ACID FROM HEAVEN

Rain isn't right any more. And where it falls, it creates a nasty mess — environmentally and politically.

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This is the first of two articles.

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Once an angler's dream, 170 Adirondack lakes have become fishless due to acid rain.

It's a perfect science fiction plot. An invisible force begins insidiously attacking Scandinavian lakes and rivers in the 1950s, killing trout and salmon. In the late 1960s, it spreads across the seas, leaving hundreds of lakes in New York's Adirondack Mountains and in eastern Canada fishless and overgrown with sphagnum moss. Salamanders disappear and the chirps of frogs are heard no longer. Reports crop up of statues crumbling, soils rendered poisonous, soybeans and other crops blighted and spoiled. Like a growing, twisted vine, it spreads from the northeast to the Carolinas, the Smoky Mountains and the Great Lakes. Isolated spots in California report it. Finally, late in 1979, it is found high in a Colorado wilderness.

Many wish it were only science fiction, but it's not. It's acid rain. It is a human product and it has all the effects mentioned above and more. It is the child of the energy crisis, the rallying cry of environmentalists, the death knell of the Clean Air Act and the environmental issue of the decade.

So what causes it? In the United States, most of the guilt lies with midwestern coal- and oil-fired power plants and smelters as well as with vehicles and industrial sources. Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from such sources combine with oxygen in the atmosphere and produce dehydrated sulfuric and nitric acids. If these compounds are deposited very near the source, only a small percentage has a chance of being converted to acids. But, in a misguided effort to alleviate local pollution, many utilities and industries began about 20 years ago equipping their plants with very tall smokestacks — many more than 500 feet tall. While the taller stacks clear the air locally, they also kick the sulfur and nitrogen oxides higher into the prevailing westerly winds. As the oxides are carried aloft for two to four days, they have time to undergo little-understood photochemical reactions and to become acids. According to one estimate, after three days of wafting with the winds, about half the sulfur dioxide from a source is converted to acidic compounds. The pollutants are portaged thousands of miles from their source to atmospherically and topographically favorable dump sites. Some of the acid pollutants drop out as particles — a process called dry deposition. But most are washed from the air by rain, snow, mist or hail, and voilà — acid rain.

The dissolved pollutants can increase the acidity of rain 100 to 1,000 times — from a pH 5.6 for "normal" rain to the pH 3.0 and 4.0 now routinely recorded in parts of New England. (Acidity is measured by the "pH" scale. It is a logarithmic scale that ranges from pH 1 — very acid — to pH 14 — very alkaline. Every unit drop in pH represents a ten-fold increase in acidity. Distilled water has a pH of 7, while "normal" rain is slightly acidic due to dissolved CO_2.)

Moreover, by a geological quirk of fate, the places most likely to receive acid rain are those least equipped by nature to cope with it. Precipitation is most likely to form when air masses are lifted and cooled — as they are when they reach the mountains of New England and the Scandinavian countries. But those mountain soils are thin and contain few alkaline agents to buffer the effects of the acids. Without that natural pretreatment, the water that runs off into the mountain lakes and streams is highly acidic and acts quickly to alter their chemistry.

When it falls, acid rain's acerbic hand seems to touch every part of an ecosystem. Its effects are best understood in lakes and rivers; the effects on vegetation, forests and agricultural soils are little known or not known at all. But if one were to construct a blow by blow account of the death by acid of a mountain lake, it might go as follows.

The waters of a healthy lake usually measure above pH 8. Even when subjected to several years of acid rain, the lake's natural buffers can keep it fairly alkaline. But continued doses of acid precipitation can gradually deplete that reserve, or the sudden spring flush of acid runoff from melting snow and ice can critically lower a lake's pH. Rapid changes in pH from 8 to 6 may change the composition of the water community and put additional stress on competing organisms. At pH 7.0, which is neutral on the acid-alkaline scale, the level of calcium in the water begins to decline. The eggs of several species of salamanders fail to hatch in small breeding ponds adjacent to the lake, possibly because a certain level of calcium is necessary to maintain a delicate nutrient exchange within the eggs. At pH 6.6, snails begin to die. At pH 6.0, no tadpole shrimp can be found, and the eggs of other species of salamanders fail to hatch.

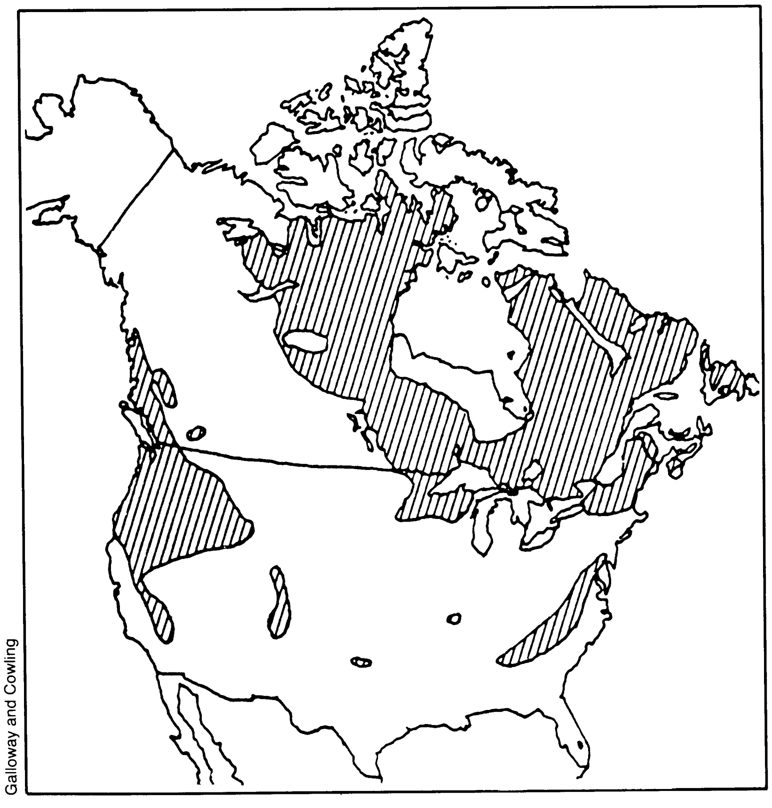
From pH 6 to about 5.5, the number and diversity of species drops rapidly. Leaf litter and other organic debris collect on the lake bottom as the bacterial decomposers begin to die. Plankton, the base of the food chain, start to drop out. The disrupted calcium balance begins to upset the exchange of ions across the gill membranes of fish such as small mouth bass and trout; in others, such as walleye, it prevents the production of eggs. Toxic metals such as aluminum, mercury, lead, cadmium, tin, beryllium and nickel are released from lake bottom sediments or leached from surrounding soils. Many of these become more dangerous than the acidity itself. At pH 5.9, an acid concentration that many fish are known to withstand, aluminum toxicity can damage the gills of fish enough to kill them. In waters below pH 6, mercury is converted to its organic form, monomethyl mercury, and absorbed by fish.

Below pH 5.5, acidophilic mosses, fungi and filamentous algae have nearly choked out the other aquatic plants. Other species of fish — northern pike, suckers and perch — continue to die. Those eggs that are produced cannot survive the acid waters; mature fish die from lack of food, gill damage or toxicity. As the pH drops further, sphagnum moss, usually a land plant, finds the water's acidity to its liking and becomes an aquatic plant. Because it is unsuitable food and it withdraws even more calcium from the water, the moss further starves the remaining fauna.

When the pH hits 4.5, all the fish are dead. Most of the frogs and many insects have died. Surface living insects that can tolerate the acidity, such as backswimmers, water boatmen and water striders, abound in the absence of their predators. The lake is deceptively clear and blue because all microorganisms have been wiped out and blown-in organic debris falls unscathed to the bottom. The sphagnum and algal-fungal growths on the lake bottom form a tight mat and prevent the release of any nutrients from the sediments. Very low rates of bacterial action eventually consume all the oxygen under the dense mat and anaerobic (non oxygen consuming) bacteria take over, producing carbon dioxide, methane and hydrogen sulfide. The entire ecosystem of the lake has changed.

When acid rain falls on vegetation, it packs a double whammy. "[T]he foliage is assaulted from above while the roots are starved and poisoned in the soil," explains Norman R. Glass of EPA's Environmental Research Laboratory in Corvallis, Ore. The inventory of effects on vegetation is not as complete as that for aquatic systems and little field work has been done. But experiments by Ellis B. Cowling of North Carolina State University and others show that acid precipitation can damage the protective waxy surface of leaves, interfere with transpiration and gas exchange, poison the plant by letting acidic substances diffuse into the leaves and branches, and decrease photosynthesis and seed germination. Forest species such as white pine, jack pine, trembling aspen and white birch are believed to be among the most susceptible to acid rain. Few crops have been surveyed for their vulnerability (SN:7/10/76, p. 25), but recent studies show that bush beans, radishes and possibly soybeans may be easily damaged. Tomatoes and other soft fruit might be spoiled; the spotting of apples appears to be related to some component of acid precipitation.

In the soil, acid rain releases its second salvo. Nutrients such as calcium, magnesium, potassium and sodium are leached from the soil and carried away by runoff. In their place, acid rain makes toxic metals such as aluminum, manganese, iron, mercury, cadmium and lead more soluble and more easily absorbed by the roots. Microorganisms that break down plant litter are killed by acid rain and the soil is robbed of that important nutrient material. Even nitrogen-fixing bacteria, which are vital to certain plants, fall prey to increasing acidity. David Shriner of Oak Ridge National Laboratory has shown that the average number of nodules that house these bacteria on bean and soybean plants decreases from 65 at pH 6.0 to 25 at pH 3.2.



Many lakes in North America may face the same fate as those in the Adirondack Mountains. This map shows one estimate of lake-containing areas that are believed to be sensitive to acid rain. The estimate is based on the buffering ability of the region's bedrock.

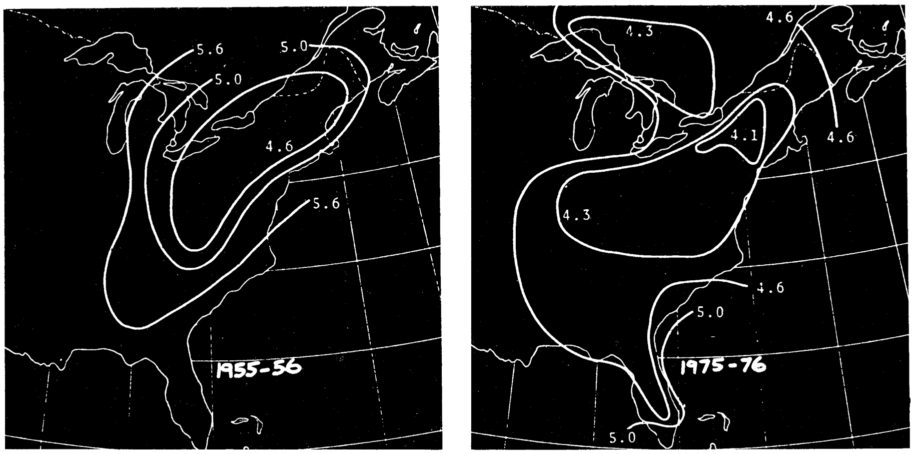
Galloway and Cowling

Though humans are the apparent cause of acid rain, its direct effects seem to have bypassed us so far. Copper and lead leached from pipes into drinking water may be a serious danger, but this effect has not yet been confirmed as a result of acid rain. Mercury poisoning as a result of eating contaminated fish is also a possibility. According to a recent Canadian report, 42 percent of 764 North American Indians surveyed in Quebec, Ontario and the Northwest Territories showed abnormal levels of mercury in blood and hair samples. Most people do not rely on fish as much as do Canadian Indians, but New York State officials are advising that pregnant and lactating women should eat no freshwater fish and others should eat it only once a week. The most significant effect on humans, however, will be economic — the cost of restoring lost lakes, forests and crops and of reducing air pollution.

Few could have foreseen that this mixture of geologic, meteorologic and human ingredients could have produced such a dreadful potion. But a spectacularly progressive scientist might have noticed the problem at the onset of the industrial revolution. The precipitation that fell during that time is preserved in glaciers and continental ice sheets; its acidity can be measured today by taking cores from the ice. Scientists examining the acidity of 180-year-old ice cores in Greenland, for example, have found the pH ranges from 6.0 to 7.6, up to 100 times less acidic than precipitation measures today.

Acid rain was "discovered" after the European Atmospheric Chemistry Network was set up in the 1950s. Because the prevailing southerly winds dump western Europe's acidic offal on Norway and Sweden, those countries were the first to cry foul. Norwegian Fisheries Inspector A. Dannevig first described in 1959 the connection between acid precipitation and declining fish populations in Norwegian and Swedish lakes and streams. In 1968, Svante Oden of Sweden pointed out that the problem was more widespread: Precipitation throughout Europe had become more acidic since the network was established.

By the mid-1960s, concern had spread to the United States. When wildlife officials in New York first noticed changes in fish populations, they blamed logging, decaying vegetation from windstorms and beavers. But data from scattered precipitation networks showed that the northeastern United States was receiving the most acidic rainfall in the country and observers soon linked the events. In 1972, Gene Likens and F. H. Borman of Cornell University and co-workers brought the phenomenon to the scientific fore. And with C. V. Cogbill in 1974, Likens showed just how bad the situation was (SN: 6/15/74, p. 383). Their data showed that from 1955 to 1956, acid rain averaging pH 4.5



March of acid rain: Numbers mark annual average pH; low numbers mean high acidity.

Likens

was confined primarily to the northeast and parts of Ohio and West Virginia. But between 1972 and 1973, rainfall averaging pH 4.5 had spread southwest into Alabama, Georgia and the Carolinas and west into Illinois. More recent data show that the pH 4.5 line has crept even further west and southwest.

Now, few places seem untainted by acid rain. In 1975, Carl Schofield and coworkers at Cornell University surveyed 214 Adirondack lakes above 2,000 feet. They found that 52 percent of the lakes had a pH known to be critical for fish survival (less than 5.0) and 82 of them were fishless. An April 1979 survey counted 170 lakes that no longer supported fish. By contrast, only 4 percent of these lakes had a pH below 5.0 or were without fish in the 1930s. The Boundary Waters Canoe Area is a one-million-acre wilderness ecologically similar to the Adirondacks that is located along the Minnesota-Ontario border and contains more than 1,500 lakes. A 1978-1979 survey of 85 BWCA lakes by Gary E. Glass of the EPA in Duluth, Minn., showed that two-thirds are teetering on the brink of the fish-critical pH. The nearby Great Lakes region is receiving precipitation that is from five to 40 times more acidic than pure pH 5.6 precipitation. According to a July 1979 report to the U.S.-Canada Great Lakes Advisory Board, the large volume and high buffering capacity of the lakes themselves protects them from becoming acidified. But the report points out that two bays of Lake Huron are becoming increasingly acidic and that some lakes in the Haliburton-Muskoka area of Canada, which drain into Lakes Huron and Ontario, "have lost 40 to 75 percent of their acid neutralizing ability in a decade or less." Two headwater streams in the New Jersey Pine Barrens now commonly have pH readings of less than 4.0, an event quite rare before 1970, according to a Nov. 16, 1979, report in SCIENCE by University of Pennsylvania's Arthur H. Johnson. In Pennsylvania's Kane County, the Cooperative Fish and Wildlife Service of Pennsylvania State University found the average pH during the summer of 1978 to be 3.4, more than 100 times the acidity of natural rain. Streams in Shenandoah National Forest in Virginia and the Great Smoky Mountains National Park in Tennessee also show faltering resistance to acid rain.

Even the western states are not exempt, though some researchers speculate that acid rain might be beneficial to sulfur- and nitrogen-starved western soils (SN: 10/13/79, p. 244). A survey of rainfall in the Los Angeles basin during 1978 and 1979 found that the average pH ranged from 4.4 in Pasadena to 5.4 in Big Bear. Data taken in 1955 and 1956 and from 1960 to 1966 suggest an average pH for the basin of about 7, according to researchers James J. Morgan of California Institute of Technology and Howard M. Liljestrand of California State University in Los Angeles. The pH of precipitation in the 9,500-foot-elevation Indian Peaks Wilderness area 30 miles from Denver has declined in four years from 5.39 to 4.67, say William M. Lewis and Michael C. Grant of the University of Colorado in Boulder. And the long distance nature of the problem means it doesn't stop at the U.S. border. Those air masses sweeping from the Ohio Valley to New England also often flow into eastern Canada and drop their poisonous package. Canada's Department of Environment reports that 140 lakes in geologically susceptible Ontario have no fish and estimates that 48,000 lakes in the province are similarly threatened.

Considering the sources of acid rain's ingredients, it is not surprising that its spread parallels our growing appetite for energy. According to a recent report by a U.S.-Canada research group, in 1950 the burning of coal and oil for electric power in the United States produced about 5.4 million tons of SO_2. By 1975, that figure had reached 18.6 million tons, and now represents about two-thirds of all SO_2 emissions in the United States. According to a 1978 report to the Electric Power Research Institute, the research arm of the electric industry, most SO_2 emissions are concentrated in the upper Ohio Valley — eastern Ohio, northern West Virginia and western Pennsylvania — where high-sulfur-containing coal is burned in a knot of large power plants that have few emission controls.

In addition, the EPA estimates that more than 40 percent of the NO_x emissions in the United States come from vehicles, while electric utilities contribute about 30 percent. Total NO_x emissions in the United States rose from 9.0 million tons in 1950 to 24.4 million tons in 1975.

And the energy picture doesn't look better for the future, particularly with the expected three-fold increase in coal burning. Despite the emissions restrictions set for new plants last June, the EPA predicts that SO_2 emissions from power plants will increase by nearly 2 million tons during the next 15 years. Approximately 75 percent of those emissions will come from plants built before 1971, which are now exempt from control by the Clean Air Act. Moreover, NO_x will become more of a problem. Currently, researchers estimate that about 60 percent of acid rain results from SO_2, about 40 percent from NO_x. But no controls now exist for NO_x and the EPA estimates that by 1995, those emissions will nearly match SO_2 emissions. What this means is that places such as Los Angeles, where NO_x already outweighs SO_2 in the atmosphere, will see their acid rain problems get worse.

Nor does the political climate look favorable. This summer, EPA proposed relaxing SO_2 emissions standards for two plants of the Cleveland Electric Illuminating Co. Environmentalists claim that the eased regulations will allow the plants to emit more SO_2 than all 13 power plants owned by Consolidated Edison in New York. Ohio claims that restrictions will force them to turn to low-sulfur coal from other states and will destroy the coal industry in Ohio. Pennsylvania Gov. Richard Thornburgh recently proclaimed he would like to make coal "the most-favored fuel" in his state and to make Pennsylvania the "energy capital of the Northeast." And this while his state is suing West Virginia for unchecked SO_2 emissions that waft into Pennsylvania.

All of this goes to show that controlling acid rain is not simply a matter of putting the clamps on the sources. Acid rain exists in a political limbo with similar environmental issues. While EPA is bemoaning the lack of a legislative handle on the problem, environmentalists are pointing to sections of the Clean Air Act that they claim give EPA the authority to act. The Electric Power Research Institute insists that not enough data are in to justify restrictions; other researchers protest that by waiting for the final tally they will be "selling tickets to an autopsy." But the loudest howl is heard from the utilities who claim they can scarcely meet present air quality requirements and shake a rate increase in the face of those who would counter them.

But none of this means that something — scientifically or politically — cannot be done to harness acid rain. A future article will deal with those endeavors. ☐