Future trends in atmospherically induced acidic deposition

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1. Introduction

Future perspectives regarding the environmental problems which will result from emissions of oxides of sulfur and nitrogen have not yet been considered in any detail. Instead, most of the effort to date seems to have been spent in documenting the trends over the past half-century or more and in discussing the present view of the problem. This discussion, therefore, will emphasize possible frameworks within which future trends might be considered rather than a detailed analysis of present trends. A simple example of energy projections is, however, used to show the difficulty and the degree of effort required in making accurate predictions about future trends.

There are a number of important factors that one must consider when assessing future trends. The conceptual base must be carefully examined because the scale of the assessment is very large in space (global) and time (decades). These scales alone require analyses of the entire ecosystem including social-economic-political structures. In addition, the long time scale tends to limit conclusions to existentialistic statements, the existence of numerous possibilities for change suggests an eclectic approach to the analysis of possible trends, and the scientific conclusions will tend to be formulated in more simplistic deterministic modes. Somehow all of these various perceptions must be considered in the development of future predictions. Figure 1 is a cartoon that illustrates one possible scenario for the estimation of trends over time.

The analysis of future trends should consider what human perturbations are probable; the perturbations, at a given time, may be judged as magnifying the then perceived problem (pollution) or as a solution to the then perceived problem (management). Estimating future trends with confidence is difficult because the technical aspects of the problem may change and the management methods invoked to remedy the problem may change. These changes may be confounded even further by fundamental changes in personal attitudes and lifestyles.

The following section develops the concept of a major ecosystem (man included) experiment for which the major assessment tools are postdictive and related to models of past human perturbations of the ecosystem. Then follows consideration of a few examples for past trends, recent spatial trends, and possible future trends. I conclude with a proposal for an additional study.

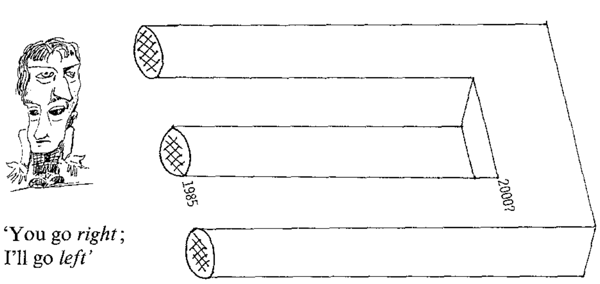

Figure 1. One possible future perspective (adapted from the Worm Runner's Digest *2* (1970–71) 88, and a sketch by Roger Hayward).

2. Conceptual framework

There are three fundamental points argued in the following discussion. The first is that for any kind of proper assessment, the entire ecosystem must be considered. Thus all of the interacting phases within a defined system must be assessed simultaneously, and anthropogenic aspects are invariably an important portion of the ecosystem. More often than not, in the assessment of acidic deposition, only portions of the ecosystem have been considered. This is understandable because of the difficulty of knowing all of the important interacting portions of a system.

The second point is that human perturbations of the ecosystem are viewed as directed experiments from which valuable information may be gained for the next experiment; and that this information is best attained by assessment of past experiments.

The third point is that the best means of assessment is the development of multiple models[4] of the system under consideration, and the most accurate validation of the various models is that of invalidation. The other approach of 'verification' or 'validation' of models is an assessment that produces results that are possible but not necessary. Therefore the use of models in the management process, although often invoked, is not deemed to provide an acceptable basis for action. Moreover, invalidation of one model should not by itself automatically increase the confidence in an alternate model.

Future trends in acidic deposition will result from ecosystem experiments that will be carried out and possibly be modified over time. In order that these experiments be carefully thought out with the proper time and space perspectives, there needs to be continuous effort to define precisely the system under discussion relative to acidic deposition and effects. The perceived system also needs to be assessed rigorously by study and evaluation of past experiences including human actions. The best means for doing this assessment is that of setting up models and attempting to *invalidate* them. There is the inference that those *ecosystem* models which stand intensive scrutiny are those that should be used when carrying out the next experiment.

3. Assessment of past, present and future trends

The ability to predict future trends in precipitation depends mostly upon the degree of confidence in understanding past and present trends. Study and interpretation of the past relies upon the ability to interpret a finished experiment. Any difficulties encountered are generally in data interpretation, owing to changes in technology and incomplete information about how data were obtained. In addition, attempting to duplicate earlier analyses, using today's materials, would often yield somewhat different results. Therefore, when interpreting historic data, the details of historic material and methods and the respective changes relative to the present must always be considered.

Study of present trends emphasizes spatial distributions and the correlation of different trends. Here the difficulties may be existentialistic biases and the apparent inability to collate and consider all trends critically, probably due to the incompleteness of the experiment. Often patterns and results are not scrutinized for inconsistencies. Thus there is more effort applied to the verification and validation of certain aspects rather than on invalidation. Overall there is a generally used hypothesis that links industrialization to emissions of sulfur and nitrogen oxides which are linked to an increasing deposition of acidic gases and liquids (and sometimes solids) upon the land and water. The affected receptors commonly considered are susceptible water bodies, flora and fauna. Long distant transport on the scale of 1000 km along with consequent increases in the acidic status of remote soft water lakes since the 1940s are also often invoked in assessments of past and present trends.

The above hypothesis is considered generally or in detail in a few examples. Tests are made for consistencies and inconsistencies in trend examples pertaining mostly to aquatic effects in North America. This type of critical assessment is the basis for establishing the degree of confidence upon which projections for future trends can be made.

3a. Past trends

Trend studies dealing with historic data have often emphasized changes in the water quality of remote headwater lakes in non-calcareous regions. For example, numerous reports have shown that as much as 75% of the surface waters of certain regions in North America have become more acidic over the last 50 years[12]. These studies considered the change in alkalinity and pH; all of the studies showed increasing acidic trends in lakes and rivers from about the 1930s to date, exhibited by a decrease in alkalinity or pH or both. Many of the studies correlated the increased acidic status with increased acidic deposition.

Only one of the aquatic studies[3] attempted to adjust historic data for changes in methodology, specifically the change from use of colorimetric methods in the past to electrometric methods now. A more recent study[7] has carried out a careful assessment of the data for New Hampshire and New York and concludes, after adjustment for methods and testing the adjustment, that some lakes have increased in acidic status, a large number have stayed the same, and some lakes have decreased in acidic status with an average increase in alkalinity for New Hampshire lakes and no-change for New York. Thus there is a strong bias owing to differences between historic and present methods for analysis of alkalinity and pH which accounts in large part for many of the previous conclusions regarding the change in acidic status of lakes. Smith and Alexander[11] have assessed the trends at the US Geological Survey 'Bench-mark' stations over the past 10–20 years. They conclude that alkalinity has increased for this time span in the Northeastern USA while decreasing or not changing in other areas; they also show a decrease in sulfate ion concentrations for the Northeastern USA consistent with a simple acid-base titration model[5] and strongly suggestive of decreasing atmospheric deposition. But other Survey geologists[10] studying the same data set conclude that pH has decreased in the Northeastern USA. This apparent inconsistency in conclusions regarding pH and alkalinity trends has not been pointed out nor has the importance of the differences been adjudicated.

There are apparently similar concerns about published trends regarding pH and alkalinity for some of the European data. The original discussion showing a decline in pH in Scandinavian rivers was based upon colorimetric pH data[9]. Recently Blakar and Digernes[2] have shown the influence of colorimetric dyes on the pH of very dilute waters. The commonly used indicator, bromthymol blue, is shown to increase the pH of dilute waters up to two units while having no effect upon high alkalinity waters; this follows acid-base theory. Even the study of Blakar and Digernes must be used with caution in that they used present day purer indicators in their studies and different dilutions from those used in the historic surveys.

Andersson[1] has recently assessed the long-term changes of lake water chemistry for various regions of Sweden. He concludes that the lake pHs are nearly the same as 30–50 years ago, with some showing increases and some showing decreases; he also shows that alkalinity has decreased and sulfate has increased in soft water lakes. He does not explain the apparent inconsistency of constant pH compared to decreasing alkalinity.

Sulfur emission trends can be plotted for the past century or more if industrial census data are available and if one assumes that the sulfur is completely emitted to the atmosphere upon use. Husar[6] has recently done such an analysis for regions of the USA. Taking into consideration distribution of different sulfur bearing minerals, petroleum and coal over time and space, he concludes that emissions in the Northeastern USA rose rapidly prior to 1900, have risen only slowly since the 1920s and have dropped significantly since 1970. In contrast, emissions in the Southern USA has increased three-fold since 1920 and presently show a continuing upward trend.

A quantitative assessment of emissions linked to an atmospheric transport and deposition model can give an assessment of historic depositional trends over time, which can be compared to lake water trends. This has yet to be carried out in a rigorous fashion; however, the sulfur emission pattern of slightly increasing emissions from 1920–1970 with a decrease thereafter for the Northeastern USA shows the same general pattern as the lack of change in lake alkalinity from the 1930s to present with evidence from the Bench-mark analysis of increasing alkalinity in the past decade. This trend analysis is somewhat different from that usually discussed. It results from a rigorous analysis of methodologies and data as well as a careful quantitative inventory by region of fuels and metals.

3b. Present trends

The analysis of present trends relies more upon spatial patterns than on temporal changes. For example, there exists a strong decreasing gradient (from southwest to northeast) of precipitation sulfate deposition in northeastern North America. Is there a parallel trend in lake sulfate fluxes for remote unexploited areas? Wright[13] shows a statistically strong correlation between average lake and precipitation sulfate concentrations for various regions of the USA and Canada. When atmospheric depositional fluxes are compared to lake outflow fluxes of sulfate for individual lakes, however, the correlation is poor. Figure 2 is a plot of the sulfate precipitation flux and lake flux for 626 lakes in Northeastern USA and Eastern Canada. There appears to be a monotonic increase between precipitation and lake fluxes, but when data for Quebec are excluded from consideration, the relationship is not statistically significant. Furthermore there are many examples of marked departure from equality of precipitation and lake flux; some of the cases of excess lake flux can be explained by proximity to rocks containing sulfur minerals, and other departures are at present not explicable.

3c. Future trends

Future trends are best estimated by concentrating upon possible variations in the amount and type of emissions. The various emission possibilities can then be used in models that consider chemical changes, transport and deposition in order to determine the atmospheric flux. Finally the estimated fluxes can be compared to present fluxes for both amount and spatial distribution.

The correlation between atmospheric deposition and effects is not quantitatively well-defined at present, due often to the presence of other confounding processes in

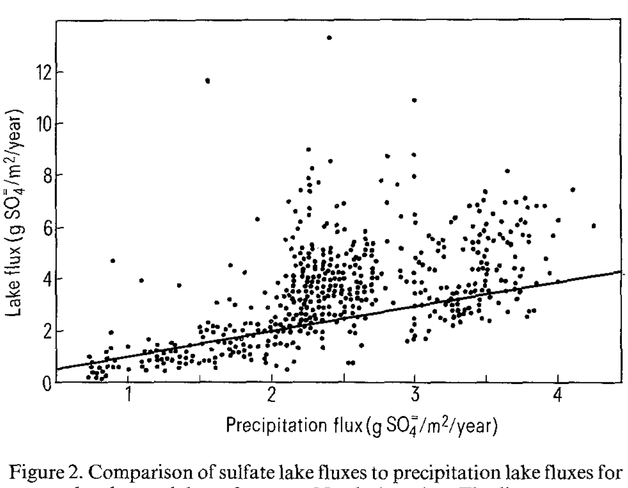

Figure 2. Comparison of sulfate lake fluxes to precipitation lake fluxes for remote headwater lakes of eastern North America. The line represents equality of fluxes. Note the excess lake flux suggestive of other sources of sulfur in these lakes.

the ecosystem. One may postulate with some degree of confidence that effects will be reflected by changes in atmospheric deposition.

The following are statements regarding future trends of sulfur oxide emissions with emphasis on North America:

1) Coal will be the significant fuel especially for thermal generating plants. Petroleum will be used primarily for transportation. Energy production using coal will approximately double over the next few decades.

2) Electrical generation from thermal plants will become a more important form of energy, resulting in a lower ratio of usable energy to gross energy due to conversion efficiency limits.

3) There is a variation of approximately one order of magnitude in the various forecasts of energy use over the next 2–3 decades[2]. The forecasts have tended to become lower in recent years as prices have increased, and society has become more conscious of atmospheric pollution problems and the conservation ethic. Estimates for the US range from a low of about 30% of the actual 1978 consumption (approximately the highest to date) to about 3 times the 1978 estimate.

4) Various predictions for change suggest that a pricing increase coupled with technological improvements in efficiency and use of waste heat, will decrease energy consumption to about the same degree as will a major change in societal and consumer attitudes.

5) The average sulfur content in coals used for generations will decrease further to perhaps 1 + percent. This shift will be brought about by increased use of lower sulfur (<1% S) Western USA coals compared to Eastern USA coals (1–4% S). The impetus for this increased use of low sulfur coal will probably come from legislative demands. It is quite possible that the reduction in emission and deposition for the Northeastern USA since 1970 has resulted from the use of lower sulfur coal.

6) 'Surprise' price increases may have a profound effect upon the consumer and may elicit a renewed consciousness of energy conservation. The effect of a change in consumer attitude must not be overestimated, and change in consumer attitudes may also change the focus of the atmospheric pollution problem. For example, a change to the use of individual wood heating units (the 'conservation symbol') may switch the problem of atmospheric emissions from being a regional to being a local concern.

Needless to say, the possibility for change is very large. The potential cut-back in atmospheric emissions by combinations of the above changes could easily meet the 50–90% reduction in emissions that might be achieved by technological removal of pollutants. It is even possible that the problem of emissions may change entirely to involve some other substance or some other spatial dimension. It is apparent, however, that there is more than enough variability in factors that determine the kind and amount of emissions to support the prediction of a very wide range of possible trends for emissions in the future.

It might be worthwhile for future scenarios to develop models of what is possible by defining what is impossible in terms of technology and social acceptability. In the end, there are two possible approaches to correlating emission levels with measures to control them. One is to decide the level of control to be invested – technology, legislative action, taxes etc., and then determine how much effect this investment can have in reducing emissions. The other approach is the reverse; society decides what is an acceptable level of emissions and expends the resources to bring emissions down to that level.

One could start by defining a series of goals with respect to kind of emissions produced and then amount and spatial distribution; this definition of goals would presumably be obtained from a consideration of the environmental impact, and it would be a 'given' for the calculations. The next step would be to estimate different energy demands for different societal requirements. Specific subgroupings of industrial products, domestic requirements and transportation might be considered, and various limiting estimates for the sub-groupings would be considered. Then emission factors would be considered for each sub-grouping; once again, it would be best to use limiting values for emission factors. Multiplication of the use and emission factor matrix would result in values for different categories of emissions. Other manipulations would give an idea of the sensitivity to change for various use categories. At this point, data on the emissions by category would need to be adjusted to show effects of technological changes, political actions (taxing, other legislation), consumer reactions and pricing. Here past trends would be of help in assessing legislative impacts and effects of pricing. Consumer reaction might best be assessed by case studies of surprise events including the duration of such reaction. There would evolve a series of estimates of emissions, where the emphasis of the estimates would be upon what is not achievable or not permissible without a change in a particular ecosystem attribute. The other conclusion of this study would be what is fundamentally not permissible if the given emissions are to be met.

This kind of study is not a new approach; there exist already results for portions of the study. What probably needs emphasis is the necessity of examining the entire ecosystem, not just specific portions. In this regard, consumer reactions and pricing should always be considered because they influence strongly the subcategories of use and the emission factors for the categories.

4. Conclusions

Past, present and future trends result from total ecosystem experiments that involve human perturbations. These experiments need to be examined in a total concept in order to develop ideas for future experiments. In the assessment of past, present and future trends, emphasis needs to be placed on the invalidation of models and of 'truths'. In the case of acidic deposition, some critical appraisals of past and present trends for aquatic impacts have been given as examples of this kind of critique. More needs to be done.

It is argued that there is a very large potential variability in estimates of future emissions; in fact, changes may be such as to refocus the problem. In order to assess possibilities as well as ecosystem sensitivities, estimates of emissions should be made for different sub-categories of societal uses, and these estimates should be evaluated particularly for price and consumer reaction sensitivity. Continuing evaluation and assessment of impacts should result in decreased emissions and a more flexible system to meet surprises in the future.

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