Acid Precipitation: Scientific Progress and Public Awareness

Ellis B. Cowling

Ellis B. Cowling was educated at the State University of New York College of Forestry at Syracuse University. He completed Ph.D. degrees in plant pathology and biochemistry at the University of Wisconsin and in physiological botany at the University of Uppsala in Sweden. He is presently Assistant Director, North Carolina Agricultural Research Service, Associate Dean for Research, School of Forest Resources at North Carolina University. Dr. Cowling is also Chairman of the National Atmospheric Deposition Program. In 1981 he was appointed United States Co-chairman of a Canadian-United States Joint Scientific Committee on Acid Precipitation. This committee was established by the National Academy of Sciences and the Royal Society of Canada. Dr. Cowling is President of The Acid Rain Foundation, Inc., a public, tax-exempt organization aimed toward public awareness, education, and research. [*Editor's note:* Some portions of this article have been published previously.]

In recent decades, "acid rain" has become a dominant feature of people-induced change in the chemical climate of the Earth. Wherever fossil fuels are burned, metal ores are smelted, and materials are processed on a large scale, various gaseous, aerosol, and particulate waste products are released into the atmosphere. These substances and their reaction products are dispersed by meteorological processes and deposited on vegetation, soils, and surface waters, often at great distances from the source of emissions. Concern has arisen in many countries about effects on forests, fish, crops, water quality, materials, and human health. The result is a growing concern among scientists and the public about international exchange of air pollutants, wet and dry deposition of strong acids and other acidifying substances, as well as the associated deposition and mobilization of toxic metals and the leaching of nutrient substances.

The phenomenon of acid rain has important implications for the general public and in turn for many persons who educate the public . . .

These concerns developed originally among the Scandinavian countries, Great Britain, and Germany, and other industrial nations of central Europe. More recently they have also developed between Canada and the United States. International cooperation between atmospheric scientists and biologists and among leaders of forestry, agricultural, water-resource, industrial, and governmental organizations is resulting in a general consensus about both the phenomena involved and about strategies for the management of acid deposition. The phenomenon of acid rain has important implications for the general public and in turn for many persons who educate the public, among which are synthesizers of information, i.e., science and environmental educators, reporters for the printed and electronic media, lecturers, and authors.

The purpose of this article is to describe certain perspectives on scientific research and on the public debates about acid deposition and its effects. Primary attention will be given to European and North American research since they are best known, but the ideas developed here should be understood to be relevant in any part of the world in which regions sensitive to acid deposition occur near regions of intense industrialization.

Early Awareness of the Acid Deposition Phenomenon

Since the industrial revolution began in England, it should be no surprise that the first scientific studies of acid deposition and its effects were made in Great Britain. An English chemist named Robert Angus Smith was the first to discover the phenomenon in the middle of the 19th century. In 1852, Smith (1852) published a detailed report on the chemistry of rain in and around the city of Manchester, England. In this remarkable early account, Smith called attention to the changes in precipitation chemistry as one moves from the middle of a polluted city to its surrounding countryside:

> We may therefore find three kinds of air, that with carbonate of ammonia in the fields at a distance, that with sulphate of ammonia in the suburbs, and that with sulphuric acid, or acid sulphate, in the town.

Smith also pointed out that the sulfuric acid in city air caused the colors of textiles to fade and metals to corrode.

Twenty years later, in an extraordinary book entitled *Air and Rain: The Beginnings of a Chemical Climatology*, Smith (1872) first enunciated many ideas that are part of our present understanding. On the basis of detailed studies in England, Scotland, and Germany, Smith demonstrated that precipitation chemistry is influenced by such regional factors as combustion of coal, decomposition of organic matter, wind trajectories, proximity to the sea, and the amount and frequency of rain or snow. Smith proposed detailed procedures for the proper collection and chemical analysis of precipitation. He also noted acid-rain damage to plants and materials and commented on the atmospheric deposition of arsenic, copper, and other metals in industrial regions.

Robert Angus Smith's pioneering work has been overlooked by almost every subsequent investigator of the acid-deposition phenomenon. Eville Gorham (1981) developed the first detailed analysis of Smith's early work for a report by the National Academy of Sciences.

Modern Awareness of Acid Deposition

Contemporary concern about acid deposition and its effects originated in three seemingly unrelated fields of science: limnology, agriculture, and atmospheric chemistry.

Progress in Limnology—The relationship between rain or snow and the water in streams and lakes was obvious even to prehistoric man. But the connection between changes in the chemistry of rain and snow and alterations in the chemistry of lake and stream waters remained obscure until the 20th century.

In a series of papers beginning in 1955, Gorham (1955, 1957, 1958a-d, 1961, 1965) built the foundations for our present understanding of the causes of acid deposition and its consequences in aquatic ecosystems. On the basis of research both in England and in Canada, Gorham and his colleagues demonstrated the following principles:

1) much of the acidity in precipitation near industrial regions can be attributed to atmospheric emissions produced by the combustion of fossil fuels;
2) progressive losses of alkalinity in surface waters and increases in the acidity of bog waters can be traced to the atmospheric deposition of acid substances in precipitation;
3) much of the free acidity in soils receiving acid precipitation is due to sulfuric acid;
4) the incidence of bronchitis in people can be correlated with the acidity of precipitation; and
5) fumigation with sulfur dioxide and resultant acid rain contribute to the deterioration of vegetation, soils, and lake-water quality around metal smelters.

Thus, by the early 1960s, Eville Gorham was the second scientist to establish a major part of our present understanding of the sources and environmental consequences of acid deposition. But his pioneering research, like that of Smith, was met by a thundering silence from both scientists and the public. The lack of recognition of Gorham's work resulted in a further lag in both scientific and public awareness of acid deposition.

Progress in the Agricultural Sciences—The importance of the atmosphere as a source of nutrients for the growth and development of plants was first recognized by Robert Hooke in 1687 (see also Gorham 1965). From 1855 to 1916, scientists at the Rothamstead Experiment Station in England also demonstrated the relationship between nutrients in air and the growth of various crop plants (Way 1855).

In the mid-1940s an imaginative Swedish soil scientist, Hans Egnér, developed a systematic way to investigate the fertilization of crops by nutrients from the atmosphere. Working from the Agricultural College near Uppsala, Egnér created the first 20th-century network for the collection and chemical analysis of precipitation. Sampling buckets were set out at experimental farms all over Sweden, and the major chemical constituents in what we now call bulk deposition (rain, snow, and dust fall) were measured on a regular monthly basis. The acidity of precipitation was one of several chemical parameters that were measured. Other agricultural scientists gradually expanded this network—first to Norway, Denmark, and Finland, and later to most of western and central Europe. This network came to be called the European Air Chemistry Network and it provided the first large-scale and long-term data on the changing chemistry of precipitation and its importance for agriculture and forestry (Emanuelsson, Eriksson, and Egnér 1954; Egnér, Brodin, and Johansson 1955). In 1956, the International Meteorological Institute in Stockholm assumed responsibility for further coordination of the network. In 1957, as part of the International Geophysical Year, it was further expanded to include Poland and the Soviet Union. In marked contrast to monitoring efforts elsewhere in the world which lasted only a few years, the original European Network has remained in continuing operation with more than 100 collection stations for nearly three decades.

Progress in the Atmospheric Sciences—Under the imaginative leadership of Christian Junge in Germany and Carl Gustav Rossby and Erik Eriksson in Sweden, the science of atmospheric chemistry began in Europe and later spread to North America (NAS 1975). Junge, Rossby, and Eriksson were convinced that atmospheric processes were efficient mechanisms for the long-distance as well as the short-distance dispersal of many different substances. The data for Egnér's precipitation chemistry network provided the means to test hypotheses about the trajectories of air masses, turbulent dispersal processes, and atmospheric scavenging and deposition processes (Rossby and Egnér 1955). These observations led Eriksson to enunciate a general theory to describe the biogeochemical circulation of matter on the Earth (Eriksson 1952, 1959, 1960).

The transport and deposition of water by atmospheric processes has been well known since the earliest observations of evaporation, cloud movement, and rain. But the notion that atmospheric transport and deposition were major means for dispersal and chemical transformation of many other substances was still only a working hypothesis in the early 1950s. Junge, Rossby, and Eriksson championed these then-novel ideas and initiated various experimental tests of their hypotheses. Junge worked for a period of time in the United States (Junge and Werby 1958). Rossby and Eriksson sponsored a series of European conferences on atmospheric chemistry and dispersal processes and attracted the interest of scientists in many other fields of inquiry including biology, forestry, agriculture, meteorology, and medicine.

Thousands of lakes such as this one in the Adirondacks are already unable to support fish and plant populations. (Photograph courtesy of the Canadian Embassy.)

European Research and Awareness

The first major integration of knowledge about acid deposition in limnology, agriculture, and atmospheric chemistry was achieved by Svante Odén, a soil scientist at the Agricultural College near Uppsala in Sweden. In 1960, Odén started a Scandinavian network to measure surface-water chemistry. When data from this network were combined with those from the European Air Chemistry Network, a series of general trends and relationships began to emerge and were published by Odén in two different media—Stockholm's newspaper *Dagens Nyheter* (Odén 1967) and in an Ecology Committee Bulletin (Odén 1968). The newspaper report outlining Odén's ideas about an "insidious chemical war" among the nations of Europe captured the attention of the press which began the process of public education about acid deposition in Europe. In much the same way, the Ecology Committee Bulletin stimulated scientific interest in both the acid deposition phenomenon and its ecological effects. Odén's analyses of air-mass trajectories and temporal and geographical changes in precipitation chemistry showed that:

1) acid deposition was a large-scale regional phenomenon in Europe with well-defined source and sink regions;
2) both precipitation and surface waters were becoming more acidic;
3) long-distance (100-2,000 km) transport of sulfur- and nitrogen-containing air pollutants was taking place among European nations;
4) there were seasonal trends in deposition of major ions and acidity; and
5) long-term trends in acidity of precipitation could be detected in many countries of Europe.

Odén also postulated that the long-term ecological consequences of acid precipitation would include the following:

1) changes in surface water chemistry;
2) decline of fish populations;
3) leaching of toxic metals from soils into surface waters;
4) decreased forest growth;
5) increased plant diseases; and
6) accelerated damage to materials.

These conclusions and hypotheses led to a veritable storm of scientific and public debate about acid deposition and its effects. Suddenly, limnological, agricultural, and atmospheric scientists began to argue and debate with each other about Odén's unconventional ideas and his general theory of atmospheric influences. Multidisciplinary discussions and international conferences ensued as scientist after scientist designed experimental tests to confirm or refute Odén's ideas.

The Swedish government responded to the growing public and scientific controversies by initiating an inquiry which culminated in Sweden's Case Study for the United States Conference on the Human Environment—"Air Pollution Across National Boundaries: The Impact of Sulfur in Air and Precipitation" (Bolin, *et al.* 1972).

The important ideas in both the Ecology Committee Bulletin and the Swedish Case Study were debated all over Europe. Two major scientific initiatives followed. The first occurred in 1972 when three organizations in Norway joined together to establish the so-called SNSF Project: The Norwegian Interdisciplinary Research Programme, "Acid Precipitation—Effects on Forest and Fish." The annual budget for the SNSF Project was about 10,000,000 Norwegian Kroner (U.S. $2,000,000) per year from 1972 to 1980. This huge project had two comprehensive goals:

1) to establish as precisely as possible the effects of acid precipitation on forests and freshwater fish; and
2) to investigate the effects of air pollutants on soils, vegetation, and water to the extent required to support the primary objective.

The project produced a steady stream of technical and scientific reports on various aspects of acid deposition and its effects. The SNSF project also sponsored two major international scientific conferences, one at Telemark, Norway, in June 1976, and the second at Sandefjord, Norway, in March 1980. Braekke (1976) and Ambio (1976) published reports about the conference at Telemark. The conference at Sandefjord was designed to provide a forum for evaluation of recent research within the SNSF Project, as well as the research currently being done elsewhere in the world (Drabløs and Tollan 1980). A final report and bibliography from the SNSF Project were published in 1980 (Overrein, Seip, and Tollan 1980; Tollan 1980).

The second major scientific initiative was an international study of the long-range transport and deposition of atmospheric sulfur in eastern and western Europe. It was initiated by the Organization for Economic Cooperation and Development (OECD) in 1973-75. Brunjulf Ottar (1976) of the Norwegian Institute for Air Research provided leadership for this study. The OECD findings, published in 1977, showed that the area receiving highly acid deposition included almost all of northwestern Europe. The findings confirmed the idea that air pollutants are transported over both short and long distances and showed that air quality in each European country is measurably affected by emissions from all other European countries (OECD 1977).

In October 1977, the Economic Commission for Europe (ECE) originated the Cooperative Programme for Monitoring and Evaluating the Long-Range Transmission of Air Pollutants in Europe. The Economic Commission has nearly completed formulating a multinational convention governing nations' responsibilities for combating the long-range transboundary transport of air pollutants.

In June 1982, the Swedish government sponsored the 1982 Stockholm Conference on Acidification of the Environment. This major international conference consisted of two scientific Expert Meetings followed by a Ministerial Conference attended by representatives from 28 other countries in Europe and North America. The conclusions from the Expert Meetings and the preconference document, *Acidification Today and Tomorrow* (Swedish Ministry of Agriculture and Environment 1982) provided the scientific foundation for a major new advance in international understanding and commitments about: 1) the nature and magnitude of biological effects, and 2) the ECE Convention and other approaches that could be used to achieve significant decreases in emissions of acid-deposition precursors, especially sulfur dioxide. A prominent role in the Ministerial Conference was played by representatives of various central European countries who acknowledged, some for the first time, that control of long-distance transport at its source was both necessary and desirable, and that the magnitude of desirable decreases in emissions would be on the order of 50% of 1980-81 emissions.

North American Research and Awareness

Concern about acid deposition and its ecological effects in North America developed first in Canada and then later in the United States. Initial interests were focused on the effects of sulfur dioxide exposure and associated wet and dry deposition of acids and heavy metals in the vicinity of metal smelting and sintering operations (Katz 1939; Gordon and Gorham 1963), especially those near Sudbury, Ontario (Gorham and Gordon 1960; Hutchinson and Whitby 1974). During the early 1970s, interest spread to other parts of Canada as declining fish populations were discovered in more and more lakes, streams, and rivers in southern Ontario and Nova Scotia remote from local sources of atmospheric sulfur (Beamish and Harvey 1972).

The first detailed research about precipitation chemistry in the United States was completed by MacIntyre and Young (1923). Emphasis was given to the importance of airborne nutrients for the growth of crops. This work was followed by the work of Junge and other atmospheric scientists during the 1950s (Junge and Werby 1958). The first regional monitoring network for precipitation chemistry was maintained by a group of State Agricultural Experiment Sta-

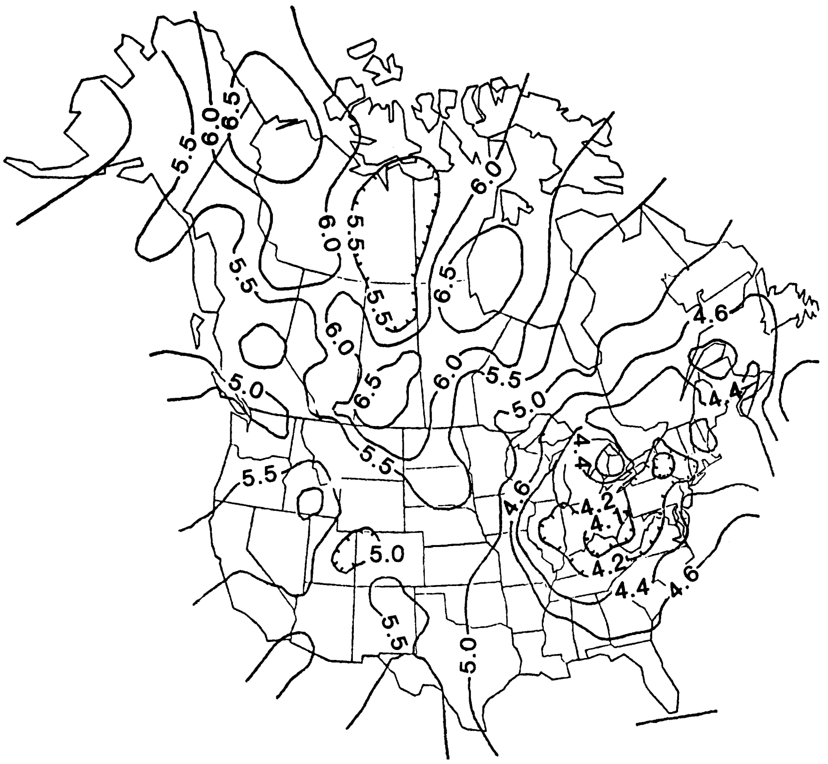

FIGURE 1. Average annual pH of precipitation in Canada and the United States during 1980. The data shown on this map were developed by the Canadian Network for Sampling Precipitation (CANSAP) in Canada and the National Atmospheric Deposition Program (NADP) in the United States.

tion scientists from 1953-55 (Jordan, *et al.* 1959). The first national monitoring program was established under the auspices of the Air Pollution Program within the Public Health Service Laboratory at Cincinnati, Ohio. The data for 1960-66 were summarized by Lodge *et al.* (1968). As has been the case for all such studies in North America, however, these early programs were redirected and/or terminated so that no continuing records are available of long-term trends in precipitation chemistry.

Scientific and public interest in acid deposition and its ecological consequences were stimulated in North America by Svante Odén by lectures at various institutions in the United States during the fall of 1971, and also by Torsten Ahl and Odén at the 19th International Limnological Congress in Winnipeg, Manitoba in 1974. Publications by Gene Likens, Charles Cogbill, James Galloway, Carl Schofield, and others provided further stimulus (Likens, Bormann, and Johnson 1972; Cogbill and Likens 1974; Galloway and Likens 1976; Likens 1976; Schofield 1976; Galloway, *et al.* 1978; Likens, *et al.* 1979). Experimental studies of various biological effects of acid deposition were initiated at Cornell, North Carolina State, and other universities. David Shriner's (1976) dissertation demonstrated both direct injury to vegetation and various indirect effects through pathogens and parasites. Carl Schofield's (1976) research on the extinction of fish populations in the Adirondack Mountains was especially alarming.

Growing awareness of the consequences of acid deposition on fish populations and potential effects on forests led the U.S.Forest Service to sponsor the First International Symposium on Acid Precipitation and the Forest Ecosystem in May 1975. The Proceedings of this Symposium and the associated Workshop Reports were published by Dochinger and Seliga (1976a,b). At Congressional hearings in July 1975, I testified about the inadequacy of research on acid deposition in the United States. Specifically, I said that the lack of a coordinated research program on ecological effects and the absence of a stable monitoring network were the primary causes of the profound ignorance in North America about acid deposition and its effects (Cowling 1976).

Both Canada and the United States have recently initiated long-term programs for the chemical analysis of acid deposition. The Canadian Network for Sampling Precipitation began in 1976; the National Atmospheric Deposition Program was started in the United States in 1978 (Galloway and Cowling 1978). By early 1982, 50 sampling stations were operating in Canada and 100 in the United States.

The data from these programs (fig. 1) show that the area receiving acid precipitation now embraces about two-thirds of the total land area of North America. Although sulfuric acid has been found to be the dominant source of atmospheric acidity both here and in Europe, nitric acid accounts for almost one-third, and the fraction is rising.

In 1978, the governments of Canada and the United States established a Bilateral Research Consultation Group on the Long-Range Transport of Air Pollutants

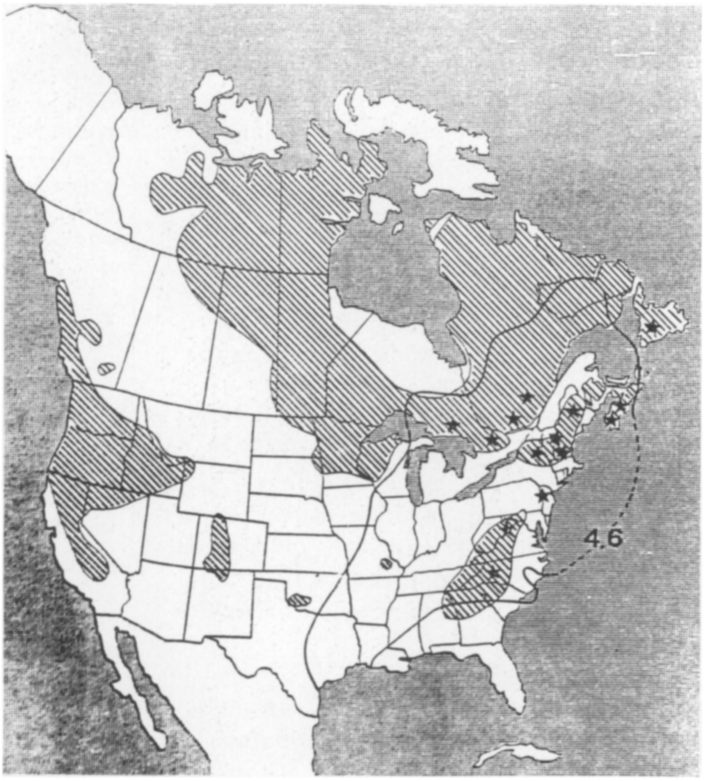

FIGURE 2. Regions of Canada and the United States where lakes and streams have been acidified by acid deposition. The isopleth line defines the area receiving an annual average pH of precipitation below 4.6 during 1979. These data were provided by the CANSAP and NADP monitoring programs. The shaded area identifies regions containing lakes and streams that are sensitive to acidification by acid deposition because surface waters within this region have low acid-neutralizing capacity. The stars indicate where lakes and streams have been acidified by acid deposition from the atmosphere. (Used by permission of J.N. Galloway.)

to coordinate the exchange of scientific information on acid deposition. This group documented the transboundary flow of air pollutants in eastern North America, and showed that about 11 times more oxides of nitrogen and two to four times more sulfur oxides are transported from the United States to Canada than the reverse (Altshuller and McBean 1979, 1980).

During the late fall of 1978, the U.S. Congress passed a resolution calling for bilateral discussions with Canada to preserve and protect mutual air resources. A joint statement on the issues was prepared in July 1979, and on August 5, 1980 the governments of Canada and the United States signed a Memorandum of Intent to develop a bilateral agreement on transboundary air pollution including "the already serious problem on acid rain." To provide a suitable technical and scientific foundation for the formulation of such an agreement, five bilateral workgroups were established to prepare scientific reports on the following specific aspects of the problem:

1) impact assessment;
2) atmospheric modelling;
3) strategies development and implementation;
4) emissions, costs, and engineering assessments; and
5) legal, institutional arrangements, and drafting.

Preliminary drafts of the first four of these reports were completed in 1982 and are presently being reviewed in preparation for their submission to the Canadian Department of External Affairs and the United States Department of State.

Future International Research and Negotiation

In May 1981, the following steps leading to the development of a management plan for acid deposition and its effects were submitted in testimony before a subcommittee of the United States Senate Committee on Environment and Public Works:

1) Determine the geographical location of sensitive natural resources and materials (lakes, streams, crop lands, forests, engineering structures, etc.) which are now being affected by acid deposition or may be affected in the future.
2) Identify those resources which society wishes to protect.
3) Conduct a comparative analysis of various strategies by which the protection desired by society might be achieved. Alternative strategies would include the following:
   (a) decrease the amount of emissions leading to acid deposition;

(b) use ameliorative treatments such as liming of lakes or application of protective coatings to materials; or
(c) develop acid-tolerant forms of life and structural materials.

4) Assuming that decreased emissions is the alternative of choice, as suggested in the recent Atmosphere-Biosphere Report of the National Academy of Sciences (1981), determine the amount by which acid deposition will need to be decreased in order to avoid undesired effects on the resources selected for protection.
5) Determine where and by how much emissions of acid-deposition precursors will have to be decreased in order to achieve the extent of decrease in deposition that will be required in the regions selected for protection.
6) Evaluate specific management strategies and tactics by which each selected source region could do its part to achieve the total emissions decrease that would be necessary. Possible methods would include the following:
(a) conserve fossil fuels;
(b) alter the mix of energy sources to include a higher proportion from non-polluting sources such as solar or possibly nuclear;
(c) use of some combination of fuel cleaning, combustion modification, flue-gas treatment, etc.;
(d) alter regulations to include existing as well as new sources, encourage "least-emissions-dispatching," permit the purchase and exchange of "pollution rights."

A major part of the requirements for step 1 were provided by the data shown in figure 2. These data were developed originally for an earlier House of Representatives hearing on acid rain.

Major progress toward steps 3 and 4 was achieved in the Atmosphere-Biosphere Report of the National Academy of Sciences (1981). Page 181 of that report reads as follows:

> Of the options presently available only the control of emissions of sulfur and nitrogen oxides can significantly reduce the rate of deterioration of sensitive freshwater ecosystems. It is desirable to have precipitation with pH values no lower than 4.6 to 4.7 throughout such areas, the value at which rates of degradation are detectable by current survey methods, as mentioned above. In the most seriously affected (average precipitation pH 4.1 to 4.2), this would mean a reduction of 50% in deposited hydrogen ions.

Also in June 1982, the Swedish Ministry of Agriculture and Environment (1982) submitted the following statement for consideration at the 1982 Stockholm Conference on Acidification of the Environment:

> Given the knowledge we now have, there are several ways of formulating what might be an "acceptable" level of deposition, that is to say, how much the sensitive ecosystems can stand without suffering cumulative damage. All these bases of calculation give similar results. A sulphate deposition of about 0.5 grams of sulphur per square metre per year could be tolerated without entailing any risk of large-scale acidification damage. If we wish to prevent the acidification of even the most susceptible lakes and water sources, the sulfate deposition will have to be reduced to not more than 0.3 grams of sulphur per square metre per year. It should be pointed out, however, that every measure which reduces the deposition is positive and that there is no threshold value that has to be achieved before one can discern a positive effect on the environment.

These related recommendations of "biologically acceptable" target loadings were developed by separate groups of scientists. If they are accepted, the stage is set in both North America and in Europe for step 5 in the above list of steps leading toward management of acid deposition on both continents. The critical question then becomes:

Where and by how much will it be necessary to decrease emissions of acid-deposition precursors so as to achieve the decrease in deposition that is recommended?

Conclusions

Acid deposition has become a major environmental issue in both Europe and North America during the past two decades. Much has been learned already but much more remains to be learned about various aspects of the problem. The challenge for scientists, in Europe and in North America, is to develop a more complete understanding of the atmospheric processes, soil transformations, vegetational changes, alterations in water quality, effects on materials, and physiological influences of acid precipitation. The challenge for science teachers is to educate their students and the public at large so that informed judgments can be made on the basis of the best available information.

The challenge for industrial and political leaders continues as always—to make decisions about complex issues under conditions of uncertainty. The uncertainties involved in management of acid deposition and its effects are analogous with those that surrounded the debates about the role of phosphorus in the eutrophication of Lake Ontario and Lake Erie in the early 1970s. The experts then could not agree. Some said a 40% increase in loading would be needed; others said 75%; still others said nitrogen was to blame, not phosphorus. Environmentalists warned of "possible irreversible harm." Industry said more research was needed. Finally, a political decision was reached—a plan should be developed. More debates were held. A theoretical model was used to predict that a 50% decrease in phosphorus loading might be sufficient and a management plan was finally implemented. After some time the Lakes began to improve. The theoretical estimate was too low, but with some further adjustments the plan worked and the Lakes are now on the road to recovery.

After a decision is made to proceed with preliminary evaluation of policies to protect sensitive regions from acid deposition, it probably will take at least five years to debate the scientific and management issues sufficiently to formulate appropriate policies and plans for management of air quality and acid deposition. Also, at least another five years may well be required to achieve an actual reduction in emissions. During the period of debate, new biological, atmospheric, chemical, and meterological insights will be developed which will help refine whatever management strategies may be recommended. Therefore, it seems prudent that the nations in North America and Europe continue with the debates now underway, recognizing that:

1) research is continuing;
2) a decision to extend present policies is one among many possible alternatives; and
3) being good national and international neighbors requires a timely search for mutually acceptable understandings and courses of action.

Control of technology in a democratic society requires an informed citizenry. Biology teachers can play a crucial role in this process. It is necessary to help students develop a better understanding of the biology, the available technologies, and most importantly, the processes of public decisionmaking. Developing habits of critical thought, a desire to know, and the willingness to participate in public discussion and debate on critical issues will help improve the quality of life on local, state, regional, national, and international levels. Science and science education are major keys to improving understanding of biological systems. Similarly, lifetime public awareness is the key to wisdom in public decisionmaking, not only about complex environmental problems, but in all the other affairs of society as well.

References

ALTSHULLER, A. P., and MCBEAN, G. A. (Co-chairmen) 1979, 1980. *The LRTAP problem in North America: A preliminary overview prepared by the United States-Canada Bilateral Research Consultation Group on the Long-Range Transport of Air Pollutants.* Downsview, Ont.: Atmospheric Environmental Service. Part I (1979), Part II (1980).

Ambio 1976. Report of the International Conference on the Effects of Acid Precipitation in Telemark, Norway. *Ambio* 5:200-252.

BEAMISH, R. J., and HARVEY, H. H. 1972. Acidification of the LoCloche Mountain Lakes, Ontario and resulting fish mortalities. *J. Fisheries Research Board of Canada* 29:1131-1143.

BOLIN, B., *et al.* 1972. The impact on the environment of sulfur in air and precipitation. *In Sweden's case study for the United Nations Conference on Human Environment: Air pollution across national boundaries.* Stockholm: Norstadt and Sons.

BRAEKKE, F. H. (ed.) 1976. *Impact of acid precipitation on forest and freshwater ecosystem in Norway.* Res. Rep. 6/76. SNSF Project. As, Norway.

COGBILL, C. V., and LIKENS, G. E. 1974. Acid precipitation in the northeastern United States. *Water Resources Res.* 10:1133-1137.

COWLING, E. B. 1976. Testimony on research and development relating to sulfates in the atmosphere, pp. 398-440. *In* Research and Development Relating to Sulfates in the Atmosphere—Hearings before the Subcommittee on the Environment and the Atmosphere of the Committee on Science and Technology. U.S. House of Representatives, 94th Congress, First Session, Washington, D.C.

__________. 1980. *An historical resume of progress in scientific and public understanding of acid precipitation and its biological consequences.* Research Report No. 18, SNSF Project. Oslo, Norway.

__________. 1982. Acid precipitation in historical perspective. *Environ. Sci. Technol.* 16:110A-123A.

DOCHINGER, L. S., and SELIGA, T. A. 1976a. *Proceedings First International Symposium on Acid Precipitation and the Forest Ecosystem.* USDA Forest Service, Gen. Tech. Rept. NE-23, Northeast. For. Exp. Sta., Upper Darby, Pa.

__________. 1976b. *Workshop report on acid precipitation and the forest ecosystem.* USDA Forest Service, Gen. Tech. Rept. NE-25. Northeast. For. Expt. Sta., Upper Darby, Pa.

DRABLØS, S., and TOLLAN, A. (eds.) 1980. *Ecological impact of acid precipitation.* Proc. Intl. Conf. SNSF Project. Oslo, Norway.

EGNÉR, H., BRODIN, G., and JOHANSSON, O. 1955. Sampling technique and chemical examination of air and precipitation. *Kungl, Lantbrukhogskolan Ann. Uppsala, Sweden* 22:369-410.

EMANUELSSON, A., ERIKSSON, E., and EGNÉR, H. 1954. Composition of atmospheric precipitation in Sweden. *Tellus* 6:261-267.

ERIKSSON, E. 1952. Composition of atmospheric precipitation. I. Nitrogen compounds. *Tellus* 4:215-232. II. Sulfur, chloride, iodine compounds. Bibliography. *Tellus* 4:280-303.

__________. 1954. Report of an informal conference in atmospheric chemistry held at the Meteorological Institute, University of Stockholm, 24-26 May 1954. *Tellus* 6:302-307.

__________. 1959, 1960. The yearly circulation of chloride and sulfur in nature: Meteorological, geochemical and pedological implications. Part I (1959) *Tellus* 11:375-403. Part II (1960) *Tellus* 12:63-109.

GALLOWAY, J. N., and COWLING, E. B. 1978. The effects of precipitation of aquatic and terrestrial ecosystems: A proposed precipitation chemistry network. *J. Air Pollut. Control Assoc.* 38:228-235.

__________., and LIKENS, G. E. 1976. Calibration of collection procedures for the determination of precipitation chemistry. *Water, Air, and Soil Pollut.* 6:241-258.

__________., COWLING, E. B., GORHAM, E., and MCFEE, W. W. 1978. *A national program for assessing the problem of atmospheric deposition (acid rain).* National Atmospheric Deposition Program, Fort Collins, Col.: Natural Resources Ecology Laboratory.

GORDON, A. G., and GORHAM, E. 1963. Ecological aspects of air pollution from an iron sintering plant at Wawa, Ontario. *Can. J. Bot.* 41:1063-1078.

GORHAM, E. 1955. On the acidity and salinity of rain. *Geochim. Cosmochim. Acta* 7:231-239.

__________. 1957. The ionic composition of snow lowland lake waters from Cheshire, England. *Limnol. and Oceanogr.* 2:22-27.

__________. 1958a. Atmospheric pollution by hydrochloric acid. *Quart. J. Royal Meteorol. Soc.* 84:274-276.

__________. 1958b. The influence and importance of daily weather conditions in the supply of chloride, sulphate, and

other ions to fresh waters from atmospheric precipitation. *Phil. Trans. Royal Soc. London, Ser. B.* 247:147-178.
___________. 1958c. Free acid in British soils. *Nature* 181:106.
___________. 1958d. Bronchitis and the acidity of urban precipitation. *Lancet* ii:691.
___________. 1961. Factors influencing supply of major ions to inland waters, with special reference to the atmosphere. *Geol. Soc. Amer. Bull.* 72:795-840.
___________. 1965. Thomas Brotherton, Robert Hook, and some neglected experiments in the plant physiology during the late seventeenth century. *BioScience* 15:412.
___________. 1981. Scientific understanding of atmosphere-biosphere interactions: A historical overview. *In* National Academy of Sciences *Atmosphere-biosphere interactions: Toward a better understanding of the ecological consequences of fossil fuel combustion.* Washington, D.C.: National Academy Press.
___________., and GORDON, A. G. 1960. The influence of smelter fumes upon the chemical composition of lake waters near Sudbury, Ontario and upon the surrounding vegetation. *Can. J. Bot.* 38:477-487.
HUTCHINSON, T. C., and WHITBY, L. M. 1974. Heavy metal pollution in the Sudbury mining and smelting region of Canada. 1. Soil and vegetation contamination by nickel, copper, and other metals. *Environ. Conserv.* 1(2):123.
JORDAN, H. V., BARDSLEY, C. E., ENSMINGER, L. E., and LUTZ, J. A. 1959. *Sulfur content of rain water and atmosphere in southern states as related to crop needs.* U.S. Dept. Agr. Tech. Bull. No. 1196.
JUNGE, G. E., and WERBY, R. 1958. The concentration of chloride, sodium, potassium, calcium, and sulfate in rain water over the United States. *J. Meteorology* 15:417-425.
KATZ, M. (ed.) 1939. *Effect of sulphur dioxide on vegetation.* National Res. Council of Canada. Publ. No. 815. Ottawa.
LIKENS, G. E. 1976. Acid precipitation. *Chem. Eng. News* 54(48):29-44.
___________., BORMANN, F. H., and JOHNSON, N. M. 1972. Acid rain. *Environment* 14:33-40.
___________., WRIGHT, R. F., GALLOWAY, J. N., and BUTLER, T. J. 1979. Acid rain. *Scientific American* 241(4):43-51.
LODGE, J. P., PATE, J. B., BASBERGILL, W., SWANSON, G. S., HILL, K. C., LORANG, E., and LAZRUS, A. L. 1968. *Chemistry of United States precipitation.* Final report on the National Precipitation Sampling Network. National Center for Atmospheric Research, Boulder, Co.
MACINTYRE, W. H., and YOUNG, I. B. 1923. Sulfur, calcium, magnesium, and potassium content and reaction of rainfall of different points in Tennessee. *Soil Sci.* 15:205-227.
NATIONAL ACADEMY OF SCIENCES. 1975. *Atmospheric chemistry: Problems and scope.* Com. Atm. Sci., Nat. Res. Council, Washington, D.C.
___________. 1981. Atmosphere-Biosphere interactions: Toward a better understanding of the ecological consequences of fossil-fuel combustion. Com. Atm. Bios. Washington, D.C.: Nat. Acad. Press.
ODÉN, S. 1967. *Dagens Nyheter.* October 24, 1967.
___________. 1968. *The acidification of air and precipitation and its consequences in the natural environment.* Ecology Committee Bull. No. 1. Swedish National Science Research Council, Stockholm. Translation Consultants, Ltd., Arlington, Va.
ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT. 1977. The OECD Programme on long range transport of air pollutants. Paris, France: OECD.
OTTAR, B. 1976. Monitoring long-range transport of air pollutants: The OECD Study. *Ambio* 5:203-206.
OVERREIN, L. N., SEIP, H. M., and TOLLAN, A. 1980. *Acid precipitation—Effects on forests and fish.* Final Report to the SNSF Project, 1972-80. SNSF Research Report No. 19. SNSF Project. Oslo, Norway.
ROSSBY, C. G., and EGNÉR, H. 1955. On the chemical climate and its variation with the atmospheric circulation pattern. *Tellus* 7:118-133.
SCHOFIELD, C. L. 1976. Effects of acid precipitation on fish. *Ambio* 5:228-230.
SHRINER, D. S. 1976. Effects of simulated rain acidified with sulfuric acid on host-parasite interactions, pp. 919-925. *In* DOCHINER, L. S. and SELIGA, T. A. (eds.) *Proceedings First International Symposium on Acid Precipitation and the Forest Ecosystem* USDA For. Serv. Gen. Tech. Rep. NE-23. Upper Darby, Pa.
SMITH, R. A. 1852. On the air and rain of Manchester. *Philosophical Society of Manchester, Vol. 10 (Series 2).*
___________. 1872. *Air and rain: The beginnings of a chemical climatology.* London: Longmans Green.
SWEDISH MINISTRY OF AGRICULTURE AND ENVIRONMENT. 1982. *Acidification today and tomorrow.* Stockholm: Ministry of Agriculture.
TOLLAN, A. 1980. Annotated bibliography 1974-80. SNSF Project. Oslo, Norway.
WAY, T. 1855. The atmosphere as a source of nitrogen to plants. *Roy. Agr. Soc. Jour.* 16:249-267 (see also 17:123-162 and 618-621).