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EVALUATION OF WATER QUALITY MODELS:
A Management Guide for Planners

Office of Air, Land and Water Use
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EVALUATION OF WATER QUALITY MODELS

A MANAGEMENT GUIDE FOR PLANNERS

By

G. Paul Grimsrud
E. John Finnemore
H. James Owen

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Project Officer

Donald H. Lewis

Office of Air, Land, and Water Use
Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

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ABSTRACT

This report is designed as a handbook specifically oriented to water quality and water resources planners and managers. It presents a large amount of basic information concerning water quality modeling including procedures for: model evaluation, model selection, integration of modeling with planning activities, and contracting modeling projects.

Planners without previous experience in water quality modeling may use the information and procedures included in the handbook to determine whether a water quality model could and should be used in a particular planning program, and which specific model would be cost effective. This includes a step-by-step procedure leading to the rejection or selection of models according to specific project needs.

The handbook discusses the implications which accompany the decision to model, including the needs for additional labor and specialized technical expertise which are generated. Methods and procedures for integrating the use and results of water quality models with other activities of the planning process are described as well as the respective merits of in-house and contracted modeling. The handbook also deals with the procedures for obtaining and using contractual services for water quality modeling. Step by step instructions are provided for the preparation of solicitations, evaluation of proposals and selection of contractors.
U. S. Government Employees are cautioned that the guidance on obtaining contractual services contained herein does not supplant Federal Procurement Regulations (FPR) or their own agency contracting procedures.

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CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

An explicit goal of maintaining and enhancing water quality has been established by the Congress and most states. Many interstate authorities, regional organizations, and local governments have followed suit. The extent of the nationwide commitment to the goal of clean water, and the priority given its accomplishment, are evidenced by the magnitude of the investment being made for prevention and abatement of water pollution.

The Federal Water Pollution Control Act of 1972, Public Law 92-500, authorizes federal expenditures totaling $27 billion. Additional large, non-federal expenditures are encouraged by the Act's cost-sharing provisions, and by its requirements for industry wastewater control expenditures to meet effluent standards. An undetermined further investment is being made by governments at all levels, industries, and other entities through diverse water quality control programs other than those mandated by the Act.

In addition to the measurable financial costs associated with the maintenance and enhancement of water quality, less easily identified costs are also incurred. Among others, these include the social costs and the opportunity costs attendant to various water pollution control programs. While the measurement of these and other less visible costs cannot be made explicitly, they are undoubtedly large.

The attention focused on achieving water quality goals and the massive investment at stake make management decisions affecting water quality of the utmost importance.

Major decisions regarding water quality management are being made daily as a part of numerous planning programs. It is incumbent on planners to assure that the expenditures associated with their recommendations be justified and that actions taken will fully achieve all of the expected results.

The principal types of planning programs now underway affecting water quality management are those which result in the preparation of one or more of the following:

1) Long-range framework plans for the comprehensive and coordinated management of water and/or land and related resources over large areas, such as:

   - state water plans;
   - state land-use plans, and
   - framework studies pursuant to Section 102 of the Water Resources Planning Act of 1965, Public Law 89-80.

2) Medium-range plans proposing or identifying specific actions for the development, protection, conservation, and use of water, land, and/or other resources, such as:

   - basin plans for water quality management pursuant to Sec. 303(e) of Public Law 92-500;
   - areawide waste treatment management plans pursuant to Sec. 208 of Public Law 92-500;
   - Level B studies pursuant to Sec. 209 of Public Law 92-500 or Public Law 89-80, and
   - specific functional plans for water resources development, energy, transportation, land use and other purposes.

3) Detailed site-specific studies such as those related to:

   - facilities planning pursuant to Sec. 201 of Public Law 92-500, and
   - evaluation of discharge permit applications.

Planners and managers responsible for the performance of the above and other types of planning programs must usually deal with the engineering, economic, financial, legal, institutional and environmental aspects of water quality. The detail required in the analysis of these aspects depends upon the study purpose. Broad framework plans seldom require the detailed analysis appropriate to an areawide waste-treatment management plan or determination of the best location for an industrial outfall.

One of the first crucial decisions encountered by planners and by managers of planning activities is selection of planning methodologies which are appropriate to the situation and capable of execution within the limits of time and funds. The selection of planning methodologies must take into account the types of analyses which are needed and the number of analyses to be made.

Difficult technical problems are frequently encountered in making certain evaluations. These may include:

- the location, nature, extent, and impact of non-point sources of waste;
- the complex biological, chemical and physical interactions which take place over time between effluents and receiving waters;
- effects of various types and amounts of waste treatment or of the generation and release of various pollutants which directly affect water quality; and
- water quality impacts resulting indirectly from modification of hydraulic regimes, land use, or other actions.

In addition to their technical difficulty, the number of waste-water management alternatives which exist and require evaluation may be large. The complexity of water quality analysis and the need for investigation of large numbers of management alternatives has stimulated the development of a variety of tools to assist planning. These tools range from simple graphical techniques to sophisticated computerized models.

Water quality models have assumed an important role in the decision-making process. They enable types and numbers of analyses which would otherwise be impractical in many cases. However, the use of water quality models can be costly and time consuming. It is essential that planners give careful attention to insuring that their use is cost-effective.

1.2 PURPOSE OF HANDBOOK

The purpose of the handbook is to assist planners in selecting and using techniques of water quality analysis which are cost-effectively matched to their planning responsibility. More specifically, the handbook is intended to provide planners a sufficient introduction to water quality modeling to enable effective communication with systems analysts and administrators regarding water quality modeling.

1.3 PROJECT SCOPE

Water quality modeling is a highly specialized technology. Detailed description of every aspect of that technology would be impractical. However, the overview presented in this handbook provides planners the information needed to answer basic questions regarding water quality modeling and recognize when more expert assistance is required. References are included to facilitate further investigation by those desiring to do so.

The number of water quality models described in the handbook is limited. Those chosen for inclusion are readily available and likely candidates for frequent future use. They also demonstrate a range of model types.

The information regarding the included models is based on the experience of the authors in developing, modifying or using a number of them and on review of documentation reports and other available information. All of the model codes were examined in detail as a part of handbook preparation. However, it was not within the scope of that effort to test run the models. It should therefore be recognized that minor deviations from execution times and other stated characteristics may occur in particular applications.

The methodology for selection of the water quality model best fitting a particular need was developed especially for inclusion in the handbook. Though new, the methodology has been tested and progressively improved in a series of case studies carried out in cooperation with federal, state, and local planners. The case studies included critical review of the methodology by potential users and demonstration of its application to water quality planning for the Snohomish Estuary at Everett, Washington.

The information provided herein which deals with the technical and administrative aspects of acquiring, using, and managing consulting services is necessarily general. Each case is likely to be more or less unique depending on the nature and urgency of any need for assistance, the prevailing legal framework and other factors. U. S. Government personnel should realize that the guidance on obtaining contractual services contained herein does not supplant Federal Procurement Regulations (FPR) or their own Agency contracting procedures.

CHAPTER 2

MATHEMATICAL MODELING

2.1 INTRODUCTION

The water resources planner, or manager, must concern himself in part with understanding the behavior of the hydrologic system with which he works. Understanding is gained through use of existing scientific knowledge, by employing tools of analysis such as mathematics, and through the design and evaluation of experiments. Beyond understanding the existing system, the planner or manager must also be concerned with how the systems would behave as a result of decisions or actions that may be taken now or occur in the future. Planning, in particular, must assess the extent to which specific objectives may be achieved through the creation of facilities that did not exist before; as, for example, the planning of a sewage treatment plant to satisfy new water quality standards. In addition, the planner or manager must be able to determine more efficient resource management strategies that would improve the performance of the existing system.

One way to plan, analyze, and decide on an appropriate course of action is to make the considered changes in the actual system's operation and observe the effects directly. Whenever practical, this kind of controlled experimentation is highly desirable. However, such direct experimentation on a river system is usually impractical. Few planners would propose constructing treatment plants at all proposed locations in order to select the most effective one, nor propose the severe disruption of service to test emergency strategies or contingency plans. Instead, the planner may find it necessary to model the physical system in a way that will permit him to analyze the essential cause and effect relationships. The model may be a scaled down replica of the actual system, or it may be a mathematical description based on known physical laws and empirical formulas. A water quality model, as defined in this project, is a representation of receiving water quality (the system) as a function of various man-induced and natural inputs (system elements) such as effluent discharges, storm runoff and solar radiation. In a mathematical model, the relationships that exist between the various system elements are represented by a set of mathematical equations. Depending on the type of questions to be answered about the behavior of the actual system, the mathematical model may range from a few simple equations that can be solved by hand computation to hundreds of complex equations that can be solved only through the use of a digital computer. No matter what level of complexity the equations take, when these models simulate the behavior of the physical system (water quality) under various conditions, the model is called a mathematical simulation model.

The objective of this Chapter is to briefly describe the merits and limitations of mathematical simulation models, with particular attention placed on those for prediction of water quality in rivers, lakes, and estuaries. Various types of models exist and each varies in its applicability to specific situations. The information contained in the following chapters is intended to aid the planner in deciding whether, in a particular situation, the use of a simulation model is warranted and to suggest guidelines for the selection of a specific model.

Mathematical simulation models, when used properly and with an understanding of their limitations, can greatly expand the range of alternatives a planner may consider and assist in providing information in an organized form. It should be stressed, however, that such models are nothing but tools to assist planners in the difficult task of evaluating alternatives. They are <u>not</u> a substitute for experience and good judgment, but a means for permitting these qualities to be used more effectively.

2.2 MATHEMATICAL MODELS VS. OTHER TYPES OF MODELS

There are a multitude of ways in which a particular system can be modeled. Models can be classified by their structuring characteristics as follows:

1) Physical (Iconic) Models - These models are intended to "look like" the subject of inquiry. They are usually characterized by the use of scaling techniques. Examples of this type of model include the globe, still pictures, etc. Very few models of this type exist for water quality modeling, although physical hydraulic models of certain water bodies have been extensively used.

2) Analog Models - These are characterized by the use of a convenient transformation of one set of properties for another in accordance with specified rules. For example, certain mechanical systems may be represented by an electrical equivalent. Other examples of analog models include: block diagrams, flowcharts, plant layouts, etc.

3) Mathematical (Symbolic) Models - These are characterized by the fact that the components of the subject of inquiry and the interrelationships among them are represented by symbols, both mathematical and logical.

Of the model types listed above, only the symbolic models appear deserving of consideration in most water quality planning activities. The physical models are often useful in studying the physical characteristics of certain water bodies; however, in order to apply the model on new prototypes an entirely new model must be constructed. The construction of a useful physical water quality model for a single water body is very expensive. Also, its usefulness is quite limited. The analog models in the class of logical flowcharts are often useful for very general planning, but only in describing qualitative relationships. Electrical and mechanical analogue models are rarely useful in water quality problems.

2.3 TYPES OF MATHEMATICAL MODELS

No single general model exists that can simulate all aspects of water quality. Furthermore, it is not clear that such a model should be developed. Its resulting complexity, assuming that it could be created, the amount of data needed to validate it, and the cost of operation would likely make its use impractical. Instead, a wide variety of specialized models have been developed to efficiently handle particular aspects of water quality of interest to planners. From the planner's viewpoint, models can be classified by their applicability to various parts of a hydrologic system, the effects simulated by the model, and the method of analysis.

Applicability to Type of System

Models may be applicable to streams, estuaries, lakes, or impoundments. Some may be used to simulate more than one type of water body, e.g., the RECEIV portion of Storm Water Management Model is applicable to both rivers and estuaries.

Water Quality Constituents

Models can be classified according to the water quality constituents that they can simulate and also according to methods of their simulation. Models have been developed for the concentrations of various subsets of numerous conservative* and nonconservative* physical, chemical and biological substances such as temperature, dissolved oxygen, zinc, coliforms, etc.

Method of Analysis

This classification is a broad one and can be subdivided into several others according to the level of complexity and the method of approach:

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*Words with asterisks are defined in the glossary.

A. Static - Dynamic: Static models are used to evaluate steady-state conditions in which the values of the variables do not change with time. When some parameters are time varying or the effects of transient phenomena, such as storm runoff, must be evaluated, then dynamic models are used. Static models tend to be simpler and require less computational effort. Static solutions can be attained from dynamic models if the time horizon is sufficiently long so that steady-state conditions are achieved. However, this is generally an inefficient use of a dynamic model if only information about steady-state conditions is needed.

B. Spatial Dimensionality: Although real systems are three dimensional, sufficiently accurate results can quite often be obtained by modeling a system using only one or two dimensions. For example, one-dimensional models would often be adequate to describe the gross nature of water flows in river systems, most lakes or segments of lakes, and shallow, well-mixed estuaries through representation by a network of channels. Two-dimensional models would be appropriate for stratified estuaries, or for harbors and estuaries where one-dimensional representations too severely constrain the flow and transport directions.

C. Deterministic - Stochastic: Deterministic models are based on physical laws of classical physics, such as mass and momentum conservation, and on empirical formulas; they are frequently regarded as expected-mean-value models. Stochastic (or probabilistic) models take into account the randomness in many phenomena. Although stochastic models (which occur in tremendous variety, depending upon the assumptions about the physical processes and the type of mathematics used) may be a more realistic representation of physical processes such as diffusion, their validation in water quality modeling is difficult since excessive prototype data are necessary to establish the various probabilities. Most of the simulation models in use are deterministic.

Method of Computation

This type of classification separates the various techniques used for solving mathematical equations. These techniques range from hand computation and nomograph solutions to sophisticated computer simulation.

The principal advantages of hand calculation and nomograph solution techniques are that they are inexpensive to use for simple, non-extensive problems, and they offer a planner more opportunity to get a quantitative feeling of the system processes. The main disadvantage of this solution technique is that they are feasible when only a limited number of computations are needed. For applications involving thousands of computations, this approach becomes tedious, human errors often arise, and the project costs become large.

A basic argument for using computer simulation models is that they can yield simulation results for even complex planning problems quickly and accurately. The execution of the computations required for a water quality simulation may only take a few seconds or minutes and the corresponding machine time cost may be of the order of $5-200, depending on the specific program and the cost of computer time. The main objection to computer solutions is the high cost of model development and set-up needed before actual computation can be made.

Other classifications of simulation models could be made (e.g., size of computer memory required, computational methods, used, etc.) but these are generally of more interest to designers of models and system analysts than to planners.

2.4 USES OF MODELS

In addition to being responsible for preparing specific plans, the planner must also identify and analyze management alternatives and make recommendations on the basis of his experience and such technical analyses as he may be able to accomplish. Frequently these several tasks are subject to severe constraints of available time, personnel, and funds. A primary consideration should then be whether use of a model will assist him in water quality management planning.

Mathematical simulation models cannot provide answers to all questions related to water quality planning. Since the basis of the models is the mathematical representation of pertinent relationships between physical variables such as streamflow, temperature and concentration, the simulations can provide quantitative estimates of the quality effects due to changes in either the physical aspects of the hydrologic system or the waste loads discharged into the system. Although ingenuity in the use of models and interpretation of simulation results can provide the planner with additional insights into the behavior of a particular river system, caution should be exercised so as not to exceed the limitations imposed by the model's underlying assumptions. For example, the magnitude of the peak flow that can possibly occur in a particular river reach cannot generally be inferred from static analyses that estimate maximum steady-state flows.

The basic value of a simulation model lies in its use to study the behavior of real or proposed systems without the need for making observations on the physical system itself. Some important uses of models can be classified into the three broad categories of system simulation, prediction of performance, and model calibration.

Systems simulation is the most common use of models. Simulation of existing systems enables determining their behavior under a variety of conditions, aids in understanding of the interrelationships between elements of the system, and indicates the existence of possible trouble areas. The simulation can range from evaluation of simple steady-state stream flows to the dynamic behavior of flows, temperatures, and concentrations of many water quality constituents. Although occasionally observations on the actual system may be made for these purposes, this is often impossible because of inability to control certain natural phenomena.

Once verified, simulation models can be used to assess the effect on water quality of possible changes in the hydrologic system such as the addition of new waste loads or treatment plants or changes in the nature of effluents from such sources. This ability to simulate the performance of proposed or planned systems by using mathematical simulation models where no direct observation on the actual system would be possible enables the comparison of alternative plans for water quality management. The use of criteria such as water quality standards as a basis for evaluating the acceptability of various plans in conjunction with the models' capability to predict water quality levels resulting from alternative plans can provide the planner considerable insight into plan selection. Furthermore, it is often possible to infer from the simulation results the direction a plan should take to satisfy certain water quality criteria. For example, in trying to determine the optimum location of a treatment facility, a simulation model may make it readily apparent that the new plant could not improve the water quality to the desired extent regardless of its location, and that another approach should be taken.

Simulation models are also commonly used to achieve their own calibration on specific prototypes. Certain input-output prototype data are in this case used to obtain values for unknown model parameters or inputs. From these values, it is also possible to estimate the relative importance to water quality of modeled component processes and relationships in the corresponding prototype. An important use of this technique is in the estimation of non-point effluent sources, which are difficult to measure. In this case the data on prototype water quality are used in conjunction with the model to calibrate its non-point source inputs and thus estimate the non-point sources.

These several applications of computer simulation models make them useful tools for the technical analyses planners must make to obtain information about the performance of existing or proposed systems. Furthermore, the information obtained from the simulations can be used to evaluate and compare different water quality plans. However, it is again stressed that the simulations provide only useful information. The critical evaluation of that information remains the responsibility of the planner.

2.5 ADVANTAGES AND LIMITATIONS OF MODELS

Mathematical simulation models can be used in the planning process in a variety of ways as described in the previous section. Whether they should be used is a separate and important question. Unfortunately, there is no direct answer to this question that would apply to all or even most situations. Instead, the planner needs to carefully assess the requirements of each case and make this decision accordingly. This decision must take into account whether a suitable model is available or whether an existing model should be modified, or even whether a new one meeting specifications should be developed. Time constraints, data availability and data collection requirements all exert a strong influence on decisions to model and may differ widely from case to case. Detailed guidelines for consideration of these factors are presented in Chapter 4. However, by considering the advantages and the inherent limitations of computer models, some broad guidelines regarding the utilization of models can be suggested.

The basic advantage of using mathematical simulation models is their ability to give quantitative answers to complex planning problems, such as the cause-effect relationships of water pollution. Depending upon the solution technique used, these quantitative answers can be derived quickly and inexpensively. For example, the execution of the computer computations required for a water quality simulation generally takes no more than a few minutes, and incurs only nominal costs.

This is, however, only a portion of the time and cost necessary to carry out a successful simulation. It assumes, for example, that a suitable model is already operational, that the verification with actual data has been accomplished, and that all data needed to carry out the simulation are available in the prescribed format and ready for use. The validity of these assumptions and their implications regarding costs are discussed below.

Model Availability

A wide variety of operational water quality models are already available. In addition, new and more accurate models are being developed and existing ones are being extended to include the behavior of more water quality constituents. As the library of mathematical models becomes larger, the assumption that an appropriate model is available becomes more valid. The use of existing models eliminates the costs of developing new ones or modifying the existing ones, provided, of course, that the existing models can yield the required information. It is also conceivable that as planners are asked in the future to produce even more detailed plans and to consider more alternatives, water quality models will have to be constantly expanded and made more accurate.

Data Availability

A major consideration in the use of any model is the type, amount, and accuracy of data needed to carry out reliable simulation experiments. Data are needed for calibration and verification of the model, as well as for the simulation experiments (application).

Model calibration is considered to be a separate activity from model verification. Calibration is performed using one or more synchronous data sets on model inputs (effluents, stream flow, etc.) and outputs (stream quality) to adjust and tune the model itself (see Figure 2.1). Verification is performed using an independent set of input and output data to test the calibrated model. Verification can occur only when the data set used is independent of that used for calibration. Preferably, the conditions for verification should differ from those used for calibration. One verifies a calibrated model by comparing model predictions for a given input condition with the corresponding field data.

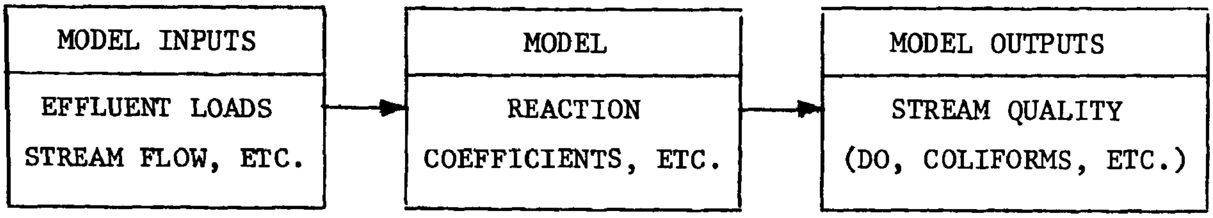

FIGURE 2.1 MODEL RELATIONSHIP WITH INPUTS AND OUTPUTS

The collection of the field data for calibration and verification or the assembly of historical data may be a costly and time consuming procedure. For the application of a model to a particular system, the model normally need only be verified a single time. Once this is accomplished, repeated simulations may be carried out at a relatively small extra cost. Once a verified model is available, data describing the state of the system are necessary in order to carry out simulation experiments. Sometimes these data are available directly, or can be extracted from existing data that are expressed in different form. Sometimes they have to be inferred from past data or determined from observations of the prototype, with or without operational experiments. Since operational experiments are costly and for water systems often impossible to perform, much of the experimentation and data collection has to be done indirectly at considerable cost and effort. This is especially true when the performance of planned systems is to be predicted.

Model Complexity and Accuracy

The more complex and detailed a model is, the more data it can use to describe the system and the state of the quality constituents. However, since data collection and reduction is time consuming and costly, the planner must carefully evaluate the tradeoff between the level of detail provided by a particular model and the cost of the data necessary to fully use its capabilities. Increased complexity may also have an adverse effect on the efficiency of the computational techniques used in the simulation and may thus increase the cost of model operation. The introduction of additional detail does not necessarily increase the accuracy of the simulation. Although increased accuracy does usually imply increased complexity, the reverse is not true and a common fallacy is to mistake complexity for accuracy. The accuracy of the simulation results depends on the accuracy of the model, the accuracy of the values of the model parameters determined during the calibration process, and the accuracy of the input data. One of the common pitfalls in using mathematical simulation models is to attribute much greater accuracy to the simulation results than is warranted by the data used to evaluate the model parameters and verify the model. Such over-reliance on the simulation results may be counter-productive and lead to misinterpretation of the data. A final consideration is the tradeoff between accuracy and time. A plan based on simulations that yielded results within known error bounds but available in time for use in decision making may be far more preferable than one based on a highly accurate or complex model but not available until a later time.

In spite of their limitations, computer simulation models have certain distinct advantages over hand calculation approaches. The use of nomographs and hand calculations is limited to relatively simple problems because more complicated ones would require an excessive amount of time. Furthermore, these methods are not conducive to the study of a large number of alternatives because the analysis of each alternative would require an approximately equal effort. The use of computer simulation models, on the other hand, is characterized by an extensive effort necessary for carrying out the first simulation while only marginal effort, usually changing a few input values, is needed to carry out all other simulations. Therefore, numerous alternative plans can be evaluated quickly and at low cost. The actual cost of machine time is sufficiently low that this feature occurs whether the problem is complex and requires extensive computation or is relatively simple. This ease with which alternative plans can be prepared, or "what-if" questions can be answered, is one of the strongest arguments for investing time and effort to develop or adapt, verify, and use computer simulation models.

The decision to use a computer simulation model is not the only alternative to the use of simple nomographs or other techniques designed for hand computation. The strengths and advantages of the computer can be used in a wide range of activities between these extremes. The repetitious solution of even simple equations can warrant consideration of computerization. In those cases where emphasis is to be placed on developing a continuing planning process for further use, even these more limited models may have great value.

2.6 CONCLUSIONS

Mathematical simulation based on equations of physical processes is a relatively new tool that has become available to the water quality planner. Its usefulness depends on his ability to obtain sufficient data that can be used to calibrate and verify the model and carry out the desired simulation experiments. The planner may have to decide whether an existing model would be appropriate or whether a new one should be developed. He should estimate the cost and effort associated with the use of computer models, make comparisons with all other suitable methods of approach, and take into account the quality and extent of information he can obtain from alternative approaches. If he determines that a model should be used, then his task is to determine which model is most appropriate for his planning problem. Although the use of computer simulations requires a highly organized approach to planning, it enables the study of a range of alternatives that might otherwise be beyond the scope of study by other methods due to cost.

While no clear-cut rule can be formulated regarding the use of simulation models as planning tools, a few simple guidelines can be stated on the basis of the analysis presented so far in this manual. The guidelines should not be interpreted as strict rules, but rather as broad statements that are meant to serve as reminders. Their validity as guidelines will probably be demonstrated by the frequency with which they are violated. The list is left open ended; additions, deletions, or modifications will be necessary as experience is gained in the use of models for planning.

1. The first step is to define the problem and determine both what information is needed and what questions need to be answered.

2. Use the simplest method that can provide the answers to your questions.

3. Use the simplest model that will yield adequate accuracy.

4. Do not try to fit the problem to a model, but select a model that fits the problem.

5. Do not confuse complexity with accuracy.

6. Always question whether increased accuracy is worth the increased effort and cost.

7. Do not forget the assumptions underlying the model used, and do not read more significance into the simulation results than is actually there.

The following two chapters provide more detailed discussions on whether to use a mathematical model, how to evaluate existing water quality models, and how to select a model for specific planning applications.

CHAPTER 3

EVALUATION AND COMPARISON OF MODELS

3.1 INTRODUCTION

This chapter demonstrates a systematic way of evaluating water quality models. The evaluation procedure consists of answering many specific questions about them; the questions, and their answers, have been organized for convenience into tabular form (Tables 3.1 through 3.14) within this chapter. The tables represent the condensation of large quantities of descriptive text, enabling far more rapid information retrieval, and greatly facilitating the comparison of different models.

This method of evaluation has been used directly in the procedures developed for model cost-effectiveness analysis and for final model selection (see Chapter 4). In some areas of evaluation, the answers are quite general and dependent upon the application. These areas must be looked into carefully, but only used for evaluation on a relative scale.

The 14 models described in this handbook are all useful for the prediction of water quality and provide a wide range of capability and applicability. They seem to represent a large portion of the models expected to be in use in the near future. This does not imply that another model, not described here, might not be preferable in a particular case. Other models, not selected for evaluation here, are discussed in Section 3.4 below. In the event models not included here are considered, the user is advised to consider them carefully in the light of the evaluation procedure presented in this chapter.

3.2 GENERAL DESCRIPTION OF SELECTED MODELS

The models selected for evaluation in this handbook are all deterministic simulation models of varying complexity. Their names and the six groups they have been arranged into, in accordance with their areas of applicability, are:

Group I	Steady-state Stream Models	
		DOSAG-I SNOSCI Simplified Stream Models (SSM)
Group II	Steady-state Estuary Models	
		ES001 Simplified Estuary Models (SEM)
Group III	Quasi-dynamic Stream Models	
		QUAL-I QUAL-II
Group IV	Dynamic Estuary and Stream Models	
		Dynamic Estuary Model (DEM) Tidal Temperature Model (TTM) RECEIV SRMSCI
Group V	Dynamic Lake Models	
		Deep Reservoir Model (DRM) LAKSCI
Group VI	Near-field Models	
		Outfall PLUME

The choice of these six groupings is governed by the model characteristics summarized in Columns 1-3 of Table 3.1.

The models used to simulate only stream conditions are least complex due to the one-dimensional characteristic of flow. Models for simulating stratified lakes and reservoirs fall next in line of complexity, followed by estuarine models. Estuary models are more complex because the prototype flow is usually in at least two dimensions, and the boundary conditions, such as tides, vary rapidly compared with those in lakes. The costs of model application tend to be proportional to their complexity.

With regard to the time domain, the models may be divided into the following three major categories: dynamic, dynamic-equilibrium, and steady-state.

In the dynamic models, both the major inputs (drivers) and the outputs (solution) may vary freely with time. In dynamic-equilibrium models they may vary only in a cyclically repetitious manner. In steady-state models they are unchanging with time. The dynamic models are generally the most expensive to implement, and the steady-state models are the least expensive. These relative costs are due to the cost of data acquisition and manipulation, as well as programmer/analyst and computer costs to run the models.

An intermediate time category of models (Group III of Tables 3.1-3.14) have been named "quasi-dynamic," since only their weather (meteorological) inputs may be dynamic. These directly affect water temperature and algae, and indirectly affect most other constituents. The resulting solutions have steady-state hydraulics, but dynamic water quality.

With regard to the space domain, the models summarized here fall into three categories. The outfall PLUME model is the only member of the near-field category, in which very localized effects are simulated. The one-dimensional far-field category includes the stream, simplified estuary, and deep* lake models; in the case of these lake models, the one dimension is vertical, since the lake is simulated as a series of horizontal layers. The quasi-two-dimensional far-field category consists of the dynamic estuary models (Group IV of Tables 3.1-3.14), in which two horizontal dimensions are simulated by a branched network or system of one-dimensional flow paths.

Two of these model categories (Groups IV and V) differ from the rest in their structure. The dynamic estuary, stream, and lake models are composed of definitely separated quantity and quality submodels. The quantity submodels first solve for the hydrodynamics (velocities, water surface elevations, etc). These solutions are then provided as inputs to the quality submodels, which use the then known hydrodynamics to solve for the movements of and changes in the quality constituents. One variation

*For definition see Ref. 23, page 16.

upon this theme is that the lake models must include the temperature solution in the quantity submodel, since temperature is the principal cause of the stratification which governs a lake's behavior.

It should be noted that none of the models evaluated here are applicable to frozen conditions.

The documentation corresponding to most of the models listed is, or soon will be, available to the public through government agencies. A very nominal fee is usually charged for such documentation. At present some of this documentation probably does not give adequate directions to potential users (see Table 3.11). In such cases it is necessary to secure the aid of experienced experts familiar with those models to help initiate the model implementation. In any case, depending upon the circumstances, the use of specialized and knowledgeable assistance could greatly improve the efficiency of modeling efforts.

The following sections review the origins of the selected models, and briefly compare them within each of the six groups.

Steady-state Stream Models (Group I)

The three models evaluated in this category are DOSAG-I, SNOSCI, and the Simplified Stream Model.

DOSAG-I is a computer program which uses the classical Streeter-Phelps dissolved oxygen sag equation to simulate BOD and DO variations. It was prepared by the Texas Water Development Board [1]* by improving a basic code originally developed, and provided to them, by the Federal Water Pollution Control Administration (subsequently the E.P.A. Water Quality Office). It is particularly useful for the rapid evaluation of a number of varying stream conditions.

*Numbers in square brackets [ ] refer to the References listed in the back of this handbook.

SNOSCI is a modification of DOSAG-I, prepared by Systems Control, Inc., and first applied to the rivers of the Snohomish and Stillaguamish River basins in Washington [2, 3]. The principal modification was the added capability to simulate many more water quality constituents than just BOD and DO (see Table 3.2).

The Simplified Stream Model (SSM) refers to those portions of the Simplified Mathematical Modeling Methodology which pertain to non-tidal streams; it was developed by Hydroscience, Inc. [4, 5] for the E.P.A. Water Programs Office. Once the prospective user is familiar with the User Guide and the simplifying assumptions made in their development, the various tables, charts, nomographs, figures and technical data incorporated in the Simplified Mathematical Models may be used to analyze water quality and to estimate treatment levels needed to meet specific receiving water quality standards. Normally only hand calculations, with the help of a slide rule or possibly a technical desk calculator, are required; no computer programs are included.

The Simplified Mathematical Models (SSM and SEM) are intended to assist and facilitate only interim planning, and should be used with discretion. Complex river systems or complex water quality problems, such as eutrophication, are not covered by the simplified analysis.

<u>Steady-state Estuary Models (Group II)</u>

The two models evaluated in this category are ES001 and the Simplified Estuary Model. Since the behavior of estuaries is clearly not steady state, but more cyclical due to the dominating influence of tides, these models simulate only the net flow or tidally averaged effects. They do simulate, however, longitudinal dispersion, which is generally negligible in streams.

ES001 is a computer model which simulates BOD and DO variations. It was prepared by the EPA [6, 7] to improve upon and document some water quality models previously developed for them by Hydroscience, Inc. [8]. It is particularly useful for the rapid evaluation of a number of varying estuary and wasteload conditions.

The Simplified Estuary Model (SEM) refers to those portions of the Simplified Mathematical Modeling Methodology [4, 5] which pertain to estuaries and tidal rivers; it has the same features, purposes, and provisos as mentioned above for the SSM.

Quasi-dynamic Stream Models (Group III)

The two models evaluated in this category are QUAL-I and QUAL-II. They are both computer programs.

QUAL-I was developed during September 1969 - September 1970 by W. A. White, R. J. Brandes, and Dr. F. D. Masch, in collaboration with the Texas Water Development Board [9, 10]. It is more accurate and provides a more precise definition of the stream conditions than does DOSAG-I described above (in Group I). QUAL-I is designed to simulate the spatial and temporal variations in water temperature and conservative mineral concentration as well as BOD/DO, and is thus a more flexible model. These added features are obtained with a substantial increase in computational time. The two programs are designed to be used as complements to each other. DOSAG-I can provide the user with a rapid evaluation of a number of alternative conditions, whereas QUAL-I permits a more detailed analysis of the meteorologically-affected physical phenomena in the stream system.

QUAL-II is a modification of QUAL-I, prepared by Water Resources Engineers, Inc., during June 1972 - May 1973 for the EPA Systems Development Branch [11], and first applied to rivers of the Chattahoochee-Flint, Upper Mississippi, Iowa and Cedar, and Santee River Basins. The principal modification was the added capability to simulate eight more water quality constituents (see Table 3.2).

Dynamic Estuary and Stream Models (Group IV)

The four models evaluated in this category are the Dynamic Estuary Model (DEM), the Tidal Temperature Model (TTM), RECEIV and SRMSCI.

The DEM was originally developed by Water Resources Engineers, Inc. (WRE) for the Public Health Service, Division of Water Supply and Pollution Control [12], and was then developed further for the FWPCA [13] and for the State of California [14]. The FWQA completed its development and refinements for use in studies of the San Francisco Bay-Delta estuary and the San Diego Bay, resulting in the FWQA version of the DEM [15] evaluated here.

The TTM [16, 17], also known as the Columbia River estuary model, was developed by the Pacific Northwest Water Laboratory of the FWPCA by incorporating meteorological inputs and dynamic water temperature simulation into a similar WRE version as that used to develop the DEM.

RECEIV is the name of the receiving water module of the Storm Water Management Model [18] developed by Metcalf & Eddy, Water Resources Engineers, and the University of Florida during 1969-1970. RECEIV was developed, principally by WRE, by incorporating into a previous dynamic equilibrium model the capability to simulate the transient behavior (toward a dynamic equilibrium) and associated problems caused by dynamic storm water inflows.

SRMSCI is a modification of RECEIV, prepared by Systems Control, Inc., and first applied to the Snohomish and Stillaguamish River estuaries of Washington [2, 3]. The principal modification was the added capability to simulate many more water quality constituents (see Table 3.2).

None of these four models are applicable to a strongly stratified estuary. This should be kept in mind when modeling an estuary, since it is a common occurrence for an estuary to be effectively mixed during the low flow period of the year and stratified into two distinct layers during the high flow period of the year. The principal factors contributing to mixing are: low river flow, high tidal velocity, large estuary width, and shallow estuary depth. Several good general descriptions of estuarine modeling techniques and problems are available [19, 20, 21]. It is recommended that the user of any estuarine model familiarize himself at least briefly with the general concepts involved before making any decisions.

While all the estuary models may be used to simulate streams, the steeper the stream the less appropriate and convenient they become (see, for example, Ref. 27, p. 26).

All these four estuary models utilize a chosen tidal cycle which repeats itself, resulting in a quantity (hydrodynamic) solution which also repeats itself every tidal period (dynamic equilibrium). The DEM and TTM are truly dynamic equilibrium models, since they accept only steady-state wasteload inputs. However, RECEIV and SRMSCI have been categorized as dynamic models, since they accept transient inputs, such as dynamic (non-steady and non-cyclic) storm water inflow (quantity and quality), resulting in a dynamic, transient solution which tends back to the pre-storm dynamic equilibrium.

Another difference between these estuary models is that only RECEIV and SRMSCI can simulate tidal flats, i.e., areas which go dry at low tide. DEM and TTM represent the water surface area as remaining constant, which may not be very appropriate for some estuaries which have extensive tidal flats.

Differences of simulation method and convenience at the seaward boundary of the estuary models are that constituent concentrations in incoming tides must be specified for DEM and TTM, while RECEIV and SRMSCI compute them from a specified ocean exchange or transfer coefficient. This governs the fractions of the departing constituents which return, after dilution and decay in the adjacent ocean. These alternative boundary conditions must be specified at only one seaward boundary location for DEM, TTM, and RECEIV. For SRMSCI, they may be specified differently at two locations, which is convenient for a branched estuary with sloughs.

Dynamic Lake Models (Group V)

The two models evaluated in this category are the Deep Reservoir Model (DRM) and LAKSCI.

The Dworshak Reservoir version [22] of the DRM was selected for evaluation because it was determined to contain improvements over the original version, and yet was not as site-specific as subsequent versions. It simulates the thermal behavior of deep, or strongly stratified [23, p. 16], impoundments.

A weakly stratified version of the same impoundment model [23, 24] was not evaluated since it has been far more difficult to apply and verify on account of the far greater amounts of data it needs.

DRM was first developed by WRE in 1967 for the California Department of Fish and Game [25]. WRE added considerable detail and refinement in 1968-1969, for the EPA Water Quality Office [23, 24]. They prepared the Dworshak Reservoir version [22] by September 1969 for the Walla Walla District Office of the Army Corps of Engineers.

LAKSCI is a modification of the DRM, prepared by Systems Control, Inc., during 1973-1974 for the EPA [26, 27]. It was developed for and first applied to two lakes of the Spokane River Basin in Washington and Idaho. The principal modification was the addition of a capability to simulate many more water quality constituents than just water temperature.

Near-Field Models (Group VI)

The only model evaluated in this category is the Outfall PLUME model [28], developed in 1971 by the Pacific Northwest Laboratory of the EPA, Region X. It is based on earlier ocean outfall design development work by the FWPCA [29], and it solves for the geometric and dynamic behavior of a buoyant round plume of sewage or industrial waste issuing from a port into stagnant, density-stratified surroundings.

3.3 DETAILED MODEL EVALUATION

The model evaluation tables have been categorized according to their purposes and contents as shown in Table 3.0.

TABLE 3.0 MODEL EVALUATION CATEGORIES

SUBJECT	TABLE
MODEL CAPABILITIES	
Applicable Situations	3.1
Constituents Modeled	3.2
Model Factors Accounted For	3.3
DATA REQUIRED	
For Model Inputs	3.4
Additional, for Calibration and Verification	3.5
MODEL COSTS	
Initiation Costs	3.6
Utilization Costs	3.7
MODEL ACCURACY	
Representation	3.8
Numerical Accuracy	3.9
Sensitivity to Input Errors	3.10
EASE OF APPLICATION	
Sufficiency of Available Documentation	3.11
Output Form and Content	3.12
Updateability of Data Decks	3.13
Modification of Source Decks	3.14

The evaluation scheme and the detailed evaluation of the selected models is provided in Tables 3.1-3.14. The answers provided in these tables are organized into a column for each question. The columns are numbered for the convenience of reference in Chapter 4, where their contents are used in the model selection procedure.

The following explanations of the contents of these tables are organized into numbered Notes, for convenience of reference in the tables. The numerical portion of the note number identifies the table of concern, and the alphabetical portion sequences the notes pertaining to that table. Terms have not generally been defined in these notes; definitions of terms are provided in the Glossary and the Abbreviations, at the end of this handbook.

Note 3.1.A: Distributed Loads

While the documentation for the Simplified Stream and Estuary Models [4,5] describes applications to point sources only, the technique may frequently be extended to uniformly distributed loads, such as the average effects of photosynthesis, respiration, benthal oxygen demand, and nutrients released from decaying organic materials on the bottom. Such an extended technique is discussed in the ES001 documentation [6, p.27].

Note 3.1.B: Discretization

For the purposes of simulation by computer models, the area to be simulated must be broken up into a number of discrete elements. The means of this division, and the naming of these elements, varies from model to model. As a result, the same names are sometimes given to different types of elements in different models, and vice versa. Here the element names given in the original documentation (see Table 3.11) are used.

The steady-state and quasi-dynamic stream models (Groups I and III) are representated by branched, one-dimensional networks. These are quite similar in nature, no doubt on account of the similarity in their origins. The streams are divided up into series of "reaches", each having fairly

TABLE 3.1 MODEL SUMMARY: MODEL CAPABILITIES, APPLICABLE SITUATIONS

	MODEL	WATER BODY TYPES(S) (Column 1)	WATER BODY CHARACTERISTICS (Column 2)	TIME VARIABILITY (Column 3)	DISCRETIZATION LIMITATIONS[1] (Column 4)	SPECIAL FEATURES AND/OR LIMITATIONS (Column 5)
I	DOSAG-I	Stream.[2]	Far field, i.e., only longitudinal variations.	Steady state.[3]	≤10 headwaters, ≤20 stretches, ≤20 junctions, ≤50 reaches.	Flow augmentation option. Both point and distributed non-point sources.
	SNOSCI	Stream.[2]	"	Steady state.	As above, but ≤99 reaches.	As above, plus power plant option for excess temperature.
	Simplified Stream (SSM)	Stream.[2]	"	Steady state.	None.	Point sources only.[4]
II	ES001	Estuary.[5]	Best for narrow tidal rivers. Far field.	Steady state.	≤ 100 junctions, ≤ 50 to 100 sections, section length < 20 miles.	Net velocity <1 fps. Dispersion coeff. 1-20 mi^2/day. Pt. & uniformly distributed loads. Incl. effects of dams.
	Simplified Estuary (SEM)	Estuary.[5]	"	Steady state.	None.	Point sources only.[4]
III	QUAL-I	Stream.[2]	Far field, i.e., only longitudinal variations.	Steady state, except weather inputs can be dynamic.[3]	≤ 25 reaches, ≤ 25 point discharges or withdrawals, ≤ 5 headwaters, ≤ 5 junctions.	Flow augmentation option. Point sources only.[6]
	QUAL-II	Stream.[2]	"	"	≤ 75 reaches, ≤ 90 point discharges or withdrawals, ≤ 15 headwaters, ≤ 15 junctions.	"
IV	Dynamic Estuary (DEM)	Stream[2] or estuary.[5]	Non-steep streams. Far field. Single recurring tidal cycle. Best for channelized waters.	Dynamic equilibrium.[3]	≤1300 channels, <840 junctions.	Does not handle tidal flats, i.e., areas which go dry at low tide. Constant wasteloads.
	Tidal Temperature (TTM)	Stream[2] or estuary.[5]	"	Dynamic equilibrium with dynamic weather.	≤300 channels, ≤300 junctions.	"
	RECEIV	Stream[2] or estuary.[5]	"	Dynamic.[3]	≤225 channels, ≤100 junctions.	Handles tidal flats. Wasteloads may be dynamic.
	SRMSCI	Stream[2] or estuary.[5]	"	Dynamic.	"	"
V	Deep Reservoir (DRM)	Lake or reservoir.	Deep, strongly stratified lakes.[7] Far field.	Dynamic.	≤200 layers, ≤365 days.	1, 2 or 3 outlets. 0 or 1 tributary inflow. See footnote 8.
	LAKSCI	Lake or reservoir.	"	Dynamic.	≤100 layers, ≤365 days.	As above, except footnote 8.[9]
VI	Outfall PLUME	Lake, ocean or estuary.	Includes stratification. Very near field.	Steady state.	≤50 layers.	Receiving water assumed at rest. Only solves for initial dilution of effluent.

1. Terms used in Discretization Limitations are not always consistent, but correspond to those used in the respective documentation (see Table 3.11, and Note 3.1.B in Section 3.3).
2. Stream models can simulate shallow, well mixed impoundments.
3. The meanings of these time variability terms are discussed in Section 3.2; also see the Glossary.
4. Technique may frequently be extended to uniformly distributed loads (see Ref. 6, p. 27, and Note 3.1.A in Section 3.3).
5. Only non-stratified estuaries; includes tidal rivers. Better for channelized basins.
6. Non-point sources may be simulated as a number of point sources, but the constraint on the total number of point sources in the model limits this capability.
7. See Ref. 23, p. 16 for definitions.
8. May conveniently repeat simulations when meteorological inputs are unchanged.
9. The repeat capability (see Footnote 8) could easily be restored (add tape read for restart, only) by a programmer.

TABLE 3.2 MODEL SUMMARY: MODEL CAPABILITIES, CONSTITUENTS MODELED

	MODEL	ORIGINAL MODEL (Column 1)	POSSIBLE, WITH MINOR MODIFICATIONS[1] (Column 2)
I	DOSAG-I	DO, BOD (carbonaceous and nitrogenous).	———
	SNOSCI	DO, BOD, T. coli, F. coli, algae, NH_3, NO_2, NO_3, OPO_4, Cu, Pb, temperature excess, four conservatives.[2]	Any 4 conservatives,[2] and any 4 non-conservatives[2] with first order[3] decay.
	Simplified Stream (SSM)	Conservatives,[2] singular non-conservatives[2] with first order[3] decay (coli, BOD, nutrients), coupled[4] BOD-DO deficit.	———
II	ES001	BOD, coupled BOD-DO deficit; both as non-conservatives with first order kinetics.[3] Uniform BOD/DO loads and demands of algae and benthos.	Conservatives; any non-conservatives or coupled[4] non-conservatives with first order kinetics.
	Simplified Estuary (SEM)	Conservatives, singular non-conservatives with first order decay (coli, BOD, nutrients), coupled with BOD-DO deficit.	———
III	QUAL-I	BOD, DO, temperature and any 3 conservative constituents.	(See Column 1)
	QUAL-II	BOD, DO, temperature, NH_3, NO_3, NO_2, algae, phosphorus, benthic demand, coliforms, radioactive materials, 3 conservative constituents.	(See Column 1)
IV	Dynamic Estuary (DEM)	Up to 5 constituents with the following properties: 1) any can be conservative 2) any can have 1st order decay 3) any can be linked[4] to one other[5]	(See Column 1)
	Tidal Temperature (TTM)	As above, with added feature that one of the constituents can be water temperature.	(See Column 1)
	RECEIV	Any six constituents including DO, BOD, conservative constituents, and non-conservative with 1st order decay. All constituents must be in concentration units of mg/L.	(See Column 1)
	SRMSCI	Excess temperature, DO, BOD, T. coli, fecal coli, NH_3, NO_2, NO_3, OPO_4, Cu, Pb, and two conservatives.	Any 2 singular[4] non-conservatives with 1st order decay, or 2 more conservatives, in place of Cu and Pb.
V	Deep Reservoir (DRM)	Temperature.	———
	LAKSCI	The following interlinked non-conservatives: Carbonaceous BOD, coliforms, and three heavy metals with first order kinetics; DO, algae, temperature; NH_3, NO_2, NO_3, and PO_4 with first or second order kinetics. Also total N, chlorides, and three heavy metal ions as conservatives.	Other conservatives, and non-conservatives with first order kinetics.
VI	Outfall PLUME	Conservative substances only.	(See Column 1)

1. Change of format statement listing constituent names. See also Note 3.2.D of Section 3.3.
2. See Note 3.2.A of Section 3.3, regarding mass conservation.
3. See Note 3.2.C of Section 3.3, regarding reaction kinetics.
4. See Note 3.2.B of Section 3.3, regarding constituent linkages.
5. Linkage requires special attention.

TABLE 3.3 MODEL SUMMARY: MODEL FACTORS ACCOUNTED FOR

	MODEL	PRINCIPAL DRIVING FORCE(S) (Column 1)	BOUNDARY FACTORS (Column 2)	INTERNAL PROCESSES SIMULATED	
				PHYSICAL (Column 3)	DECAY AND/OR GROWTH (Column 4)
I	DOSAG-I	Net flows.	Upstream rivers, point and non-point waste loads.	Dilution, advection.	1st order decay, BOD-DO coupling, reaeration. Temperature effects.[1]
	SNOSCI	Net flows.	"	"	1st and 2nd order decay, reaeration. Linking of many constituents. Temp. effects. Benthal releases & demands.
	Simplified Stream (SSM)	Net velocity and flow.	River inflows, single or multiple point wasteload(s).	"	1st order decay, BOD-DO coupling, reaeration, temperature effects.
II	ES001	Net flows.	River inflows, point and non-point waste loads. Effects of completely mixed bays.	Dilution, advection, longitudinal dispersion.	As above, plus demands and releases of algae and benthos.
	Simplified Estuary (SEM)	Net velocity and flow.	Point inflows, single or multiple point wasteload(s).	"	First order decay, BOD-DO coupling, reaeration. Temperature effects.
III	QUAL-I	Net flows.	Upstream rivers and tributaries, point wasteloads, bottom friction, weather.	Dilution, advection.	BOD 1st order decay. BOD-DO coupling, reaeration. Temperature effects.
	QUAL-II	Net flows.	"	"	Numerous algae-nutrient interactions, BOD-DO coupling, 1st order decay, reaeration, temp. effects.
IV	Dynamic Estuary (DEM)	Tides, net river flow.	Tides, constant upstream river flows and concentrations. Constant wasteloads, bottom friction, transient seaward bound flow and concentration.	Dilution, advection, eddy diffusion.	1st order decay, BOD-DO coupling, reaeration for DO.
	Tidal Temperature (TTM)	As above, plus weather.	As above, plus heat exchange at surface.	"	"
	RECEIV	Tides, net river flow	Tides, constant or dynamic upstream flows and concentrations. Constant or dynamic effluent wasteloads, bottom friction. Seaward bound flow and concentration.[2] Wind stress and rain.	Dilution, advection.	"
	SRMSCI	"		"	As above, plus 2nd order decay, nutrient-algae cycle, and temperature effects.
V	Deep Reservoir (DRM)	Net heat exchange, flows.	Inflow rates and temperatures, outlet positions and outflow rates, weather (meteorology).	Advection, diffusion, heat budget.	———
	LAKSCI	"	Inflow rates and quality, outlet positions and outflow rates, weather (meteorology).	"	1st and 2nd order decay, reaeration; linking of many constituents; temperature effects; benthal releases and demands.
VI	Outfall PLUME	Discharge momentum, water densities.	Water surface position, plume discharge.	Dilution, turbulent mixing, density.	———

1. See Note 3.3.A of Section 3.3 regarding temperature effects.
2. Both the RECEIV and SRMSCI models compute the concentrations on incoming tides using a prescribed seaward exchange coefficient, and considering dilution processes outside the boundary. RECEIV models the seaward boundary concentrations as a constant value over the incoming tide. SRMSCI, more realistically, computes a variable concentration on incoming tides.

TABLE 3.4 MODEL SUMMARY: DATA REQUIRED, FOR MODEL INPUTS[1]

	MODEL	HYDROLOGIC (Column 1)	HYDRODYNAMIC[2] (INCLUDING GEOMETRY[3]) (Column 2)	WATER QUALITY (Column 3)	EFFLUENT (Column 4)	DECAY RATES (Column 5)	OTHER (Column 6)
I	DOSAG-I	Headwater flows, tributary and discharge flows, withdrawal flows, groundwater flows (all constant).	Reach lengths.	Constituent concentration (constant) at headwaters and tributaries; water temperature.	Flow rates and constituent concentrations.	Reaeration and two deoxygenation coefficients, temperature correction factors.	Treatment factors.
	SNOSCI	"	Reach lengths.	"	As above, plus cooling water temperature rise.	Rate coefficients, temperature correction factors.	Treatment factors.
	Simplified Stream (SSM)	Net river flow.	Depths, velocities; distance from outfalls.	As above, plus background DO deficit.	UOD loading rate.[4]	Deoxygenation coefficients.	———
II	ES001	Net river flow* (constant), flow over dam*	Csa's[5]; lengths; water depth; bay volume*	As above plus bottom oxygen demand,* dispersion coeff., algal photosynthesis and respiration.*	Uniform waste input*; point waste input.*	Rate coefficients, temperature correction factors.	Tidal exchange coefficient;[6]* salinities at boundaries*
	Simplified Estuary (SEM)	Net non-tidal flow.	Average water depths, csa's, velocities.	As SSM, plus dispersion coefficient.	UOD loading rate.[4]	Reaeration and deoxygenation coefficients.	Salinities at boundaries*
III	QUAL-I	Headwater flows, tributary flows, withdrawal flows, groundwater flows, (all constant).	Depths and widths, bottom roughness (Manning's n) all throughout stream.	Constituent concentration (constant) at headwaters and tributaries.	Constant flow and concentrations.	BOD decay rate.	Weather, lat-long of basin, day of year, evaporation coefficients.
	QUAL-II	"	"	"	"	Numerous parameter decay rates and settling coefficients.	"
IV	Dynamic Estuary (DEM)	As above, plus (if in estuary) the seaward tides.	Channel depths and widths, bottom roughness, initial velocities.	Constituent concentrations of tributary/river inputs (constant). Varying constituent conc. at tidal bound. Initial conc. throughout modeled area.	"	First order decay rates or all non-conservative constituents.	———
	Tidal Temperature (TTM)	"	"	"	"	"	Weather at specified intervals inc. net radiation, wet & dry bulb temperature and atmospheric pressure.
	RECEIV	Constant headwater flows; constant or dynamic tributary and effluent discharge flows; constant groundwater flows; seaward tides in estuary.	"	Constant or dynamic constituent wasteloads from tributaries & headwaters, seaward exchange coef.	Constant or dynamic constituent loads from effluents.	"	Seaward exchange coefficient.[6] Windspeed and rain.
	SRMSCI		"	"	"	1st and/or 2nd order decay rates.	"
V	Deep Reservoir (DRM)	Inflow and outflow rates; evaporation coefficients.	Reservoir length, depth/area relation, outlet elevations; dam width(s). Initial and maximum water surface elevations.	Daily inflow temperatures; initial temperature conditions; extinction depth; diffusion parameters.	———	None.	Simulation dates; reservoir elevation, latitude and longitude; dry bulb air temperature; wet bulb or dew point temperature; short wave solar radiation; sky cover; atmospheric pressure; wind speed.
	LAKSCI	"	"	Ditto, plus initial and daily inflow constituent concentrations.	———	Reaeration, decay and settling rate coefficients; temperature correction factors.	
IV	Outfall PLUME	None.	Ambient water temperatures and salinities or densities at various depths.	None.	Port diameter, density of effluent, effluent flow.	None.	Number of discharge points, their diameters, angle from horizontal and depth.

1. All measurements must be for selected "simulation periods."
2. Channel bed conditions (Groups I-IV) may be used as a guide in selecting benthal oxidation and reaeration coefficients [Ref. 4, p. 62].
3. Data defined by the user in the discretization processes (such as reach and channel lengths and connection schemes) are not included here.
4. This may be obtained from charts, knowing the design population and the level of treatment.
5. Cross-sectional area.
6. See Note 3.4.a of Section 3.3 regarding seaward exchange coefficient.
* Optional, depending upon application.

TABLE 3.5 MODEL SUMMARY: ADDITIONAL DATA REQUIRED, FOR CALIBRATION AND VERIFICATION

MODEL		HYDROLOGIC	HYDRODYNAMIC	WATER QUALITY (Column 3)	OTHER (Column 4)
I	DOSAG-I	Streamflows within modeled area.	Stream velocities within modeled area.	Constituent concentrations within modeled area.	———
	SNOSCI	"	"	"	———
	Simplified Stream (SSM)	———	———	"	———
II	ES001	———	———	"	Salinity concentration distribution.
	Simplified Estuary (SEM)	———	———	"	"
III	QUAL-I	Streamflows within modeled area.	Stream velocities within modeled area.	"	———
	QUAL-II	"	"	"	———
IV	Dynamic Estuary (DEM)	Net flows in channels of the modeled area.	"	"	Salinity or dye data[2] for calibration of seaward boundary concentration inputs.
	Tidal Temperature (TTM)	"	"	"	"
	RECEIV	"	"	"	"
	SRMSCI	"	"	"	"
V	Deep Reservoir (DRM)	Water surface elevation history.	———	Time-varying temperature profiles and outflow temperatures.	———
	LAKSCI	"	———	Time variations of constituent concentrations, including temperature, in the lake profile and in the outflows.	———
VI	Outfall PLUME	———	———	Conservative constituent concentration within initial plume.	———

1. All these measurements, required to assess the accuracy of the model outputs, must be taken during "simulation periods" (at least two different periods, representative of different flow regimes). See Note 3.5.A of Section 3.3.
2. Because of their conservative nature, salt and dye are often used as control constituents for the determination of the seaward boundary exchange coefficient. See Note 3.4.A of Section 3.3, and Ref. 15 for results of dye studies.

TABLE 3.6 MODEL SUMMARY: MODEL COSTS, INITIATION COSTS

Group	MODEL	COMPUTATION MODE (Column 1)	MODEL ACQUISITION (Column 2)	TYPE OF STAFF REQUIREMENTS (Column 3)	EQUIPMENT REQUIREMENTS (Column 4)
I	DOSAG-I	Computer	Nominal cost, from EPA Planning Assistance Branch, D.C.	At least one programmer or engineer familiar with programming.	Requires any computer with ~27,000 word storage and a FORTRAN IV (level G) compiler. No tapes or disks are needed.
	SNOSCI	Computer	Nominal cost from Snonomish County Planning Dept., Wa., or SCI, Calif.	"	"
	Simplified Stream (SSM)	Hand	Handbook from the EPA Planning Assistance Branch	At least one junior level engineer with some experience in modeling.	Hand calculator which computes logs and exponentials would be helpful.
II	ES001	Computer	Nominal Cost, from EPA Region II, N.Y.	At least one programmer or engineer familiar with programming	IBM 370 or equivalent.[1]
	Simplified Estuary (SEM)	Hand	Handbook from the EPA Planning Assistance Branch	At least one junior level engineer with some experience in modeling.	Hand calculator which computes logs and exponentials would be helpful.
III	QUAL-I	Computer	Nominal cost, from EPA Planning Assistance Branch, D.C.	At least one programmer or engineer familiar with programming.	Any computer with >35,000 words of storage and FORTRAN IV compiler. No tapes or disks.
	QUAL-II	Computer	"	"	As above, but with >45,000 words of storage.
IV	Dynamic Estuary (DEM)	Computer	"	At least one engineer experienced in water quality modeling and one experienced programmer.	Requires: • ~50,000 words of storage • Two tapes and/or disks • Any FORTRAN IV compiler
	Tidal Temperature (TTM)	Computer	EPA, Environmental Research Laboratory, Corvalis, Oregon	"	"
	RECEIV	Computer	"	"	As above, but FORTRAN IV (G level) compiler.
	SRMSCI	Computer	Nominal cost from Snohomish County Planning Dept., Wash., or SCI, Calif.	"	"
V	Deep Reservoir (DRM)	Computer	Nominal cost, from EPA Planning Assistance Branch, D.C.	"	Any computer with ≥ 35,000 words of storage and a FORTRAN IV compiler.
	LAKSCI	Computer	Nominal cost, from EPA Region X, Seattle, or SCI, Calif.	"	Any computer with ≥ 50,000 words of storage and a FORTRAN IV (G level) compiler.
VI	Outfall PLUME	Computer	EPA, Environmental Research Laboratory, Corvalis, Oregon	One programmer.	Any computer with ≥ 10,000 words of storage and a FORTRAN IV compiler.

1. The ES002 model is ES001 modified to run on an IBM 1130 system.

TABLE 3.7 MODEL SUMMARY: MODEL COSTS, UTILIZATION COSTS[1]

MODEL		MACHINE COSTS[2]	MANPOWER COSTS		
			SET UP[3] (Column 2)	RUNNING (Column 3)	ANALYSIS (Column 4)
I	DOSAG-I	$1 - $5	2-6 manweeks.	Negligible.	Small.
	SNOSCI	$2 - $10	4-8 manweeks.	Negligible	Small.
	Simplified Stream (SSM)	Zero	1-2 manweeks.	From a few man hours to several man days, depending upon application.	Small.
II	ES001	Approximately $2 - $10	2-6 manweeks.	Negligible.	Small.
	Simplified Estuary (SEM)	Zero	1-2 manweeks.	From a few man hours to several man days, depending upon application.	Small.
III	QUAL-I	$5 - $50	2-6 manweeks.	Negligible.	Small - at most a few hours.
	QUAL-II	Likely to be a little greater than comparable QUAL-I run.	4-10 manweeks.	Negligible.	As above, except for runs of nutrient-algae behaviour which require at least several hours.
IV	Dynamic Estuary (DEM)	Quantity run $20 - $300. Quality run $10 - $100.	5-20 manweeks.	Routine runs take only nominal time.	The complexity of the model (particularly in the estuary) requires at least several hours of analysis and interpretation for each run to be evaluated.
	Tidal Temperature (TTM)	Somewhat more than a comparable DEM run if temperature is simulated.	5-20 manweeks.	"	"
	RECEIV	Quantity $15 - $100. Quality $10 - $50.	5-20 manweeks.	"	"
	SRMSCI	Similar to RECEIV with increase of quality expense proportional to increase of number of constituents.	5-20 manweeks.	"	"
V	Deep Reservoir (DRM)	$30 - $100	8-15 manweeks.	"	"
	LAKSCI	$40 - $150	8-20 manweeks.	"	"
VI	Outfall PLUME	$0.50 - $3	1-5 man days.	Negligible.	Small - at most a few hours.

1. For all runs, including calibration, verification, and subsequent use.
2. Approximate range for a single run on a typical application using a commercial IBM 370/55 during daytime hours. These costs are dependent on many factors, and thus should be used more for their relative magnitudes rather than for their absolute value. See Note 3.7.A of Section 3.3.
3. Set-up time for each model depends upon the complexity of application, the form of available data, and staff capabilities.

TABLE 3.8 MODEL SUMMARY: MODEL ACCURACY, MODEL REPRESENTATION INACCURACIES[1]

MODEL		SIMPLIFYING ASSUMPTIONS - QUANTITY (Column 1)	SIMPLIFYING ASSUMPTIONS - QUALITY (Column 2)	OTHER ALGORITHM INACCURACIES (Column 3)
I	DOSAG-I	Assumes stream velocity is constant throughout a reach (or section). No vertical and lateral velocity variations.	Assumes BOD 1st order decay.	Errors in Table 1 of [1].
	SNOSCI	"	Assumes 1st order decay, except NH_3, NO_2; NO_3 and PO_4 may have 2nd order.	
	Simplified Stream (SSM)	"	Assumes 1st order decay.	
II	ES001	"	"	
	Simplified Estuary (SEM)	"	"	
III	QUAL-I	"	Assumes BOD 1st order[2] decay. Uses empirical evaporation equation.	
	QUAL-II	"	Somewhat simplified nutrient-algae cycle. 1st order decay only.	
IV	Dynamic Estuary (DEM)	Neglects: Wind stress, lateral and vertical velocity variation within channels, changes in channel cross-sections with tides. Cannot account for tidal flats which dry up at low tide.	Assumes: 1st order decay, vertical homogeneity, source immediately mixed throughout junction.[3]	Use of connected 1 dimensional channels to simulate 2 dimensional flow and transport.
	Tidal Temperature (TTM)	"	As above, plus simplified evaporation term.	"
	RECEIV	As above, except can account for cross section changes through tidal flat option.	Assumes: 1st order decay, vertical homogeneity, source immediately mixed throughout junction.	"
	SRMSCI	"	As above, except NH_3, NO_2, NO_3 and PO_4 may have 1st or 2nd order decay.	"
V	Deep Reservoir (DRM)	Neglects horizontal velocities.	Neglects horizontal temperature variations.	
	LAKSCI	"	Assumes horizontal homogeneity and 1st order decay, except NH_3, NO_2, NO_3 & PO_4 may have 2nd order.	
VI	Outfall PLUME	Assumes no ambient water flow.	Treats conservative constituents only.	

1. Factors mentioned in this Table are limited to those considered to be of potential significance to model applications.
2. See Note 3.2.C in Section 3.3.
3. See Footnote 1 of Table 3.1, and Note 3.1.B in Section 3.3.

TABLE 3.9 MODEL SUMMARY: MODEL ACCURACY, NUMERICAL ACCURACY

MODEL		SOLUTION TECHNIQUE[1] (Column 1)	STABILITY BEHAVIOR (IF APPLICABLE) (Column 2)	TIME STEP CONSTRAINT FOR STABILITY (Column 3)	RELATIVE EXTENT OF NUMERICAL DISPERSION (Column 4)
I	DOSAG-I	Evaluation of integrated equations (LaGrangian), mass balance.	N/A	N/A	———
	SNOSCI	"	N/A	N/A	———
	Simplified Stream (SSM)	Hand calculation or chart solution of analytical equations	N/A	N/A	———
II	ES001	Solve simultaneous equations by matrix inversion.	N/A	N/A	———
	Simplified Estuary (SEM)	Hand calculation or chart solution of analytical equations	N/A	N/A	———
III	QUAL-I	Finite difference implicit solution.	Unconditionally stable.	None.	Low.
	QUAL-II	"	"	None.	Low.
IV	Dynamic Estuary (DEM)	Finite difference explicit solution.	Conditionally stable.	$\Delta t < \frac{L}{gh}$ [3]	Moderate to high.
	Tidal Temperature (TTM)	"	"	"	Moderate to high.
	RECEIV	"	"	"	Low.
	SRMSCI	"	"	"	Low.
V	Deep Reservoir (DRM)	Analytical and finite difference solution.	"	Generally $\Delta t < 1$ day	Low.
	LAKSCI	"	"	"	Low.
VI	Outfall PLUME	Similarity solution.	N/A	N/A	———

1. See Note 3.9.A of Section 3.3 regarding mathematical terms.
2. With unstable procedures, any errors (e.g., truncation, roundoff) can grow through the solution; they will not do so with stable procedures. See discussion in Section 4.8 of Chapter 4.
3. Δt = time step in the quantity portion of the models. L is the length of a given channel, h is the maximum depth of the channel and g is the acceleration due to gravity.

TABLE 3.10 MODEL SUMMARY: MODEL ACCURACY, SENSITIVITY TO INPUT ERRORS[2]

MODEL		KNOWN SENSITIVITIES (Column 1)			ESTIMATED SENSITIVITIES (Column 2)		
		HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
I	DOSAG-I	—	—	—	Wasteloads, velocities.	Streamflow, decay coefficients.	
	SNOSCI	NH_3 volitization coefficient.	Streamflow, decay coefficients.		"	Reaeration coefficients.	
	Simplified Stream (SSM)	—	—	—	"	Streamflow, decay coefficients.	
II	ES001	—	—	—	Reaeration coefficient.	Deoxygenation coefficient; net velocity; dispersion coefficient.	—
	Simplified Estuary (SEM)	—	—	—		Streamflow, decay coefficients, wasteloads, velocities.	Dispersion coefficient.
III	QUAL-I	Depth, weather. [1]	Streamflow, evaporation coefficient, source loads. [1]	Initial conditions, dust attenuation coefficient, headwater temp & friction coefficient. [1]	Wasteloads, flow velocities.	Decay coefficients, streamflow.	Depth, friction and reaeration coefficients
	QUAL-II	"	"	"	"	As above, plus settling coefficients.	"
IV	Dynamic Estuary (DEM)		Quality time step size.	Quantity time step size, diffusion coefficient, channel length.	Net flow, waste loading rates.	Tides, decay coefficients, headwater concentrations.	Friction coefficient, initial conditions.
	Tidal Temperature (TTM)		"	"	As above, plus depth,weather inputs	As above, plus evaporation coefficient.	"
	RECEIV		Quality time step size, decay coefficients.		Net flow, waste loading rates.	Tides, headwater concentrations.	As above, plus channel lengths.
	SRMSCI	NH_3 volitalization coefficient.	"		"	"	"
V	Deep Reservoir (DRM)	—	Eddy conductivity coefficient.	—			
	LAKSCI	Time step size. BOD decay coefficient.	As above, plus NH_3 decay & volitization coefficients, zinc settling coefficients.	Reaeration coefficient.			
VI	Outfall PLUME				Port depth,ambient stratification, effluent density, number of ports.	Port diameter, effluent flow.	

1. Known sensitivities for QUAL-1 are for temperature simulation only.
2. For conditionally stable models (see Column 2 of Table 3.9), if the time step size required for stability is exceeded, the sensitivity may become so high that model results are completely unreliable.

TABLE 3.11 MODEL SUMMARY: EASE OF APPLICATION, SUFFICIENCY OF AVAILABLE DOCUMENTATION

	MODEL	AVAILABLE DOCUMENT [1] (Column 1)	INDIVIDUAL DOCUMENT(S) (Column 2)	OVERALL SUMMARY (Column 3)
I	DOSAG-I	[1]	Good theoretical background. Generally adequate for use by programmers and engineers.	Generally good.
	SNOSCI	[2, 3]	[2] Adequate for use by engineers and programmers, but no program listing. [3] Good theoretical background.	Good.
	Simplified Stream (SSM)	[4, 5]	[4] Adequate for use by engineers; but meager discussion parameter sensitivities and example applications. [5] A helpful addendum.	Good.
II	ES001	[6, 7]	[6] Good theoretical background. Generally adequate for use by engineers and programmers, but poorly finished. [7] Verification Report, incomplete and poorly organized and finished.	Generally good; [7] provides little additional help.
	Simplified Estuary (SEM)	[4, 5]	[4] Adequate for use by engineers; but little discussion of sensitivities and no example applications. [5] A helpful addendum.	Good.
III	QUAL-I	[9, 10]	[9] Good theoretical background. [10] Adequate for use by programmers.	Good.
	QUAL-II	[9, 11]	[11] Adequate for programmers. [11] & [9] together give good theoretical background.	Good.
IV	Dynamic Estuary (DEM)	[15]	Adequate for use by engineers and programmers not familiar with the model's theory and use.	Good.
	Tidal Temperature (TTM)	[16, 17]	"	Good.
	RECEIV	[18]	General program description. Very little detail.	Poor.
	SRMSCI	[2, 3]	Adequate for use by engineers and programmers not familiar with the model's theory and use.	Good.
V	Deep Reservoir (DRM)	[22, 23, 24]	[22] Adequate but imperfect User's Manual for the Dworshak Reservoir version. [23] Good theoretical background and description of model studies. [24] Adequate User's Manual for programmers (with [22]).	Generally good.
	LAKSCI	[26, 27]	[26] Adequate User's Manual for use by programmers. [27] Good theoretical background, results of model applications	Good.
VI	Outfall PLUME	[28]	Reasonably good user documentation. Very little theoretical discussion.	Adequate.

1. The numbers in brackets correspond to the References at the back of this handbook.

TABLE 3.12 MODEL SUMMARY: EASE OF APPLICATION, OUTPUT FORM AND CONTENT

MODEL		OUTPUT FORM (Column 1)	OUTPUT CONTENT (Column 2)
I	DOSAG-I	Computer printout.	a) Descriptive listing of input data; b) DO, CBOD & NBOD concentrations at start and end of each reach, plus size and location of minimum DO concentration in each reach.
	SNOSCI	Computer printout.	"
	Simplified Stream (SSM)	Hand calculations.	DO deficit and DO concentrations.
II	ES001	Computer printout.	a) Listing of input data cards, without headings; b) BOD & DO deficits at one-tenth points of each section.[1]
	Simplified Estuary (SEM)	Hand calculations.	Maximum DO deficit and minimum DO concentrations.
III	QUAL-I	Computer printout.	a) Constituent concentrations in each element at specified timesteps. b) Maximum, minimum and average concentrations during simulation period for each reach.
	QUAL-II	Computer printout.	a) Constituent concentrations in each element at specified timesteps. b) Final constituent concentrations at end of simulation. c) Average reach coefficient used in simulation.
IV	Dynamic Estuary (DEM)	Computer printout. Channel velocities also written on tape by quantity model.	Summary of each tidal cycle including max. and min. flows, velocities, heads and net flow; and max., min. and average concentrations at each junction.[1] At prescribed time intervals, also: channel flows and velocities, junction depths, and constituent concentrations.
	Tidal Temperature (TTM)	"	"
	RECEIV	"	"
	SRMSCI	"	"
V	Deep Reservoir (DRM)	a) magnetic tape b) computer printout	a) Dates, meteorology, inflows and outflows, water surface elevations, outflow temperature objective. b) See Footnote No. 2.
	LAKSCI	"	a) As DRM, plus daily outflow constituent concentrations. b) See Footnote No. 3.
VI	Outfall PLUME	Computer printout.	a) Labeled input values. b) Dilution levels along the effluent plume centerline. c) Elevation at which plume stabilizes.

1. See Footnote No. 1 of Table 1.1, and Note 3.1.B in Section 3.3.
2. Echo check of all input data; time variations of water surface and thermocline elevations, net short and long-wave radiation rates, net heat loss, evaporation rates, atmospheric vapor pressure, air and reservoir surface temperatures, outlet and downstream temperatures, depth variations of water temperature, (horizontal and vertical) flows, diffusion coefficient.
3. As DRM (see Footnote No. 2 above), plus daily constituent concentrations of the outflow, and depth variations of the constituent concentrations.

TABLE 3.13 MODEL SUMMARY: EASE OF APPLICATION, UPDATEABILITY OF DATA DECKS

MODEL		CARD CHANGES (Column 1)	RECOMPUTATION TIME (Column 2)	HELPFULNESS OF AVAILABLE DOCUMENTATION (Column 3)
I	DOSAG-I	Few.	Very small.	Good.
	SNOSCI	Few.	Very small.	Good.
	Simplified Stream (SSM)	None.	Relatively large.	Good. Needs thorough study and good understanding, before using charts.
II	ES001	Few.	Small.	Good.
	Simplified Estuary (SEM)	None.	Relatively large.	Good. Needs thorough study and good understanding, before using charts.
III	QUAL-I	Very small, except for changes of weather data which may involve many cards.	Small.	Good.
	QUAL-II	"	Small.	Good.
IV	Dynamic Estuary (DEM)	Few in most cases.	Small.	Good.
	Tidal Temperature (TTM)	Small, except for weather inputs.	Small.	Good.
	RECEIV	Small, except for transient waste inputs.	Small.	Poor.
	SRMSCI	"	Small.	Good.
V	Deep Reservoir (DRM)	Small, except for weather data.	Small.	Generally good. The three comprising documents are less convenient to use.
	LAKSCI	Small, except for weather and inflow quality data.	Small.	Good.
VI	Outfall PLUME	Minor changes, of at most a few cards.	Very small.	Adequate.

TABLE 3.14 MODEL SUMMARY: EASE OF APPLICATION, MODIFICATION OF SOURCE DECKS

MODEL		CODE LANGUAGE (Column 1)	HELPFUL COMMENT STATEMENTS (Column 2)	ARE THESE HELPFUL SUBROUTINES? (Column 3)	DOES DOCUMENTATION HELP IN PROGRAM MODIFICATION? (Column 4)
I	DOSAG-I	FORTRAN IV	Many	Many	Yes
	SNOSCI	FORTRAN IV	Many	Many	Yes
	Simplified Stream (SSM)	N/A	N/A	N/A	Yes[1]
II	ES001	FORTRAN IV	Few	Many	Yes, generally adequate.
	Simplified Estuary (SEM)	N/A	N/A	N/A	Yes[1]
III	QUAL-I	FORTRAN IV (G level)	Many	Many	Yes
	QUAL-II	FORTRAN IV (G level)	Many	Many	Yes
IV	Dynamic Estuary (DEM)	FORTRAN II	Some	Some, but the main programs are still very long and complex.	Yes
	Tidal Temperature (TTM)	FORTRAN IV	Some	"	Yes
	RECEIV	FORTRAN IV (G level)	Some	Some, but could be more.	Very little.
	SRMSCI	FORTRAN IV (G level)	Some	"	Yes
V	Deep Reservoir (DRM)	FORTRAN IV	Many	Many	Yes
	LAKSCI	FORTRAN IV	Many	Many	Yes
VI	Outfall PLUME	FORTRAN IV	Some	No, but they are not needed in such a short program.	Little

1. Helps to modify the procedure rather than the program.

uniform conditions within it. Different streams join at "junctions", where three or more reaches meet. The most upstream reach on each branch is a "headwater", where considerable inflows may occur if the smaller, upstream streams are not being simulated. The steady-state (Group I) stream models have one additional, unique category of element, named "stretches," which consist of groups of adjacent reaches between headwaters and junctions.

ES001, the only computer model in Group II: Steady-state Estuary Models, is comprised of "sections" and "junctions". These sections are similar to the reaches of the Groups I and III models; the junctions differ from Groups I and III type, but instead are points of connection of the sections. ES001 offers a choice of four types of section and 14 types of junctions, including the effects of dams and completely mixed bays.

The dynamic estuary and stream models (Group IV) represent water bodies by a grid or branched network of one-dimensional flow paths called "channels"; at the ends of all channels, where they are connected together, are "junctions". These junctions are of a third type, differing from those in the Group I, II & III models in that these contain between them the entire volume of water in the simulated system. The volumes and levels of water in each junction are computed, together with the flow rates and velocities in the channels. The channels are similar to the Group II sections, except that for the channels the flow rates and velocities are not prescribed but instead are computed from the channel characteristics.

The dynamic lake models (Group V) represent impoundments by a series of fixed, horizontal layers or volumes, through which water and constituents pass. Only the top layer may have a changing thickness, to account for water surface level changes.

In summary, all the names of the discrete elements included in the models evaluated here have unique meanings, except for the term "junction", which has the three different meanings described above. More details of the discretization scheme employed by each model are provided in the documentation (see Table 3.11).

Note 3.2.A: Mass Conservation

Water quality constituents may be divided into two broad categories, conservative and non-conservative. With conservative constituents, the total mass or quantity of the constituent is conserved, even though its concentration may change as a result of dilution. Non-conservative constituents experience an actual loss or gain in total constituent quantity (in addition to change in concentration), as a result of such processes as decay, consumption, settling out, growth, and death.

Note 3.2.B: Constituent Linkages

The presence of many water quality constituents in receiving waters may have effects on the behavior of other constituents, in a variety of ways and to various extents. For example, decaying organic materials consume oxygen, and toxic materials may kill or slow the growth rates of aquatic plants and animals.

Singular constituents are those not affected by the presence of other constituents.

Coupled constituents are defined as those whose behavior is affected (in each case) by the presence of only one other constituent.

Linked constituents are defined as those whose behavior is affected by the presence of one or more other constituents. Thus, coupling is a special case of linking.

Note 3.2.C: Reaction Kinetics

The most common type of change of total constituent mass (see Note 3.2.A) is that in which the rate of change with time (t) is proportional to the amount (m) present, namely

$$\frac{dm}{dt} = -Km$$

K is known as the rate or decay coefficient; negative values of K represent growth processes. This equation represents what is known as first order kinetics. It may be integrated to yield the exponential relationship

$$m(t) = m(o)e^{-Kt}$$

where m(o) is the initial condition.

Occasionally, the behavior of some constituents are found to be better represented by second order kinetics, the corresponding equation being

$$\frac{dm}{dt} = -Km^2$$

Thus the order of the kinetics is seen to be the power to which m is raised in the right-hand side of the equation.

Note 3.2.D: Modifications to Constituents Simulated

Table 3.2 indicates that, for certain models, the list of constituents which may be modeled can be somewhat changed by making minor modifications to the computer programs. For the examples cited, only minor modifications are required; namely, changes in the computer code governing the printing of the constituent names, a relatively simple task.

The list of alternative constituents could clearly be extended by making more extensive changes to the code. However, these are not mentioned in Table 3.2, since they depend upon the availability of far more advanced expertise and time to deal correctly with the effects of constituent interlinkages (see Note 3.2.B) and changes in units.

Note 3.3.A: Temperature Effects

The rates of most kinetic reactions are significantly affected by temperature. This is generally accounted for in water quality models by making the rate coefficient K, defined in Note 3.2.C above, a function of temperature. This function is typically of the form

$$K_T = K_{20}\ \theta^{(T-20)}$$

where T = water temperature, ^{o}C

θ = a constant, commonly in the range 1.02 - 1.12

These relationships are the temperature effects referred to in Table 3.3.

Note 3.4.A: Seaward Exchange Coefficient

This coefficient (also known as the ocean exchange or transfer coefficient) has been incorporated into many estuary models as a simple alternative to specifying all constituent concentrations in incoming tides at the seaward boundary. It prescribes the fraction of the (computed) departing constituents which return, after dilution and decay in the adjacent ocean. While simple in concept, it should be used with some caution, since the amount of discharged water which returns is strongly dependent upon the tidal wave form. Further, this fraction should really be a time-varying function, since its value for returning water will strictly depend upon the length of time it has been outside the boundary.

Note 3.5.A: Calibration and Verification

A model is considered to be calibrated and verified when the uncertain or unknown values of the various model parameters have been adjusted until the model predictions correspond acceptably closely to the observed prototype behavior.

Calibration is the first state of parameter adjustment, with a first set of prototype input and output data for a first simulation period. Verification then involves modelling at least one different simulation period (with a different set of input and output data) using the originally calibrated parameters. If the model predictions for the subsequent simulation period(s) do not also agree sufficiently closely with the corresponding prototype behavior, then the model is not yet verified and further calibration, or recalibration, is necessary. It is important that the various simulation periods used for verification should correspond to significantly different prototype conditions.

It should be remembered by the calibrator that, when all calibration attempts seem unable to attain the required accuracy of predictions, the input and/or output data may contain errors and at such times they must be reviewed accordingly, or the model may be inappropriate for the physical situation being simulated.

Note 3.7.A: Cost Impact of Discretization and Complexity

Since the cost of computer runs obviously increases with the number of segments the model is divided into, the number of time steps the simulation period is divided into (where appropriate), and the number of constituents simulated, the run cost for a given problem will vary across the range reported in Table 3.7 depending upon the level of discretization and complexity specified by the user.

Here, the number of segments would be the number of reaches (model Groups I & III), sections (ES001 model), junctions/channels (Group IV), or layers (Group V) which comprised the model (see also Note 3.1.B).

Note 3.9.A: Mathematical Terms

Although the mathematical terms and qualities mentioned in Table 3.9 probably have more meaning to analysts familiar with advanced mathematics and numerical methods, they can indicate to the planner factors which should be considered. The fact that various models employ different solution techniques and/or constraints does not necessarily imply any kind of superiority or inferiority; the most appropriate technique will vary with the model structure. It is here presumed that the model designers and builders considered such matters when developing their models, and incorporated the most appropriate methods into them. However, these qualities of the models may serve the planner as a guide to their suitability for unusual or special applications.

3.4 OTHER MODELS

The models evaluated in this handbook are all deterministic simulation models. There exist many other models different from those selected for this evaluation, as well as other versions of those evaluated here. Several of these, which were evaluated in a previous study by the authors [30], along with others too recent to have been evaluated in this study are listed in Table 3.15. It is expected that much the same questions would be used in the evaluation of these other models, and that only different answers would be obtained in some areas.

One area of modeling notably different from those evaluated herein is that of ecologic modeling of receiving waters [31,32; see also 30], in which the life forms are of prime interest. Another different area is that of the truly two-dimensional models [33,34], in which velocity components are determined in two perpendicular directions over a grid of points covering the water body. These two-dimensional models are more complex than any evaluated in this handbook.

Three-dimensional models are still more complex. Their development is being approached on a number of fronts, but presently they are far from being ready for wide use in planning. One of these approaches is the quasi-three-dimensional model, an example of which is the Puget Sound Model presently undre development by Water Resources Engineers, Inc., for the EPA. It will represent the Puget Sound as three interconnected layers, each layer being simulated by a quasi-two-dimensional model.

Table 3.15 OTHER MODELS

MODEL	AREA OF APPLICABILITY	PARAMETERS MODELED	COMMENTS	AVAILABILITY
Hydrocomp Simulation Model	Lake, Stream	Temperature, BOD, coliforms, algae, zooplankton, sediment, organic nitrogen, DO, TDS, nutrients and conservative constituents.	This model is particularly useful in its capability to predict water runoff and the resulting stream quality as a function of varying weather conditions. The quantity portion is well established; however, the quality part has been applied to only 2 streams.	Proprietary: Available from: Hydrocomp, International 1502 Page Mill Road Palo Alto, California 90430
Estuary Ecologic Model (ECOMOD)	Stream, Estuary	Zooplankton, benthic animals, fish, pH, nutrients, conservative constituents, non-conservative constituents with 1st order decay.	Models estuarine systems by linking One-dimensional channels in a two-dimensional fashion. For this reason the schematization process requires expert guidance. ECOMOD has had only limited use. Simulates tidal flats.	At Nominal Cost From: National Technical Information Service 5285 Port Royal Road Springfield, Va. 22151
Lake Ecologic Model (LAKECO)	Lake	Zooplankton, benthic animals, fish, pH, nutrients, conservative constituents, non-conservative constituents with 1st order decay.	LAKECO is a derivative of the Deep Reservoir Model. Most useful in simulating well-stratified lakes and reservoirs. Has been used successfully on numerous prototypes.	At Nominal Cost From: National Technical Information Service 5285 Port Royal Road Springfield, Va. 22151
RECEIV-II	Stream, Estuary	BOD, coliforms, nutrients, DO, salinity, conservative constituents, non-conservative constituents with 1st order decay, chlorophyll-a.	A modified version of the EPA SWMM RECIEV-II model. Handles multiple tidal inlets, upstreams dams. Well calibrated and tested.	At nominal cost from: EPA, Planning Assistance Branch Washington, D.C. 20460 or Raytheon P.O. Box 360 Portsmouth, R.I. 02871
WRECEV	Stream, Estuary	DO-BOD (linked), any four conservative or 1st order non-conservative.	Compatible with EPA Stormwater Management Model (SWMM). Well calibrated and tested.	At nominal cost from: EPA, Planning Assistance Branch Washington, D.C. 20460 or Water Resources Engineers 3445 Executive Center Dr. Medina Bldg, Suite 220 Austin, Texas 78731

The deterministic models discussed thus far are all "event" models, with which a short or relatively short simulation period is modeled. There is a growing awareness of the limited capability of such models to provide sufficient information to enable the long term probabilistic effects, and consequently benefits, of alternative management schemes to be determined. The use of "continuous" deterministic models [35,36 (see also [30]), 37-41], whose output can be statistically analyzed, is recommended for such purposes.

While considerably more input data is required for continuous simulation, the types of data required are identical with those required for event models, and they are mostly available in the U.S. in computer compatible form from the National Weather Service and the U.S. Geological Survey. But the much longer record (typically about a year's) of water quality data needed for calibration and verification, and the far longer computer run times, still remain as disadvantages to continuous modeling. The resulting increased costs may be justified in certain cases where the planned facilities are large and costly.

An advantage of continuous models is that their long simulation periods prevent "false calibration" by the adjustment of the initial conditions, as may be possible with the simulation of shorter events (up to 2 or 3 weeks long, depending on the flow regime). On the other hand, when there are insufficient records at the site of interest, such as for streamflows, the uncertainty introduced by extending or synthesizing records for continuous simulation may equal that obtained with far less labor by using event models.

Stochastic models [e.g., 42] provide an alternative approach to the question of probabilities. They attempt to take into account the randomness in many observed phenomena. They exist in great variety, depending upon the assumptions they make about the physical processes, and upon the type of mathematics they employ. They also have the disadvantage of requiring very large quantities of prototype data in order to establish the various probabilities. As a consequence, most of the simulations models in present use are deterministic.

CHAPTER 4

MODEL SELECTION AND COST EFFECTIVENESS EVALUATION SYSTEM

4.1 INTRODUCTION

The process of selecting a water quality model for any wastewater management planning project may involve numerous complex considerations. One of the objectives of this project was to identify the important factors which influence the selection of models by planners, and to structure the consideration of these factors in a manner such that confusion is minimized. This chapter presents a methodology which can be used for model selection and cost effectiveness evaluation, and detailed instructions on how to use it. The methodology does not tell planners what decisions on models to make, but provides them with the essential questions and thought structure upon which they or their contractors can make the decisions. If a consultant is used, the procedure also gives guidance to planners as to the types of evaluations to request and expect from consultants.

The model selection process is designed to give users a choice of several levels of detail they may want to consider. The process is divided into four phases, each going into progressively more detail and requiring progressively more effort. These phases are:

Phase I: Model Applicability Tests
Phase II: Cost Constraint Tests
Phase III: Performance Index Rating - Simplified
Phase IV: Performance Index Rating - Advanced

The rejection of candidate models in one phase reduces the number of models to be evaluated in the next phase. The phases are designed accordingly. All considerations in the selection process are based upon model evaluations of candidate models as presented in Chapter 3.

The amount of effort required to select an appropriate model depends upon how many phases the planner uses and how well he understands the problem at hand. Once the planning problems are clearly defined and modeling objectives identified, model selection based upon Phase I considerations alone should require only a few hours of planner effort. Completion of additional phases may require a substantial addition in effort. Planners may estimate the amount of effort required for each phase by examining the appropriate evaluations described in Chapter 3 which are the basis of final model selection. These model evaluations are presented in Tables 3.1-3.14 of Chapter 3 and are associated with the Phases as listed below:

Phase I - Tables 3.1, 3.2, 3.3.C1-C2,* 3.4, 3.5
Phase II - Tables 3.6, 3.7
Phase III - Tables 3.1, 3.2, 3.3.C1-C2, 3.4, 3.5, 3.6.C3
Phase IV - Tables 3.3.C3-C4, 3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14

The various required evaluations also guide the planner as to whether he should consider the use and selection of a water quality model in the overall planning program. In most cases the model selection will need to be preceded by the problem identification and data inventory portions of a planning program. Any monitoring that can be accomplished within the program should be postponed until after the models are selected.

4.2 DECISION TO USE A MODEL

Prior to model selection, the more basic decision whether any water quality model should be used must be made. This decision must take into account whether a model would be helpful in plan formulation and whether a suitable model and sufficient data are available. Generally, water quality models are useful in any area where the quantitative relationship between varying wasteloads and resulting water quality must be known. This relationship between wasteloads and receiving water quality will be of prime importance in all "Water Quality Limited" areas of the country [43]. In "Effluent Limited" areas, waste treatment alternatives will often be fixed by Federal

* The number 3.3.C1-C2 refers to Table 3.3, columns 1 and 2.

Effluent Standards, thus eliminating the necessity of a water quality model. The recently completed studies under Section 303e of PL 92-500 specify all "Water Quality Limited" areas of the country. If the quantitative relationships between water quality and varying waste-loads are needed by a planner, he should go ahead with the model selection process presented in this chapter. If water quality modeling is inappropriate or inefficient in a particular planning application, the model selection process will make this fact apparent, as the candidate models will not pass various applicability and constraint tests. In this case the planner must consider other quantitative analysis techniques such as data acquisition and interpretation.

4.3 SELECTION OF CANDIDATE MODELS

A set of candidate models must be identified before the model selection process is initiated. Those models evaluated in Chapter 3 could be used as the candidate set. However, many other models are available which could be considered. Most available water quality models can be located at the following agencies:

- Environmental Protection Agency, Planning Assistance Branch (WH-454) Waterside Mall, Washington, D. C. 20460.
- Army Corps of Engineers, Methods Branch, 609 Second Street, Davis, California, 95616.
- U.S. Geological Survey, 12201 Sunrise Valley Drive, Reston, Virginia, 22092.
- State Water Quality Planning Offices.
- Colleges and Universities dealing with water quality problems.

The planner should select his set of candidate models using as many sources as possible. Since many model titles describe the type of receiving water they are applicable to, the planner should review the titles and prescreen those obviously not applicable to his particular problem. In some cases planners will be interested in several types of receiving waters, such as lakes, rivers and/or esturaries, and they should deal with them separately in the model selection process.

4.4 MODEL SELECTION PROCESS

The model selection and cost effectiveness evaluation procedure is structured to avoid unnecessary effort by screening out inappropriate models early in the process. The evaluations of candidate models, as shown in Chapter 3, should be accomplished concurrently with the appropriate tests and ratings in each phase. For example, the evaluations of various models' abilities to handle water body types and characteristics (see Table 3.1, Columns 1-2) should be performed for all models while performing the water body applicability tests in Phase I. As models are rejected in various applicability and constraint tests, later evaluations of these rejected models can be avoided.

The following sections give detailed instructions on how to select a water quality model. A flowchart is presented for each phase so that the user can keep track of where he is in the model selection process. The more phases the planner uses in the model selection, the more confidence he can have in his selected model. In many cases, however, adequate confidence in the model selection can be attained after the first one or two phases of the process are completed.

4.5 PHASE I - APPLICABILITY TESTS

The first phase of the selection process is important, because many of the preselected models can be rejected at this stage. The applicability tests are intended to ask basic questions about the appropriateness of the models with respect to the problem at hand. Those models that are inappropriate for the case at hand are then rejected from further study. A schematic flow chart illustrating the methodology used by the planner during Phase I is presented in Figure 4.1. The user may take all candidate models through the steps of a phase simultaneously, or one at a time, but he should not proceed to any subsequent phase until all aspects of the preceeding phase are complete.

Tables 4.2-4.5 (presented at end of this Chapter) present work sheets upon which decisions on the various models can be recorded. Similar tables should be used for record keeping of the applicability tests and subsequent Phase III performance index ratings. Any candidate models should be listed on the

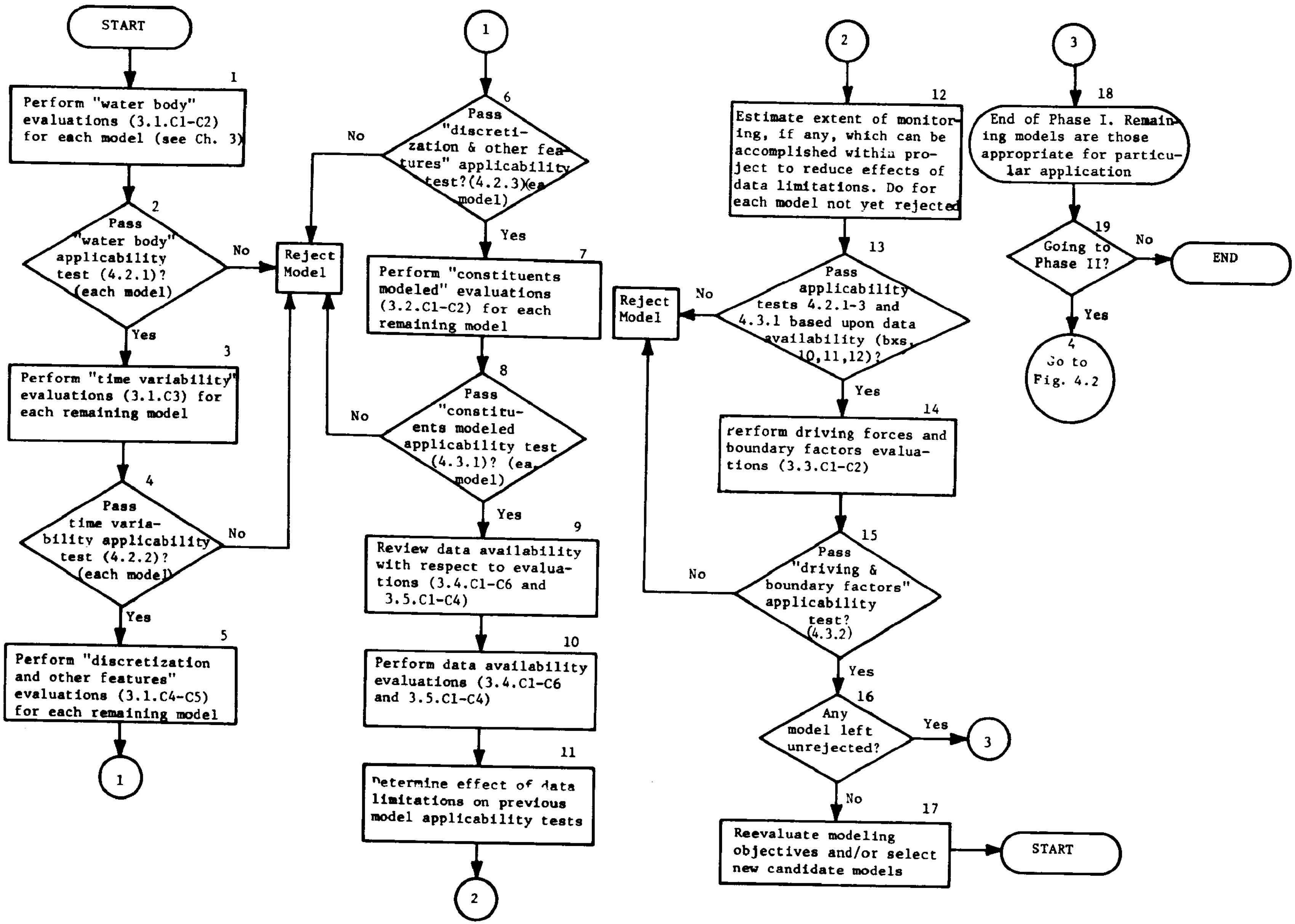

FIGURE 4.1 FLOWCHART OF PROCEDURE FOR MODEL SELECTION AND COST EFFECTIVENESS EVALUATION: PHASE I - APPLICABILITY TESTS

left side of these work sheets. The particular models included here in Tables 4.2-4.5 for the purposes of an illustrative example are those evaluated in Chapter 3. Results of applicability tests should be recorded as "yes" for applicable models and "no" for non-applicable models in the appropriate columns as shown in Tables 4.2-4.5. As the various tests proceed, rejected models should be crossed out or deleted from subsequent work sheets to avoid unneeded work performing tests and ratings of previously rejected models.

Type of Water Body

The ability of a model to simulate the behavior of the correct type of water body is of prime importance. Most model documentation reports provide information on the types of water bodies they are capable of simulating and have previously been applied to. For a cursory analysis, the user can simply consider what the model documentation says and base his applicability test and performance rating accordingly. However, for a deeper understanding of the problem the following analysis should be made. First, the user should determine the spatial dimensions for which variability of water quality or flow are important. Consideration must first be given to the scale of interest, i.e., far-field. Most existing water quality standards are specified in terms of concentrations outside an initial mixing zone, thus requiring a look at the large-scale, far-field effects of water pollution.

Next, the extent of concentration and/or flow variability in the prescribed field (i.e., scale) of concern must be considered. If a parameter is fairly constant in a certain dimension, then it can be averaged over that dimension without excessive error in the analysis. This is demonstrated in the far-field view of a river. In this case, pollutant particles are usually quite evenly distributed over both vertical and lateral directions (i.e., over the cross-section). Only in the longitudinal direction do significant concentration variations exist. Similarly, in shallow, vertically well-mixed estuaries large concentration and flow variations may occur in any horizontal direction, but not in the vertical direction. Conversely, in strongly stratified lakes variations are primarily important in the vertical direction and not in the horizontal directions.

Time Variability

The basic concern in this test is to determine which model variables, if any, must be considered as time-varying. For this the user should determine: 1) the type of simulation period he wants to use, i.e., short-term low flow, storm flow periods, long-term; and 2) which of the inputs, particularly flow, effluent loads and weather, are known to vary significantly over the simulation period.

Models should be evaluated for applicability and effectiveness in this test based upon their ability to handle the appropriate time variations. Many water quality models solve for time-varying concentrations, but only account for one or two time-varying inputs. For many so-called dynamic models, effluent loads can only be accepted as constant inputs. It should be remembered that time varying models can be used to obtain steady-state solutions, but steady-state models cannot be used to solve for time-varying solutions.

Descretization and Special Features

The limitations on the number of spatial grids, or segments, in those models presently available is not a problem in most applications. However, as three-dimensional models are developed and applied, limitations in computer storage will become a major factor. One way of solving this problem is to divide the water body into sections to be modeled separately, and then to connect or mesh the water quality results at the boundaries. For the models evaluated in Chapter 3, and most other models presently being used by planners, spatial grid limitations do not represent major constraints.

There are certain special features of the prototype receiving waters which may be important in water quality simulations. These may include the presence of tidal flats, flow augmentation sources, storm loadings, etc. In most situations these features are not vital, but they can be of useful assistance. If a special feature is considered vital, the applicability test should be used to reject inappropriate models.

Constituents Modeled

A list of water quality constituents of interest to the planner should be made. This may include constituents showing existing or potential problems based upon historical water quality data and knowledge of present and future point and non-point pollutant sources. It is possible that several of the constituents which are desired for analysis are not found in any candidate models. For example, color and odor are two parameters which are found in most water quality standards, but are not included in models due to limitations in the state of the art of water quality modeling. For this reason, planners must compare their desired list of constituents with those offered in candidate models.

Some models can be used for a whole class of constituents given by a certain type of kinetic reaction, e.g., first order decay. This does not apply to coupled constituents such as dissolved oxygen and algae, since their nature is unique.

Candidate models which are capable of simulating the appropriate constituents pass the applicability test and can be given Phase III ratings based on their relative adequacy in modeling those constituents.

Model Input Data

Another of the most important factors to be accounted for in model selection is the availability of data for model inputs. The ability for a model to simulate system characteristics is limited by the quality of input data.

Input data limitations will likely limit the applicability of the candidate models. For example, a model accounting for transient effluent loads may be more appropriate in a certain case than a steady-state model, but also more expensive. If, at the present time, only single measurements of the effluents have been made, the transient input mode of the model can not be accurately exercised. In this case, the transient model would probably be used with constant effluent inputs, thus negating its increased usefulness.

Two further input data considerations must be made with respect to the scope of model studies:

1) Can additional data be acquired within the project?

2) Will the model be used over a number of years (i.e., the next 20 years) in which the needed additional data will probably become available, or is the model only to be used at the present time, eliminating the possibility that future data improvements will be helpful?

If the scope of a planning/modeling project can accomodate a monitoring program, the planner must determine the amount of data needed for each model which can be obtained. This data should then be included in the data evaluations (evaluations 3.4.C1-C6), and model applicability tests.

Reliance on uncertain future data acquisition programs should not affect the applicability screening tests, but data from these programs may influence the applicability of the models in the future. Therefore, the usefulness of future data programs should be accounted for in the Phase III applicability ratings.

Input data ratings should be based upon the general accuracy that the various inputs can be specified. Input data with poor accuracy should be rated low.

These considerations for data inputs may show that the data base is completely insufficient for all candidate models. In this case, models are probably not useful and other, less rigorous forms of analysis such as data acquisition and interpretation should be proposed.

Driving Forces and Boundary Factors

All important driving forces which tend to move pollutants in the real water system should be listed. These may simply be flows and velocities or, where these are unknown, bed slope (gravitation), tides (gravitation), wind, and density currents due to water temperature gradients. The planner should be careful in selecting only those driving forces which are important in the movement of pollutants in the subject receiving waters. Then he may compare his list with those driving forces offered by the various models.

Also to be included in this test is the consideration of all receiving water boundary conditions affecting the concentrations of pollutants. These may include:

Headwater Inflows
Tributary Inflows
Goundwater Inflows
Slope of Bed
Bottom Friction
Water Depth (Hydraulic Radius)
Point Effluent Discharges
Non-Point Effluent Discharges (Including Benthal Exchanges)
Weather (Heat Budget, Wind, etc.)
Water Withdrawals

The need for including these boundary factors as time varying inputs should also be determined. This requires consideration of time variability for each significant boundary factor.

The model applicability tests in this category should account for each model's ability to handle the significant boundary conditions and driving forces, and should be entered into a table similar to Table 4.3.

Summary of Phase I

The tests in this first phase of the model selection process are intended to compare hard constraints of the particular user application with the various characteristics of candidate models. Those models clearly not meeting a user constraint should be rejected. However, if the tests show that a model is marginally applicable, then it may be maintained for further consideration in Phase III, where the level of applicability is given a rating.

At the end of Phase I the user has the option of continuing the selection process with Phase II, or selecting a model based only on Phase I considerations. If all the candidate models are rejected in Phase I, then the user must either find new candidate models, re-evaluate his applicability constraints, or abandon attempts to use a water quality model for his planning needs.

4.6 PHASE II - COST ESTIMATION

This phase presents a costing system which can be used in model selection. Both elapsed project time and dollar cost are considered as cost items which, for each model, must be compared with user constraints. Those models that require too much project time, or far too many funds, should be rejected at this point. The dollar costs estimated in this section are used in final cost effectiveness comparisons. A task flow diagram of all planner activities in Phase II is given in Figure 4.2.

Tables 4.6 and 4.7 (presented at the end of this Chapter) show sample work sheets to be used for time and cost estimation and constraint tests. These work sheets should be used to keep records of the various costs for final effectiveness evaluations performed in Phase III or IV.

Model Acquisition Costs

Most of the existing water quality models are in the public domain. They should require only nominal materials and shipping costs, and a few weeks time for acquisition. Some models are privately owned, however, and can be used only under a lease or purchase agreement. Acquisition costs may include a surcharge on each run made, i.e., a certain percent of the computer charges. Documentation for these programs may also cost the user. The total cost of acquisition, including any use surcharge should be estimated according to the expected amount of use.

Equipment Requirements

Consideration of equipment requirements should be based upon comparisons of available capabilities with any hardware requirements. This may include slide

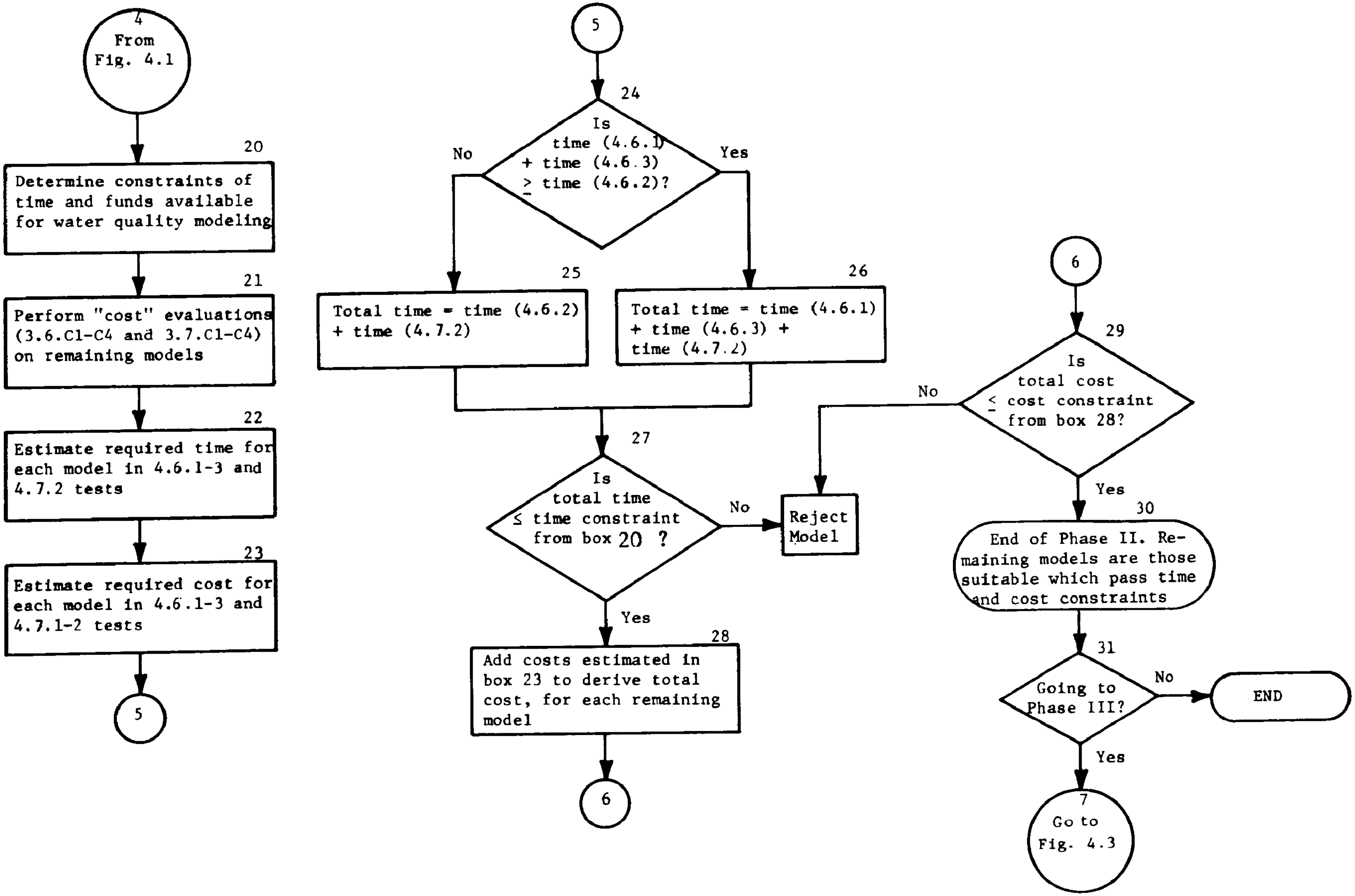

FIGURE 4.2 FLOWCHART OF PROCEDURE FOR MODEL SELECTION AND COST EFFECTIVENESS EVALUATION: PHASE II - COST AND TIME CONSTRAINT TESTS

rules and desk calculators as well as high speed digital computers. If digital computers are needed, additional consideration must be given to requirements of keypunching equipment, card readers, tapes, output printers and other devices. Use of large computer facilities does not necessarily require its physical proximity. Many of the services needed are available through use of remote terminals that may be more conveniently located. Both time and cost of equipment acquisition should be included in the cost estimates.

Data Acquisition Costs

As a result of the input and calibration data considerations discussed in Phase I, monitoring programs may optionally be considered as part of each candidate model application, and accordingly, should be included in cost estimates. Both the time and cost for implementing these monitoring programs must be estimated by the planner (see [44], for assistance in these cost estimates).

Machine Costs

All machine charges for computation during the course of the project should be estimated under this category. These charges may be for computation time, data storage on tapes or disks, data transfer, and output display. Estimates can be made by determining the approximate cost of a single computer run. Model documentation reports generally provide information on computer run times for various computers. If the documentation does not provide this information, then past users of the models should be contacted for information on their run times or computer costs. For a particular model the computation time is about proportional to:

1) The number of constituents modeled,

2) The number of segments (i.e., reaches, junctions) modeled, and

3) The number of time steps used (for time varying models).

Thus, projections of computer run times can be made using information on the numbers of constituents, segments, and time steps corresponding to past model run times. From these considerations and the expected number of runs, the user can determine the approximate machine costs for each candidate model.

Manpower Costs

The number of personnel and level of expertise needed in a modeling project is another important consideration. The ultimate usefulness of models is often limited by the ability of personnel to properly implement the models and analyze the results.

The specification of needed staff for implementation of each model should be based upon the level of model complexity, the amount of time needed to implement the model, and the time span allocated for the project. Planners may choose to use contractors for certain modeling tasks. A detailed discussion of the advantages and disadvantages of this alternative is given in Chapter 5.

Manpower time for modeling must include the times to:

1) Obtain and/or train personnel for the job;
2) Set up the models for implementation including the assembling of input data;
3) Run the model and analyze the results for each run.

Approximate manpower costs can be obtained using the manpower times and the project salaries for the various personnel.

Cost Constraint Tests

In this phase of the selection process, the total estimated costs can be obtained. The total time required for a candidate modeling project, not including reporting time, can be estimated from the following (refer to Tables 4.6 and 4.7).

a) If $T(4.6.1) + T(4.6.3) > T(4.6.2)$
   Then Total Time $(T) = T(4.6.1) + T(4.6.3) + T(4.7.2)$

b) If $T(4.6.1) + T(4.6.3) < T(4.6.2)$
   Then Total Time $(T) = T(4.6.2) + T(4.7.2)$

Model and data acquisition, and acquiring and setting up the required equipment can be accomplished simultaneously.

The total cost required for a candidate modeling project is simply the total of all the incremental costs

$$\text{Total Cost } (C) = C(4.6.1) + C(4.6.2) + C(4.6.3) + C(4.7.1) + C(4.7.2)$$

Since the estimates of cost and time for use of the various models will usually be very approximate, some discretion should be used in rejecting models. For example, only those models whose cost estimates grossly exceed the modeling budget should be rejected in this phase.

4.7 PHASE III - PERFORMANCE INDEX RATING: SIMPLIFIED

This portion of the model selection process gives a method for estimating the effectiveness of the candidate models. The effectiveness is obtained through a "Performance Index Rating," which is divided into two parts. The first, "simplified" part accounts for the more basic, and usually more important model attributes which have previously been discussed in the Phase I and Phase II tests. The second "advanced" part of Performance Index (PI) rating, performed in Phase IV involves much more detailed, and usually somewhat less important considerations of the models. Since these additional considerations require a large addition of work for the planner, he is not discouraged to make his final model selection based only upon considerations through the simplified PI rating (Phase III). In most cases, this will give the planner a very good idea of which model is best for his particular planning problem. A brief review of the contents of the second part (Phase IV) will then usually indicate whether those further considerations are necessary.

A task flow diagram of all planner activities in Phase III is given in Figure 4.3. Work sheets for the simplified performance index ratings are provided in Tables 4.2-4.5 and 4.7.

Performance Index System

The estimated performances of various candidate models in a particular application are quantified in terms of certain model attributes. The attributes to be examined in Phase III are given in various columns of Tables 4.2-4.5 and 4.7. As shown in these tables, each attribute can be assigned a rating and weight. The attribute ratings are based upon the expected model capabilities given a certain user application. For each attribute the ratings are given as follows:

10 - excellent
8 - good
6 - fair
4 - poor
2 - very poor
0 - completely inadequate.

The weights are used to adjust the impact of each attribute rating on the overall Performance Index, based upon their relative importance. For example, if the "Time Variability" capability of a model is much more important than the "Constituents Modeled" capability, then it should have a larger weight. Attribute weights are specific to each application. They must be assigned by the planner based upon his judgement of the importance of each attribute to his planning problem. In assigning weights the most significant factor is the relative importance of the various attributes. For a particular application a single set of weights should be used for all candidate models. Further details on the assigning of weights are given in Section 4.9.

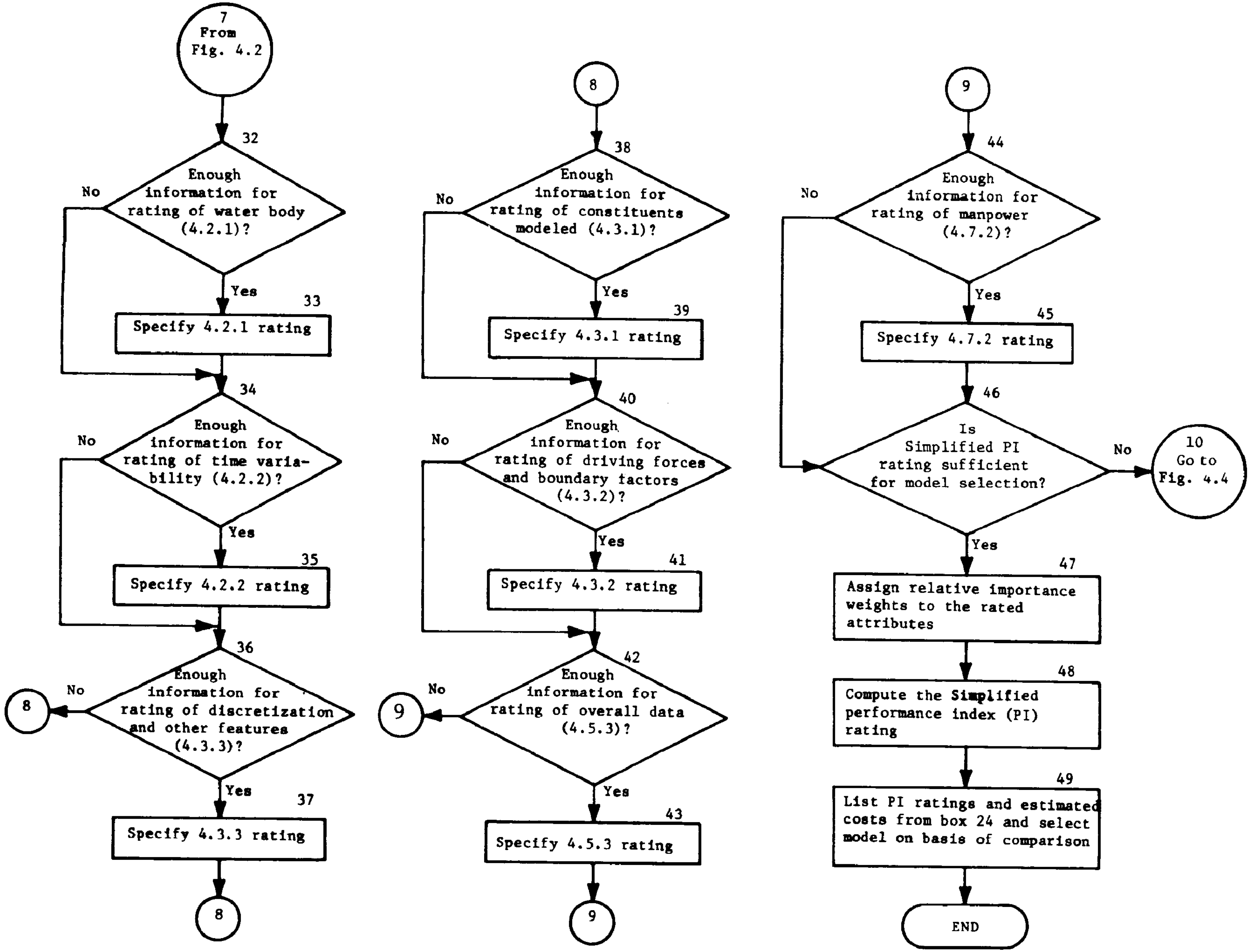

FIGURE 4.3 FLOWCHART OF PROCEDURE FOR MODEL SELECTION AND COST EFFECTIVENESS EVALUATION: PHASE III - PERFORMANCE INDEX RATING, SIMPLIFIED

The overall performance index of the jth model can be computed using the equation:

$$PI(j) = \frac{\sum_{i=1}^{n} [\text{Rating } (i,j)]\ [\text{Weight } (i)]}{\sum_{i=1}^{n} \text{Weight } (i)}$$

where i = the attribute numbers
n = number of attributes considered

The ratings for each attribute, based upon the appropriate model evaluations (Chapter 3), must be specified by the user. Ratings are determined using the same considerations as those in the Phase I, model applicability tests. This includes limitations on applicability due to expected data limitations. As stated above, the ratings are a function of how well a model can represent the prototype system. They are given as either excellent, good, fair, poor, very poor and completely inadequate.

In some cases there may not be enough information available to assign a rating. If this is true and the attribute is of relatively minor importance, that attribute can be completely left out of the PI rating for the model in question. Then, that attribute will have no effect on the rating. If the evaluator feels that an attribute is of major importance, he should attempt to obtain the necessary information on it.

Applicability Ratings

Ratings in this category include those for consideration of water body (4.2.1, Table 4.2), time variability (4.2.2.), discretization and other features (4.2.3), constituents modeled (4.3.1, Table 4.3), and driving forces and boundary factors (4.3.2). For these ratings the same subjects should be considered as in the applicability tests discussed in Phase I. This includes limitations on model applicability due to data insufficiencies. The user should enter these ratings in the appropriate columns of tables similar to Tables 4.2 and 4.3.

Data Rating

This rating should be based on the overall quality and accuracy of data needed for input and calibration of the candidate models. The rating should not include effects on model applicability due to limitations in the data base, as these effects are accounted for in the applicability ratings. The quality of all needed input and calibration data included in tests on the Table 4.4 and 4.5 work sheets must be accounted for. This may be done by rating each of the categories of data needs on a scale of 0-10, and entering the ratings into Tables 4.4 and 4.5.

Generally, model results are only as accurate as the least accurate inputs. Thus, for overall rating of input data, the lowest rated category should be used. For example, if the input water quality data (test 4.4.2, Table 4.4) have the lowest rating, then that rating should be used to represent the quality of all input data.

The quality and accuracy of calibration and verification data should be used to alter the input data rating, thus providing an overall data rating (Table 4.5). If the calibration and verification data are excellent, they may be used to tune some of the weak inputs, and the overall data rating may be improved from the input data rating. Conversely, if the calibration and verification data are very poor, the overall data rating should be reduced to account for the limited ability to assure accurate model results.

Manpower Rating

The capability of the manpower proposed to operate the candidate models and analyze their results is an important factor in the model PI ratings. For most project staffs this ability will be excellent in the case of very simple models. As models become more complex the manpower rating (see Table 4.7, test 4.7.2) of a given staff should be reduced. The extent of this reduction depends upon the staff capability.

In assigning the manpower rating consideration should be given to the amount of time available for staff training, and the level of expertise of possible contractors. Chapter 5 gives detailed discussions of these subjects. This rating for each model should be placed in the appropriate column of Table 4.7.

Summary of Phase III

This section presents the first part of the PI rating system. If the planner decides not to perform the more advanced, second part given in Phase IV, he should then select his attribute weights and make his final model selection as discussed in Sections 4.9 and 4.10 below. Otherwise, he should continue with Phase IV as presented in the next section.

4.8 PHASE IV - PERFORMANCE INDEX RATING: ADVANCED

The final phase of the model selection and cost effectiveness evaluation process is provided for more intensive probing into details of various candidate models. Most of the ratings in this phase require extensive user insight and experience in water quality analysis and modeling. For this reason it is included as optional in the overall selection process. A task flow diagram of all planner activities in Phase IV is given in Figure 4.4. Table 4.8 shows the work sheet for the Phase IV ratings. All of the ratings can be based on the appropriate evaluations given in Chapter 3. The guidelines for deriving ratings and weights are the same as those for Phase III.

Internal Factors

The purpose of this rating is to determine which models have the capability of handling appropriate internal factors including; dilution, advection, diffusion, biological decay, settling, and reaeration. To assign this rating the user must determine which internal processes have significant effect on his water quality problem. Then he should perform the pertinent evaluations shown in Chapter 3 (Table 3.3) for each candidate model. Ratings should be based upon a comparison of modeled internal process with those expected to be significant in the receiving water system, and should be entered into Table 4.8.

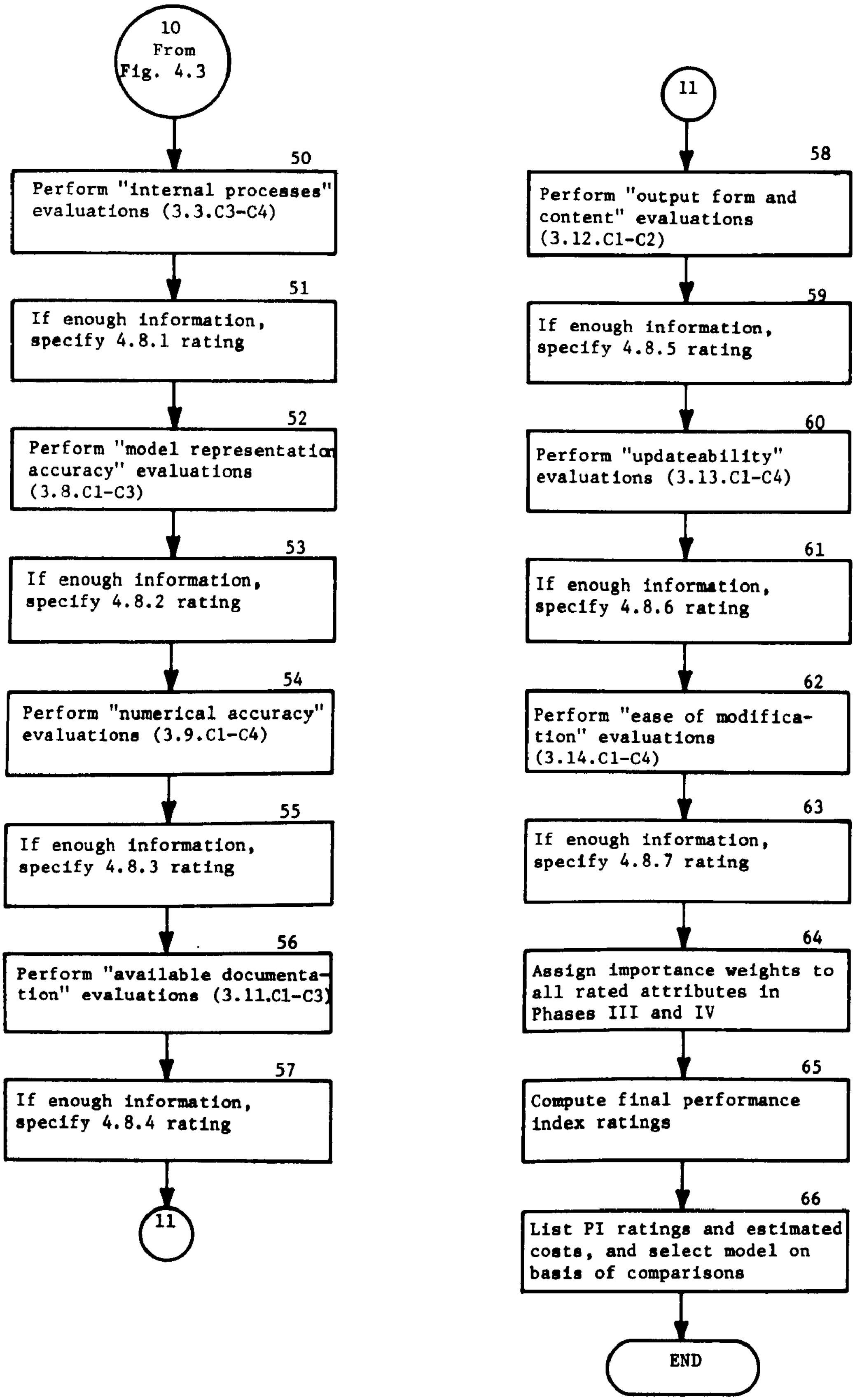

FIGURE 4.4 FLOWCHART OF PROCEDURE FOR MODEL SELECTION AND COST EFFECTIVENESS EVALUATION: PHASE IV - PERFORMANCE INDEX RATING, ADVANCED

Model Representation Accuracy

Model algorithms generally represent simplifications of events occurring in the real water system. These algorithms are usually in the form of mathematical equations which are arrived at under certain simplifying assumptions. Therefore, the simplifying assumptions used to derive model algorithms should be identified using available documentation and program listings, and their possible impact on overall model accuracy assessed.

The planner must rate each model on the basis of its ability to represent the actual water quality processes that it attempts to account for. Thus, he should examine each process modeled (generally found in theoretical descriptions in the model documentation), determine the simplifying assumptions used in representing these processes, and approximate the overall effect on the model outputs (water quality predictions) due to these simplifying assumptions. This is obviously not an easy task and requires much insight into water quality processes and the candidate models.

Numerical Accuracy

Another important factor which determines the accuracy of a mathematical model is its numerical characteristics. This is especially true of the so-called finite difference methods which rely on numerical approximations of differential equations to generate solutions. Models that solve analytical equations without these numerical approximations have no numerical problems, and therefore can be given an excellent rating in this category. For the other models two main factors must be considered in determination of numerical accuracy; stability and numerical dispersion (mathematically known as discretization error caused by the use of large spatial grid sizes).

Stability. Models which are unconditionally stable are generally safer to use than others which can develop huge errors under certain conditions of time-step size. Models which are conditionally stable can be successfully used, but more care must be taken in space step (Δx) and time step (Δt) selection to assure reasonable results. A typical stability constraint is of the form

$$\Delta t \text{ must be less than } \left[\frac{\Delta x}{V}\right]$$

V = A characteristic velocity, such as the tidal wave velocity.

As the desired spatial grid becomes smaller, the timestep must be made smaller to ensure preservation of stability in conditionally stable models. Reasonable costs must also be assessed, since computational costs are usually proportional to timestep smallness and the number of spatial grids.

Numerical Dispersion. The other factor, numerical dispersion, is very elusive and difficult to quantify. It is an undesirable quality brought about by solving equations in discretized grid form. In general, it is difficult to control and creates inaccuracies in model results. The extent of this problem varies greatly between models and even between applications of a single model. Models which, from historical experience, have had significant problems with numerical dispersion should be rated very low in this category, if only due to the unpredictable accuracy of the results.

Both stability and numerical dispersion are difficult factors to precisely quantify. For those planning staffs not familiar with these terms, it is wise to steer away from models which have been shown through any literature to have numerical stability or dispersion problems, or where information is not available to fully explain the numerical accuracy of past applications.

Ratings for numerical accuracy should be based upon the above considerations and entered into Table 4.8.

Sufficiency of Available Documentation

This and the following three ratings are for consideration of the relative ease of applications. The quality of available documentation can be very important in the successful set up and implementation of water quality models.

Excellent documentation would posses all of the following:

1) Detailed theoretical description;
2) Discussion of the numerical characteristics and parameter sensitivities;
3) Detailed discussion of how to set up the model including grid layout (descretization);
4) Program description including flowcharts;
5) Card by card description of model inputs including the assumed units;
6) Description of how to use model options, such as a flow augmentation option;
7) Detailed definitions of all variables used in the models;
8) Presentation and description of the model outputs;
9) Discussion of calibration and verification;
10) Program listings;
11) References.

The ratings in this category should account for the documentation coverage of each of these areas, and should be entered into Table 4.8.

Output Form and Content

The form and content of water quality model outputs can be of special importance to the planner. Some typical output forms are:

- Printed tables with headings,
- Plots of water quality and/or flow velocities,
- Magnetic tape or disk file storage,
- Long strings of numbers representing concentrations, but without headings.

The first three of these forms can each be particular benefit for certain applications. The last form is usually difficult to work with, requiring added analysis time, and may still lead to added analysis error. Generally, outputs should be well structured and labled in order to minimize user confusion.

The primary output of water quality models is a description of water quality distribution in the subject receiving waters. The content of this output may include:

- Statistical characteristics of water quality over simulated time periods,
- Water quality at each time step,
- Water quality only at end of simulation,
- Combinations of the above.

Other output contents which may be of importance are: printed input data (helpful in checking the input files); flows and velocities computed in the model; and kinetic coefficients computed in the model.

The ratings on this category should be made according to the above considerations of output form and content, and entered into Table 4.8.

Data Deck Design

One important use of mathematical models is to obtain answers quickly to various "what-if?" questions for possible alternative future events. Answering many such questions requires repeated applications of the model(s) with appropriate changes to the inputs. Therefore, input decks should be designed in a compact and efficient manner, and available documentation should give all the information needed to make the appropriate changes.

The rating in this category should be based upon the relative amount of effort needed to make re-runs of the models. This includes consideration of the number of cards needing changes, recomputation time, and the helpfulness of available documentation. The ratings should be entered into Table 4.8.

Ease of Modification

In many cases, some modifications to available models may be needed for specific applications. The ease of these modifications can vary greatly between models. The main factors which contribute to easy modifications are: proper code language, the use of many comment statements in computer code, the use of many subroutines in computer models, and the adequacy of available documentation (chapter 3, Table 3.14). Ratings in this category should be based upon the expected modifications needed for each model and upon the above-listed factors concerning the ease of modification, and should be entered on Table 4.8. If program modifications are definitely not needed, this category should not be rated.

4.9 SELECTION OF ATTRIBUTE WEIGHTS

The assignment of attribute weights should be made after the user has specified all his ratings (at the end of Phase III or IV, as shown in Figures 4.3 and 4.4). At this point he should have a good feel for the relative importance of each rated attribute.

As stated earlier, the weights are intended to account for the relative importance of the various attributes in a certain application. Typical ranges of weights for each attribute are shown in Table 4.1. The attribute weights should be recorded in the appropriate table (Tables 4.2 - 4.8) for final calculations of the Performance Index Ratings.

4.10 COST EFFECTIVENESS EVALUATIONS

Final model selection at the end of Phase III or Phase IV involves simple utilization of information derived in earlier tasks. This information consists of:

1) The total dollar costs derived in Phase II for each model:
2) The overall Performance Index ratings either from Phase III, or from both Phases III and IV.

TABLE 4.1 Attribute Weight Ranges

Attribute	Weight Range
Water Body	.8-1.5
Time Variability	.8-1.5
Discretization & Other Features	.4-1.2
Constituents Modeled	.5-1.2
Data Accuracy	.5-1.5
Manpower	.6-1.6
External Processes Accounted For	.7-1.2
Internal Processes Accounted For	.5-1.0
Model Representation Accuracy	.5-1.2
Numerical Accuracy	.5-1.5
Documentation Sufficiency	.2-1.0
Output Form and Content	.2- .8
Updateability	.2- .8
Ease of Modification	.2- .7

Note:

Values are normalized so that the average weight of the attributes is about 1.0

The dollar costs and PI ratings should be tabulated as illustrated in Table 4.9. Here, the expected performance and cost of each model can be compared for cost effectiveness ranking and model selection. In the last column of Table 4.9, the performance index to dollar cost ratio is given. The user can optionally use this ratio directly in model selection. However, in the final analysis the planner should use his own best judgment in conjunction with the computed values in this table.

4.11 DEMONSTRATION OF COST EFFECTIVENESS AND MODEL SELECTION METHODOLOGY

The major features of the methodologies presented in this chapter are demonstrated for a particular planning problem on the estuarine portion of the Snohomish River Basin in Washington State. The demonstration represents a realistic, although hypothetical water quality problem which could be addressed in an Areawide Waste Treatment Management Study [43] as required by Section 208, Federal Water Pollution Control Act Amendments of 1972.

Example Problem

The Snohomish Estuary is subject to municipal, and industrial wastewater, storm drainage, and extensive agricultural runoff. Many of these wastes are known to have substantial time variance. Wastes may also enter the estuary from its outer boundary, Puget Sound, through tidal movements. Most of the estuary is highly channelized, with several branching sloughs. The problem, which may require a mathematical water quality model, is to predict the varying levels of water quality as a result of future increasing point and non-point wastewater discharges.

Presentation of Results

Tables 4.2 - 4.8 present the work sheets which demonstrate results of the various tests and ratings for the example problem. The tables should be entered and read by proceeding in order of Phases, first for Phase I portions, then Phase II, etc. The numbers in these Tables are intended to be realistic, but are only used for illustrative purposes. Ratings and/or weights in phases III and IV could differ from those shown (even though the same models were being evaluated) depending on the nature of the receiving water body studied and the particular requirements of the individual model user.

Table 4.9 presents the final ranking of unrejected models. In this example RECEIV ranked highest. Had it been a requirement to model the full range of pollutants handled by SRMSCI, it would have been the model of choice. The costs, however, would have been higher because of the added costs of computer time, and the requirement for gathering additional data for calibration and verification. Furthermore, models are continually being changed and updated and the ratings could be much different for newer versions. The reader is cautioned, however, that as stated previously, a more complex model is not necessarily a better one. It is best to stick to the simplest model that will accomplish the task at hand.

TABLE 4.2 APPLICABLE SITUATIONS

CANDIDATE MODELS	4.2.1 WATER BODY			4.2.2 TIME VARIABILITY			4.2.3 DISCRETIZATION AND OTHER FEATURES		
	PHASE I APPLICABLE?	PHASE III RATING	PHASE III WEIGHT	PHASE I APPLICABLE?	PHASE III RATING	PHASE III WEIGHT	PHASE I APPLICABLE?	PHASE III RATING	PHASE III WEIGHT
DOSAG-1	NO								
SNOSCI	NO								
Simplified Stream (SSM)	NO								
ES001	YES			NO					
Simplified Estuary (SEM)	YES			NO					
QUAL-I	NO								
QUAL-II	NO								
Dynamic Estuary (DEM)	YES	8	1.2	YES	4	1.4	YES	6	0.6
Tidal Temperature (TTM)	YES	8	↓	YES	4	↓	YES	6	↓
RECEIV	YES	8	↓	YES	8	↓	YES	8	↓
SRMSCI	YES	8	↓	YES	8	↓	YES	8	↓
Deep Reservoir (DRM)	NO								
LAKSCI	NO								
Outfall PLUME	NO								

TABLE 4.3 CONSTITUENTS MODELED

CANDIDATE MODELS	4.3.1 CONSTITUENTS MODELED			4.3.2. DRIVING FORCES AND BOUNDARY FACTORS ACCOUNTED FOR		
	PHASE I APPLICABLE?	PHASE III RATING	PHASE III WEIGHT	PHASE I APPLICABLE?	PHASE III RATING	PHASE III WEIGHT
DOSAG-I						
SNOSCI						
Simplified Stream (SSM)						
ES001						
Simplified Estuary (SEM)						
QUAL-I						
QUAL-II						
Dynamic Estuary (DEM)	YES	6	1.1	YES	6	0.9
Tidal Temperature (TTM)	YES	7		YES	7	
RECEIV	YES	6		YES	8	
SRMSCI	YES	8		YES	8	
Deep Reservoir (DRM)						
LAKSCI						
Outfall PLUME						

TABLE 4.4 DATA REQUIREMENTS FOR MODEL INPUTS

CANDIDATE MODELS	4.4.1 HYDROLOGIC AND GEOMETRIC			4.4.2 WATER QUALITY		
	PHASE I		PHASE III	PHASE I		PHASE III
	APPLICABLE?	APPLICABILITY LIMITATIONS	RATING	APPLICABLE?	APPLICABILITY LIMITATIONS	RATING
DOSAG-I						
SNOSCI						
Simplified Stream (SSM)						
ES001						
Simplified Estuary (SEM)						
QUAL-I						
QUAL-II						
Dynamic Estuary (DEM)	YES	NONE	7	YES	NONE	5
Tidal Temperature (TTM)	YES	NONE	7	YES	NONE	5
RECEIV	YES	NONE	7	YES	NONE	6
SRMSCI	YES	NONE	7	YES	NONE	6
Deep Reservoir (DRM)						
LAKSCI						
Outfall PLUME						

TABLE 4.4 (Cont.) DATA REQUIREMENTS FOR MODEL INPUTS

CANDIDATE MODELS	4.4.3 EFFLUENT			4.4.4 OTHER		
	PHASE I		PHASE III	PHASE I		PHASE III
	APPLICABLE ?	APPLICABILITY LIMITATIONS	RATING	APPLICABLE ?	APPLICABILITY LIMITATIONS	RATING
DOSAG-I						
SNOSCI						
Simplified Stream (SSM)						
ES001						
Simplified Estuary (SEM)						
QUAL-I						
QUAL-II						
Dynamic Estuary (DEM)	YES	Only constant point source	4	———		
Tidal Temperature (TTM)	YES	"	4	———		
RECEIV	YES	"	4	———		
SRMSCI	YES	"	4	———		
Deep Reservoir (DRM)						
LAKSCI						
Outfall PLUME						

TABLE 4.5 DATA REQUIREMENTS FOR CALIBRATION AND VERIFICATION

CANDIDATE MODELS	4.5.1 HYDROLOGIC AND HYDRODYNAMIC			4.5.2 WATER QUALITY			4.5.3 OVERALL DATA RATING	
	PHASE I		PHASE III	PHASE I		PHASE III	PHASE III	
	APPLICABLE ?	APPLICABILITY LIMITATIONS	RATING	APPLICABLE ?	APPLICABILITY LIMITATIONS	RATING	RATING	WEIGHT
DOSAG-I								
SNOSCI								
Simplified Stream (SSM)								
ES001								
Simplified Estuary (SEM)								
QUAL-I								
QUAL-II								
Dynamic Estuary (DEM)	YES	NONE	8	YES	NONE	6	6.0	0.8
Tidal Temperature (TTM)	YES	NONE	8	YES	NONE	6	6.0	
RECEIV	YES	NONE	8	YES	NONE	6	6.2	
SRMSCI	YES	NONE	8	YES	NONE	6	6.2	
Deep Reservoir (DRM)								
LAKSCI								
Outfall PLUME								

TABLE 4.6 INITIATION COSTS (PHASE II)

CANDIDATE MODELS	4.6.1 MODEL ACQUISITION		4.6.2 EQUIPMENT REQUIREMENTS		4.6.3 DATA ACQUISITION	
	TIME T(4.6.1)	COST C(4.6.1)	TIME T(4.6.2)	COST C(4.6.2)	TIME T(4.6.3)	COST C(4.6.3)
DOSAG-I						
SNOSCI						
Simplified Stream (SSM)						
ES001						
Simplified Estuary (SEM)						
QUAL-I						
QUAL-II						
Dynamic Estuary (DEM)	1 week	$40	0	0	20 weeks	$18,000
Tidal Temperature (TTM)	2 weeks	$40	0	0	20 weeks	$18,000
RECEIV	2 weeks	$40	0	0	20 weeks	$16,000
SRMSCI	2 weeks	$40	0	0	22 weeks	$20,000
Deep Reservoir (DRM)						
LAKSCI						
Outfall PLUME						

TABLE 4.7 UTILIZATION COSTS (PHASE II)

CANDIDATE MODELS	4.7.1 MACHINE COSTS		4.7.2 MANPOWER COSTS				TOTAL COSTS		COST CONSTRAINT TESTS	
	COST PER RUN	TOTAL C(4.7.1)	TIME T(4.7.2)	COST C(4.7.2)	RATING	WEIGHT	TIME	COST	TIME OK ?	COST OK ?
DOSAG-I										
SNOSCI										
Simplified Stream (SSM)										
ES001										
Simplified Estuary (SEM)										
QUAL-I										
QUAL-II										
Dynamic Estuary (DEM)	$190	$5,500	17 weeks (2 men)	$27,200	6.0	1.0	38 wk	$50,740	YES	YES
Tidal Temperature (TTM)	$195	$6,000	20 weeks	$32,000	6.0	↓	42 wk	$56,040	YES	YES
RECEIV	$200	$5,000	20 weeks	$32,000	7.0	↓	42 wk	$53,040	YES	YES
SRMSCI	$210	$6,500	21 weeks	$34,000	6.0	↓	45 wk	$60,540	YES	YES
Deep Reservoir (DRM)										
LAKSCI										
Outfall PLUME										

TABLE 4.8 PERFORMANCE INDEX RATING: ADVANCED (PHASE IV)

CANDIDATE MODELS	4.8.1 INTERNAL FACTORS ACCOUNTED FOR RATING	4.8.1 INTERNAL FACTORS ACCOUNTED FOR WEIGHT	4.8.2 MODEL REPRESENTATION ACCURACY RATING	4.8.2 MODEL REPRESENTATION ACCURACY WEIGHT
DOSAG-I				
SNOSCI				
Simplified Stream (SSM)				
ES001				
Simplified Estuary (SEM)				
QUAL-I				
QUAL-II				
Dynamic Estuary (DEM)	5	0.6	7	0.5
Tidal Temperature (TTM)	5		7	
RECEIV	6		7	
SRMSCI	8		8	
Deep Reservoir (DRM)				
LAKSCI				
Outfall PLUME				

TABLE 4.8 Cont. PERFORMANCE INDEX RATING: STAGE 2 (PHASE IV)

CANDIDATE MODELS	4.8.3 NUMERICAL ACCURACY RATING	4.8.3 NUMERICAL ACCURACY WEIGHT	4.8.4 SUFFICIENCY OF AVAILABLE DOCUMENTATION RATING	4.8.4 SUFFICIENCY OF AVAILABLE DOCUMENTATION WEIGHT	4.8.5 OUTPUT FORM AND CONTENT RATING	4.8.5 OUTPUT FORM AND CONTENT WEIGHT
DOSAG-I						
SNOSCI						
Simplified Stream (SSM)						
ES001						
Simplified Estuary (SEM)						
QUAL-I						
QUAL-II						
Dynamic Estuary (DEM)	4	0.8	7	0.5	8	0.3
Tidal Temperature (TTM)	4	↓	7	↓	8	↓
RECEIV	8	↓	6	↓	8	↓
SRMSCI	8	↓	7	↓	8	↓
Deep Reservoir (DRM)						
LAKSCI						
Outfall PLUME						

TABLE 4.8 Cont. PERFORMANCE INDEX RATING: STAGE 2 (PHASE IV)

CANDIDATE MODELS	4.8.6 UPDATEABILITY RATING	WEIGHT	4.8.7 EASE OF MODIFICATION RATING	WEIGHT	OVERALL PI RATING (PHASE III & IV)
DOSAG-I					
SNOSCI					
Simplified Stream (SSM)					
ES001					
Simplified Estuary (SEM)					
QUAL-I					
QUAL-II					
Dynamic Estuary	6	0.6	8	0.3	5.96
Tidal Temperature (TTM)	6		7		6.14
RECEIV	6		6		7.15
SRMSCI	6		7		7.64
Deep Reservoir (DRM)					
LAKSCI					
Outfall PLUME					

TABLE 4.9

COST EFFECTIVENESS COMPARISON

RANK	MODEL	PI RATING (From Phases III &IV)	TOTAL COST OF APPLICATION (From Phase II)	PI*104 / DOLLAR
3	DEM	5.96	$50,740	1.17
4	TTM	6.14	56,040	1.09
1	RECEIV	7.15	53,040	1.35
2	SRMSCI	7.64	60,540	1.26

CHAPTER 5

MANAGEMENT OF MODELING

5.1 INTRODUCTION

The approach to water pollution control has changed significantly in recent years. Emphasis is being placed on comprehensive planning for increasingly larger regions than heretofore and on the implementation of plans. The extremely high financial and social costs of plan implementation has required increasingly more explicit and detailed analyses of greater numbers of alternatives.

The foregoing and other trends have affected the manner in which water quality planning is conducted. Interdisciplinary teams working within short time frames are responsible for guiding the efficient expenditure of large amounts of planning funds and for the use of sophisticated technologies, among which modeling is eminent. It is assured that the use of water quality models will become even more widespread in the future.

Those persons responsible for supervision of significant water quality planning programs must be prepared to deal extensively with decisions related to modeling. Reluctance to use water quality simulation models where their analytical strengths are applicable will severely handicap planning. Yet, many of the agencies presently being assigned water quality planning responsibility do not have an already developed capability for modeling and many planners are not experienced in supervision of water quality modeling programs.

Adequate administration of water quality modeling programs requires that managers be prepared to develop or acquire appropriate technical capability and effectively integrate this capability with the remainder of the planning team. This Chapter addresses some of the management considerations attendant to undertaking a water modeling program.

5.2 NEED FOR ASSISTANCE

The planning manager must assess the adequacy of the existing in-house staff to undertake and complete any new program which is to be initiated. The earliest possible recognition of deficiencies is beneficial in that it allows maximum flexibility in remedial action.

Types of Assistance Required

The major reasons for securing assistance are the need for specialized expertise and need for additional manpower. Occasionally the two needs may merge. It is important that the nature of need be explicitly recognized, as it may affect the procedures for obtaining assistance and the sources which are considered.

Specialized Expertise. One of the basic decisions affecting the need for obtaining specialized expertise is selection of the type of modeling, if any, to be used. While the less complex modeling procedures based on nomographs may be readily applied by most planning staffs, the introduction of computerized models often represents a substantial increase in complexity and requires an entirely new set of skills.

The particular disciplines required in a computerized water quality modeling program depend on the type of model or models to be used, the availability of data and facilities, and the detail of the results which is expected. The skills needed may range from those for preparation of data inputs and model execution to those required to modify an existing model or develop a new model appropriate to the situation at hand. Generally, the decision to model implies a need for capability in the selection of the specific type and version of model to be adapted or constructed, data analysis, programming, key punching, machine operation, and interpretation of results. Less obviously related capabilities may also be needed, such as those for directing or accomplishing water quality sampling and analysis. Assessment of the full range of expertise which is needed to conduct a water quality modeling program must be based on a thorough identification of each step in the intended program. This assessment requires some familiarity with both modeling and planning.

Additional Manpower. A need for contractual services for water quality modeling or related services may arise quite apart from the need to obtain specialized expertise. Even if adequate technical capability is available on staff to carry out all of the modeling related activities, the existence of other commitments, accelerated time schedules, or the need for simultaneous conduct of activities at several locations may require obtaining assistance. The planning manager should carefully appraise manpower needs with regard to the type and level of experience required. If adequate technical capability exists on staff to make all decisions and to provide supervision, less experienced and less expensive assistance can be obtained. Similarly, in arranging assistance primarily to obtain additional manpower, some thought should be given to the effectiveness of how that manpower is used. While it might be most convenient, for example, to press all available personnel into service to conduct a widespread water quality sampling program, the use of contracted professionals for that purpose is not likely to be cost-effective.

Timing of Assistance

The stage of the planning process at which water quality modeling expertise is required and the extent of assistance needed vary according to the type and purpose of the plan to be prepared. It is largely independent of whether such expertise is available on staff or obtained through contracting.

It would be desirable, of course, for the planning manager to maintain constant and detailed coordination with all members of the planning team. Practicality prevents this, however, particularly in the early stages of the planning process. At that time, the full identification of the planning participants may not be complete, but may include individuals from multiple federal, state, and local agencies and from the private sector. In addition to defining the planning process in sufficient detail to proceed, the planning manager may be engaged in the development of organizational arrangements, preparation of applications or requests for funds, and miscellaneous other activities. Time is at a premium under such circumstances and crucial errors may be made if modeling related considerations are not given adequate attention. It is particularly important that realistic budgets and schedules for water quality modeling be established from the outset and that a proper decision be made as to the general type and level of modeling to be included. Detailed consideration of the modeling program is also important during design of the inventory phase of the planning process, development of procedures for plan formulation and evaluation, and in arrangements for future updating of the plan.

While some specific attention must be given to water quality modeling (or at least to whatever technique of analysis is to be used) at each of several stages in the planning process, the detail and intensiveness of consideration depend on the overall importance of water quality and the analysis techniques to meeting project purposes. Water quality modeling is clearly a more major part of a planning effort than one to guide land use or general water resources development. The same types of concerns discussed in Chapter 4 relating to selection of cost effective procedures of analysis indicate the stress to be placed on water quality modeling as opposed to other elements of the plan.

At whatever stages of the planning process decisions regarding water quality modeling are made, and regardless of the importance of water quality modeling vis-a-vis other planning elements, experienced and expert counsel should be available to the planning manager. It should be recognized that the information contained in Chapters 2, 3 and 4 is only a rudimentary introduction to modeling. This material is intended to assist planners in communicating with modeling specialists and to assist in some basic decisions regarding water quality modeling. Some additional points of greater complexity than those included or indicated therein may be important in a particular case.

5.3 IN-HOUSE vs. CONTRACTUAL SERVICES

The decision as to whether modeling or other services related to modeling should be carried out by in-house staff or on a contractual basis warrants particular attention. Depending on the circumstances at hand, the appropriate extent of contractual services may range from none to a preponderate portion of any particular project. Careful analysis of project requirements and objectives as well as in-house capability is required to assure that the proper types and amounts of services are contracted.

Advantages of In-House Efforts

There are considerable advantages to carrying out some or all of the water quality modeling portions of a planning effort with in-house staff. Among others, these include certain aspects of the following:

1. Coordination
2. Ease of supervision
3. Management flexibility
4. Implementation capability
5. Updating capability
6. Cost

Whether the advantages of the above outweigh the advantages of contracting for services to accomplish a particular planning elements depends on the applicable circumstances and the importance attached to each potential benefit.

Coordination. The use of in-house staff considerably eases problems of achieving a desirably high level of coordination, particularly where only one agency is furnishing all or the bulk of the required staff effort. The familiarity of staff members one with another and their prior experience in cooperatively conducting other programs facilitates the development of smooth and productive working relationships. Where staff members have responsibility for management of or participation in other agency programs, cognizance of those programs and their relationship to the planning effort is automatically assured.

Aside from the achievement of coordination, the mechanics of performing coordination can frequently be made simpler, less formal, and far less time consuming if only staff members are involved. Transmittals of information may be supplemented by frequent discussions; group meetings are less difficult to arrange; and events may be managed on a day to day basis.

Ease of Supervision. A far greater capability usually exists for close technical supervision if water quality modeling activities are carried out in-house. When outside assistance is used, it is generally necessary to specify in some detail the procedures to be followed, unless arrangements are made on a time and materials basis. In some cases, such as those where the identification of problems to be addressed has not been completed, specification of all technical procedures may be difficult and prone to error. Any errors which are discovered may be difficult and expensive to correct if contractual modifications are required. This is not to suggest that in-house modeling efforts can or should be undertaken without detailed fore-thought or pursued without well prepared guidance. However, errors or deficiencies may be detected earlier and corrective action more readily initiated when only staff members are involved.

Management Flexibility. Problems inevitably arise in any planning program which affect the intended smooth flow of activities. Disruptions may include sudden changes in funding, acceleration or delay in schedules and/or the introduction of new objectives resulting from federal or state legislation or other sources. Any of these may require changes in the planning program ranging from minor adjustments to thorough revisions. The types of corrective action required to accomodate unforeseen conditions may be severely constrained by contractual commitments or at least expensive to undertake.

Water quality modeling programs are particularly vulnerable to changes in approach because of their complexity and the substantial preparation which precedes model use. The type and purpose of planning may, and probably will, affect the likelihood of such changes. For example, the extent of water quality modeling which might be used in a framework study pursuant to Section 102 of the Water Resources Planning Act of 1965 (Public Law 89-80) may not be critical to the success of the plan. If modifications are necessary to conserve time or funds, water quality modeling may be considered as a minor program element and either abbreviated or totally eliminated in favor of other techniques of analysis. This type of modification is far less likely to occur in those planning programs in which water quality management is the principal concern. In short, in-house accomplishment of water quality modeling may offer substantial benefits where uncertainties exist in the future of the planning program.

Capability to Implement. The objective of most planning programs is implementation of one sort or another. The range of potential implementation action which might be undertaken for water quality control purposes is large. Framework level studies seldom result directly in project development since they are not suitably detailed to serve as a congressional authorization document. They may give rise, however, to further functional planning for water quality improvement, development of specific project plans, and other similar activities. Basinwide water quality planning may result in identification of regional treatment schemes, needs for new facilities or modification of existing facilities, and standards of ambient or effluent quality. Areawide waste treatment management plans directed by Sec. 208 (b) of Public Law 92-500 are assured of requiring a diversity of actions which may include structural programs for point and nonpoint sources of pollution, regulatory programs for point and nonpoint sources of pollution, and further efforts at problem identification and planning.

Implementing water quality management plans of various types will require knowledge of and perhaps further application of the analytical techniques used in planning. Benefits may correspondingly result from maintaining the continuity of experienced individuals and organizations. The magnitude of any such benefits and their consequent impact on the decision to develop in-house capability for water quality modeling or to use contracted services may vary. Factors to be considered in making the decision include, among others, the certainty of the necessary funding, authorization, and other requirements for any anticipated future activities.

Capability to Update. Few plans of significant scope are firmly fixed in time, and some updating of plans is normally anticipated. Modifications may come about through general revision and improvement or through adjustments to specific items of new information. Water quality models and other planning aids involve significant investments. The opportunity for their repeated use in updating or otherwise revising the plan makes their original use more cost-effective. The continued use of water quality models may also be useful in testing the effect of proposed developments or policies, or assuring their consistancy with the plan. These or other reasons may indicate the future need to apply the same water quality models on a repetitive basis. Where this need is anticipated, there may be advantages to assuring the capability to update or modify plans or operate the models for other purposes exists on an in-house basis. The capability to update implies a thorough understanding of the tools for analysis including their limitations, applicability, and the assumptions on which they are founded. The most certain way of assuring this capability is to perform all original work on an in-house basis. When this is impractical, inclusion of adequate provisions for staff training by the contractor may be necessary.

The importance of achieving the capability for future model use in deciding to perform water quality modeling on an in-house basis depends on the extent, nature, and timing of the expected future use. Some plans, such as broad statewide plans, Level A framework studies, and the Level B studies pursuant to Public Law 89-80 may only be scheduled for revision or updating every 5 to 10 years. Considerations of future model use in such cases must include the possibility of staff turnover, development of improved analytical techniques and any uncertainty of need. Similarly, updating may not be a factor in planning for specific facilities which are not expected to be updated in the future. However, for some types of planning, updating is mandatory. Areawide waste treatment management plans, for example, are to be updated on an annual basis [Sec. 208(b)(2)(A)]. Other types of water quality control planning directed by Public Law 92-500 such as that pursuant to Sec. 303(e) are to be maintained on a continuing basis. Where the near future need to update is assured, the development or use of in-house capability for water quality modeling has significant advantages.

Cost. Assuming that time-consuming and expensive staff training can be avoided, the conduct of water quality modeling programs is less expensive if done using in-house capability. In addition to the obvious elimination of the profit component of a contractor's cost, savings may arise from other sources including elimination of travel, costs of contracting and contract administration, salary differential, and allocation of overhead. The magnitude of the savings resulting from a decision to develop in-house capability may be substantial under certain conditions. Their appraisal should not overlook the following:

1. Recruitment costs (if additional staff are required);
2. Cost of compensation including salary, taxes, and other parts thereof;
3. Overhead including costs for space, utilities, administration, supervision, and supporting services; and
4. Costs resulting from non-productive time such as vacation, sick leave, periods of low workload and others.

If the appraisal of cost indicates that it is advantageous to carry out water quality modeling activities on an in-house basis, and such an approach would be consistent with other program needs or constraints, then the risk of doing so should be carefully reviewed. If experienced and expert staff are already available or can be recruited quickly, there is little risk in proceeding. However, if the water quality modeling program is to be initiated and pursued while the development and training of staff is underway, the opportunity for serious errors may overshadow any cost savings. In this event, consulting assistance of at least an advisory nature can be very useful.

Advantages of Contractual Services

The use of contractually arranged services has several potential advantages. As previously noted, contracting offers one means of obtaining technical expertise, additional labor, or both. Contractual services also provide a means for initiating and pursuing programs concurrent with development of the staff capability needed to implement and update plans which are prepared. In addition to those important advantages, the use of contractual services may save time, result in a lower overall cost, and assist in staff management.

Time Savings. Well established consulting firms operating within their area of special expertise can be of considerable use in the prompt initiation and aggressive pursuit of a planning program. Such firms often have expert staff available who can assist in making many of the technical decisions without the need for lengthly research. Frequently, if consulting staff have participated in programs similar to those being undertaken, their familiarity with state, federal, and other requirements may help in expediting the preparation of a detailed plan of work and initiation of the planning process.

In some cases, considerable time may be saved by the selective retention of contractors who have particular experience. For example, water quality analyses and modeling conducted as part of areawide waste treatment management planning pursuant to Sec. 208 of Public Law 92-500 might be considerably aided in some of its parts by appropriate use of contractors who are engaged in or who have completed related work for one or more communities within the designated area. Conversely, specific facilities planning might be accomplished more efficiently by use of contractors who have had specific experience in the region as a part of areawide or basinwide planning. In either case, the contractor's familiarity with the local situation is a valuable commodity which enhances his technical capability and helps assure coordination between at least the modeling related portions of different planning programs. Similar to the preceding, some benefits may be obtained by the use of common contractors for the preparation of appropriate portions of Level B studies and water quality plans pursuant to Sec. 303(e) of Public Law 92-500.

Additional time savings may result from using contractual services for water quality modeling due to the contractor's access to equipment and the availability of specific models or other needed items which may have been prepared or used previously.

Chapter 6 includes a discussion regarding the procedures for assuring potential contractors have the requisite capability to be of immediate assistance.

Cost. Notwithstanding the usually higher cost of contractual services on a man-hour basis, there may be some financial savings attendant to their use. As an example, the wider array of specialists available through an appropriate contractor may increase the efficiency with which particular technical tasks are accomplished. In addition, there may be substantial savings of an administrative nature, since the contractor's fee normally includes payment for the technical and other supervision necessary to provide whatever product was specified and to assure its adequacy. In some cases, the schedule for planning may not require the continual participation of modeling specialists and, in that event, the contractor absorbs the cost of idle time.

Management. Difficulties are commonly encountered in balancing staff size against workload, particularly for smaller offices. Initiation of new programs for water quality planning or other purposes frequently require expansion of the existing staff. If the new program is to be pursued only for a limited period of time, managers are faced with the need to reduce staff until a new expansion in personnel is needed for some later project.

Even if desirable as a management approach, there are several obstacles to such a staffing policy.

The time required to locate, interview, recruit, orient and train new staff prior to their fully effective participation may require several months. In addition, potential employees may be reluctant to accept employment on a short term basis at normal compensation levels. Difficulties can be encountered in quickly locating sufficient numbers of persons with appropriate qualifications. Wide variations in the number of technical staff members may also adversely impact the overall management and operation of relatively small organizations through stimulation of undesired growth in administrative and other supporting staffs. If staff expansions of major scope are undertaken to accomplish projects of limited duration, administrators must anticipate a difficult period during which employees are terminated.

Use of contractually arranged services to meet peak workload requirements can relieve many of the management problems which would otherwise exist. Staff growth and selective recruitment of individual staff members can be oriented more specifically to the long term needs and goals of the organization. Similarly, the supporting services for the technical assistance thus obtained is largely or wholly provided by the contractor.

5.4 INTEGRATION OF MODELING AND PLANNING

Water quality models are tools for accomplishing one portion of the planning process. Their effective use demands more than the technical expertise to select, prepare, execute and interpret the results of whatever model may be used. It is imperative that the use of such analytical tools and the analyses performed be properly and thoroughly integrated with the numerous other portions of the planning process. Adequate integration of activities does not occur automatically. It requires that the analyst and planner both recognize explicitly the different nature of their respective roles, the relation between modeling and planning, and the means whereby coordination can be achieved.

Nature of Planning and Modeling

Planning and modeling are distinctly different activities. However, they cannot be separated to the extent that planners are isolated from the modeling-related decisions or that analysts do not participate in planning. The close cooperation of both is needed and when secured, is mutually beneficial.

Planning Process. The planning process required to support resource management decisions in the public sector is enormously complex for all but the simplest cases. Generally, decisions of any magnitude are arrived at only after extensive consideration of numerous alternatives. Participants in the decision making process frequently include the public or some part of the public forming the constituency of the decision makers; federal and state officials, agencies, and departments; and various local entities including general and special purpose governments and special interest groups. Each of these participants may view whatever problem is to be addressed in different terms according to their objectives. Each may accordingly place various constraints on the types of solutions which are acceptable and the methods of implementation which will be supported.

It is the planner's task to describe the problem satisfactorily. This includes describing its severity and urgency, assembling and interpreting the information necessary to identify alternative solutions, and assisting in selection of the preferred solution. As part of the foregoing, the planner must articulate or participate in the articulation of objectives and goals, identify informational needs and appropriate techniques of analysis, and develop the criteria for selection among feasible alternative plans. The planner must also find suitable ways of presenting the results of the planning effort in a meaningful way which facilitates its use by other participants in the planning process.

The major types of planning programs which are either specifically undertaken for water quality control purposes or which include consideration of water quality control as one of their principal purposes require that consideration be given to all aspects of the problems addressed and the solutions proposed. Generally the planner must investigate the engineering, financial, economic, environmental, social and perhaps other aspects of alternative plans. The number of alternative actions which could be taken may be large. Their evaluation requires that the planner have the capability available to systematically apply suitable analytic techniques. Water quality models are one available technique.

Modeling. The process of modeling or otherwise performing the analyses needed for planning requires that the analyst participate in the description of the problem and in the selection of the analytical techniques to be used. In addition to performing the analyses, the analyst should be prepared to assist in the selection of alternative plans to be considered, evaluate the effect of assumptions, and assist in the presentation and interpretation of results.

Depending on the type of planning undertaken, analysts concerned with water quality modeling may represent only a portion of the analytical capability on the planning team. In such cases the water quality analysts must be prepared and able to effectively cooperate with analysts having other responsibilities and to achieve compatibility among the technologies employed.

Relation of Modeling to Other Planning Activities

As suggested in the preceding discussion of the nature of planning and modeling activities, the planning process includes a number of elements which can be accomplished more effectively with the assistance of the analyst and the availability of models. A comprehensive and detailed discussion of the relationship between modeling and planning would depend on discussion of a specific case. However, the general and broadly applicable relationships of modeling to major portions of the planning process merits note.

Most plans, including broad framework studies and statewide plans, Level B studies and other basinwide plans and more specific plans for smaller areas are approached in a similar fashion. The general steps include description of the problem and organization for planning, data gathering, development and evaluation of alternatives and recommendation of the preferred solution.

Description of the Problem. The full description of water quality problems or the water quality component of problems requires identification of the location, nature, and magnitude of the pollution sources as well as the resulting impact on water quality. Preparation of a complete problem description may be relatively easy in the case of individual point sources of waste which have been or can be readily monitored and where ambient water quality changes can be directly related to specific effluents. In other and more complex cases, arriving at an adequate description of the problem may constitute a major portion of the planning process. In these more difficult cases, the water quality analyst, using modeling or other appropriate techniques, becomes a key member of the planning team.

Nonpoint sources of pollution occurring with variable severity throughout an area or different portions of an area and in conjunction with one another present a particularly difficult task for a planner. Component parts of such pollution loads must be identified and quantified in at least general terms. Otherwise, corrective actions are likely to be proposed on a more or less arbitrary basis and without assurance or even a knowledgeable estimate of their efficacy. The financial and social costs of pollution abatement measures are too large to permit such speculative planning. It falls then to the analyst and the planner to set forth an analytical procedure which will remove the mask of complexity and enable clear understanding and description of the problem.

The kinds of analytical assistance required by the planner in problem definition varies. In many cases, the analyst's assistance is needed to accumulate the water quality and other data which is already available, transform it into the most useful format and terms, and help infer its meaning. More detailed and/or more complex analyses may be necessary for areawide waste treatment management planning, facilities planning, waste-load allocations studies, and other specific types of plans. It may be necessary in some instances to use sophisticated models to help interpret available information. Regardless of the level of problem definition which is required, it is generally useful for planners to anticipate that some analytical assistance will be needed for proper problem definition and to provide for its early availability.

Inventory Phase. Some forethought must be given to planning to insuring the availability of required information in the form and at the time it will be needed. The analyst should play an important part in itemizing the types of data and information to be used throughout the planning process, comparison of the data and information needed and available, and identification of needed data collection. Water quality models have specific data requirements as noted in Chapters 3 and 4. Review of the data and information to be used in the modeling or other analytical procedures can be a major aid in assessing the overall data requirements of the planning program.

Development and Evaluation of Alternatives. The analyst may be of substantial assistance to the planner in the development of alternative plans and plays the key role in evaluation of their potential impact on water quality. Assistance in the development of alternative plans may include identifying all of the factors whose modifications would favorably affect water quality, describing the sensitivity of water quality to various types of changes which might be planned, and displaying alternative plans in a systematic fashion which facilitates their study. Based on the experience gained in testing early alternatives and observation of the reaction of the system to various proposed modifications, the analyst may be particularly helpful in suggesting the scale and location of various plan features.

It is a principal responsibility of the analyst to identify the water quality impacts likely to result from whatever alternative plans are developed. Given an alternative plan, the analyst must translate the plan into appropriate mathematical terms, perform the analysis using a simulation model or whatever other technique has been selected and report the results in an understandable fashion.

The analyst and the planner must work together closely throughout the plan formulation and evaluation portion of the planning process. The planner must simultaneously coordinate the effort of the water quality analyst with those analysts evaluating other aspects of each alternative to assure the overall assessment gives appropriate attention to all important points.

Recommendation of the Preferred Solution. When the evaluation of various feasible alternatives has been completed, the planner is usually required to recommend or suggest a preferred plan which best meets the original objectives within the applicable constraints. Often, the planner is required or desires to present other meritorious alternatives for public and official review.

Full display of alternative plans for water quality control or for plans of larger scope including water quality control measures is difficult. To promote understanding on the part of lay reviewers, displays should be brief and relatively simple. Yet, oversimplication can obscure important points. The planner and the analyst must cooperatively identify the characteristics of each plan to be displayed and the best method of display. Importantly, the analyst should itemize all of the assumptions on which the assessment of water quality rests and the probable effect of errors therein, point out the accuracy of the analytical procedures which were used, and array results in some organized form.

Achieving Integrated Planning

The frequent and extensive interaction between the planner and the analyst described in the preceding sections can be achieved if the arrangements for planning are made with such interaction in mind. In particular, specific attention should be given to the nature of the relationship between planning and modeling while preparing the plan of work and the schedule and budget therefore.

Plan of Work. The plan of work becomes a guide to performance of the planning effort when it is completed. Where grant funds are involved, the plan of work may also become a part of the contractual arrangement between grantee and grantor. Extreme care is needed in preparing the plan of work for complex planning efforts to insure the activities described and their sequence will result in successful completion. Unless the planner is well versed in the details of the analytical procedures to be used, the analyst should participate fully in the preparation of the plan of work. The descriptions of individual tasks within the plan of work should be in sufficient detail to identify all of the interrelationships between analytical and planning efforts. Special care should be taken to insure that no important steps are omitted and that the sequence of activities will enable the maximum integration of activities.

Schedules and Budgets. Scheduling and budgeting a plan of work is frequently made difficult by the number of constraints imposed by legislation, grantor agencies and perhaps other sources. Along with the obvious need for consistency with time and funding constraints, schedules and budgets must be prepared so as to properly pace the planning process and to place appropriate emphasis on each aspect of the effort. The time and cost of water quality modeling should be adjusted to provide a level of detail and accuracy which is commensurate with other analyses to be performed. Schedules and budgets must reflect the full cost and time of steps preparatory to modeling as well as for the modeling effort. These and other types of considerations make it mandatory that analysts assist in the preparation of schedules and budgets. Failure to give proper attention to the details of analytical procedures during schedule and budget preparation usually results in underestimation of the time and cost required. If this occurs, the planner will face an unduly difficult problem in integrating modeling and the prospect of making major adjustments in the planning process after work has begun.

CHAPTER 6

USE OF CONTRACTUAL SERVICES - ADMINISTRATIVE, LEGAL AND PLANNING CONSIDERATIONS

6.1 INTRODUCTION

Decisions to use mathematical models to assist in water quality management planning should be based on a well defined need. Likewise, selection of the particular model or type of model to be used must be made considering the model will be used in the planning process. These assessments as well as the carrying out the planning process requires expertise in mathematical modeling and planning. Sufficient expertise may exist in-house or may be obtained through the use of contractual services. This Chapter discusses the several steps of obtaining contractual services for purposes related to water quality modeling and contains some suggestions of procedures therefore.

The usual purpose in using contractual services for the preparation or use of water quality models is either to obtain access to skills which are not available on an in-house basis or to supplement the amount of manpower available. In either case, the objective is to obtain a needed product or service at a fair price, on a timely schedule, and in a manner most compatible with other parts of the planning process.

The general steps involved in securing and using consultant services which are dealt with in this chapter include:

- Planning the Procurement;
- Preparation of the Request for Proposal;
- Preparation of the List of Bidders;
- Solicitation of Proposals;
- Evaluation of Proposals;
- Contractor Selection;
- Contract Negotiation Preparation, and Award; and
- Project Administration.

Many of the basic procedures which must be followed by governmental bodies in carrying out the above steps are frequently established by Federal and State statutes, rules and regulations, ordinances and/or explicit policies controlling the business practices of public agencies. No specific effort has been made to tabulate or identify specific legal requirements of these types. However, the discussion calls attention to those points likely to be subject to particular legal requirements. The discussions presented herein describe generally beneficial practices. They are not intended to replace an adequate legal review of procedural requirements.

6.2 PLANNING THE PROCUREMENT

Consideration should be given to certain general aspects of contracting before any effort is made to prepare a Request for Proposal. The principal preparatory steps include an evaluation of the type of contractural arrangement to be developed and the capability of the in-house staff to conduct the procurement process satisfactorily.

Types of Procurements

Procurement of assistance in water quality modeling may be done on either a competitive or non-competitive basis. A competitive procurement, in turn, can either be advertised or negotiated. An advertised procurement includes bids and award of the contract to the lowest responsive bidder, based on compliance with a detailed study design or plan of work. A negotiated procurement usually involves reaching agreement with a contractor without formal advertising for bids, but after soliciting proposals from several qualified sources. A non-competitive (sole source) procurement is a contract negotiated directly with a single source. Each of the several types of procurement procedures have different characteristics which affect their suitability for use in differing planning situations.

Advertised Procurements. The publicly advertised procurement is probably the best known procedure in the public works area or in general governmental use. This procedure may sometimes be suitable for use in obtaining, modeling or modeling-related assistance. However, there are several criteria which should be considered in determining whether an advertised procurement should be used in searching for a suitable contractor. Unless comparison of the situation to those criteria indicates that this type of procurement is in order, the costs associated with the advertisement process may not be recouped. The principal criteria which should be met are:

1. The modeling or modeling-related services required can be defined in sufficient detail to permit qualified contractors to bid a fixed price for completion of the desired services on a relatively equivalent basis;
2. The modeling or other services required are such that the contract can be awarded on the basis of only the fixed price without a technical evaluation of the contractor's proposed techniques;
3. A number of qualified sources exist which could conceivably respond to the advertisement (a later section titled "Identification of Prospective Contractors" addresses this determination); and
4. The anticipated value of the procurement is large enough to warrant the expense of an advertised procurement. Local regulations will frequently specify minimum procurement value.

Negotiated Procurement. The more flexible negotiated procurement is frequently used for modeling services. The conditions indicating use of this procedure often fit the situation which exists at the time water quality planning efforts are initiated. Those conditions include:

1. The modeling-related services desired cannot be explicitly described in sufficient detail to eliminate all considerations but cost; and
2. The work to be performed is of sufficient complexity and depth that an evaluation of the approach and techniques proposed for accomplishment is warranted.

If it is determined that a negotiated procurement will be made, either a competitive or non-competitive route toward negotiation may be followed. Before deciding on the use of non-competitive negotiation for a particular procurement, a detailed investigation of legal matters should be made to assure correct procedure. Non-competitive procurements are usually restricted to special circumstances.

Legal Considerations. While most types of contracting arrangements are enabled for governmental bodies, strict regulations sometimes exist as to the circumstances under which each may be used. The need to obtain the most favorable conditions normally requires consideration of more than one contractor and competition is frequently required by law unless unusual conditions warrant the use of a non-competitive (sole source) negotiated procurement. While the specific requirements justifying a sole source procurement may differ between various governmental units, they generally include one or more of the following:

1. The procurement is excluded from competition due to small cost, procurement from another public agency, or a finding that the desired service is only available from a single source. (This latter basis is not likely to exist with regard to water quality modeling services);
2. The procurement is a continuation of previous work;
3. A substantial investment already made in one Contractor's work would have to be duplicated by another; or
4. The service required is patented, copy-righted, or proprietary.

Planning Considerations. It is important to note that in undertaking any contracting for modeling or modeling services, the nature of the services or products sought must be identified to the fullest degree possible. Any uncertainty pertaining to the technical aspects of the modeling, the type of simulation desired, or the role of modeling within the overall planning program, should be specifically recognized. Planners should insure that administrative staff and others involved in a potential procurement are aware of the degree of uncertainty on these and any other important points.

The range of effort on the part of the contractor which might be needed to respond to these uncertainties may play an important part in the selection of procurement procedures and the type of contractual arrangement to be used. In particular, advertised and competitive procurements tend to be most applicable to those cases in which little uncertainty exists and the services needed can be exactly described.

Conducting the Procurement Process

Before beginning the procurement process, an assessment should be made of the in-house capability to conduct each step of the process without assistance. It should be particularly noted that preparation of the technical portions of an adequate RFP requires nearly the same knowledge and skills as those being solicited. If these capabilities are not available in-house, the Purchaser may be well advised to retain a consultant to assist in making a preliminary assessment of the type and amount of assistance needed, the relationship between modeling and planning, and in preparing the RFP. When proposals are received, the same consultant can perhaps render valuable assistance in their evaluation. However, retention of a consultant for these purposes should exclude that consultant from consideration in contracting for carrying out those or other closely related portions of the work.

If it appears that a consultant will be needed to assist in any part of the procurement process, the necessary services should be arranged at an early date.

6.3 PREPARATION OF THE REQUEST FOR PROPOSAL

Several potential contractors are usually considered in any substantial procurement involving a fixed scope of work. As one basis for selection, it is usually necessary that each contractor to be considered provide a proposal or offer of services for review. The basis for such offers is the Request for Proposal (RFP) issued by the purchaser. The purpose of the RFP is to describe the work desired in sufficient detail to bring forth proposals which are clear, to the point, and which contain the information needed for their comparison and analysis. The RFP should also be sufficiently explicit to avoid the submission of unqualified or poor proposals due to misunderstanding of the services which are sought.

A well prepared RFP is a major step toward a satisfactory project in any undertaking. This is especially true in the case of a rapidly developing technology such as water quality modeling. The extra effort spent in the methodical preparation of a well defined and well written RFP results in submission of better organized and more responsive proposals from the potential contractors. This, in turn, simplifies the subsequent evaluation and contractor selection tasks and helps assure ultimately satisfactory performance by the contractor. The proposal request and proposal evaluation activities are so closely interrelated that each section of the RFP should be developed with the idea in mind of evaluating the contractor's response to that section.

Prior to writing the RFP, consideration should be given to at least the following questions:

1. What is the type and level of planning, purpose and importance of the planning in which the Purchaser is engaged or about to undertake; what is the role of modeling in the overall project; and, what in-house resources are available to complete or participate in completion of the work?

2. Is a contractor needed to provide expertise or additional manpower; and, what are the specific qualifications or expertise required for providing the needed assistance?

3. On what basis will the prospective contractors be evaluated and a successful contractor be selected?

4. What type of contract (i.e., fixed price, time and materials, cost plus fixed fee, etc.) is expected to result from the procurement?

5. How will the contractor's performance be monitored, and what will constitute satisfactory performance?

6. In what way will the contractor's end results aid the Purchaser and the agencies working with the Purchaser in achieving their objectives?

These broad questions should be answered, at least in a preliminary form, at the time preparation of the RFP is begun, rather than during or after preparation. The answers should largely be the result of an early analysis of what level of modeling, if any, is required. The first and last questions in particular require that detailed consideration be given to the relationship between modeling and other parts of the planning process.

The remainder of this section gives some suggestions for the structuring and content of an RFP. The subheadings that follow may, with minor variations as appropriate, be the ones used in the RFP. Administrative, legal and technical knowledge are needed to compose a complete RFP.

Program Objectives

Before undertaking preparation of the RFP, the originator should have at hand a clear statement of the problem, the objectives of the project, and the desired end results. In addition, he should possess some knowledge of the procedural requirements to be followed in the procurement process. Assembly of this information requires a joint effort of the planning, administrative, and/or legal staff members. At this point, it may not be clear yet what type of water quality model is needed or exactly what types of data might be required to support their use. However, the RFP should leave no doubt about what specific problems the Contractor is to address, what specific end items he is to deliver, and what these deliverables are to accomplish for the Purchaser.

A good definition of the work to be contracted is highly desirable and aids the Purchaser in several area including:

1. Preparing and organizing the entire RFP document;

2. Estimating the scope, duration and nature of the needed consulting services;

3. Assessing the probable data requirements and the availability of data;

4. Determining the type of contractual arrangement best suited for the desired services;

5. Evaluation of proposals and selection of Contractors; and

6. Ensuring that the entire contract effort will be aimed at producing the specific end items needed to satisfy job requirements.

A clear statement of the problems to be addressed by the Contractor and the specific objectives to be met also helps the potential contractors to prepare responsive proposals. An RFP which unambiguously identifies the Purchaser's needs and the Contractor's responsibilities is particularly beneficial for a number of reasons which, among others, include:

1. Encouraging contractors to concentrate proposal efforts on meeting the prescribed needs and responsibilities, rather than attempting to interpret the Purchaser's requirements;

2. Reducing the need for the Contractor to request clarification of requirements as he prepares his proposal.

3. Encouraging a greater number of responses through a reduction both in the cost (and risk) of proposal preparation and in the uncertainties of estimating the cost of project performance.

The description of the technical objectives of proposed contractural services is seldom undertaken by administrative staff. However, contractural arrangements for water quality modeling often have specific objectives closely related to administrative decisions. One commonly encountered example is that of training. If an administrative decision has been made to develop in-house capability in the modeling area, a contractor may be expected to provide training in addition to the performance of selected technical tasks. If this is the case, appropriate objectives should be identified by the administrative staff to guide that portion of the effort. Other areas for administrative consideration include the desired visibility of consultants through participation in public meetings, their relationship to other involved agencies and the matters of how work is performed, transmitted, and coordinated.

The major portion of the effort required to accurately describe the technical objectives of the services to be contracted is normally the responsibility of the planning staff. The description of objectives should be as specific as possible. As an example, a statement such as "the objectives include selecting, verifying, and applying a model to predict water quality" in a river, lake, or estuary leaves many questions unanswered. The objectives could, in addition, very usefully describe the particular constituents to be modeled, the desired accuracy of prediction, the specific reaches of water to be modeled and other basic information.

In those cases where the planning to be undertaken is guided by well defined federal or state programs, quoting or referencing legislatively established objectives or those included in published guidelines may be useful.

Scope of Work

Once the technical and administrative objectives of the project have been determined, the extent and type of consulting services which are needed can be established. It is usually advantageous to prepare a Scope of Work statement. If prepared, the Scope of Work should summarize the individual tasks to be performed and the expected end items (usually called deliverables) to be provided by the Contractor. The Scope of Work should also explain the specific responsibilities which the Purchaser will assume to aid the Contractor in carrying out his work.

The Scope of Work should identify the practical limitations on the services to be performed by the Contractor. These limitations may be due to the portion of the overall planning budget allocated to the modeling related services, the available data, the desired time schedule, or other more subjective considerations.

It is important for all Proposers to clearly understand the Purchaser's needs and to have a realistic concept of his resources. This information is best conveyed to the Proposer as an integral part of the written RFP as oral communications about the scope of work are too easily misinterpreted. If discussions concerning the Scope of Work take place during preproposal interviews, it should be clearly impressed upon the Proposer that such comments are informal and that the written Scope of Work provides the official description of the services desired.

Background of Program

The RFP should contain a section presenting a sufficient amount of appropriate background information to familiarize Proposers with the subject of the solicitation. The background statement may include historical information and describe existing conditions, expected developments, and any major decisions which are already made or pending. It should also describe any unusual complexities which might arise during the project. The foregoing and any other considerations should be presented which, in the Purchaser's judgment, are necessary for a Proposer to acquire a good understanding of the reasons for issuing the RFP and the problems addressed in the RFP.

Background information of a technical nature is particularly useful to potential Proposers in sizing up the problem and in anticipating the manner in which the project will be pursued. Information on past studies and the principal conclusions thereof, pending physical developments, and imposed schedules supplements and assists in interpretation of the Scope of Work and Objectives sections of the RFP. Particular agencies which will be participating in the project should be identified and the procedures for coordinating their respective efforts should be stated. In most cases, specific identification of the particular program (e.g., areawide waste treatment management planning pursuant to Section 208 of Public Law 92-500, or wasteload allocations pursuant to Section 303 of Public Law 92-500) toward which the contracted services are to contribute will aid considerably in conveying the expected level of detail.

Depending on the nature of the consulting services requested, the necessary background information may be condensed into a short paragraph or it may require an extensive discussion with illustrations. In the latter case, it may be convenient to provide the narrative and/or the illustrative material as an appendix or separate attachment to the RFP.

It is appropriate in some cases to provide the necessary background information orally to each Proposer during a pre-qualification interview (Section 6.4.2). Distributing this material in writing, however, assures that all Proposers receive exactly the same information and, consequently, that none of them obtain a privileged position.

Technical Information and Data

Depending on the nature of the planning which is to be conducted, the water quality models and/or modeling-related services which are needed may have substantially different data requirements. Some of the needed data may be available from various studies carried out previously, while others must be measured, estimated or assumed.

All of the types of data thought to be needed should be identified and its availability determined before preparation of the RFP. In addition to identifying its availability, the validity of data from various sources should be examined. Comparison of suitable existing data to the data needed for the various types of models (see Section 4.2.5) will indicate the magnitude of any data deficiencies.

Data deficiencies warrant special attention due to the high cost which can be encountered in field investigations. Needs for data which are identified may be met in some cases by use of "typical" values from the literature at a cost far less than that for field collection of data. The suitability of one method over another depends on the particular type of data needed, the sensitivity of model results to factors dependent on the missing data and expectations of model accuracy. Care should be taken to avoid requiring a higher degree of accuracy in data inputs than is justified by the intended use of the model results.

Using the results of the preliminary investigation of data needs and availability, the Purchaser should carefully design the portions of the RFP which deal with the data related aspects of the project. It is generally convenient to sub-divide this portion of the RFP into sections dealing with Purchaser supplied information and Contractor supplied information.

Purchaser Supplied Information. In this section of the RFP the Purchaser should identify and provide the types of technical information which will enable the Contractor to define the various tasks of his proposal in sufficient detail for accurate identification of the associated time and costs. Data needed for the Contractor's proposal preparation effort should be presented in the body of the RFP if it is not too extensive. If the information cannot be conveniently presented, then appropriate and readily available references containing such data should be listed in the RFP. Requiring contractors to spend an excessive amount of time and effort to secure the information necessary for proposal preparation could discourage presentation of a thoughtful and productive proposal which might otherwise be forthcoming.

The RFP should outline in detail the types of data that would be made available to the selected Contractor for the performance of the contract and the form and sources thereof. Data to be used in the work effort may include information which is already available to the Purchaser or to be gathered and compiled by the Purchaser prior to or after award of a contract. The RFP should also describe or note any information available from various sources which is subject to approval and/or modification by the Purchaser before its use.

Finally, the data thought or known to be needed which is not available from the Purchaser should also be identified. Such information may already be available to the Contractor from other sources or have to be collected and compiled by the Contractor after award of a contract. Alternatively, some information may not be available from any known source, and must therefore be assumed by the Contractor subject to approval by the Purchaser.

Contractor Supplied Information. While the RFP should identify in detail at least the types of data that the Purchaser is capable of and planning to supply to the Contractor, the Contractor-supplied data may be identified in broader terms. It may sometimes be appropriate to include a requirement in the RFP for the Bidder to state all data requirements for the project, whether or not the Purchaser is able to supply certain types of information. In this case, the Bidder should be requested to identify overall data requirements, suggest methods for acquiring all input data, and discuss the importance or value of each type of information for the purpose of the modeling or other effort to be contracted. Analysis of the responses to these types of requirements will give a good indication of the Bidder's understanding of the problem, the project objectives, and the type of services desired.

Estimated Time and Effort

It is in the Purchaser's interest for the RFP to indicate his commitments and resources, as well as his needs. When preparing a proposal, a Bidder should have a reasonably good idea about the desired schedule and/or completion date and the general level of effort desired by the Purchaser.

The RFP may indicate the desired level of effort by stating an anticipated or approximate dollar value for consulting services. Alternatively, the RFP may indicate the Purchaser's estimate of the magnitude of the needed Contractor's effort in man years or man months. Finally, the RFP may specify only time schedules, tasks, and deliverables and ask the Bidders to estimate the cost of services independently.

Availability of information concerning the approximate number of dollars to be spent can partially compensate for inadequacies in the description of work required. However, the manner and detail of information provided may be subject to strict control. A legal review of this point should be obtained before issuance of an RFP containing such information or before responding to inquiries.

By all means, care should be taken not to expose the amount of money certified or otherwise available when the procurement is essentially a competition between qualified bidders based on the lowest price. Likewise every effort must be made to avoid exposing such information to one and not another of the bidders.

The various preceding considerations are vital to determination of the price which will eventually be paid for the requested services. Whichever approach is chosen, the Purchaser should keep in mind that buying professional engineering services is different from buying equipment or non-professional labor, and differences in prices do not tell the whole story about the amount and quality of services rendered. An unsatisfactory situation may easily occur if the price ultimately agreed upon is not equitably matched to the expected products or services.

Project Organization and Work Statement

The RFP should specify, in as much detail as practical, any individual tasks, steps or phases into which the Purchaser desires the work to be divided. The products or deliverables which are expected to result from each increment of the project should be identified. The section of the RFP containing this description may be titled "Statement of Work", "Organization of Work", "Guidelines for the Contractor", "Tasks and Deliverables", or some other heading appropriate for the particular project and the RFP. By whatever name it is called, the purpose of this section of the RFP is to:

1. Organize the project into major tasks;
2. Define the deliverable end items at the conclusion of each task; and
3. Pave the way for the definition of a contractually binding work statement for the selected Contractor.

The Purchaser is well advised to describe each task and each deliverable in detail if adequate information and knowledge is available concerning the consulting work to be performed, the requirements for and availability of input data, and the expected end results. A detailed work statement may enable the Bidder to size up his tasks with sufficient confidence to quote prices without consideration of any additional cost for contingencies due to uncertainty.

The inclusion of a detailed work statement in the RFP is not always practical and may involve considerable risk because of the nature of the project. In such a case, the RFP should encourage or require the Contractors to describe the tasks and deliverables in detail in their proposals. In this event, the detailed definition of tasks and the structuring of the project becomes one of the most important requirements of a responsive proposal and should specifically be discussed in the RFP.

The RFP should require each proposal to include a complete Statement of Work in which each major task and deliverable is individually identified and described. If possible, each major task and deliverable should also be priced out separately. There is an advantage in avoiding a too general work statement with a large single lump-sum cost. Contracts of this type are difficult to manage and the price is difficult to substantiate.

Emphasis in pricing should be placed, however, on major tasks (e.g., no less than $5,000 to $10,000 per task), since too many small tasks unnecessarily complicate contract management and can escalate administration expenses.

A logical and consistent format should be used in the RFP for specification of tasks, division of the work into phases and other matters which help organize the technical portions of the project. If overall study schedules are established and flow charts prepared, they should be presented and may provide the needed organizational concept through the time sequencing of activities. In the absence of a sound schedule, activities can be grouped according to their type such as inventory, analysis, plan formulation and evaluation, and review. However done, the organizational concept should be stated and instructions given as to how proposals should relate to the concept.

The difficulty of proper and timely evaluation of a number of proposals places a premium upon obtaining some uniformity among the proposals presented.

Project Monitoring

The RFP should deal explicitly with the procedures which the Purchaser will follow in reviewing and approving the Contractor's performance. A section of the RFP should be devoted to this and, at a minimum, should describe the following:

1. All major points (milestones) of review and approval;

2. Reports required of the Contractor including periodic progress reports, oral presentations, written or published interim reports, papers, technical notes, deliverable items specified in the Contract Work Statement, and final reports;

3. Statement of the time periods required for Purchaser's approval of each Contractor supplied report or deliverable item; and

4. Description of the mechanics of the reporting, review and approval process with particular attention to who receives what report in

how many copies, and what constitutes approval.

The clear definition of the review and approval process is very important, especially if deliverables other than periodic progress reports are to be provided. Overall monitoring of project progress can be facilitated if deliverables subject to acceptance or approval by the Purchaser mark the conclusion of major tasks. Such deliverables, if agreed to represent task completion when approved, enable both parties to measure progress more accurately.

Care should be taken in describing the arrangements for monitoring projects to assure the contractor anticipates and commits to supply meaningful information. Periodic written progress reports should follow a carefully prescribed format which facilitates comparison of consecutive reports. In addition, the detail of technical information to be contained in progress reports should be specified. Any Contractor supplied estimate of completion should be clearly defined as to whether it is to be on the basis of dollars expended, hours of effort, or some other measure of progress. Written progress reports should also require the contractor to explicitly identify and describe any difficulties encountered in carrying out the work effort and any actions necessary on the Purchaser's part to rectify the situation.

In addition to written progress reports, it may be useful to require the participation of the contractor in periodic meetings of all key project participants to enable and assure coordination of all aspects of the planning process.

Project Staffing

As a rule, the RFP should request the Contractor to provide a comprehensive staffing plan for the project. Contractor supplied information should include the names of all key personnel the Contractor expects to be involved in the project and the extent of their availability for project work.

The RFP should require that the Contractor's Project Manager or Principal Investigator who will be responsible for the Contractor's technical and financial performance on the project be identified by name in the proposal. A statement should also be required which outlines his responsibilities to the Purchaser, his position in the Contractor's organization and the authority given him to represent the Contractor in prosecution of the project. As appropriate, other key personnel should also be identified by name, position, related experience and the nature of their assignment to the project. For a major contract, other experienced personnel who are available to the Contractor and may be assigned to the project on an "as-needed" basis should also be identified.

A description outlining staff assignments planned by the Contractor for each major task of the project should be requested whenever appropriate. Such a description may include the specific responsibilities of each key individual on each task, and the percentage of his time to be spent on this assignment over a specified period. Alternatively, the RFP may ask for identification of the number of professional hours or days anticipated to be contributed by each individual to each task. The availability of the key personnel who are identified for particular assignments or whose qualifications are particularly cogent should also be stated, and possibly guaranteed, in the proposal. To enable evaluation of the availability of the staff proposed by the Contractor, it is helpful to request identification of any other projects for which the proposed staff members have concurrent responsibility.

In all considerations of project staffing, the Purchaser should bear in mind that Contractors' employees are subject to variations in their performance, and that Contractors may sometimes experience staffing problems unforeseen at the time of proposal. Reasonable flexibility in Contractor staffing should be anticipated and allowed for in the Purchaser's enforcement of any submitted staffing plans. As a general rule, changes in proposed staffing should not be a source of conflict as long as the Contractor's performance is not detrimentally affected.

The contractor's capability to coordinate his efforts with those of other contractors and/or in-house staff may be important if the modeling or modeling-related services to be procured cannot be clearly separated from other portions of the planning process. In this event, the RFP should specifically request the Contractor to identify the staff proposed for this function and to describe their prior experience and other qualifications with emphasis on planning management.

Project Schedule

One of the most important aspects of management of a planning program is its timely execution. The high level of interdependency between various planning activities makes it essential that all parties responsible for an identifiable portion of the work, including contractors, have well defined schedules. Adherance to schedules generally becomes increasingly important as the complexity and scope of planning increases and as additional disciplines are incorporated in the study program.

The RFP should require the Contractor to provide an explicit schedule for completion of the proposed work. The schedule should include the time for performance of all separately identified tasks, the dates of deliverables, schedules for presentations, Purchaser's approvals, report production and publication. It is generally unimportant whether schedules are summarized in tabular, bar-chart or PERT-chart form. Whether constructing a schedule to be included in the RFP or reviewing a Bidder proposed schedule, the reasonableness of the individual work items and deadlines of the schedule should be very carefully examined. For example, schedules should be evaluated to assure adequate time is provided for data collection after allowance for unforeseen difficulties and seasonal limitations, model verification, report preparation, report approval, staff training, and other project tasks. Schedules should also contain some provisions for contingencies. It may also be useful for the Purchaser to determine how the proposed schedule compares with those of other similar projects, and with the schedules of any other major projects which a Contractor may have underway or planned.

The analysis of any requested or proposed schedule should be sufficient to convince the Purchaser of its feasibility, any assumptions of abnormally high level of effort or efficiency on the part of the Contractor's or Purchaser's staff members.

Project Costs

The cost of the modeling or other services must be addressed in the RFP regardless of the role of price in the evaluation of proposals. It is convenient to devote a separate section of the RFP to a discussion of the project costs and the specific cost information expected to appear in Contractor's proposals.

Each Proposer should be required to state the total price of his proposed services. This price may be a single figure of total cost in the case of a firm fixed-price contract or a price ceiling not to be exceeded without prior approval by the Purchaser in case of a cost-plus-fixed-fee contract. As may be applicable, the RFP should state either that any modification of the price wil- require renegotiation of the contract, or that requests for price increases cannot be considered. If permitted, any modification of the cost after execution of a contract should always be based on a demonstration of clear advantage to the Purchaser.

If the Statement of Work adequately identifies all major tasks, it is often to the Purchaser's advantage to request a breakdown of the total cost to separate major tasks. This approach encourages good financial management of the project by the Contractor and enables closer monitoring of the Contractor's progress by the Purchaser.

With the notable exception of the fixed-price contract, most types of contractual arrangements require quotation of the Contractor's labor rates by categories of personnel, as well as identification of the type and amount of the various burdens which will be added to labor and direct costs.

Any details concerning cost which are requested by the RFP should preferably be submitted as a separate cost proposal accompanying the technical proposal. While the latter may include the total price but not the cost breakdown, it is desirable to completely eliminate cost information from the technical proposal in the case of competitive bidding. The inclusion of all cost information in the cost proposal enables easier handling of the technical proposals during evaluation if the Purchaser desires to insure the technical evaluation is separate from and not influenced by price considerations. The separation of cost and pricing data from technical proposals should not prevent evaluation by the technical staff of the Contractor's proposed level of effort. Proposers should be requested to include labor hours and other non-dollar information in the technical proposal.

Provisions for cost escalations or cost overruns should be stated in the RFP when such escalations may reasonably be expected and will be permitted. Similarly, the RFP should describe any penalties which will be imposed for non-performance, unsatisfactory performance or excessive delays due to negligence on the part of the Contractor.

Acceptance Period

The RFP should identify the time period for evaluation of the proposals and for entering into contract negotiations with the successful Proposer. The Contractor's proposal should be required to state an acceptance period for which the proposal remains in effect, in conformance with the time period requested in the RFP.

Contractor Qualifications

The RFP should request the Proposer to furnish relevant information on specific factors that qualify the Contractor to provide the particular services which are sought including:

1. General background and history of the Proposer's organization in providing modeling-related services and in water quality planning;

2. Staff organization;

3. Office locations and facilities pertinent to the project;

4. Specific experience of the Proposer's organization and of individual staff members in the detailed subject matter of the RFP including familiarity with the specific models to be used, the use of models for water quality planning, and the type or level of planning to be undertaken;

5. Specific experience and staff qualifications in the general area of water quality modeling and water quality planning;

6. References to similar or analogous projects completed and/or underway by the Contractor;

7. Technical and financial references; and

8. Biographies, resumes or other appropriate information concerning key staff members and consultants.

Basis For Evaluation

The procedure to be followed in the proposal evaluation process and the main factors to be considered should be stated in the RFP. This information is important as it guides the Proposer in preparing a proposer responsive to the needs of the Purchaser and which can be easily evaluated.

A separate section of the RFP can be devoted to proposal evaluation. This section can be brief, but should include among others, the following items of information:

1. The major criteria for proposal evaluation such as overall quality, understanding of the problem, soundness of technical approach, data requirements, ease of implementation, contractor qualifications, price, or others important to the Purchaser;

2. The approximate or relative weights to be given to each criteria in the evaluation process;

The RFP should state if the evaluation of technical and cost proposals will be done independently. In general, it is preferable to handle the technical evaluation completely independently from the cost evaluation and consider prices only after the technical evaluation is complete. This procedure eliminates the need for detailed analyses of the cost and pricing data for technically inadequate proposals.

The role of a consultant in assisting the Purchaser to prepare the RFP or evaluate proposals should be clearly stated in the RFP whether or not the Consultant is identified. In general, identification of any consultant involved in the evaluation process is preferable.

The evaluation of proposals can be faciliated by instructing Proposers in regard to the format to be used. The objective of such instructions is to have the principal proposal elements relating to the evaluation criteria clearly identified. Proposer compliance with organizational instructions will minimize the time and effort for the comparison of proposals to the requirements of the RFP.

Establishment of the criteria for technical evaluation is an important step toward eventually obtaining the most suitable services. If criteria are general and non-specific, they may not provide an adequate explanation to Proposers of those points thought most important by the Purchaser. Development of the appropriate technical criteria is largely a planning responsibility.

Instructions To Proposers

The RFP should discuss the procedures to be followed by the Proposer in submitting the proposal and the Purchaser's method of handling proposals. The discussion of these points should include a description of:

1. The names and address of the individual or department to the technical and cost proposals should be mailed or delivered;

2. The deadline for delivery of proposals and whether the date of postmark or date of receipt determines compliance with the deadline;

3. The Purchaser's handling of proposals (e.g., complete confindential treatment; non-disclosure of proprietary information only; or full disclosure, as well as the ownership or return of submitted proposals);

4. Notification to Proposer of receipt of proposals;

5. Procedures for Proposers to follow in requesting clarification of points in the RFP during proposal preparation and the Purchaser's method of responding to such requests (e.g., questions to be submitted and answered in writing only; questions to be asked at Bidder's conference only; or any other preferred method);

6. Notification to Proposers concerning the return, if any, of their proposals;

7. Any oral interviews and discussions of proposals which are planned, the basis on which Proposers will receive such invitations, and the method of conducting interviews; and

8. The method of initiating contract negotiation with the successful Proposer.

Any instructions necessary to protect the Proposer's interests such as marking of proprietary information should be specified. Likewise, instructions to protect the Purchaser's interests such as formalizing any discussions during the proposal period should be explicitly described. Specific dates and places of Bidders' conferences should be identified if they are scheduled in advance. Possible contingencies to contract execution such as agency approval or availability of funding, should be clearly stated.

If the Purchaser represents several agencies who will participate in the evaluation, contracting or contract monitoring procedures, all parties should be clearly identified in the RFP.

6.4 PREPARING THE BIDDERS LIST

Before the RFP can be made available to Contractors the means of distribution should be explicitly decided. The adequate review of proposals for complicated technical efforts is time consuming and expensive. It is often desirable to determine to whom the RFP will be provided before its first release. This determination generally includes the identification and qualification of prospective contractors and establishment of a List of Bidders.

Identification Of Prospective Contractors

There are two alternative approaches for compiling a list of firms or individuals from which the prospective contractors (i.e., Bidders) will be selected. A direct solicitation of Contractor interest may be undertaken through advertisement, announcements, press releases, or other similar means. Alternatively an indirect solicitation of promising prospects may be made using information from other sources such as federal and state agencies which have used various contractors for similar purposes.

Governmental purchasers are frequently required by law or regulations to award contracts on a competitive basis in certain situations. In such cases, it may be expedient to solicit an expression of interest from prospective Bidders through some type of widespread advertisement. This approach makes the Purchaser's plans known to a large cross-section of potential Bidders and the Purchaser may establish contact with some very capable and qualified consultants theretofore unknown to him. The disadvantage of solicitation of advertisement is the effort and time required to receive and sort out the many responses, only some of which may be relevant to the Purchaser's needs. It also entails the burden of time and cost required to answer the many personal or telephone contacts that may follow as a result of such solicitation. If an advertisement is used, it should advise that its purpose is solely that of securing an expression of interest by potential Contractors, and that receipt of responses will not be acknowledged nor will the Purchaser be obligated to issue an RFP to any of the respondees. In addition, the Purchaser may choose to advise that the procedure and results of the pre-qualification process will not be disclosed.

Qualification Of Prospective Contractors

The objective of either of the approaches described in the preceding section or a combination of them is to establish a list of prospective Bidders. This first list may be expected to require some screening in order to arrive at the List of Bidders to whom the RFP will be issued.

Depending upon the number of prospective contractors identified and the number of Bidders to be identified, several steps may be necessary to carry out the qualification process including reference checks, pre-qualification and selection of Bidders.

Reference Checks. The method of checking references is particularly important if the pitfalls of irrelevant information are to be avoided. Reference checks should involve contacting more than one source of reference. A single good recommendation may not assure the prospective Contractor's capabilities or his suitability to the Purchaser's specific needs. Similarly, care should be taken that a single unfavorable comment does not eliminate an especially well-qualified consultant. Reference checks should attempt to identify the reasons behind either a favorable or unfavorable opinion and the context in which any recommendation is made.

Pre-Qualification. The preliminary list of prospective bidders established after the initial screening of expressions of interest and references must generally be further narrowed to a final List of Bidders to whom the RFP will be issued. While the exposure to a number of alternative approaches and different ideas is highly desirable, the Purchaser's resources for assimilating and evaluating proposals may be limited. What constitutes a reasonable number of bidders depends on the particular situation. If a medium range plan requiring extensive and detailed analysis of numerous waste water management alternatives is to be prepared and modeling is intended to be used as a principal tool, then the sizeable costs involved may make it worthwhile to carefully study a large number of proposals.

Several procedures may be used to reduce the number of potential bidders to the few which are best qualified. The two methods most commonly used for this purpose are requests for written pre-qualification statements and the conduct of oral pre-qualification interviews.

Both approaches have their advantages and disadvantages. Written pre-qualification statements provide formal brief but well-organized material which can be evaluated efficiently. However, reliance upon written statements does not provide personal contact with the contractor's key staff members or the opportunity to ask and pursue relevant questions. A personal meeting with the contractor often gives additional insight into his capabilities and the potential working relations which might be established.

The oral interview provides a great deal more flexibility and requires less preparation on the part of the Purchaser. However, it requires the participation of more Purchaser staff members in the meeting and in a post-meeting evaluation and it is likely to lead to a more subjective evaluation of the prospective bidders.

If a request for written "Statements of Qualifications" is issued, the Purchaser should summarize the background and main objective of the planned project in the request so that the recipient can judge the applicability of his experience and qualifications. It is to the Purchaser's advantage to state clearly those specific questions he wants to be answered in a summary form. In addition, the request for the statements should prescribe that the statements meet any criteria important to the Purchaser. Frequently, such instructions require statements to do the following:

1. Be brief (e.g., not more than a certain number of pages specified by the Purchaser; omit necessary illustrations or irrelevant material);

2. Be factual (e.g., refer to accomplished facts which can be easily checked rather than generalities or future plans);

3. Answer specific questions; and

4. Demonstrate only relevant experience, capabilities and facilities.

If oral interviews are conducted for pre-qualification they should:

1. Provide equal time for each party interviewed;

2. Attempt to provide the same information to and ask the same questions of each party interviewed; and

3. Permit the prospective Bidder to use his own discretion in

presenting his qualifications within the time limit set forth in advance.

Selection of Bidders. After the prospective Bidders have submitted their qualifications either in writing or via interviews, the evaluation and selection of Bidders may take place. Preferably this should be performed by more than one member of the Purchaser's staff and is frequently accomplished by a committee effort. Assuming a committee is assigned for the task, the evaluation procedure might include the following sequence of steps:

1. Establishment of a ranking of the prospective Bidders by each member of the committee including a brief justification for the recommendation to "retain" or "eliminate", and for the ranks assigned in the group of prospective Bidders recommended to be retained;

2. Committee review and comparison of the recommendations of its individual members. Should the recommendations widely differ for certain prospective Bidders, the members of the committee should jointly examine each such case and try to reconcile differences in opinion;

3. Re-evaluation by individual members of the committee of any unresolved cases after having heard the arguments for and against their inclusion in the List of Bidders; and

4. Decision by the person having the final authority (e.g., the appointed Project Manager, Department Head, etc.) if, after an additional joint meeting, some cases still remain unresolved.

The number of prospective contractors to be finally retained and issued the RFP depends on the nature of the project and the desired consulting services as well as on the ability of the Purchaser to give a thorough evaluation to each proposal submitted. In some cases the list may be limited to two or three firms while for other projects inclusion of up to a dozen competitors may be warranted.

Bidders who are considered to be only marginally qualified should not be placed on the list. The cost of preparing a proposal for a sizeable complex project is substantial and only the viable candidates should be requested to bear this expense. Issuing the RFP to a candidate whom the Purchaser considers unqualified or unpromising is a disservice to the contractor and has no benefit to the Purchaser.

If the Purchaser becomes convinced prior to receipt or review of proposals that one of the prospective contractors has far superior qualifications to do the job, there may be no reason for competitive bidding. Unless the Purchaser is prepared to make reimbursement, it is unfair to request Bidders to undertake the effort and bear the cost of proposal preparation just to "keep the other fellow honest". In such cases, the Purchaser may be better advised to concentrate his efforts on justification of sole-source procurement and negotiation rather than on the handling and review of numerous proposals.

The Purchaser should avoid premature committments to any one Bidder during the qualification process. Pressure by Bidders or their representatives should be discouraged, and the entire qualification process should be kept on a strictly formal basis.

Regardless of whether written statements, oral interviews, or both are used to identify the best qualified potential contractors, the planner must be prepared to elicit responses which are factual and which will be of real usefulness in reaching a decision. Questions to be used as a basis for written statements or asked during oral interviews should be carefully prepared and framed in such specific terms that evasive or incomplete answers are minimized.

Both fairness and the need for information make it desirable to ask the same basic questions of all potential contractors. Accumulating an expanding list of questions as interviews proceed may bias the interviews to the detriment of the Purchaser or the potential contractors. However, a portion of each interview might be reserved for extemporaneous discussion of particular aspects of the potential contractor's presentations and experience, clarification of any unclear or apparently conflicting statements, and for other purposes. Planners should be particularly alert to the opportunity to gain insight into the interviewee's understanding of the needs and procedures of integrating modeling activities with other planning activities.

6.5 SOLICITATION OF PROPOSALS

Subsequent to the identification of the List of Bidders by whatever procedure is chosen, the RFP can be distributed. To insure fairness, care should be taken that all copies of the RFP are mailed or otherwise distributed simultaneously. After the distribution of the RFP, the Purchaser must be prepared to respond to questions and to receive and evaluate proposals.

Responding To Questions And Contractor Contracts

Proposers may have legitimate questions prior to receiving the RFP as well as during the proposal effort. Questions relating to the Proposers' understanding of the Purchaser's needs deserve careful attention and full answer. However, due to the nature of competitive bidding, Proposers may attempt to obtain privileged information which would strengthen their competitive position. To avoid future misunderstandings and potential legal complications, the Purchaser's contacts with all prospective Bidders are best kept at a formal level from the initial steps of contractor consideration until the selection process is complete. The maintenance of formal relations can be encouraged by the following:

1. Designation of one person (Purchaser Representative) on the Purchaser's staff to be responsible for handling all contacts with prospective contractors. All inquiries and unsolicited

contacts can be referred to this individual. During the bidder-qualification phases, the name, title and phone number of the Purchaser Representative should be given to all prospective Bidders for future contacts.

2. Directing the Purchaser Representative to make a brief note or memorandum about each personal contact or phone conversation where information of any significance to the Purchaser's planned project is requested or exchanged.

3. Maintaining contacts on a formal and noncommittal basis. The Purchaser Representative may listen to ideas, but should not solicit any suggestions.

4. Discouraging prospective Bidders from disclosing any information they consider confidential, proprietary or in the nature of a trade secret. Prospective Bidders should be warned against informally disclosing any information which they would request the Purchaser to keep confidential.

5. Discouraging inclusion in proposals of proprietary information unless the nature of such information is clearly identified in the proposal and the RFP has specifically provided for confidential treatment of such marked proprietary information.

6. Restricting informal discussions between Proposers and the Purchaser Representative after the RFP has been issued. Questions by each Proposer can be sumitted in writing. For fairness, such questions can be answered by the Purchaser in written form with both the questions and answers distributed to all Proposers (there is no need, however, to identify the Proposer asking the question). An alternative method of avoiding informal or unfair discussion is organization of a joint meeting with all Proposers to answer all questions (Bidder's Conference). Minutes of such meetings which summarize the answers to the questions asked, should be distributed to all Proposers.

A potential conflict may arise if, in the judgment of the Purchaser, a particular contractor is likely to provide services far superior to those of any other prospective contractor, but his superior qualifications are a result of certain proprietary ideas, techniques or trade secrets. Where permissible by law, the Purchaser may consider engaging such a contractor on a sole-source procurement basis. In a competitive situation, all potential Proposers should be given an opportunity to present their ideas and approaches and demonstrate the special benefits of each to the Purchaser prior to the selection of the List of Bidders and finalization of the RFP.

Another potential problem concerns the possibility of a Proposer submitting an alternative proposal, or a proposal with ideas and approaches different from those requested in the RFP. Alternative proposals should be admitted for detailed evaluation only under very special circumstances, including, among others, the following:

1. They meet all stated objectives of the RFP;
2. They differ from the requested approach only in details, and
3. They meet, or preferably exceed, the requirements of the RFP.

There is no single "best" solution to the problem of handling proposals with alternate approaches or with exceptions. If an alternate proposal is particularly attractive from both the technical and cost aspects in part or in whole, the Purchaser may consider negotiation over the approach, rejection of all proposals and reissuance of a revised RFP, subdivision of the project, or encouragement of team formation among one or more Bidders. If these perogatives are to be considered, however, the necessary flexibility to do so should be reserved by so stating in the RFP.

All the above types of negotiations may involve sensitive material and conflicting interests, and must therefore be handled with great care. If the RFP allows for alternate proposals or exceptions, the related statement of the RFP will govern the evaluation and Contractor selection procedures. In case of situations not foreseen in the RFP, the Purchaser must be governed by applicable laws and regulations supplemented by his own judgment and established practices.

Receipt, Acknowledgement And Control Of Proposals

Bidders naturally have a high degree of interest in the consideration of their proposals. To insure fairness to all parties and to insure against jeopardizing the evaluation process, procedures for the receipt, acknowledgement and control of proposals should be established prior to proposal submittals.

The deadline for the submittal (or receipt) of proposals should be observed, in accordance with the procedure specified in the RFP. All proposals received should be acknowledged by the Purchaser (whether hand carried or sent through the mail). Use of a standard letter format to acknowledge proposal receipt prior to the deadline is adequate. It may be desirable in many cases to request the Proposers to clearly identify the package (proposal ID number, or other form of identification) to assure timely delivery to the proper individual within the Purchaser's organization.

It is generally a good practice to specify a proposal opening date and time in the RFP and to refrain from opening proposals prior to the time specified. This insures against accidental compromise of sensitive proposal information during the submittal period but also requires a clear identification of the proposal package by the Proposer. If this practice is to be followed, the Proposers should be advised as to what information should appear on the wrapping of the proposal package to assure its immediate recognition and proper handling.

If technical proposals and cost proposals are to be handled separately by the Purchaser, the RFP should provide for their separate submittal by the Proposers. In this case the technical evaluation team should preferably not be informed about costs until their evaluation is complete. One way of assuring the separation of technical and cost proposals is to have them addressed to two different individuals or departments. If technical and cost proposals are to be sent in a single package, placing the cost proposal in a separate sealed envelope can be specified.

When the evaluation is completed and the preferred Proposer identified, unsuccessful Proposers should be notified. This notification should not precede determination that a satisfactory contract can be developed with the preferred bidder nor be later than the date of the contract award. At the time of notification, proposals may also be returned to the unsuccessful Proposers if they and the Purchaser so desire. Any communication with an unsuccessful Proposer about reasons for rejection of his proposal should be confined to the discussion of the strong and weak points of his proposal. No other proposals, or ranking of proposals, should be discussed. Furthermore, such post-selection discussions should be conducted only at the Proposer's request.

6.6 EVALUATION OF PROPOSALS

Preparation for the evaluation of proposals begins at the time the Purchaser organizes the contents and format of the RFP. If well-designed, the RFP specifies the organization of the proposal, its contents, and the specific areas the Purchaser wants emphasized in the Proposer's response. The evaluation of the proposals then consists mainly of comparing each response with the requirements specified in the RFP. The purpose of the evaluation is to identify the most favorable offer of services or, in general, the evaluation must include an analysis of the technical proposal, the cost proposed and the Proposer qualifications.

Technical Evaluation

The extent and difficulty of the technical evaluation depends very greatly on the subject matter of the proposals. In general, proposals relating to substantial amounts of work in water quality modeling and water quality planning can be expected to be complex. A careful procedure is required to analyze each of the technical elements of each proposal.

Technical Elements. The more detailed and specific the RFP in spelling out the proposal requirements, the easier becomes the task of identifying the individual technical elements to be evaluated. The section titled "Preparation of Proposal Request" pointed out that the major technical evaluation criteria should be outlined in the RFP. The Proposers's response to the evaluation criteria should provide information on the overall project plan and the proposed technical approach. In addition, it should include a contractually binding Statement of Work.

The overall project plan should provide information regarding the Contractor's understanding of the desired project scope, organization of the project into logical tasks, and staffing of each task. Deliverable items and detailed schedules of performance should be clearly spelled out. The overall project plan should also describe any probability of not meeting proposed deadlines and the contingency plans for conduct of the project in that event. The procedures for project management and conformance with the monitoring and other procedures specified in the RFP should be unequivocal.

The elements of the overall project plan give a good indication of the Contractor's understanding of Purchaser's needs and intents. Then also indicate the importance attached by the Contractor to this particular project, his ability to organize and manage projects of this type, and the probability of success in meeting the Purchaser's objectives within the allocated time and budget.

The technical approach should closely reflect understanding the technical requirements of the RFP. The discussion of approach should discuss the models and techniques to be used, data requirements, procedures for data collection, provisions for any field work, expected results and quality of data to be generated for the deliverables. The proposed content and expected quality of each deliverable end item should be explicitly described.

The proposed technical approach provides insight into the detailed plans of the Contractor for meeting or exceeding the requirements of the RFP. These are of great importance in assessing the Contractor's technical capabilities, expertise and proposed methods for performing the individual tasks of the project. Specific modeling techniques, data requirements, data acquisition and management approaches, and the use of available technologies should be explained by the Contractor in sufficient detail to enable the Purchaser to compare and evaluate alternative approaches. The expected findings and results and their organization into reports and other deliverables should be discussed in detail. If any proprietary elements are involved, they should be clearly identified so that their relative merits can be properly considered in the evaluation. In summary, the Contractor's proposed approach explains how he is planning to achieve the project objectives, and the Purchaser's appraisal should reflect his level of confidence in these plans as well as his assessment of the extent to which these plans will satisfy his requirements.

Although the overall project plan and the technical approach are important for assessing the expected performance of the Contractor, the contractually binding Work Statement in the proposal is vital. The Work Statement should be characterized by its completeness, clarity and conformance with requirements.

As opposed to the Method of Approach, the Statement of Work simply states what the Contractor will complete and deliver in fulfillment of the contract. While the explanation of the approach is an important part of the proposal for purposes of evaluation, only the Statement of Work generally becomes a part of the contract binding on all parties. A careful evaluation of the proposed Statement of Work is necessary to ascertain that it meets the Purchaser's needs and fulfills the intent and requirements of the RFP. The Statement of Work should be concise and factual. It should include all the elements the Purchaser wants to be performed but without any unnecessary reference to the how's and the why's that tend to obscure the Contractor's or Purchaser's responsibilities and obligations. A proposed Statement of Work should not be vague, or else the Purchaser cannot enforce the intent of the contract. In some situations, the Purchaser may want to have a "flexible" Statement of Work for his own protection. This, however, can lead more often to misunderstandings or misinterpretations later during the project, with the possibility of legal problems. In summary, while the technical approach of a proposal is intended to convince the Purchaser about the advantages of selecting that particular Contractor, the purpose of the Statement of Work is to clearly define the Contractor's obligations in performing the contracted services.

Procedures for Technical Evaluation. The overall criteria and the specific technical elements of evaluation have been established and documented, and a convenient and fair evaluation procedure must be implemented. The use of an appropriate evaluation form can be helpful to the members of an evaluation committee in uniformly appraising proposals. Weights reflecting the importance of the several features evaluated can then be assigned and a general ranking accomplished.

The importance of each technical element of the RFP to which the proposal responds can be expressed by a weight. The sum of each evaluator's grade of quality for each technical element times the assigned weighting points gives an assessment of the proposal's overall quality and can be used for an initial ranking of overall technical quality.

This or other similar grading procedures must be handled with care. If there are major differences between the individual evaluators' ranking of the proposals, these differences should be discussed and, if possible, reconciled through detailed study of the reasons for any discrepancies. Any ranking order established should be used as a guideline only for the elimination of the weak proposals. The more promising proposals which are retained for detailed evaluation should be reexamined with specific emphasis on their differences in each important technical aspect. The grading technique and weighting points can be refined for the final analysis to emphasize important technical elements or to consider special attributes of proposals not considered in the original evaluation.

After the evaluation is complete, it is desirable that the members of the committee be in agreement with respect to the ranking. If two or more proposals are very close in quality and satisfactory from a technical point of view, other considerations must govern the final ranking of Proposers.

Use of Consultant in Evaluation. The evaluation of proposals for provision of modeling services to assist in conducting water quality planning creates a situation not unlike that of RFP preparation. That is, the skills necessary to conduct the evaluation are very nearly those proposed to be obtained. If the Purchaser has these skills in-house and the purpose in obtaining contractual services is to supplement the available labor force, then no problem may exist. However, if the purpose in issuing the RFP is to secure services of a type not available on a staff basis then it is unlikely that existing staff members can perform a fully competent evaluation of proposals.

In the latter case described above, it may be cost effective to have a consultant assist the Purchaser in the technical evaluation. In this event, it is desirable to also involve the same consultant in the preparation of the RFP. Sufficient expertise in RFP preparation and proposal evaluation phases can aid in mutual understanding between Purchaser and Contractor and help insure against work which may be unnecessarily expensive due to misinterpretation of project requirements.

Documentation of Technical Evaluation. After completion of the technical evaluation, it is important that the evaluation findings be documented. This should include technical data and narrative which clearly state the conclusions reached about the proposals. This information is important both for subsequent negotiations and as a basis for responding to Contractor inquiries.

The documentation of the technical evaluation should adequately describe the recommendations of the evaluation team and explain the reasons why any Proposers were thought unable or unsuitable to perform the work. The information prepared should include the specific reasons for which a Proposer was rated low or high, strong points and/or weakness in the proposal, and items which require discussion or clarification during negotiation. The latter may include definitions of important terms, work proposed which is in excess of that required by the RFP and adequacy of the proposed labor for project completion.

Cost Evaluation

As with the case of the technical evaluation, a well defined RFP can simplify the task of cost evaluation. The extent of the analysis performed will depend on the nature of the contractural arrangement to be used as well as the cost and complexity of the overall project.

Cost Elements. The cost information required by the RFP must be determined in anticipation of the type of contract to be let. The least amount of information is required for firm fixed-price proposals, while detailed financial data concerning the Contractor may be necessary for cost reimbursement type arrangements.

To simplify the presentation of cost information in a uniform and easily comparable manner, it is often useful to provide or stipulate forms for cost summaries. Such forms may call for showing of labor costs including the basic rates, estimated hours and extended totals as well as direct and indirect costs, payroll burndens, and fee. Some flexibility must be allowed Contractors to display the elements of their proposal however as the accounting systems in use vary considerably.

Some information affecting cost is not suitable for tabular display and provision should be made for contractors to furnish certain information in narrative form. Such information might include policies for travel and subsistance costs, material aquisition procedures and composition of overhead and other indirect costs.

Procedures for Cost Evaluation. There are multiple objectives in undertaking the evaluation of proposed costs. Completion of the evaluation normally involves careful examination of each proposal for arithmetic correctness, analysis of rates and subtotals of cost for separate major tasks, as well as distribution of cost among the various elements.

Cost should not be the sole criterion of contractor selection and ethical conflicts can arise if such is the case. However, even where cost is one of the major deciding factors, far more than a simple comparison of total costs offered by technically suitable contractors is warrented. The purpose of the review of the cost proposal is insuring that the quoted price is realistic and does not depart from the estimated price so far as to indicate misunderstanding or overoptimism regarding accomplishment of the required scope of work, and to insure that the price is consistent with available funds.

A portion of the cost analysis should include evaluation of the level of effort proposed. If anticipated labor hours have not been included in the technical proposal, this information should be extracted from the cost proposal and furnished to those performing the technical evaluation so that its reasonableness can be determined. Acceptance of a proposal bearing an unrealistic price or labor input practically assures later difficulty.

Firm Qualifications

Even though an extensive qualification procedure may have been used to identify and assure providing the RFP only to carefully selected contractors, further evaluation is usually undertaken at the time proposals are evaluated. The Contractor's response to the requirements of the RFP and to the stated criteria for selection should include information both on qualifications and on the Contractor's commitment to the project.

The qualifications presented should include a description of the staff, facilities and general background applicable to the project. Particularly relevent experience should be detailed as well as the capabilities of any expert consultants or specialized subcontractors.

The Contractor's commitment to the project is evidenced through the availability of key staff members, requirements of current contracts, and other such information. The proposal should make it convincingly clear that the Contractor not only has the capability to carry out the proposed project but will, in fact, place an adequate priority upon doing so.

The portion of the proposal review directed toward assessment of the qualifications of the Contractor's firm or organization should emphasize both resources and capabilities. Resources include facilities and equipment which may be required as well as adequate support services for staff which would be involved in leading and performing the proposed project.

The personnel proposed for conducting a study should either be already available to the Contractor or suitable arrangements should exist for acquiring them. In addition to simply having sufficient numbers of appropriate staff employed or accessible, their availabiltiy should be reviewed. Specific staff requirements depend on the nature of the project, but generally both management and technical skills are required.

Information on experience in conducting similar projects should be provided for both the organization and the staff. Close review of the organization's work, and perhaps investigation of the success with which the work was accomplished, can be informational. However, as in the case of the reference check discussed previously, care should be taken to insure full understanding of circumstances. This is particularly necessary if the investigation turns up adverse information.

6.7 CONTRACTOR SELECTION

If the evaluation of the proposals has not been conclusive, a face-to-face meeting with one or more Contractors may be necessary to enable the Purchaser to ask specific questions about the Contractor's technical approach, obtain any necessary clarifications, and generally size up the proposed manager and key members of the project team. There is little to be gained in conducting such interviews with all Contractors who submitted proposals unless their several proposals are quite comparable in technical quality. If oral interviews are desired by the Purchaser, they should be arranged only with the few highest-ranking Proposers from whom the Contractor will be selected.

The Purchaser may elect to conduct an interview solely with the highest-ranking Proposer if evaluation of the proposal received results in a clear preference pending the resolution of certain specific points. An interview with the next-ranked Bidder is then necessary only if no satisfactory arrangement can be reached with the first-ranked Bidder.

If oral interviews are to be conducted with several top-ranked Bidders, notification to each of the other invitees is neither necessary nor desirable. Confidentiality on this point is difficult to maintain. However, if achieved, confidentiality will encourage the Bidders to focus their statements and answers on the project rather than on their competition.

There are no fixed rules for conduct of an oral interview. In general, the objective of the questions should be to clarify certain aspects of either the technical or cost proposal, and pursue the proposed technical approach in such detail as may be of interest. Specific questions may address the contractual arrangements, project management, project costs, terms and conditions, guarantees, or any other point of legitimate interest to the Purchaser. It is especially important in such a meeting to clearly establish a measure of Contractor performance if it has not been adequately defined in the proposal. This raises the question of what constitutes satisfactory performance, its method of measurement, and the means by which the Purchaser can enforce requests for the Contractor to correct any incidents of non-satisfactory performance.

Minutes of the meeting should be taken for the record to aid in evaluation and for use in the subsequent contract negotiation. The Contractor should be advised that statements or commitments made during the oral interview will be considered as contractually binding. The minutes should be approved in writing by the Contractor.

After the interview, the Contractor's specific response and general attitude must be evaluated by the Purchaser. Such an evaluation should take place soon after the oral interview, and desirably should involve all Purchaser representatives who participated in the interview.

Finally, based on the evaluation of proposals, interviews, and other efforts at selection which may be made, a preferred Contractor must be chosen. Since the subsequent negotiations leading to contract execution may be unsuccessful, one or more alternate Contractors should be identified. In the case of a firm fixed-fee contract, the selection often entails only identification of the several Contractors who adequately meet the requirements, and comparison of the bid price.

6.8 CONTRACTING

The sequence of activities in contracting includes negotiation, contract preparation and contract award. Each of these steps are important and must be given close attention.

Negotiation

Netotiation, assuming all factual matters and questions are settled, consists of two distinct parts. The first part includes reaching agreement on any differences which exist between the parties which can be satisfactorily compromised. The second part, commonly referred to as bargaining, involves the tradeoff of any remaining points of difference.

As in the case of managing the solicitation of proposals, one individual should be identified as the negotiator for the Purchaser and be responsible for this phase of the project. Similarly, confusion can be avoided if each contractor or contractor team identifies a single representative.

Where negotations are conducted with more than one Contractor, formal relations and confidentially must be maintained. In such multiple negotiations, the Purchaser should keep the arrangements strictly separate. Under no conditions should an "auction" of services be permitted or encouraged by revealing competing bids or conditions. The Purchaser should always attempt to negotiate the contract form most advantageous for the performance of the work at hand. The Purchaser must keep in mind that

that the Contractor must also be able to operate efficiently within the framework of that arrangement for the duration of the project. This requires that the Purchaser make a realistic assessment of the funds required for the project. Any major discrepancy in the views of Purchaser and Contractor as to budgets, schedules or other major points should be examined to determine if it indicates a lack of mutual understanding with regard to the extent, scope or detail of work expected. Resolution of any such misunderstandings should be achieved during negotiation. Ultimately, the "best" contract in each situation is the one that will help achieve the project objectives in the most cost-effective and timely manner.

Contract Preparation

Preparation of the contract should be begun prior to negotiation and completed after agreement is reached. Normally, the contract consists of several parts, including those dealing with:

1. Purpose of the project;
2. Scope of work;
3. Contract period;
4. Reporting requirements;
5. Cost collection, billing, and payment; and
6. General provisions.

Items (5) and (6) above tend to be standard statements specified for all contracting by an agency and frequently are readily available for inclusion in the contract as an attachment or appendix. If unavailable, examples can be readily obtained from the contracting officers of various state or federal agencies.

Purpose and Scope. The purpose of the project and its scope should be relatively well defined based on the preparation of the RFP. Commonly, the contractual Scope of Work both reiterates the requirements specified in the RFP and incorporates the successful proposal by reference.

The section of the contract which deals with the time of performance should include the dates for beginning and completing performance and spelling out the conditions under which amendments to the schedule will be requested or granted, as well as the procedures for such changes. Review periods for deliverables should be specified and the impact of delays defined.

However described, the contract should finally achieve the Purchaser's requirements. To avoid later difficulty, the Purchaser should recognize that the Contractor is obligated to perform only the minimum work which is specified and specify the work accordingly. It is important that responsibility for each major portion of the work be clearly assigned if a joint effort of the Purchaser and Contractor are required. The sequence in which activities are to be undertaken should be stated either in schedules or charts.

Procedures for approving contract deliverables or units of work should be clearly defined. To improve clarity, tiems or aspects which are mutually agreed not to be included in the scope of work should also be described where their omission would cause doubt.

Contract Period. This section of the contract should define the effective date of the contract, the time when work is to begin, and the length of the time available or a completion date. Contract periods are normally specified in calendar time without regard to "work days". If interim dates are important to the Purchaser, accomplishment of certain tasks or portions of work may be specified to be completed by particular dates. This is likely to be the case when modeling or model results must be integrated with the results of economic, engineering, financial, environmental and other studies.

Any conditions which affect the initiation or effectiveness of the contract should be enumerated. These conditions may include approval of funds, the contractor or the contract by other agencies or political bodies.

Care should be taken to avoid any confusion in the project schedules that may be brought about by specifying a schedule in the contract and simultaneously incorporating differing schedules (such as proposal schedules) by reference. Resolution should be provided by identifying the prededence in authority of statements contained in the contract and in other documents which are referenced. The contract should also provide for the eventuality of contract termination prior to its completion or the finish date. Termination may be warranted under several conditions, and the contract should adequately protect the interests of both parties. Provisions for termination as well as contractual disputes should be determined in cooperation with legal counsel.

Reporting Requirements. A number of types of reports may be required, including periodic progress reports, technical descriptions of work elements, various documentation reports and overall project reports. In addition, one objective of the work undertaken may be to produce some specialized report. Each of the reports which are to be prepared during the course of the contracted effort should be carefully defined and scheduled. The description of each report should state its purpose, content and form. If an opportunity for review and approval is desired, the procedure for review should be stated. For major reports, the development and submission of an outline should be required in advance of actual report preparation. The content of progress reports should be sufficient to present a clear picture of both the technical accomplishments of the project and to enable comparison of progress with the time and funds committed and remaining. Reports should be scheduled with care. Adequate time must be allowed not only for the Purchaser and Contractor staffs to prepare, review, revise and publish reports, but also for the participation of the public and official bodies. In addition, report scheduling must consider their use as essential information for other planning activities. In general, the Purchaser should not anticipate that the Contractor will provide any reports or other written material except that called for by the contract. If either the Purchaser, a grantor agency, or some other related agency has specific requirements for the content or form of reports, they should be incorporated in the contract, either in full or by reference.

Cost Collection, Billing and Payment. The normal procedure for all but relatively small value contracts provides for periodic payments based on progress. For such purposes, progress can be measured by contractor input in labor and other costs on a time basis or by completion of portions of work. In either case, payments are usually limited so that a sum remains unpaid until final project completion to assure contractor performance.

If multiple sources of funds are to be used to meet Contractor Billings, then the billing information required by each as a basis for payment should be identified. The contract should give explicit instructions to the Contractor on the content and form of information to be submitted on invoices.

General Provisions. This section of the contract covers routine administration matters. Included are such things as the use of subcontractors, prior approval of certain items, patents and other similar items.

The use of subcontractors in any significant amount should be foreseen by the contractor at the time of proposal preparation. Therefore, some limitation is warranted to avoid the later diffusion of responsibility for accomplishment of the work. However, conditions can arise unexpectedly in which use of a subcontractor having specialized capabilities can be of substantial value. Permission to use contractors can reasonably be made subject to Purchaser approval based on demonstrated benefit, qualifications, cost and other factors.

Prior approval of expenditures is sometimes retained by Purchasers for such items as equipment purchases, travel and other items to be charged against the project. While possible and reasonable, a situation could easily develop in which the Purchaser is overburdened dealing with approval requests, and the Contractor is unduly restricted. Only sufficient control is necessary to prevent impractical or clearly inefficient project expenditures is warranted.

Contract Award

When negotiation is complete and a contract drawn which fully describes the understanding between parties, the stage is set for the execution of the contract.

The award is normally accomplished by forwarding one or more copies of the prepared contract to the Contractor for signature and return. The documents are then signed by the necessary official(s) for the Purchaser and a copy returned to the Contractor.

If not done earlier, unsuccessful bidders should be notified at this time of the contract award.

6.9 PROJECT ADMINISTRATION

After the execution of the contract and initiation of work, the Purchaser must assume a dual role. The contract must be administered; and, simultaneously, the Purchaser and Contractor must develop and maintain close cooperative working relations.

Liaison With Contractor

Contract between the Purchaser and Contractor should be frequent enough to enable close coordination of respective work efforts and the earliest possible identification of problems. Liaison can be carried out in a number of ways, including telephone, correspondence, and personal conferences. In all but the smallest projects, questions of procedure inevitably arise due to unforeseen problems or points not covered in the written Work Statement. To avoid later problems, resolution of such questions should be documented in writing.

In carrying out the liaison portion of contract administration, the Purchaser should strictly observe the Contractor's freedom to manage his work as he sees fit within the limits of the contract. Unless serious problems are clearly evident, and appear sure to affect the quantity and work, the Purchaser should be concerned only with results.

Evaluation of Progress

Measuring the accomplishment of the Contractor is important both to assure project objectives are being met and as a basis of payment. Progress is a combination of both the volume and quality of work produced under the contract.

The volume of work can be established on the basis of periodic progress reports, preparation of reports on specified technical topics and liaison activities. Initiation of projects or major tasks of projects is frequently accompanied by a variable amount of work for which no clear product is produced. While this time devoted to "start up" is necessary, it should be kept within reasonable bounds. The Work Statement should provide for the sequential completion of tasks to avoid the difficulties which can occur if the Contractor elects to "start up" numerous tasks without pressing for completion of any.

The portion of progress evaluation devoted to measuring the quality of the work which is accomplished is more difficult. If the Purchaser originally secured the Contractor's services as a supplement to his work force and has the necessary skills available, these staff can probably provide an adequate evaluation. If, however, the Contractor's services were obtained to secure expertise not otherwise available to the Purchaser, he may be in a poor position to judge the technical acceptability of the Contractor's work. In this case, assistance can be sought from various sources, such as federal and state agencies, but the Contractor's reputation and demonstrated competence becomes of prime importance.

Receipt of Deliverables

Items specified as contract deliverables should be accounted for and handled in very specific fashion. Receipt of such deliverables by the

Purchaser should be formally acknowledged to the Contractor. Review comments and approvals of acceptable deliverables should likewise be documented to firmly establish the status of each task and the project.

Assessment of Performance

At the conclusion of the Contractor's effort, an assessment of performance must be made as a basis of final payment. This performance assessment should emphasize comparison of the Contractor's accomplishment against the contract requirements. The Purchaser must refrain from allowing the assessment to be affected by any outside considerations. The specific elements of the evaluation should be directed toward the accountable items in the Work Statement, including the quality and timeliness of their accomplishment.

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GLOSSARY

advection	The hydraulic mechanism by which water quality constituents are transported in the direction of the water flow.
aeration	The process or state of being supplied or impregnated with air.
algae	Largely aquatic nonvascular plants that grow in either sea water or fresh water; seaweeds and pond scum are algae.
algorithm	A rule or procedure for solving a logical or mathematical problem, frequently as incorporated into computer programs.
ambient	Surrounding. In this handbook, a representative volume of surrounding receiving waters.
augmentation of flow	The release of water from dam-controlled reservoirs when stream level is low.
basin	A region in which the strata or layers of rock dip in all directions toward a central point. Thus, it is any hollow or trough in the earth's crust, whether filled by water or not. (Also see: drainage basin; river basin.)
benthic, benthos	Relating to the bottom underlying a body of water (for example, mud-dwelling mollusks are benthic organisms, or benthos).
biota	Living things; the plant and animal life of a region.
bit	A basic unit of computer storage, symbolically capable of representing only a "1" or a "0."
BOD	See oxygen demand, biochemical.
boundary conditions	The conditions around the spatial boundary of a problem area, which govern its solution. Here, the forces applied at the receiving waters' boundaries, and the flows crossing them.
byte	A few bits (typically 6 or 8, depending upon the computer) of computer storage, required to store one character. See "bit."
calibration	The procedure of assigning values to the uncertain or unknown parameters in a simulation model and adjusting them until model predictions correspond acceptably closely with observed prototype behavior. See also Note 3.5.A of Section 3.3.

channel	An elemental one-dimensional flow path having the usual properties of a water channel, which is used to construct certain receiving water simulation models.
coliform bacteria	Any of a number of organisms common to the intestinal tract of man and animals, whose presence in waste water and receiving waters is an indicator of pollution.
compiler	A programmed component of a computer, which converts sophisticated programming language into elementary instructions and binary code.
confluence	The point at which one stream flows into another or where two streams converge and unite.
conservative constituent	A constituent (see below) whose total mass or quantity in receiving waters is conserved, even though its concentration may change as a result of dilution. <u>See</u> Note 1.2.A of Section 3.3.
constituent	A physical, chemical or biological quantity whose presence in water is a factor in, or indicator of, water quality.
continuous model	A model which simulates continuously varying processes over a long period of time, typically many years.
coupled constituent	A constituent whose nonconservative behavior is affected by the presence of a second constituent. <u>See</u> Note 3.2.B of Section 3.3.
diffusion	A process by which water quality constituents are transported, primarily depending upon the concentration gradients. Therefore can occur in directions different from the flow direction.
dilution	The reduction of a constituent concentration by mixing in water containing a lower concentration.
discharge	The volume of water that passes through a given cross-section of a channel or sewer during a unit of time; commonly measured in cubic feet per second.
dispersion, longitudinal	The process by which prototype concentrations are changed as a result of the non-uniform velocity distribution at a channel cross-section.
dissolved oxygen (DO)	The oxygen freely available in water. In unpolluted water, oxygen is usually present in amounts of 10 ppm or more. Adequate dissolved oxygen is necessary for the life of fish and other aquatic organisms. About 3 - 5 ppm is the lowest limit for support of fish life over a long period of time.

dissolved solids (DS)	The total amount of dissolved material, organic and inorganic, contained in water or wastes. Excessive dissolved solids can make water unsuitable for industrial uses, unpalatable for drinking, and even cathartic. Potable water supplies may have dissolved solids content from 20 to 1000 mg/l, but sources which have more than 500 mg/l are not recommended by the U.S. Public Health Service.
distributed load	A constituent load which enters the receiving water over a considerable distance, as in the case of groundwater seepage, rather than at a point as with a sewer outfall.
DO	See "dissolved oxygen."
DO deficit	The extent by which the DO concentration falls below its saturation level.
drainage basin	The area which contributes runoff to a stream at a given point (an individual section of a watershed).
driving forces	The forces promoting movement in the receiving water, primarily gravity and tides.
dynamic	A process which may vary freely with time. This includes both the inputs and the solution in a computer model.
dynamic equilibrium	A process which may vary with time, but only over a limited period (e.g., one day) which repeats itself in cycles. Also known as dynamic steady state.
estuary	The mouth of a river, where tidal effects are evident and where fresh water and sea water mix.
event model	A model which simulates the processes occurring in just a single event, typically for a near-steady-state condition or for only one major variation during a relatively short period of time.
exchange coefficient	The fraction of material leaving an embayment during ebb tide, which returns on the following flood tide.
extinction depth (of lake)	The depth below a lake surface at which the light intensity is only 1% of its intensity at the surface.
FORTRAN	A scientific language commonly used by programmers to direct computer activities.
groundwater	Water in the pores and crevices of the earth's mantle rock which has entered them chiefly as rain water percolating down from the surface. As opposed to the rain water which runs off in streams; all water below the water table.

headwater	The most upstream portion of a river, stream, or creek.
heat budget	The accounting of the various factors governing water temperature.
hydrology	The science of the behavior of water in the atmosphere, on the earth's surface, and underground.
impoundments	A water reservoir or lake formed by its confinement and storage.
junction	In rivers, the point of connection of two upstream stretches or segments. In some estuary models a junction is a segment of the estuary.
kinetics	The dynamics of physical, chemical and biological reaction processes.
linked constituent	A constituent whose nonconservative behavior is affected by the presence of one or more other constituents. <u>See</u> Note 3.2.B of Section 3.3.
numerical dispersion	Error in models using numerical approximations, caused by the use of grids of discrete size. Also called discretization error.
nutrients	Chemical compounds upon which plant life commonly feeds. Ammonia, nitrates, nitrites and phosphates are the most common nutrients.
Manning's n	A coefficient used to describe boundary (i.e., stream bed) roughness in hydrodynamics.
model	A physical, analog, or mathematical system for representing a prototype.
nonconservative constituent	A constituent whose total mass reduces in receiving waters as time proceeds through certain physical, chemical or biological interactions.
oxygen demand, biochemical (oxygen-depleting effect; BOD)	The amount of oxygen required for aerobic bacteria to oxidize completely the organic decomposable matter in water within a specified time and at a given temperature - an index to the degree of organic pollution in the water. When discharged to a watercourse, waste containing BOD constituents will consume dissolved oxygen in the water; the BOD indicates the amount of oxygen used up. Waters that receive high BOD waste undergo reduction of oxygen and consequent damage to aquatic life.

pH	Hydrogen ion concentration which reflects the balance between acids and alkalies. The extreme readings are 0 and 14. The pH of most natural water falls within the range 4 to 9. A pH of 7.0 indicates neutral water. A 6.5 reading is slightly acid; an 8.5 reading is alkaline. Slight decrease in pH may greatly increase the toxicity of pollutants such as ammonia. Alkaline water will tend to form a scale; acid water is corrosive; good water should be nearly neutral.
pollutant	A constituent which pollutes waters by its presence in excessive quantities.
pollution (of water)	Contamination or other alteration of the physical, chemical or biological properties of water, including changes in temperature, taste, color, or odor of the water, or the discharge into the water of any liquid, gaseous, radioactive, solid, or other substance that may create a nuisance or render such water detrimental or injurious to public health, safety or welfare. Broadly, pollution means any change in water quality that impairs it for the subsequent user.
reach	A discrete portion of river, stream or creek. For modeling purposes a reach is somewhat homogeneous in its physical characteristics.
reaeration	*See* aeration.
river basin	The total area (also called a watershed) drained by a river system. The river basin is increasingly coming to be regarded as a social and economic unit for community development and conservation of water, soil, forests and related resources.
river basin concept	The notion that each river system, from its headwaters to its mouth, is a single unit and should be treated as such. This concept recognizes the interrelationships of resource elements in a single basin, and assumes that multiple-purpose development can take these interrelationships into account. It extends the principle of ecological balance to the whole of the area and its occupants.
section	A portion of a river basin, generally larger than a segment, which is bounded by headwaters or major river junctions.
segment	A discrete portion of a water body of somewhat homogeneous character, as represented in mathematical models. (*Also see*: reach, junction.)
simulation	The representation of a system by a device that imitates the behavior of the system.

singular constituent	A constituent whose behavior is not affected by the presence of other constituents.
stability	A characteristic of numerical models. Unstable models develop large numerical errors as computations proceed. Numerical errors reduce in stable models as computations proceed.
steady-state	Quantities (e.g., inputs and solution) do not vary with time (but may vary over space).
stretch	See section.
simulation period	A characteristic time for which a mathematical model simulates a system, using data obtained during that time period.
thermocline	Zone of rapid temperature change with water depth.
tidal averaging	Averaging of processes such as water currents and pollutant transport over an entire tidal cycle. This averaging may reduce or eliminate the need to solve for time variations in tidally influenced waters.
transient	A temporary and brief time-varying solution during readjustment to equilibrium or dynamic equilibrium, resulting from a sudden change in input(s).
treatment factor	Percentage by which pollutants in effluents are reduced in wastewater treatment.
UOD	Ultimate oxygen demand. Generally about 1.5 x 5-day BOD.
verification	The act of testing a model's accuracy using a different simulation period, i.e., an independent set of input and output data, from that used in calibration. See also Note 3.5.A of Section 3.3.
watershed	See river basin; drainage basin.
word (of computer storage)	A few bytes (typically 4 or 6, depending upon the computer) of computer storage, required to store one variable. See "byte," "bit."

ABBREVIATIONS

ASCE	- American Society of Civil Engineers
DEM	- Dynamic Estuary Model
DRM	- Deep Reservoir Model
EPA	- Environmental Protection Agency
FWPCA	- Federal Water Pollution Control Administration
FWQA	- Federal Water Quality Administration
NTIS	- National Technical Information Service
NWS	- National Weather Service
SCI	- Systems Control, Inc.
SEM	- Simplified Estuary Model
SSM	- Simplified Stream Model
TTM	- Tidal Temperature Model

BOD	- biochemical oxygen demand (5-day)
cf	- cubic feet
cfs	- cubic feet per second
COD	- chemical oxygen demand
coli	- coliform bacteria
csa	- cross-sectional area
Cu	- copper
DO	- dissolved oxygen
F. coli	- fecal coliforms
fps	- feet per second
ft	- feet
hr	- hour
in.	- inches
JCL	- job control language
lb	- pounds
lb/day	- pounds per day
mgd	- million gallons per day
mg/L	- milligrams per liter
mi.	- miles

mi^2/day	- square miles per day
min	- minutes
MPN	- most probable number
NH_3	- ammonia
NO_2	- nitrite
NO_3	- nitrate
OPO_4	- orthophosphate
Pb	- lead
pH	- hydrogen ion concentration (see Glossary)
ppm	- parts per million (weight/weight)
Pt.	- point
sec	- second
sq ft	- square feet
SS	- suspended solids
T. coli	- total coliforms
UOD	- ultimate oxygen demand
yr	- year
Δ	- an increment of

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16. ABSTRACT

This report is designed as a handbook specifically oriented to water quality and water resources planners and managers. It presents a large amount of basic information concerning water quality modeling including procedures for: model evaluation, model selection, integration of modeling with planning activities, and contracting modeling projects. Planners without previous experience in water quality modeling may use the information and procedures included in the handbook to determine whether a water quality model could and should be used in a particular planning program, and which specific model would be cost effective. This includes a step-by-step procedure leading to the rejection or selection of models according to specific project needs. The handbook discusses the implications which accompany the decision to model, including the needs for additional labor and specialized technical expertise which are generated. Methods and procedures for integrating the use and results of water quality models with other activities of the planning process are described as well as the respective merits of in-house and contracted modeling. The handbook also deals with the procedures for obtaining and using contractual services for water quality modeling. Step-by-step instructions are provided for the preparation of solicitations, evaluation of proposals and selection of contractors. This report is submitted in fulfillment of Contract Number 68-01-2641, under the sponsorship of the Office of Research and Development, Environmental Protection Agency.

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