Acid Deposition: A Review of the Scientific Evidence

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Introduction

The subject of acid deposition has received a considerable amount of attention in both the technical and lay communities. It has developed into a major environmental issue, enmeshed in controversy. Environmental groups and the Canadian government claim that industrial polluters (primarily the Midwestern utility industry) are making the rain so acidic that it is having an adverse impact on the environment, primarily on the lakes and streams of the northeastern United States. They encourage the imposition of additional sulfur dioxide emission controls, reasoning that without an immediate and substantial reduction in emissions (50 per cent or 8-10 million tons of sulfur dioxide per year), widespread irreparable damage to the environment is certain to occur. On the other side of the controversy, Consolidation Coal Company and others claim that data indicating a trend toward increasing precipitation acidity are suspect and that no direct linkage between air pollutant emissions (sulfur dioxide) and the purported effects of acid precipitation can be substantiated by the currently available evidence. Consol encourages a more cautious approach, noting that the imposition of hastily contrived additional control strategies based on incomplete and possibly erroneous data could impose a significant financial burden on the American consumer; inhibit industrial expansion; and, if the selected strategy is incorrect, give a false sense of security that the alleged problems have been solved, thereby delaying the institution of a truly effective strategy. Consol believes that current air pollution control regulations are more than adequate to protect the environment during an interim period of investigation.

At the base of the controversy lies the fact that acid deposition is an extremely complex and, as yet, very poorly understood phenomenon. It is generally accepted that acid precipitation is occurring in many parts of the country. There is, however, no consensus as to how acid precipitation is formed or what effects acid precipitation may have on the environment. Similarly, there is no consensus on the existence or direction of any trend in the rate of acid deposition or the rate of damage. At present, there is neither sufficient data nor theory to completely describe acid deposition or the effects of acid deposition.

Even though acid deposition remains a controversial issue complicated by technical as well as social, economic and political considerations, the chemistry of atmospheric acidity and its impact on sensitive ecosystems are much better understood today than they were only two or three years ago. As a result, the impact of acidity on lakes and fish and on crops and forests is perceived differently now by many informed scientists. Some of the widely held impressions voiced by early observers and by the popular media have been shown to be unfounded. Some are erroneous. It is instructive to review the popularly held beliefs about the sources and effects of acid deposition and compare them with our present knowledge.

Popular Theory

The popular theory beg ins with the observation that fish populations have declined or disappeared altogether in some lakes and streams in the Northeast, with no apparent cause. Fishing in the Adirondacks and other places is said not to be as good as it used to be. Some lakes and streams which have been sampled are observed to be acidified.

The popular theory then evolves into a series of logical steps in an effort to identify the cause of these observed environmental effects as acid precipitation:

- The pH of rain is more acidic than normal (pH less than 5.6).
- The rain acidity is increasing, especially since the 1950's.
- Rain acidity is caused by the long range transport of man made sulfur dioxide emissions from the Midwest to the Northeast.
- The source of these emissions is coal fired power plants located in the Midwest.
- Long range transport is enhanced by the use of tall stacks.

The popular theory sounds plausible. The chain of circumstantial evidence may even seem compelling to some. Parts of it may be supportable by technical facts. However, newer knowledge now suggests that the popular theory is either altogether wrong or overstated.

A pH of 5.6 has been said to be the value for "clean" or "natural" rain, and values below pH 5.6 (i.e., more acidic) have been said to represent pollution by human activity, largely from fossil fuel combustion. Current knowledge and interpretations make pH 5.6 an unrealistic and misleading value for a benchmark defining the acidity of rain. Many scientists now believe that the acidity of normal rain in the Northeast would be about pH of 5, although rain acidity is highly variable, both in time and space. The annual average pH of rain in the Northeast ranges from 4.0 to 4.6, which means that it is true that rain is more acidic than normal, but not to the degree (e.g., 1000 times) that once was claimed.

It has often been said that rain has become increasingly acidic in the Northeast, particularly in New York's Adirondacks. But where the data are the most extensive, this is not supported. The longest continuous record of rain pH is that from Hubbard Brook Experimental Forest in north central New Hampshire from 1963 to 1978, with no significant long-term trend in acidity over the 15 year period, although the sulfate component declined by about 30 per cent while the nitrate component may have increased by about 5 per cent. Data stretching back as far as 1910 show that sulfur deposition in the Eastern United States has remained more or less constant and may have declined since the 1950's. The data of the U.S. Geological Survey for several sites around New York State between 1965 and 191.8 show no statistically significant trends for hydrogen ion concentration, pH, or concentration of any other cation or anion. Another study investigating individual sites in New York did find a 30 per cent reduction in sulfate concentration at some locations near to the Adirondacks.

Early reports that acidity had increased in the Midwest from the mid-1950's to the mid-1970's are now explained by analysis of the acid-related constituents of rain. Researchers have found that the precipitation of the 1950's had unusually high levels of acid-neutralizing cations (calcium and magnesium) that are now attributed to drought-induced dust storms. - When the drought abated, calcium and magnesium levels returned to more usual concentrations and the acidity appeared to increase. It is noteworthy that sulfate and nitrate concentrations were not materially different in the two periods. Thus, where the historical data record is the most complete, no long-term trends in acidity have been demonstrated, and certainly no significant increases in acidity have been substantiated.

Tall stacks on midwestern power plants were once said to have caused the spread of acidity farther eastward. But this is not supported by research findings. Not only has there been no demonstrable increase in the acidity of rain in the Northeast, but atmospheric scientists have concluded that the differences between tall stacks and stacks of conventional height are impossible to detect at distances beyond about 100 miles from the emission point.

It is popularly believed that most or all of the acidity arriving in the sensitive ecosystem region of the Adirondacks and New England is from the Ohio River Basin and the Midwest in general. This is not supported by either simple meteorological principles or by experimental evidence. While it is true that air masses travel on the average in west-to-east pathways, clouds, rain and the accompanying acid precursors move with the winds that circulate clockwise around high pressure centers and counter-clockwise around lows. Thus, the rain arrives in the Northeast by a variety of pathways that differ from the major air mass movement patterns. Historical emission and deposition trends studies show a much closer match between northeastern deposition and emissions from the northeast than from emissions in the midwest, suggesting that the northeast emissions may be the dominant cause of their acid deposition.

It is clear now that there are a number of chemical compounds in addition to sulfur dioxide that are present in the atmosphere that can contribute to the chemistry of cloud droplets or the rain or snow that precipitates. The way the constituents react with each other depends on the concentrations present, time and temperature for reactions to occur,. light, oxygen, ozone and a host of other influencing factors. The whole system is quite variable, depending on how much of what materials are in the atmosphere, the rate and way they react, the dilution that occurs as winds mix the air, and the rate at which they are removed by precipitation and dry deposition.

While long range transport of acidic materials from the Midwest to the Northeast remains a viable hypothesis for at least a portion of the observed acidic deposition, it now appears that the role of local sources in the Northeast (less than 500 miles) has been grossly understated. Researchers are re-examining the atmospheric conditions necessary for production of acid compounds by sources of pollution in the Northeast and their subsequent deposition to the earth in the Northeast. It is this "new" way of looking at the facts that suggests a broad based (31-state) emission rollback strategy may not reduce the deposition loadings to "acceptable" levels in the sensitive areas. These findings strongly suggest that any effective acid precipitation control program must preferentially control emission sources in the Northeast.

The conditions that are necessary for the local production of acid compounds and subsequent deposition in sensitive areas include the following:

- A substantial annual emission inventory in absolute terms of sulfur dioxide, oxides of nitrogen, and volatile organic compounds must exist.
- A high emission density of these pollutants must be present.
- The emissions must be in close proximity to the sensitive ecosystem areas.
- A high potential for the formation of oxidants must exist which can convert SO 2 and NO to their acid forms.
- Certain fossil fuel characteristics should exist such as those present in the fuel burned in oil fired power plants.

All of these conditions are present in the Northeast. Evidence is beginning to accumulate that indicates local sources are much more important in the formation of acidic substances than are distant sources. There are case histories such as in the Netherlands, Japan, and Sweden that indicate local control of oil fired SO_2 and NO_x sources resulted in dramatic improvements in rainfall acidity (pH increases) within these countries.

Alleged Environmental Impacts

Pro control advocates have produced a litany of environmental damage due to acid deposition. The alleged impacts of acid deposition on the environment include:

- Acidification of lakes and streams and subsequent modification of the aquatic system,
- Damage to forests, especially red spruce, and forest soils,
- Damage to agricultural crops,
- Damage to buildings, monuments, and other materials of construction, and
- Damage to public health.

Effects on Lakes and Streams

The acidification of lakes and streams has been observed at several locations in the northeast United States, Canada, and other parts of the world. While several potential causes of this phenomenon have been suggested, acid deposition remains a viable working hypothesis. The greatest degree of acidification of lakes observed in the United States has occurred in areas in the Northeast. The number of lakes that have actually been sampled is small. Of those that have been sampled, no more than 25 per cent are said to be acidified (i.e., pH less than 5). Very little historical data is available to assess trends and that which is available is of dubious quality. Certainly, no trends are evident over the last five years in lakes for which there is good quality data. If rain has not become increasingly acidic in recent decades, it should not be surprising that lakes have not become increasingly acidic. one researcher found only 188 lakes in the United States for which pH measurements spanned at least 9 years. Of those 188 lakes, 18 showed a trend toward increased acidity, 71 toward decreased acidity, and 99 had no significant change. Another researcher found no significant long term trends in the acidity of New York streams from 1965 to 1978. Whatever damage is occurring (if any) is taking place at such a slow rate that it is improbable that any significant changes will be identified over the next decade or two.

Acidification of lakes and streams appears to result in the modification of communities of aquatic flora and fauna at all ecosystem levels. The number of species is reduced or in some cases eliminated and changes in the biomass of some groups of plants and animals have been observed. Decomposition of leaf litter and other organic substrates is hampered, nutrient recycling is retarded, and nitrification is inhibited at pH levels frequently observed in acid-stressed waters.

It is widely claimed that precipitation acidity is the primary determinant of the acidity of lakes, at least those lakes with inadequate buffering capacity. However, the role of acid deposition in lake acidification has been obscured by changes in fish stocking practices, changes in land use, and the use of pesticides, but those complicating factors may not be present at all acidified lakes. There is increasing recognition of the role of the forest floor, acidic forest soils, and adjacent wetlands (bogs) as primary sources of acidity reaching lakes and streams in mountain watersheds. It appears that these factors may be of primary importance at most lakes and in many watersheds; however, even they may not alone be able to account for the degree of acidification observed in general.

Effects on Forests

Determining what effects, if any, acid deposition has or may have on forest productivity is a very complex undertaking. Available information suggests that any effects will be very difficult to identify and will likely depend on tree species, soil conditions, deposition characteristics, climate and other site specific variables. It is not surprising that results of greenhouse, laboratory, and controlled and uncontrolled field experiments have indicated either beneficial, adverse, or no detectable effects of acid deposition on forest productivity. The current state of knowledge certainly does not support broad generalizations such as acid deposition is adversely affecting forest productivity in areas with sensitive soils. Conclusive evidence of negative effects does not currently exist.

Recently, a significant decline in the growth of several coniferous species, including red spruce was noted in various parts of the northeastern United States. In the case of red spruce, the growth decline was accompanied by considerable mortality. These trends supposedly were not accounted for by climatic patterns or biological agents, and it has been suggested that acid rain may have been a factor. A severe drought in the 1960's may be the most likely explanation of the mechanism that triggered the forest decline. However, more recent information suggests that ozone by itself or in concert with other air pollutants may be the cause. At present, no link has been established between acid deposition and the observed forest decline.

Effects on Crops

Acidic precipitation is frequently cited as a potential threat to agricultural productivity in the United States primarily because of the coincidence of patterns of acid deposition with major regions of agricultural productivity. Ozone, which has been shown to damage agricultural crops has much the same pattern of incidence as does acid precipitation.

Conclusive evidence of agricultural losses due to ambient levels of acidic precipitation, beyond this coincidence of occurrence with ozone, does not exist. Mechanisms for an effect have been hypothesized, but little evidence exists on which to base conclusions. It is not currently possible to assess acid rain crop impacts as has been done for ozone. Chemical management (e.g., liming, fertilizing) of agricultural fields is likely to mask any effects of acid precipitation should they actually be occurring. The most consistent conclusion to be drawn across research at all scales (e.g., laboratory, greenhouse, field) and with all species has been one of "no effect" at current average ambient pH levels (pH 4.0-4.6).

Effects on Buildings, Monuments, and Materials of Construction

Demonstrating and quantifying the specific contributions of anthropogenic air pollutants to materials damage is extremely difficult. While there is general agreement that air pollution can and does do damage to materials, in most cases, the damage itself is indistinguishable in appearance from that caused by natural damage agents such as moisture, oxygen in the air, sunlight and so on. The effect of air pollution usually is seen as an increase in the rate of damage, not a change in the type of damage.

Distinguishing between the damage related to local pollutants and that related to pollutants from distant sources is even more difficult. The chemical nature of local emissions can occasionally be duplicated by long range pollutants under infrequent meteorological conditions. However, valid relationships between the damage to materials and pollutants involved in long-range transport do not exist. The materials for which the best quality and quantity of information on pollutant-material interactions is available, and that have been shown to have significant economic implications are steel, zinc (as used in galvanized coatings) and paint.

The impact of SO_2 emissions on these materials appears to be vanishingly small. Based on the lack of significant correlations between reported materials damage rates, it may be concluded that there is in fact little relationship between the observed damage and long-range pollutants.

Effects on Public Health

Over the past several years, reports have suggested that atmospheric sulfates in ambient concentrations may be responsible for tens of thousands of "excess deaths" a year in the United States. An examination of these reports shows that health, medical, and other scientific evidence will not support a conclusion that ambient sulfate concentrations cause mortality.

Recent studies which used better data collection and analyses suggest that no mortality results from existing ambient sulfate levels. In fact, controlled human experiments show that medically significant changes do not generally occur below concentrations more than ten times higher than the highest ambient levels we observe now.

The highly publicized mortality estimate was based on a sulfate mortality factor which was in turn based on outdated and flawed data. Atmospheric sulfates at present concentrations do not appear to threaten public health.

Assertions have been made that acid precipitation leads to indirect adverse health effects via the ingestion of drinking water. These claims are based on the supposition that acid precipitation will mobilize certain metals in drinking water and that this incremental increase will result in the consumption of drinking water containing metallic contaminants above safe drinking water limits. Concern over increased human exposure to metals as a result of acid precipitation is largely founded on the speculation that there ought to be a relationship; i.e., metals are typically more soluble at lower pH's and acidic water is more corrosive. At the present time there is insufficient evidence to support a conclusion that acid precipitation produces or contributes significantly to adverse health effects by the mobilizing of metals in drinking waters.

The quality of precipitation is altered by many biological, chemical, and physical processes as it moves through water-sheds, aquifers, water treatment plants and distribution systems. The complexities of the pathway are staggering, resulting in the virtually impossible task of partitioning the effect of the quality of precipitation as it falls to the quality of drinking water as it is consumed.

There are a few studies in sensitive areas of the Northeast that show the presence of metallic ions in concentrations that exceed safe drinking water limits. However, acid precipitation has not been identified or established as the ultimate cause of any of these observations.

Drinking water is not, in general, a major route of exposure of the alleged contaminants to humans. Food by far is the more important source of exposure to lead, aluminum, and cadmium. There is at present no evidence that incremental levels of contaminants that may be caused by acid precipitation have any significant effect on human health through the drinking water pathway.

There is no evidence as to the population at risk or the magnitude of the risk. For most of the people of the United States, there is likely to be little or no relationship between the quality of their tap water and the acidity of the rain which is its original source.

Conclusions

Based upon Consol's interpretation of the scientific and technical literature, the following conclusions appear to be justified:

- A pH of 5.6 is not a defensible value for defining the acidity level of "clean" or "pure" or "unpolluted" rain.
- The sensitive ecosystem region in the United States for which there is some reasonable documentation of damage to aquatic systems is largely confined to the Adirondacks area in New York and portions of New England.

- Large areas of the northeastern United States receive precipitation with an annual average pH ranging between 4.0 and 4.6.
- There is no evidence of increasing acidity in the precipitation falling on the Adirondacks. or New England over the last two decades.
- There is no evidence of increasing acidity in the lakes and streams in the Adirondacks or New England over the last two decades.
- Lake chemistry is affected by a variety of factors -- with the natural acidity of soils and adjacent wetlands being important, perhaps the major source of acidity.
- Many lakes even in the absence of man made air pollution are undoubtedly inhospitable environments for sustaining fish populations.
- Fish restocking practices and fishing pressure must be taken into account when using fishing quality as an indicator of environmental influences.
- Fewer than 25 per cent of the sampled lakes in the ' Adirondacks are acidified (i.e., pH less than 5.0) and the rate of change is so slow (if at all) that it is questionable whether any changes-can be detected over the next decade or two.
- Alleged damage to forests by acid deposition, especially red spruce, is unverified at this time. Declines in forests seem to be tied to a drought which occurred during the late 1950's and early 1960's and/or to high levels of atmospheric ozone.
- Alleged impacts on agricultural crops and materials of construction are only hypothetical at the present and there is no scientific evidence supporting these claims.
- Alleged impacts on public health, especially the claim that sulfates cause 51,000 excess deaths per year are totally unsupported by credible scientific evidence and analyses.
- There is no evidence to support a conclusion that acid precipitation produces adverse health effects in drinking waters.
- Tall stacks do not have the effect on long-range transport once believed.
- Sulfur dioxide, oxides of nitrogen, and reactive hydrocarbons are all involved in the production of acid deposition.
- The Northeast has a significant emission inventory of sulfur dioxide, oxides of nitrogen, and volatile organic compounds.
- Emission densities are a better indicator of the potential for acid deposition formation than are absolute emission rates. Emission densities of these pollutants are about the same in the Northeast as in the Midwest.
- The potential for production of oxidants is higher in the Northeast than in the Midwest suggesting that rapid transformation of precursors from sources in the Northeast to acid deposition in the Northeast is occurring.
- Pathways by which precipitation and acidity arrive at points of concern are varied; less than half seems to arrive from the direction of the Midwest industrial region while more than half seems to be generated in the Northeast.
- Wet deposition trends at Hubbard Brook in sulfate and nitrate are closely matched with emission trends of SO_2 and NO_x in the Northeast suggesting that sources in the Northeast may be controlling the chemical composition of wet acidic deposition falling in the Northeast and that emission sources in the Midwest play a relatively minor role.

The above conclusions seem to suggest that (1) we do not have an environmental crisis at our doorstep; (2) there is still a great deal that is unknown or only partially understood; (3) additional research is warranted before additional emission control programs are instituted; (4) the present Clean Air Act will provide continuing protection to the environment while the research is being conducted; (5) the components of the popular theory are not securely founded on fact; and (6) an effective control program to protect the sensitive ecosystem areas in the Northeast must focus on controlling acid deposition sources of SO_2, NO_X , and volatile organic compounds in the Northeast.

The annual average pH of unpolluted rain in the Northeast would be about five.