Rochester, 75 witnesses testified and 965 exhibits were entered into the record. More than 8,000 people signed petitions supporting "acid rain standards to protect Minnesota's natural resources now and for future generations," and more than 800 letters were received in support. In their testimony and exhibits, the public overwhelmingly favored adoption of the rule. Most acknowledged that the rule would raise electric bills, but they supported adoption nonetheless.[31]

The expert witness testimony Judge Klein heard was frequently controversial, with witnesses cross-examined at length by opposing parties. NSP funded the Electric Power Research Institute to conduct separate modeling of long-range transport air dispersion, lake and watershed modeling, and statistical analyses of the data. Besides Eville Gorham and David Schindler, among the many notable scientists testifying were Charles Driscoll (Syracuse University), Michael Oppenheimer (then with the Environmental Defense Fund), Patrick Brezonik (University of Minnesota), Steven Lindberg (Oak Ridge National Laboratory), and Jerald Schnoor (University of Iowa). Many days of hearings turned into battles of the experts on the minutia of scientific technicalities, something that "confounded" Klein.[32]

In June 1986, Judge Klein released a 56-page report with 177 Findings of Fact. In summary, he found that the MPCA had 1) fulfilled all relevant requirements of law; 2) documented its statutory authority; and 3) demonstrated the need for and reasonableness of the proposed rules. Klein recommended that the proposed rules be adopted. The MPCA Citizens' Board adopted the rules in July, and in August they were published in the State Record, becoming state law.[33]

FURTHER DEVELOPMENTS

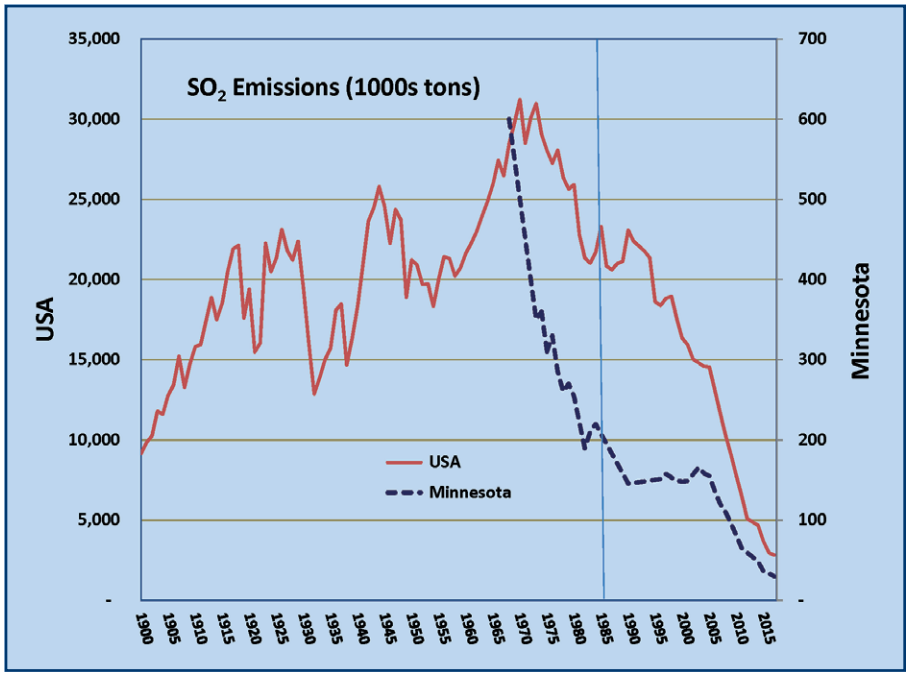
After more than 10 years of study, along with leadership changes in Washington, DC, in 1990 Congress reauthorized the Clean Air Act, expanding Title IV to include acid deposition control. Two phases were prescribed. The first phase required 110 of the largest power plants to

The Sherburne County Generating Station (Sherco) is the largest coal-burning power plant in Minnesota. Xcel Energy, which owns the plant, has announced plans to close the facility's three units by 2030.

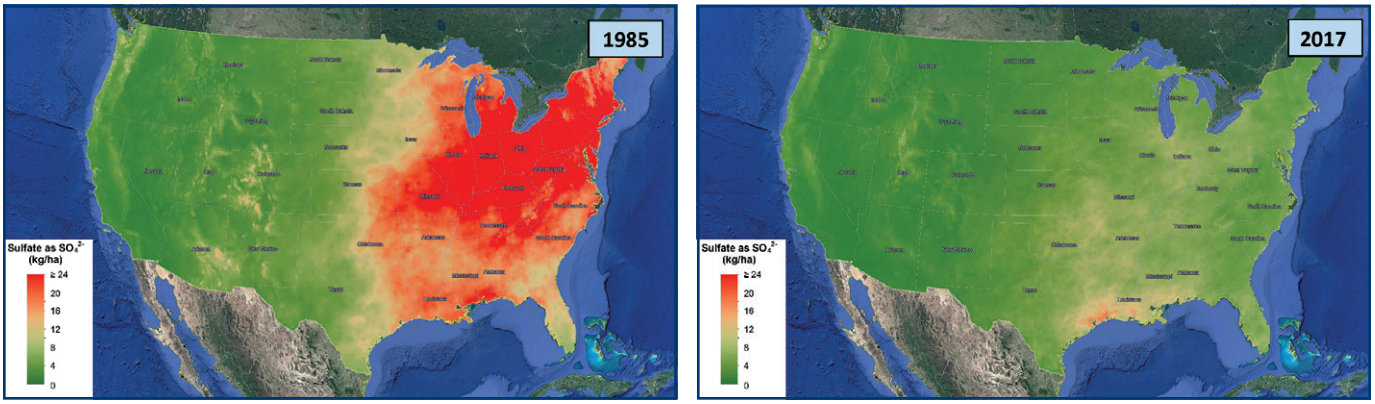
reduce their sulfur dioxide emissions to 2.5 pounds per million British thermal units (Btu) by 1995 (with an extension to 1997 possible). The second phase required 2,000 utilities to reduce their sulfur dioxide emissions (to 1.2 pounds per million Btu) by the year 2000. The overall effect was to reduce sulfur dioxide emissions to an estimated 10 million tons per year—nearly half of the 1980 levels. A 50 percent drop was what Eville Gorham had recommended earlier as a starting point. For utilities that reduced their emissions below the required limits, the act set up a national trading plan to sell credits to other utilities who could then emit above the requirements. The final result was deemed politically and technically feasible at the time, although later analyses found that additional reductions were needed to protect sensitive resources.[34]

The technology-based reductions enacted by Congress were nearly identical to those already in the Minnesota rules. The Minnesota standard remains the only acid deposition standard promulgated in the United States at a level to protect sensitive ecosystems. Ongoing monitoring showed that Minnesota attained and maintained compliance with the standard. Over time, sulfur dioxide emissions decreased dramatically nationwide, and acidic deposition declined proportionately. The Minnesota rule and its enabling statutory language were repealed in 2013 as no longer needed. Decreasing trends in coal mining, sulfur dioxide emissions, and sulfate deposition all support the conclusion that the nation's regulatory process effectively addressed the acid rain problem in the United States.[35]

Minnesota's acid deposition story marked a watershed point in environmental regulation. Problems could no longer be laid at the doorstep of the local polluter. Issues had become national and international in scope, and solutions required a wide lens and multiple cooperators. This trend has accelerated. We now recognize that some of our most intransigent problems are caused by nonpoint pollution coming from the



Sulfur dioxide emissions in the United States and Minnesota, 1900–2015. (Minnesota data from the Minnesota Pollution Control Agency. US data from S. J. Smith, et al., "Anthropogenic Sulfur Dioxide Emissions, 1850–2005," Atmospheric Chemistry and Physics 11, no. 3 [2011]: 1101–16)



Sulfate deposition in the United States, 1985 and 2017. (Data from the National Atmospheric Deposition Program)

cumulative effects of small actions by whole populations, as opposed to a single point source. The solutions require altruistic actions similar to those in the Minnesota acid deposition story.

The current climate crisis facing humanity has many impacts, including those to energy, transportation, and economic infrastructure—all with global implications. Like the acid rain story, national and international actions must go beyond single jurisdictions. No single state or nation can solve the climate problem, and action may disadvantage the actor in the short term. In contrast to acid rain, climate change solutions are orders of magnitude more difficult. Despite ample cause for concern about the future of our planet, Eville Gorham held an optimistic perspective, writing, "There is reason for hope. It may seem unimaginable that we can learn to manage consciously the entire planetary ecosystem. We should, however, remember that throughout our relatively short history, the unimaginable repeatedly has morphed into the commonplace."[36]

Notes

This essay originated in a paper I presented in 2012 at a conference at the Minnesota Historical Society on Minnesota's environmental history. It further evolved from conversation with other participants and the conference conveners, George Vrtis and Chris Wells. I'd also like to extend my sincere thanks to Betsy Haugen, Minnesota legislative reference librarian, for her outstanding assistance in helping me locate documents in the state legislative archives. I also thank J. David Thornton, Judge Allan Klein, David Schindler, Ann Cohen, Kevin Proescholdt, and Peter Ciborowski for agreeing to be interviewed, and especially Professor Eville Gorham for his mentorship, his friendship, and his critique of an early draft.

1. I use the terms "acid deposition" and "acid rain" interchangeably for the sake of convenience. The terms include a spectrum of deposition from wet to dry, and the deposition is often in the form of acidifying substances rather than strong acids, per se.

2. Mark Hertsgaard, "Saving Earth Day," *The Nation*, May 7, 2012. President Richard Nixon signed the Clean Air Act and the National Environmental Policy Act, but Hertsgaard asserts, "Nixon did all this not because he was a closet tree-hugger—the poor man wore wingtips to walk on the beach—but because he was a calculating politician. . . . Nixon was keenly aware that 20 million Americans—roughly 10 percent of the population in 1970—took some kind of civic action that first Earth Day." Nixon vetoed the Clean Water Act, but Congress passed it over his veto. He then impounded half of the funds for its implementation.

William Ruckelshaus laid the foundation for the Environmental Protection Agency's success, hiring its first leaders, defining its mission, and setting up an organizational structure. He also oversaw implementation of the Clean Air Act. President Ronald Reagan appointed him to a second stint as EPA administrator in 1983 to stabilize the EPA following a crisis of mass resignations over mishandling of the Superfund program. In 2015 Ruckelshaus was awarded the Presidential Medal of Freedom by President Barak Obama. He died in 2019.

3. James Gustave Speth, *Red Sky at Morning: America and the Crisis of the Global Environment* (New Haven, CT: Yale University Press, 2004).

4. Earl Barrett and Gunnar Brodin, "The Acidity of Scandinavian Precipitation," *Tellus* 7, no. 2 (1955): 251–57; Eville Gorham, "On the Acidity and Salinity of Rain," *Geochimica et Cosmochimica Acta* 7 (1955): 231–39.

5. Eville Gorham, "Reflections on the Life in a Deteriorating World: How Chance Made Me an Environmental Activist," *Journal of Opinions, Ideas & Essays* 2 (2015).

6. The Nuclear Test Ban Treaty is formally known as the Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water.

Following the 1957 death of his father, Eville Gorham returned to Canada and the University of Toronto, where he began a collaboration with fellow Canadian Alan Gordon. The two conducted seminal studies on the effects of sulfur dioxide emissions from copper-nickel smelters on lakes and vegetation surrounding Sudbury, Ontario. The pressures resulting from these studies led the smelting company (then Inco) in 1970 to build the Inco Superstack to more widely disperse the flue gases containing sulfur dioxide. Until 1978, this 1,250-foot-high smokestack was the world's tallest stack. In 2020, the Inco Superstack owners announced that the structure will be decommissioned and dismantled.

7. Jenna Ross, "University of Minnesota's Eville Gorham, 'the Grandfather of Acid Rain Research,' Dies at 94," *Minneapolis Star Tribune*, Jan. 29, 2020. Gorham's awards include membership in the National Academy of Sciences, Fellow of the American Association for the Advancement of Science, the Society of Wetland Scientists Lifetime Achievement Award, and Regents Professorship at the University of Minnesota. A video interview in which he discusses his career is available at https://cbs.umn.edu/about/cbs-greats/gorham.

8. An avid sailor, Svante Odén disappeared in July 1986 while sailing near Stockholm under what some consider mysterious circumstances.

9. G. E. Likens, F. H. Bormann, and N. M. Johnson, "Acid Rain," *Environment* 14 (1972): 33–40; J. N. Galloway, G. E. Likens, and M. Hawley, "Acid Precipitation: Natural Versus Anthropogenic Components," *Science* 226 (1984): 829–31. Likens and others expected clean rainfall in equilibrium with atmospheric carbon dioxide to have a slightly acidic pH of about 5.6, but the rainfall they collected at Hubbard Brook had pH values near 4.0. Since pH is on a logarithmic scale, a change of 1.0 represents a tenfold difference. A change from pH 5.6 to pH 4 is a 40-times increase in acidity.

10. David Schindler joined the University of Alberta in 1989 as Killam Memorial Chair and professor of ecology. Before his appointment, he headed the Experimental Lakes Area (ELA) project in Ontario, which provided evidence of the role of phosphorus in fish-killing algae blooms. He continued to advise the ELA from his position at the University of Alberta. His 2021 death was noted worldwide in the scientific community; see, for example, www.cbc.ca/news/canada/edmonton/david-schindler-obituary-1.5938189.

11. Lesley Evans Ogden, "The Bittersweet Story of How We Stopped Acid Rain," BBC Future, Aug. 7, 2019.

12. Cassandra Willyard, "Acid Rain and Our Ecosystem," *Smithsonian Magazine*, Apr. 18, 2010.

13. Ogden, "The Bittersweet Story of How We Stopped Acid Rain."

14. David Schindler, email communication with the author, Mar. 31, 2020.

15. National Research Council, *Atmosphere-Biosphere Interactions: Toward a Better Understanding of the Ecological Consequences of Fossil Fuel Combustion* (Washington, DC: National Academy Press, 1981).

16. Carl Pope, "The Candidates and the Issues," *Sierra*, Sept. 10, 1980. Reagan's statement is considered misleading, as noted in scientific literature, e.g., Thomas D. Sharkey, et al., "Isoprene Emissions from Plants: Why and How," *Annals of Botany* 101, no. 1 (2008): 5–18. In March 1966, then governor Ronald Reagan of California,

in opposing expansion of Redwood National Park, was quoted in the *Sacramento Bee* as saying, "A tree's a tree. How many more do you need to look at?" Anne Gorsuch Burford and James Watt overextended their anti-environmental zeal, and both eventually resigned in disrepute.

17. In a 1988 article, environmental attorney Marilynne Roberts, who represented a consortium of environmental groups in the Minnesota proceedings, contrasted Minnesota's experience with the failure to act at the federal level. See Marilynne K. Roberts, "Acid Rain Regulation: Federal Failure and State Success," *Virginia Journal of Natural Resources Law* 8, no. 1 (1988): 1–74. The Minnesota Pollution Control Agency supported environmental policy until 1991, but support waned when newly elected Republican governor Arne Carlson appointed Chuck Williams as MPCA commissioner, the first to come from industry rather than government or the environmental community.

18. The 1973 state environmental policy act provided guidelines under which departments and agencies could promulgate rules specifying the types of projects requiring review. Such rulemaking proceeded during the ensuing years and still comes up from time to time. Other state actions at the forefront of environmentalism include the ban on disposal of taconite tailings in Lake Superior, the Minnesota Clean Indoor Air Act (1975), chlorofluorocarbon (CFC) product bans (1990), the establishment of the Boundary Waters Canoe Area Wilderness (1978), and more recently, the Clean Water, Land, and Legacy Constitutional Amendment (2008).

19. Minnesota politicians were divided on the BWCAW issue. The original 1975 wilderness bill, authored by US representative Jim Oberstar, called for dividing the area into a wilderness section and a recreation area open to logging and motorized vehicles. A year later, US representative Donald Fraser introduced a competing bill giving wilderness designation to the entire area. Following congressional hearings in St. Paul and Ely, US representative Bruce Vento coauthored a full wilderness bill that eventually became law.

The State of Minnesota entered the lawsuit opposing the wilderness designation due to concerns about state jurisdiction over the water bodies and about the federal government overstepping its authority by imposing regulations on motor vehicles in the BWCAW.

The coalition of environmental groups included the Friends of the Boundary Waters Wilderness, the Audubon Society, the Izaak Walton League, the League of Women Voters, Minnesota Environmental Control Citizens Association, Minnesota Rovers, Minnesota Ornithologists' Union, the Wilderness Society, Wilderness Inquiry, and the Sierra Club.

20. Kevin Proescholdt, email communication with the author, 2014. Proescholdt is the coauthor, with Miron Heinselman and Rip Rapson, of *Troubled Waters: The Fight for the Boundary Waters Canoe Area Wilderness* (St. Cloud, MN: North Star Press, 1996).

By the 1980s, mining of eastern, mostly underground, high-sulfur coal was plateauing while surface mining of low-sulfur western coal from places like the Powder River basin in Wyoming was growing rapidly. Minnesota's sulfur dioxide emissions peaked in about 1970, a decade earlier than the national trend, with the reductions driven by increased use of western coal and improved emissions-control technology on many new power plants.

21. The committee was the House Subcommittee on Oversight and Investigations of the Committee on Interstate and Foreign Commerce. This committee took testimony owing to the interest of representatives serving on the committee and the potential international implications of acid rain.

22. Minnesota Legislative Reference Library, "Party Control of the Minnesota House of Representatives, 1951–Present," Minnesota Legislature website. Since 1913 Minnesota legislators were elected without party designation; however, they ran and caucused as "liberals" or "conservatives," essentially equivalent to the Democratic-Farmer-Labor and Republican Parties, respectively. House candidates began running again with party designations in 1974, and the senate followed suit two years later.

23. "Quie Could Make Acid Rain Law Nation's First," *St. Paul Pioneer Press,* Mar. 13, 1982.

24. Representative Willard Munger came to be known as "Mr. Environment" for his leadership on environmental matters in the state. Gerald Willet later served as MPCA commissioner from 1987 to 1991.

25. In 1983 the Minnesota State Legislature again passed a Superfund bill, which was signed by Quie's successor as governor, Rudy Perpich (DFL).

26. Sampling results are tabulated in MPCA, "Statement of Need and Reasonableness in the Matter of the Proposed Adoption of Minnesota Rules parts 7005.4010 to 7005.4050, relating to an Acid Deposition Standard and Control Plan," 1985, available at the Legislative Reference Library or via an MPCA archives search. State of Minnesota, Office of Administrative Hearings, "Report of the Administrative Law Judge, In the Matter of the Proposed Adoption of Minnesota Rules, Parts 7005.4010 – 7005.4050, Relating to an Acid Deposition Standard and Control Plan, PCA-85-002-AK, 6-2200-34-1," acknowledges the SONAR finding of the total number of lakes and their breakdown by alkalinity: https://mn.gov/oah/assets/22008502.86_tcm19-159084.pdf. See also 1986 Biennial Report to the Legislature on the Acid Precipitation Program, which summarizes many of the findings in the SONAR and is held in the MPCA archives.

A sensitive lake is defined as one having fewer than 200 microequivalents per liter of buffering capacity as HCO3-. In less technical terms, a sensitive lake does not have a good capacity to neutralize acidic inputs.

27. MPCA, "Aquatic, Terrestrial, and Peatland Ecosystems in Minnesota Considered Sensitive or Potentially Sensitive to Acid Deposition," 1983.

28. Minnesota Statutes, Chap. 14: Administrative Procedure. The executive head of the MPCA was called "director" until 1986, when the title was changed to "commissioner."

29. Office of the Legislative Auditor, Program Evaluation Division, Report on Administrative Rulemaking, 1993. Approximately 20 percent of rules require a public hearing.

30. MPCA, Statement of Need and Reasonableness, 1985. A pH value of 7 is considered neutral. Unpolluted rainfall is slightly acidic (~pH 5.6) due to the presence of carbon dioxide in the atmosphere. pH is measured on a logarithmic scale, so a pH of 4.7 is nearly 10 times more acidic than unpolluted rain.

31. MPCA offices were located in Roseville until the fall of 1986, when they moved to their current location in St. Paul.

32. Allan Klein, conversation with the author, May 22, 2019. As an MPCA researcher who authored major portions of the Statement of Need and Reasonableness, I presented a half day of affirmative testimony and was cross-examined for a full day by Northern States Power, Minnesota Power, and environmental group attorneys.

33. State of Minnesota, Office of Administrative Hearings, "Report of the Administrative Law Judge."

34. US Environmental Protection Agency, "Air Topics," http://www.epa.gov/air/caa/title4.html; Eville Gorham, "Acid Rain: What We Must Do," *The American Biology Teacher* 45, no. 4 (1983): 203–10.

35. In an effort to streamline and update Minnesota Rules, and repeal those no longer needed, the rules pertaining to Acid Deposition were repealed in 2013. See Article 4, Sec. 108 in https://www.revisor.mn.gov/laws/2013/0/Session+Law/Chapter/114/.

36. Eville Gorham, unpublished manuscript. The quote was highlighted on the program at Gorham's memorial service, Feb. 9, 2020.