UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

EPA-SAB-EEC-89-012

OFFICE OF
THE ADMINISTRATOR

January 13, 1989

Honorable Lee M. Thomas
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Dear Mr. Thomas:

The Environmental Engineering Committee of the Science Advisory Board has prepared the attached resolution for your consideration on the use of mathematical modeling for regulatory assessment and decision-making. This is the second time the Science Advisory Board has acted on the issue of modeling; a 1984 letter called the Agency's attention to this important concern.

Over the last few years the Environmental Engineering Committee has reviewed a number of EPA environmental modeling studies. In doing so, the Committee has noted a number of problems in the development and implementation of models within the Agency that were common to modeling efforts sponsored by a variety of offices. The Committee believed that these common problems would be best called to the Agency's attention through a more general resolution on modeling.

Drafts of the resolution were presented and widely discussed at a series of Committee and Executive Committee meetings during 1988. For instance, an earlier draft of the resolution was quoted at length in the Radiation Advisory Committee's recent report on the sources and transport of radionuclides. While encouraging the overall approach of quantitative risk assessment and modeling for environmental decision-making, this Committee noted a number of common problems in the use of models by the Agency. The following items summarize the main points that are addressed in the attached resolution:

1. There should be a better balance between field and laboratory data collection efforts and modeling analysis for effective environmental assessment;

2. Models for regulatory assessment and decision-making which incorporate state-of-the-art scientific understanding of the environmental processes involved should be developed and used;

3. There should be better confirmation of models with laboratory and field data;

4. Sensitivity and uncertainty analysis of environmental models and their predictions should be conducted to understand level of confidence in model predictions, as well as to identify key areas of future study;

5. An Agency-wide task-group to assess and guide model use by EPA should be formed;

6. There should be an increased effort to hire and support engineers and scientists with modeling development and application skills;

7. There is a need for systematic management of model use within EPA and a careful review of emerging technologies such as personal computer-based models and expert systems; and

8. Peer review at various levels should be coordinated to ensure proper development and application of models.

The resolution identifies a number of ways in which the use of models by the EPA can be improved. The Committee believes that successful implementation of these recommendations will require the establishment of a formal institutional mechanism with responsibility for review, oversight and, coordination of model use in EPA.

We are pleased to have had the opportunity to be of service to the Agency, and look forward to your response on this issue.

Sincerely,

Raymond C. Loehr

Raymond C. Loehr, Chairman
Executive Committee
Science Advisory Board

Richard A. Conway

Richard A. Conway, Chairman
Environmental Engineering Committee
Science Advisory Board

Mitchell J. Small

Mitchell J. Small, Chairman
Modeling Resolution Subcommittee
Science Advisory Board

Attachment: Modeling Resolution

cc: John A. Moore
Donald G. Barnes

EPA-SAB-EEC-89-012

RESOLUTION ON THE USE OF MATHEMATICAL MODELS BY EPA FOR REGULATORY ASSESSMENT AND DECISION-MAKING

by the

Environmental Engineering Committee
Science Advisory Board
U.S. Environmental Protection Agency

January 1989

INTRODUCTION

The use of mathematical models for environmental decision making has increased significantly in recent years. The reasons for this are many, including scientific advances in the understanding of certain environmental processes, the wide availability of computational resources, the increased number of scientists and engineers trained in mathematical formulation and solution techniques, and a general recognition of the power and potential benefits of quantitative assessment methods.

Within the US Environmental Protection Agency (EPA) environmental models which integrate release, transport, fate, ecological effects and human exposure are being used for rule making decisions and regulatory impact assessments. This report is directed to the development and validation of such models, an issue which was first addressed in December 1984 by Norton Nelson, Chairman of the Executive Committee of the SAB. In a letter to the EPA Administrator, William Ruckelshaus, it was recommended that a systematic effort of model validation be initiated, including an identification of the appropriate balance between monitoring and modeling. It was further recommended that the relative utility of exposure modeling approaches be evaluated in the form of case studies in various media including model validation and uncertainty analysis.

The Environmental Engineering Committee reaffirms and amplifies these recommendations, based on review of a number of integrated environmental modeling studies during the past few years. Examples include a review of the report, "Comparison of Risks and Costs of Hazardous Waste Alternatives: Methods Development and Pilot Studies" (SAB-EEC Report, July 1985); a review of the Code for Transport in the Unsaturated Zone (FECTUZ) and its potential use for determining whether a waste is hazardous for listing decisions (SAB-EEC-88-030); a review of risk-based regulations for alternative disposal and reuse options for sewage sludge (SAB-EEC-87-013, SAB-EEC-87-015); a review of the Underground Storage Tank (UST) Release Simulation Model (SAB-EEC-88-029); and a review of the draft risk screening analysis for mining wastes (SAB-EEC-88-028). While encouraging the overall approach of modeling for environmental decision-making by EPA and acknowledging the progress made by various offices within the Agency, the committee noted a number of problems in the development and application of models, including: the increased reliance on models rather than background data collection and analysis, an inadequate level of laboratory and field validation for models employed, a lack of studies quantifying the uncertainties associated with model predictions, and concurrently, the potential misuse of particular uncertainty analysis techniques. The following resolutions address these issues, and identify the need for an institutional mechanism within EPA to ensure their implementation.

RESOLUTIONS

1. **A balanced program of field and laboratory data collection and modeling analysis is required for effective environmental assessment.**

The realistic characterization of an environmental problem requires the collection of laboratory and field data - the more complex the problem, the more extensive and in-depth are the required studies. In some cases involving more complex issues, future projections of environmental effects, larger geophysical regimes, inter-media transfers, or subtle ecological effects, mathematical models of the phenomena provide an essential element of the analysis and understanding. However, the models cannot stand alone; adequate data are required. Indeed, a major function of mathematical models is as a tool to design field studies, interpret the data and generalize the results.

A number of recent studies of integrated exposure and risk reviewed by the committee have exhibited an over-reliance on models at the expense of the acquisition of needed data. This trend should be reversed.

2. **Mathematical models for regulatory assessment and decision-making should Incorporate, to the extent possible, the state-of-the-art scientific understanding of the environmental problem.**

Mathematical models should ideally be based on a fundamental representation of the physical, chemical and biological processes affecting environmental systems. In the regulatory domain, there may be a need to sacrifice model complexity and rigor because of inadequate process insight, the need for computational efficiency, or because of a lack in available supporting data. There should not, however, be too ready a willingness to abandon fundamental, scientific approaches simply because the required research and data are too difficult to obtain in a short time-span. If this were done, two undesirable results would likely occur. First, an improperly formulated model can lead to serious misjudgements concerning environmental impacts and the effectiveness of proposed regulations. In this regard, a bad model can be worse than no model at all. Second, by accepting an improperly formulated model, the use of a weak scientific approach can become institutionalized within the Agency, and the opportunity to motivate the needed research and data collection can be lost. Rather, shortcomings in process understanding and available data should serve as an incentive for research and data acquisition to improve the foundations for models.

It must be recognized that research and data acquisition to support state-of-the-art model development and validation is a long-term, iterative process involving many scientific and engineering disciplines. A commensurate, long-term commitment to support this effort is required from the Agency.

3. **There is a need for models used in regulatory applications to be confirmed with laboratory and field data.**

There are a number of steps needed to confirm the accuracy and utility of an environmental model. As a preliminary step, the elements of the basic equations and the computational procedures employed to solve them should be tested to ensure that the model generates results consistent with its underlying theory. The confirmed model should then be calibrated with field data and subsequently validated with additional data collected under varying environmental conditions. After the particular regulatory program has been implemented, field surveys and long-term monitoring should be conducted for comparison with model projections. The stepwise procedure of checking the numerical consistency of a model, followed by field calibration, validation and a *posteriori* evaluation should be an established protocol for environmental quality models in all media, recognizing that the particular implementation of this may differ, for surface water, air and ground water quality models. It is also recognized that the degree and extent to which the process of validation is conducted for a model depends on the significance of the environmental issue and the consequence of an erroneous decision concerning the problem.

It is recommended that EPA establish a general model validation protocol and provide sufficient resources to test and confirm models with appropriate field and laboratory data.

4. **Sensitivity and uncertainty analysis of environmental models and their predictions should be performed to provide decision-makers with an understanding of the level of confidence In model results, and to Identify key areas for future study.**

A number of methods have been developed in recent years for quantifying and interpreting the sensitivity and uncertainty of models. These methods require careful application, as experience with uncertainty analysis techniques is somewhat limited, and there is a significant potential for misuse of the procedures and misinterpretation of the results. Potential problems include the tendency to confuse model uncertainty with temporal or spatial variation in environmental systems, the tendency to rely on model uncertainty analysis as a low-cost substitute for actual scientific research, and the tendency to ignore important uncertainties in model structure when evaluating uncertainties in model parameters. To address the latter issue, sensitivity analysis of a broader nature is required, considering the impact of

alternative model assumptions and omitted processes. As is the case for model validation, the extent to which sensitivity and uncertainty analysis should be performed depends upon the importance of the environmental issue and the relative role of the model in determining the regulatory decision.

Consideration of model sensitivity and uncertainty should be included in all modeling studies. The implications of errors in model structure, as well as errors in model parameters, should be evaluated to determine possible effects on the ultimate regulatory decision.

5. **There Is a need for a central coordinating group within the EPA to assess the status of environmental models currently used or proposed for use In regulatory assessment, and to provide guidance In model selection and use by others in the Agency.**

In the selection of mathematical models for regulatory applications, a thorough understanding of the capabilities, limitations and degree of validation of available models is required. There have been instances where a model developed for a particular purpose was used in a new application without the appropriate steps taken to properly adapt and validate the model in the new problem setting. Conversely, there are cases where available computational programs for models have been ignored and new, but similar, procedures developed at unnecessary effort and expense. Recognizing the need for improved model selection and use, the Sources, Fate and Transport Subcommittee of the SAB Research Strategies Committee (SAB-EC-88-040, SAB-EC-88-040A) recommended that EPA formalize mechanisms for review and acceptance of environmental models for all media. Methods such as those used by the EPA Office of Air Quality Planning and Standards (EPA-450/2-78-027R) were recommended. This would involve identifying tested or recommended models for particular media or environmental settings, establishing procedures for demonstrating the acceptability of alternative models, and instituting a Model Clearinghouse to compile and test models, conduct periodic workshops to ensure consistency in modeling guidance, and promote the use of the most appropriate models and data bases. The Subcommittee also indicated the need to identify currently applied models where improved validation is needed, and to develop a priority list for these validation efforts.

To address the issues of model validation and model selection and use within the EPA, we suggest the establishment of a task-group on mathematical models for environmental quality assessment. Such a group would evaluate the state-of-the-art of models in each of the media, as well as emerging multi-media models, evaluate environmental models used by other government agencies, and provide oversight for model development, validation and application within the EPA. The group would also rank current models as to their relative importance and need for further validation studies. This Agency-wide task-group should be established as soon as possible.

6. **EPA must him and support engineers and scientists with appropriate model development and application skills.**

This issue is closely linked to the recommendation of the SAB Research Strategies Committee that EPA increase the numbers and sharpen the skills of the scientists and engineers who conduct environmental research (SAB-EC-88-080). Modeling is not a separate discipline, rather it is a particular skill that is part of the overall environmental science and engineering approach to problem-solving. There has been a tendency to allocate the development of models to the computer specialist, who frequently lacks the understanding of the basic equations and their significance to the environmental problem. Similarly, there has been a tendency to presume that the users of models need not understand the basis for the models. This is incorrect. The proper development and application of models requires engineers and scientists trained in the fundamental principles of the environmental transport problem and computational methods, so that they can develop and work with the model in an informed manner, not just as a black box which is manipulated to obtain numerical output. Note that often the most critical and effective application of models is made by users not involved in the development of the model, as they are more likely to question and challenge the implicit perspectives and assumptions of the model approach. As such, skilled model developers and model users are both required for effective problem-solving.

The Agency should increase its efforts to hire and retain engineers and scientists who are qualified in the area of model development and model use, having both broad and problem-specific skills. The EPA should support their efforts through the program of the Agency task-force on modeling discussed in the previous resolution.

7. **The need for a systematic management of model use within the EPA is heightened by the introduction of new computer systems and modeling technologies.**

The wide availability of personal computers has brought increasing numbers of models to an increasing number of potential users. As a result, the problem of ensuring code validity and proper model use is that much more difficult. Special challenges are also raised by the growing technology of knowledge-based expert systems. Expert systems allow the automation of a wide range of scientific analysis and inference, and are currently being developed for a variety of environmental engineering

problems. EPA should require strict review and critique of expert systems, recognizing that they can, in many ways, be treated like other environmental models. They are tools to aid the decision-maker, they must be rigorously confirmed with field data prior to regulatory application, they require a careful consideration of model sensitivity and uncertainty, and they require trained users familiar with both the fundamental physical principles of the environmental system being considered and the way in which the expert system uses this information to arrive at its recommendation for a design or regulatory decision.

The recommended EPA task group on modeling should pay particular attention to emerging technologies, such as personal computer-based models and expert systems. Careful review, oversight and validation are needed for these beneficial, but relatively untested approaches to environmental modeling.

8. **Peer review at various levels is required to ensure proper model development and application.**

Peer review is an essential element of all scientific studies, including modeling applications. Peer review is appropriate in varying degrees and forms at different stages of the model development and application process. The basic scientific representation incorporated in the model should be based on formulations which have been presented in the peer reviewed scientific literature. Ideally, the model itself and initial test applications should also be presented in peer-reviewed papers. However, this is not always possible given the pace of scientific development and regulatory need. Peer review panels are thus often required to review the scientific capabilities of proposed models and their intended applications. These expert panels should include some combination of internal Agency staff and outside experts. Innovative approaches to model review should be considered, such as the use of "round robin' reviews in which the same modeling task is addressed by a number of independent groups, or the use of benchmark data-sets for testing model accuracy.

The recommended EPA task group on modeling should identify the needs for peer review of models and establish procedures for coordinating the necessary peer review panels.

SUMMARY

The resolutions presented in this report address critical issues that must be confronted to improve the use of models by the EPA. These issues include the need for a better balance between data collection and modeling, the use of state-of-the-art models, the need for model confirmation and

sensitivity and uncertainty analysis, the need for a central coordinating group to provide oversight and guidance on model use within the Agency, the need for more scientists and engineers with modeling skills, the need for review of new modeling technologies, and the need for peer review of model development and application. Many of the recommendations in this report can be implemented by individuals and individual offices within the EPA. This will undoubtedly lead to a more effective use of models by the Agency. The Committee believes, however, that a full and successful response to these resolutions will require the establishment of a formal, institutional mechanism which can promote better review and coordination of model use throughout the EPA. The actual structure of this group and its relationship to previous or ongoing initiatives is an issue that requires further consideration by the Agency. It is hoped that these resolutions will provide further motivation and direction for this effort.