Impact Models to Assess Regional Acidification

edited by

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Modeling in the field of acid precipitation is a dynamic and very rapidly changing discipline. In recent times, modelers have been devoting an increasing amount of attention to the possible use of their acidification models in a decision-making context. To provide meaningful information for management purposes, a model should be dynamic in nature, it should analyze the long-term behavior of the environment, it should be applicable over a large regional scale and, finally, it should produce well-defined illustrative information as output. *Impact Models to Assess Regional Acidification* assesses modeling in relation to these decision-related criteria.

The book is divided into three major parts. In the first, the terrestrial effects of acidification are dealt with in three chapters describing, respectively, models of soil acidification in the Netherlands, the effects of acid deposition on agricultural soils, and the factors controlling forest growth.

The second part of the book, comprising seven chapters, focuses on the aquatic effects of acidification, describing groundwater aquifer sensitivity to acidification, the response of fisheries to acid deposition, synoptic lake survey data, a Monte Carlo simulation of long-term responses to acidification in Norway and southwest Scotland, a method for the regional calibration of models, and a simple 'direct distribution model'.

In part three the issues of model reliability and utility are explored via a comparison between the prediction of the RAINS model with actual data, an evaluation of stochastic calibration procedures, inherent uncertainty in the MAGIC model, and an integrated assessment model.

The book closes with a summarizing chapter by the editor which identifies some important directions for future research.

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Foreword

Sensitive receptors such as soil and fresh bodies of water are at the end of a long chain of events in the process of regional acidification. This chain begins thousands of kilometers upwind at the emitters of acidifying pollutants. The topics covered in this book are important in the study of regional acidification for two reasons. First, it is important to assess the sensitivity of terrestrial and aquatic ecosystems to the deposition of acidifying pollutants. If the sensitivity of an ecosystem is known, then international control strategies can be developed to reduce deposition in the receptor areas of greatest importance. This is an important factor in designing the most effective strategies because of the very high costs of reducing emissions of acidifying pollutants.

Second, it is important to be able to predict changes in ecosystems for decades into the future, whether it be an improvement owing to decreases in acidifying emissions or, alas, a further deterioration because control strategies are nonexistent or inadequate. In either event, it is important to be able to judge the results of our actions.

Decision makers tend to be mistrustful of models unless they can judge their reliability. The application and testing of the models in Part III of this book cover, therefore, an important facet of model building.

This book is an ideal companion to another book that is forthcoming from the Transboundary Air Pollution Project at IIASA: *The RAINS Model of Acidification: Science and Strategies in Europe*. The latter book is a description of the development and use of the Regional Acidification INformation and Simulation (RAINS) model, an integrated assessment model for developing and determining control strategies to reduce regional acidification in Europe. Much of the research described in this book forms part of the foundation of the RAINS model. These two books cover a great deal of the present knowledge about assessing and dealing with a very important environmental problem in Europe – regional acidification.

R. W. Shaw
Leader
Transboundary Air Pollution Project

Introduction

Acidification of the Environment

Acidification of the environment is, like most recent environmental problems, a consequence of change in the natural cycles of elements. Some chemical substances that during millions of years leaked from the biosphere are again being emitted to the atmosphere. Owing to these anthropogenic emissions, fluxes of acidifying compounds to the soils and waters have increased manyfold since preindustrial times.

The whole problem of air pollution is transboundary in nature; its geographic dimensions are difficult to define. Pollution sources are scattered in many countries, the consequences extending far away. Acidifying sulfur and nitrogen oxides can persist in the air up to a few days, long enough to be transported hundreds or even thousands of kilometers from the place they were emitted. During this transit time, gaseous pollutants undergo a complicated chemical conversion into nitric and sulfuric acids, which are deposited as particles or as droplets of water. Thus, practically all industrial countries are responsible for the problem. And, since the sources are international, the resolution of the problem likewise requires cooperative international action.

Air pollutants cause numerous changes in the biotic and abiotic environment. The series of chemical reactions, starting from the emissions of sulfur dioxide and nitrogen compounds to the depletion of the natural acid-neutralizing capacity of soils and waters, has been established in extensive research programs of Scandinavia and North America. This depletion of acid-neutralizing capacity is termed *acidification*. Two factors appear sufficient to explain the magnitude and the geographic distribution of soil and water acidification: the amount of acidic atmospheric deposition and the inherent sensitivity of the recipient.

Acidification has been recognized as a fairly complex process involving many mechanisms both in the terrestrial and the aquatic catchment. Although some of these mechanisms are not understood quantitatively, research is continuously expanding the level of knowledge of various aspects of the problem. Numerous attempts have already been made to identify and quantify lake acidification in order to estimate changes over past decades when historical data are lacking or unreliable.

Scientific knowledge on the whole acidification phenomenon has increased tremendously since Professor Svante Oden of Sweden mapped the changing acidity of precipitation as a regional phenomenon in Europe and postulated this acidity as a probable cause of decline in fish populations. Since that time acidification research has developed from a few single studies to a new field of science. Before any theories were established to account for acidification, there remained competing hypotheses and alternative explanations for the widely observed regional surface water acidification.

This development of acidification science resembles the Kuhnian route to normal science. Kuhn described normal science as research firmly based upon past scientific achievements, paradigms, which some particular scientific community acknowledges as supplying the foundation for its further practice. Before any paradigms, laws, or theories could be established in acidification, competing hypotheses and alternative explanations for the widely observed regional surface water acidification had to be resolved.

Now consensus seems to be near that acidic deposition plays an important role in soil and water acidification and that certain soil chemical processes regulate acidification. The scientific community takes these paradigms for granted, and there is no longer need to start anew from first principles and justify each concept used.

Modeling Acidification

The difficulty of scientific prediction has been well demonstrated in serious attempts to estimate, for example, future oil prices, currencies, or weather. The performance of predictive methods depends on how well the laws governing the deterministic system or the initial conditions of the system are known. Prediction becomes quite reliable when the laws of the system have been clarified; e.g., solar eclipses can be calculated centuries ahead of time with great accuracy. For any such well-established system the factor limiting predictive power is knowledge of initial conditions. When observation techniques allow the initial conditions to be determined only approximately, predictions based on deterministic laws are also approximations.

Natural systems are extremely complex. Nevertheless, to avoid the destruction of sensitive ecosystems, we must understand both these systems themselves and the consequences of human actions on them. Only in recent years, with the availability of efficient computers, has the analysis of ecological systems become a practical possibility. The purpose of such computer-based studies, termed systems analyses, is the better understanding of a given system, usually to permit reliable predictions and better management decisions based on them. This implies a description of the system and its processes, i.e., a development of a model representing the real system, the behavior of which resembles that of the real system as closely as possible.

A model can obviously never be as complex as the real system itself. Models work with aggregated representations of reality. Uncountable interactions among system components are reduced in the model description to a few mathematical equations. Model development is a selective and, hence, a partly subjective procedure that involves several sequential steps. In model conceptualization there are choices regarding the level of spatial and temporal aggregation; the separation between chemical, physical, and ecological elements; as well as the processes to be incorporated into the model structure.

After the decision has been made as to how the system will be represented, the model builder has to choose from several possible model types. There is a choice, for example, between dynamic and steady state models, distributed and lumped models, as well as between internally descriptive (mechanistic) and black-box (input–output) models. The model builder's selections depend upon the goals and objectives of the final model application and on the availability of data. A study investigating the future long-term effects of land-use changes on water quality, for instance, necessitates a different kind of model than a study attempting to predict the effects of a particular sewage discharge.

Predictive models can in a very broad sense be classified into two categories on the basis of their application objectives. First, models can be applied as research tools to indicate further directions of investigation. Especially in early stages of research on a badly defined system, time series data are likely to be scarce, and the only way to progress in this situation is to use some form of simulation model in the hypothesis-generating role. Necessarily, the simulation model produces no immediate practical applications; whereas the second type, management models, assumes that the applications are known and carefully specified. The term management can in this context include objectives such as long-term planning, designing environmental policies, estimating environmental consequences of human actions, and designing treatment facilities for pollutants.

Conceptualization of the acidification phenomenon has naturally been based on recent findings in soil and water chemistry. Yet, since we are dealing with a new problem area and thus with a fairly poorly defined system, the modelers have not always identified the same processes as the key mechanisms that determine system behavior. Additionally, the computational approaches chosen to represent these various processes and observed water quality patterns have varied. The modeling approaches used to date represent practically all existing model types, ranging from simple to complex, from dynamic to steady state, and from black-box to highly deterministic models.

Concerning process-oriented mechanistic approaches, there is a significant convergence of thought about the key processes involved. The models developed so far contain many similar assumptions about a number of soil chemical processes. The models use fluxes of strong acid anions, mainly sulfate, as the most important driving variable. Most of these models more or less explicitly incorporate the anion mobility concept. The importance of sulfate adsorption, cation exchange, and aluminum dissolution, as well as weathering reactions, can be easily gleaned from recent modeling efforts. The convergence of opinion on the importance of these mechanisms would not have been possible without a great number of model applications, performance evaluations, and further model development. It has been not only the successes of various applications that have increased our knowledge on the acidification mechanisms; failures to predict