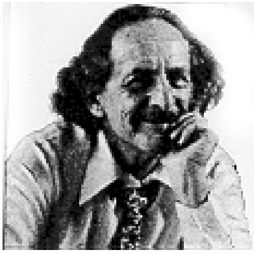
Essays of an Information Scientist, Vol:8, p.77-86, 1985
Current Contents, #9, p.3-12, March 4, 1985



Current Comments®

EUGENE GARFIELD
INSTITUTE FOR SCIENTIFIC INFORMATION®
3501 MARKET ST., PHILADELPHIA, PA 19104

Acid Rain. Part 1. What Is It and What Does It Do?

Number 9 March 4, 1985

Many issues of concern to scientists have a significant impact on the general public. Political, economic, and social issues often revolve around questions that can be resolved only through scientific inquiry. Such questions frequently arise from man's use of technology. In previous essays we have reviewed issues in which this is the case, such as indoor workplace pollution[1] and the benefits and risks of new technologies.[2]

One environmental issue that is currently attracting growing public attention is that of acid rain. This issue in particular is one in which technology and industrialization have produced at least part of the problem. While acid rain is causing growing concern around the world, public perceptions of the problem vary. In the US, for example, much has been written about acid rain. However, according to John E. Carroll, associate professor of environmental conservation, University of New Hampshire, Durham, the general public seems relatively uninformed about the problem.[3] (p. xii; 2) In contrast, Europeans regard acid rain as one of the most important current political problems.[4]

My purpose is to delineate the problem based on the current scientific evidence. But because important political, economic, and social issues are involved, it is also important to assess the public perception of the problem as indicated by the coverage given acid rain by the popular press.

Since a search of the literature revealed that there is a large volume of information about acid rain, the essay is divided into two parts. This first part will consider a definition of the problem, sources of acid rain, and the effects on living organisms, ecosystems, and humans. We will also identify the core literature and the research fronts related to acid rain. Part 2 will address the global status of acid rain, how people perceive the problem, how human institutions react to it, and possible solutions to the problem.

The literature on acid rain encompasses a wide variety of publications, including journal reports of scientific research, newspaper stories, transcripts of government hearings, and analyses of political and economic processes. Sources of information range from very specialized journals to the popular press. Robert H. Boyle, senior staff writer, *Sports Illustrated*, and R. Alexander Boyle, Trinity College, Hartford, Connecticut, have written a book that summarizes much of what has been written on acid rain.[5] A larger, more detailed account of current knowledge is provided by *Acid Deposition Phenomenon and Its Effects: Critical Assessment Review Papers*, a two-volume work compiled by the US Environmental Protection Agency (EPA).[6]

To some, the term "acid rain" conjures up an image of some terrible chemical catastrophe contrived by modern witchcraft and alchemy. The more imaginative soothsayer expects the world to dissolve in a huge, smoggy torrent of vitriol (the archaic term for sulfuric acid). While the reality may not be so extreme, many observers nevertheless believe that acid rain represents a serious threat to many forms of life.

Ellis B. Cowling, president, Acid Rain Foundation, Inc., St. Paul, Minnesota, and program director, the EPA/North Carolina State University Acid Precipitation Program, Raleigh, has summarized the history of research into acid rain.[7] The term acid rain was coined by chemist Robert Angus Smith in 1852 when he described the changing chemistry of rain in the industrial city of Manchester, England.[8] Smith described three types of air: that found in fields remote from cities, which contained carbonate of ammonia; that found in the suburbs, which contained sulfate of ammonia; and that found in the cities, which contained sulfuric acid. Later investigators found the term acid rain too restrictive, since snow, sleet, dew, mist, and fog can also carry significant amounts of acid. They substituted the term acid precipitation. When the capacity of wind to deposit dry acids or their precursors was recognized, another term, acid deposition or dry deposition, was coined.[5] However, for the sake of simplicity, I will use the term acid rain throughout this discussion.

Why is acid rain important? Why is it coming to the forefront again a century after it was first recognized? In reviewing current knowledge of the subject, Roger W. Bybee, Department of Education, Carleton College, Northfield, Minnesota, summarizes a few answers to these questions.[9] In a world with an increasingly large population, many regions have experienced a significant change in the chemistry of rain since the Industrial Revolution. This change is reflected by a change in pH, the exponential measure of acidity. Normal rain is usually slightly acidic with a pH around 5.6, the pH of rain in equilibrium with CO_2 in the atmosphere. Industrialization appears to be the primary culprit in strongly acidic rain. This increased acidity is reflected by a pH often well below 5.6, indicating a high concentration of acidic hydrogen ions. In fact, the pH of rain sometimes reaches 3.0, the pH of vinegar, or even lower.

As mentioned earlier, research into acid rain began with Smith in 1852.[8] Most of the research has been done much more recently, however. In the mid-1940s, a Swede, Hans Egnér, Agricultural College, University of Uppsala, Sweden, devised a way to study systematically the fertilization of crops by nutrients from the atmosphere.[10] His work led to the founding of the European Air Chemistry Network, which has been in operation for three decades. In 1960, another Swede, Svante Odén, also of the Agricultural College, provoked a great deal of debate with his concept of an "insidious chemical war" among European nations.[11] Odén postulated changes in surface-water chemistry, declines in fish populations, leaching of toxic chemicals from soils into surface water, decreased forest growth, and other effects as a result of chemicals released into the atmosphere.

Concern over acid rain and related issues has stimulated a variety of research projects, such as the Norwegian Interdisciplinary Research Programme and programs in Canada, the US, and Europe, among others.[7] This historical recap is far from complete. It merely reminds us that the acid rain problem is by no means a recent phenomenon.

What does the research tell us about acid rain and its effects? Normal rain derives its weak acidity from carbon dioxide in the atmosphere, which reacts with water droplets to form carbonic acid. Such normally acidic rain can be found in areas far from industrial centers and other sources of air pollution. In areas affected by various man-made processes, the situation is quite different. According to the Interagency Task Force on Acid Precipitation's *1983 Annual Report to the President and Congress*, the artificial injection of stronger acids and their precursors into the atmosphere greatly increases the acidity of rain.[12] (p. 13-14)

Of primary concern in the production of acid rain are sulfur oxides, often designated SO_x, and nitrogen oxides, designated NO_x. The former predominate in emissions from coal-burning industrial facilities, such as smelters and electric power plants. The latter predominate in emissions from automobiles. Both types of compounds are precursors to strong acids. SO_x and NO_x react with moisture in the atmosphere to form sulfuric acid and nitric acid, respectively. The best estimates show that in typical acid rain, sulfates account for about 60 percent of the acidity, nitrates for 30 percent, and chlorides for 10 percent. These and other data are presented in a report prepared for the US Department of Energy by the GCA Corporation of Bradford, Massachusetts, a firm that produces analytical instruments.[13] (p. 2-10)

The atmospheric emissions that produce acid rain stem from two principal types of sources: natural and anthropogenic, or man-made. Natural sources include a variety of processes, such as the decay of organic matter, eruptions of volcanoes, lightning, and the like. Of the anthropogenic sources, the principal one is the burning of fossil fuels. Current evidence indicates that anthropogenic sources account for the largest proportion of acidity in the atmosphere in areas where the pH of rain is well below 5.6.[9]

Perry J. Samson, assistant professor of atmospheric science, Department of Atmospheric and Oceanic Science, University of Michigan, Ann Arbor, has reviewed the findings of a conference on the meteorology of acid rain in the *Journal of the Air Pollution Control Association*.[14] Since acid precursors require a certain length of time to be converted into acids, the timing of their release into the atmosphere can influence the production of acid rain. If rain washes the precursors out of the atmosphere before they are converted to acids, less acid rain is formed. (Some of the precursors may be converted to acid rain right in the precipitating cloud.) The longer the compounds remain aloft, however, the greater are the chances that acids will be produced. Since the acids and their precursors travel with the wind, the time aloft also plays a role in determining where acid rain will fall.

Weather patterns play a significant role in the way acids in the air are deposited. Depending on various factors, such as prevailing and seasonal wind patterns, the altitude of prevailing winds, and smokestack heights, acids may be deposited locally, or they may be carried hundreds or even thousands of miles.[13] As we shall see, the possibility that a source of acidic emissions can affect distant areas has great economic and political significance for intra- and international relations.

A great deal of scientific research is now going on to determine the effects of acid rain precisely. Many areas of uncertainty still remain, and more research will be needed. In the US, one source of uncertainty lies in the fact that most studies of the environmental effects of acid rain have at some point been either redirected or discontinued. According to the Department of Energy report,[13] long-term data collected by consistent methods are lacking. The uncertainties have contributed to political disputes related to acid rain, which we will consider in Part 2. Substantial evidence is already available, however, on some specific effects of acid rain. For clarity, the discussion of these effects is organized according to effects on plant life, soils, water, fish, humans, and so forth. It should be remembered, though, that all of these categories represent parts of a single system we call Earth, or as the late Buckminster Fuller called it,[15] "Spaceship Earth." What affects one part of the system may well affect other parts, directly or indirectly, and our current dilemma with acid rain demonstrates this more clearly than most environmental controversies.

How acid rain affects a given geographic area depends at least in part on the characteristics of that area. While conditions may vary locally, regions tend to be resistant, somewhat sensitive, or extremely sensitive to acid rain. According to the *1983 Annual Report to the President and Congress*, areas that have a high buffering capacity are relatively immune to the effects of acid rain; alkaline compounds present in the rocks, soil, and water neutralize acids in the rainwater. Areas that have a high natural acidity lack this buffering capacity and are quite sensitive to acid rain. It is in such areas that acid rain can have the greatest effects on various forms of plant and animal life and even on inanimate objects. Other geographic areas have an intermediate buffering capacity and therefore an intermediate sensitivity.[12]

Evidence from both field and laboratory experiments indicates that acid rain significantly affects the growth and longevity of certain types of trees. According to J. Pankrath, Umweltbundesamt (Federal Environmental Office), West Berlin, Federal Republic of Germany, acidity reduces the growth and yield of forests.[16] (p. 3-6) Its damage ranges from stunted growth to the death of entire forests. In Germany, where forests such as the Black Forest are not only economically important but a significant part of the national psyche, as many as one-third of the trees in the nation's vast forests may be dying.[17] People whose livelihoods depend on forests are quite naturally concerned.

Philip Forsline, Robert Dee, and Richard Melious,[18] New York State Agriculture Experiment Station, Geneva, showed that acid rain can inhibit the growth of apple seedlings. By exposing the seedlings to artificial "rain" of varying pH, they demonstrated that the inhibition was greatest at the lowest pH. Some inhibition, however, occurred at a pH as high as 5.6. They also found necrotic lesions on leaves at a pH of 3.25 or lower. Other researchers have been studying declining growth and other problems affecting tree species including beech, spruce, and pine. Gregory S. Wetstone, director of the Air and Water Program at the nonprofit Environmental Law Institute, Washington, DC, notes that while certain species may benefit in the short run from deposition of nitric acid, there are fears that acid rain may lead to the collapse of major forest systems.[19]

The effects of acid rain on crops are uncertain. Some investigators point out that farmers have long used fertilizers containing nitrogen compounds, and that they are accustomed to liming their fields to maintain the proper soil pH. According to the *1983 Annual Report to the President and Congress*, the few studies done so far suggest that most crops are not highly susceptible to acid rain.[12]

Soils are an important part of any regional ecosystem since they support most land plants and also because they filter much of the water that flows into lakes, streams, and groundwater supplies. Soil changes can thus have indirect effects on many other parts of the ecosystem.

B. Ulrich, R. Mayer, and P.K. Khanna, University of Göttingen, Federal Republic of Germany, studied changes in the soil of a West German forest between 1966 and 1979. They found a general shift in the chemistry of the loess-derived soil, which they attributed to acid rain. Findings included increases in the soil aluminum-ion concentration and in the organic-matter storage on the forest floor. Acid rain induced internal hydrogen-ion production in the soil, due partly to the buildup of organic matter low in nitrogen and partly to a change in the type of nitrogen nutrition of the trees.[20]

N. van Breemen and colleagues, Department of Soil Science and Geology, Agricultural University, Wageningen, the Netherlands, have reported that, in acidic soils, the hydrogen-ion loading resulting from external sources (e.g., acid rain) often exceeds that from internal sources and that the increased acidity allows aluminum in the soil to dissolve and pass into runoff water, while sulfate is retained. This means that the acid rain not only can contribute to the acidity of water supplies but also permits increased pollution by toxic substances such as metal ions.[21]

Not everyone agrees, however, that changes in the soil are caused entirely by acid rain. Edward C. Krug and Charles R. Frink, the Connecticut Agricultural Experiment Station, New Haven, believe that other factors may play equal, if not more important, roles. They note that factors commonly thought to make areas susceptible to acid rain are the same factors that, in the natural process of soil formation, create strongly acidic soils. They believe that alkaline soils may actually be more susceptible to leaching by acid rain than are acid soils. They also contend that humic acids in acid soils buffer the acids in acid rain. If their position is correct, the changes in the acidity of soils and, consequently, in lakes and streams may result from such factors as changes in land use, the recovery of forests after long periods of misuse, and vegetational succession.[22]

In 1955, Eville Gorham, then of the Freshwater Biological Association in the Lake District of England, began reporting on the effects of acid rain on aquatic ecosystems. He found that deposition of acids in precipitation contributed to the progressive loss of alkalinity of surface waters and the increased acidity of bog waters. Further, he attributed these effects to the burning of fossil fuels, and in particular to sulfuric acid in emissions. He noted a deterioration of vegetation, soils, and lake water near metal smelters.[23]

Terry Haines, the United States Fish and Wildlife Service, University of Maine, Orono, reviewed what was known about aquatic ecosystems in 1981.[24] He noted that where the acid-neutralizing capacity of the soil and water are low, acid rain causes the pH of lakes and streams to decrease, while the concentrations of metal ions increase. In addition, organisms living in the water show the effects of increased acidity. Decomposers, primary producers, and primary and secondary consumers—in other words, all levels of the food chain—are affected. Specific effects include decreased abundance, production, and growth. Sensitive species have disappeared from some affected waters. In the US, aquatic effects of acid rain are particularly evident in the Adirondack Mountains of New York.

Paul O. Fromm, Department of Physiology, Michigan State University, East Lansing, has summarized the variable effects of acid rain on freshwater fish.[25] Acidity can reduce or eliminate fish populations from affected waters by interfering with normal reproduction. It also can cause precipitation or coagulation of the mucus and membranes of adult fish gills, with serious effects on respiration. Low pH may also interfere with ionic regulation and normal transport of respiratory gases. Some of the adverse effects of acidity are believed to be caused by aluminum, which becomes more soluble and therefore more readily absorbed in harmful quantities by living organisms.

Man's sensitivity to acid rain is not clearly understood at this time. In testimony before a subcommittee of the US Senate, however, two physicians testified that acid rain may be related to the incidence of Alzheimer's disease, a brain disorder particularly common among the elderly.[26] (p. 50-9) Umberto De Boni, University of Toronto, Ontario, and Daniel Perl, University of Vermont Medical School, Burlington, both told the senators that brain cells from patients with Alzheimer's disease show an accumulation of aluminum. Whether this accumulation causes the disease or is caused by it has not yet been determined. While conceding that there is insufficient evidence at this time to incriminate acid rain as a cause of Alzheimer's disease, the doctors called for more research. Their studies suggest that aluminum converted to soluble form by acid rain may be ingested in drinking water, with adverse effects on those who drink it.[27,28] We discussed Alzheimer's disease in more detail in a previous essay.[29]

Others question the suggested link between ingested aluminum and Alzheimer's disease. E.I. Hamilton,[30] Institute of Marine Environmental Resources, Devon, England, commenting on published reports about Alzheimer's disease,[27,28] provided a number of facts suggesting that the intake of aluminum through the human digestive tract may not be sufficient to cause disease. Like De Boni and Perl, though, Hamilton sees a need for more research.

Acid rain's effects are not limited to living organisms. Buildings, water pipes, and other man-made objects also can be damaged. One effect not usually included in economic analyses of acid rain is the often irreversible damage to cultural resources such as architecture and outdoor art.[12] (p. 51-2) Among the architectural treasures already damaged are the Parthenon in Athens, Cologne Cathedral in the Federal Republic of Germany, and London's St. Paul's Cathedral.[4]

Much of the research we have discussed strongly supports the view that acid rain presents a major environmental threat that demands action now. Not everyone accepts this view, however. Gwyneth D. Howells and Anthony S. Kallend, Central Electricity Research Laboratory, Surrey, England, are two who disagree.[31] They note uncertainties and a lack of data in many areas of research. These uncertainties are frequently pointed out by spokespeople for the power industry and others who oppose mandatory emission controls. As we shall see in Part 2, scientific uncertainty plays a major role in the political controversy about acid rain that is so heated, particularly in Europe and parts of North America.

Research Fronts on Acid Rain

A great deal of scientific material about acid rain has been published, particularly in the last few years. A search of ISI®'s files shows that there are at least six research fronts on or related to acid rain. These are listed in Table 1. One research front is #81-1253, "Effects of acid-rain components on plant growth and aquatic ecosystems." Three core documents help identify this front, all coauthored by Gene Likens and colleagues,[32-34] Section of Ecology and Systematics, Cornell University, Ithaca, New York. The 1974 paper was coauthored by F. Herbert Bormann, Yale University; the 1979 paper by Likens and colleagues at Cornell appeared in *Scientific American*.[34]

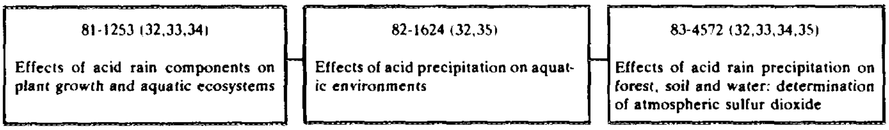
Research front #81-1253 carries through to research front #82-1624, "Effects of acid precipitation on aquatic environments," which includes another core paper by Likens.[35] This in turn carries through to #83-4572, "Effects of acid rain precipitation on forest, soil and water; determination of atmospheric sulfur dioxide." The work cited most often by papers in #83-4572 is the paper by Likens and Bormann.[33] It was cited by 26 of 164 papers published in 1983 for this research front.

The year-by-year overlap of the core literature for the string of these fronts is

Table 1: *SCI*• research fronts on acid rain. A = number. The first two numbers indicate the year of the research front. B = name. C = number of core papers. D = number of citing papers for the year indicated.

A	B	C	D
81-1253	Effects of acid rain components on plant growth and aquatic ecosystems	3	52
82-1624	Effects of acid precipitation on aquatic environments	2	35
83-1341	Effects of acid rain on pollen germination and stomatal changes in plants exposed to sulfur dioxide	9	51
83-1991	Transport, deposition and atmospheric chemistry of sulfur, aerosols and other substances	14	116
83-4572	Effects of acid rain precipitation on forest, soil and water; determination of atmospheric sulfur dioxide	21	164
83-8322	Acid rain and forest decline	3	18

Figure 1: Cluster string showing the relationship of acid rain clusters. The numbers in parentheses correspond to the reference numbers of the overlapping core documents.



shown in Figure 1. The 1974 article by Charles V. Cogbill and Likens[32] cited above continues to be well cited, as well as the other core papers[33-35] by the Cornell group.

A key method paper used in this field involves "Fixation of sulfur dioxide as disulfitomercurate (I) and subsequent colorimetric estimation." Published in *Analytical Chemistry* in 1956 by Philip W. West and G.C. Gaeke, Louisiana State University, Baton Rouge,[36] this paper has been explicitly cited at least 316 times since 1956.

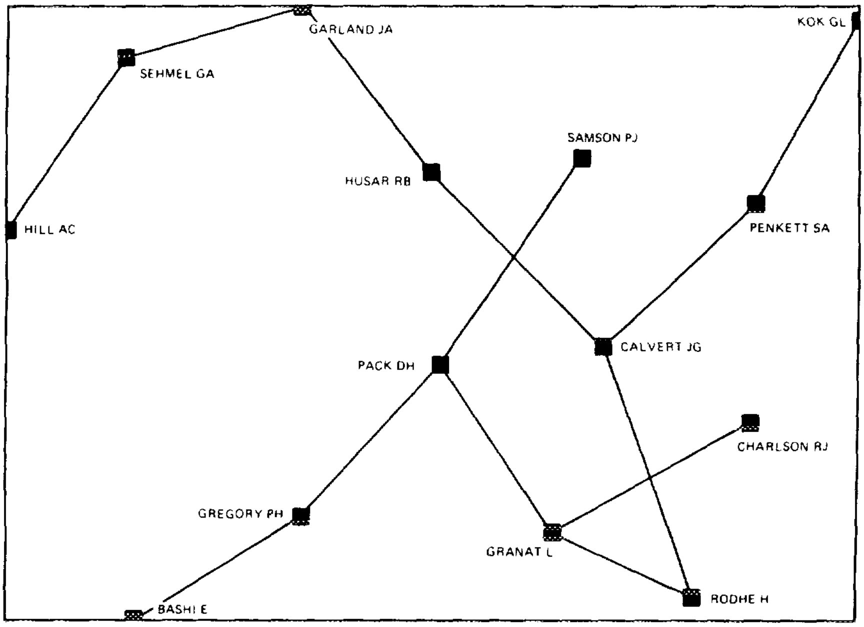
Another research front, #83-8322, concerns "Acid rain and forest decline." Three key papers in this small research front discuss topics like cloud droplet deposition in subalpine balsam fir forests[37] by Gary Lovett and colleagues, Dartmouth; the effects of acid deposition on forest ecosystems, by K.E. Rehfuess, University of Munich, Federal Republic of Germany;[38] and the work by Ulrich and colleagues mentioned earlier.[20]

Over 50 papers were published on the "Effects of acid rain on pollen germination and stomatal changes in plants exposed to sulfur dioxide" (#83-1341). The paper most cited by other papers in this front is "Effect of simulated sulfuric acid rain on yield, growth and foliar injury of several crops," by Jeffrey Lee and coworkers, Corvallis Environmental Research Laboratory, US Environmental Protection Agency, Corvallis, Oregon.[39] This paper was cited by 12 of the 51 papers published on this topic in 1983.

Figure 2 is a multidimensional scaling map of the co-citation relationships among the 14 core papers of #83-1991, "Transport, deposition, and atmospheric chemistry of sulfur, aerosols, and other substances." The paper most frequently cited by other papers in this front is "The importance of atmospheric ozone and hydrogen peroxide in oxidising sulphur dioxide in cloud and rainwater," by S.A. Penkett.[40] It was cited by more than 20 of the 116 papers published. The bibliography of core papers is included in Figure 2.

Some of the primary journals that have published articles on acid rain appear in Table 2. As the list indicates, the

Figure 2: Multidimensional scaling co-citation map for research front #83-1991.



Bashi E, Ben-Joseph Y & Rotem J. Inoculum potential of *Phytophthora infestans* and the development of potato late blight epidemics. *Phytopathology* 72:1043-7, 1982.

Calvert J G, Su F, Bottenheim J W & Strausz O P. Mechanism of the homogeneous oxidation of sulfur-dioxide in the troposphere. *Atmos. Environ.* 12:197-226, 1978.

Charlson R J & Rodhe H. Factors controlling the acidity of natural rainwater. *Nature* 295:683-5, 1982.

Garland J A. Dry and wet removal of sulphur from the atmosphere. *Atmos. Environ.* 12:349-62, 1978.

Granat L. Sulfate in precipitation as observed by the European Atmospheric Chemistry Network. *Atmos. Environ.* 12:413-24, 1978.

Gregory P H. *The microbiology of the atmosphere.* New York: Wiley, 1973. 377 p.

Hill A C. Vegetation: a sink for atmospheric pollutants. *J. Air Pollut. Contr. Assn.* 21:341-6, 1971.

Husar R B, Patterson D E, Husar J D, Gillani N V & Wilson W E. Sulfur budget of a power plant plume. *Atmos. Environ.* 12:549-68, 1978.

Kok G L, Holler T P, Lopez M B, Nachtrieb H A & Yuan M. Chemiluminescent method for determination of hydrogen peroxide in the ambient atmosphere. *Environ. Sci. Technol.* 12:1072-6, 1978.

Pack D H, Ferber G J, Heffter J L, Telegadas K, Angell J K, Hoecker W H & Machta L. Meteorology of long-range transport. *Atmos. Environ.* 12:425-44, 1978.

Penkett S A, Jones B M R, Brice K A & Eggleton A E J. The importance of atmospheric ozone and hydrogen peroxide in oxidising sulphur dioxide in cloud and rainwater. *Atmos. Environ.* 13:123-37, 1979.

Rodhe H, Crutzen P & Vanderpol A. Formation of sulfuric and nitric acid in the atmosphere during long-range transport. *Tellus B—Chem. Phys. Meteorol.* 33:132-41, 1981.

Samson P J. Trajectory analysis of summertime sulfate concentrations in the northeastern United States. *J. Appl. Meteorol.* 19:1382-94, 1980.

Sehmel G A. Particle and gas dry deposition: a review. *Atmos. Environ.* 14:983-1011, 1980.

Table 2: Some of the main journals that published research on acid rain with the year each began publication. The 1983 impact factor for each is listed.

Journal	Impact Factor
Ambio—1972	.6
Atmospheric Environment—1967	2.0
Canadian Journal of Fisheries and Aquatic Sciences—1901	1.7
Environment—1958	.5
Environmental Conservation—1974	.1
Environmental Management—1977	.3
Environmental Pollution Series A—Ecological and Biological—1970	.9
Environmental Science & Technology—1967	2.4
Forestry—1927	.9
International Journal of Environmental Studies—1970	.2
Journal of Environmental Management—1973	.4
Journal of Environmental Quality—1972	1.1
Journal of Environmental Science and Health. Part A—Environmental Science and Engineering—1968	.6
Journal of Forestry—1902	.4
Journal of Soil and Water Conservation—1946	.7
Journal of the Air Pollution Control Association—1951	.7
Journal of the Water Pollution Control Federation—1928	1.0
Science of the Total Environment—1972	.7
Soil Science—1916	.6
Water, Air, and Soil Pollution—1971	1.2
Water Research—1967	1.5
Water Resources Research—1965	1.4
Water Science and Technology—1964	.3

types of journals that have published acid rain articles are quite varied. Some are environmental journals, some forestry publications, while others deal with water and soil conservation. Also included in the table are the years that each of the journals began publication and the impact factor for each journal as reported in our *Journal Citation Reports*® (*JCR*™).

It should be apparent that there is an important link between the basic and applied aspects of this problem. That so many core papers in this field turn up in botanical, chemical, and other journals should be a warning to those who seek simplistic solutions to complex problems, like those who would have solved the problem of polio with a massive iron-lung program. The solution to acid precipitation will be found only by a combination of basic or applied research together with appropriate legislation.

The evidence considered so far suggests both that acid rain may be a significant problem and that there are ways that this problem might be reduced or eliminated. Part 2 of this essay will discuss the global status of the acid rain problem and the nature of the information that the public is receiving. It will also survey suggested solutions to the problem and discuss some of the organizations that are concerned with acid rain.

* * * * *

My thanks to Terri Freedman and Robert Hand for their help in the preparation of this essay.

REFERENCES

1. **Garfield E.** Indoor pollution: why environmental protection may also be an inside job. *Essays of an information scientist.* Philadelphia: ISI Press, 1983. Vol. 5. p. 66-71.
2. --------------. Risk analysis, Part 1. How we rate the risks of new technologies. Part 2. How we evaluate the health risks of toxic substances in the environment. *Ibid.* p. 643-51; 659-65.
3. **Carroll J E.** *Acid rain: an issue in Canadian-American relations.* Washington, DC: Canadian-American Committee, 1982. 80 p.
4. **O'Sullivan D A.** European concern about acid rain is growing. *Chem. Eng. News* 63(4):12-8, 1985.
5. **Boyle R H & Boyle R A.** *Acid rain.* New York: Nick Lyons, 1983. 146 p.
6. **Altshuller A P & Linthurst R A.** *Acidic deposition phenomenon and its effects: critical assessment review papers.* Washington, DC: US Environmental Protection Agency, Office of Research and Development, September 1984, 2 vols. NTIS/EPA/600/8-83/O16F.
7. **Cowling E B.** Acid precipitation: scientific progress and public awareness. *Amer. Biol. Teach.* 45:194-202, 1983.

8. **Smith R A.** On the air and rain of Manchester. *Manchester Literary Phil. Soc.—Ser. 2* 10:207-17, 1852.
9. **Bybee R W.** Why acid rain? *Amer. Biol. Teach.* 45:192-3, 1983.
10. **Egnér H, Brodin G & Johansson O.** Sampling technique and chemical examination of air and precipitation. *Kungl. Lantbrukhogskolan Ann.* 22:369-410, 1955.
11. **Odén S.** The acidification of air and precipitation and its consequences on the natural environment. *Swedish Nat. Sci. Res. Council Ecol. Bull.* 1:1-87, 1968. (TR-1172, Translation Consultants, Ltd., Arlington, VA.)
12. **Interagency Task Force on Acid Precipitation.** *National Acid Precipitation Assessment Program. 1983 Annual Report to the President and Congress.* Washington, DC: GPO, 1983. 72 p.
13. **US Department of Energy.** *Acid rain information book. Draft final report.* Washington, DC: Office of Environmental Assessments, December 1980. DOE/EV/10273-1.
14. **Samson P J.** The meteorology of acid deposition—a specialty conference summary. *J. Air Pollut. Contr. Assn.* 34:20-4, 1984.
15. **Fuller R B.** *Operating manual for spaceship earth.* New York: Dutton, 1963. 143 p.
16. **Pankrath J.** Comments on the investigation of the deposition of atmospheric pollutants. (Georgii H-W & Pankrath J, eds.) *Deposition of atmospheric pollutants.* Boston, MA: Reidel, 1982. p. 3-6.
17. One-third of German trees hit by acid rain. *New Sci.* 100:250, 1983.
18. **Forsline P L, Dee R J & Mellous R E.** Growth changes of apple seedlings in response to simulated acid rain. *J. Amer. Soc. Hort. Sci.* 108:202-7, 1983.
19. **Wetstone G S & Foster S A.** Acid precipitation: what is it doing to our forests? *Environment* 25(4):10-2; 38-40, 1983.
20. **Ulrich B, Mayer R & Khanna P K.** Chemical changes due to acid precipitation in a loess-derived soil in central Europe. *Soil Sci.* 130:193-9, 1980.
21. **van Breemen N, Driscoll C T & Mulder J.** Acidic deposition and internal proton sources in acidification of soils and waters. *Nature* 307:599-604, 1984.
22. **Krug E C & Frink C R.** Acid rain on acid soil: a new perspective. *Science* 221:520-5, 1983.
23. **Gorham E.** On the acidity and salinity of rain. *Geochim. Cosmochim. Acta* 7:231-9, 1955.
24. **Haines T A.** Acidic precipitation and its consequences for aquatic ecosystems: a review. *Trans. Amer. Fish. Soc.* 110:669-707, 1981.
25. **Fromm P O.** A review of some physiological and toxicological responses of freshwater fish to acid stress. *Environ. Biol. Fish.* 5:79-93, 1980.
26. **US Congress. House. Select Committee on Aging. Subcommittee on Human Services.** *Hearing on Alzheimer's disease: is there an acid rain connection?* 98th Congr., 1st sess., 1983. Comm. Pub. No. 98-400.
27. **De Boni U, Scott J W & Crapper D R.** Intracellular aluminum binding; a histochemical study. *Histochemistry* 40:31-7, 1974.
28. **Perl D P & Brody A R.** Alzheimer's disease: X-ray spectrometric evidence of aluminum accumulation in neurofibrillary tangle-bearing neurons. *Science* 208:297-9, 1980.
29. **Garfield E.** Senility: a major health problem in need of a solution. *Essays of an information scientist.* Philadelphia: ISI Press, 1983. Vol. 5. p. 138-42.
30. **Hamilton E I.** Aluminium and Alzheimer's disease—a comment. *Sci. Total Envir.* 25:87-91, 1982.
31. **Howells G D & Kallend A S.** Acid rain—the CEGB view. *Chem. Brit.* 20:407-12; 441, 1984.
32. **Cogbill C V & Likens G E.** Acid precipitation in the northeastern United States. *Water Resour. Res.* 10:1133-7, 1974.
33. **Likens G E & Bormann F H.** Acid rain: a serious regional environmental problem. *Science* 184:1176-9, 1974.
34. **Likens G E, Wright R F, Galloway J N & Butler T J.** Acid rain. *Sci. Amer.* 241(4):43-51, 1979.
35. **Likens G E.** Acid precipitation. *Chem. Eng. News* 54(48):29-31; 35-7; 42-4, 1976.
36. **West P W & Gaeke G C.** Fixation of sulfur dioxide as disulfitomercurate (II) and subsequent colorimetric estimation. *Anal. Chem.* 28:1816-9, 1956.
37. **Lovett G M, Reiners W A & Olson R K.** Cloud droplet deposition in subalpine balsam fir forests: hydrological and chemical inputs. *Science* 218:1303-4, 1982.
38. **Rehfuess K E.** Über die Wirkungen der sauren Niederschlage in Waldokosystemen (On the effects of acid precipitation on ecosystems). *Forstwiss. Centralbl.* 100:363-81, 1981.
39. **Lee J J, Neely G E, Perrigan S C & Grothaus L C.** Effect of simulated sulfuric acid rain on yield, growth and foliar injury of several crops. *Environ. Exp. Bot.* 21:171-85, 1981.
40. **Penkett S A, Jones B M R, Brice K A & Eggleton A E J.** The importance of atmospheric ozone and hydrogen peroxide in oxidising sulphur dioxide in cloud and rainwater. *Atmos. Environ.* 13:123-37, 1979.