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# LONG RANGE TRANSPORT OF AIR POLLUTION -- A UNITED STATES PERSPECTIVE ON ACID RAIN AS AN ECOLOGICAL PROBLEM

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## INTRODUCTION

Acid rain and its accompanying heavy metals and organic micropollutants have been recognized in the detailed fact sheet accompanying President Carter's second environmental message to the U.S. Congress on August 2, 1979, as "one of the most serious global pollution problems associated with fossil fuel combustion", rivalled only by the buildup of carbon dioxide in the atmosphere. Although certain aquatic ecosystems have received the earliest impact, many terrestrial forest ecosystems appear to be at risk over the long term, and agricultural crops may not be exempt from harm. Corrosion damage to metal and stone structures by acid rain is another current problem of considerable magnitude. Whether human health may be affected by acid aerosols has yet to be discovered. The question of how far concomitant additions of plant nutrients (e.g., N, S, Ca, K) to ecosystems may counterbalance the deleterious effects of acid rain also needs to be addressed.

Insofar as sulphur oxides cause acid rain, the situation in the U.S.A. is not likely to improve in the near future, because by 1995 emissions are likely to increase about 10% above 1975 levels even with recently promulgated performance standards for new sources. Without these standards the increase might be more than 25%. Emissions of nitrogen oxides are the other main contributor to acid rain, and quadrupled between 1940 and the present. They may decline as automotive emissions are reduced, but increasing power plant emissions, and increased use of nitrogenous fertilizers that may be transferred in part to the atmosphere, may well counteract such reductions. If the energy crisis results in a relaxation of air quality standards, a severe worsening of acid rain and its effects may be anticipated.

Research on acid rain in the U.S.A. has lagged behind efforts in Scandinavia and Canada. Fortunately, however, several initiatives have been taken to remedy this situation. Early in 1978 the U.S. Council on Environmental Quality (CEQ) set up a committee to designate research needed for an adequate assessment of acid rain and its diverse effects. Its report, entitled A National Program for Assessing the Problem of Atmospheric Deposition (Acid Rain), was issued in December, 1978; and provided the basis for President Carter's recent directive that a 10-year program be developed to identify and mitigate the effects of acid rain, with current research to be doubled to $10 million per year. This directive, it is hoped, will eventually reverse cuts imposed earlier this year when the Carter budget for "anticipatory research" by the U.S. Environmental Protection Agency (EPA) was cut by the House Appropriations Committee from $16.8 million ($2.6 million of which was for research on acid rain effects) to $10.8 million.

ELEMENTS OF THE U.S. PROGRAM

Up to now, two major initiatives have been taken by the U.S. government to stimulate research on acid rain. One has been the setting up of a National Atmospheric Deposition Program (NADP), to monitor atmospheric deposition. The first samples were collected in July, 1978. The NADP now has a network of 38 sites across the country, and several more are expected to be added, particularly in the south and west where coverage is far from adequate. Wet deposition is analysed weekly, and dry deposition in alternate months, for pH, $SO_4$, $NO_3$, $PO_4$, Cl, $NH_4$, K, Na, Ca, Mg and conductivity. Several heavy metals may be added after preliminary tests of network procedures by the U.S. Geological Survey. The NADP is supported by the U.S. Department of Agriculture, Forest Service, Geological Survey, Environmental Protection Agency, National Oceanographic & Atmospheric Administration (NOAA), Department of Energy (DOE), and numerous State Agricultural Stations. Further support is anticipated from the National Park Service and the Bureau of Land Management.

The second major initiative has been the recent award of an EPA contract to coordinate long-term, short-term, and in-house EPA research on the effects of acid rain. This contract, with projected funding of $4,500,000 over 5 years and a first-year budget of $500,000, was awarded to the NADP; and the program will be managed by an Effects Governing Board with North Carolina State University as the fiscal headquarter. Initial research projects will be selected from a diverse set submitted as part of the NADP proposal, with intent to describe the geographic distribution of sensitive ecosystems, identify their current degree of alteration, model ecosystem responses to changing atmospheric deposition, and determine effects of atmospheric deposition upon native and commercial vegetation. In the coming year the EPA also expects to spend $400,000 on acid rain research in the north central states of Minnesota, Wisconsin and Michigan.

In addition to these major programs on acid rain and its effects, many others have been set up by diverse agencies. Notable among these are several devoted, at least in part, to elucidating the modes of formation and transport of acid rain:

(1) Project STATE (Sulfur Transport and Transformation in the Environment), sponsored by the EPA, seeks to measure the transformation of $SO_2$ to $SO_4$ in point-source plumes and larger air masses, and their subsequent transport and removal. This program unites older MISTT (Midwest Interstate Sulfur Transformation and Transport) and RAPS (Regional Air Pollution

Study) programs based on aerial and ground sensors respectively.

(2) The MAP3S project (Multistate Atmospheric Power Production Pollution Study), sponsored first by DOE and now by EPA, is intended to improve our ability to simulate changes in pollutant concentration, atmospheric behaviour and precipitation chemistry consequent on changes in air pollution by large-scale power production.

(3) The SURE study (Sulfate Regional Experiment), sponsored by the Electric Power Research Institute (EPRI), aims to predict ambient $SO_4$ levels in the atmosphere from $SO_2$ emissions by local sources.

(4) The APEX effort (Atmospheric Precipitation Experiment) by scientists at the National Center for Atmospheric Research and various universities, funded by the National Science Foundation and the EPA, uses aircraft flights from the central U.S.A. out over the Atlantic Ocean, together with fixed and mobile ground collectors, to investigate the physics and chemistry of the processes by which airborne pollutants are deposited.

(5) The Tennessee Valley Authority maintains 49 collectors for wet deposition at 21 sites within its area.

(6) The World Meteorological Organization also has 17 stations for wet deposition in the U.S.A., funded by the EPA and NOAA.

Substantial efforts are also being made by U.S. scientists to study various effects of acid rain:

(1) Scientists at several universities, funded by EPRI, are investigating the amounts of acid rain and associated pollutants falling upon three Adirondack Mountain watersheds of widely differing susceptibility, and their ecological, microbiological and geochemical effects -- particularly upon the lakes in these watersheds.

(2) A group at the EPA Environmental Research Laboratory in Corvallis, Oregon, is examining effects of artificial acid rain upon the growth,

yield, and other characteristics of major crop plants grown in experimental situations. Laboratory leaching experiments will also be carried out there on several major U.S. soil types.

(3) The continuing, long-term studies of the Hubbard Brook Experimental Forest include a variety of investigations of acid rain and its effects.

It is especially gratifying to note that U.S. scientists from the Lamont-Doherty Geological Observatory of Columbia University are collaborating with Canadian Government scientists at the Experimental Lakes Area in N.W. Ontario. Efforts have focused on the experimental acidification of sensitive lakes and examination -- particularly by means of radioisotopes -- of effects upon biogeochemical cycling.

A PERSONAL VIEW OF MAJOR RESEARCH NEEDS

The CEQ report mentioned earlier provides a detailed listing of research needs, the major categories of which are shown in Table 1. From this it is possible to select a number of personal preferences for emphasis, as regards both atmospheric deposition and its ecological consequences (leaving effects on human health and on materials for others to consider).

In my view there are several aspects of atmospheric deposition that especially deserve more attention than they are receiving. First, it is of major importance to bring more than circumstantial evidence to bear on the question of the relative roles of sulphuric and nitric (and in certain circumstances hydrochloric) acids in lowering the pH of precipitation. This in turn requires a more thorough investigation of both atmospheric chemistry and atmospheric deposition within and around major urban/industrial areas. The NADP should, in my view, add several sites within such areas. These would also allow a more effective assessment of the association of heavy metals and organic micropollutants (not presently analysed) with acid rain and the nutrient elements that accompany it. More intensive and better coordinated examination of extreme "worst-case" point sources (available in Canada at the Sudbury and Wawa metal-processing sites) might provide insights not otherwise available into the ecology and biogeochemistry of air pollution and acid rain.

Investigation of possible natural, biogenic sources of acid rain -- for instance the coastal salt marshes and freshwater wetlands of the Hudson Bay Lowlands, and the saline pothole regions of the American and Canadian prairies -- might yield very interesting results. Stratigraphic studies of peatlands, in particular of deep Sphagnum bogs whose vegetation is dependent for chemical inputs solely upon the atmosphere, might provide excellent records of temporal as well as spatial variation in atmospheric deposition over northern North America, especially of certain heavy metals for which such peats are effective sinks. Lastly, the significance of dustfall from cultivated soils and other sources, particularly in arid prairie regions, ought not to be ignored. The mineralogical and chemical nature of the finest dust particles, and the possibility of their long-distance transport, certainly deserve investigation.

There are also several aspects of research upon the effects of acid rain that I wish to emphasize. First is the recommendation in the CEQ report to set up calibrated watersheds in vulnerable areas (see Table 2), including in them linked uplands, wetlands, streams and lakes where chemical mass balances of diverse toxins and nutrients can be performed; and where associated studies of plant and animal growth, nutrition, pathology and population dynamics can be made. Such calibrated watersheds require a large funding commitment over a period of decades, of the kind suggested by three recent National Science Foundation Conferences on Long

Term Ecological Measurement; but it is likely that some can be watersheds already calibrated for other purposes (for instance the Hubbard Brook Experimental Forest). Another part of the above-mentioned CEQ recommendation involves the experimental manipulation of ecosystems, along lines similar to those now being followed in the Canadian Experimental Lakes area and the Norwegian SNSF project. Some such experiments might be located at the Experimental Ecological Reserves proposed by the Institute of Ecology as a national network for the study of ecosystem function and development. Acidification of whole watersheds, and investigation of the linkages between upland, wetland and aquatic ecosystems, should be the primary focus; and could presumably utilize the same sorts of irrigation equipment now employed in the addition of sewage wastewater to forests and wetlands.

Among small-scale studies, many of which could be associated with the Calibrated Watershed Program or with a particular Experimental Ecological Reserve, the following seem particularly important to me. One is the development of dose/response data for sensitive "indicator" organisms under a variety of closely defined conditions. Another is the concurrent investigation of synergism and antagonism among the diverse toxins and nutrients associated with acid rain. In this connection a very important conclusion of the 1978 NATO Conference on Acid Rain, held at Toronto, must be borne in mind: "In experimental work, attempts to compress the time scale by increasing acid concentration and/or input rates may produce results that would not occur if the concentration was reduced and spread over time".

Another suggestion is that the aquatic community of the surface film in lakes (the neuston) be examined as a possible early-warning system, because the concentrations of both heavy metals and organic micropollutants there are orders of magnitude greater than in the bulk water beneath, and acid neutralization also begins there.

A different type of initiative deserving to be pursued more actively, because of the likelihood that acid rain will not soon be brought under control, is research on amelioration of its effects. This must take two forms, first the restoration of damaged ecosystems by liming, fertilization, etc., of the kind already being undertaken at Sudbury in Canada, but with attention to whole watersheds and ecosystem linkages; and second, the development of resistant strains of commercially significant or ecologically vital organisms. Amelioration cannot, of course, be practised over large areas of the Laurentian Shield; but may nevertheless be of value in specific localities, especially near to major point sources such as metal smelters.

Finally, an absolutely necessary accompaniment of any and all research projects is a vigorous program of public education, without which acid rain and its damaging ecological effects cannot possibly be brought under control.

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TABLE 1. RESEARCH PROGRAMS AND ANNUAL BUDGETS RECOMMENDED BY THE COUNCIL ON ENVIRONMENTAL QUALITY

| | | | |
|---|---|---|---|
| A. | Measurement program -- atmospheric deposition of acids, metallic and organic toxins, and nutrients. | | $2,600,000 |
| | 1. Spatial and temporal variations of deposition | $1,700,000 | |
| | 2. Nature of acid inputs | $ 200,000 | |
| | 3. Improved assessment of dry deposition | $ 700,000 | |
| B. | Calibrated watershed program -- chemical linkages between the atmosphere, terrestrial, wetland, and aquatic ecosystems | | $2,680,000 |
| | 1. Chemical mass balances | | |
| | 2. Mobilization of toxins and nutrients in soils | | |
| | 3. Experimental manipulation of ecosystems | | |
| C. | Biological effects program -- impacts on physiological functions, organisms and ecosystems. | | $3,100,000 |
| | 1. Agriculture | $1,000,000 | |
| | 2. Forestry | $ 900,000 | |
| | 3. Wetlands and aquatic ecosystems | $1,200,000 | |
| D. | Economic assessment and criteria development | | $ 550,000 |
| | 1. Estimate of current losses | $ 200,000 | |
| | 2. Identification of vulnerable organisms, soils, waters and ecosystems | $ 250,000 | |
| | 3. Criteria for action | $ 100,000 | |
| | | GRAND TOTAL | $8,930,000 |

TABLE 2. FACTORS AFFECTING THE VULNERABILITY OF ECOSYSTEMS TO ACID RAIN

A. Anthropogenic.

1. Spatial and temporal patterns of urban/industrial development.
2. Kinds and amounts of energy resources in use.
3. Controls on atmospheric emissions.
4. Degree of agricultural activity (cultivation, liming, fertilization).

B. Geologic.

1. Nature of bedrock, as regards both basic minerals and acid-soluble toxic metals.
2. Patterns of glaciation.
3. Depth, texture, mineralogy and organic content of soil.

C. Climatic.

1. Amount of precipitation.
2. Atmospheric humidity, as it affects gas absorption and particle impaction.
3. Direction and speed of winds and air-mass movements.
4. Temperature, especially as it affects the proportions of rain and snow.
5. Ratio of precipitation to evaporation, as it affects leaching, and the residence time of water in lakes.

D. Topographic.

1. Altitude, as it influences soil depth, precipitation, etc.
2. Order of streams and lakes in the hydrologic network.
3. Lake depth and ratio of watershed area to lake area, controlling residence time of water.

E. Biotic.

1. Height, type and duration of leaf canopy.
2. Magnitude of transpiration.
3. Sensitivity of critical species, including the microbes mediating biogeochemical cycles.

F. Natural, episodic.

1. Volcanoes, producing locally acid rain.
2. Fires in deposits of fossil fuel such as coal or lignite.
3. Forest fires, entraining alkaline particulates into the atmosphere.
4. Duststorms, entraining alkaline soil particles into the atmosphere.