Chapter 1

Summary, Issues, and Options

Contents

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SCOPE

This assessment is intended as a guide for Congress on the potential to develop and use mathematical models to more effectively and efficiently analyze the Nation's water resource problems. Policy options are presented for improving the use of these tools within both Federal and State water resource agencies.

The assessment reviews the current technical capabilities of models; the current and potential use of models by Federal and State agencies; and general impediments to effective model development, use, and dissemination. It draws on the results of surveys of water resource professionals in 27 Federal agencies and offices, from all 50 States, and from universities and the private sector.

Mathematical models are new technologies that are increasingly being used for water analysis. The Office of Technology Assessment (OTA) focused on mathematical modeling as a means of assessing the broader issue of our ability to analyze and plan courses of action to deal with current and long-range water problems. OTA did not investigate the more traditional forms of water resource analysis that are being replaced by mathematical models, or the less commonly used physical models.

The technical capabilities of models vary greatly among the water resource issues analyzed in this report; however, **the assessment finds that models capable of analyzing many pressing water resource issues are currently available, and have significant potential for increasing the accuracy and effectiveness of information available to managers, decisionmakers, and scientists.** Institutional constraints to model use, including lack of information about available models, lack of training in model use and interpretation, lack of communication between decisionmakers and modelers, and lack of general support services, are identified as major impediments to increased model use for water resource analysis.

The full report includes:

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INTRODUCTION

Between 1950 and 1975, the Federal Government spent over $45 billion to develop, maintain, and improve the Nation's water resources; 1 expenditures have spiralled to even higher levels over the past decade. Federal efforts range from constructing dams to increase the reliability of water supplies, generate hydroelectric power, improve flood control, and provide recreational opportunities; to studies for determining whether flood plain areas are sufficiently safe to permit building activities; to providing wastewater treatment for reducing health and environmental risks due to polluted rivers, streams, and lakes.

Decisions affecting water resources are made by the Federal, State, and local governments, and by the private sector. These decisions include designing day-to-day management procedures for operating facilities most efficiently, as well as planning and implementing long-range policies for water resources management and construction. Decisions of the latter kind involve large sums of money, and may affect the availability and quality of water for many decades to come. As the Nation grows, and excess water resource capacities diminish, it becomes increasingly important to manage existing facilities, improve the efficiency of water use, and make long-range plans in ways that maximize the return on natural, capital, and human resources.

Mathematical models are among the most sophisticated tools available for analyzing water resource issues. They can use the capabilities of today's digital computers to perform and integrate millions of calculations within seconds, in order to understand and project the consequences of alternative management, planning, or policy-level activities. Models only assist in decisionmaking—they provide information that people must interpret in light of existing laws, political and institutional structures, and informed professional and scientific judgment. Nonetheless, models can significantly improve the informational background on which decisions are based, and substantially reduce the cost of managing water resources. Although the Federal Government spends approximately $50 million on water-related mathematical models annually, such tools are instrumental in planning billions of dollars of annual water resource in-

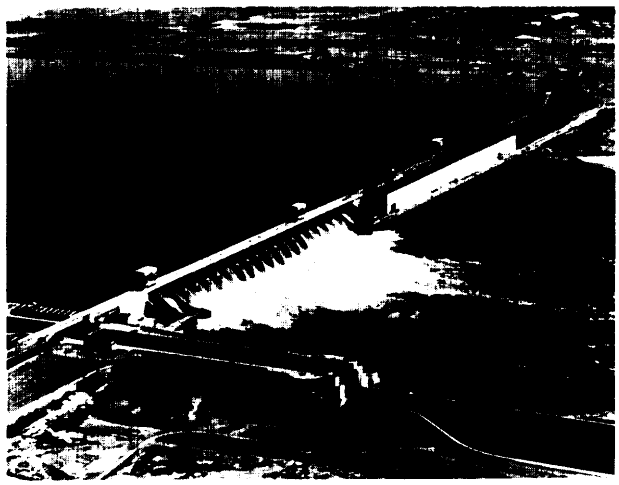
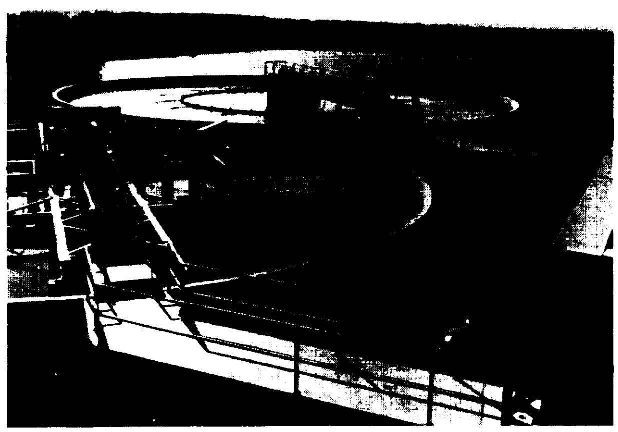


Photo credit: Environmental Protection Agency



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Federal, State, and local governments, and the private sector, provide billions of dollars to support the construction of dams, reservoirs, and water treatment facilities. Mathematical models are becoming increasingly important in determining the need for such facilities, and in planning, designing, and operating them. Models can be used to help operate existing structures such as the McNary Dam on the Columbia River (top), as well as to develop and run new facilities like the illustrated water purification system in Duncan, Okla. (bottom)

[1]Viessman, et al., *The Nation Water Outlook to the Year 2000.* The $45 billion estimate includes expenditures by the Army Corps of Engineers, the Bureau of Reclamation, the Soil Conservation Service, the Tennessee Valley Authority, and the Environmental Protection Agency's Construction Grants Program outlays.

vestments, and managing hundreds of billions of dollars of existing facilities.

The role of models in managing water resources has grown dramatically over the past decade—a period in which water resource management itself has become increasingly important. High rates of economic and population growth in water-short areas of the country, decreased availability of water from major ground water aquifers, and increased public concern for the quality of its drinking water, lakes, and rivers have made it even more necessary to manage water resources carefully. In addition, the issue of who is to manage water resources has gained prominence in the political arena, as ways are sought to increase States' responsibilities for assuring adequate and safe water supplies.

The magnitude of the national investment in water resources calls for systematic use of the best analytic tools available to manage this investment. Over the past 20 years, models and sophisticated data processing systems have been advanced as promising great improvements in water resources management, planning, and policy. Yet many consider that these tools have not yet lived up to earlier expectations. OTA was requested to study the use of models in freshwater resources analysis in order to determine their current capabilities, identify appropriate roles for their use, and suggest options for improving modeling efforts and model use.

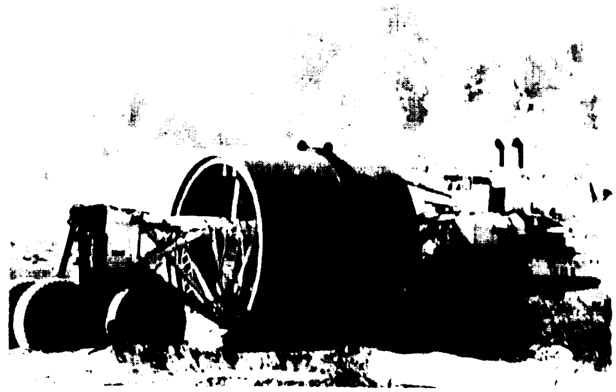


Photo credits; :' Ted Spiege/, 1982

Pipelines to provide new supplies of water for the State of Arizona (top) and the New York City water tunnel (bottom) demonstrate the magnitude of the Nation's water resource needs. Reliable forecasts of an area's water requirements are critical for designing efficient and adequate water transport and distribution systems. Models can be used to estimate future demands for water, and to assist in water system design

FINDINGS

Mathematical models have significantly expanded the Nation's ability to understand and manage its water resources. They are currently used to investigate virtually every type of water resource problem; for small- and large-scale studies and projects; and at all levels of decisionmaking. In some cases, models have increased the accuracy of estimates of future events to a level far beyond "best judgment" decisions. In other areas, they have made possible analyses that could not be performed empirically or without computer assistance. Further, models have made it feasible to quantitatively compare the likely effects of alternative resource decisions. A few examples of situations in which models have been applied will illustrate their uses:

- Water in excess of amounts needed by crops is often applied to fields to leach out accumulated salts. This results in high water use and high salt loadings in irrigation flows returned to streams. New Mexico scientists developed a computer model to estimate the minimum amount of leaching water required to maintain crop yields and favorable soil salinities. The model has resulted in annual savings in water costs of $500,000 for the Pecos River basin in New Mexico. In addition, the lower irrigation return flows have reduced the salt input to the Pecos River by 235,000 tons per year.

- The Clean Water Act currently requires dischargers to meet effluent—or 'end-of-pipe' '—standards. and, in addition, to discharge no more of a pollutant than receiving waters can safely carry, according to a fixed receiving water quality standard. Models are an effective means of projecting the receiving water quality that results from different levels of discharge. and are thus a major aid in determining what levels of discharge are permissible under receiving water standards.
- For the northern Virginia area, 1977 was the driest year since 1950. The Occoquan Reservoir serving northern Virginia was nearly empty, and daily withdrawals exceeded daily inflows. Using its extended streamflow prediction model, the National Weather Service (NWS) determined that there was a 10-percent risk of reaching emergency reservoir levels—a risk deemed unacceptable by local authorities. The model was then used to project that an acceptable 2- to 3-percent risk of reaching emergency reservoir levels would require reducing withdrawals by about 20 percent.[3,4]
- Reservoirs are usually multiple-purpose facilities, many of whose objectives conflict or compete. Reservoir managers need to retain sufficient water to ensure an adequate future supply for users, yet must release enough for flood control purposes, as well as to ensure adequate low-flow levels to protect aquatic life and minimize the cost of pollution control downstream. Additional objectives include maximizing hydropower production (by releasing water) and recreational opportunities (retaining water for reservoir lake users, and releasing water for stream and downstream lake users). Mathematical models have been used on many of the Nation's major river systems to address conflicting use demands by suggesting optimal amounts and timing of reservoir releases.
- Cornell University investigators developed a systems optimization method to design a sewer network for the Long Island Regional Planning Board. The resulting analysis indicated that a sewer network that would meet community needs could be built and operated for $40 million less than could a design developed by a firm using conventional analytical methods.[5]

Models are often the best available alternative for analyzing complex resource problems. While many of the economic and social factors in water resource decisions cannot be fully enumerated, models can be used to integrate the available data, and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different resource policy options, and are often less expensive than conducting comprehensive surveys and using other traditional approaches.

Models have the potential to provide even greater benefits for water resource decisionmaking in the future. As models are refined and receive wider acceptance, they will be able to increase the efficiency of water resource management and encourage cost-effective decisionmaking. Such models can do much to increase the rationality of regulations and the standard-setting process, and can generally provide a sound scientific basis for water policy. The following examples illustrate the potential benefits of future expansion in model use:

- Between 1950 and 1975, the Tennessee Valley Authority (TVA) spent over $2 billion for water resources development and management. Improving rainfall forecasting and reservoir scheduling can make a *very significant* contribution to the benefits that accrue from these water development projects. Recent

[2] *Impacts of the University Water Research Program*, Task Force on Research and Education in Water Resources, U.S. Department of the Interior, March 1981, p. 9.

[3] D. C. Curtis and J. C. Schaake, Jr., "The National Weather Service Extended Streamflow Technique." Conference on Reservoir System Regulation, ASCE, Boulder, Colo., Aug. 14-17. 1979.

[4] D. P. Sheer, "Analyzing the Risk of Drought: The Occoquan Experience," *Journal of the American Water Works Association*, May 1980.

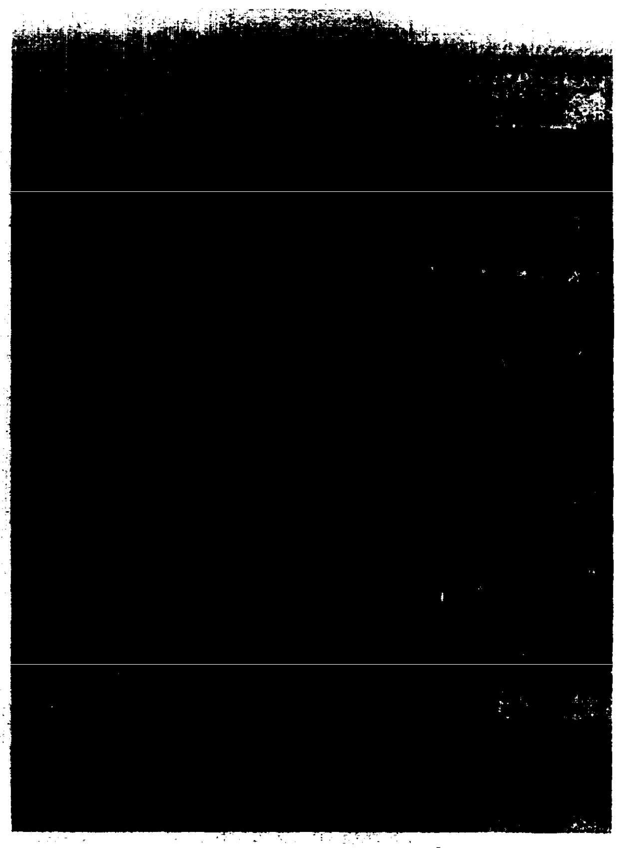
[5] *Impacts of the University Water Research Program*, op. cit., p. 4.

studies on six TVA reservoirs found the potential for a 20-percent improvement in operations and annual savings of $4 million through the implementation of a system of reservoir scheduling models.[6]

- NWS estimated that the installation of a $200,000 modeling system to forecast floods on the Connecticut River basin would provide a reduction in flood damages exceeding $1.5 million per year.[7]
- Models assist farmers in scheduling irrigations to optimize water conservation while maintaining crop productivity. In Nebraska, improved irrigation scheduling has resulted in 25- to 35-percent savings in water pumped and energy costs per year.[8]

Water resource models vary greatly in their capabilities and limitations and must be carefully selected and used by knowledgeable professionals. Some models are designed for management within small watersheds; others are used in planning for large geographical areas. Some are designed to provide highly accurate numerical estimates; others will provide only general approximations. Some models are designed for situations in which data are scarce: other models require large amounts of data. In some instances, decisionmakers need only "ballpark" accuracy to make decisions, but in other instances model accuracy may be extremely important. A decisionmaker may require a different model in each case, even though similar kinds of problems are being analyzed.

Since modeling is a rapidly advancing and highly specialized field, it is extremely difficult for decisionmakers and managers to stay abreast of new developments, or even to fully understand the capabilities and limitations of the tools they currently employ. Under such circumstances, a certain amount of model misuse and mistrust is virtually inevitable. A manager who uses a given model to analyze a situation it was not designed to address, or who overrelies on" the accuracy of



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Agriculture accounts for over 80 percent of U.S. water use. Critical shortages of water for irrigation in many areas of the country make models for scheduling irrigation a valuable tool for stretching limited and increasingly expensive supplies. These models determine when plants require water, and how much they will need; same can estimate reductions in crop yields if irrigation is delayed or reduced

model results, may wrongly reject any future use of models. Managers may also perceive models as an undesirable constraint to their authority and decisionmaking capabilities. However, models are most effectively used as an *aid* to decisionmaking, rather than as a *substitute* for the decisionmaker's judgment.

Models are not explicitly required in any Federal water resource legislation, but they are often the method of choice to meet the requirements of legislation. Many current laws regarding water resources require analytical work normally [illegible]

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[6] W. D. Wunderlich, "Planned Enhancement of Water Management Methods for the TVA Reservoir System," paper presented at the National Workshop on Reservoir Systems Operation, American Society for Civil Engineers, Aug. 13-17, 1979.

[7] H. J. Day and K. K. Lee, "Flood Damage Reduction Potential of River Forecast Services in the Connecticut River Basin," NOAA Technical Memorandum NWS HYDRO-28, February 197

[8] *Impacts of the University Water Research Program*, op. cit., p. . .

legislation associated with model use at Federal, State, or local levels includes:

- Clean Water Act (Public Law 95-217) —sections 107, 201, 208, 209, 301, 302, 303, 307, 311, 314, 316, 404, and 405;
- Safe Drinking Water Act (Public Law 93-523) —sections 1412, 1421, 1422, 1424, 1443, and 1444;
- Toxic Substances Control Act (Public Law 94-469)—sections 4, 5, and 6;
- Resource Conservation and Recovery Act (Public Law 94-580)–sections 1008 and 8006;
- Endangered Species Act (Public Law 93-205) —section 7;
- Surface Mining Control and Reclamation Act (Public Law 95-87)–sections 506, 510, and 515;
- Soil and Water Resource Conservation Act (Public Law 95-192)–sections 5 and 6;
- Water Resources Planning Act (Public Law 89-80)—section 102;
- Coastal Zone Management Act (Public Law 94-370)—section 305;
- Executive Order No. 11988 (Floodplain Management);
- Flood Control Act of 1936 and Amendments—sections 1, 2, and 3;
- National Flood Insurance Act of 1968—section 73;
- Water Research and Development Act (Public Law 95-467)—section 1360;
- Federal Reclamation Act of 1902 and Amendments—43 U.S.C. 421 and 422;
- National Environmental Policy Act (Public Law 91-190)—sections 102 and 103; and
- Atomic Energy Act of 1954—10 CFR 20, 50, 61.

In translating legislative requirements into management practices, agencies often recommend procedures that depend on the use of models. The Clean Water Act, for instance, requires States to determine the "total maximum daily loads" for those sources of pollutants that cannot meet water quality standards through effluent limitations regulations. This requires States to predict the water quality resulting from a number of point-source loadings—a responsibility that implicitly requires the use of 'wasteload allocation' models. EPA's Waste Load Allocation Guidance Memorandum (Sept. 5, 1979) strongly encourages the use of models for performing wasteload allocations. The memo reads:

> The link between wasteload allocations and stream standards is a mathematical model to predict water quality as a function of waste discharges. Such models exist and are integral parts of the methodology.[9]

9 'Funding of Waste Load Allocations and Water Quality Analyses for POTW Decisions, Construction Grants Program Requirements Memorandum, U.S. Environmental Protection Agency, PRM No. 79-11, Sept. 5, 1979, "Preliminary Technical Guidance for WLA Studies," p. 4

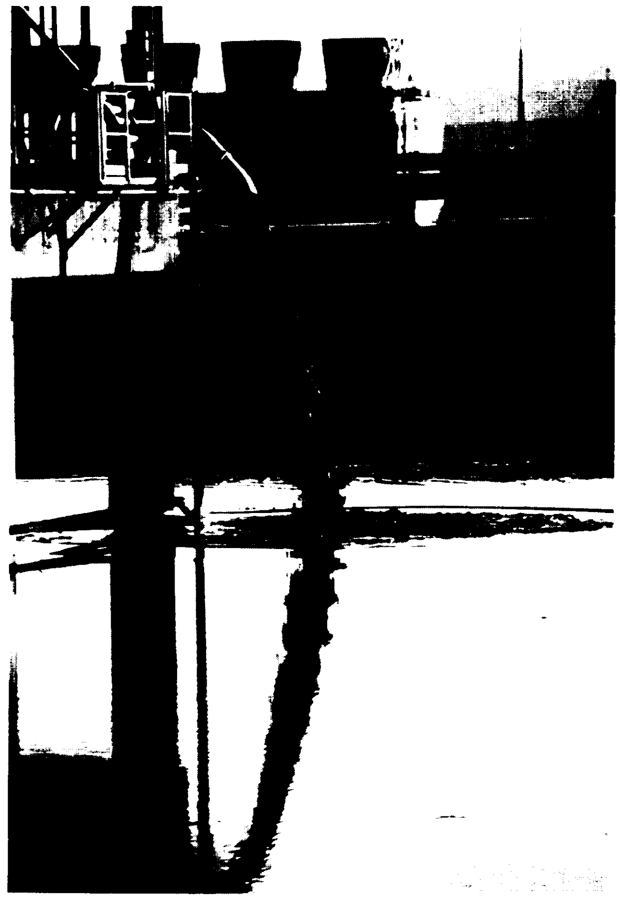

Photo credit: © Ted Spiegel, 1982

Models are important tools for determining whether individual point-sources of water pollution will prevent rivers, lakes, and streams from meeting Federal water quality standards. Using models, planners can determine what levels of discharge would be acceptable *before treatment facilities are installed;* such information is extremely valuable for designing effective treatment strategies

Developing and using models is a complex undertaking, requiring personnel with highly developed technical capabilities, as well as adequate budgetary support for computer facilities, collecting and processing data, and numerous additional support services. Such capabilities presently reside primarily within the Federal Government, or are secured from the private sector with Federal funding. For fiscal year 1979, direct and indirect Federal expenditures in support of model development, dissemination, and use for water resources are estimated at $40 million to $50 million annually. The Army Corps of Engineers, the U.S. Geological Survey (USGS), and the Environmental Protection Agency (EPA) are the principal agencies involved in water resource modeling activities, and together they account for approximately 70 percent of the funds spent in support of water modeling at the Federal level. These expenditures represent an ongoing investment in information that supports and improves expenditures of billions of dollars annually for water resource development and management.

Federal training and assistance is also important in assuring the continuing availability of hydrologists, engineers, and modelers with expertise in water resource issues. The demand for well-trained water resource professionals at Federal, State, and local government levels, as well as in the private sector, far exceeds the number of individuals who graduate annually with relevant skills from American colleges and universities. Federal support for university-level research and training, through the University Water Research Program of the Department of the Interior, amounted to about $11 million in fiscal year 1980. In addition, a number of Federal agencies offer important training opportunities in water resources analysis and modeling for Federal and non- Federal employees alike. While such training is often critical for keeping professional employees abreast of developments in these fields, current levels of instruction are clearly insufficient to meet the growing needs of Federal, State, and local personnel.

Virtually all Federal modeling activities are currently managed on an agency-by-agency basis. Little coordination of model development, dissemination, or use occurs among Federal agencies, and effective joint modeling efforts are rare. Agencies generally have little information about models available through or being developed by other agencies; consequently, agencies tend to develop new models before taking advantage of previous or ongoing modeling efforts of other agencies. While independent agency-level development may produce tools that are more responsive to specific agency needs, the lack of cooperative development has often resulted in agencies being unable to muster the resources to adequately develop and support needed models. Testing models is a difficult, expensive process and very often a major barrier in the way of model use. OTA found instances in which more than one agency had developed similar models, none of which were used for lack of adequate testing and validation.

Most Federal agencies have no overall strategy for the development and use of models; consequently many legislative requirements and decisionmaker needs for information are not being met. Due to the newness and technical complexity of the modeling field, levels of communication between decisionmakers and modelers are low, and little coordination of model development, dissemination, or use occurs within individual Federal agencies. Developers, working either as Federal employees or as private contractors, tend to have a relatively free hand in creating and using models. While the independence afforded to their development has facilitated rapid advances in design, the lack of accountability has resulted in models that often fail to address decisionmakers' needs for information, require impractical amounts of data, or are not well enough explained to enable others to use them.

Successful modeling requires adequate resources for support services, such as user assistance, as well as for development. Presently, model development has outstripped corresponding support for models. In the past, model developers have put a premium on developing models, while support for models—documentation, validation, dissemination, user assistance, and maintenance—has been neglected. Often, resources are focused on development, but are unavailable for support activities. The neglect of model support has led to a multiplicity of models, most of which are underutilized. Many of these models cannot be used by personnel other than the developer, due to lack of documentation, access to the model, and user assistance.

Federal agencies that have had considerable success with modeling have devoted substantial attention to the problem-solving needs of potential users and decisionmakers, and to providing adequate support services. These programs generally include a central responsibility for disseminating software and documentation, providing training and technical assistance, and updating and maintaining models.

State governments frequently use water resource models, although many wish to use them more extensively than is currently possible. OTA'S survey of State water resources professionals indicates that potential levels of model use at the State level are at least twice as high as current use levels. Technical capabilities at the State level tend to be limited—stalls are small, and prevailing salary scales prevent many States from hiring and/or retaining adequate numbers of personnel with modeling skills. Consequently, most States depend primarily on the Federal Government to provide them with suitable models, technical expertise, and training in model use. Those Federal agencies that have had considerable success in.assisting States have made substantial commitments to providing support services—USGS runs a cooperative program that currently assists over @Xl&ate and local agencies in developing and applying models, while the Corps of Engineers Engineering Center (HEC) widely provides services to State and local governments, an@- them in using HEC-built models.

Lack of @#&nation is a major barrier to State and bed'@% models~personnel are often unaware that models for a given type of analysis already exist. Additionally, many federally developed models are inappropriate for use at the State level. The specific needs of States are infrequently co&de@@in federal model development. Many States reported that their analytic and modeling capabilities must be expanded if States are to assume a larger role in future water resource decisionmaking.

ISSUES

The issues discussed in this section focus on the potential to improve the Federal role in developing, using, and disseminating water resource models. opportunities for increasing the efficiency and effectiveness of current model-related efforts and programs are noted, although the general nature of the options set forth prohibit development of specific cost estimates or estimates of the potential savings associated with a given option. Each option presented for congressional consideration is designed to increase the productivity of the billions of dollars invested annually in water resources and water resource management. Issues 1 and 3, "Improving Federal Problem-Solving Capabilities," and "Establishing Appropriate Modeling Strategies Within Individual Federal Agencies, " are directed toward making more effective use of the approximately $50 million per year spent by the Federal Government on water resource modeling; issues 2, 4, and 5, "Meeting the Needs of the States, " "Providing Potential Users With Information About Existing M&&" and "Federal Support for Model-Related Training," focus on improving modeling capabilities through the provision of augmented model-related services.

Issue 1: Improving Federal Problem-Solving Capabilities

Many of the analytic responsibilities mandated by Federal and State water resources legislation cannot adequately be carried out without models. However, the analytic tools needed to fulfill many legislative requirements and decisionmaker information needs are currently unavailable. The majority of Federal agencies have no overall strategy for developing, using, disseminating, and maintaining these tools. Models tend to be built on an ad hoc basis, in response to immediate problems, rather than as a result of integrated planning. In the absence of any comprehensive model development and support strategy, Federal agencies are often unresponsive to State and Federal problem-solving needs, or to congressional directives expressed in water resources legislation.

The OTA survey of Federal agencies reveals great variation in the use of water resource models. Although a particular law may assign similar analytic responsibilities to a number of agencies, some agencies will employ the most sophisticated computer tools available for their analyses, while others rely primarily on simpler approaches. In some cases, this may be all that is needed; however, in many instances, implementation of legislative requirements could be improved by more sophisticated Federal analytic capabilities. While a few agencies are extensively involved in developing modeling expertise (e. g., Corps of Engineers and USGS) most agency modeling efforts vary greatly from issue to issue, from program to program, and from decisionmaker to decisionmaker.

Most water resource problems, and the Federal legislation that deals with them, affect a number of Federal agencies. However, each agency is individually responsible for developing and funding the analytic tools it requires. While many models have widespread potential use among a variety of Federal institutions, it is often impossible for anyone agency to commit the personnel and financial resources necessary to bring them to completion. Developing these tools is expensive and technically complex. For example, the problem of collecting enough data to fine-tune models and test their accuracy can inhibit model development by a single agency.Unless clear direction and priority-setting mechanisms are provided by Congress and the Executive Office of the President, the best analytic tools will not be available throughout the Federal Government, and many needed models will not be built or supported.

At present, minimal Federal oversight exists for the finding of applied research and development (R&D) activities. The mechanisms that rently exist for coordinating water resources analysis "fins almost entirely on research needs. Neith@t% information required for solving policy problems nor the analytic techniques needed to aid in decisionmaking are directly addressed in the current process for coordinating the Federal R&D agenda in water resources. Under the water Research and Development Act of 1978, the Secretary of the Interior is presently directed to develop a 5- year water resources research program, drawing on the expertise and advice of appropriate Federal agencies, the State water resources research institutes, and other appropriate entities. The program is to indicate goals, objectives, priorities, and funding recommendations to the President and Congress for water resources R&D. That document is intended to serve as the basis for funding allocations in the budget processes of Congress and the Executive Office of the President.

While the 1978 act recognizes the need to strengthen, "The capability for assessment, planning, and policy-formulation , . . at the Federal and State level, " it provides no specific direction to determine what mix of research and problem-solving capabilities can best meet Federal needs. Moreover, by concentrating primarily on research needs, it misdirects mission agency priorities toward research per se rather than toward coordinated development and utilization of scientific knowledge and related analytic capabilities. The research focus of the current act also reinforces tendencies within individual agencies to fund projects that reflect the agency's mission, rather than priority problems identified by Congress and the Executive Office of the President.

Options available to Congress include:

OPTION 1-A:

Congress could amend the Water Research and Developement Act of 1978 to specify the development of a multiyear plan emphasizing a mix of R&D needs, unable analytic tools, and supp:~w' services for ensuring to ~@& that these tools are , managers.

Under the act, Congress has directed the Secretary of the Interior to develop a 5-year water resources research program. This mechanism for coordinating Federal efforts to help solve water resource problems might be more effective if a broader range of problem-solving needs were considered.

Over a dozen reports defining Federal water resources research needs have been prepared over the last 20 years.[10] The latest of these, the National Research Council review of the draft Five-Year Plan specified by the act, lists major water resource problems, and further states that:

> For many of the foregoing problems the basic and applied research has already been accomplished in substantial part, if not entirely. What is often lacking, however, is adequate technology transfer . . . Solution of many other problems requires research and development to advance the state of knowledge.

The individual agency research plans submitted for use in developing the Five-Year Plan gave high priority to the development of mathematical models. Similarly, a 1977 report on research needs by the Committee on Water Resources Research stated that, "Throughout this 'catalog of needed research, there is a strong theme that calls for continually improving mathematical and physical modeling capability."[11]

As with previous plans, the latest Five-Year Plan proposal has not been as effective as it might have been, due to its emphasis on a research agenda. While models have been acknowledged as important research tools, little attention has been paid to developing the analytic tools and support capability needed to meet Federal and non-Federal water resource problem-solving responsibilities. Major gains in the effectiveness of Federal modeling efforts can be achieved through systematic provision of such support services as assistance in locating and obtaining usable existing models, testing and evaluating models for application to different conditions and decisionmaking needs, and training and technical assistance in using the models.

Mathematical models are an important component of the water resource analysis needs of Federal agencies. However, as with other forms of R&D, creating these tools is only the first step in establishing needed analytic capabilities. Congress could expand the scope of the Water Research and Development Act to specifically address a broader range of analytic and problem-solving needs for water resources decisionmaking, and provide a mechanism (such as an interagency coordinating committee) to carry out the intent of the act.

OPTION 1-B:

> Congress could establish an interagency unit whose responsibilities include developing a multiyear plan for water resource analytical needs and coordinating the implementation of the plan.

Interagency representation may be necessary for successful coordination. This unit might be housed either within the Office of Science and Technology Policy or in an interagency water resources policy organization similar to the Water Resources Council or its potential successor. The unit might be directed to work closely with the Office of Management and Budget for budgetary review.

OPTION 1-C:

> When addressing priority problems through legislation, Congress could establish specific mechanisms to provide adequate Federal water resource analytic capabilities to meet the intent of the legislation. .

Congress could explicitly direct Federal agencies to provide institutional support for the analytic capabilities needed to implement legislative goals. A number of approaches could be used for providing these capabilities, including centers of excellence at universities, operating units within existing Government organizations, and agency and interagency demonstration programs for creating support units. Examples of such support units as the Fish and Wildlife Service Instream Flow Group are described in chapter 4.

Issue 2: Meeting the Needs of the States

Most of the Nation's major water resource legislation is based on the concept of a strong State-Federal partnership for managing and planning the use and protection of the Nation's water. If States are to fulfill their responsibilities, and take on an increasing share of water resource management delegations in the future, it is in the Nation's best interest to ensure that the States have ac-

[10] *Federal Water Resources A Review of the Proposed Five-Year Program Plan,* Water Resources Research Review Committee, Commission on National Resources, National Research Council: National Academy Press, 1981

[11] *Directions in U.S. Water* Research 1978-1982, Committee on Water Resources Research of the Federal Coordinating Council for Science, Engineering, and Technology (Springfield, Va. : National Technical Information Service PB 274278, October 1977),

cess to, and are capable of using, the best available analytic tools.

Many States depend heavily on Federal agencies for assistance in modeling, and rely primarily on models that: 1) are widely available, 2) have a long history of use, and 3) are well supported by Federal agencies. Most States lack the financial resources and the technical expertise required to develop models independently. States frequently share common responsibilities or problems, and can take advantage of federally developed models designed for application to a wide variety of natural, social, and economic situations. Even for situations where differences among States require substantially different models, agencies of the Federal Government are important centers of expertise to which States. turn for modeling assistance.

However, many of the models that Federal agencies routinely use are inappropriate to assist the States in fulfilling their water resources responsibilities. Even when agencies develop models that relate to State concerns, they often have no mandate to assist the States in analyzing their water resource problems. Consequently, many States find that such models are too complex to use, require more input data than States can afford to collect, or fail to meet specific State analytical needs.

Although a few agencies, such as EPA, solicit general input from the States through advisory panels or other means, State needs are largely neglected in Federal agency modeling processes. If State agencies are to utilize Federal models to a greater extent, practical mechanisms must be devised for providing State input into the model development processes within individual Federal agencies.

In addition, for the Federal Government to be effective in assisting States to analyze water resource issues, it must first develop reliable means of obtaining information about State needs. Mechanisms for assuring State input into Federal R&D processes, as specified under the Water Research and Development Act of 1978, are inadequate. The current act directs the 54 State (and territorial) water resources research institutes to develop 5-year research program reports in close consultation with appropriate State agencies, and to submit these to the Secretary of the Interior for use in developing a 5-year coordinated Federal water resources research program. As outlined in Issue 1, ‘ ‘Improving Federal Problem-Solving Capabilities, such a procedure focuses primarily on water resources research, and does not give adequate consideration to developing and supporting analytic tools for solving important water resource problems. In addition, it makes the State water resources research institutes the primary liaisons between the States and Federal water resource planning. The institutes, many of which were created by Federal legislation and operate primarily through Federal funding, are primarily research centers.

The capacities and functions of the State water research institutes vary widely, Some compete extensively for discretionary Federal research funding, while others operate primarily on the small basic allocation provided to all 54 institutions. Some are actively involved in pursuing solutions to water resource problems that affect their States, while others concentrate on scientific problems that may have few near-term practical ramifications.

Perhaps most importantly, the institutes have a federally authorized research focus that makes it difficult for them to adequately account for the applied research and problem-solving needs of State and local water resources agencies. While they play a vitally important role in the long-term development of expertise, the institutes are in a relatively weak position to voice State agency needs to the Federal Government.

Two additional pressing needs identified in the OTA survey of State water resource agencies are discussed in detail under issues 4 and 5: 1) better access to information about existing models; and 2) increased training opportunities in model use for State personnel.

Options available to Congress include:

OPTION 2-A:

> Congress could direct the States to designate a lead State agency to assist the Secretary of the Interior, or other designee, in developing a multiyear plan for water resource analysis needs.

The Water Research and Development Act directs the State water resources research institutes, in consultation with State agencies, to provide input to the Five-Year Plan mandated by the act. If the Federal Government is to assist States in meeting water-related responsibilities, it must take into account a wide range of State water resource agency information and analytic needs. Congress could amend the act to allow the States to designate a lead State agency or a water resources research institute to participate in planning a broader multiyear Federal agenda.

OPTION 2-B:

Congress could strengthen the States' own capabilities to undertake sophisticated water* source analysis.

As the States' water resource management responsibilities have increased, so have the States' requirements for sophisticated water resource analysis. Improving the States' own analytic capabilities, either through federally sponsored training or by funding the States to develop and use their own analytic tools, could allow States to be less dependent on Federal agencies for analysis.

For example, the Clean Water Act (Public Law 95-217) directs the Administrator of EPA to make grants to planning agencies to develop a comprehensive water quality control plan for a river basin. Congress might consider, similar programs for water resource development programs. If the States are to assume a greater role in the priority-setting process, Congress might consider including formula funding to strengthen States' analytic capabilities.

OPTION 2-C:

Congress could direct Federal water resource agencies to respond to the analytical needs of the States whenever States are to implement Federal programs.

For example, under the Safe Drinking Water Act, the States have primary enforcement responsibility for public water systems. The act specifically directs the Administrator of EPA to conduct research and demonstrations of improved methods (i) to identify and measure the existence contaminants in drinking water (including methods which may be used by State and local health and water officials), and (ii) to identifi the source of such contaminants." One activity undertaken by EPA—funding the Holcomb Ground Water Model Clearinghouse—helps the States obtain ground water quality models used to identify the transport and fate of pollutants.

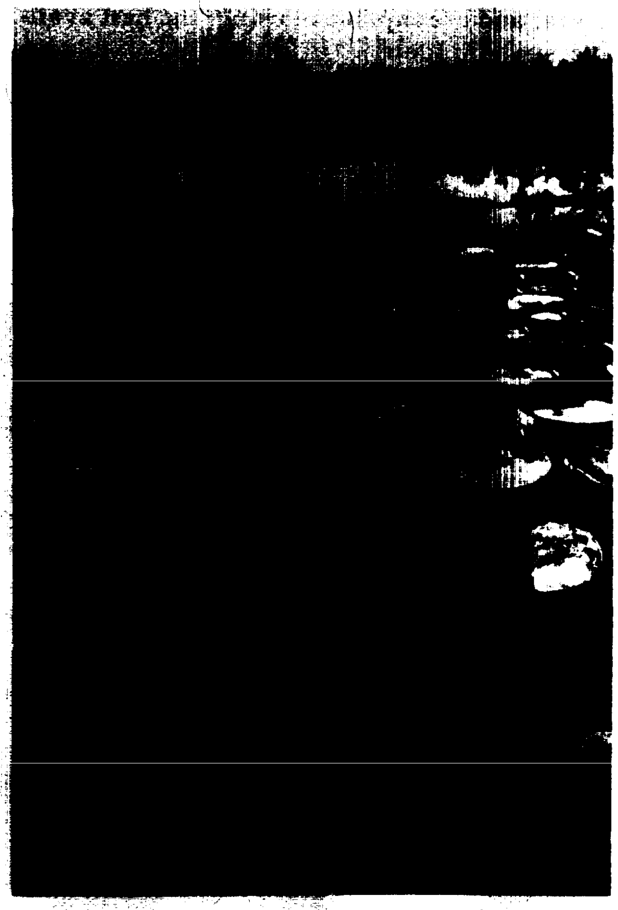

Photo credit: © Ted Spiegel, 1982

Toxic wastes from dump sites can migrate into ground and surface waters, contaminating public and private water supplies, and endangering aquatic and other wildlife. Models of contaminant transport, although still in early stages of development, are useful in estimating the spread of contaminants from improper disposal sites, and in designing new landfills to minimize leakage of toxic materials

Congress could direct Federal agencies to establish similar mechanisms to assist the States whenever Federal programs are to be implemented by the States, and ensure, through its oversight responsibility, that these programs are adequate.

Issue 3: Establishing Appropriate Modeling Strategies Within Individual Federal Agencies

Many of the major Federal water resource agencies lack an intergratedplan for developing and supporting models. These agencies generally develop models *in* response to an immediate need to solve particular problems. Few attempts have been made to integrate related modeling efforts within each agency. Moreover, many models are produced without serious attention to decision-makers' needs or significant managerial input. Models may not have been tested to determine their ranges of error and applicability to different conditions, and model assumptions and results may not be explained well enough to allow decision-makers to interpret them properly. Consequently, some agencies may have a multiplicity of models, only a few of which are actuaIly usable.

A few Federal agencies or offices, however, have established comprehensive strategies for developing and supporting models. These strategies generally take two different forms,: 1) develop= ing the capacity to analyze priority water resource problems encountered by many users, through a limited number of carefully selected models; or 2) developing a general capability for analyzing individual problems on a one-time or limited basis. Each involves different mixes of model development and support activities.

Outstanding examples of both modeling approaches currently exist within the Federal Govern*ment. The* Hydrologic Engineering Center (HEC) has extensively developed the capacity to maintain and support 12 Corps-built models. HEC support services include training in model use and technical assistance to users. EPA, upon the completion of its Stormwater Management Model (SWMM), es? tablished the SWMM Users' Group to encourage the model's dissemination and use. Since its inception in 1973, membership has grown to over 500 users, who meet to exchange information and ideas relating to the model's use, assist each other in running it, and explore alternative analytic tools. A description of HEC and SWMM User Group activities is provided in chapter 4 of this report,

Developing selective modeling capabilities can bean effective strategy when frequently occurring priority problems appear' to be solvable with some kind of standard technique. Models for dealing with these problems are generally developed in anticipation of repeated application by a variety of users. Their design must give close attention to user needs and capabilities. Models must be thoroughly explained, or documented, tested for use over a wide variety of conditions, easily accessible, and usable on many different computer facilities without ma@ modifications.

To assure that the models are widely and appropriately used, the sponsoring agency must further develop a coordinated program of user support services, including;l) training programs—with "hands-on" instruction, if possible; 2) one-on-one technical assistance, for problems that arise in the course of running the Model and interpreting its results; and 3) model maintenance, to incorporate improvements and assure that users are informed of such modifications: -

Agency expenditures support of such a program need not be large .Services for frequently used models are often provided by the private sector on a paid **COnsultant basis.** Agencies may need only to provide rudimentary services, directing users to appropriate sources of further assistance. However, the agency would need to ensure that the necessary support is available of the highest quality.

More general modeling capabilities have been developed by USGS, which maintains a cooperative assistance program that provides services on a cost-sharing,. to over 600 State and local agencies. To meet the requirements of these dispersed users, USGS maintains numerous models that can be adapted,.by its staff to specific local situations. USGS model-related activities are described in detail in chapter4 of this report. The diversity of user needs, particularly for ground water modeling, makes this approach particularly helpful for assisting non-Federal agencies lacking inhouse modeling capabilities.

For users with unique information and analytic needs,developing standard models to an**ticipate such** needs may be inappropriate. In t$@~,sJ@**uatio**,Jr's, strategies emphasizing general **modeling capabilities,** which stand in readiness **to produce or adapt** a model appropriate to each **user's particular** needs, may be more effective, Such a strategy requires personel capable of routinely coordinating model development, bringing scientific knowledge and modeling expertise to bear on unique situations. While the individual models require appropriate support (e. g., adequate testing and documentation), the process focuses on the needs of a single decisionmaker or decisionmaking group, rather than on those of many dispersed users. Developers must work closely with the user to adapt the model to the particular issue, test and apply the model, and interpret its results.

Developing comprehensive strategies for building and disseminating water resource models is a pressing need for each of the Federal agencies involved in this field. Decisions on what kinds of modeling capabilities to develop, and what levels of funding to allocate in support of them, need to be made at top policymaking levels within each agency for the agency as a whole, taking into consideration its present and future responsibilities, and its role in providing other Federal, State, and local government entities with assistance in model use. While issue 1 addressed strategies for improving interagency coordination of water resource modeling activities, long-range intra-agency planning for the models and related support services within each agency's purview must supplement interagency coordination efforts.

An option available to Congress includes:

OPTION 3-A:

Congress could, through its oversight responsibilities, direct each of the major Federal water resource agencies to develop a coordinated strategy for the development, dissemination, and use of models.

OTA case studies indicate that coordinated planning is necessary for providing effective institutional support to encourage model development, dissemination, and use. While the approaches used in existing programs differ widely, successful efforts have two elements in common: 1) the models are of high quality, have been evaluated over a wide range of conditions, and are responsive to users' needs; and 2) the models are well documented and maintained, easily accessible, and are associated with adequate technical assistance. Oversight activities to ensure the development of a strategy incorporating each of these elements could help promote a more effective problem-solving capability within Federal agencies.

Two elements that are integral to the development of comprehensive modeling strategies—training and the availability of information about models —are discussed below as issues 4 and 5.

Issue 4: Providing Potential Users With Information About Existing Models

Many models currently developed by Federal agencies are intended for a single application—once they have been built, and are used to analyze a single problem, they are considered to have served their purpose, and are shelved. Since they are not designed for distribution, information on their existence is not typically made available outside the agency. Consequently, other agencies with potential uses for these models may be unaware that such models even exist. Often the models are not tested to determine their accuracy and applicability to other situations, nor are they sufficiently documented so that others may choose to use them. Models developed by outside contractors, but which are left undocumented or are documented inadequately, may not even be usable by other personnel within the same agency.

No entity within the Federal Government is specifically charged with providing information to potential users—Federal or non-Federal—about the governmentwide availability of water resource models. Three existing units provide such information as part of a more general mission; each, however, is limited in its ability to gather comprehensive information on existing Federal models, rapidly access that information for users, and match user needs to available models.

The Water Resources Scientific Information Center (WRSIC) has supported two major sources of water resource information, *Selected Water Resources Abstracts,* and the Water Resources Research in Progress File. Both have provided reference services geared to trained water resource professionals— information on modeling activities is included, but not in a format that allows for ready access to specific types of models. Moreover, the services do not reference models or documentation directly. They can at most identify publications in which models are cited or described, or ongoing research projects that involve modeling activities. Recent cost-saving initiatives are projected to substantially curtail WRSIC activities, particularly in the area of printed material; however, computer-based information retrieval services for accessing published work are expected to be maintained.

The National Technical Information Service (NTIS) collects and sells data files, computer programs, and model documentation manuals from Federal sources. The sheer magnitude of the NTIS mission— responsibility for disseminating over 1 million publications—makes it extremely difficult for NTIS to provide detailed assistance to potential computer model users. Its information retrieval system is not well suited for locating available computer tapes of models. Recently, NTIS files of computer tapes have been combined with those of the General Services Administration's Federal Software Exchange Center (FSEC).

FSEC serves as a central repository for computer programs that Federal agencies consider to be widely applicable. Its holdings span an extremely wide range of subjects, and water resource models comprise only a small portion of the available software. Since FSEC has a very limited staff, it cannot assist users in determining the capabilities and limitations of its models, running them, or interpreting results. Moreover, agencies provide models to the Center on a purely voluntary basis, and FSEC regulations prohibit the Center from identifying the agency that developed the model to potential users without the agency's expressed consent. Lacking access to the individuals who developed the model, users may have difficulty in applying it to the problems they need to analyze. The organization's inability to provide user support limits its primary utility to professionals with highly developed modeling expertise.

All of these organizations provide information on models that have been documented and supplied to them by various Federal agencies. However, many Federal models are not entered into any of these systems, and many that have been entered have been inadequately documented.

A number of attempts have also been made at agency levels to provide relatively detailed information on models dealing with specific subject areas. Two of the larger systems dealing with water resource concerns are the Department of Agriculture's Land and Water Resources and Economic Modeling System, and the EPA Center for Water Quality Modeling, both of which are described in detail in chapter 4 of this report.

In recent years, the concept of a model *clearinghouse* has gained many adherents in the scientific and managerial community. Such clearinghouses would be designed to organize models for easy access by users with specific analytical needs. To test the utility of the clearinghouse approach, EPA has sponsored the development of the International Clearinghouse for Ground Water Models (ICGWM) at the Holcomb Research Institute. An extensive description of ICGWM is provided in chapter 4 of this report. Preliminary findings indicate that ICGWM has been very successful in improving the accessibility of ground water models. Clearinghouses, however, remain a controversial approach. Some water resources professionals are skeptical of their cost effectiveness, and of any one organization's ability to provide expertise about large numbers of mathematical models.

options available to Congress include:

OPTION 4-A:

Congress could direct the Federal water resource agencies to make information on agency models available to outside users and to establish mechanisms to distribute these models on request.

Several water resource agencies have already established catalogs of existing models, but on the whole, it is extremely difficult to obtain information about the existence and specifications of federally developed models. This information is generally unavailable to potential users in local, State, or other Federal agencies.

A second component of information transfer is the dissemination of the computer program for the model. Such programs are also generally difficult to obtain. One office with extensive capabilities for distributing models to potential users is HEC, described in chapter 4. Congress could direct agencies that do not presently distribute the results of federally funded modeling activities to do so at reasonable cost to the user.

OPTION 4-B:

Congress could expand the role of existing information transfer agencies to be more responsive to the modeling information needs of water managers, and encourage water resource agencies to use these existing mechanisms.

Either FSEC or WRSIC could be expanded to serve as a Federal Government-wide repository of water resource models and model information. Each of these groups currently provides limited information about water resource models-FSEC focuses directly on models, but has no water resource-related mission or expertise, while WRSIC is a comprehensive information source for water resource research, with no model-related mission or expertise. Neither provides the support services required for assisting potential model users.

Water resource agencies would have to be encouraged to assist the chosen information transfer agency in expanding its services.

OPTION 4-C:

Congress could establish a national clearinghouse system for the distribution of water resource models.

Though several model clearinghouses currently exist in the United States, many important water modeling areas are not covered by any existing organization. The Holcomb Clearinghouse contains an extensive file of ground water models, and EPA's newly established Center for Water Quality Modeling contains information on a few of the most popular surface water quality models.

Due to the substantial interconnections and overlaps among water resource modeling activities, many professionals consider it desirable to develop a comprehensive center to which a water resource manager could turn to obtain complete information on the availability of models. Such a center would bring together models developed by the Federal Government, States, and the private sector. A centralized clearinghouse, or a series of clearinghouses, containing information on models of all aspects of water resources—quality and quantity of both ***ground*** and surface waters, as well as the social and economic implications of water use—could assist water managers to choose amongst the multitude of available tools.

"Seed money" would be required to start a national clearinghouse, but after several years of operation, equitably designed user fees could cover a substantial portion of clearinghouse operation costs. The clearinghouse should provide, at a minimum, information about available models. Additional services could include providing computer programs, or more extensive services such as training courses.

OPtion 4-D:

Cogress could fund an interagency demonstration project to evaluate and compare existing models for a representative range of field conditions.

Though thousands of water resource models are currently available few have, been evaluated for conditions other than those under which they were developed. Information about the accuracy of models is difficult to obtain-and for many models is nonexistent. Poor validation of models is a major complaint of potential users and a significant constraint on model use.

For common types of analyses, such as projecting water quality changes from a proposed sewage treatment plant, Congress could direct the appropriate agencies to choose several models, evaluate them under a wide range of conditions, and compare their strengths and weaknesses for different purposes. Because of the benefits that such an evaluation would provide to the professional water re-source community professional societies might be willing to jointly undertake the project. The results of these evaluations would assist professionals in choosing tools appropriate to their needs, and give decisionmakers greater confidence nce in the results.

If the demonstration program is successful, a more formal mechanisfor interagency model evaluation might be established.

Issue 5: Federal Support for Model-Related Training

Federal funding currently provides much of the support for training personnel to develop, use, *and* interpret water resource models. However, Federal, State, and private sector personnel reported that the inadequacy of current levels of model-related training is a major impediment to meeting the needs of local, State, and Federal agencies. State water resource professionals considered increased federally sponsored training opportunities to be a top priority. In addition, officials of Federal agencies that sponsor training programs acknowledge that inadequate resources are presently provided for training nonagency personnel, and that current agency training opportunities fall far short of demand. If models are to be used effectively in water resource analysis, training in basic concepts of modeling and in proper interpretation of model results must be offered to decisionmakers at all levels of government. Finally, 'Federal support for the academic training of future water resource professionals has been threatened by recent cost-saving initiatives.

There are three major aspects to model-related training: 1) general educational opportunities in water resources research and analysis; 2) specific training in the use of individual water resource models; and 3) continuing education for manager/decisionmakers and users. Each involves a different kind of Federal training support.

Educating water resources professionals involves extensive academic training and **requires support** for research and related overhead. Since 1965, the Office of Water Research and Technology (OWRT) of the Department of Interior has sponsored the University Water Research Program. The program provides seed money, through the State water resources research institutes, for training students in water-related studies and providing equipment for students and faculty research work. Individuals who benefit from the program may become m&M developers, or water resources managers, or analysts who use water resource models. Federal expenditures for the program amounted to approximately $11 million for fiscal year 1980. Funding has been provided on a matching basis

Photo credit: Ted *Spiegel,1982*

A hydrologist at USGS headquarters In Reston, Va., instructs staff in the use of one of the agency's. streamflow models at a desktop computer terminal

with State governments, which contributed over $17 million to the institutes during the same fiscal year. Over the past 16 years, the program has made a significant contribution to alleviating the shortage of qualified technical manpower for water resource management. Federal appropriations for the University Water Research Program for fiscal year 1982 have been reduced to approximately $6 million. The fate of the University Water Research Program is still uncertain. OWRT has been scheduled for elimination, with its responsibilities to be transferred to other offices and programs, before the end of the current fiscal year.

Model users require specific training to enable them to use a particular model and apply it to actual problems. Such training is a critical component in transferring modeling technologies from the developer to the organizations charged with solving water resource problems. Many models go unused, or are underused, because such training is not widely available. USGS and HEC are among the Federal agencies that presently conduct training courses in model use—HEC training courses reserve approximately 10 percent of classroom places for State and non-Corps of Engineers Federal personnel in 24 weeks of formal training programs per year. These courses have greatly expanded the use of HEC and USGS models, and improved the proficiency of water resource professionals in using them. While both agencies strongly support the concept of one-on-one training and "hands-on" workshops in model use, the cost involved in providing these forms of training limit their present use. Using a different approach from that of HEC, the SWMM User's Group provides such assistance informally, or on a fee basis among members. Use of the SWMM model has become so widespread that a number of universities around the country have begun to provide training courses in its use; EPA has not been obliged to provide formal training instruction since the fall of 1976.

Short training courses in a number of the more widely used models are available through public and private universities. These courses are highly valuable in providing users with the information necessary to operate models and interpret their results.

Managers and decisionmakers are often unprepared for the problems and complications associated with model use for water resource problems. Many have completed their formal education prior to the widespread use of computer modeling techniques, and do not understand the concepts underlying computer-based simulation and analysis. Few Federal agencies have yet made a significant commitment to decisionmaker education and retraining to accommodate modeling techniques. The Instream Flow Group currently conducts an executive training program to enable field personnel and administrators to use model-based recommendations; ICGWM has recently begun a series of ground water modeling workshops, the most introductory of which discusses the application and limitations of models for policymakers and decisionmakers. Nonetheless, Federal efforts to provide continuing education in model use for management-level personnel are still in very early stages.

Options available to Congress include:

OPTION 5-A:

> Congress could allocate resources to water resource agencies specifically for establishing inhouse and extramural training programs for their personnel, and for water managers in State and local agencies.

Two types of training programs are needed: 1) courses on the use of specific models for potential model users; and 2) continuing education for managers and decisionmakers to understand t: e strengths and weaknesses of model-based analyses.

Several examples of training programs are described in chapter 4. These range from courses offered by HEC to the informal conferences of SWMM'S Model User's Group. While excellent examples of training programs exist for agencies to follow, the need for additional programs is great.

A variety of approaches could be used for developing adequate training programs. Agencies could arrange to fund training provided by universities with acknowledged expertise in water resource modeling, or develop inhouse training capabilities through agency personnel or outside contractors.

OPTION 5-B:

Congress could expand the current programs assisting university-level water resources education.

Training grants to universities, and research grants that provide the opportunity for students to obtain experience in analyzing water resource problems, are two mechanisms by which Congress can help provide an adequate supply of well-trained professionals.

Educating students in state-of-the-art analysis techniques, often available at universities throughout the country but not within Federal, State, and local agencies, brings these techniques to the agencies when these students graduate and are hired. Research and training programs offered through the National Science Foundation and OWRT are important mechanisms for meeting future agency-level analytical needs.