Chapter 3
General Issues in Model Development, Use, and Dissemination

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Models are increasingly used to analyze a wide variety of resource issues because they can provide information that is either unavailable from other sources, more accurate than that provided by other sources, or quicker and less costly than that provided by other sources. However, as with many new information technologies, institutions have encountered problems in integrating modeling and model-generated information with established operating procedures, professional responsibilities, and channels of communication.

When modeling efforts are supported by public funds, institutions that develop models have responsibilities for ensuring the availability y and usability of such tools for other institutions. To effectively carry out these responsibilities, model-sponsoring organizations must devise strategies to inform potential users of the existence of relevant models, ensure that the model's purpose and workings are explained in writing so that decisionmakers can determine its applicability to a given problem, and disseminate the model to those who request it. Additional support services include developing programs to train and assist users to operate models and interpret results, maintaining and improving existing models, and designing models for ease of use by other institutions.

The process of developing and using models also requires extensive consultation between highly trained technical and scientific personnel on one hand and mid- and upper-level managers on the other. Yet decisionmakers are often unprepared to involve themselves in the modeling process, and may consequently be uncertain of how to use model results. Similarly, modelers may be equally unprepared to build models that provide the kinds of information decisionmakers need. For institutions to make effective use of models, links must be created among modelers, model users, and decisionmakers, and effective incentives be devised to make model development and use an interactive process among them. Further, institutions need to develop procedures for evaluating the models they use, overseeing model development, and assessing the legal implications and consequences of their model use.

This chapter reviews the major issues associated with the development, use, and dissemination of water resource models. Many of the significant problems associated with current model use for water resource analysis are encountered throughout the modeling profession; they tend to reflect the newness of the modeling field, and institutional unpreparedness for overseeing, supporting, and guiding model use.

The chapter is comprised of two major secf "ens: Support Services for Disseminating and Using Existing Models Effectively; and Issues in the Development and Use of Models.

SUPPORT SERVICES FOR DISSEMINATING AND USING EXISTING MODELS EFFECTIVELY

Once a model is operational, any potential user normally needs a great deal of information from the developer if he or she is to become proficient in running the model and interpreting its results. A model may have been rigorously developed and thoroughly evaluated, yet in the absence of adequate user-oriented support services, it is likely to remain unused by anyone other than its developer. Within the modeling profession, *such support services* are called technology transfer *and assistance.* This section discusses those aspects of modeling that aid users in employing an existing model. Five support activities are treated in depth; the section concludes with an overview of additional model characteristics that are linked to technology transfer capabilities:

- documentation;
- informing users of available models;
- training;
- user assistance;
- maintenance and improvement of models; and
- additional model characteristics affecting ease of model use.

Documentation

Documentation is the process of setting out explicit written instructions on how to use a model and interpret its results. Although documentation is critical to the proper use and dissemination of models, it is rarely carried out adequately, and is considered by professionals to be one of the most neglected aspects of modeling. The lack of proper documentation prevents potential users from discovering existing models that suit their needs—causing costly duplication in model development—and increases the difficulty and cost of using previously developed models.

Documentation has two purposes. First, it provides a nontechnical description of the basic concepts employed in a model, and its limitations. Such a description must include sufficient information to allow a decisionmaker to determine whether a given model is suitable (and available) for a specific use. Second, it provides technical information on the basis of which a user/analyst can evaluate, duplicate, and operate the model. Three kinds of documents are generally used to document computer models:

1. a detailed description of the model's purpose and assumptions;
2. users' manuals, which give instruction on running the model—i. e., how to prepare input to get the desired output; and
3. programmers' manuals, which explain the model's logic and internal functions, enabling the user to adjust and adapt the model to fit his particular needs.

Good documentation is difficult to prepare. Modelers and computer programmers usually have a highly developed command of technical computer languages—it is in these languages that they actually work. Documentation requires translating the instructions written in these languages into clearly understandable English. The task is not only time-consuming— a medium-sized computer program may consist of 4,000 sets of instructions—but it is also one for which a technical specialist may have little skill or motivation. The developer of a model has no inherent need for documentation, other than as a reminder of what he may forget. Documentation is principally for successive users, and few incentives currently exist for the developer to take user needs into account in the process of model development,

Consequently, for most models, documentation either does not exist, or exists in inadequate form, lacking in detail, and failing to serve users' needs. [1] Model documentation is typically so brief or poorly written that the user is forced to resort to a trial-and-error approach to learn proper use of the model, or to seek personal assistance from those who developed the model.

Documentation is the primary mechanism for informed communication among those involved in modeling efforts—developers, users, analysts, and decisionmakers. Without it, the purpose, premises, and capabilities of the model remain obscure, and it becomes impossible to: 1) decide whether a model applies to a given problem, 2) operate the model independently of the developer, and 3) adequately interpret and use model results. [2] Further, competent documentation is important in facilitating model evaluation by third parties, and in encouraging continued maintenance and updating to keep models current.

Few institutions encourage proper documentation. Seldom are funds specifically provided for the documentation phase of model development. Even when funds are provided, if the funding organization lacks a unit that critically evaluates documentation in the context of using the model, developers

[1] S. Gass, *Computer Model Documentation A Review and An Approach*, NBS Special Publication 500-39, National Bureau of Standards, 1979.

[2] G. Fromm, W. L. Hamilton, and E. E. Hamilton, *Federally Supported Mathematical Models Survey and Analysis*, GPO stock #038 -000-00221-0 (Washington D. C.: Government Printing Office, 1975), p. 44.

may have little incentive to spend time and effort on the quality of their documentation work. In most modeling efforts, documentation is done "after the fact, as part of the cleanup operation at the end of the project, necessitating searches through old records at a point when both time and money are in short supply.

Moreover, modelers and programmers have little professional incentive to produce high-quality documentation work. Documentation is a long and tedious process. Most developers see it as noncreative, in that it calls not for analytical or technical skills, but rather for communicative abilities that the modeler frequently lacks. At present, documentation is also seen as contributing little or nothing to the modeler's standing in his field.

If documentation is to be upgraded, it must become an integral part of model development. The most efficient mode of creating written documentation is to do so concurrently with the development of the model—this helps to ensure that the written instructions accurately reflect the actual computer program.

Informing Users of Available Models

Although numerous models are available to assist water resources managers, these models are difficult for users to identify, locate, and obtain. OTA found that many potential model users, and even modelers themselves, considered the need for effective communication about existing models more important than the need for developing new models. Frequently, the difficulty of identifying and locating a suitable model causes the decisionmaker to either forego model use for water management decisions, or leads to the development of a new model. Developing new models is extremely costly and time-consuming, while existing models that have been evaluated may need only minor adjustments and ' 'fine tuning' to be applied to the user's problem.

Presently, most information on existing models is available only in technical journals. These technical publications are geared primarily to use by scientists and modelers. Few journals aim to communicate with decisionmakers and managers, and their distribution is often limited to a handful of subscribers. Most take over a year to publish a submitted manuscript, causing significant delays in communicating the availability of a model.

Three ways to make information on existing models available to potential users were suggested at the OTA workshops: 1) catalogs, 2) newsletters, and 3) model clearinghouses.

Catalogs

Various Government agencies and research organizations have published catalogs of available models. Such attempts to distribute model information have had mixed success. In the rapidly advancing field of modeling, many catalogs quickly become outdated, since new models are regularly introduced and old models must continually be updated to remain current. Consequently, the maintenance and updating of a usable catalog must be performed on a continuing basis by a staff with relatively high levels of expertise.

A number of Federal organizations have included model-related information in catalogs dealing with water resources—most importantly, the *Selected Water Resources Abstracts* and the *Water Resources Research in Progress File Catalog* of the Water Resources Scientific Information Center. and various publications of the National Technical Information Service. However, these services are not designed to rapidly access modeling information, and are too far removed from developers to be extensively used or adequately maintained.

In addition, the Federal Software Exchange Center (FSEC) publishes catalogs of computer programs that Federal agencies consider to be usable by other Federal, State, and local government agencies. However, the catalogs are not intended to provide comprehensive coverage of even federally developed models, and provide relatively scanty information regarding the models that have been included, Moreover, FSEC regulations prohibit disclosure of the identity of the developing agency without its prior consent, frequently precluding further inquiries by and assistance to potential users.

An extensive discussion of the functions of these organizations that relate to modeling is provided in chapter 4 of this report.

Newsletters

Newsletters are a useful vehicle for disseminating information about available models. An organization can publish newsletters relatively inexpensively as a service to current and potential users of its models. Newsletter services for the Environmental Protection Agency's (EPA) Stormwater Management Model (SWMM) Users's Group and the EPA Center for Water Quality Modeling are described in chapter 4 of this report.

Model Clearinghouses

Clearinghouses offer a comprehensive approach for disseminating information about models available from a broad range of participating agencies and organizations. Model clearinghouses serve as a central resource for obtaining information about available models, and help to address such modeling problems as duplication of model development efforts, and improper selection of models.

A clearinghouse's primary function is to collect models and model-related information, and disseminate these models and information to the user community. The majority of persons contacted for this study indicated a strong need for a model clearinghouse. One established clearinghouse for ground water models at the Holcomb Research Institute is discussed in chapter 4 of this report.

Of those surveyed by OTA, most who favored the model clearinghouse concept felt that the clearinghouse's primary or central role should be to inventory existing models. This inventory might consist of a central catalog of models by subject area, a list of available models, a list of agencies that use models, and a notation of a contact person or agency for further information about each model. For Federal agencies, an inventory would help avoid duplication of existing models and could improve interagency coordination of modeling efforts. For State agencies, an inventory would serve as a source of information on available state-of-the-art modeling tools.

To meet model users' needs, the clearinghouse could also establish a catalog of model characteristics to help users compare the advantages and disadvantages of different models. Users seeking informat ion on a particular model, or on models for a specific problem, would submit information on the nature of the pertinent water resource problem and on any other requirements that influence the choice of a model—such as cost, level of complexity, assumptions of the model, etc. In turn, trained clearinghouse staff could quickly locate models that generally fulfill these requirements.

Clearinghouses can provide assistance in other areas as well. State survey respondents indicated a need for information on sources of technical assistance, training, and data, as well as information on existing models. Some respondents suggested that clearinghouses serve as technical assistance and training centers. Clearinghouses could also have evaluative functions—developing standards for assessing the materials submitted, and providing technical help in evaluating the utility of available choices.

It is unlikely that a clearinghouse could initially be self-financing. Seed money would invariably be needed to get it started, and outside funding might be needed throughout its existence. Clearinghouses could be partially funded by private business or Federal agencies, and earn the remaining necessary operating funds by charging for their services. Another option is for the clearinghouse to conduct and charge tuition for training courses, which would publicize the organization as well as generate income.

Training

User training is among the most effective means for improving the use of water resource models. Both model developers and model users who were contacted during the OTA study consider training an important aspect of model support. At the present time, neither governmental water resource agencies nor the private sector are providing the necessary training for applying models to the decisionmaking process. In response to an OTA survey, State-level water resource professionals ranked federally sponsored training a priority second only to data needs, and indicated a need for training assistance in all phases of modeling activities.

Several mechanisms can be employed for training model users and decisionmakers. Individuals surveyed for this study generally agreed that one-

Photo credit: Ted Spiege/, 1982

A senior hydrologist at USGS headquarters in Reston, Va., **demonstrates steps in modeiing river currents.** A tape from the underwater monitoring equipment pictured in left foreground **provides data as** input to the model, which is run on the computer terminal above. A **portion of the model converts numerical information into charts and maps of current patterns in the river itself.**

to-one interaction between developer and user is the most successful training approach; however, it was also identified as the most expensive training method. Hands-on workshops, which allow users to run models on computers under supervision, were identified as the next best method. Traditional seminar approaches were the third choice for user training.

A number of Federal agencies conduct user training programs. The U.S. Geological Survey conducts numerous courses in many aspects of modeling, while the Army Corps of Engineers' Hydrologic Engineering Center (HEC) provides extensive training courses in the use of its major models. The Instream Flow Group (IFG) at the Department of the Interior specializes in training both managers and technicians in instream flow analysis, problem solving, and related model use. Federal training efforts are described in detail in chapter 4 of this report. Some agencies are using videotapes of training sessions *as less* expensive teaching tools. other innovative techniques may be applicable to training model users, including programed teaching aids and self-instruction methods.

User Assistance

Documentation, training, and other user aids can go a long way in preparing the decisionmaker for using water resource models. However, direct assistance by experienced modelers and computer programmers will often be needed. Sometimes the problem can be solved simply by a phone call; at other times, direct contact with a modeler or programer who is familiar with the model **may be** needed.

User assistance may range from merely providing information on the status of a new model, to advising on model application or preparing input data and analyzing results. User assistance also helps the modeler to better understand the problems of applying models by interacting with the decisionmaker-user. Complex models may even require "tutored application" in which modeling specialists and users work together in applying the model to the user's problem. Federal agency user support groups that have devised procedures for assisting users include the SWMM User's Group, HEC, and IFG. Their experiences in this area are described in chapter 4 of this report.

Maintenance and Improvement of Models

The development and improvement of models seldom stops at evaluation and fine-tuning for real-world applications. Models are constantly modified and improved based on users' experience, new information, or new methodologies and techniques. Each change in a model must be documented, and the users notified of the modification and adjustments in operating procedures that it requires.

It is important that the institutions that sponsor and support model development make provisions for updating and maintaining models after they become operational. Unfortunately, history has shown that few institutions, whether Government agencies or academic institutions, provide for the contingencies of model updating and maintenance. Clearinghouses or central repositories can play an important role in ensuring that models are updated and improved. OTA workshop participants suggested assigning ' 'lead agency' responsibility to a Federal Government entity for systematically tracking Government-wide model development and upkeep.

Modeling support groups such as HEC are effective means for assessing model deficiencies, maintaining and improving a model, and notifying users of subsequent changes in a model.

Additional Model Characteristics Affecting Ease of Model Use

In addition to the technical assessment of a model's capabilities and the qualitative evaluation of its credibility through operational testing (described in the following section, Issues *in the Development and Use of Models),* there are other factors that affect the value of models as aids to decisionmakers. These incude:

1. computational efficiency-is the **model Cost** effective in terms of computer use;
2. ease of use—is the model understandable and easily operable by users; and
3. transportability-is the model designed for use on a range of different computers?

Computational Efficiency

Computational efficiency pertains to computer costs associated with operating a model. It is generally achieved by carefully designing the model to make the best use of the capabilities of a particular computer and by applying state-of-the-art procedures for manipulating and solving equations within the model itself.

Ease of Use

The ease with which a model can be used depends on the design of its input and output characteristics. The input characteristics of a good ' 'user-oriented' model, i.e. , a model that is designed for use by persons other than the modeler, ensures that information and data needed for running the model can be introduced into the model with the least effort and with minimum chances for errors. Such a model checks the data for completeness and reasonableness, and transforms it into usable form for processing. The output of a good user-oriented model can be adjusted to provide the level of detail and organization of information that best suits the user. If a computer run cannot be completed due to errors or incompatibility of data, an effective model will provide an analysis of the problem encountered (diagnostic information), and will warn when computer-generated information exceeds predetermined bounds.

Transportability

Model transportability is the ease with which models can be transferred from one computer system to another. Characteristics of computer systems vary substantially among manufacturers. A model designed to take full advantage of the various features of a particular computer system, e.g., for storing information or solving equations, may need major revisions for use on another computer system. Costs associated with restructuring and retesting models can be substantial. If a model is intended for use on a number of different computer systems, the modeler must avoid using system-dependent features of any particular computer system. However, designing a transportable model often results in sacrifices of computational efficiency and ease of use.

Designing for transportability requires knowledge of the characteristics of a variety of computer systems. Such knowledge is difficult to acquire and is not widespread among model developers, since it must be gained through operating experience on a range of computer systems.

ISSUES IN THE DEVELOPMENT AND USE OF MODELS

The model development process begins when a decisionmaker, scientist, or manager identifies an information need that can best be met through some form of mathematical analysis. A team of professionals subsequently analyzes the issue and gathers data on it, develops the mathematical equations that comprise the model, fine-tunes the model to specific conditions, evaluates model results, and presents the model-generated information to the individual requesting it. Oversight from the supporting organization must be provided to assure that model development proceeds effectively, and that model results are appropriately used. This section assesses four major aspects of the process of developing and using mathematical models:

- interaction between modelers and decisionmakers;
- evaluating models for use by water resource managers;
- mechanisms for assuring adequate oversight of model development; and
- legal aspects of model use in administrative processes.

Interaction Between Modelers and Decision makers

The goal of the modeling process is normally to provide results that are usable in decisionmaking processes—including day-to-day operations and management, medium- and long-range planning, regulatory purposes, and policymaking. To effectively aid decisionmaking, models must provide information that is relevant to the decision alternatives at hand. In addition, model results must be considered reliable by those responsible for making decisions.

Because modeling is a relatively new field, few decisionmakers have had an opportunity to use models as part of their formal education, or to participate in model development processes. While this trend is changing as a new generation of water resource managers assumes positions of responsibility, lack of familiarity with models and modeling concepts remains a key impediment to increased reliance on model-based information. Individuals contacted or surveyed by OTA repeatedly stated that models are not used in many water resource areas because ' 'they are not trusted' by those responsible for management and decisionmaking. Conversely, models tend to enjoy high levels of credibility among users and decisionmakers who are familiar with modeling techniques and with the results of specific models.

Managers who are inexperienced in the use of these techniques tend to base their judgments about the value of models on the experience of others. Dr. William Johnson of HEC observed that ' 'the cllterion of trustworthiness is determined by an acceptable record of use (preferably by those other than the model developer). Results of OTA surveys and workshops on modeling* suggest that the use of models in water resources management can be broadened by a concerted effort to familiarize resource managers and decisionmakers with the development and operation of mathematical models.

*OTA sponsored a series of workshops for modelers from the Federal Government and the private sector in October and November of 1979, results of which are summarized in ch. 4 and app. A. A written survey of water resources professionals working at the State government level was conducted in May of 1980, results of which are summarized in ch. 5 and app. E.

When a decisionmaker initiates a model development effort, the value of the information he ultimately receives depends directly on his ability to specify what he needs to know. Yet many professionals routinely state their information objectives in qualitative terms, and their conception of the problem to be solved may not lend itself to quantification. Decisionmakers may also look to the model to explain the issue, when in fact a clear specification of the issue is a prerequisite to developing models of it.

A modeler who is confronted with an imprecise request for information will normally attempt to provide the kind of results that he or she considers critical to the decision—often without success. Modelers usually have a technical or scientific background that is significantly different from that of the decisionmaker, although there are some exceptions. Without inputs from decisionmakers, modelers may tend to concentrate on ' 'technically correct' solutions without regard to political considerations that may affect the outcome of a decision.

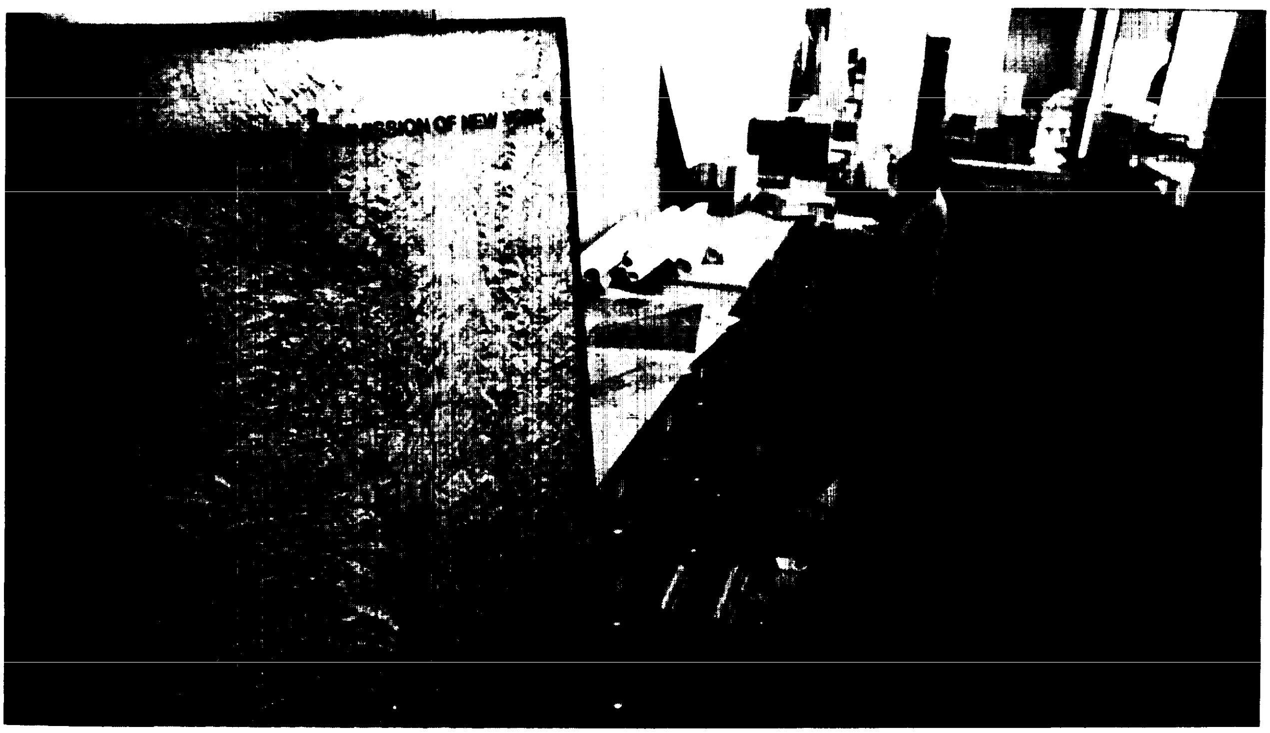


Photo credts: @ Ted Spiegel, 19S2

Evidence that PCB levels in the Hudson River had the potential to interfere with commercial shad fishing led the New York State Hudson River Valley Commission to develop models to analyze the problem

Modelers may also have professional motivations that lead them to concentrate on developing modeling techniques and mathematical sophistications for the primary purpose of advancing the state of the modeling art. Rewards are frequently given on the basis of professional contribution to the field of modeling rather than for developing models that have utility for the decisionmakers. A 1975 survey of model development project directors conducted by Fromm, Hamilton, and Hamilton,[3] found that the two most frequently identified benefits of modeling were: 1) ' 'educated the model builders' (78 percent); and 2) "pointed a way for further research' (76 percent). " Helped in making policy choices' ranked only fifth (58 percent). The modeler's preoccupation with advancing the state of the art of modeling, while highly useful for anticipating future needs and identifying critical emerging issues, often leads in the short run to overly complicated models that require more information and data for their use than is practically available to the user/decisionmaker.

Finally, unless the modeler thoroughly instructs the decisionmaker on how to interpret model results, the information provided may inadvertently be misleading. By constructing the model, a modeler normally gains an appreciation of its capabilities and limitations—in particular the range of error associated with various model results. If the decisionmaker is merely presented with a set of figures and projections, he or she may tend to overrely on the model accuracy or misinterpret the meaning of the information produced. Such overreliance may result in a misdirected decision, and cause the decisionmaker to avoid the use of models in the future.

The most effective way to avoid these pitfalls in model development and use is to ensure that modelers and decisionmakers interact and communicate with each other throughout the model development process. The institutional setting should encourage multidisciplinary approaches to problem solving, involving scientists, modelers, model users, and manager-decisionmakers. The success of the modeling effort will often depend on stimulating and maintaining communications among these groups.

[3]Fromm, Hamilton, and Hamilton, op. cit., p 66

The modeler-decisionmaker team needs to ensure that four questions are continually addressed during model development or use:

- Are we developing or using the model to answer the proper questions?
- Is the model capable of producing sufficiently accurate answers?
- Will the model be an improvement over existing techniques?
- Will the improvement in results justify model costs?

Neither model developers nor decisionmakers can answer these questions in isolation from each other. But bringing the expertise of each group to bear jointly on model development and use is in itself a complex undertaking. Creating appropriate incentive structures in institutions where modeling activities take place can have a major influence on how well the interested parties work together to produce appropriately designed models. The professional climate established by top policymakers plays an important role in encouraging the use of models, training decisionmakers to use models effectively, and stimulating the development of usable modeling tools.

Evaluating Models for Use by Water Resource Managers

Once developed, models must be evaluated to ensure that the information they generate adequately covers the range of conditions that the decision objectives demand. This requires not only an assessment of the technical capabilities and limitations of the model, but also qualitative judgments concerning the nature and extent of the information needed for the decision at hand.

The evaluation process aims to answer three questions concerning the model:

- How well does the model's structure correspond to the structure of events in the real world? Since models *are* simplified mathematical representations of real, complex relationships, we need to know how adequately such simplifications reflect the essentials of these real-world relationships. Are the model's assumptions about real-world behavior reasonable? Does the model take account of the factors that actually characterize and control the real-world phenomenon? Is the model sensitive to changes in those factors that could affect the real-world response?

- How accurately does the model predict events in the real world? What is the degree of possible error gaged by some measure of performance?
- Does the model provide the degree of accuracy and flexibility required by the user? Is information provided at an appropriate level of detail?

The first question is conceptually the most difficult, and requires both technical and qualitative analysis of any given model. The second is quantifiable and can be addressed by a procedure called "validation. The third addresses the relevance of the information provided, and involves subjective analysis of the nature of the problem being studied. Modelers and decisionmakers must understand the outcomes of all three kinds of questions if they are to evaluate the models they use and the information that models provide them. The following discussion outlines the major techniques used to provide these answers.

Photo credit: @ Ted Spiegel, 1982

Researchers take ice core samples to measure PCB deposits at Thompson Island Dam, Ft. Edwards, N.Y. Often, data-gathering must be closely coordinated with modeling activities if models are to provide information relevant to the problem at hand. Models can also be used to help pinpoint those aspects of the problem for which additional data collection is required

Technical Assessment of Models

Three technical procedures collectively determine the accuracy of a mathematical model: 1) verification—assuring that the computer program actually performs as designed; 2) calibration-developing values for the constants and coefficients in the computer program from field data, in order to accurately predict real-world events; and 3) validation-assessing the model's accuracy in predicting real-world events.

Verification. —A model is said to be verified when it is determined that the designer's conception of the model is accurately embodied in the program written and run on the computer. Such a procedure is applicable to any model, and involves technical checks to ensure that:

- the written program accurately describes the model's design;
- the program is accurately mechanized on the computer; and
- the mechanized program runs as expected.

Verification of a computer model may require considerable effort to "debug' (adjust the program so that it runs properly), particularly if the model is large and complex. Although the process of verification is straightforward, and to a large extent mechanical, the expense and time delays to debug a program can be significant.

Calibration. —Models must be "fitted' or "fine-tuned' to the specific characteristics of the real-world system being studied. Each model contains a set of parameters, i.e., values of coefficients, that establish the relationship between the model's predictions and the information supplied to the computer for analysis. A model is considered to be calibrated when model results match experimental observations taken from the particular system under investigation. Calibration is, thus, the procedure used to determine a specific mathematical value for the parameters of a model.

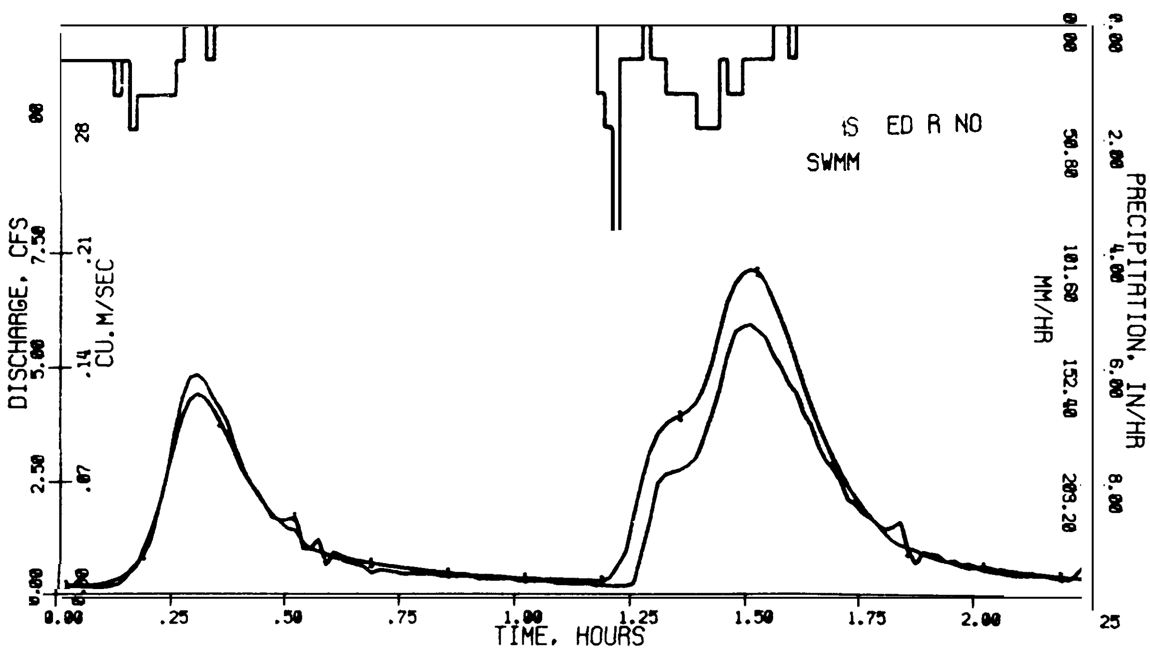
Calibration depends on a reliable set of data collected under conditions as similar as practical to those prevailing at the time of the decision. Often, however, data are not available, and the modeler must depend on assumed values or average values observed previously for estimates of the parameters. The use of assumed or hypothetical values often reduces the reliability of the model.

Validation. —Validation is the process of determining how accurately the model can predict real-world events under conditions different from those on which the model is developed and calibrated. To validate a model, a different set of field data is used as input to the model and the output is compared to actual observations of the new field conditions. Where possible, validation uses a completely new set of data, gathered at a different time or place than those data used to develop and calibrate the model. However, in instances of limited data, a single data set may be split, and the two halves be used for calibration and validation respectively.

The simplest validation measure is a graphic comparison of observed data and computed values. It allows the analyst to make qualitative judgments about the adequacy of the model and its suitability for additional use, and provides a clearly visible, easily understood assessment of model results. An example of simple graphic comparison is present in figure 6. More complex models may require statistical indicators of accuracy to supplement or supplant graphic presentation. Simple statistical measures comparing observed and computed values include correlation coefficients, computation of relative error, and comparison of means.

Validation depends on a reliable standard for comparison. The lack of comparative data often

Figure 6.–Comparison of Measured and Computed Runoff for the storm **of Aug. 2, 1963–Oakdale Avenue Catchment—EPA Stormwater Management Model**



The graph above compares measured runoff to SWMM estimates of runoff for a single storm event at an individual stormwater catchment. Amounts of precipitation falling during the course of the storm are shown at the top, and are calculated by the scale at the right; actual and estimated discharge to the catchment is shown by the lower lines, and is measured by the scale at the left.

SOURCE EPA **Stormwater Management Model,** precludes adequate validation. If a model describes a unique system or event, then comparisons with data from other systems (or times) may be impossible. Some models, e.g., models of physical processes which are governed by law of physics and engineering, are often adaptable for a wide range of applications. Such models can be validated from time-series observations at a single location—comparing results with prior historical data—or in combination with similar data from other locations.

Social and economic behavioral models, however, are difficult to validate in the strict sense. Human behavior cannot be analyzed in the same sense as interactions that take place in the physical sciences. Human interactions may be extremely complex, and involve many factors not readily subject to quantification. At best, social scientists can estimate statistical variations in human behaviors under a set of assumed conditions— yet there is no way to gage the likelihood that the assumed conditions will come to pass. This difficulty is compounded by the necessity to forecast changes in a number of highly uncertain economic and social variables, e.g., inflation, commodity prices, and demographic and employment patterns. Moreover, the complex interactions of the economic and social systems are dynamic, i.e., the nature of the system itself continues to change, thus requiring constant changes in the model. Under circumstances of changing system structure, it is nearly impossible to use long-term time-series data for validating models.

Qualitative Assessment of Models

Socioeconomic and integrated models are used by decisionmakers to predict the likely economic and social effects of policy decisions. As explained above, such models cannot be validated in the technical sense because there are no statistical means for assessing the accuracy of the model's predictions until the predictions have come to pass—or failed to do so. Moreover, the presence of factors that have influenced the outcome but have not been included in the model may preclude any statistical check on the model's accuracy. One must therefore rely on qualitative indicators of the model's credibility and reasonableness to assess its usefulness and reliability. Properly understood, such procedures permit policymakers to determine whether a model's predictions are sufficiently reliable to serve as an input to decision processes.

Three techniques can be used to assess complex predictive models in a qualitative or semiquantitative manner: 1) parts of a complex model can sometimes be validated independently of the remainder of the model, using historical data to test the accuracy of the projections; 2) professional consensus can be obtained among experts who review the reasonableness of the model's parameters and structure; and 3) users can perform sensitivity analyses, i.e., comparing the changes in model output that result when the model is run successively with small changes in model assumptions. Sensitivity analysis places less emphasis on the absolute accuracy of projections, and more on the differences that result from incremental changes in policy, for example.

The decisionmaker must be a major participant in the qualitative assessment of a model. In the absence of statistical and objective measures of performance, one must rely on the intuition and experience of the decisionmaker in judging the quality of the information the model supplies and in weighing that against the informational needs for decisionmaking. Similarly, the user/decisionmaker must be the final arbiter in evaluating the sensitivity of the model to changing inputs and conditions.

Assessing the Relevance of the Model

A major reason for expending the time, effort, and funds necessary for using a model is to provide information that is not available from other sources. A model's utility to the decision process depends both on its ability to analyze information and on the relevance of the information to the decisions to be made. Thus, in the find analysis, the decisionmaker must gage the usefulness of the model against the profile of the decision itself.

In some instances, a model's primary use may be to identify further information that may be needed to approach the decision; thus the evaluation of the model proceeds as an integral part of the issue analysis. The term *forum analysis is* sometimes used to indicate a procedure in which a number of models are analyzed to determine their relevance to a given issue. The forum analysis begins as a comparative exercise, in which different

Photo credit: @ Ted Spiegel, 19S2

Decisionmakers must understand the assumptions underlying model-generated information to use it in deciding policy questions

models are run with the same data set in order to determine the fundamental differences in their procedures and results. The information generated is then used as a focal point for examining the issue itself, as participants attempt to specify the factors that influence the situation in the real world, and to improve the model's capacities to reflect those factors. The "forum' for carrying out this assessment simultaneously involves modelers, model analysts, and policymakers. Forum analysis can be a powerful tool to advance the state of the art of modeling for a specific problem area, and can also contribute to a better understanding of the problem by providing an analytical framework for considering the issues.

A recent World Meteorological Organization forum analysis project compared 10 hydrological models that provide short-term forecasts of streamflow.[4] The project used data sets from six rivers with different physical and climatological characteristics to determine the models' relative advantages and disadvantages for assessing streamflows in a variety of river types, and under differing institutional constraints and accuracy requirements. The exercise allowed participants in a technical conference to compare the performance of the tested models, and to develop guidelines for model selection based on such criteria as the purpose of the forecast, the prevailing climate within the river basin, and the quality and type of data and computers available.

Mechanisms for Assuring Adequate Oversight of Model Development

Although there is broad agreement among the modeling community that additional measures are needed to standardize and improve the quality of models, there is significant disagreement among modelers as to how this should be achieved. Among the means of ensuring quality control of models are: guidelines, standards, contractual agreements, and peer review. Each of these could potentially limit the individual modeler's flexibility and freedom to approach problems, hence any proposal to create standards and impose uniformity is a contentious Issue.

Guidelines and Standards

Proponents of establishing Government-wide guidelines for model evaluation consider guidelines an effective means of standardizing and ensuring compatibility among model development efforts, as well as a way to screen bad models while enhancing the acceptance of good ones. Such guidelines could promote uniformity in evaluation criteria, and contribute to achieving compatibility among model results.

Opponents point out, however, that the wide variety of user needs may preclude the use of uniform guidelines. Since a model needs primarily to match

[4] "Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting," World Meteorological Organization, WMO No. 429, Geneva, Switzerland, 1975.

the informational needs of an individual user, the user is in the best position to determine appropriate standards. Guidelines written to deal with a range of models would likely be either too vague to be potentially useful, or limited in applicability to a few specific models. In either case, guidelines could inhibit innovative modeling efforts which depart from accepted practice. This could inhibit advances in the state of the art in modeling research.

A further difficulty arises in the use of guidelines within an organizational framework. Procedures intended as general suggestions to *guide* model development and use may tend in practice to be used as *standards* governing modeling activities. A manager's natural desire to minimize risk and preclude responsibility for failure could place pressure on users and developers alike to follow accepted, conventional procedures. In the rapidly advancing field of modeling, such a bias could conflict strongly with the objective of incorporating the best available knowledge into current modeling activities.

A General Accounting Office (GAO) report[5] supports the guideline concept, while acknowledging that variations in model development efforts require that guidelines be highly flexible. GAO's survey of model developers in the Northwestern United States revealed skepticism about guidelines—both in general, and in reference to specific GAO proposals:

> A primary concern was the fear that the guidance factors could become requirements for all modeling efforts. Respondents noted that model development efforts are not all the same. They differ in size, complexity, and level of the technology being applied. In addition, the contractual process as well as the contractual management relationship will vary from project to project. Respondents pointed to these structural and management differences as evidence of the need for flexibility in implementing any set of guidance factors. More specifically they noted the need to allow the manager freedom in determining which factors to consider and the level of activity required.

Survey responses prompted GAO to qualify its proposals for modeling guidelines:

> The guidance factors are not intended as absolute requirements. Rather, they represent a preliminary listing of procedures a manager should consider when undertaking a model development effort. These techniques are meant to provide the manager with an awareness of the total development process—not necessarily to establish a checklist for compliance. Most of the people we talked to stated that such guidance would be useful if it remained flexible.

Standards developed for use by a single organization are less likely to encounter objections. For example, the Corps of Engineers has established guidelines for models that are incorporated in the Corps' Engineering Computer Programs Library.[6] The stated objectives of the guidelines are to assure that models distributed through the library are: 1) immediately usable, broad in scope, easy to modify; 2) consistent with accepted engineering principles and practices; 3) uniformly and well documented; and 4) readily understandable by others and easy to set up and apply.

The standards specify the programing language to be used, and suggest specific programing practices that will enhance program usability. Detailed guidelines are provided for preparation of model documentation. Models that are incorporated in the library are placed in one of three categories, depending on the nature of the model and the level of review it has received. For example, a model in the highest category will have been designed for Corps-wide application, and will have received independent review and approval by the Corps' Office of the Chief of Engineers. A further discussion of Corps' procedures for developing and disseminating water resource models is included in the description of HEC in chapter 4.

Contractual Mechanisms

Numerous proposals have emerged for strengthening quality control by requiring the performance of certain procedures or the attainment of performance standards as part of the legal contract for developing a model. For example, developers might be

[5] *Ways to Improve Management of Federally Funded Computerized Models*, U.S. Government Accounting Office, LCD-75-111, 1976.

[6] B. Eichert, "Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models, Technical Paper No. 56, Hydrologic Engineering Center, 1978.

required to provide specific levels of documentation acceptable to a review panel, or to achieve a specific level of accuracy before final payment on their contracts.

Another GAO proposal called for Federal agency review of contractor performance at the end of each of five phases in developing models. Both the agency and the developer would have an opportunity to terminate the development process at the end of each phase:

> A contract with a breakpoint at the end of each phase should be used so that a developer cannot proceed from one phase to the next without written approval from the user. Each phase or breakpoint should be separately priced so that a termination at the end of a specific phase will limit the Government's liability under the contract to those costs incurred for the contractor's performance up to the breakpoint . . . . This gives the manager the opportunity to stop development if the model is not going to be useful.

Such procedures could increase an organization's control over ongoing model development projects, and, if properly managed, could offer incentives for developers to maintain professional standards and provide adequate user-oriented services. However, additional contractual specifications inevitably add to the complexity of monitoring model development.

Peer Review

Peer review procedures have been proposed as a means of identifying and promoting high-quality models without losing the flexibility required for innovative modeling. Review panels, composed of high-caliber professionals who are sensitive to the applications for which individual models are designed, could provide valuable advice to model developers, and assure sponsoring institutions of the value of the models they fund.

Opponents of the peer review approach cite the bureaucratic burden of establishing and maintaining review policies and procedures, and they question the relative value of the additional information as compared to its probable cost. These opponents also point out that seasoned modeling professionals are in relatively short supply—obtaining their services for a review panel on a continuing basis might be impossible. The use of less qualified reviewers for such a panel would reduce the weight and value of its recommendations.

Legal Aspects of Model Use in Administrative Processes

Models are often used to project the effect of a proposed administrative action, Managers employ model forecasts to minimize the possibility of causing costly errors or potential damages associated with inappropriate decisions. Major decisions involving millions of dollars may be based on model-generated information. If, for some reason, the models do not accurately simulate real conditions, administrative decisions based on model results could misdirect regulations, misguide management directives, and misallocate capital investments. Using models in regulatory processes raises the prospect that unforeseen **errors** may cause administrative actions to either fall short of their intended purpose or unreasonably burden those who are regulated.

Legal issues regarding the use of models in administrative processes have arisen in three areas: 1) standards for Federal judicial review; 2) judicial review of State-level regulations; and 3) use of models for planning and program development.

Standards for Federal Judicial Review

Although judicial consideration of water resource models dates back to a 1943 Supreme Court case involving an interstate dispute over water rights,[7] virtually all judicial notice has been in the context of recently promulgated water quality effluent limitations.[8] Courts have also examined water quality models that have been used as the basis for analyzing an environmental impact statement under the National Environmental Protection Act.[9]

[7] *Colorado v. Kansas,* 320 U S. 383 (1943)

[8] *Association of Pacific Fisheries* v. E P A , *61.5* F 2d 794 (9th C ir , 1980); *Kennecott Copper v. E. P A* 612 F.2d 1232 (10 Cir. , 1979); *BASF Wyandotte Corp v. Costle,* 598 F 2d 637 (1st Cir. , 1979); *National Crushed Stone Association v. E P A* 601F.2d 111 (4th Cir.,1979); *American Iron and Steel Institute* v. *E P A (1* 1), *568* F 2d 284 (3rd Cir. , 1977); *FMC* v. *Train,* 539 F.2d 973(4th Cir. , *1976); API v, E P A ,* 540 F. 2d 1023 (10th Cir.,1976); *A I S I* v *EPA* (1), *568* F.2d *284* (3rd Cir.,1977).

[9] *Ohio Ex Rel Brown* v. E P A , 460 F, Supp. 248 (S D oh,, 1978); *Conservation Council of North Carolina* v. *Froehlke,* 435 F Supp. 775 (M D N C , 1977).

Models used for agency rulemaking are administrative actions reviewable by the courts.[10] The review standard is narrow:

> As in other cases involving review of an administrative agency's rulemaking actions we are governed by an "abuse of discretion' standard—in other words, we must not substitute our judgment for that of the agency, but must determine whether the administrator's actions were ' 'arbitrary, capricious, are abuses of discretion, or otherwise not in accordance with law . . . .' In order to facilitate meaningful judicial review, we should require administrative agencies to ' 'articulate the standards and principles that govern their discretionary decisions in as much detail as possible . . . . "[11]

Most courts reviewing models as a basis for administrative decisions rely on the standard set out in the U.S. Supreme Court case, Citizens *to Preserve Overton Park v. Volpe,*[12] that a court reviewing an agency's action should conduct a searching and careful inquiry into the facts, but should not substitute its judgment for that of the agency. The court held that the agency's use of the model should be accorded a ' 'presumption of regularity. "[13]

This judicial standard has significant implications for an agency's use of models in regulation, and grants broad discretion to the agency. When other models have been used to challenge an agency's model, the courts have examined only whether the agency's model constitutes a "rational choice.[14] Although judicial inquiry will include a thorough evaluation of a model, it does not extend to the determination of the "best possible approach. '[15]

However, the documentation of the model must provide an "adequate explanation' of the basis for the regulation, absent which the court will overturn the regulation.[16] What constitutes "sufficient material upon which to make a reasoned decision, though, leaves a great deal of latitude to an agency. Thus, there is a disinclination to "second guess the agency's expert determinations as to the model . . .

Federal courts have proved relatively flexible in applying the "reasonable basis' test to disputed regulations. In a case where a model simplified the simulation of complex hydraulic flows in plastic manufacturing plants to the degree that the range of flows departed from the model's results by a factor of 10, the court found no reasonable basis for the challenged regulation. In another instance, although the court heard arguments that the challenged model process differed from actual operation by a factor of 5, it sustained the contested regulation, being convinced that a reasonable explanation for the variation existed.[20]

The courts' reluctance to involve themselves in evaluating models per se is further illustrated by a case involving proprietary models. In *Cleveland Electric,* which challenged the imposition of a sulfur dioxide control plan based on the use of an EPA model, the agency's model was contested as inferior to a proprietary model developed by an engineering company. Although expert witnesses testified that a superior method of control existed, the company refused to reveal the operating details of its model. As the court saw the problem:

> While such withholding may be both defensible as a matter of law and understandable as a matter of economics, this court cannot consider Enviroplan's model as available technology until and unless it is fully disclosed and evaluated by United States E.P.A. —the agency charged by Congress with making these decisions.[22]

[10]The Federal Administrative Procedure Act provides that "except to the extent that—(1) statutes preclude judicial review; or (2) agency action is committed to agency discretion by law, 5 U. SC. sec. 701 (a) (1976), ' 'final agency action for which there is no other adequate remedy in a court (is) subject to judicial review. 5 U. S.C. sec. 704(1976). For a discussion, see, D. P, Currie,' 'Judicial Review Under Federal Pollution Laws, 62 *Iowa Law Review* 1221 (1977).

[11]*A. I. S. I. v. E P A. (1),* 526 F. 2d 1027 (3d Cir., 1975).

[12]*Citizens to Preserve Overton Park, Inc v. Volpe,* 401 U.S. 402 416 (1971).

[13]*Overton Park,* 401 U.S. at 415.

[14]*Cleveland Electric Illuminating* CO. v. *E. P. A.,* 572 F.2d 1150, 1161 **(6th Cir., 1978),** *cert. denied, 439* U.S. **910 (1978);** *U. S. Steel Corp. v. E. P. A., 605* **F.2d 283, 292 (7th Cir., 1979).**

[15]*Cleveland* **Electric, 572** F. 2d at 1150, 116 1; see *also, Vermont Yankee Nuclear Power Corp v. NRDC, 435* U.S. *519, 549 (* 1977).

[16]*Kennecott Cooper* v. *E. P. A ,* 612 F.2d 1232, 1240 (10th Cir., 1979).

[17]*Association of Pacific Fisheries* v. *E. P. A , 615* F. 2d 794, 803 (9th Cir., 1980).

[18]*Pacific Fisheries,* 615 F. **2d at 810.**

[19]*FMC Corp.* v. *Train,* 539 F, 2d **973, 980** (4th Cir., 1976).

[20]*Pacific Fisheries,* **615** F. 2d at **810, 814.**

[21]**572** F.2d at 1163.

[22]Ibid,

Judicial Review of State-Level Regulations

Relatively few legal controversies have arisen over use of models by a State government as a basis for decisionmaking. The lack of reported cases may be partly attributable to a general lack of model use by States for regulatory purposes. Another reason may be the close link between Federal and State programs —such conflicts may arise in the context of the applicable Federal programs.

States have occasionally used models as evidence in administrative proceedings to determine whether a violation of an environmental control *law* has occurred; this is particularly true in the area of air pollution control .23 For instance, the Illinois Pollution Control Board applied a "general theoretical formula" to the processing data of a smelting company to find the company in violation of air pollution standards, However, upon review, an Illinois court held that such modeling evidence was insufficient to support the board's determination.[24]

Litigation over regulations predicated on information from a ground water model occurred in the State of Washington in 1975. The State had developed a computer model for defining maximum rates of withdrawal and issuing new rights to ground waters. For the Odessa area, which had been declared a critical ground water region, the State issued regulations to establish ceilings on withdrawals with the assistance of the developed models. 25 Affected ground water users disputed the accuracy of the model results;[26] however, the courts upheld the regulation. Subsequent corrections to the model have altered model results, though not to the degree of affecting the regulation's efficacy in the eyes of State officials. Nonetheless, no further challenges to the regulation have been offered .27

[23] For a discussion, see, R. A. Brazcuer, "Air Pollution Control; Sufficiency of Evidence of Violation in Administrative Proceedings Terminating in Abatement Orders, " 48 *A L R 3d* 795

[24]*Allied Metal Co* v *Illinois Pollution Control Board*, 22111 App. 3d 823,318 N E.2 257, 264 (1974).

[25]G. E, .Maddox, et al., ",Management of Groundwater in Eastern Washington,'' Engineering, Geology, and Soils Symposium, 13th Annual Proceedings, University of Idaho, Moscow, Apr. 2-4, 1975, p. 201, published by Idaho Transportation Department, Division of Highways, Boise, 1975.

[26]Conversation with Alan Wald, Hydrologist, Washington Department of Ecology.

*[27]Conversation with Charles Roe, Senior Assistant Attorney General, Washington Department of Ecology.

Use of Models for Planning and Program Development

Probably in no other area is the use of models more prevalent than in planning and program development. However, errors in planning programs which are based solely on analysis by models can be perpetuated in decisions made on the basis of such plans. Mandated "consistency' requirements are potentially a major avenue for institutionalizing this kind of error.

For example, the Clean Water Act requires that the National Pollution Discharge Elimination System permits issued for point sources of pollution must not conflict with an approved section 208 areawide management plan.[28] In this manner, Congress established a "consistent' planning system, linking different elements to areawide planning under section 208. Consistency requirements also extend to construction of publicly owned treatment facilities, which must conform with the approved section 208 plan to be accepted.[29] Section 208 plans depend heavily on modeling. This statutory linkage between the areawide planning programs and regulation or construction activities raises the question of whether unforeseen modeling errors in plans may cause significant problems during implementation, and subsequently lead to litigation.

An important corollary to this issue is the question of a modeler's liability for the effects of inaccurate model results. No ruling yet exists on whether model use involves an express or implied guarantee that the operation of a system will substantially conform to model-generated information. If an individual or organization is placed in the position of certifying compliance with regulatory standards based on model results, whose responsibility is any subsequent nonattainment of such standards?

Absent any definitive ruling on the issue, new regulatory programs involving modeling and the use of highly sophisticated modeling analysis may increase the liability of the design professional. Similar problems have arisen over the professional liabilities of technically trained staff in other fields. The modeling community has already indicated its concern over exposure to liability in the context of

[28]Clean Water Act, sec. 208(e), 33 U. SC. **sec. 1288(e).**

[29]Clean Water **Act,** sec. 208(d), 33 U.S.C. sec. 1288(d).

certifying compliance with building energy performance standards under the Energy Conservation Standards for New Buildings Act of 1976.[30]

[30] Milt Lunch, "DOE's New BEPS Pose Many Legal, Liability Questions for Design Professionals," *Engineering Times*, April 1980; Statement of E. K. Riddick for the National Society of Professional Engineers on the Proposed Building Energy Performance Standards, Mar. 24, 1980, pp. 14-16.

[31] Testimony of D. Carter for the American Consulting Engineers Council, hearings before the Senate Governmental Al'fairs Committee, Nov. 20, 1979, p. 167.

Increased use of complex modeling systems, and layered model use to develop State ' 'equivalent' standards or programs under Federal mandates, may compound initially acceptable modeling errors, and also increase a modeler's potential liability.