REPORT ON THE USAGE OF COMPUTER MODELS OF ESTUARIES BY EASTERN COASTAL STATES

Katrina Smith
Technical Assistant
Water Quality Section
Division of Environmental Management
N.C. Department of Environment, Health and Natural Resources

Special Report Series SRS-10

August 1992

ACKNOWLEDGEMENTS

The author wishes to thank all those who have contributed to this report, particularly the many estuary modelers who took time to complete the survey and participate in follow-up interviews. This project would not have been possible without the initiative, support and encouragement of the North Carolina Division of Environmental Management Technical Support Branch staff. Funding for the report was provided by the Sussman Fund. The survey and the author's time were funded by the Water Resources Research Institute.

Readers are encouraged to comment upon and respond to this report. Contact Trevor Clements or Ruth Swanek at:

NCDEHNR
DEM
P.O. Box 29535
Raleigh, NC 27626-0535

(919) 733-5083

TABLE OF CONTENTS

SUMMARY

INTRODUCTION

This report is the result of an initiative by the State of North Carolina to investigate how estuary models are used by other East Coast states. There were two motivations behind this work. First, the North Carolina Division of Environmental Management (NCDEM) has embarked upon a program of Whole Basin Planning. In their evaluation of estuary models for use in this effort, the NCDEM needed more information about the adequacy of their existing modeling tools, as well as potential alternatives. Second, the NCDEM Technical Support Branch staff noted that state agency modelers have a different set of concerns than do federal, private, or academic modelers. Therefore, this project was also intended to foster a network of state-level estuary modelers to discuss these concerns.

This project began in the Spring of 1992 with a written survey. Nineteen responses were received, primarily from experienced modelers. Follow-up telephone interviews were conducted to obtain more details about state estuary modeling programs and specific models.

This report presents the results of these information gathering activities. Section I introduces the study and Section II describes in greater detail the methods used. In Section III, the estuary modeling programs of eastern coastal states are analyzed, including typical features, common problems, and parties involved. Specific programs from each of the participating states are described in Section IV. In Section V, a summary of models is presented; a full list is given in Appendix B. Section VI contains recommendations synthesized from study results for improving estuary modeling. Section VII is the concluding section. In addition, references and a sample survey (Appendix A) are provided.

MAJOR FINDINGS

Survey results indicated that states use one of two general frameworks for modeling their estuaries. Either they have large scale `precalibrated' models which are used repeatedly, or they draw from a set of models for each individual application. The relationships between actors in the modeling process (state modelers, permit writers, permittees, consultants, etc.) vary from state to state.

Many state estuary modelers share a set of concerns about their estuary modeling programs. Modeling programs are universally resource-limited; this limits their choice of models and extent of calibration. The uncertainty of simulations is assumed to be high, but this uncertainty is not reported with model results. Numerous modelers expressed concern for the defensibility of model results and standards for verification.

CONCLUSIONS

This report is intended as a starting point. It is hoped that individuals interested in estuary modeling will make use of the contacts provided to obtain more details about specific models and to foster a network between modelers. In addition, this report provides a basis for a discussion of issues which concern all state level modelers.

I. INTRODUCTION

North Carolina's estuaries support some of the state's most valuable natural resources. Many of these resources are dependent on the estuaries' high water quality. Often, water quality models contribute important information to decisions about how to preserve the water quality of estuaries.

The North Carolina Division of Environmental Management (NCDEM) sponsored this study to collect information about estuary models currently in use by eastern coastal states. The NCDEM intends to use this information to help select estuary models to be used as part of its whole basin planning process. Many types of models, including mixing models, water quality models and non-point source models were included in the study. It is hoped that the information in this report will be useful to other states with estuary modeling programs.

This report examines existing estuarine models used by eastern coastal states. Descriptions of the models are provided so that estuary modelers may easily identify models which might be useful to them. The estuary modeling programs of states that participated in this study are summarized. Finally, contacts in each of the states are listed. This list is intended to foster a network of people interested in estuary modeling at the state level and to facilitate further investigation of the models.

Because this study was carried out for a state agency estuary modeling program, it focuses on models appropriate for use at the state level. This report does not attempt to summarize the latest advances in estuary modeling. While state-of-the-art models may be more complex and sophisticated than many of the models described in this report, they are not necessarily appropriate for state use. More often than not states are limited by time and money in their estuary modeling applications. Therefore, the model descriptions and analyses focus on user friendliness, data collection requirements and technical support availability. Issues of common concern to state level modelers are discussed. In addition, recommendations intended to be helpful for state modelers are provided.

II. METHODS

This study began in January 1992. The first step was the development of a mail survey. The basic format of the survey was similar to a survey about models used in Superfund Programs (OSWER, 1990). The survey questions were based on the recommendations of the North Carolina Division of Environmental Management estuary modelers. The survey was designed to gather basic information about other states' estuary modeling programs, the models used by other states and the level of satisfaction with estuary modeling at the state level.

Twenty-one surveys were returned. All of the eastern coastal states (including the District of Columbia) responded to the survey except for Delaware, Florida, Massachusetts, and Pennsylvania. Little estuary modeling is carried out by these states - they are served by regional or federal programs. Several states returned multiple surveys. In addition, Chesapeake Bay National Estuary Program staff and the Delaware River Basin Commission (DRBC) completed surveys.

In June 1992, follow-up telephone interviews were conducted in order to augment the survey information. At that time, more detailed information about the user friendliness, accuracy and data requirements of the models was obtained. Results of these interviews were drafted and returned to the states for comment.

Despite efforts to be as comprehensive as possible, several states, programs and models are probably omitted in this report. Accuracy of the model and program descriptions depends on the completeness of surveys returned. Analysis and recommendation sections have been reviewed only by the NCDEM staff and are the responsibility of the author.

Additions and corrections to this report are welcome. It is hoped that this document will encourage an ongoing exchange of information about estuary models and state modeling programs.

III. ANALYSIS OF STATE ESTUARY MODELING PROGRAMS

INTRODUCTION

Estuary modeling by states is characterized by time and financial restrictions. Ongoing federal or academic programs, on the other hand, are generally less limited by resources than are state agencies. The purpose of this section is to characterize the modeling programs of eastern states, focusing on problems characteristic of state agencies. Highlighted are common problems, ingenious solutions, and opportunities for exchange.

States usually model their estuaries in order to predict the impact of pollution. The most common purpose of estuary modeling is to determine limits for National Pollution Discharge Elimination System (NPDES) permits. However, some modeling is done simply to learn more about a particular estuary. Estuary water quality modeling has traditionally focused on predicting Dissolved Oxygen (DO) for NPDES permits. However, the use of modeling is expanding to the effects of eutrophication, toxics, and nonpoint sources in estuaries.

The written survey contained a section asking respondents to describe their level of satisfaction with their state's modeling programs. All of the respondents felt models are useful tools for water quality management and that resources spent on models are justified. One third believed that model results are not used appropriately. Two thirds of the respondents felt that resources spent on estuary modeling are inadequate. It should be noted that most of the survey respondents are experienced modelers.

STATES' USE OF ESTUARY MODELS

Although the states have similar purposes and concerns regarding estuary modeling, there are many differences between state programs. The states' estuary modeling programs differ greatly in resources, organization and models used. Overall modeling approaches are characterized below into two broad categories. One approach is to calibrate a large scale model for the estuary and to reuse it for waste load allocations - the "one model" approach. In this report, such a model is refered to as "precalibrated." Other states have numerous models ranging from desktop to fully calibrated - a "bag of tricks". Different models are selected and applied based on the particular case.

ONE MODEL

Several states work with large scale precalibrated models of their estuaries which are used repeatedly. Examples of this approach are AWEST (Mississippi), the Delaware Estuary Model (DRBC) and the Potomac Estuary Model (Metropolitan Washington Council of Governments - MWCOG). Most of these are based on a general model such as WASP4. This approach has the advantage of storing calibration information in one place. It avoids having to collect and input field data for every detailed model application. On the other hand, these models were often described by users as old, outdated and in need of recalibration. It seems that more is invested in such a model, making it more difficult to switch to a new model or update the approach.

It is important that a large-scale model for repeated use be simple enough for the state's modelers to apply easily. The disadvantages of an extremely complex whole-estuary model for state use are demonstrated by the Chesapeake Bay Water Quality Model (CBWQ). CBWQ is so large and complex that it must be run through the Chesapeake Bay Project office on a supercomputer, at $8000 per run. This makes it nearly impossible for the individual states to use it on an experimental or case-by-case basis. In response, Virginia is developing a whole bay model (Three-dimensional Hydrodynamic Model, VIMS) which may be used in a desktop mode, is user-friendly, and is accessible to the state.

Factors which determine whether a single model is appropriate may include the physical type of estuary, the data available and the purposes of the modeling. Overall, a precalibrated model seems advantageous for complex estuaries when the state is committed to maintaining the model. In addition, the model must be simple enough to be useful on a daily basis.

"BAG OF TRICKS"

The other approach to estuary modeling is to use several models. North Carolina, South Carolina and Virginia are examples of states which use this approach. In a screening application, a desktop model might be used. In a more complex application where more time and money are available, a fully calibrated model might be selected and applied.

This approach is intuitively appealing. However, it can present problems if staff have to continually learn new models and calibrate them for areas that have been modeled before. In addition, "one time" special project models, such as that done for Savannah Harbor, Georgia between 1980 and 1989, can be inefficient. Often they are developed by consultants and are so complex that, once the initial project has ended, the state can no longer use it interactively.

Applying models case-by-case is probably most effective when a state carefully chooses a set of models for different circumstances. This is obviously more efficient than constantly searching for new models for new cases. Having a pre-selected set of models also provides a guide to consultants as to which models are acceptable. In addition, this prevents state model reviewers from having to learn a new model every time a consultant's results are submitted.

ACTORS IN THE ESTUARY MODELING PROCESS

There are, of course, many people interested in and involved with estuary modeling other than the state modelers. Since the relationships between these parties vary from state to state, it is interesting to explore how different structures affect the estuary modeling programs.

STATE AGENCY MODELERS

Most of the states have at least one office with staff that engage in estuary modeling. As mentioned above, the primary task of these people is to prepare models for NPDES permits. They also may be involved in review of consultants' work, permit writing, model development, model selection and broader model applications.

STATE AGENCY PERMIT WRITERS

The permit writers receive applications for WLAs and send them to the modelers. The extent to which model results are used in permits varies somewhat from state to state, but generally the recommendations of modelers are adopted. There are a few cases in which recommendations are not always followed. On the other extreme, in some states permit writers actually do the modeling. Many respondents noted that close contact between the modeling and permitting groups insures a good understanding of and use of model results.

STATE AGENCY MONITORING STAFF

States' estuary monitoring programs vary widely. The degree of connection between monitors and modelers varies greatly. Some states' monitors and modelers are so separate that it was difficult to get an estimate of the average amount of money spent on monitoring each year. In Georgia, on the other hand, the primary estuary modeler is also in charge of estuary monitoring. More typical is the situation in which modelers use existing data, which is seldom tailored to their needs. They negotiate with surveyors in important cases in which more data are needed. It seems that close communication and cooperation between monitors and modelers is critical for efficient use of resources and the most accurate estuary modeling possible.

PRIVATE CONSULTANTS

To a greater or lesser degree, most states employ consultants for some phase of their modeling program. Consultants develop models, apply models and conduct monitoring. They are contracted by states and by dischargers required by the state to perform modeling studies as part of their NPDES permit.

There are advantages and disadvantages to using consultants. In many cases, state agency staff do not have the time nor expertise to carry out complex model applications. Connecticut has had difficulty using complex models because of staff turnover and lack of training. In addition, consultants have helped numerous states develop or tailor models for their particular needs and have provided ongoing support.

On the other hand, states often lose control of estuary modeling when consultants are hired. In order to check model calibrations and runs for accuracy, the state staff essentially has to learn the model. Since this is seldom possible, quality control is difficult. Consultants hired for a single complex project seldom develop models which the state modeling staff can easily modify. Therefore, the resulting models are not necessarily useful to the state.

Hiring consultants is advantageous in complex situations when the state maintains close contact throughout the modeling process and staff learn to interpret and reapply the model.

ACADEMIC MODELING COMMUNITY

Working with academic institutions can provide similar services as consultants, but has the same disadvantages. In the search for elegance and truth, academicians may be even more likely to develop a model too complex for a state to take over and use on a regular basis.

FEDERAL AGENCIES

The EPA is the primary federal agency involved with states' estuary modeling programs. The EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, Georgia develops and supports some of the most popular estuary models. Many states select EPA models because of the technical support and training programs offered by the EPA. The Army Corps of Engineers has also developed several estuary models.

In addition, the National Estuary Programs have supported many of the larger estuary modeling and monitoring projects on the East Coast, including the Chesapeake Bay Project and the Long Island Sound National Estuary Program. Most of these projects are involved to some extent with the states' individual projects.

LOCAL GROUPS

The survey did not collect much information about the involvement of local groups in estuary modeling. However, in North Carolina, citizens do monitor estuaries. Citizen water quality monitoring is also done through the Chesapeake Bay Program. Although there are concerns about quality control, this is an inexpensive and potentially very useful source of data for estuary modeling.

MODEL SELECTION

This section examines how states choose the particular estuary models they use. Few of the states surveyed chose models by carefully specifying their needs and looking at the entire range of models. This implies that there is room for improvement in the selection of models to meet states' requirements. In addition, identifying what characteristics of models are important to states can help inform future model development.

Model selection at the state level logically involves three steps:

1) Identify the problem to be solved (ie., predict DO in a far-field, one dimensional steady state situation, etc.)
2) Generate a list of models which would help solve the identified problem.
3) Select a model from the list subject to data, time and resource constraints.

However, the selection process does not always follow these steps. Other factors, many of which are functions of state agencies' limited resources, play a significant role.

State agencies seldom have the resources to develop a truly exhaustive list of options (of course, it is hoped that this report will make such a list easier to generate). Several respondents noted that they use a given model "because it was there." In many cases, a consultant had recommended or developed the model many years ago. Models used by state agencies seem to be characterized by longevity. The most common reason given for switching to a new model was that it was more up to date and therefore perceived as more defensible, according to the modelers. Another reason given for model selection was EPA support. WASP and QUAL2E enjoy wide use, probably because of the availability of training workshops, telephone support and good manuals.

It should be emphasized that cost is generally an overriding factor for states. Often, states simply use basic desktop models except for a few priority cases in which sufficient time and money are available. In these cases, resources limit the level of detail, field calibration or complexity of the model.

ISSUES OF CONCERN TO STATE ESTUARY MODELING PROGRAMS

UNCERTAINTY

The uncertainty of model results is relevant to every state's modeling program. Of the models in this study, only QUAL2E provides a routine that estimates uncertainty (QUAL2E-UNCAS). Although modelers routinely perform sensitivity analyses, these efforts are not organized into a standard procedure. In addition, a measure of uncertainty is not included with results.

Permit writers may take into account a particularly uncertain result by proposing a conservative limit. Since existing models are treated as the best tools available for performing wasteload allocations, model results will be used regardless of uncertainty. Perhaps this is why few respondents seem to think that a quantitative acknowledgement of uncertainty is necessary. In addition, according to several respondents it would be extremely difficult (and probably disheartening) to estimate the true uncertainty in estuary model results.

DEFENSIBILITY

The most immediate goal of state agency modelers regarding uncertainty is to maintain defensibility. Thus, the actual uncertainty of model results is not of direct concern to most permit writers. Permit limits are virtually uncontested in places like South Carolina, which developed its modeling framework in conjunction with the dischargers. In Mississippi, challenges are rare since field studies often yield more stringent permit conditions than does the model. Nonetheless, permit limits are sometimes challenged by permittees. However, remarkably few of these challenges make it to court. Questions are usually resolved by communication between the permittee and modeler.

VERIFICATION

Verification is another area of concern to many state estuary modelers. First, not all models are verified, due to a lack of field data. Second, as one respondent pointed out, estuaries are such variable systems that even if a model appears to be adequately verified, it may not be viable for different wind or storm conditions. Nonetheless, numerous modelers claimed to have successfully verified their models. This points out that there is no quantitative nor standard method for judging how "good" a model is. The appropriate degree of fit, robustness and accuracy of a model are a matter of judgment by the modeler.

IV. DESCRIPTIONS OF STATE ESTUARY MODELING PROGRAMS

This section provides a summary of the estuary modeling programs of the states which participated in the survey. Summaries are based only on surveys received and telephone interviews. Therefore, they may not be complete. Surveys were returned by all East Coast states except Massachusetts, Delaware, Pennsylvania and Florida.

It should be noted that estuary modeling in many states is done by consultants, National Estuary Program staff or regional commissions. Information received about regional work is described under individual state descriptions to maintain a consistent format. For instance, the Delaware River Basin Commission involves Delaware, New Jersey, New York and Pennsylvania but is described under New Jersey's section.

Each summary contains information about the resources devoted to modeling by the state. Frequently, modelers were unsure of their state's total annual budget for modeling, particularly when several agencies carried out modeling and monitoring. Nonetheless, this information provides an estimate of the extent of a state's modeling program.

To facilitate comparisons by state, a brief characterization of the estuaries in each state is given. In addition, the purposes for which the state uses estuary models are described. A list of estuary models used by the state and general comments about the state's program are provided.

Finally, the survey respondents and contacts are listed. The respondent descriptions in this section are derived from the "respondent profile" section of the written survey. (Appendix A). This section asked respondents to describe their experience and involvement with modeling and to list other contacts in their states.

Generally, only state agency personnel are listed. However, private consultants, federal and regional agency contacts are included when they appear to have the most expertise with a given model.

ALABAMA

1. Estuarine Modeling Resources

In the past, over 75% of estuary modeling in Alabama has been done by consultants. However, in the future this is likely to change, with the state performing more modeling.

2. Estuary Characterization

The Alabama coastal area consists of two estuaries - Mobile Bay and Bon Secour Bay. Since Bon Secour is actually a part of Mobile Bay, the following comments refer to all of Mobile Bay. Mobile Bay averages 11 miles across and 31 miles long. It has a surface area of 248,000 acres. Average depth is 9.7 feet, maximum is 50 feet. The mouth of the bay is protected by a barrier island (Dauphin Island) and a peninsula (Fort Morgan Peninsula). Water circulation is a result of lunar tides, river discharge and wind. Wind has an especially strong impact. Stratification can be present in the bay, particularly during periods of low river discharge. Not taking tidal effects into account, residence time is approximately 152 days.

3. Applications

Models are used for point source waste load allocations. Oxygen-consuming wastes and nutrients are modeled in the estuaries.

4. Models Used

WASP4 (EPA)

5. Other

Although it is anticipated that DEM will start doing its own estuarine modeling sometime in the future, the agency's resources are limited.

6. Survey Respondents

Charles Reynolds
Environmental Engineer
Alabama Department of Environmental Management
Water Quality Branch, Water Division
1751 Cong. Dickinson Drive
Montgomery, AL 36130
(205) 271-7842

Mr. Reynolds is a knowledgeable modeler who runs models and uses modeling results for making recommendations. He also writes reports for field calibrated/verified models. The additional contacts in Alabama are at the same address:

Lynn Sisk
Senior Engineer, Water Quality Branch
(205) 271-7827

James McIndoe
Chief, Water Quality Branch
(205) 271-7826

CONNECTICUT

1. Estuarine Modeling Resources

Over 75% of estuary modeling in Connecticut is performed by the Division of Environmental Protection Water Management Bureau, with less than a quarter of the modeling being done by consultants. There are two full-time modelers in the state. 3200 hours (over half by interns) and $200,000 per year are spent on data collection. On average, two estuaries are modeled per year.

2. Estuary Characterization

Most of the estuarine areas in Connecticut are tidally influenced rivers. In addition, the National Estuary Program models Long Island Sound.

3. Applications

Model results are used in Connecticut's hearing process for point source waste load allocations. Oxygen-consuming wastes and nutrients are modeled in the estuaries.

4. Models Used

CE-QUAL-W2 (ACOE), HAR-O3 (EPA) and WASP4 (EPA).

5. Other

The respondent noted that in the near future, estuary modeling resources will be severely curtailed due to budget cuts. Therefore, future work will likely be contracted out to consultants. In addition, the respondent encouraged states to recognize their limitations in modeling, since he felt Connecticut modelers had wasted time and effort tackling projects beyond their capabilities and training. They have also had problems with staff turnover. At present, nonpoint sources are not explicitly modeled.

6. Survey Respondents

Art Mauger
Supervising Sanitary Engineer/Water Quality Modeler
CT Division of Environmental Protection
Water Management Bureau
122 Washington Street
Hartford, CT 06106
(203) 566-2588

Mr. Mauger is a modeling expert who selects, develops, runs and reviews models and uses modeling results for making recommendations and decisions. Another contact at the same address is:

Bob Smith
Director, Planning and Standards
CT Division of Environmental Protection
Water Management Bureau
122 Washington Street
Hartford, CT 06106
(203) 566-2588

The consultant for the Thames River Estuary project, which is using CE-QUAL-W2 is Charles Becker.

Charles Becker, LMS
One Blue Hill Plaza
Pearl River, NY 10965
(914) 735-8300

GEORGIA

1. Estuarine Modeling Resources

Over 75% of estuary modeling in Georgia is done by the state's Environmental Protection Division. Additional modeling is done by consultants. One and a half person-years are devoted to modeling, while data collection receives 1740 person-hours per year (1140 routine, 600 intensive). In addition, the state spends $2500 on equipment for modeling and $20,000 for monitoring per year. One or two estuaries are examined each year by the state. Universities and researchers do additional modeling.

2. Estuary Characterization

Georgia has a wide variety of estuaries, so no general classification is possible. They include: open bays and sounds (3-D), the intracoastal waterway (2, 3-D), braided channel networks (2-D), dredged harbors (2, 3-D), non-freshwater fed linear coastal rivers (1-D), and freshwater fed linear coastal rivers (1-D).

3. Applications

Models are used for point source waste load allocations (80% of all estuary modeling), non-point source management, obtaining general information about estuaries (for shellfish protection, etc.), designing sampling and monitoring programs and setting water quality standards. Oxygen-consuming wastes and nutrients are modeled locally and in whole estuaries.

4. Models Used

Georgia Estuary Model (Georgia Environmental Protection Division); HAR-03 (EPA); MIT Transient Water Quality Network (Massachusetts Institute of Technology).

5. Other

The respondent noted that the Georgia Estuary Model will be upgraded to include branching systems and to improve interface. Georgia has found "estuary modeling to be a very valuable tool and has used it successfully to develop defensible wasteload allocations."

6. Survey Respondents

Roy Burke
Environmental Engineer
Environmental Protection Division
7 Martin Luther King Drive
Agriculture Annex, 6th Floor
Atlanta, GA 30334
(404) 656-4905

Mr. Burke is a modeling expert who selects, develops, and runs models. He developed the Georgia Estuary Model described in this report. He also reviews model applications and uses modeling results. He promotes estuary models and development of coastal dissolved oxygen standards. He listed as another contact Mr. Mork Winn, Program Manager, at the same address.

MAINE

1. Estuarine Modeling Resources

Estuary modeling in Maine is performed by the Division of Environmental Protection. There is one full-time modeler in the state who spends 25% of his time collecting data. In addition to human resources, Maine invests $10,000 per year in modeling and $20,000 per year on data collection to model one or two estuaries.

2. Estuary Characterization

Maine has a variety of estuaries, most of which are tidally driven. Stratification often occurs at the source of the estuary where freshwater inputs occur. Two dimensional models are often necessary. For most estuaries, flushing times are rapid. To date, most of the estuaries that have been modeled have flushing times less than 10 tidal cycles. The tidal ranges vary from around 8.5 feet in Southern Maine to more than 20 feet Down East.

3. Applications

Models are used for point source waste load allocations. Oxygen-consuming wastes and nutrients are modeled in sections of and in whole estuaries.

4. Models Used

QUAL2E (EPA) and WASP4 (EPA).

5. Other

The Maine respondent noted that WASP4 is very user friendly. Nonpoint sources are not modeled.

6. Survey Respondents

Paul Mitnik
Civil Engineer
Maine Department of Environmental Protection
State House Station 17
Augusta, ME 04333
(207) 289-7810

Mr. Mitnik is a modeling expert who selects models and uses modeling results for making recommendations and decisions.

Additional contact:
David Courtesan
Division Director, Biologist
(207) 289-7789

MARYLAND

1. Estuarine Modeling Resources

More than half of the estuary modeling in Maryland is performed by state agency staff; the remainder is contracted out to consultants. Eight person-years are spent on modeling; in addition, four to six person-years are spent collecting data each year. Beyond human resources, $5000 are allocated for modeling and $25,000 for data collection. Between four and ten estuaries are modeled yearly.

In addition, three person years are spent by the Chesapeake Bay Program, with an additional cost for modeling of $60,000 per year and for data collection of $140,000 per year. A total of 20 staff-years have been spent on data collection from 1984 to 1992.

In addition, in the Chesapeake Bay program, there are three modelers. 15,000 to 20,000 person hours are spent yearly collecting data. 500,000 to 1 million dollars are spent on modeling and 2-3 million on data collection per year. Four or five modeling projects are undertaken per year.

2. Estuary Characterization

The estuaries in Maryland primarily include sub-estuaries of the Chesapeake Bay and the mainstem Chesapeake. These estuaries are of the classical salt wedge, stratified variety. The mainstem is modeled with a three dimensional hydrodynamic/water quality model with an interactive sediment layer. Tributies are modeled with a two dimensional hydrodynamic/water quality model with an interactive sediment layer. Progress is being made now on linking an ecosystem (trophic layer) model.

3. Applications

Models are used for point source waste load allocations, nonpoint source management and obtaining general information about estuaries. Oxygen-consuming wastes, nutrients, hydrodynamics and toxics are modeled in whole estuaries and in local portions of the estuaries. The sediments of Chesapeake Bay are also modeled.

The Chesapeake Bay Program and the Special Programs office of the Maryland Department of the Environment (MDE) focus on basin-wide large-scale modeling. The MDE Permits office focuses on smaller scale applications for waste load allocations (WLA's).

4. Models Used

Chesapeake Bay Water Quality Model (ACOE and Hydroqual, Inc.); HSPF (EPA); SPAM (Hydroscience, Inc.); WASP4 (EPA).

5. Other

Three surveys were returned from Maryland. The above is a synthesis of their responses.

6. Survey Respondents

Yogendar S. Dusaj
Chief, Modeling Section
Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224
(410) 631-3678

Mr. Dusaj is a Water Resources Engineer with experience in running and developing models. Additional contacts at the same address are:

Harry Wang
Water Resources Engineer
(410) 631-3681

Narendra Panday
Chief, Modeling and Analysis Division
Chesapeake Bay and Special Projects
(410) 631-3681

Michael S. Haire
Program Administrator, Chesapeake Bay and Special Projects

Michael Haire is a knowledgeable modeler who selects, runs and reviews models and uses modeling results.

The final survey was returned by the USEPA-Chesapeake Bay Program. Charles Spooner, Special Projects Manager, is a
non-modeler who uses modeling results for making recommendations. He gave as an additional contact Lewis Linker, Env. Engineer and Ed Stigall. All are at the following address:

USEPA Suite 109
410 Severn Ave.
Annapolis, MD 21403
(410) 267-0061

MISSISSIPPI

1. Estuarine Modeling Resources

All estuarine modeling in Mississippi is performed by the state's Department of Environmental Quality. Each year, 100 person-hours are devoted to data collection and 400 to modeling. Three estuaries are modeled annually.

2. Estuary Characterization

The estuaries of Mississippi are shallow and empty into Mississippi Sound. Residence times are relatively short due to high freshwater inputs. Mixing is somewhat inhibited until the barrier islands are passed. Due to these conditions, two dimensional modeling gives adequate simulation of in-situ occurrence.

3. Applications

Estuary models are used to model oxygen consuming wastes for NPDES permits in localized parts of estuaries. Permit writers base WLA limits on model calculations.

4. Models Used

AWEST (developed by Mississippi State University for MS DEQ)

5. Other

Although no changes are expected in the model (AWEST) used by Mississippi, studies slated for the future will provide data that will be used to recalibrate the Back Bay of Biloxi estuary model. Mississippi does not presently model nonpoint sources, but hopes to begin taking them into account in calculating total maximum daily loads.

6. Survey Respondents

Rob Millette
Mississippi Office of Pollution Control
PO Box 10385
Jackson, MS 39289
(601) 961-5149

Mr. Millette is a knowledgeable modeler who runs existing models. The additional contact listed was Randy Reed, Branch Chief, at the same address (TEL: (601) 961-5158).

NEW JERSEY

1. Estuarine Modeling Resources

Most estuary modeling for the state of New Jersey is performed by the Bureau of Water Quality Standards and Analysis (BWQSA). Less than 25% is performed by consultants and contractors. In addition, the Delaware River Basin Commission (DRBC), which serves four states, models the Delaware River. The New York/New Jersey Harbor TMDL Committee also does some modeling. A quarter of a person-year is spent on modeling each year by the DRBC, and one person-year by the Bureau of Water Quality Standards and Analysis. The BWQSA spends an additional $5000 per year on equipment. Data collection is carried out by other agencies.

2. Estuary Characterization

The Delaware Estuary is shallow and relatively well-mixed vertically. It has a small freshwater inflow relative to the volume of the tidal prism. The upper reaches are significantly impacted by urban/industrial discharges and combined sewer overflows. The upper reaches are two-dimensional. Salinity levels in the lower estuary are regulated by flow maintenance from a storage reservoir. Net seaward advection is controlled by fresh water inflow.

Tidal tributaries are part of the New Jersey/New York Harbor Complex. With the exception of the Hudson River, their residence times are relatively long due to low fresh water inputs. There are additional estuaries along the New Jersey Coast.

Most of these systems are shallow. Circulation is affected by both wind stress and tidal variation. In many cases, routine dredging is required to maintain navigational uses.

3. Applications

Models are used for point source waste load allocations, to obtain general information and to predict chlorine concentrations as a function of reservoir operation. In addition, oxygen-consuming wastes are modeled in the estuaries.

4. Models Used

DEM-DYNDEL (EPA); Toxiwasp (EPA); Transient Salinity Intrusion Model (Harleman and Thatcher); WASP4 (EPA).

5. Other

No significant changes in estuary modeling are expected in the near future. The USGS has developed a GIS-based nonpoint source model of New Jersey which has been applied through the EPA to predict the benefits of a phosphorus detergent ban.

6. Survey Respondents

Three respondents from the Delaware River Basin completed surveys. Seymour Gross, Supervising Engineer, is a novice modeler who runs models and uses modeling results (DEM-DYNDEL). Richard Tortoriello, Operations Branch Head, is a modeling expert who runs models (Transient Salinity Intrusion Model). Thomas Fikslin, Estuary Toxics Management Program Director provided information about Toxiwasp.

All list the contact person for New Jersey as:

David Pollison
Head, Planning Branch
Delaware River Basin Commission
PO Box 7360
West Trenton, NJ 08628
(609) 883-9500

In addition, a survey was received from the Office of Regulatory Policy (ORP). This survey was completed by Assistant Administrator Dr. Shing-Fu Hsueh, who is a modeling expert. He selects and develops models, reviews model applications and uses modeling results. He also makes policy assessments based on technical information.

Shing-Fu Hsueh
Bureau Chief
Bureau of Water Quality Standards and Analysis
NJDEPE
401 E. State Street
Trenton, NJ 08625
(609) 633-7020

The additional contacts at the ORP are at the same address and telephone number:

Dr. Dhun Patel
Acting Section Chief

Dr. Patel is involved in policy assessment

Dr. Phil Liu
Environmental Scientist

Dr. Liu is a modeling expert who selects and develops models.

NEW YORK

1. Estuarine Modeling Resources

Most estuary modeling in New York is contracted out; less than 25% is done by the NYSE. Around a third of a person year is spent on modeling and a half of a person year on data collection. In addition, however, millions of dollars have been spent on estuary modeling through the National Estuary Program on Long Island Sound over the past five to seven years. The state has provided a quarter of this funding in in-kind services.

2. Estuary Characterization

The primary estuarine areas in New York are: Long Island Sound, New York Harbor, Hudson River Estuary and Peconic Bay. Long Island Sound is a semi-enclosed body of water divided by several submerged sills. New York Harbor includes the harbor from the Peirmont Marsh /Sandy Hook-Rockaway transect out to the summertime 30 ppt salinity isopleth. The Hudson River Estuary is defined as the Hudson River from the Troy dam to the Verrazano narrows. The Peconic system is an interconnected series of shallow coastal embayments at the eastern end of Long Island.

3. Applications

Models are used for point source waste load allocations, nonpoint source pollutant management and to obtain general information about estuaries. Parameters modeled include oxygen-consuming wastes, nutrients and toxics in the estuary portion of the watershed.

4. Models Used

Long Island Sound Water Quality Model

5. Other

New York participates in the Long Island Sound National Estuary Program. In addition, the state has special projects addressing the "brown tide" algal bloom in Peconic Bay. The respondent felt that the substantial resources spent on the NEP were justified by the high cost of pollution control measures. Models used by NY are not "off the shelf"; rather, they are constructed specifically for given applications. Models are similar to the Chesapeake Bay model or TOXIWASP.

6. Survey Respondents

Albert W. Bromberg
Environmental Engineer/Technical Program Manger
NYSE Rm. 328
50 Wolf Road
Albany, NY 12233-3503
(518) 457-4352

Mr. Bromberg is a knowledgeable modeler who reviews model applications by consultants and uses modeling results.

NORTH CAROLINA

1. Estuarine Modeling Resources

Around half of the estuary modeling in North Carolina is performed by the state Division of Environmental Management. The remainder of modeling is done by consultants and contractors. Less than one person-year for estuary modeling and a person-year for data collection are spent to model two estuaries per year.

2. Estuary Characterization

The estuaries in North Carolina are primarily shallow and protected by barrier islands. Residence times are relatively long due to low freshwater inputs. Circulation is mostly wind-driven, rather than tide-driven. Due to the presence of a salt wedge in the lower portions of these estuaries, stratification often occurs and two dimensional modeling is necessary. North Carolina has one estuary (Cape Fear) that opens directly to the Atlantic Ocean. It is characterized by four foot lunar tides and strong mixing and flushing patterns.

3. Applications

Models are used for point source waste load allocations and to obtain general information about estuaries. Oxygen-consuming wastes, salinity and toxics are modeled in local portions of estuaries. Some modeling of nutrients is being done.

4. Models Used

CORMIX (Cornell University), Georgia Estuary Model (Georgia Environmental Protection Division), NCWQAP (North Carolina Division of Environmental Management), QUAL2E (EPA), WASP4 (EPA).

5. Other

In the future, North Carolina will be using models to estimate nonpoint source inputs from the whole basin.

6. Survey Respondents

The primary modeling contact in North Carolina is:

Trevor Clements
DEHNR
Division of Environmental Management
PO Box 29535
Raleigh, NC 27626-0535
(919) 733-5083

Additional contacts are Ruth Swanek, Betsy Johnson and Mike Scoville. They may be reached at the phone and address given above.

SOUTH CAROLINA

1. Estuarine Modeling Resources

Over 75% of estuary modeling in South Carolina is performed by the SC Department of Health and Environmental Control, with less than a quarter of the modeling being done by consultants and USGS. There is one full-time estuary modeler in the state. Roughly 500 hours per year are spent on data collection for modeling needs.

On average, thirty to forty estuaries are modeled per year, ranging from tidal creeks to large, dredged, stratified harbors and estuaries. These models are primarily for WLAs and may be simple desktop models or more complex field calibrated models.

2. Estuary Characterization

Estuaries in South Carolina range from small shallow systems to large deep estuaries with maintained channels for shipping. Tidal ranges can be as large as six to seven feet. Most have low freshwater inputs, but some have dam-regulated highly-variable freshwater flows. Stratification is evident from field data in some systems, for which two and three dimensional modeling is needed.

3. Applications

Models are used for point source waste load allocations. Oxygen-consuming wastes are modeled in the estuaries on a watershed basis. Modelers' recommendations are incorporated into NPDES permits.

4. Models Used

BLTM (USGS), CWQM (Lawler, Mutusky and Skelley), the EPA Simplified Math Model (EPA, SCDHEC) and WASP4 (EPA).

5. Other

No significant changes in estuary modeling are expected, although the state is beginning to organize its modeling into a basinwide approach. At this time, nonpoint source calculations are made using rough land use estimates and export coefficients. However, a project is underway to develop a detailed nonpoint source loading model as part of a study on Charleston Harbor.

6. Survey Respondents

Terry Sicherman
EQMIII/ Modeler for Waste Load Allocations
SCDHEC - Division of Water Quality
2600 Bull Street
Columbia, SC 29201
(803) 734-5315

Ms. Sicherman is a modeling expert who selects and runs models. She reviews model applications and uses modeling results. Another contact in South Carolina is:

Terry Borders
EQMIII/ Modeler for Waste Load Allocations
SCDEH - Division of Water Quality
2600 Bull Street
Columbia, SC 29201
(803) 734-5317

VIRGINIA

1. Estuarine Modeling Resources

Much estuary modeling for state purposes in Virginia is performed by consultants. The Virginia State Water Control Board and educational institutions (Virginia Institute of Marine Sciences and University of Virginia) do somewhat less than half the modeling. Two person-years are devoted by the state to modeling, with four to six person-weeks being spent on data collection per year. One or two estuaries are modeled each year for WLAs.

2. Estuary Characterization

Estuaries in Virginia generally have tidal driven circulation, stratified lower portions and moderate to low freshwater inputs. In addition to the Chesapeake Bay and its tributaries (Rappahennock River, York River, James River, Elizabeth River), there are many small tidal creeks which empty directly into the ocean. The James River is serpentine and is dominated by municipal and industrial point sources while York River is linear and has few direct discharges. Virginia also employs an embayment model for wasteload allocations for the Potomac River.

3. Applications

Models are used for developing nutrient reduction strategies for Virginia including point source waste load allocations. Oxygen-consuming wastes, nutrients and toxics are modeled in local portions of the estuaries.

4. Models Used

AUTOSS (EPA); QUAL2E (EPA); HEM (VIMS); JRWQM (VIMS); SIM (VIMS); TPM (VIMS); VMP (VASWCB).

5. Other

The respondent noted that modeling will probably shift from far field DO/DOD models to near field mixing models as the emphasis in state and federal programs shifts to the control of toxic materials. Virginia is relying more and more on consultants hired by permit applicants for field calibrations modeling.

6. Survey Respondents

M. Dale Phillips
Engineer
Virginia State Water Control Board
PO Box 11143
Richmond, VA 23230
(804)527-5076

Mr. Phillips is an experienced modeler who selects, develops, and runs models. He also reviews model applications and uses modeling results.

Arthur Butt
Environmental Engineer
Virginia State Water Control Board
PO Box 11143
Richmond, VA 23230
(804)527-5176

Dr. Butt is a knowledgeable modeler who selects, develops and runs models; he reviews model applications by consultants and uses modeling results.

Winston Lung
Department of Civil Engineering
Tahnton Hall
University of Virginia
Charlottesville, VA 22903
(804) 924-3722

Dr. Lung is an expert modeler and model developer who provided information about the James River Water Quality Model.

John Hamrick
Virginia Institute of Marine Sciences
Gloucester Point, VA
(804) 642-7210

Dr. Hamrick is the developer of the Three-dimensional Hydrodyanmic Model with James River Applications

WASHINGTON, D.C.

1. Estuarine Modeling Resources

Most estuary modeling in metropolitan Washington is done by the Department of Environmental Programs at the Metropolitan Washington Council of Governments. 1.5 person years are spent on modeling and 2 on data collection per year. An additional $50,000 are spent on modeling and $300,000 on data collection yearly. Approximately three estuary modeling applications are done each year.

2. Estuary Characterization

Estuaries in the Metropolitan Washington Region vary in depth from 3 to 30 feet (Potomac) and 6 to 20 feet (Anacostia). Summer residence times are fairly long due to low freshwater inputs, with droughts dramatically affecting the Anacostia. Due to the salt wedge in the Potomac, nutrient trapping occurs and 2-D or 3-D modeling needs to be used. Both estuaries are affected by upstream nonpoint source loads and adequate storm monitoring to characterize these loads are necessary. The Potomac also has 10 embayments which are primarily shallow and require the use of coupled hydrodynamic and water quality models.

3. Applications

Models are used for point source waste load allocations, non-point source management and obtaining general information about estuaries. One of the models is being used to study the impacts of Combined Sewer Overflows. Oxygen-consuming wastes and nutrients are modeled in the estuaries.

4. Models Used

HSPF (EPA); PEM (HydroQual, Inc.); TAM (MWCOG)

5. Other

The MWCOG used to model nonpoint sources with HSPF. MWCOG found HSPF too difficult and stopped using the model. However, MWCOG modelers are hoping to develop a GIS-based non point source loading model.

The modeling approach of MWCOG may change to focus on non-point source modeling, toxics, and more computer intensive hydrodynamic and water quality models. The latter will be more expensive, requiring specialized tools.

6. Survey Respondents

Adrienne Nemura
Chief, Water Quality Modelling and Technical Services
Dept. of Environmental Programs
Metropolitan Washington Council of Governments
777 N. Capitol Street, NE Suite 300
Washington, DC 20002
(202) 962-3352

Ms. Nemura is a knowledgeable modeler who selects and runs models, reviews model applications and uses modeling results. She listed four additional contacts:

Jim Fitzpatrick
Associate
HydroQual, Inc.
1 Lethbridge Plaza
Mahwah, NJ 07430
(201) 529-5151

Paul Freedman
President
Limno-Tech, Inc.
2395 Huron Parkway
Ann Arbor, MI 48104

Stuart Freudberg
Director, Dept. of Environmental Programs
Metropolitan Washington Council of Governments
777 N. Capitol Street, NE Suite 300
Washington, DC 20002
(202) 962-3340

Gajindar Singh
District of Columbia Environmental Regulation Administration
Water Resources Management Division
2100 Martin Luther King Junior Ave., SE
Washington DC 20020
(202) 404-1120

V. SUMMARY OF MODELS

The purpose of this section is to provide a list of estuary models currently in use by eastern states. Hopefully this list will be useful to states which are trying to select a set of appropriate models. In addition, this section should help identify what types of models are readily available and which are not. Many states have adapted models such as WASP4 to meet their own needs; the innovations may be helpful to other states.

Numerous older models are described below. Many of these are still in use, but users complain about their lack of user-friendliness, outdated manuals, lack of technical support and slow computer run time. It would probably not be worthwhile to transfer these models to another state. Nonetheless, these models have been included in the listing. Several of these models have interesting adaptations, such as custom pre-processors.

Models are used for many different purposes - screening studies and detailed allocations, toxics and nutrients, tidal rivers and three dimensional estuaries. Data needs vary from desktop applications with no field data to field calibrated models requiring frequent monitoring of multiple parameters. Different models are appropriate for different situations. The descriptions below are organized by model purpose - DO/eutrophication, toxics, nonpoint and salinity. An alphabetical listing of all the models is provided in Appendix B.

Dissolved Oxygen and Eutrophication Models

As mentioned above, WLAs are the most common use of estuarine models. For WLAs, modelers generally try to simulate DO concentrations. Some states, such as North Carolina, have Chlorophyll a standards as well. Therefore, models which predict eutrophication as well as DO are often used.

DO models are available for virtually every hydrologic situation and data set (See Table 1).. Fewer models simulate eutrophication as well; those that do may predict chl a, nutrients or phytoplankton.

Toxics Models

As several respondents noted, toxics are likely to become a greater part of WLAs in the future. Although many states already model toxics, interest in toxics modeling is expanding. Near field models are available, but the only far field model reported by respondents is TOXIWASP, a very complex model. It is likely that a simpler far field toxics model would be helpful to many states.

CORMIX - near field, three dimensional mixing model

TOXIWASP - far field, one dimensional mixing model

VMP - near field, three dimensional mixing model calibrated for Virginia's estuaries.

Nonpoint Source models

State water quality modelers, including estuary modelers, are becoming increasingly interested in nonpoint source pollution (NPS). Although some states have used HSPF, most find it too cumbersome for a routine application. Some states, like North Carolina, are trying to develop a GIS-based export coefficient model. This would be better matched to the state's needs and resources than are the existing models. Although HSPF is the only model listed by the survey respondents, Dillaha (1987) provides information on other available NPS models.

Salinity

Several models were described which simulated salinity under various conditions. While many water quality models are capable of predicting salinity, some models are designed for salinity simulation alone. They are used in situations such as the Delaware River, which must manage reservoir releases to maintain optimal salinity in the Delaware Estuary. The two models described in returned surveys are the Salinity Intrusion Model and the Transient Salinity Model

TABLE 1

DISSOLVED OXYGEN AND EUTROPHICATION MODELS

Dimensions	State	Near Field	Far Field
one	steady	AutoQual NCWQAP Qual-2E	GAEST HEM* James River WQ* Simplified Math Tidal Prism Model
	dynamic	BLTM	DEM-DYNDEL MIT Model PEM* TAM*
more than one	steady	CWQM SPAM	AWEST HAR-03
	dyanamic	WASP4*	CE-QUAL-W2* CBWQ* 3-D Hydrodynamic WASP4*

* Model simulates eutrophication as well as Dissolved Oxygen

VI. RECOMMENDATIONS

These recommendations are based on the survey responses and follow-up interviews. They reflect strategies that east coast states have found to be the most effective approaches to estuary modeling. The recommendations are intended to be general. Naturally, states should consider their existing programs and special circumstances before adopting any of these strategies.

1. Modeling Approach

The "precalibrated" whole-estuary model approach described in Section III is probably worthwhile when there are multiple dischargers in an estuary, although near field models may still be needed for localized impacts. The model need not be complex and completely field calibrated at first. Rather, the state should set up the model with existing data. Then, statewide priorities should be set for the degree of accuracy needed in different estuaries. Based on these priorities, a monitoring program may be established to "fill in the gaps" and meet accuracy needs. Meanwhile, more complex kinetics may be added to the models as time and money allow.

In addition, once a modeling approach is established, it is critical to have an active maintenance program to update existing calibrated models. Many of the calibrated models currently in use by states are outdated. R. Thomann notes in the EPA's Technical Guidance Manual (Part 4: Critical Review of Estuarine WLA Modeling, 1991) that "All models must be continually updated: if not, model `atrophy' sets in and credibility deteriorates. Estimated model `half-life' is about one to two years."

2. Model Selection

Improvements in model selection could be achieved by carefully following the model selection process outlined above in section III (identifying needs, listing models, and selecting subject to resource constraints). It is important to identify what is needed from the model such as degree of accuracy, useful parameters and appropriate scale. An initial list of models can be generated by using the Table 1 from section V. Modelers in other states, the EPA and consultants may be able to suggest other models. When resource limitations are considered, the cost of each model should include: data requirements, computer needs, training time and application time.

In addition North Carolina Division of Environmental Management modelers have hypothesized that several other factors are important criteria for model selection. These include user-friendliness and transferability. "User friendliness" characterizes the ease with which a model may be learned and applied effectively. This obviously contributes to the cost of model application. It also is likely to affect the quality of model application. The most user-friendly models encourage sensitivity analysis, aid in parameter selection, help trouble shoot for errors. Transferability is important when a model will be used many times under varied conditions. For example, it may be more efficient to support a single three dimensional model for use in all multidimensional situations, rather than maintaining separate two- and three-dimensional models.

Finally, in selecting models, it may be worth considering how the degree of complexity contributes to accuracy, uncertainty and cost. According to R. Thomann (1991), "the best models are often the simplest." A more complex model is not necessarily more accurate if little data are available; in fact, it may obscure the true uncertainty by giving detailed, but inaccurate, predictions. Indeed, in most situations faced by state modelers, sparse data are available.

Model developers are beginning to respond to the fact that states have limited data collection resources. For example, the Georgia Estuary Model was specifically designed to require limited data that a state agency can generally afford to obtain. Likewise, more attention is being paid to the user-friendliness of models. WASP4's new post-processor is an example of an effort to make model results easier for a state-level modeler to use.

North Carolina has considered its selection of nonpoint source models with respect to the attributes described above. Careful attention to these characteristics showed that simpler, lower cost models were optimal for most situations (McGeogh, Smith and Warmerdan, 1992).

3. Uncertainty

Generally, uncertainty in estuarine models for WLAs is explored using a sensitivity analysis. Uncertainty is acknowledged by setting conservative permit limits if uncertain inputs are significant. State level modelers might consider the advantages of including some expression of uncertainty with model results. If permittees were educated about this approach, model results would be no less defensible than they are currently. It would be advisable to work with permittees and other affected parties while developing this approach so that they understand the meaning of uncertainty estimates. This would likely reduce the number of challenges of permit results.

This approach may also be coupled to monitoring. Once areas of significant uncertainty are identified, they can be used to quantify how much money should be spent on different monitoring projects.

One other aspect of uncertainty that might be explored is the use of data from multiple sources. Often, states do not have the opportunity to conduct intensive monitoring. However, data may be available from a permittee, old studies, citizen monitoring data and limited recent state-gathered field data. An expert system could be developed to pool all available data. The pooling method would involve weighting by the relative quality of the various data sources (Reckhow, 1982). This would result in a lower variance than for one source of data taken alone.

4. Monitoring

Many respondents identified monitoring as the weakest link in the estuary modeling process. "A well-designed data collection program is the best confidence builder," writes G. Orlob in the EPA Technical Guidance Manual (1991). Given limited resources, however, priorities for monitoring must be established. Calculating the uncertainty of model results could be used to help prioritize areas where monitoring could substantially reduce uncertainty. One contact recommended that monitoring should be a particularly high priority for the NPS model development. It seems stream monitoring could do more to improve accuracy than further refinement of export coefficient calculations (D. Moreau, personal communication 1992).

Finally, states that currently do not use citizen estuary water quality monitoring might want to explore its potential role in improving estuarine field data. Citizens' data has been used in the Chesapeake Bay Program. A primary concern about citizen monitoring is quality control The Chesapeake Bay Program has demonstrated that a system can be designed to insure the quality of citizen-gathered data.

5. Specific Models

Every state has a range of estuary modeling situations. In order to make initial model selection easier, a single model is listed below for each general category of estuary modeling. For each case, a model was sought which is user-friendly, has good documentation, and requires as few resources as possible. These recommendations are based on information gathered in the surveys. More research should be done before a model is selected for a specific situation.

Dissolved Oxygen and Eutrophication Models

One Dimension, steady state

Near Field: QUAL2E - it is commonly used, well documented and has an uncertainty routine.

Far Field: GAEST - it is tailored to states' data needs. However, the manual should be improved and guidance for its use as a desktop model and for interpretation of uncertainty of results should be developed. Alternately, the James River Water Quality Model might be chosen if eutrophication predictions are needed.

One Dimension, dynamic

Near Field: BLTM is only model in this category

Far Field: all of the models in this category are calibrated for particular estuaries. Most of the models are based on WASP4. It may be best to simply apply a 3-D model in one dimension.

Two and Three Dimensions, steady state

Near Field: CWQM has moderate data requirements and is more up-to-date than the alternative, SPAM. However, it might be somewhat expensive to acquire CWQM from consultants.

Far Field: HAR-03 is probably the best available model, but it is not user friendly. It would probably be best to use a dynamic 3-D model in steady state (see below).

Two and Three Dimensions, dynamic

Near Field: WASP4 is the only model in this category.

Far Field: For two dimensions, vertically, CE-QUAL-W2 is the only model listed. For three dimensions, WASP4 and the Three-Dimensional Hydrodynamic Model are available. If, as indicated by the developer, a water quality routine is incorporated into the Three-Dimensional Hydrodynamic model, it may have superior user-friendliness, better processing, and lower data requirements than WASP4. WASP4, however, is already available and supported by EPA. As indicated above, whichever model is chosen from this category also may be used in one-dimensional or steady state conditions.

Toxics:

Near Field - Virginia has adapted a CORMIX-like mixing program to conditions typical for Virginia (VMP). The resulting model is more efficient than the general version. A model similarly tailored to local conditions might be most efficient for use by other states.

Far Field - TOXIWASP is the only available model, but may be too cumbersome in some cases. It may be worthwhile to develop a simpler far field toxics model.

Nonpoint source models:

The only model described by survey respondents is HSPF. According to Chesapeake Bay Project and Metropolitan Washington Council of Governments staff who have experience with HSPF, it was costly, cumbersome and politically volatile. However, numerous states are interested in developing a better nonpoint source model which is GIS based. Therefore, a dialogue between state agencies would probably be especially fruitful in this case.

6. Networking

Estuary modeling is a rapidly developing field. However, many of the advances are made in academic or high-resource consulting projects. These developments are not necessarily useful in addressing the most pressing needs of estuary modelers at the state level. A network between state estuary modelers might prove fruitful for addressing problems of uncertainty analysis, inadequate monitoring, model selection and verification. This network could consist of individual contacts, a newsletter, or an annual workshop.

VII. CONCLUSIONS

As the pressures of development increase along the east coast, efforts to protect estuarine water quality are intensifying. As a consequence, state level environmental agencies are expanding their estuary modeling programs. Many states are encountering similar difficulties with insufficient data collection resources, limited time, overly complex models and overwhelming uncertainty in their estuary modeling efforts.

The primary purpose of this report is to bring together state level modelers struggling with similar concerns. The state program descriptions in Section IV are intended to describe institutional arrangements for estuary modeling throughout the eastern coastal states and to facilitate individual contacts between modelers. The model descriptions and classifications in Section V provide an accessible first cut at model selection.

The recommendations in Section VI are primarily intended as food for thought. A workshop including model developers, EPA staff and state modelers might constructively develop these ideas. For instance, presentations by state agency modelers highlighting their difficulties in obtaining adequate data might inspire the development of more simple, user-friendly models. Topics such as uncertainty, coordinating monitoring, defensibility and appropriate nonpoint source models could be addressed. Strategies resulting from such a forum would more likely match state level modelers' needs than would approaches developed at the federal level or by academics. Finally, such a workshop would foster communication between estuary modelers with similar concerns who could benefit from each others' experience.

Readers are encouraged to respond to this report with comments, additions or corrections to:

Trevor Clements, Assistant Chief
Water Quality Section
Division of Environmental Management
NCDEHNR
PO Box 29535
Raleigh, NC 27626-0535
(919) 733-5083

REFERENCES

Barnwell, Thomas O. Jr. Linfield C. Brown and Raymond C. Whittemore. **QUAL2E - A Case Study in Water Quality Modeling Software.** Unpublished.

Devantier, Bruce A. and Arlen D. Feldman. **Review of GIS Applications in Hydrologic Modeling.** Draft in progress for ASCE. 1992.

Dillaha, Theo A. **Role of Best Management Practices in Restoring the Health of the Chesapeake Bay: Assessments of Effectiveness.** In: Perspectives on the Chesapeake Bay, 1990: Advances in Estuarine Sciences. Chesapeake Research Consortium, Gloucester Point, Virginia. April 1990.

Frink, Charles R. **Estimating Nutrient Exports to Estuaries.** J. Env. Qual. 20: 717-724 (1991).

Gale, Judith A. **A Guide to Estuaries of the Albemarle-Pamlico Region, NC.** Ablemarle-Pamlico Estuarine Study, 1989.

Giese, G.L. H.B. Wilder and G.G. Parker, Jr. **Hydrology of Major Estuaries and Sounds of North Carolina.** USGS Water-Supply Paper 221. 1985.

McGeogh, Una, Katrina Smith and John Warmerdan. **A Decision Theoretic Approach to Nutrien Loading Model Selection in North Carolina.** Unpublished. 1992.

OSWER Models Management Initiative. **Report on the Usage of Computer Models in Hazardous Waste/Superfund Programs.** Information Management Staff, Office of Solid Waste and Emergency Response. December 1990.

Reckhow, Kenneth H. **A Method for Information Pooling to Reduce Lake Model Prediction Error.** Proceedings of the North American Lake Management Society. USEPA, 1983.

Reckhow, Kenneth H. Jonathan B. Butcher, and Carlos M. Marin. **Pollutant Runoff Models: Selection and Use in Decision Making.** Water Resources Bulletin, Vol. 21, No.2, April 1985.

Technical Guidance Manual For Performing Waste Load Allocations. Book III: Estuaries. USEPA. 1990.

Part 1: Estuaries and Easte Load Allocation Models.

Part 2: Application of Estuarine Waste Load Allocation Models.

Part 3: Use of Mixing Zone Models in Estuaine Waste Load Allocation Modeling.

Part 4: Critical Review of Estuarine Waste Load Allocation Modeling.

Thomann, Robert V. and John A. Mueller. **Principles of Surface Water Quality Modeling and Control.** Harper and Row. New York. 1987.

APPENDIX A:

SAMPLE ESTUARY MODELING SURVEY

THIS SURVEY IS DESIGNED TO GATHER INFORMATION ABOUT THE ESTUARINE MODELS YOUR PROGRAM USES. THE RESULTS WILL BE COMPILED INTO A REPORT WHICH WILL BE SENT TO YOU. WE APPRECIATE YOUR TIME AND EFFORT IN COMPLETING THIS SURVEY.

1. ESTUARINE MODELING RESOURCES

Who performs estuary modeling analyses for your state? (circle percent of the time you rely on each)

Your office or agency	0-25%	25-50%	50-75%	75-100%
Consultants/contractors	0-25%	25-50%	50-75%	75-100%
Other (please specify)	0-25%	25-50%	50-75%	75-100%

If your state agency performs a percentage of the analyses, what is your best estimate of the resources devoted annually by your state/program to estuarine modeling?

Number of people who perform estuarine modeling ______
(answer in person-years; if someone does modeling only 50% of their time, count them as .5 person, etc.)

Person-hours per year spent collecting data______________

Annual non-human resources devoted to estuary modeling
(computers, monitoring equipment, etc.)

Modeling __________$/yr
Data Collection __________$/yr

Number of estuaries modeled annually by your program _____

2. ESTUARY CHARACTERIZATION

Please describe the types of estuaries managed by your state. Follow this example:

The estuaries of North Carolina (eg. Chowan, Neuse, Pamlico) are primarily shallow and protected by barrier islands. Residence times are relatively long due to low freshwater inputs. Circulation is mostly wind-driven, rather than tide-driven. Due to the presence of a salt wedge in the lower portions of these estuaries, stratification often occurs and 2-dimensional modeling should be considered. North Carolina has one estuary (Cape Fear) that opens directly to the Atlantic Ocean. It is characterized by four foot lunar tides and strong mixing and flushing patterns.

3. APPLICATIONS:

For what purposes do you use estuary models? (check all that apply)

_____ Point Source Waste Load Allocations
_____ Non-Point Source Management
_____ Obtain general information about estuaries
_____ Other (specify)

What types of parameters do you model in estuaries?

_____ Oxygen-consuming wastes
_____ Nutrients
_____ Toxics
_____ Other (specify)

On what scale do you apply these models?

_____ whole watershed
_____ estuary portion of watershed
_____ local portion of estuary

4. SATISFACTION WITH OVERALL MODELING PROGRAM

Please rate your opinion on how the following statements apply to your state or program (circle one)

	strongly agree	agree	disagree	strongly disagree
A. Models are valuable tools for supporting decision-making in estuarine management.	1	2	3	4
B. Resources devoted to modeling are well-justified by the benefits they provide for decision-making.	1	2	3	4
C. Decisions makers who use the results of estuarine models understand model uncertainty and use results appropriately.	1	2	3	4
D. I am satisfied with how estuarine modeling is used in my state.	1	2	3	4
E. Adequate resources are presently devoted to estuarine modeling in this state.	1	2	3	4

5. To the best of your knowledge, please describe the models used in your state or program. Attach additional sheets if necessary. For each model, please include the model's name, source, description, application, data needed, computer requirements, user, limitations, advantages, and anything else you feel is relevant. An example follows for a model used in North Carolina.

MODEL NAME: NCWQAP **SOURCE:** N.C. DEM

DESCRIPTION: 1-D, steady state, finite section model

APPLICATION: used in tidal streams **COMPUTER:** IBM PC

USER: DEM modelers **DATA:** may use field data or literature rates to calibrate.

LIMITATIONS: no user manual **ADVANTAGES:** fairly user friendly

OTHER:

MODEL NAME: SOURCE:

DESCRIPTION:

APPLICATION: COMPUTER:

USER: DATA:

LIMITATIONS: ADVANTAGES:

OTHER:

MODEL NAME: SOURCE:

DESCRIPTION:

APPLICATION: COMPUTER:

USER: DATA:

LIMITATIONS: ADVANTAGES:

OTHER:

MODEL NAME: SOURCE:

DESCRIPTION:

APPLICATION: COMPUTER:

USER: DATA:

LIMITATIONS: ADVANTAGES:

OTHER:

MODEL NAME: SOURCE:

DESCRIPTION:

APPLICATION: COMPUTER:

USER: DATA:

LIMITATIONS: ADVANTAGES:

OTHER:

6. Please give any other information you feel is relevant to the use of models in estuarine areas in your state. Do you expect any changes in your state's estuary modeling approach in the foreseeable future? Do you have any favorite references?

7. RESPONDENT PROFILE

Name: ____________________________ Agency:_________________________

Title/Job Description: ________________________

Part of the goal of compiling this survey is to establish a network of people interested in these modeling issues. Would you like to be listed as a participant in this survey in the summary of these survey results?

____YES ____NO

Please describe yourself in terms of estuary modeling experience

__A. Modeling expert (ie. extensive study, multiple years of hands-on experience)
__B. Knowledgeable modeler (ie., some academic/other coursework, some hands-on experience)
__C. Novice/inexperienced modeler (ie., little or no coursework, little or no hands-on experience)
__D. Non-modeler (user of modeling results, etc.)

8. Which of the following best describe your involvement with estuary models? (check all that apply)

__A. I select models to be used for estuarine management.
__B. I develop models.
__C. I run existing models.
__D. I review model applications by consultants/technical staff.
__E. I use modeling results for making recommendations/decisions.
__F. I have no involvement with estuarine models
__G. Other (please specify)________________________________

9. CONTACTS:

We intend to follow-up this survey with phone interviews. Please provide the names of at least one technical staff member/consultant and one manager/policy maker whom we can call.
You may include yourself.

Name:	Name:
Job Description:	Job Description:
Phone:	Phone:
Address:	Address:

10. To whom should we send the final report? (Please include job title and address if different from above)

RETURN TO: TREVOR CLEMENS, ASSISTANT CHIEF
WATER QUALITY SECTION
DEPARTMENT OF ENVIRONMENT, HEALTH AND NATURAL RESOURCES
P.O. BOX 29535
RALEIGH, NC 27626-0535 TEL: (919) 733-7015

RETURN BY APRIL 30, 1992

APPENDIX B:

ALPHABETICAL LIST OF ESTUARY MODEL DESCRIPTIONS

Model Name: Auto-Qual Modeling System (AutoQual or AutoSS)

Source: EPA, 1973

Description: Simulates D.O.; near field; one-dimensional; steady state finite difference; BOD/DO.

Application: part of an expert system for nontechnical users. Used for narrow freshwater streams and their tidal embayments.

Computer: IBM-PC (uses Fortran)

User: Virginia Soil and Water Control Board

Data: limited field observations

Discussion:

Although Auto-SS is a rather old model, Virginia modelers use a modified version frequently. Dale Phillips of the Virginia Soil and Water Control Board has written a pre-processor which makes this model a very user-friendly expert system. It is used primarily in the desktop mode with very limited field observations.

There is a users' manual for the system adapted by Virginia which is available from VSWCB for a fee. In addition, VSWCB offers limited telephone support.

Although this model has been field-verified, it is primarily used for first-cut and screening WLA analysis by NPDES permit writers.

Model Name: AWEST

Source: Developed by Mississippi State University for the state Department of Environmental Quality

Description: Simulates DO; far field, 2-D, steady state

Application: waste load allocations (WLAs)

Computer: IBM mainframe and system 36

Users: Mississippi Department of Environmental Quality

Data: may use field data or literature rates to calibrate. Because model is pre-calibrated, it takes little additional field data.

Discussion:

This model was developed by Mississippi State University for Mississippi's three estuaries: Saint Louis Bay, Biloxi Bay, and Pascagoula Bay. It is quite similar to WASP and could be adapted to other estuaries. It requires a moderate amount of effort; some use of the manual to make changes is necessary for each application.

Although it is not menu-driven and there are no helpful error messages, it is moderately easy to input data. The output is very easy to read and use and the model is considered fairly interactive. Mississippi modelers were trained in using AWEST by its developers by working through one case. A manual is available.

The model does not provide an estimate of uncertainty of results. The model results are seldom challenged. This is attributed to the fact that in the past validation surveys have shown even lower DO than the model predicted. The model was successfully field verified in the Bay of Biloxi.

The model is run on the state's mainframe computer and takes only a few minutes to run, although data input may take an hour. It is used to perform WLAs in the state's estuaries.

Generally, the users have been satisfied with the model. However, it was noted that it is cumbersome to make flow changes.

Model Name: Branched Lagrangian Transport Model (BLTM)

Source: USGS

Description: Simulates DO; far or near field; one dimension; dynamic. Unsteady state model with Lagrangian approach.

Application: WLAs in estuaries, rivers with reversing flow

Computer: Mainframe (limited PC use)

User: USGS and South Carolina Department of Health and Environmental Control modelers

Data: field data and literature values. Fairly data intensive.

Discussion:

The BLTM is used in South Carolina for WLAs when time and money are available for field calibration. Currently, an application of the BLTM on the Intracoastal Waterway near Myrtle Beach is being written up in report form.

There is no pre-processing in this model. Output is easy to read and use. Plot options exist for viewing model results. It is fairly interactive, although changes must be made and run manually.

South Carolina modelers were trained to use the BLTM by USGS staff and by using the manual in about three weeks. The manual is quite good, including a tutorial and help in interpretation of results. Training and support are available on an individual basis through the model developer and USGS staff (Reston, VA and Columbia, SC).

South Carolina modelers feel the accuracy of this model is high. Permittees are generally satisfied with the model, in part because they helped sponsor its development and acquisition by the state. Although the model does not provide the user with a measure of uncertainty, it does give basic statistics.

The BLTM is rather data and time intensive. A minimum of three field-measured parameters is useful; ideally eight should be measured. The model as set up for the Intracoastal Waterway takes 45 minutes to run on the USGS Prime network. Although a PC version is available, PCs can only handle small applications of this model.

Generally, South Carolina has been satisfied with this model. The fact that it assumes an unstratified system is seen as a limitation. Assets include that the model provides the user with helpful information when calibrating and that it is stable for any time step.

Model Name: CE-QUAL-W2

Source: Army Corps of Engineers

Description: Simulates DO and eutrophication; far field; two-dimensional; dynamic; finite difference.

Application: 2-layer estuaries

Computer: 80486/80487 preferred but can be run on 80387

User: Lawler, Mutusky and Skeller (consulting firm in Connecticut)

Data: extensive field data

Discussion:

The Connecticut Department of Environmental Protection has contacted a consulting firm to develop a water quality model of the Thames River, a eutrophic 2-layer estuary. Data collection has been extensive including multiple water quality surveys ($200,000) as well as long term current meter deployment to develop a 2-layer hydrodynamic model. The consulting firm selected CE-QUAL-W2 from among several multi-dimension models because it was best suited to this particular situation and because its code was well documented.

North Carolina has just acquired this model for possible use on the Neuse River. More information about this model will be available as these projects progress.

Model Name: Chesapeake Bay Water Quality Model

Source: Army Corps of Engineers and HydroQual, Inc.

Description: Simulates 23 state variables; far field; three dimensions; dynamic time varying model

Application: tidal Chesapeake Bay and lower tributaries

Computer: Cray II

User: Chesapeake Bay Program

Data: Chesapeake Bay bathimetry, monitoring data, tides, watershed model

Discussion:

The Chesapeake Bay Water Quality model is a very large and sophisticated model. It requires a large computer, such as the Cray. A single 10 year run takes 40 hours CPU time and costs around $8000. The various states and agencies involved with Chesapeake Bay modeling send model application requests to the Chesapeake Bay Project, which coordinates and runs the model.

Current criticisms of the model include that it has very poor resolution in important shallow waters and in the tidal tributaries. In addition, it is difficult for states to use the model for WLAs and other decisions they must make since they do not have direct access to the model and because model runs are so expensive.

Model Name: Comprehensive Water Quality Model(CWQM)

Source: Lawler, Mutusky and Skelley, Pearl River, NY

Description: Simulates DO; far or near field; three dimensional; steady state

Application: embayments and estuaries

Computer: IBM compatible PC

User: South Carolina Department of Health and Environmental Control

Data: field data and literature rates

Discussion:

This model requires a moderate amount of data and effort relative to other similar purpose models. South Carolina uses it is used when some money is available for data collection, but not enough to support an application of BLTM. It has been applied to a Beaufort River and Ashley River WLAs.

Although there is no pre- or post- processing, data input and output use are quite simple. Data is entered into seven merging files in 80 column format. The error messages are not particularly useful, but the model is interactive. Modelers in South Carolina were trained in 2 days through an individual arrangement with the consultants who developed the model. There is a good manual and the consultant is available for technical support.

The model does not provide an estimate of uncertainty, but the users in South Carolina feel it is quite accurate. Although it has been challenged, it has not been overturned. The model has been field verified with very successful results.

Field data on temperature, salinity, ammonia, DO and BOD are necessary to run the model. It takes less than 5 minutes to run the model on a PC.

South Carolina is generally satisfied with this model, which has been approved by the EPA.

Model Name: Cormix

Source: EPA (developed at Cornell University)

Description: simulates toxics (any conservative substance; a decay rate function is also available); near field; three dimensional; steady state.

Application: rivers, lakes and estuaries. Assists with the design of submerged single port discharge into variable and complex ambient conditions.

Computer: IBM-PC

User: North Carolina Division of Environmental Management

Data: literature rates or field data

Discussion:

Cormix describes behavior of a plume near a submerged single port discharge. It is intended for use in deep estuaries, but North Carolina has applied it in shallow situations (Hadnot Point, NC; written report available from NCDEM).

Cormix is fairly easy to use and apply. It is EPA supported and training sessions are offered. The model includes good pre- and post- processing and is menu driven, adding to its user friendliness. The manual is helpful, although it does not provide adequate advice on the interpretation of results.

The model was field verified by its developer. Model results have been defended successfully when challenged.

The model requires only three or four field parameters, making it very easy to apply. It takes a few seconds to run on a personal computer (20 minutes including data input). Cormix is considered particularly appropriate when toxics waste load information is needed and a dye test cannot be conducted.

One of the criticisms of the model is that the results given are not continuous. The model is time consuming because the modeler cannot retrieve data entered from a previous model run after exiting the program. This limits the interactive capacity of the model and impedes sensitivity analysis.

Cormix2, which allows for multiple port discharges, is also available.

Model Name: Dynamic Estuary Model (DEM-DYNDEL)

Source: EPA/Delaware River Basin Commission

Description: Simulates DO; far field; one dimension and pseudo 2-D); dynamic.

Application: Conventional pollutants for Delaware Estuary and tributaries, primarily for WLAs.

Computer: VAX/VMS

User: New Jersey Office of Regulatory Policy and Analysis and the Delaware River Basin Commission.

Data: field data and literature values

Discussion:

The DEM is based on a precursor to the WASP model and was originally calibrated for San Francisco Bay. Although simpler than WASP, it is sufficient for DO predictions on the Delaware River. The model could be calibrated for other two dimensional (latitude and longitude) systems. The Delaware River Basin Commission is considering whether or not the model needs to be recalibrated.

The DEM is not user friendly. However, the output is fairly easy to read. The manual is detailed but not very readable and the program itself has no helpful error messages. Data requirements are moderate. The model takes 5 minutes to run on the mainframe computer.

In the near future, the DRBC plans to use DEM in a study of Combined Sewer Overflows, which will require time variable inputs. The model will be transferred to a personal computer workstation for this application.

Model Name: Georgia Estuary Model (GAEST)

Source: Georgia Environmental Protection Division

Description: Simulates DO and salinity; far field; one dimension; steady state; finite segment approximation to finite difference solution.

Application: One dimensional tidal systems.

Computer: IBM PC

User: EPA, Georgia Environmental Protection Division, North Carolina Division of Environmental Management, consultants.

Data: moderate amounts of field data

Discussion:

The Georgia Estuary Model was developed by Roy Burke of the Georgia Environmental Protection Division and is being sponsored by the Region IV EPA. It is intended to require a level of data collection and resources affordable to states. The level of data and effort has been described as moderate relative to WASP. However, it has also been used as a desktop model.

The model has good pre- and post-processing and is generally easy to use. Error messages are generally helpful. The model is interactive; there is a menu option for sensitivity analysis. The model takes a few seconds to run on a personal computer, and data entry takes 30 - 60 minutes.

Unfortunately, no official users' manual is available. A set of instructions are available from the developer. These instructions do not give guidance for cases in which there is little data and for interpretation of results. In addition, a work-book style report from the first major application of the model to the Brunswick estuary (1984) is available. The developer provides limited phone support and is willing to contract for training sessions on an individual basis.

The model has been field verified to the extent possible. The developer notes that verification of any model is difficult in a variable estuarine system. Model results have been defended successfully against challenges by permittees.

The developer hopes to write a complete users' manual and to add a branching routine to the model in the future.

Model Name: HAR-O3

Source: EPA

Description: Simulates DO and salinity; far field; three dimensions; steady state; finite difference solution.

Application: estuaries and embayments.

Computer: Mainframe, IBM PC

User: Connecticut Department of Environmental Protection, Georgia Environmental Protection Division, EPA and consultants.

Data: extensive field data

Discussion:

HAR-03 was originally developed for use in Boston Harbor. Presently, it is used by Georgia in cases which are distinctly three dimensional or branched so the one dimensional Georgia Estuary model cannot be used. Sometimes, parts of the estuary will be run with the one dimensional model and then be fed into HAR-03 to see if other dimensions are significant.

HAR-03 is not user friendly. Data input can be difficult and the user often has to alter the FORTRAN code. Although there is no single source of information about this model, the Region IV EPA and Georgia EPD have copies of the manual.

A simple desktop application of HAR-03 might take several days, whereas a complex situation may take months. For desktop applications, developing geometry inputs takes the most time.

Georgia has applied HAR-03 to two estuaries. Connecticut has found HAR-03 useful to perform a simple DO balance if hydraulics are not too complex.

Model Name: Hydrodynamic-Ecosystem Model (HEM)

Source: Virginia Institute of Marine Science, 1985

Description: Simulates DO and eutrophication; far field; one dimension; steady state; real time; finite element.

Application: tidal streams. Used for stream water quality in the York River and in six Potomac embayments.

Computer: IBM-PC

User: Virginia Soil and Water Control Board, Virginia Institute of Marine Science and consultants

Data: requires extensive field data

Discussion:

HEM is designed to be used by an expert in water quality modeling. It is a sophisticated model which requires substantial field calibration.

HEM is has no pre- or post-processing. Therefore, it is not easy to enter data or interpret results. Technical guidance is available from the Virginia Institute of Marine Sciences on an individual contract basis. There is a users' manual, but it may not be entirely up to date.

HEM has been field verified using at least two sets of data in nine estuaries in Virginia. Users in Virginia have been satisfied with the model. However, it is only used for major WLAs and the permittees are required to pay for the data collection.

Model Name: Hydrologic Simulation Program in Fortran (HSPF)

Source: EPA

Description: nonpoint source pollution loading model.

Application: watershed analysis

Computer: VAX 8650, Sun Workstation. Can use on a PC for limited applications.

User: Chesapeake Bay Program

Data: field data and literature values for land use, point source inventory, fall line monitoring data.

Discussion:

HSPF is currently used by the Chesapeake Bay Program to estimate nonpoint source nutrient inputs to the bay for the Water Quality Model. They hope to calibrate it for Total Suspended Solids in Fall 1992. MWCOG used to use HSPF but found it too cumbersome.

Although model users complain about the extensive data collection and calibration necessary for a successful application of HSPF, it is the most widely used nonpoint source pollution model. The Chesapeake Bay Project has spent millions of dollars over 10 years calibrating a basin-wide HSPF. Despite this investment, model results are challenged and modelers are distrustful of small-scale predictions. In addition, they are dissatisfied with the number of hard-wired parameters.

Currently, HSPF is being applied with a smaller grid to several small basins around the Chesapeake. This effort may yield more accurate results.

HSPF's primary assets are its good manual, EPA support and relatively common application.

Model Name: James River Water Quality Model (JMSRV)

Source: HydroQual, Inc. (1986)/ adapted to PC by Winston Lung, University of Virginia

Description: Simulates nine parameters including DO and eutrophication; far field; one dimensional; steady state.

Application: Has been applied to the Neuse River (NC) and James River (VA).

Computer: IBM PC

User: Virginia State Water Control Board

Data: moderate amounts of field data

Discussion:

This model has been described as similar to Eutro4 (WASP4), but 100 times more efficient, since it is less generic. It also requires somewhat less data. It is transferable to other one dimensional estuaries.

Although no official technical support is available, the model has a good users' manual. Winston Lung of the University of Virginia has adapted it for PC use. This version is quite user friendly.

JMSRV has been field verified numerous times and has been shown to be quite accurate. The model is used only for predicting averages.

Model Name: MIT Transient Water Quality Network

Source: Massachusetts Institute of Technology

Description: Simulates DO and salinity; far field; one dimension; dynamic.

Application: all one dimensional water bodies

Computer: IBM PC or mainframe

User: Georgia Environmental Protection Division

Data: massive

Discussion:

The Georgia Environmental Protection Division used the MIT for a five year project on Savannah Harbor and found problems with the DO routine and the massive amounts of data required. In addition, accuracy is limited by depth averaged parameters.

The model is not user friendly. Data input and interpretation of results are cumbersome. Sensitivity analysis is difficult as well. The Georgia Environmental Protection Division developed pre- and post-processors for their application in order to make the model easier to use.

As mentioned above, the model requires large amounts of field data. In Georgia's use of the MIT model, the model took 6 - 12 hours to run on an EPA Prime computer.

The MIT Model is not actively maintained by a single organization. Therefore, it is difficult to get manuals, technical support and training. However, an experienced modeler may find the model useful because of the variety of situations it can handle well.

Model Name: North Carolina Water Quality Assessment Program (NCWQAP)

Source: North Carolina Division of Environmental Management

Description: Simulates DO; near field; one-dimensional; steady state; finite section.

Application: tidal streams

Computer: IBM-PC

User: NCDEM modelers

Data: literature values or field data

Discussion:

The NCWQAP was developed by North Carolina Division of Environmental Management modelers to predict dissolved oxygen in tidal streams. Although it is user friendly and menu driven, it has no user manual nor source of technical support. The NCDEM has switched to a similar, but better documented, model: Georgia Estuary Model.

Model Name: Potomac Estuarine Model (PEM)

Source: HydroQual, Inc.

Description: Simulates eutrophication; far field; one dimension; dynamic; time-variable finite difference model.

Application: Potomac estuary

Computer: IBM 4381, Alliant

User: Metropolitan Washington Council of Governments, Virginia State Water Control Board

Data: field data and literature values to calibrate. Extensive monitoring data for calibration/verification.

Discussion:

The Potomac Estuary Model is a WASP-based model to which pre- and post- processing were added. The consultant who adapted the model to the Potomac also provided a user's manual. For pH-alkalinity kinetics, PEM accesses the RAND corporation's chemical compositions program. Thus, it is an example of how a standard model can be adapted to meet a specific need.

The PEM requires an extensive data base for model calibration and verification. Although it can be used on a personal computer, MWCOG uses it on a mainframe computer. Individual model runs take around 25 minutes.

Model Name: QUAL-2E

Source: USEPA

Description: Simulates DO; near field; one dimension; steady state or quasi-dynamic. Structured as one main program supported by 51 subroutines. Simulates up to 15 water quality constituents.

Application: one dimensional estuaries

Computer: IBM PC

User: Maine Department of Environmental Protection, Virginia Soil and Water Control Board, North Carolina Division of Environmental Management.

Data: Field, literature. Very little field data required to run.

Discussion:

QUAL-2E is an EPA supported model developed for predicting water quality in streams. However, it is also useful in one-dimensional estuaries with no significant tidal diurnal variations.

QUAL-2E is very easy to use. It is menu driven and interactive. Data input and interpretation of results are simple. Note, however, that according to Virginia respondents, it is a complex model which requires extensive training.

The EPA offers week-long workshops on Qual-2E. Not only is the user manual helpful for running the model, but also it is a good basic guide to water quality modeling. It guides the user in interpreting results and uncertainty.

The model itself has an unusual but useful feature: an uncertainty subroutine. This subroutine performs sensitivity, Monte Carlo and first order error analysis.

Field data requirements are minimal. Of course, maximum accuracy is obtained when all parameters are field data. The model takes a few seconds to run on a personal computer. Generally, users are satisfied with this model in the one-dimensional situations for which it is appropriate.

WLA's based on the model have been challenged by permittees in North Carolina and successfully defended. In addition, North Carolina has successfully field-verified the model in the Cape Fear estuary.

Model Name: Salinity Intrusion Model

Source: VIMS, 1973

Description: Simulates salinity.

Application: used to track salinity extension into the various tributaries. Useful in assessing and predicting potential impact on critical habitats and living resources due to salinity changes.

Computer: mainframe

User: Virginia Institute of Marine Science

Data: channel geometry, currents, dispersion and salinity.

Discussion:

The Salinity Intrusion Model has been used on the James, Rappahenock and York Rivers in Virginia. It has not been used recently, since salinity intrusion studies are not often required.

The model is moderately user friendly. A manual is available from Dr. Al Kuo of VIMS, who developed the model. The model could be rewritten for personal computer use.

Model Name: Simplified Estuary Model

Source: EPA, South Carolina Department of Health and Environmental Control.

Description: Simulates DO; far field; one dimension; steady state.

Application: screening level WLAs for tidal and freshwater streams

Computer: PC

User: South Carolina Department of Health and Environmental Control.

Data: background field data and literature rates

Discussion:

This is a very simple desktop model adapted by South Carolina from the EPA's published Simplified Math Model. It is used as a screening level model for WLAs. Although absolute results may not be accurate, it is useful for simulating a relative change in DO resulting from a new waste input.

Model Name: Surface Profile Assimilation Model (SPAM)

Source: Hydroscience, Inc.

Description: Simulates DO; far field; two dimensions; finite difference steady state.

Application: estuaries, tidal rivers and larger open water bodies

Computer: IBM 360-370

User: Maryland Department of the Environment.

Data: field and literature

Discussion:

Maryland used to use SPAM for small estuaries, but no longer uses this model. They switched to using WASP because it is more modern and, they assumed, results would be easier to defend in court. It is quite simple and runs quickly.

The model has no pre- and post-processing, but data entry and model use are moderately easy. Output is voluminous. The manual is old, but quite helpful. The Maryland Department of the Environment modelers were trained by the consultant who developed the model.

SPAM and WASP 4 have been run on the same data sets. Generally, SPAM produces more conservative WLA permit conditions. It took around 30 minutes to run the model on a mainframe computer.

Model Name: Three-Dimensional Hydrodynamic Model with James River Applications (EFDCEOA)

Source: Virginia Institute of Marine Science (VIMS), currently under development

Description: Simulates salinity, hydrodynamics, DO (under development); far field; three dimensions; dynamic. Simulates a 12.4 hour tidal cycle.

Application: Has been applied to the James, York and other rivers in Virginia. It is used to simulate and study salinity intrusion, pollution dispersion, larval transport, oil spill movement, and sediment transport.

Computer: Sun Workstation

User: Virginia Institute of Marine Sciences

Data: depends on application; can be very intensive.

Discussion:

This model was developed to handle complex hydrodynamic situations. In such a case, it requires an extensive monitoring program. However, it may also be used in a desktop mode to make rough predictions about hydrodynamics.

The Three-Dimensional Hydrodynamic Model is user friendly, given its level of sophistication. It provides pre- and post-processing including animation of hypothetical dye tests. It is not menu driven; however, this means it is possible to transport the code to virtually any computer. The developer of the model at VIMS (John Hamrick) teaches his graduate students to use the model in a one-day workshop. Workshops and technical support are available by individual contract with the model developer. He chose to emphasize internal documentation and guidance as opposed to the hard-copy manual.

The cost of applying the model depends on the amount of detail and accuracy desired. Likewise, computer time is dependent upon the chosen grid size.

The model has been calibrated for the lower James River, Long Island Sound and parts of the Chesapeake Bay. The James River project involved over one million dollars in data collection and monitoring at a scale much smaller than necessary for water quality applications. The developer intends to field verify the model as the water quality routine is developed.

Model Name: Tidal Anacostia Model (TAM)

Source: Metropolitan Washington Council of Governments (MWCOG)

Description: Predicts DO and eutrophication; far field; one dimension; dynamic.

Application: tidal Anacostia River

Computer: IBM 4381 (mainframe)

User: MWCOG modelers.

Data: extensive monitoring data and literature values. Pre-calibrated for the Anacostia River.

Discussion:

The TAM is based on Virginia Institute of Marine Science's Hydrodynamic Ecosystem Model. However, MWCOG has added pre and post-processing capabilities and some of the kinetics were altered by a consultant. Thus, TAM could be transferred to another estuary with recalibration, but it would be helpful to develop pre- and post-processing.

There is a good manual for TAM. In addition, modelers rely on technical support from the consultants who helped adapt the model. Two continuous DO monitors are necessary for model calibration and verification due to the short-term impacts of upstream and CSO events. The model requires 15 minutes to run the hydrologic routine and 15 minutes to run the water quality routine on an IBM mainframe computer.

MWCOG is generally satisfied with the model, although they believe the model may need to be recalibrated. Modelers are somewhat dissatisfied at the number of parameters which are hardwired.

Model Name: Tidal Prism Model(TPM)

Source: Virginia Institute of Marine Science (VIMS, 1987)

Description: Simulates DO and eutrophication; far field; one-dimension; steady state model. Predicts the longitudinal distribution of conservative and nonconservative dissolved constituents at high slackwater (slack-before-ebb).

Application: tidal embayments. The model can be used to estimate tidal flushing of embayments.

Computer: mainframe; probably could be used on a personal computer.

User: Virginia Institute of Marine Sciences

Data: moderate data requirements (does not need hydrodynamics).

Discussion:

The Tidal Prism Model was developed by Dr. Al Kuo of VIMS, based on Ketchem's tidal prism model. The model has been applied to several small tributaries to the Chesapeake Bay, including Linhaven Bay, VA.

It is described as moderately user friendly. VIMS has manuals for the model. In addition, the model has been described in Water Science Technology: "A Modified Tidal Prism Model for Water Quality in small Coastal Embayments." (Kuo, AY and Nielsen, B. Vol 20 No. 6-7, p. 133-142. 1988).

The TPM assumes all water movements except tidal action and riverflow are negligible. Assumes complete vertical and transverse mixing with complete longitudinal mixing in segments on the flood tide. Concentrations are averaged over a segment at slack-before-ebb. Therefore, dye studies may be necessary for additional calibration if used for broader applications.

Model Name: ToxiWasp

Source: EPA

Description: Simulates toxics; far field; one dimension; dynamic.

Application: has been used in the Delaware Estuary

Computer: IBM PC compatible 386 or 486

User: Delaware River Basin Commission and NJ Bureau of Water Quality Standards and Analysis.

Data: field data and literature values

Discussion:

ToxiWasp is one of the three WASP models. It can be used to simulate toxics in branched estuaries but may be less appropriate for stratified systems.

ToxiWasp is not very user friendly, although pre- and post-processors have recently been developed which make it easier to use. The user manual is reasonably helpful; it is important to have an up-to-date version. The model provides no estimate of uncertainty.

Accurate loadings data is essential for good model predictions. In New Jersey's applications, it was often necessary to have discharges do special monitoring at a lower sensitivity level to avoid "undetects". The model is somewhat cumbersome to run, since the hydrodynamic section must be run then inputted into the toxics routine.

Model Name: Transient Salinity Intrusion Model

Source: Drs. Harleman and Thatcher

Description: Predicts salinity; far field; one dimension; dynamic (tidally averaged salinity model); segmented

Application: used in the Delaware River Estuary to relate reservoir management to chloride concentrations.

Computer: VAX 3500

User: Operations Branch, Delaware River Basin Commission

Data: calibrated from 1960's drought data

Discussion:

The Transient Salinity Intrusion Model is used by the DRBC to predict whether certain reservoir management practices will cause a violation of chloride standards in the estuary. The model could be transferred to other estuaries, given adequate calibration data.

Pre- and post-processing data programs are available but separate from the model itself. The most challenging part of applying this model is putting the data in the correct format. Hydrologic and salinity data requirements are quite intensive.

Technical support is not available except from the developer. The DRBC notes that this was the only model of its kind available when they started using it; more modern models will handle lateral and vertical circulation patterns.

Model Name: Virginia Mixing Program (VMP)

Source: VA Soil and Water Control Board though a contract with HydroQual

Description: toxics (mixing zone model); near field; three dimensions; steady state.

Application: prediction of toxics behavior in plume near source.

Computer: IBM-PC

User: Virginia Soil and Water Control Board permit writers

Data: simple physical data

Discussion:

The Virginia Mixing Program is an expert system designed for use by permit writers (non-technical staff). It is quite similar to Cormix, but has been adapted to the particular conditions found in estuaries in Virginia.

VMP is very user friendly. The model is interactive; it is easy to test for sensitivity to an input. A manual is available from Arthur Butt of the Virginia Soil and Water Control Board.

Since it was designed as an expert system, VMP requires limited field observations. It takes around five minutes to run on a personal computer. It would probably have to be re-calibrated for use in a different region. VMP has not been field verified. After the VSWCB uses this model more, its success can be better assessed.

Model Name: Water Analysis Simulation Program (WASP 4)

Source: EPA

Description: Simulates nutrients and DO; far or near field; three dimensional; dynamic; link node; finite difference.

Application: rivers, estuaries and bays

Computer: IBM PC, PC-XT, VAX or mainframe

User: Alabama Department of Environmental Management, Connecticut Department of Environmental Protection, Maine Department of Environmental Protection, Maryland Department of the Environment, North Carolina Division of Environmental Management, South Carolina Department of Health and Environmental Control, Office of Regulatory Policy of the New Jersey Department of Environmental Protection and Energy..

Data: Extensive field data and literature values

Discussion:

Because WASP is one of the most widely used estuary models, numerous responses were received. Comments from several states are synthesized below.

Generally, WASP is a data and effort-intensive model suitable for three dimensional situations. Although WASP is not easy for the first time modeler to use, many who have invested the time to become familiar with the model are very pleased with the model. In addition, pre- and post-processing software has recently become available. This software should make the model much easier to use.

In addition, WASP is supported by the EPA. The EPA offers training workshops on the model and provides telephone support. In addition, the manuals are generally good, although they do not offer well-organized guidance on how to interpret results. It is important to have an up to date version of the manual.

The model itself does not provide an estimate of uncertainty. It is fairly easy to test sensitivity to a parameter. Most, but not all, error messages are helpful. It takes about ten minutes for WASP to run on a personal computer, depending on the size of the system being modeled.

WASP can be run with literature values for parameters, but is most accurate when thoroughly field-calibrated. Because WASP is so data intensive, states generally only use it when they have adequate time and money.

Several respondents listed criticisms of the model. Some modelers were limited because WASP cannot handle more than 100 reaches. Another commented that the algal submodel is weak. Connecticut modelers have found WASP difficult to learn and apply. They note that extensive data collection is required and that the modeling code is poorly written and documented. An Alabama respondent notes that reaction rates are global; it would be much more advantageous if rates could be segment-specific.

Other respondents itemized advantages of WASP. According to Maine and Maryland respondents, WASP 4.31 is very user friendly. Connecticut reports that once the learning curve is overcome, WASP is applicable to many situations. One respondent from Maryland noted backing by EPA as an advantage; another cited its wide use, excellent user's manual and ability to write specific kinetic subroutines. Alabama respondents find it very versatile. North Carolina modelers added that WASP is very accurate if field calibrated well. Generally, WASP is considered to be a good choice in three-dimensional estuaries when adequate field data is available.