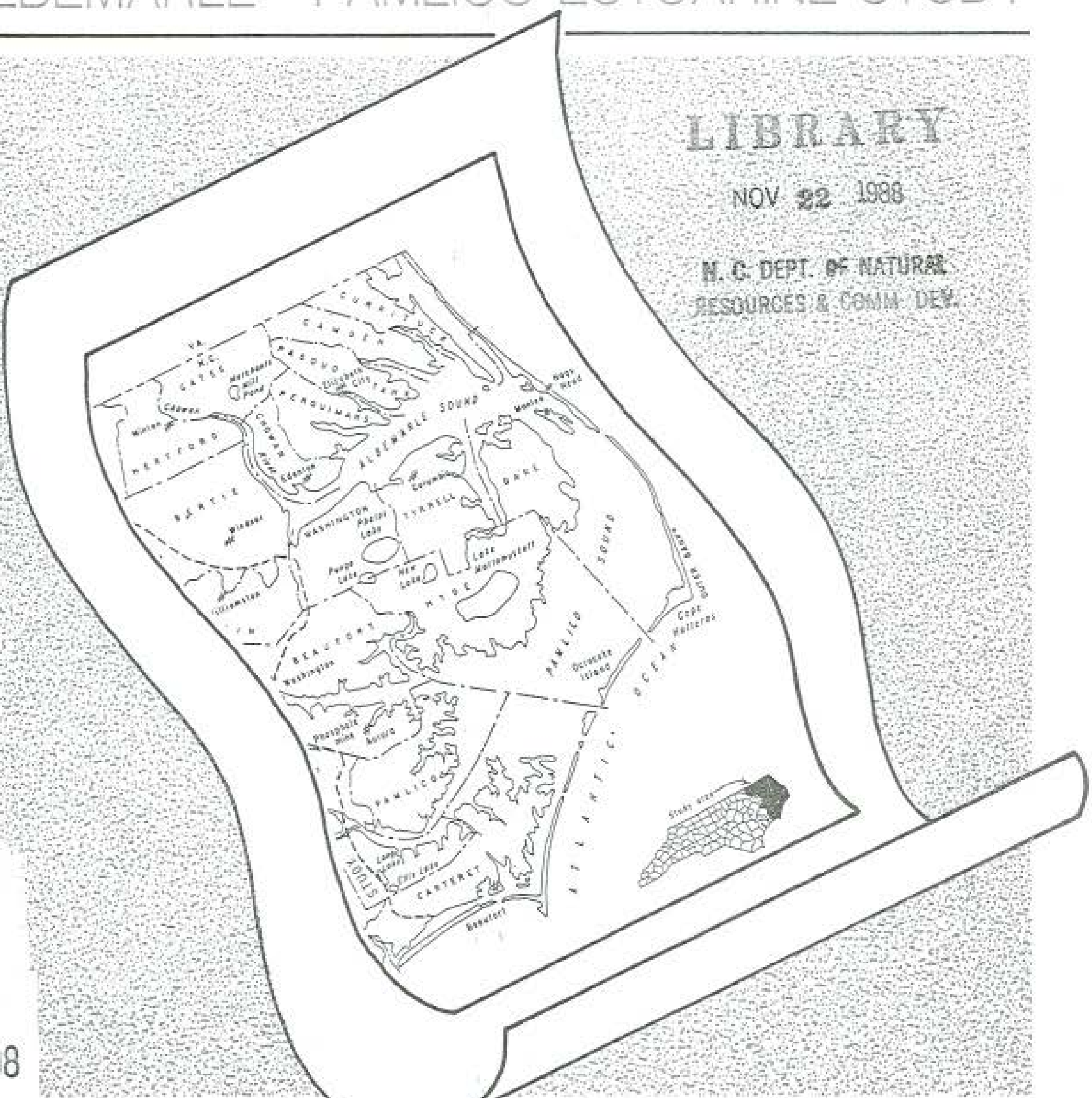
Report No. 87-03

PROCEEDINGS OF THE WORKSHOP ON HYDRODYNAMIC AND WATER QUALITY MODELS FOR THE ALBEMARLE-PAMLICO ESTUARINE STUDY

ALBEMARLE - PAMLICO ESTUARINE STUDY



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ALBEMARLE-PAMLICO

The Proceedings of the Workshop on Hydrodynamic and Water Quality Models for the Albemarle-Pamlico Estuarine Study

September 3-4, 1987
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Table of Contents

Executive Summary

Albemarle-Pamlico Estuarine Study
Hydrodynamics and Water Quality Modeling Workshop

The September 3-4, 1987 Hydrodynamics and Water Quality Modeling Workshop on Albemarle-Pamlico Sounds originated from a formal review of proposals received for funding by the Albemarle-Pamlico Estuarine Study (APES). The APES Technical and Policy Committees saw a need for a modeling scoping study in order to establish the specific value and function of mathematical models and to develop a clear management strategy for the purpose of considering and overseeing future modeling projects.

The proceedings contain the papers presented at the workshop. Organized by the Water Resources Research Institute and APES, the conference sought to bring together mathematical modelers and managers to discuss the role that models play in enhancing information toward protecting water quality and living resources. During the two day conference, modelers and scientists described ongoing activities and identified gaps and shortcomings in their methods. A question and answer session followed each presentation. Modeling experiences on several estuaries were discussed including: Chowan, Tar/Pamlico, and Neuse in Albemarle-Pamlico Sounds; Chesapeake Bay; Green Bay in Lake Michigan; Long Island Sound; and Narragansett Bay. Additionally, overviews of ongoing existing models in the State and in the Federal regional offices were given. On the last day, speakers and workshop participants evaluated the overall usefulness of models needed to address the perceived problems of Albemarle-Pamlico Sounds.

The papers illustrate that the workshop created a successful exchange of ideas among scientists and modelers. No one paper, nor presenter, provides the answers to the complex issue of selecting the most appropriate model for Albemarle-Pamlico Sounds. However, the workshop does represent a clearer focus in narrowing down the choices to be made. The following is a summary of the conclusions and recommendations made at the workshop.

- Before defining the models, there must be a clear understanding of what APES is attempting to manage. Only then must the models be defined for hydrodynamics, toxicants, BOD/DO, eutrophication and other needs. EPA Region I found that their modeling efforts did not match the management issues. First, make sure that the management issues are clear. The modelers and the managers must get together during model design. Modelers and managers must understand and stipulate the objectives of the model.

- An important area requiring focus is dispersion patterns and where the water is going. Ideally, uniform procedures should be applied to all areas of study to provide consistency and reliability of modeling.

- There is a need to have a better understanding over a basin-wide perspective of how pollutants move over-time. There does not seem to be a model that does this.

- Consideration must be given to data needs required for a model and how the data and model will fit into a long-term monitoring program.

- We need to look at average year information, such as phosphorous levels. We should not focus on special or unusual events.

- Wind factors, especially in the wind driven Albemarle-Pamlico estuary is important. In order to model, it is recommended having a good knowledge of boundary and runoff. Consideration must be given to ungaged accounts such as wind. Because wind varies from land to water, stations must be set up to account for both land and water conditions. There needs to be more than one meteorological station in designated areas in order to have a good measure over the estuary. The data must be continuous where observations/boundaries are consistent.

- First, we should focus modeling on the identified management questions and the known existing problems. Then, because of time constraints, we should focus on existing models and build upon them.

- There is a need to ensure that models are linked from the physical parameters to living resources.

- Initial modeling efforts should include: (1) to the mouths of the Tar, Neuse, and Chowan Rivers; (2) a chlorophyll a model linked to DO; and (3) hydrodynamic models only to the point that it drives chlorophyll a and DO.

- Because this is a National Estuary Program study, focus should be a system-wide approach. An alternative might be to look at the migration of a living resource and then determine how that species reacts in a river.

- Hydrodynamic modeling must address point sources. There appears to be a gap in linking the chemical processes with the biological. We need to fill-in that gap.

- We should be looking at modeling in terms of eutrophication. If the study focus is eutrophication/freshwater input, there may be enough information at the State level on freshwater recruitment to allow for scientifically sound models that provide the basis for management strategies.

- The presentations have shown that sampling stations for all new research requires coordination with modelers. A baseline monitoring program must be worked out with managers as well as modelers. The state-wide locations can be improved upon to allow for more accurate calibration.

- We must use a statistical model and develop one model. Everyone should get together to agree upon the one model to develop.

- We need a predictive watershed model--modelers must be involved in kinetic work.

- It is important that we look at the data that needs to be collected to make models accurate. Our focus should be on making sufficient data available to make modeling useful.

- All modeling proposals should begin only if clear objectives are given. These objectives should be specific, yet limited, in order to ensure realistic results from the model.

- APES should attempt to involve industry, agriculture, and other user groups in the modeling efforts. Perhaps industry might participate in funding specific modeling projects.
- We need to proceed with the APES workplan, by funding models that will answer specific questions.

Overall, participants felt that the sessions were organized for presentations and not for workshop exchange and suggested that future sessions be more workshop oriented.

INTRODUCTORY REMARKS

James Stewart
WRRI

As meeting coordinator, I wish to welcome each of you and thank you for participating in this workshop. The modeling workshop is intended to aid in the understanding of available mechanisms for making water quality management decisions. This two day forum is organized to hear about State modeling capabilities, existing modeling efforts at EPA and other institutions, and to evaluate the most appropriate direction for the Albemarle Pamlico Estuarine Study (APES). The specific objectives of this workshop are:

1. To develop an understanding of the state-of-the art of hydrodynamic and water quality models in a variety of estuarine situations.
2. To assess the State's current capabilities in hydrodynamic and water quality models that could be enhanced and utilized for addressing management questions in the Albemarle-Pamlico Estuary.
3. To benefit from the experience of other agencies that have attempted a similar approach.
4. To review examples of expertise within the region for model development and use.
5. To recommend a practical strategy for implementing an operational program to develop and maintain useful models for the Albemarle-Pamlico Estuarine Study.

Douglas N. Rader, Ph.D.
APES Program Coordinator

I want to take a few minutes to provide background on how the modeling workshop connects with the overall APES program. APES is a regional component of the EPA National Estuary Program (NEP). The NEP operates under the auspices of the Clean Water Act (as amended 1988). The major purpose of the Regional Estuary Program, (REP) is management of the estuary. The primary purpose of this workshop is to review and evaluate modeling tools that will most efficiently help in management of Albemarle/Pamlico Sounds. On the first day of the workshop, speakers will summarize existing modeling programs and explore available options. On the second day, the workshop will focus on how existing models can interface with other REP's and on recommendations for what approach APES should take on modeling efforts. The recommendations should focus on direct management returns expected from the model and with a cost effective design.

The purpose of this meeting is to determine what can be done with the modest amount of money available to address the perceived problems in the estuaries. The Albemarle-Pamlico Estuarine Study is addressing these issues:

1. What is driving anoxia, particularly in the Pamlico River. How do changes in salinity effect changes in nutrients, causing changes in algae growth, causing changes in dissolved oxygen (DO), causing fish kills.
2 What are the initial impacts of Primary Nursery Areas (PNA) in estuarine embayments.
3. Eutrophication.
4. Ulcerative micosis in fish, fish dieseases, and bacterial infections in crabs.
5. Finfish and crab stock changes.
6. Changes in macrophyte and shellfish beds.
7. Concerns on shellfish closures.
8. Pesticides and effects of toxicants.

MODEL PRESENTATIONS

Modeling Experiences in the Chowan, Tar-Pamlico, Neuse River Basins

Alan W. Klimek
Branch Head, Water Quality Planning Branch,
Division of Environmental Management (DEM)

The Division of Environmental Management has made substantial progress in studying the Chowan and in developing a model to manage the system. DEM is making use of the Chowan model for on-going modeling in the Neuse and Tar-Pamlico Rivers. The Neuse is similar to the Chowan in terms of the quantity of nutrients entering the system. The primary difference is that most of the Neuse's nutrients are point source related as opposed to the Chowan which is much more rural and dominated by non-point sources of nutrients.

Should the APES project develop any water quality models, it is important that these models: (1) answer questions of concerns; (2) allow for the transfer of models to users and for user understandability; and (3) be compatible with the available database. An underlying question which must be kept in focus is "will decision makers need to (or be able to) manage the system differently as a result of the model outputs?"

DEM made several assumptions and decisions in developing the Chowan model:

- o By setting reasonable expectations in protecting the Chowan, Albemarle Pamlico Sound will be protected (protection of the rivers gives protection of the Sounds).
- o Yearly weather patterns and initial modeling efforts showed that it was beyond the scope of our capabilities to develop a strategy of predicting and managing blooms. Therefore, a determination was made to manage the river so there is good water quality during average conditions in an average year. Figure 1 depicts the model used to relate chlorophyll a outputs (a measure of the amount of algae in the system) to the amount of phosphorus that comes into the system. Increasing amounts of phosphorus result in increasing levels of chlorophyll a. The state water quality standard for chlorophyll a is 40 ug/l. To ensure this was met even during peak bloom conditions, the target for the management strategy was set at 25 to 30 ug/l. This meant a 35-40% reduction of annual phosphorus inputs was needed from current levels.

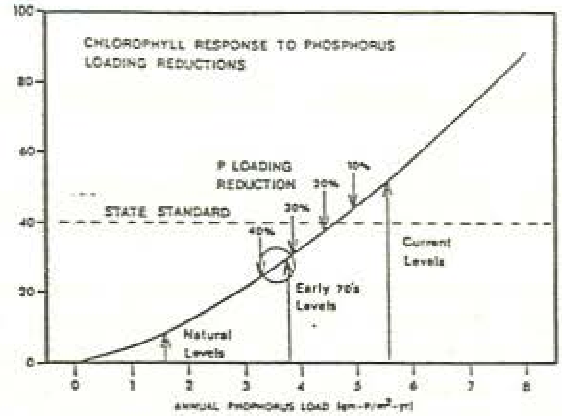


Figure 1. Changes in average summer chlorophyll a in the lower Chowan River in response to changing phosphorus loading.

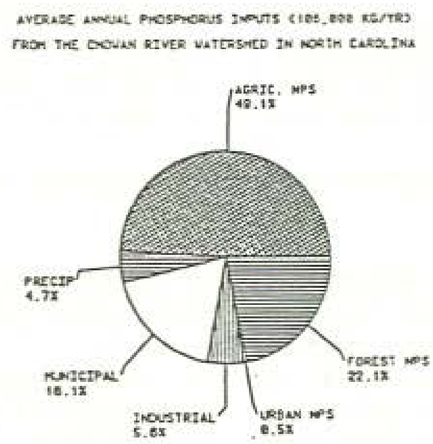


Figure 2 Distribution of phosphorus inputs to the Chowan River from the North Carolina watershed.

YEAR	W/S	S/F	BLOOM
1978	5.1	2.7	SEVERE
1979	5.4	7.3	MODERATE
1980	3.5	3.0	MODERATE
1981	2.0	5.1	NONE
LONG TERM AVERAGE	3.6	4.9	

Figure 3.

The current level of phosphorus inputs were determined from studies performed in North Carolina and national literature values relating land use to loading factors. The instream phosphorus levels predicted from the loading factors agreed well with measured instream values. Figure 2 illustrates a budget pie for the different sources of phosphorus in the North Carolina portion of the watershed.

To achieve the targeted 30-40% reduction of phosphorus, a $20 million budget was projected for improvements in waste water treatment, and a $4.5 million budget for an agricultural cost sharing program funded by the State for implementing BMP's.

While the reduction strategy was developed based on average annual conditions, the nuisance problems only manifest in years with wet springs and dry summers. Average monthly, long-term precipitation records were reviewed to relate climatological conditions to the frequency and severity of the blooms. Figure 3 shows precipitation graphs in Elizabeth City for four representative years. The average long term record for a 73 year period results in an average precipitation of 3-1/2 inches per month through the winter-spring period, and five inches per month in the summer-fall period. In 1978, one of the most severe blooms recorded occurred. This year had a very wet winter-spring and a very dry summer-fall. In 1979 both periods were wet and blooms were washed out. In 1980, average conditions prevailed with moderate blooms. In 1981, a very dry winter-spring was followed by an average summer and no blooms occurred.

It can therefore be seen that it is necessary to have both the wet winter-spring and the dry summer period for conditions to be ripe for a nuisance bloom. Prior to this review, it was thought that a moderate bloom might occur every three to four years. Both 1978 and 1983 had experienced significant blooms. However, when all 73 years of data are ranked in descending order of wettest winter-spring periods, 1978 and 1983 are number two and three respectively. When all 73 years of data are ranked in ascending order of driest summer-fall periods, 1983 and 1978 are ranked one and two respectively. It can therefore be seen that 1978 and 1983 were relatively rare occurrences, probably occurring on the order of every 20 years or so. This is encouraging in that the massive and long lived blooms of 1978 and 1983 should not be expected as frequently as originally thought. On the other hand, shorter periods of nuisance conditions will probably occur every three to five years before being washed out of the system following a heavy rain event.

While this is a very simple approach, it proved very enlightening. It illustrates a "modeling" approach that utilized intensive data and analyses from a few years and combined with a much larger (though simple) data base to predict muisance condition frequencies. Now it may be appropriate the time to move toward more sophisticated models to determine what factors are effecting water quality in the Sound. However, it is imperative to ensure that these models are chosen such that they will be able to answer the questions of concern, and that they are compatible with the available database.

QUESTIONS AND ANSWERS

Q. Have you looked at the relative precipitation in this year (1987) as there are considerable blooms in the Chowan?
A. Yes. There was about 4.4 inches in the Winter/Spring and 2.9 inches in June. (Author's note: Official records published since the presentation yielded a Winter/Spring of 4.1 inches per month and a June-July of 1.7 inches per month, followed by a washout of 4.9 inches in August.)

Q. Do you have similar experiences with looking at nitrogen as the limiting factor?
A. By putting in the nonpoint source BMP's for reducing phosphorus, we think we can reach a reduction in nitrogen as well.

Q. What is Virginia doing about phosphorus?
A. They are looking at setting state standards and are presently holding a number of public hearings. I understand they want to adopt a similar strategy as North Carolina's chlorophyll a standard.

Q. Who's modeling approach are you using?
A. Dillon and Rigler, and Chapra and Tarapchak.

DEM's In-House Modeling Capabilities

J. Trevor Clements
Modeling Technical Leader
Technical Services Branch, DEM

I. Why are water quality models employed by the State?

Water quality models are used by staff to lend insight to complex issues and, typically, form a basis for management decision-making. Most applications of modeling within the purview of state government fall into one of the following two categories.

Regulatory

Regulatory areas in which models provide useful tools include the determination of NPDES wasteload allocations, evaluation of point and non-point source nutrient controls, and the establishment of mixing zones for discharges of toxic substances.

Exploratory

Resources are examined to summarize water quality, identify parameters of major concern, and to locate water quality trends where deterioration may be a problem.

Most modeling analyses undertaken by the State have a similar objective: to effectively organize and manipulate available scientific knowledge to respond to an issue affecting the public as quickly as possible. Because of this, staff prefer to use simple, management-oriented, quantitative models. Esoteric, complex, dynamic, ecosystem models are avoided as impractical and often unreliable (unknown degree of uncertainty). Usually, the amount of time and data required to develop these latter type of models is much too prohibitive for the State to justify their use.

II. Who performs the modeling analyses for North Carolina?

Surface water quality modeling for the Division of Environmental Management (DEM) is performed by the Technical Support Unit within the Water Quality Section. The unit is currently comprised of nine staff members: 3 Modeler-I's, 3 Modeler-II's, 1 programmer/analyst, 1 environmental technician, and 1 environmental modeling supervisor. Modeler I's and Modeler

II's are distinguished by their expertise and the level of complexity of their work. Modeler II's are responsible for model development (i.e. specification, calibration, verification, etc.) whereas Modeler I's are primarily limited to model application. Two new modeling positions have been approved for FY88.

III. What constraints are placed upon the modeling staff?

Workload is the primary constraint for the modelers. The Technical Support Unit receives approximately 850 requests a year for NPDES wasteload allocations. In addition, the unit is involved in many special projects for the agency (approximately 50/mo) providing technical support. This does not allow much time to be spent on any single project nor does it allow for much exploratory analysis.

Staff are also limited by the availability of modeling frameworks, particularly those applicable to North Carolina estuaries. Many questions arise with regard to model choice: resolution (spatial and temporal), parameters of concern, kinetics, physical representation (e.g. finite section, etc.). In addition, the staff are limited in estuary modeling expertise. Given the added complexities introduced in estuary modeling, more time must be given to developing expertise in this area.

IV. What are the current staff's capabilities?

Current expertise within the unit can be aggregated into two areas of modeling: empirical and mechanistic. I am using the term "empirical" to refer to the statistical analysis of raw data. Our expertise in this light includes summarization of data distributions, examination of parameter correlation and cross correlation, regression analysis, stochastic modeling, and time series analysis. By "mechanistic," I am referring to our skills in mathematically representing the physical, biological, and chemical processes of interest for a given water system. We are most experienced in static (or tidally averaged), single dimension, deterministic models for this latter group.

V. What modeling tools are available to the staff?

The modeling staff is very fortunate to have several types of computer hardware to rely upon for their modeling needs. A modeler can use a personal computer, an IBM system-36 network, or the state mainframe computer at NCC. In most cases, therefore, equipment is not a limiting factor.

Technical support is somewhat limited in estuary modeling software, however. For empirical analyses, the staff relies on either SAS or Lotus 1-2-3. The EPA simplified Estuary Model (mass balance equation for nonconservative substance, limited to a single source, solved analytically at steady-state), or WASP (EPA finite difference model, multi-dimensional, dynamic) are available to staff. From time to time, a modeler develops his/her own modeling software for a given application. Currently, the staff is developing its own estuary model based upon Thomann's finite section approach. The model will be more "user-friendly" than any most "canned" models in that it utilizes spreadsheet entry and is structurally programmed using Turbo-Pascal which is designed for use on PC's, as opposed to outdated mainframe Fortran.

VI. What are the general areas of model application?

Current estuary water quality issues requiring modeling fall into three basic categories: oxygen-consuming waste, toxicants, and eutrophication.

Oxygen-consuming waste (i.e. CBOD, NBOD) issues are quite prevalent mainly due to historical concern and the emphasis placed upon these constituents in the federal guidelines applicable within the NPDES permitting system. There are, however, several estuary areas experiencing DO problems where models are substantially aiding management efforts. Examples include the lower Neuse River between Streets Ferry and New Bern, the lower Roanoke River near Plymouth, the New River below Jacksonville, and the Tar-Pamlico River between Greenville and Washington.

Toxic issues are usually site or case specific. Most analyses are performed using simple mass balance models for each constituent as related to a point source discharge. However, where whole effluent toxicity is evident, emphasis is placed upon determining the instream waste concentration (IWC) for incorporation of biomonitoring tests. Mixing zones and flushing are also two issues frequently encountered with toxic discharges.

Eutrophication is an issue that Technical Services has paid closer attention to in recent years. Based upon monitoring and modeling analyses performed by the staff, several estuarine systems have been classified or are being considered for nutrient sensitive status (NSW). These include the Chowan River, the New River, the lower Neuse River, the Tar-Pamlico River, and Albemarle Sound.

VII. DEM modeling information needs:

Throughout our modeling analyses, several questions have arisen that deserve further attention. These include:

Hydrodynamics

1. How do we define critical conditions (i.e. under what conditions are we trying to protect the resource)? For streams this question has been answered rather simply: under warm weather low streamflow (7Q10) conditions. It is not so easily answered for estuaries in which the modeler must consider flushing, stratification (e.g. salt wedges), wind tides, etc.

2. System specific information regarding dispersion, flushing and other physical phenomenon are needed. These efforts should be concentrated where management issues exist.

Oxygen-Consuming Waste

1. We need to define what manager's must protect. Are we protecting DO only in the surface waters, or are we trying to prevent bottom waters from becoming devoid of oxygen beyond what normally would be expected to occur? What is normally expected to occur?

2. Guidance is needed for incorporating some of the more complex components of the DO deficit when they are determined to be important. In particular, how do you (or should you even try to) incorporate a net photosynthesis/respiration rate into a steady-state model when the rate is quite dynamic? Hos does this issue relate back to design conditions? Incorporating the effects of tidal marsh areas on DO concentrations is also of interest.

Toxic Substances

1. How should mixing zones be defined? Due to lack of resources, the majority of decisions must be made by the State without the aid of dye studies. What other methods may be helpful?

2. Current methods usually ignore synergistic effects or bioaccumulation/biomagnification impacts. Should (or can) these issues be routinely addressed?

Eutrophication

1. Tools are needed to link kinetics to control measures. For example, an analytical tool for knowing how the reduction of particular nutrients (e.g. phosphorus, nitrogen) will impact chlorophyll a or generation of blue-green species, etc.

2. What attributes (i.e. chlorophyll a, phytoplankton biovolume or density, specific phytoplankton species, etc.) should be measured and/or managed. Is a single standard for chlorophyll a State-wide appropriate?

Other

1. Better guidance for collection of field information to use in model development is needed. Guidance should include things to consider (e.g. location, timing, uncertainty) when sampling within or over tidal cycles.

2. Practical methods for estimating dispersion and/or flushing in small local areas of estuaries are needed. Field data requirements should be minimal.

Questions and Answers

Q. What kind of model verification studies and formats do you use?

A. It depends upon the model. For example, for the BOD/DO model, we simply perform two field surveys under different conditions. One dataset is used to calibrate the model and the other is used to validate the model. When regression models are used, such as for eutrophication issues, multiple datasets can be used to check the model. Over time, data are collected and the data is examined to determine how well it fits with the prediction. Monte Carlo analysis can also be used, but we generally rely on field checks.

Q. If you had to identify one area of modeling in need of further information what would it be (hydrodynamic or kinetic)?
A. We need more information on where the water is going, because you can't make general assumptions on the dispersion patterns. We want to use uniform procedures and to be able to apply these to other areas. Once you know the flushing and circulation patterns, then obtaining more information about the kinetics will become more important.

Q. What kind of models do you use?
A. One-dimensional models have primarily been used. We have tried to use some multi-dimensional hydrodynamic models but they proved unmanageable and unworkable.

Q. How are you addressing stratified estuary areas with varying inter-tidal and spatial differences?
A. We are still thinking about recognizing spatial differences but with a tidal average perspective. One problem with either method is that we don't know, if once we set a model to a set of conditions, that we have looked at the right parameters.

Q. Is there a general understanding of movement into the estuary from headwater areas?
A. We just now are getting enough staff to be able to do this type of model and have not yet moved into a basin-wide perspective, at least to my satisfaction.

Q. Is the regulatory management based upon proper analysis if we don't understand movement?
A. I understand your concerns. We do need a better understanding from a basin-wide perspective.

Q. The problems seem to manifest themselves at the mouths of the rivers. If you control what affects that, do we need to model the entire Sound (from a point source perspective)? or, do we need to do more?
A. We have concentrated our modeling efforts to the mouths of the rivers because that is where we have empirically observed the problems. My thoughts regarding the Sound would be on the living marine resources and effects of water uses on them. We need to know from the biologists and workshop participants what needs to be modeled and managed to protect these resources and uses.

Q. With regard to eutrophication, can you identify what variables are of critical concern to model?

A. Perhaps chlorophyll a because we can use it to identify specific algae blooms which can in turn lead us to answers from a management standpoint. However, other parameters may deserve some attention, such as phytoplankton biovolume and density or even species type, if specific management decisions require finer resolution. We also need to enhance our ability to identify secondary impacts, whether toxic impacts or the effects on DO from respiration.

Q. Are you looking at nutrient ratios?

A. Yes we are relying heavily on nutrient budgets and combining that with biological data. A good example is Hans Pearl's work on the Neuse River. He is using bioassays to determine how much phosphorus or nitrogen would have to be removed before we notice productivity changes.

REVIEW OF CONCEPTS AND DATA RELEVANT TO HYDRODYNAMIC AND WATER-QUALITY MODELING OF THE ALBEMARLE-PAMLICO SOUND, NORTH CAROLINA

By Jerad D. Bales

INTRODUCTION

There is a perception among many managers and scientists involved in the Albemarle-Pamlico Estuarine Study (APES) that hydrodynamic and water-quality modeling of the sounds and estuaries will be needed to resolve present water-quality issues and to ensure effective future management of North Carolina's estuarine resources. There is also, however, some skepticism about the efficacy of a modeling effort, concern about potential costs, and misunderstanding about the capabilities, limitations, and resource requirements of estuarine hydrodynamic and water-quality models. This workshop addresses some of these concerns, in part, by examining modeling efforts in other estuarine systems in order to develop an understanding of estuarine hydrodynamic and water-quality models as they might be applied in the Albemarle-Pamlico (A-P) system.

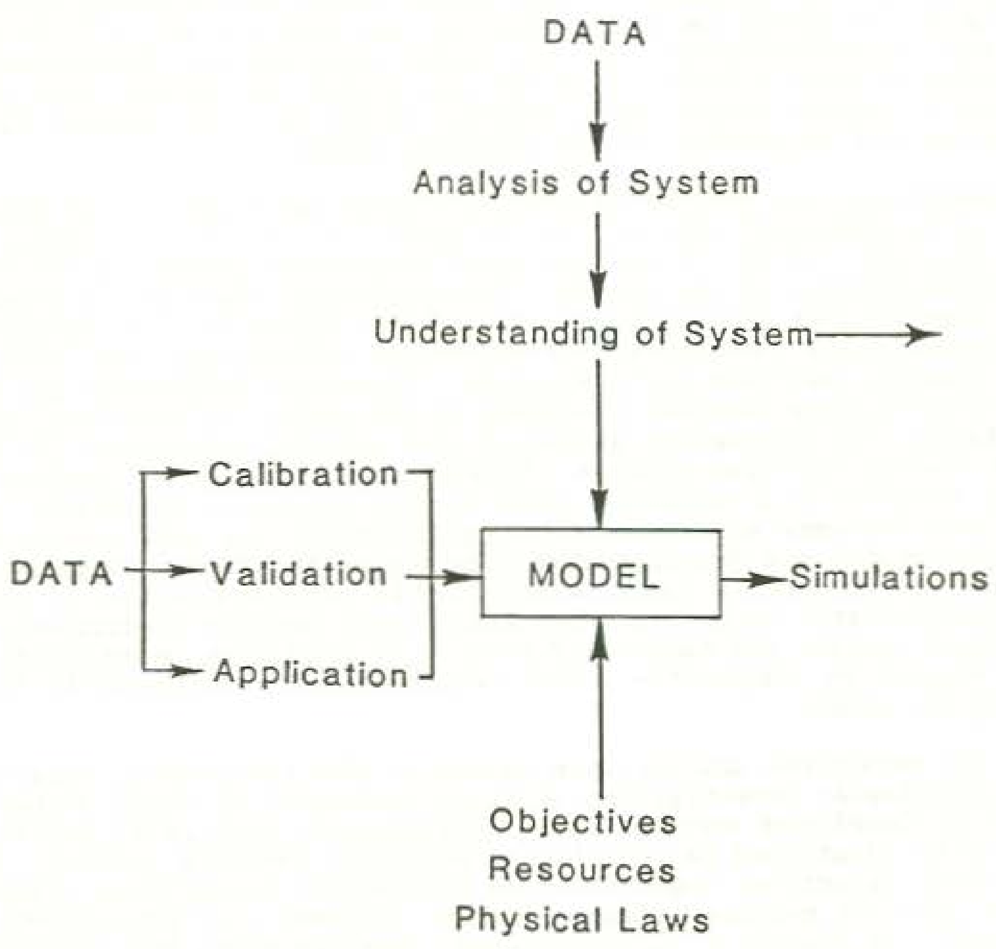
Before attempting to identify the proper modeling approach for the APES (in subsequent presentations), two issues are addressed herein. First, some basic concepts about modeling and utilization of data are discussed to provide a basis for understanding and evaluating later presentations of estuarine modeling studies. Second, an overview of available A-P hydrodynamic and water-quality data is presented. This overview, along with the discussion of modeling concepts and data utilization, may be useful in assessing future data needs for implementation of A-P hydrodynamic and water-quality models.

MODELING CONCEPTS

In many respects, concepts underlying both hydrodynamic and water-quality modeling are the same. Perhaps the greatest similarities between hydrodynamic and water-quality modeling are the benefits that can be expected from application of the two types of models. The primary economic and scientific advantage of a well-constructed, properly calibrated and validated model is that future scenarios can be evaluated quickly, inexpensively, and prior to any change in water-quality or management conditions.

The modeling process, which is a mixture of art and science, is marked by two distinct phases (fig. 1): data are a requisite part of each phase. Model development or selection, indicated by the vertical component of figure 1, generally includes analysis of data for the purpose of gaining a better understanding of the elements of the system to be modeled. Model development also requires that study objectives be defined, that the physical problem be clearly identified, and that resources needed for the modeling effort be specified. Simulation of the system, indicated by the horizontal component of figure 1, involves tailoring a computer code to simulate specific conditions and depends upon the availability of high-quality, comprehensive data sets for calibration, validation, and application of the model.

Figure 1.--Role of data in model development and use.



During the development or selection phase for both hydrodynamic and water-quality models, each physical system may be subjected to at least three levels of approximation (fig. 2). Processes acting within the system are first described by either empirical relationships, statistical functions, or differential equations. Second, these mathematical descriptions may require solution by approximate (numerical) methods; and, third, the boundary conditions of each system being modeled must be approximated to obtain a solution. Observations, or data, are required to abstract the physical system to a set of equations; that is, to formulate the theoretical basis for the model ("analysis of system" in fig. 1) as well as to approximate boundary conditions.

Errors can occur at any point in the process schematically depicted in figure 2. Hence, lack of agreement between model output and observed system response may be due to errors in data collection and analysis as well as to errors in model approximations. During model selection and development, therefore, a balance between errors from various model approximations and various levels of data-collection intensity needs to be considered with respect to the overall objectives of the modeling effort.

When determining the proper theoretical basis for a particular model application, a fundamental choice must be made, as shown in figure 3 (Overton and Meadows, 1976). Increased model complexity generally results in a better representation of the system. Occasionally, however, a model may become so complex that the representation of the system is less adequate than with a simpler model in which all of the model components and interworkings are clearly defined and understood. Increased complexity may be achieved by including more physical processes in the model, by reducing the spatial averaging, by increasing temporal and spatial resolution, or by including more elegant solution schemes. However, increased model complexity generally results in a solution that is more difficult to obtain. A complex model includes more equations requiring solution, has more points at which errors can occur, and requires more data for calibration, validation, and application. On the other hand, a simplistic representation of the system may misrepresent important processes under certain conditions or provide inadequate spatial and temporal detail. In addition, more confidence may be placed in simplistic model results than is warranted by the capabilities of the model.

In order to determine the optimum point on the horizontal axis of figure 3 for a particular investigation, a clear statement of study objectives need to be developed and both the hydrodynamic and water-quality problems need to be identified in relation to available modeling options. A statement of study objectives requires close interaction among three groups having a common goal but perhaps having different outlooks and constraints. Model developers may desire a sophisticated, detailed model for research purposes, whereas model users, acting within different time and monetary constraints, want a model that can be applied quickly and easily. Managers primarily need a reliable answer to a technical problem with some estimation of the quality of the model results. The challenge is to meet the common goal of the modeling effort while satisfying all of the constraints.

Problem identification, which is essential for evaluation of modeling options, requires that the important or governing physical and water-quality processes and their scales be specified so that they may be included in the model. A major problem that modelers face is resolving the conflict between different temporal scales of related processes. For example, estuarine

Figure 2.--Components of the modeling process.

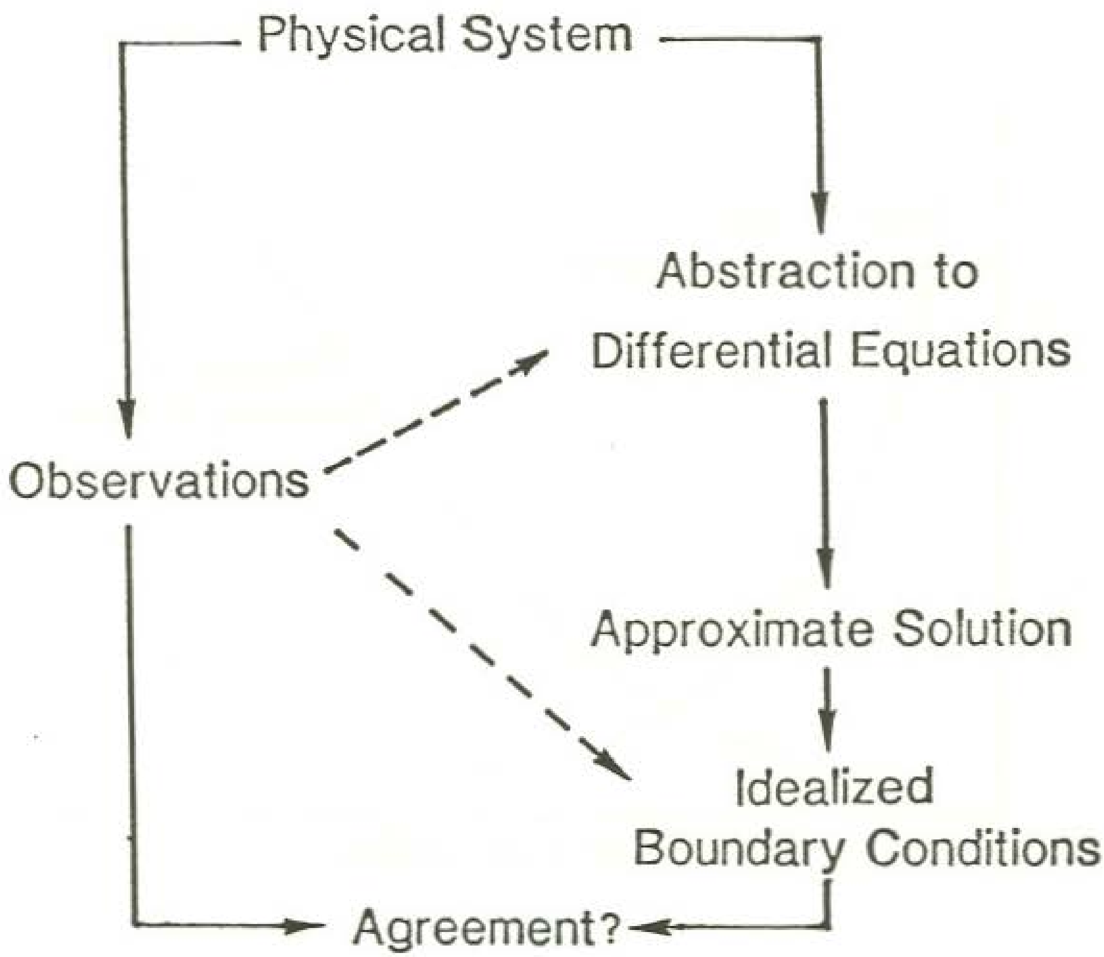
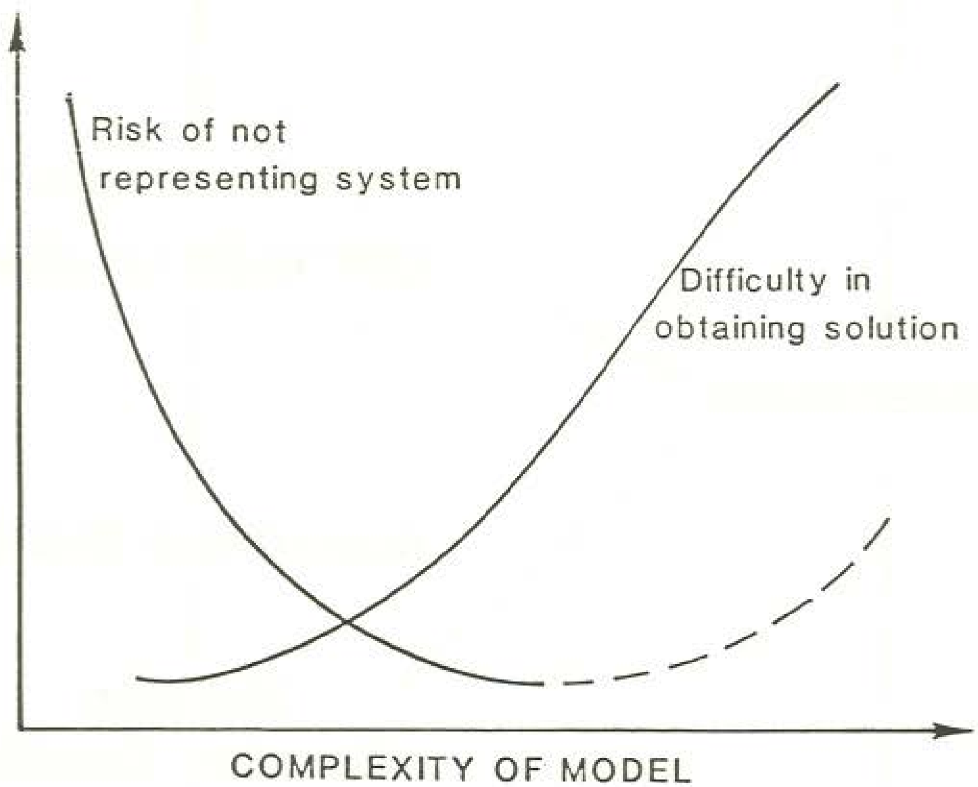


Figure 3.--Compromise associated with choice of model complexity (after Overton and Meadows, 1976).



circulation, or the hydrodynamics of the system, needs to be calculated at time scales on the order of minutes (fig. 4). On the other hand, water-quality related events such as algal blooms, which are influenced by the estuarine hydrodynamics, vary at time scales on the order of days or weeks. This difference in scales needs to be resolved because good water-quality modeling requires a reasonable solution of the flow field (Thomann and Barnwell, 1980).

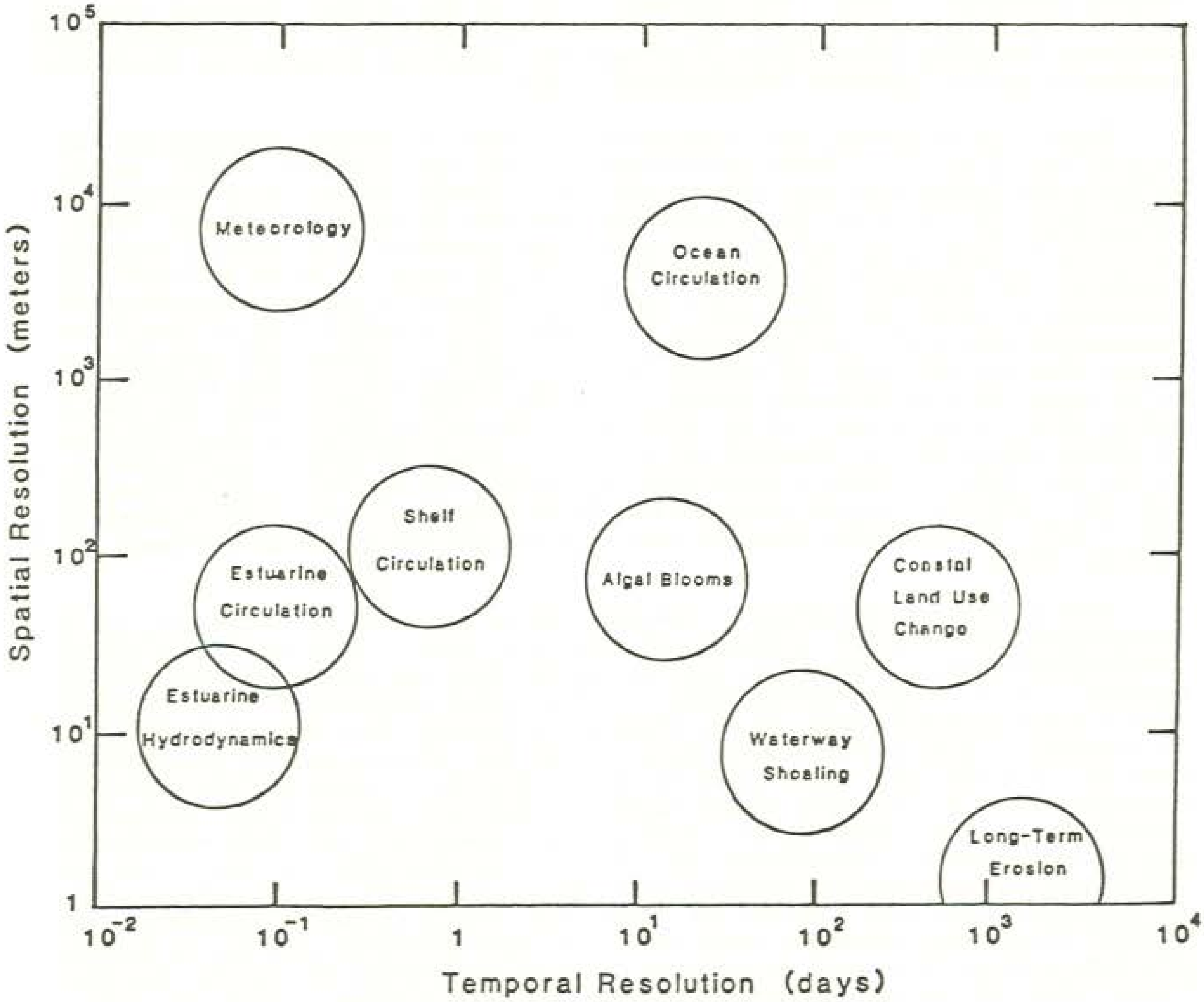
The complexity of selected models needs to match the study objectives and the identified problem rather than the a priori capabilities of an easily accessible model. The emphasis needs to be on the physical system and not on forcing a given tool to fit the problem. In general, the simplest feasible model that provides the required results is the most desirable option (Thomann and Barnwell, 1980).

Data are required for simulation as well as model development or selection (fig. 1). Model calibration is the adaptation of a model to the problem configuration and determination of model coefficient values by application of the model to an existing data set (Ditmars and others, 1987). Calibration data need to represent conditions governed by processes similar to those expected in the problem for which the model is to be applied. In addition, the variables chosen for calibration need to be representative of identified important physical processes. For example, if it has been determined that the three-dimensional flow field is important and that a three-dimensional model is needed, then the calculated velocity field needs to be compared with observed velocities rather than calibrating the model using tidal elevations, as is often done. Model calibration also requires an appreciation of the physical processes described by model coefficients. It is possible to have a model that accurately reproduces observed results for some conditions using model coefficients that bear little resemblance to those justified by the physics and setting of the problem (Ditmars and others, 1987).

The model validation process, which follows calibration, is a comparison between model output and observed data. Data used for model development and calibration are not appropriate for use in the validation process. It is important that data used for model validation be collected with a clear understanding of the physical processes that the model attempts to simulate. This means, for example, that for dimensionally simplified models, sufficient data need to be collected to conduct the spatial averaging consistent with model output. Spatial variability, temporal variability, and measurement uncertainty associated with data collection are also important considerations in the validation process. It is important to validate for conditions to which the model will be applied; it is inappropriate for a model of hurricane surge to be validated using typical tidal conditions and vice versa. A more difficult problem is how to validate a model that will be used to simulate conditions for years into the future when validation data are available for only periods of days or weeks.

Finally, a properly selected, calibrated, and validated model is of little consequence beyond the realm of research if the model is not of some use to resource managers. Some factors that may lead to improved model utility and credibility include (1) integration of data-collection and modeling efforts, (2) close interaction between modelers and managers, and (3) continuation of the modeling effort beyond the development phase to achieve meaningful and useful results (Thomann and Barnwell, 1980).

Figure 4.--Temporal and spatial resolution requirements for coastal studies.



ALBEMARLE-PAMLICO HYDRODYNAMIC AND WATER-QUALITY DATA

A complete listing of all information related to hydrodynamics and water quality in the A-P estuarine complex would be nearly impossible. The geographic vastness of the system and the variety of physical and chemical processes affecting flows and water quality contribute to the difficulty in cataloging all pertinent information. In addition, most of the existing data from the A-P system is, by virtue of the objectives and methods of the data collection, more suited for analysis of processes occurring at a particular time rather than for use in a predictive model. Nevertheless, the utility of a piece of information for modeling is determined by the objectives of the modeling effort.

Williams and other (1973) stated, "Bits of information on currents, salinities, temperatures, effects of storms, and other events including engineering projects, are scattered widely in the literature, from historical narratives to modern scientific papers, but effective physical description of these bodies of water has seldom been accomplished." This 15-year-old statement about the A-P system is still generally true. Nevertheless, the emphasis in this overview of A-P data is on information that might be of some use in an A-P modeling study to simulate estuarine flows and water quality. A necessarily brief summary is given of information concerning A-P (1) bathymetry, (2) bottom-material composition, (3) meteorology, (4) tidal stage, (5) inflows, (6) tidal velocity, (7) salinity, and (8) water quality. In general, these are the types of information that are required for application of hydrodynamic and water-quality models.

Bathymetry

Four bathymetric surveys by the National Ocean Service (NOS), or its administrative predecessor, have been conducted in A-P waters. Surveys were carried out in the 1890's, 1915-17, the 1930's, and 1978-82. Data from the two most recent surveys are available in digital form from the National Geophysical Data Center in Boulder, Colorado. The 1978-82 survey contains latitude, longitude, and depth information for about 770,000 locations, as well as bottom descriptors at about 22,000 points.

Other bathymetric data also are available for selected localized areas within the sounds. High-resolution seismic surveys of marine geologic formations, which also provide a record of bathymetry, have been conducted at various locations throughout the A-P system by researchers at East Carolina University (such as Eames, 1983), as well as by others. Numerous investigations of shoreline movement and inlet migration have been conducted along the North Carolina barrier islands (Everts and others, 1983). Plans for public works projects by the U.S. Army Corps of Engineers (COE) may, in some cases, include detailed bathymetric information, particularly projects involving dredging and navigation. Other sources of A-P bathymetric data include studies of anticipated sea-level rise (such as Hoffman and others, 1983); NOS publications, such as nautical charts, special purpose charts, U.S. Coast Pilots, and reports on tidal benchmarks; and a catalog of tidal inlet aerial photographs (Barwis, 1975).

Bottom-Material Composition

As previously mentioned, the 1978-82 NOS bathymetric survey of the A-P system included information on bottom composition at 22,000 locations; this is probably the largest single set of data on A-P bottom material. A bibliography compiled by Riggs and O'Connor (1975) contains a cross-referenced list of publications that deal with, among other topics, geologic features in the A-P region, including bottom material composition.

Meteorology

National Weather Service (NWS) meteorological stations in the A-P region are shown in figure 5. Data from the stations are published monthly in the National Oceanographic and Atmospheric Administration (NOAA) report "Climatological Data--North Carolina," and are stored in digital form at the National Climatological Data Center in Asheville, North Carolina. Meteorological data are also recorded at the Cherry Point Marine Corps Air Station (MCAS). Analysis of long-term meteorological data bases has been provided by, among others, Carney and Hardy (1967), Hardy (1970, 1971), and Pietrafesa and others, (1986).

Tidal Stage

Locations of existing tidal-stage gages (as of 1987) in A-P waters are shown in figure 6. COE needs are typically project related; consequently, COE gages tend to be short-duration installations. Short-duration historical records exist for numerous other NOS and COE gages in North Carolina. About 6 years of historical record for eight sites located on the Chowan River are also available (Daniel, 1977). In addition, tidal-stage data having a period of record on the order of months have been obtained by other researchers, such as Pietrafesa and others, (1986). Useful publications for tidal information include the following: tide tables published annually by the U.S. Department of Commerce; NOS publications "Index of Tide Stations, United States of America and Miscellaneous Other Locations," "Sea Level Variations for the United States 1855-1980 (Annual Revision)," and "Products and Services Handbook;" Ho and Tracey (1975), Harris (1981); and Ebersole (1982).

Inflows

Freshwater inflows to the A-P system are gaged by the U.S. Geological Survey. Most of the gaging stations are, however, located well upstream of the mouths of the A-P tributary rivers. About 63 percent of the 4,940 square-mile Chowan River basin is gaged; flow from about 83 percent of the 9,666 square-mile Roanoke River basin is measured; flow from only about one-half of the 4,300 square-mile Tar-Pamlico River basin and the 5,600 square-mile Neuse River basin is gaged. Some of the smaller tributaries to the A-P sounds also are gaged; but, in general, freshwater inflow rates to the A-P system are not well defined. Barker and others (1986) summarized the existing Survey stream-gaging network in North Carolina. Giese and others (1985) used long-term records and drainage-area ratios to develop a gross monthly water budget for Albemarle Sound and for Pamlico Sound.

Figure 5.--Meteorological data-collection sites near Albemarle-Pamlico Sounds.

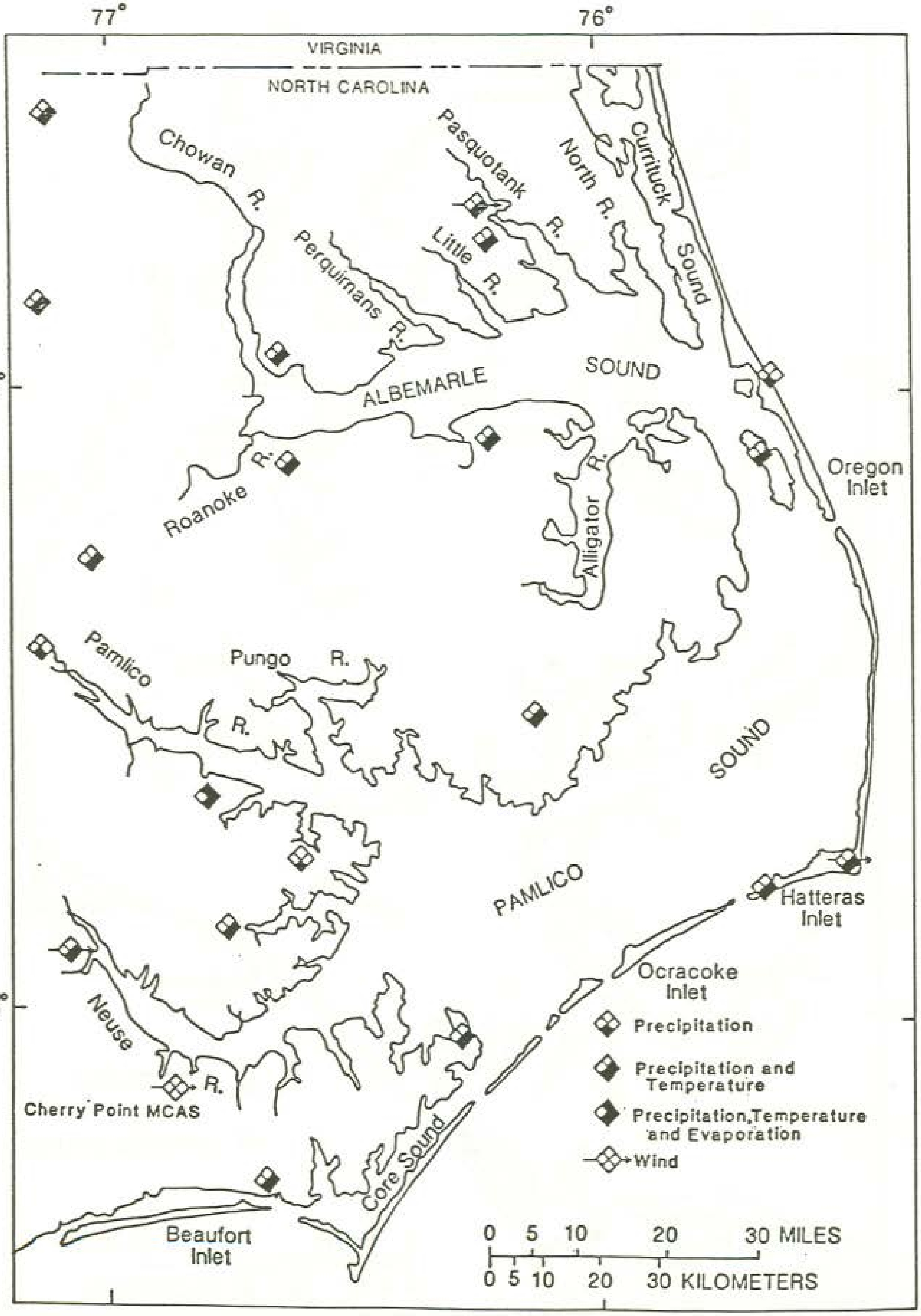
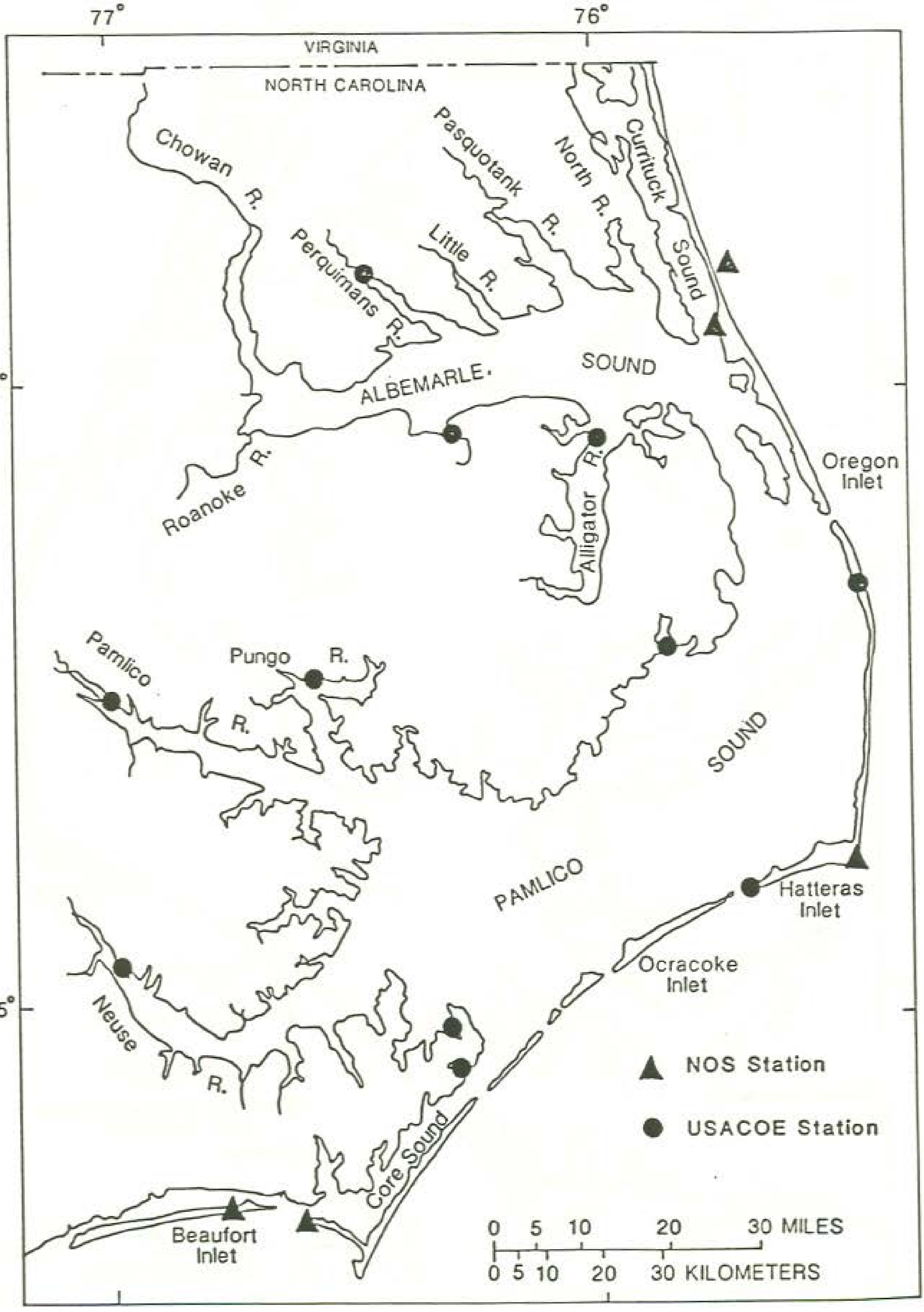


Figure 6.--Tidal-stage gages in Albemarle-Pamlico Sounds, 1987.



Even less is known about exchange of water through A-P tidal inlets than about freshwater inflows. A few short-term measurements have been made at the inlets; most of the measurements were made by the COE (Giese and others, 1985). Because of the migration of the inlets and the variability of meteorological conditions, these historical, short-term data sets would be only nominally useful for future model studies.

Tidal Velocity

There have been relatively few measurements of tidal velocity in A-P waters. One potential difficulty with utilizing much of the available velocity data for hydrodynamic model studies is that important ancillary information, such as tidal stage, salinity, and the wind field, were not obtained in conjunction with the velocity measurements. There have been several sets of velocity measurements at Oregon Inlet and Ocracoke Inlet (Giese and others, 1985). These COE data typically were taken at various times throughout a single tidal cycle. One set of velocity data was collected at Hatteras Inlet during flood flow.

Dye releases for the measurement of time of travel have been made in the Chowan River (Daniel, 1977), the Neuse River (Woods, 1969), and the Pamlico River (Horton and others, 1967). Instantaneous discharge measurements were made in the upper reaches of the tide-affected part of the Chowan River by the Survey (Jackson, 1968). Longer term velocity data were obtained from seven recording velocity meters that were moored in the Neuse River for 38 days (Knowles, 1975). Perhaps the most comprehensive set of hydrodynamic data were obtained from seven moored, recording velocity meters, two tidal-stage gages, and five thermographs located near Oregon Inlet (Singer and Knowles, 1975).

Salinity

Salinity is physically linked to the flow field by the pressure gradients generated from the salinity distribution. Yet, salinity has typically been measured as a conservative tracer (in other words, without regard to flow conditions), which renders the salinity data relatively useless for hydrodynamic model applications. In addition, salinity fluctuations are such that samples collected at monthly, or even daily, frequencies may be difficult to reasonably interpret other than to perhaps obtain seasonal trends. Salinity data collection is an example of a case in which an understanding of the theoretical foundation of the model is required to obtain useful prototype information because of the different ways in which salt transport may be modeled.

Giese and others (1985) provided a detailed analysis of historical data on saltwater intrusion in A-P tributary rivers. Summaries of A-P salinity data have been given by Marshall (1951), Hobbie (1970), Schwartz and Chestnut (1973), and Sholar (1980). Most of these summaries are based on daily and monthly information. Singer and Knowles (1975) obtained some vertical profiles of salinity with their velocity data measured near Oregon Inlet. Recent interest in the effects of upland drainage on nursery-area salinity (Pate and Jones, 1981) has resulted in the funding of additional salinity-related studies.

Water Quality

Scores of investigations that include some aspect of A-P water quality have been conducted. Results of many of these studies have been useful in promoting an understanding chemical processes, defining critical conditions for the occurrence of algal blooms and, in a few cases, evaluating trends. In general, however, past A-P water-quality data were not collected synoptically or in concert with hydrodynamic data, which makes the information difficult to utilize as model input or as a model-validation data set. There is also an enormous amount of water-quality data that has been collected as a part of the State of North Carolina's Ambient Monitoring Network. But, as noted by Thomann and Barnwell (1980), monitoring data are typically of little use in modeling efforts because data are typically collected at irregular, widely-spaced intervals and not in conjunction with hydrodynamic data collection.

Synoptically collected, spatially detailed hydrodynamic data, water-quality information, and parameter-rate data are required for effective water-quality model studies (Thomann and Barnwell, 1980). However, these data are expensive to obtain and may be specific to individual investigations.

SUMMARY

The process of model development and application is a mixture of art and science. Careful evaluation of objectives, the physical problem, and resources that can be committed to the modeling effort must be made before the model selection is made and calculations are performed. An understanding of the physical processes to be simulated will greatly aid in the proper collection of a useful data set. Finally, effective and useful modeling of the A-P estuarine system will require the synoptic collection of hydrodynamic and water-quality data and the integration of data-collection and modeling efforts, all planned by managers and scientists working in close cooperation.

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LIST OF ILLUSTRATIONS

MODELS AND ASSISTANCE AVAILABLE FROM U. S. EPA'S CENTER FOR EXPOSURE ASSESSMENT MODELING

by

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The Environmental Protection Agency (EPA), Center for Exposure Assessment Modeling, in Athens, Georgia, was formed as a result of a need for a focal point for an agency multi-media approach to modeling. The Center is responsible for the implementation, distribution, maintenance, and support of water quality models. Activities include documentation of computer codes, issuance of user's manuals, quality control designed to locate and correct model errors, peer reviews (for proper use of models), and technology transfer (workshops and distribution of newsletters). The Center is trying to put together models based upon good engineering principles.

The primary models the Center currently supports are:

- WQAM - Water Quality Assessment Methodology;
- EXAMS - Exposure Analysis Model System;
- QUAL2E - Stream Water Quality Model;
- DYNTOX - Dynamic Toxicity Model;
- SWMM - Storm Water Management Model;
- HSPF - Hydrologic Simulation Program FORTRAN;
- WASP - Water Analysis Simulation Program;
- DYNHYD - 1-Dimensional Branching or Link Node Hydrodynamics Model;
- MINTEQA1 - Geochemical Equilibrium Model;
- PRZM - Pesticide Root Zone Model; and
- SARAH - Stream Mixing Zone Exposure Model.

The users of the models have included:

- EPA Regional and Headquarters Program Offices;
- State and Local Agencies;
- Federal Agencies;
- Consultants;
- Industrial Groups; and
- Foreign Governments (Spain, China, India, Portugal, Canada, South Africa, USSR, et al).

The Center's experience in linking transport and hydrodynamics models includes direct and advisory assistance on Chesapeake Bay, Green Bay, Delaware Estuary, and Patuxent River Estuary.

Models can be used in several ways to aid large studies. A good water quality model allows for the description of the present water quality conditions, interpolates observed data, and aids in describing important processes controlling water quality.

The models available from the Center that may be useful for the Albermarle-Pamlico Study include:

(1) WASP4.1

The Center views the WASP4.1 model as a very flexible, general purpose box model. The advantages of the WASP model are threefold. One, it has the flexibility to be applied to almost any surface water system. Two, most water quality problems can be addressed by using one of the available kinetic modules (WASP4) or by constructing a new kinetic model. Presently, a eutrophication model (EUTR4) and a toxic chemical model (TOXI4) are supplied with WASP4.1. Three, separation of the biological and chemical processes describing the constituent being modeled (i.e., the kinetics) into a single sub-model (WASPB) permits the convenient modification of the kinetic descriptions.

The limitation of WASP is that kinetic models are not available for certain problem contexts (e.g., metal speciation and oil spills).

The WASP model was originally created by Manhattan College. The most recent toxicant version combines several previous models: WASTOX, TOXIWASP, EXAMSII, and Food Chain modeling algorithms. The eutrophication version includes standard algorithms for nitrogen and phosphorus species, phytoplankton, CBOD and dissolved oxygen (see Figure 1).

WASP4 can be linked with other systems. However, caution must be exercised in trying to build too much flexibility into the system due to increased complexity in using the model.

(2) DYNHYD

The one-dimensional link node hydrodynamic model (DYNHYD) model may not be the best available for the complex Albemarle-Pamlico system; but, it can be used to predict depth and velocity as functions of space and time. When linked to WASP, DYNHYD is used to provide circulation information. The linked model can be used to study eutrophication processes, particularly the combined effects of transport, phytoplankton kinetics, the phosphorus and nitrogen cycles, and dissolved oxygen balance. Figure 1 shows interactions involved.

The Athens Environmental Research Laboratory is attempting to cooperatively develop, and the Center will eventually distribute, the following models:

o Sediment Transport Models

- Vertically averaged finite element cohesive sediment model,
- 3D lake and estuary model (being developed by Peter Sheng, University of Florida), and
- 3D Eddy viscosity model from U. S. EPA's Narragansett Environmental Research Laboratory.

o Hydrodynamic Models

- Sheng's 3D Model,

- 2D vertically averaged finite element model,

- 3D Eddy viscosity model from U. S. EPA's Narragansett Environmental Research Laboratory.

The Center generally considers fully linked transport and hydrodynamics models in a developmental stage, especially for complex two- or three-dimensional waterbodys. However, the Center finds on many occasions that such models are not only useful but necessary. The inability to fully measure circulation patterns requires hydrodynamics modeling. The prediction of changes in circulation requires hydrodynamics modeling.

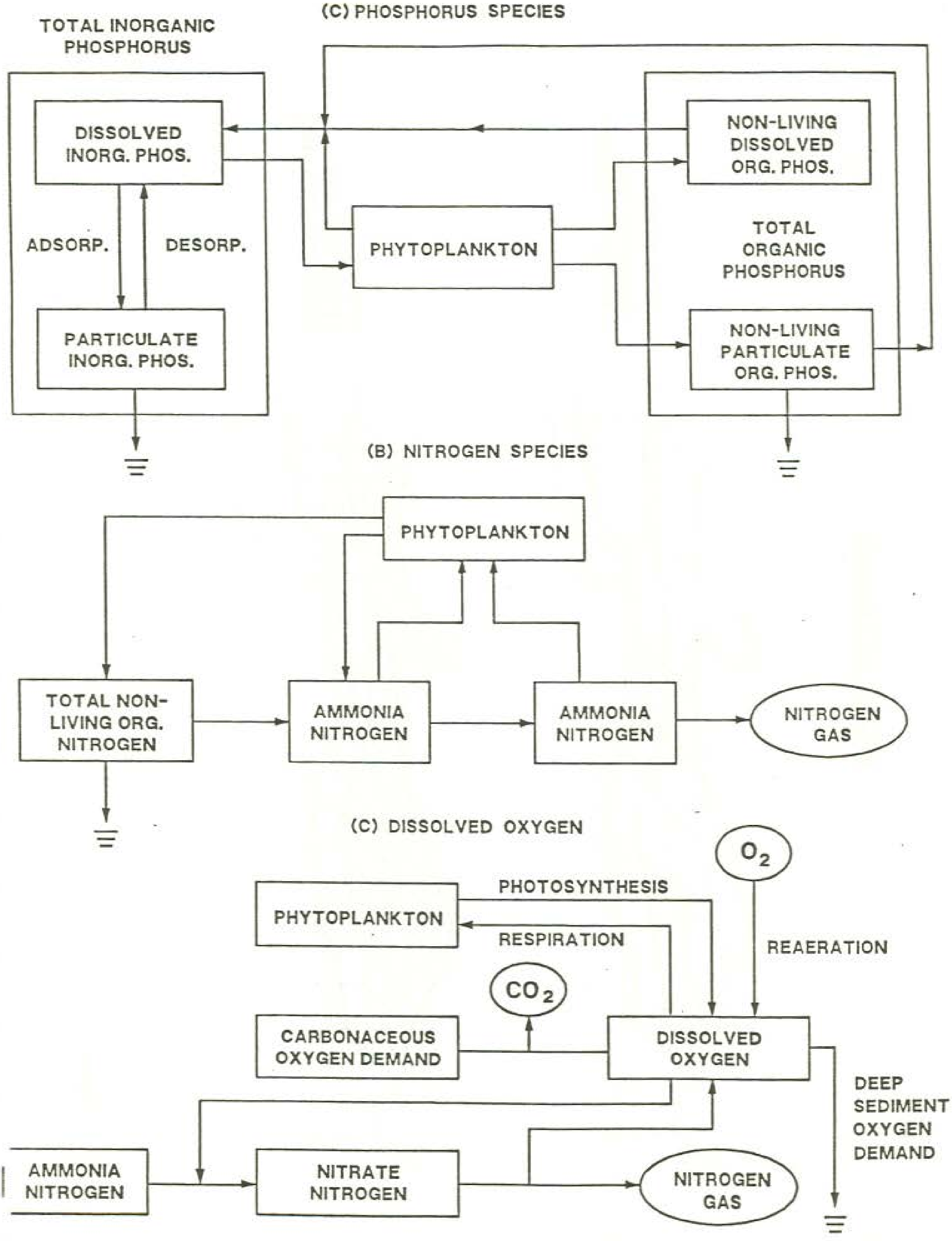
The use of any of the numeric solutions requires that a body of water be divided into small elements or segments. These segments must be small enough so that physical, chemical, and biological characteristics are approximately constant. This involves defining a model network as shown in Figure 2.

Typically, we attempt to define larger elements for water-quality modeling and average the fine scale transport field defined by the hydrodynamic model. We attempt this to save time in calibrating the water-quality model.

The most valuable experience in linking models occurred in a recent study of Chesapeake Bay. The Bay is highly advective and too large to fully measure and describe circulation. The contractor took about one to three months to calibrate a three-dimensional fine scale transport model. Unfortunately, it required about 18 months or more to calibrate a large-scale WASP-type model. An ad hoc linkage for different time and space scales (simple averaging) proved almost unworkable, and better methods must be developed.

The EPA study of Green Bay does not involve the same issued faced by the Pamlico-Albemarle Study, but there are several approaches that would be useful for any large-scale study. First, we are attempting to innovatively use modeling to guide monitoring and data collection. Second, sensitivity testing will be used to determine the levels of modeling necessary. From this we hope to avoid an imbalance of hydrodynamic and water quality modeling that seems to have plagued other studies. The presentation by John Paul will go into more detail in this regard.

The EPA Center for Exposure Assessment Modeling is also actively interested in applying waste load allocation models in estuaries. Coordination to determine how best to devise waste load allocation methods for these types of estuaries is clearly needed.



(C) PHOSPHORUS SPECIES
TOTAL INORGANIC PHOSPHORUS
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PARTICULATE INORG. PHOS.
PHYTOPLANKTON
NON-LIVING DISSOLVED ORG. PHOS.
TOTAL ORGANIC PHOSPHORUS
NON-LIVING PARTICULATE ORG. PHOS.
(B) NITROGEN SPECIES
PHYTOPLANKTON
TOTAL NON-LIVING ORG. NITROGEN
AMMONIA NITROGEN
AMMONIA NITROGEN
NITROGEN GAS
(C) DISSOLVED OXYGEN
O2
PHOTOSYNTHESIS
PHYTOPLANKTON
RESPIRATION
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CO2
CARBONACEOUS OXYGEN DEMAND
DISSOLVED OXYGEN
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FIGURE 1

MODEL NETWORKS

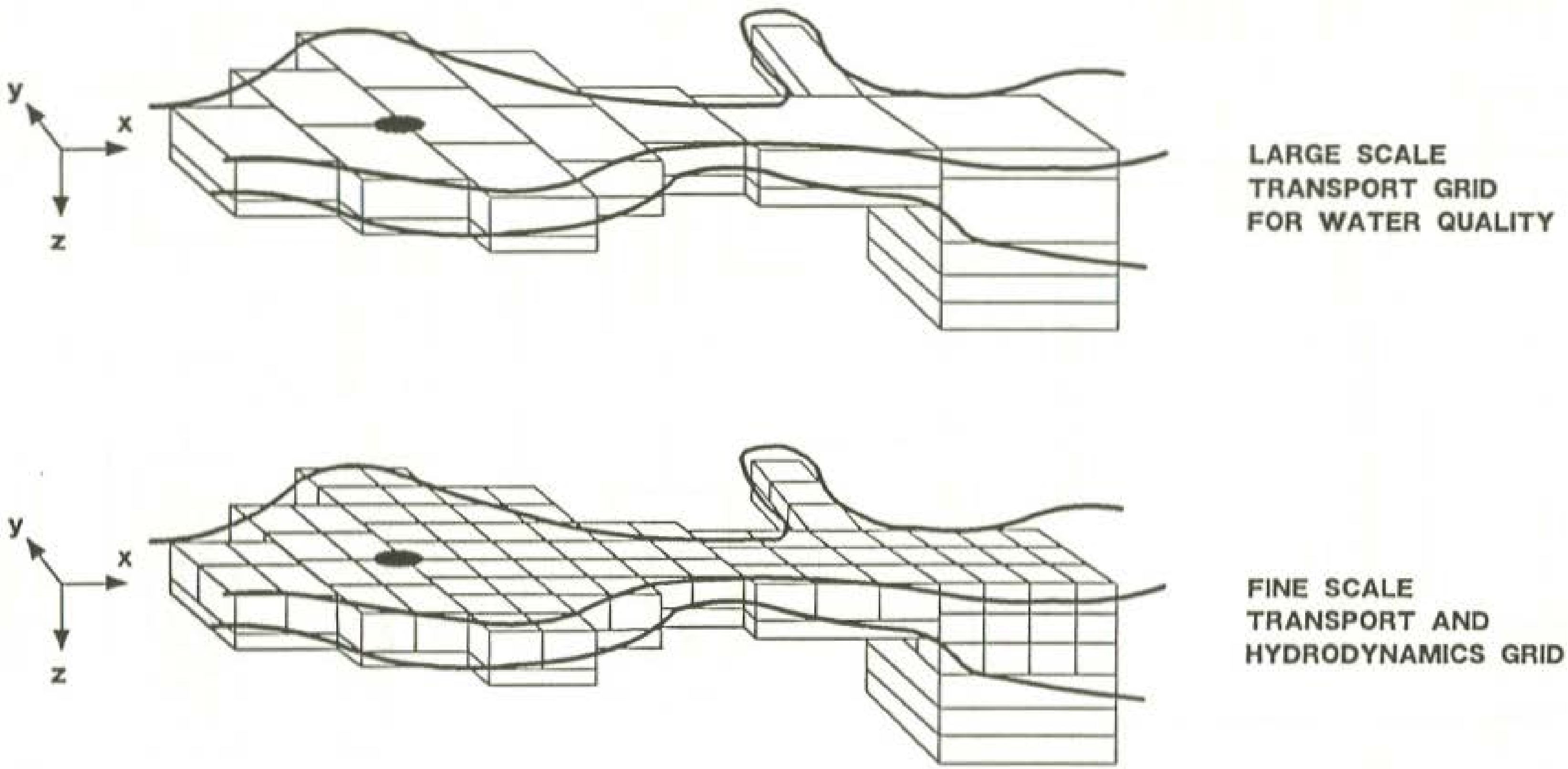

Figure 2

Hydrodynamic and Physical Transport Models

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The purpose of my discussion is to present two things. The first is a systematic approach for evaluating performance of models that has been prepared by the American Society of Civil Engineers Task Committee on Verification of Models for Hydrologic Transport and Dispersion (1). The second is how such an approach is being applied to modeling toxic substances in Green Bay, Lake Michigan (2,3).

The systematic approach for evaluating model performance has been divided into a six step process: (1) identification of problem; (2) relationship of model to problem; (3) solution scheme examination; (4) model response studies; (5) model calibration; and (6) model validation.

In identifying the problem to be addressed, you should ask yourself two questions. What are the dominant physical processes at work in the system? What are the spatial and temporal scales of these processes? These questions are model independent, but the answers are critical to the choice of model to be used.

Once the problem is identified, you need to determine the relationship of model to the problem. You must ask, "how are the physical processes incorporated in the model?" The processes to be included will depend upon what questions you want to be able to answer. For example, you must decide if you want a prognostic or a diagnostic model, i.e., will density be externally specified or calculated as part of model. You will need to know what processes are represented by the model coefficients, and what initial conditions and boundary conditions are appropriate for the problem. Do not force the problem against a model your might readily have available. Rather, pick the appropriate model to address your problem.

It is extremely important that your solution scheme be carefully examined. Documentation of your methods is important for going back and making changes at a later time. How does the solution scheme you choose affect the actual solution? There are well-known errors associated with numerical solution techniques. These include numerical diffusion and dispersion. You also need to test your computer codes to verify that they actually solve your particular equations.

Once coding is completed, you will need to do some model response studies. You must conduct benchmark testing to ensure that the model behaves as expected for simplified cases. The response studies can assess the relative importance of different processes in your model, i.e., parameter studies. This step in the approach can provide a good guide for the type of data that should be collected to provide for a good test of the model. You can not expect field collection programs to sample everything possible because of cost and time factors. Therefore, the response studies can help make appropriate selections of parameters for data collection.

The next step is model calibration. This is the application of the model to a particular problem configuration and identification of coefficient values by comparing with existing relevant databases. The choice of variables used in the calibration is important. You will need to know the interrelationship of parameters and have some feeling for reasonableness of coefficients chosen.

Finally, comparisons must be made between model output and real world data using the coefficients selected from the calibration process. It is important that you validate the model against strikingly different data sets from that used in the calibration. If you validate against the same situations that you calibrated for, you are almost certain to obtain a good validation of your model. But this is obviously not the best test of the model. You can use either visual or quantitative measures to judge the degree of success in the validation.

Validation study requires interaction with the data collection personnel during the data acquisition. It is important that data is collected for more than the external forcing for the model and the dependent model variables. Data are also needed that relate to the modeled processes.

You will find that routine monitoring programs are not adequate for calibrating and validating models. A useful monitoring program needs a framework in which the data will be used; this framework is your model. The framework will help determine the parameters, sampling frequency, spatial distributions, etc. for the data collection program.

Simplified models require data collected on compatible scales. For example, if you have a one-dimensional estuarine model which is vertically and laterally averaged, then you must vertically and laterally average the data for proper comparison with your model output.

At this point you would have a calibrated and validated model which can be applied with some level of confidence.

I would now like to give an overview of the Green Bay Toxics Substances Modeling Program. This is a three year project being funded by the Great Lakes National Program Office in EPA Region V, Chicago. The EPA regulatory goal of this project is to determine the feasibility of using a mass balance approach as a framework for large aquatic systems in determining priorities and strategies for remedial actions. This approach was successful in the Great Lakes for determining nutrient reductions. Will it apply to toxics? The environmental managers want to know what to clean-up first and what remedial action will provide the most return for the expenditure of funds.

The research goal of this project is to apply and validate existing methods and advance state-of-the-art in areas of quantifying loadings and loss rates for toxic substances in aquatic systems. The end-point to be used is the tissue residue levels in important fish species in Green Bay. Focus is on the quantification of relationships between contaminant loading rates and pollutants in fish consumed by humans.

A Green Bay modeling Committee was organized to:

- Develop a general modeling framework which will address:
  - Management questions
    - development of management tools
    - utility of tools for regulatory use
  - Technical questions
  - Associated research questions
- Design preliminary data collection program
- Prepare Request for Proposals (RFPs) for modeling contracts and grants
- Evaluate contract and grant proposals
- Establish modeling and data collection priorities
- Track implementation of modeling activities
- Evaluate results of modeling activities

The Committee is currently in the process of reviewing the responses to the RFPs.

The Modeling Committee was structured in three phases: Phase I is planning, design, and contract selection; Phase II is monitoring project implementation and reviewing progress; and Phase II is specification and evaluation of management simulations and specification of post-audit procedures.

The general model framework for the Green Bay Project will build upon existing state-of-the-art in modeling. It will not develop new models. It also is intended to apply and validate the mass balance methodology for modeling toxic substances. The initial design is for models at several levels of complexity, primarily in terms of spatial and temporal resolution. The choice of the level to use will depend upon the available resources and time frame for the study.

Whenever one goes through a modeling process, there are a number of inherent assumptions. For instance, we have assumed that a modeling framework for toxic substances is available, and that these models are available for a variety of computers, including personal computers. The Modeling Committee made the decision that the framework and model of choice is WASTOX (WASP-4 when available). This seemed to be the best available choice. Figure 1 depicts this toxic substance mass balance framework.

The modeling process as it will be applied to Green Bay will include the following: transport characteristics, organic and inorganic solids transport, particulate and dissolved phase contaminant transport, and contaminant transfer through the food chain. This entire modeling process will then be synthesized to address the various scenarios that the environmental managers will select.

Figure 2 depicts various levels of complexities that Green Bay can be modeled at. In particular, note the spatial and temporal levels of resolution that can be addressed by each level, and the spatial and temporal data collection efforts required for each level.

I have made copies of the Green Bay toxic substances modeling plan and the RFP available to the APES program office.

References

(1) J.D. Ditmars, E.E. Adams, K.W. Bedford, and D.E. Ford, "Performance evaluation of surface water transport and dispersion models," Journal of Hydraulic Engineering, ASCE, VOl. 113, No. 8, August 1987, pp. 961-980.

(2) Green Bay Modeling Committee, "Modeling toxic substances in Green Bay, modeling plan and proposal," EPA Large Lakes Research Station, Grosse Ile, Michigan, 28 January 1987.

(3) "Request for Preproposals, Modeling toxic substances in Green Bay," EPA Large Lakes Research Station, Grosse Ile, Michigan, 1987.

Questions and Answers

Q I do not agree with the concept of increasing stations and decreasing frequency of samples. Aren't you after long-term averages?

A There is an associated error in any estimate and it is dependent on the number of stations and frequency of sampling. By increasing the number of samples and by intelligent choice of stations and frequency, this error can be decreased.

Q How are you doing the parameter estimation?
A We are leaving this up to the modelers. In the RFPs, each modeler was asked to specify what procedure would be used.

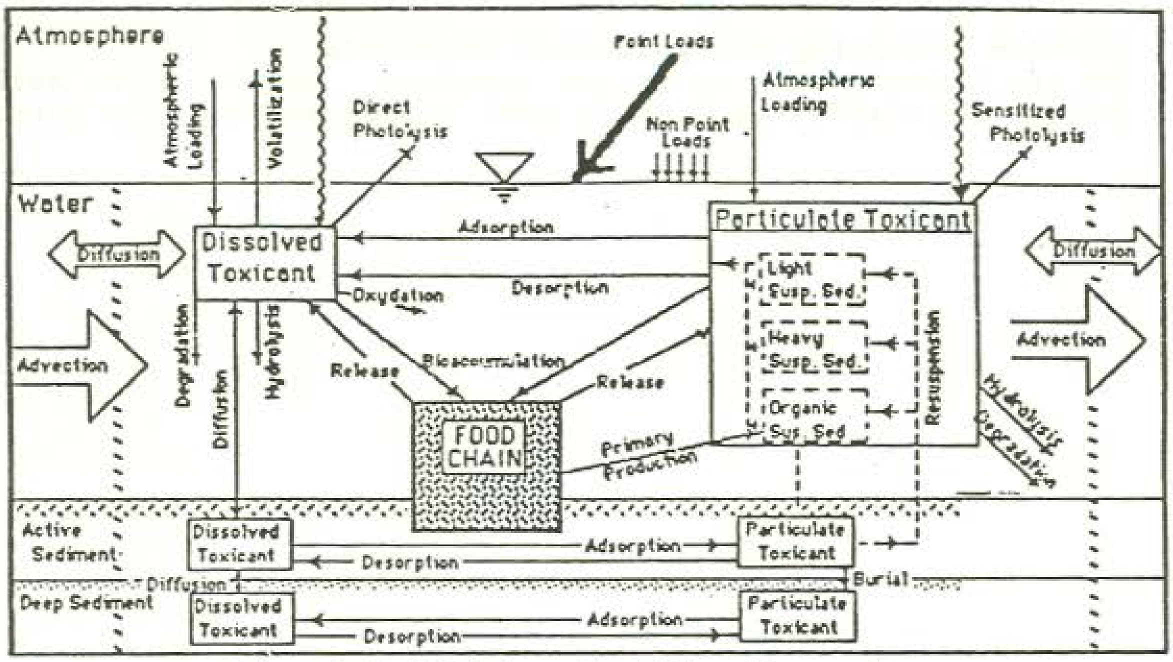
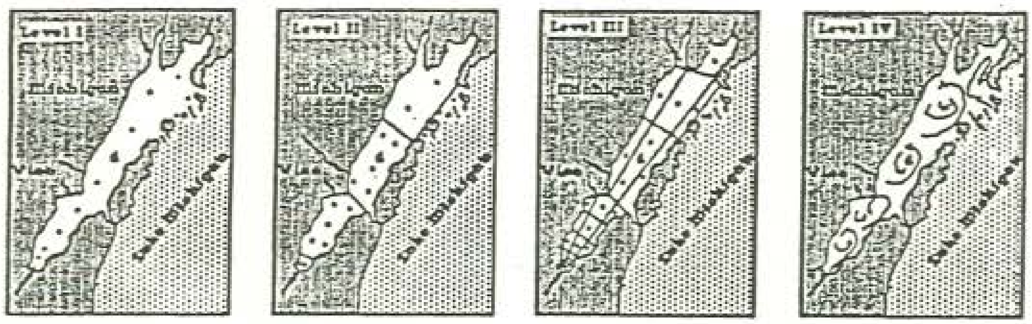


Figure 1. Toxic Substance Mass Balance Framework



GREEN BAY ALTERNATIVE MODELS

Long Term Average (1 Yr) Resolution Whole Bay	Seasonal Resolution 50 Km	Seasonal Resolution 10 Km	Episodic Resolution- 1 Km
Completely Mixed Unstratified	Vertically Strat. Horiz. Homogen. 4 Segments	Vertical Strat. Horiz/Lateral 20 Segments	(Event Driven) Vert. Stratified Mult.Vert. Seg. Mult.Horiz. Seg.
11 Stations 1 Depth (Integrated)	25 Stations 2 Depths Where Strat.	50 Stations 2 Depths Where Strat	50 Sta. 12 times/Yr Plus 2 Episodic Surveys
	10 Cruises/Yr.	10 Cruises/Yr.	
Load Total Toxicant	Loads-Part.+Diss.	Loads-Part.+Diss.	Loads-Part.+Diss.

FIGURE 2

Overview of Hydrodynamic Models and Observational Requirements

David Goodrich
Physical Oceanographer
NOAA Office of Climatic and Atmospheric Research

One of the major objectives of the Albemarle-Pamlico Estuarine Study is to address the effects of changing land use, particularly nutrient enrichment, on the water quality of the estuary. Clearly, this cannot be examined solely through an examination of historical data, though the approach has been attempted. A review of the original five-year Chesapeake Bay Program provided the following assessment:

> For nutrient enrichment and toxic substances, the CBP primarily asked what area trends can be extracted from available data. This information is useful for a first cut assessment of whether a problem exists and where. But in order to be useful in management decisions, further studies on the processes and effects on the ecosystem, and the application of this information with realistic models is essential.

The present Chesapeake Bay Program has begun an ambitious modeling effort in order to produce some rational assessment of the effect of management actions on the estuary. Examination of the historical data is a necessary first step, but it must not be considered a substitute for modeling.

The general procedure then is to construct a model that behaves like the estuary in some spatially or temporally averaged sense, then alter the waste loading and see what happens. In the case of the hydrodynamic component of the model, the question is whether or not the model is moving and mixing water like the estuary itself. To accomplish this, observational data from the estuary is needed. In comparison to other major estuaries, the data base with which to accomplish this is rather thin. A survey of National Oceanographic Data Center (NODC) physical oceanographic data indicates the following data holdings for five major estuaries:

	CTD Casts	Current Meter Months
Albemarle/Pamlico Sounds	101	48
Delaware Bay	5	166
Long Island Sound	173	36
Puget Sound	2029	988
San Francisco Bay	178	668

Observations are not needed for their own sake, but rather for understanding the system in general and for model operation and verification in particular. To give one example of what can be learned from physical observations, we can look at time series of salinity in Pamlico Sound and Chesapeake Bay (Figs. 1 and 2).

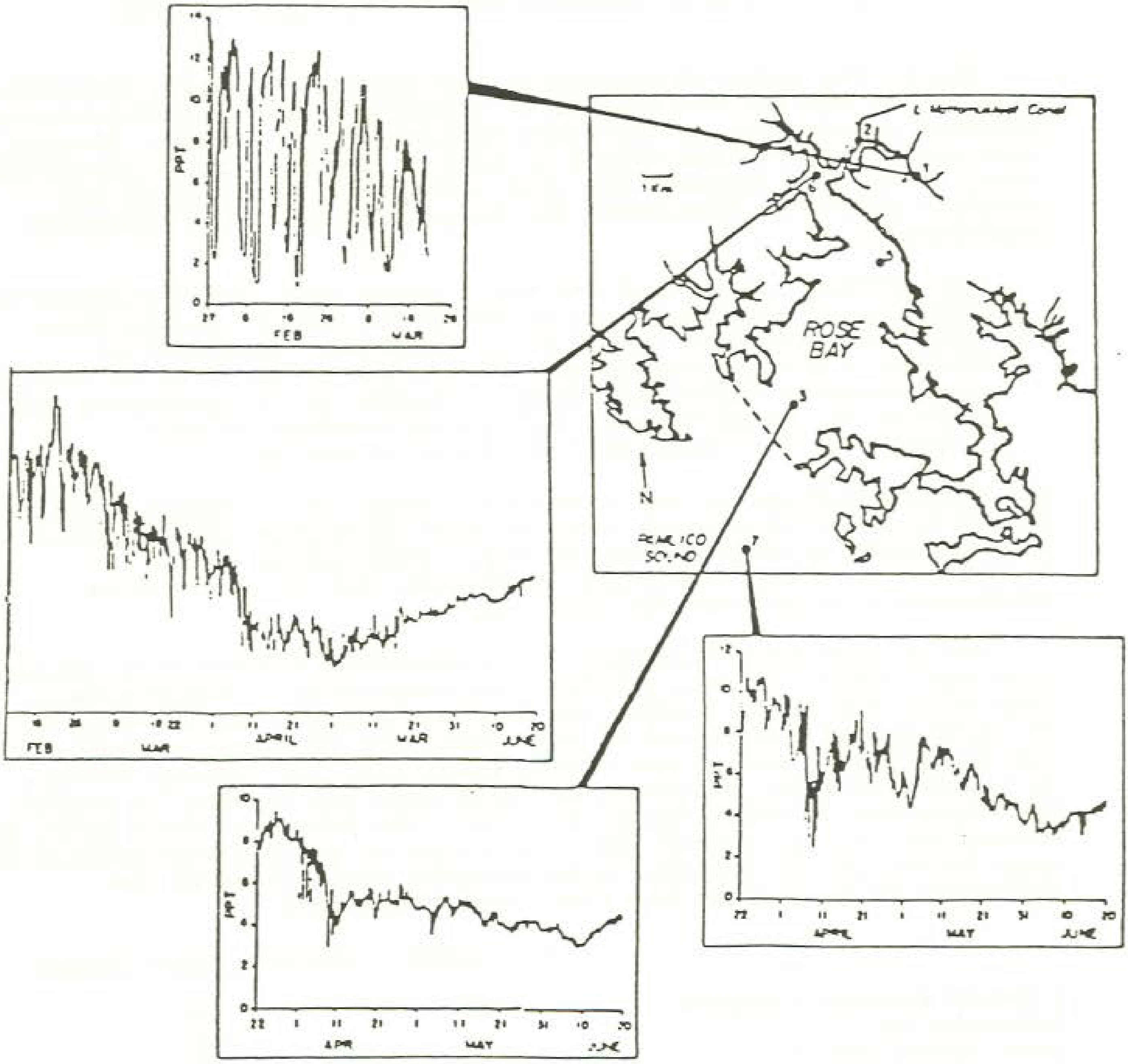


Figure 1 - Salinity variability at four stations in Rose Bay. From L. Pietrafesa, 1985: Response of Rose Bay to freshwater inputs. University of North Carolina Sea Grant Working Paper 85-2, pp. 21-61.

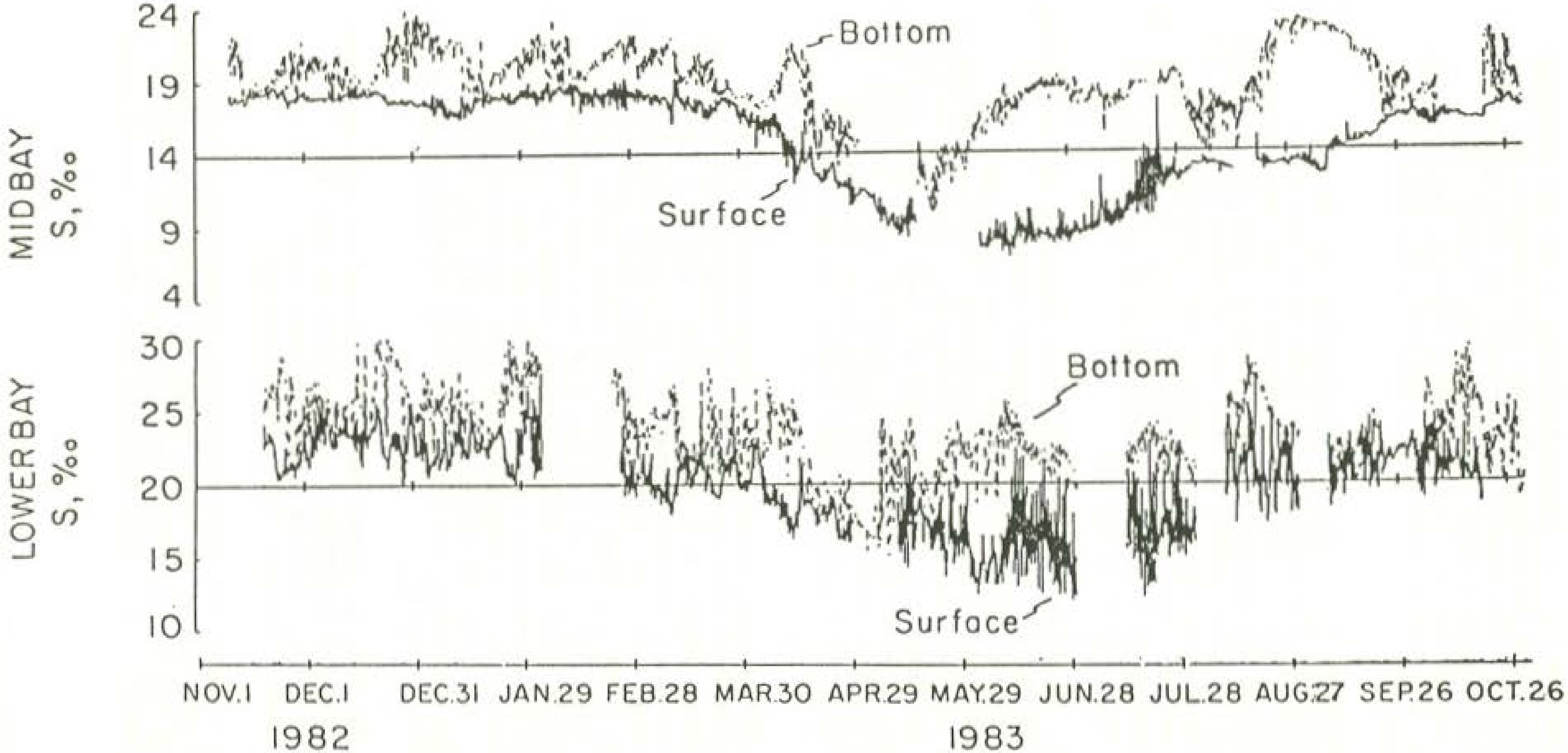


Figure 2 - Salinity variability at two stations in Chesapeake Bay. Mid-Bay station was located off the Patuxent River entrance, while Lower Bay station was north of the York River entrance.

Salinity is valuable because it is conservative, i.e. no sources or sinks in the estuary. The behavior of the parameters of interest for the eutrophication question (primarily nitrogen, phosphorus and dissolved oxygen) will be identical with the exception of source or sink terms. If a model cannot accurately simulate variability in salinity, then its ability to simulate other parameters is suspect.

Figure 1 shows salinity time series collected by North Carolina State University investigators at Rose Bay, on the northern shore of Pamlico Sound. At the head of Rose Bay, there are very large oscillations in salinity, primarily due to changes in fresh water discharge to the system. In the middle reaches of Rose Bay these oscillations tend to damp out. The variability increases again at the mouth, but the source of this variability is not from fresh water discharge but from wind-forced exchanges of water between Rose Bay and Pamlico Sound.

By comparison, Fig. 2 shows two continuous records of salinity in Chesapeake Bay from November 1982 to November 1983, demonstrating similar control of salinity on a larger scale. Looking at the mid-Bay series, there is relatively little variance at 2-10 day time scales as compared to the lower Bay record. Both series show a seasonal depression of salinity caused by the spring freshet. As in Rose Bay, there is much more wind-forced change in salinity near the mouth of the estuary, in this case driven by exchange with the coastal ocean rather than with the parent estuary.

Wind-forced circulation will clearly be important, if not dominant, in the Albemarle-Pamlico system for a number of reasons. The system is shallow (mean depth 4.5 m) and wide, with a long fetch. The connection to the coastal ocean is through narrow inlets, which tends to damp out the tidal oscillations while allowing lower frequency wind-forced motions to pass with little attenuation. Sea level variations of up to 1 m are not unknown, and it should be remembered that an estuary-wide drop of 1 m means that 22% of the water in the estuary has been forced out onto the continental shelf. A steady state assumption for circulation is thus likely to be poor. If a model does not simulate the wind-driven circulation, it is unlikely to simulate the behavior of the dissolved constituents of interest.

A central question is how to observe the system in the context of a modeling study. For this purpose, observations can be classed as boundary conditions, initial conditions and observations within the model domain for verification.

Boundary conditions - Many of the boundary observations are taken routinely. Runoff is taken at USGS gauging stations, though these data must be scaled up to correct for ungauged area within the estuarine drainage basin. For the surface boundary, wind data is routinely taken at airports, though a correction again is required. As any weekend sailor knows, wind speed over the estuary can be double that on the adjacent land, and this will have significant consequences for the movement of water. On the ocean boundary, large amplitude sea level oscillations generated on the continental shelf will propagate into the estuary, and for this reason sea level observations at the inlets are needed. Similarly, salinity can be expected to show large variation at the inlets, and some measurement strategy for boundary salinity is needed.

Initial conditions - It is particularly important to have a good initial field for salinity in the estuary, since the initial salinity conditions will influence model results for weeks to months after model initiation. Other initial conditions such as sea level, velocity and temperature are much less important.

Interior observations - A central question here is whether the model is behaving as it should within its spatial and temporal domain. In a wind-dominated system, observational constraints are relaxed somewhat, since wind-driven motions are coherent over large areas. The need is for long, continuous time series of current and salinity at a relatively few locations. For model verification, the need is also for synopticity. It does little good to have time series of one month at one station and a different month at another.

In summary, the following major points are submitted:

- The Albemarle-Pamlico system is strongly influenced, perhaps dominated, by the wind. A steady-state assumption will be a dubious foundation on which to build a modeling effort.

- The system is significantly undersampled with respect to other large estuaries, and it is doubtful whether a sufficient body of data exists to properly verify a hydrodynamic model.

- In the design of an observational program to support a hydrodynamic model, emphasis should be given to obtaining long, synoptic time series at a few points rather than a spatially intense but short "survey" program.

Modeling Approch for the Chesapeake Bay

Lee Butler
U.S. Army Corps of Engineers

The Corps of Engineers and the Environmental Protection Agency (EPA) signed a Memorandum of Understanding (MOU) in November 1984 for sharing funding equally for a full three-dimensional water quality model. The current MOU is for the development of a three-dimensional hydrodynamic/water quality model of the Bay. The MOU supports the Corps missions in the Bay, CBP goals, and advances the Corps modeling capabilities. The study will be conducted through the Corps' Waterways Experiment Station in Vicksburg, Miss. The Corps' Baltimore District is managing the project.

Mark Dortch
U.S. Army Corps of Engineers

Chesapeake Bay modeling efforts include direction from many sources, particularly the Chesapeake Bay Program (CBP) Modeling and Research Subcommittee (MARS). MARS is a representation from the Chesapeake Bay states and Federal agencies.

The three-dimensional, time-varying, hydrodynamic and water quality model for Chesapeake Bay will be used to evaluate control strategies for reducing nutrient loads and eutrophication of the Bay. Specifically, the Bay has witnessed:

* high concentrations of nutrients
* eutrophication
* increased anoxia
* decrease in submerged macrophytes
* decrease in sport and commerical fishing
* toxic chemicals in sediments

The CBP has outlined specific questions they want the model to address. These are:

* What are the reasons for the decline in the Bay?
* What are the cause/effect relationships?
* What are the effective control strategies?
* How effective are control strategies?

Two models for the Bay have been completed:

(1) a watershed model; and
(2) 2-D steady-state Bay model

The watershed model is used to evaluate land-use practices in the watershed. The 2-D steady state model was the first step in developing a water quality model of the Bay.

The advantages provided by the 3-D time-varying model over the existing 2-D steady-state model are:

* greater spatial resolution
* seasonal and annual variations
* more state variables and processes
* bed-sediment water quality submodel

One of the conclusions of the steady-state model study was that the flux of nutrients from the sediments dominates the system. Because of this, it may be years before the benefits of reducing nutrient loads are realized. Therefore, the 3-D model may have to be run for long periods (years) to evaluate control strategies.

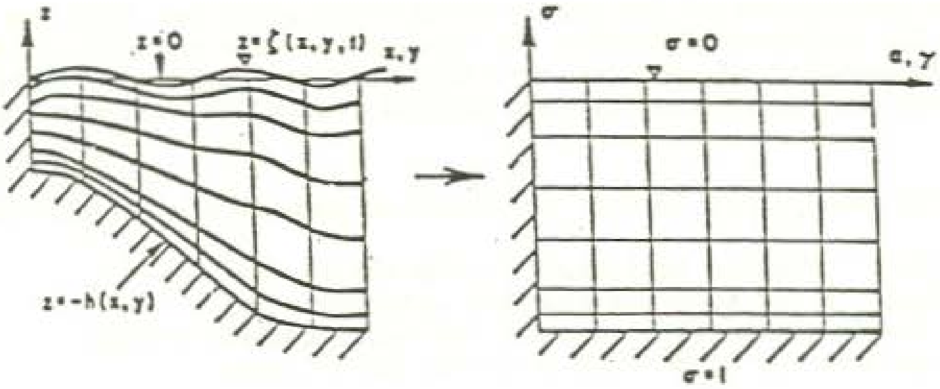
Experts will participate in four workshops to provide a concensus for:

(a) state variables to include in the model;
(b) approach for modeling sediment water quality;
(c) interfacing the hydrodynamic and water quality models;
(d) approach for conducting long-term simulations.

The 3-D hydrodynamic model to be used is CH3D developed by Sheng, University of Florida. THe grid uses horizontal boundary fitted coordinates and sigma stretching in the vertical. The sigma stretching coordinate allows the modeler to represent the sloping bottom topography (Figure 1). Figure 2 shows how boundary fitted coordinates can be used to map the geometry in the horizontal plane. The time-step required for the hydrodynamic model is on the order of minutes, whereas that for the water quality model is on the order of hours. Thus, it is necessary to time average the hydrodynamic model output to drive the water quality model. This must be done in a manner that preserves the transport characteristics.

The 3-D water quality model is based upon the concept of an integrated compartment (box) model. the advantage of this model is it can be coupled to various hydrodynamic models while employing a coarser spatial and temporal scale.

$$\sigma = \frac{z-\zeta}{\zeta+h} \approx \frac{z}{h}$$



Vertical stretching of the coordinates

Figure 1

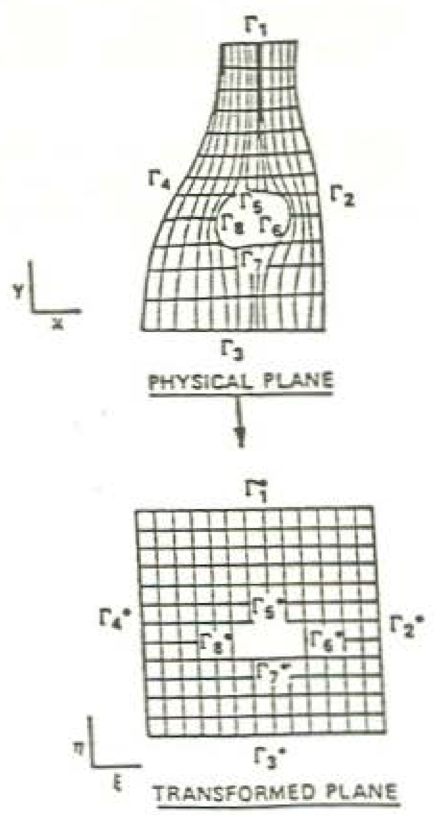


Figure 2

Uncertainty Analysis - Abstract

Keith Little
Research Triangle Institute

The objectives of the presentation were (i) to emphasize the importance of uncertainty analysis for APES modleing efforts and (ii) to provide a brief introduction to one method of uncertainty analysis (Monte Carlo simulation) for the benefit of APES committee members unfamiliar with these issues. The uncertainty analysis concepts discussed were illustrated for a QUALII-based dissolved oxygen model for Contentnea Creek, NC, developed by the Research Triangle Institute for the U.S. Army Corps of Engineers, Wilmington District.

Hydrodynamic Modeling and Field Observations in the Pamlico Sound Estuary System

Leonard J. Pietrafesa
Professor of Oceanography

and

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North Carolina State University
Raleigh, NC 27695

The two presentations will deal with several key issues: first, the state of the art knowledge of the physical oceanography of the Pamlico Sound Estuary system; and second the status of our ability to predict current and salinity fluctuations in the PSE; finally some recommendations.

To address the first issue we point out several recent publications which detail much of the recent (1978-1987) findings in the PSE. They are:

I. Pietrafesa, L.J., G.S. Janowitz, U.M. Miller, E. Noble, S. Ross and S. Epperly, 1986. Biotic Factors Influencing the Spatial and Temporal Variability of Juvenile Fish in Pamlico Sound. In Estuarine Variability, Academic Press, 341-353.

II. Pietrafesa, L.J., G.S. Janowitz, T. Chao, R. Weisberg, F. Askari, and E. Noble, 1986. The Physical Oceanography of Pamlico Sound. UNC Sea Grant College Working Paper 86-5. 125 pps.

III. Pietrafesa, L.J. and G.S. Janowitz, 1988. Physical Oceanographic Factors Influencing Larval Transport Through North Carolina Inlets. Transactions of American Fisheries Society. In Press.

The physical oceanography of the Albemarle-Pamlico Estuary System is of major importance to any resource management schemes and decisions. Whether the problem be fish recruitment or one of fish population dynamics, or of agricultural runoff, or of salinity fluctuations, etc., ultimately the hydrodynamics will play either a primary or secondary role in its cause and effect.

Amongst the recent (1981-1987) revelations about current, sea level, salinity and atmospheric variability that have come from our studies, at North Carolina State University are:

1) The thermohaline structure of sound waters is more variable both spatially and temporally than is commonly believed (cf. Figure 1). Therefore, continuous time series at fixed locations of both T

and S need to be collected. Also T-S towed surveys should be conducted to establish the existence of T-S fronts. Publication II has made strides in not only detecting but also understanding the source of T-S variability.

2) The inlets couple the sound and coastal waters. Tidal influence is greatest in and on either side of the inlets and speak to the need for a study in and on either side of the inlets. The synoptic scale physical activity through the inlets is not well known and needs to be established although the recent findings in Publication III shed new light on the processes at work in the inlets. (Figure 2 suggests several of the principal wind and tide coupled flow fields present at Oregon Inlet.) It is now suspected that the limiting factor in year class strength of spot, croaker, flounder, and menhaden in Pamlico Sound may be related to abiotic recruitment through the barrier island inlets (Publication I).

3) The wind field is the principal forcing function of the physical dynamics of Pamlico Sound spatially ontime scales of hours to days (Figure 3) and must be measured sufficiently spatially to establish its characterization as a forcing function in order to fully appreciate the response of sound waters (Publication II).

4) Sea level sets up within 10 hours of the onset of a causal wind. Sea level gradients ensue. Telescoping grids of water level recorders need to be established as a function of locale to more fully understand sea level fluctuations, ensuring pressure gradients and the wind field responsible for the variability (Publications I and II) demonstrate the wind forced response with both observations (Figure 4) and from the results of a 3-dimensional, time-dependent, telescoping grid, stretched coordinate model of the APE system. The former paper also demonstrates the importance of the wind forced response to the abiotic migration of juvenile fish to the nurseries (Figure 5).

According to the findings in Publication II:

5) Monthly to seasonal to annual fluctuations in sea level in the APE system relate directly to the rise and fall of North Atlantic (Ocean) central water and to the seasonality of the wind field as it affects the rise and fall of sea level on the coastal side of the barrier islands. Flooding and erosion of the mainland and barrier islands adjoining the sound are affected by monthly mean water levels. Several years of sea level data from the periphery of the sound and the coastal ocean need to be analyzed and compared to locales and periods of high erosion to establish a predictive capability. A study of the circulation of the sounds is a must in this regard.

6) During the late spring and early fall, wind motion aligned with the axis of Pamlico Sound appears to be more highly coherently organized relative to cross-axial wind motion, i.e. the wind field tends to be rectilinear. Consequently, sea level fluctuations are coupled to axial winds. (Figure 6)

7) During the late spring to early fall, sea level slope appears to be predominately aligned with the principal axis of Pamlico Sound and to be strongly coupled to the axial wind component. However, insufficient tide gage data exist to thoroughly assess the cross-sound

sea level slopes. Since sea level slopes drive bottom currents in the reverse direction of the slope, it is important to more thoroughly investigate this problem. (Figure 7)

8) During the late fall to early spring, wind field motion is elliptically polarized, i.e. organized motion occurs in both the direction of the main axis of the sound as well as across the sound in a coupled fashion. Sea level and sea level slopes appear to set up in an organized fashion to whichever wind component is present. (Figure 7)

9) A rule of thumb exists between wind and the water level response to these winds such that sea level slopes in the direction of the principal axis of the sound appear to set up at 02.-0.26 cm/km per dyne/cm^2 of wind stress in the direction of the wind within 10 hours while cross-sound sea level slopes take a full day to set up. Since sea level set-up inundates property and since sea level slopes drive bottom currents, these preliminary results need to be further investigated.

10) There is a degradation of the coherency between wind and sea level in the vicinity of the juncture of Roanoke, Croatan, Albemarle and Pamlico Sounds and Oregon Inlet. This degradation may be due to freshwater and coastal water fluxes. This water exchange problem may be an indicator of an Albemarle-Pamlico Sound and coastal ocean coupling of which we presently know nothing. The problem needs to be addressed.

11) Pamlico Sound can be topographically decomposed into northern and southern basins, separated by Bluff Shoals. Sea level fluctuations in Pamico Sound may be decouple somewhat into a north basin set and a south basin set. The circulation associated with this decoupling or coupling is totally unknown.

Finally, a three-dimensional, time-dependent stretched coordinate model of circulation and water level variability of the entire Albemarle-Pamlico Sound System exists at North Carolina State University and has been described in Publications I and II.

12) The three-dimensional, time-dependent model of circulation and sea level reveals that sound waters respond fully to winds within 10 hours of the onset of forcing in good agreement with data. Model bottom currents, driven by sea level slope pressure gradients, are shown to veer by as much as 180^o from mechanically driven surface currents. The 3DM model is a great aid in establishing a predictive capability for the physics of Pamlico Sound. However, the 3DM model needs improvements, including: the imposition of a variable bottom-stress condition; the incorporation of spatial variability in the wind field (which requires a commensurate field program to yield the variability of the windfield); greater topographic resolution by reducing model grid size, particularly near shoals; inlet conditions need to be reassessed, particularly via the inclusion of actual inlet data; a nonhomogeneous, T-S field should be incorporated in both diagnostic and prognostic modes; the tides, particularly the semi-diurnal mode, need to be incorporated into the model; and riverine, connective sound and drainage inputs need to be better established via a field program.

13) Vertically integrated models are shown to either underestimate or miss much of the basic physics of the sound and therefore should never be used. (Figure 8)

14) The horizontal and vertical structure as well as the temporal variability of the circulation field is essentially unknown save for a few, singular observations (Figure 9) and for the 3DM predictive output. The study reported on in section II and III of this report have introduced a new level of understanding for the physics of Pamlico Sound. However, this study simply established the foundation for a more complete study of the entire sound system. How $\overline{v}$ couples to $\overline{\tau}$, η, η_x, η_y, T-S to the coastal ocean via the inlets, to the feeder rivers, bays and sounds, to bottom topography, particularly near shoals, and to atmospheric buoyancy flux, can only be speculated upon at this time. A thorough study of the circulation must be conducted.

15) Finally, it is noted that: The gravity wave field which exists within Pamlico Sound proper and through the inlets and tributary rivers is totally unknown. This field is omnipresent and may contribute significantly to sediment transport, i.e. erosional processes and to flooding under high wind conditions.

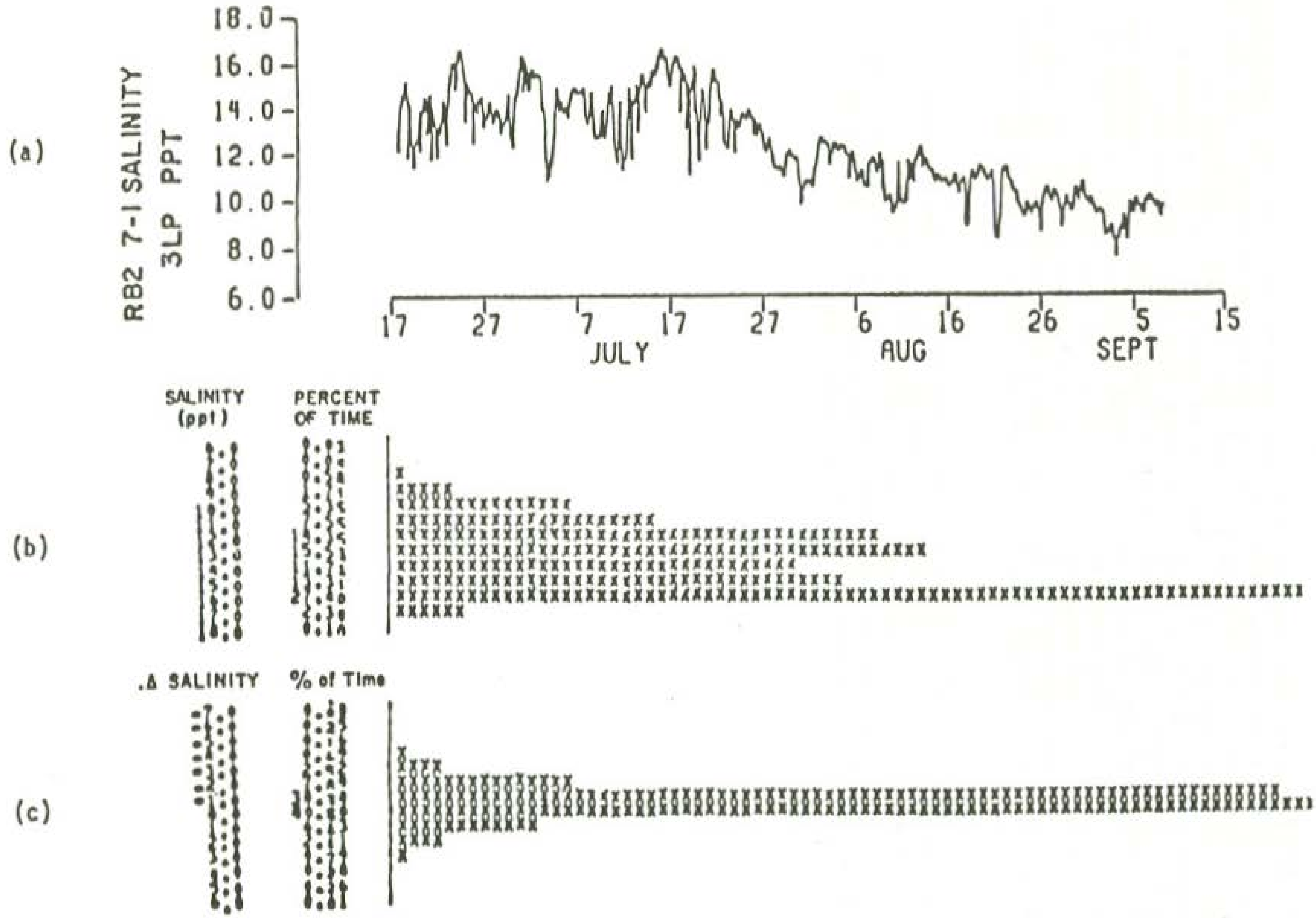

Figure 1. a. Three-hour low pass filtered salinity observations collected at station 7 (cf. Figure 5) in south basin of Pamlico Sound during summer 1982.
b. Salinity values in (a) as a function of percent of time of time series in which S was within ± 0.5 of an integer value.
c. First differences of (a) time series.

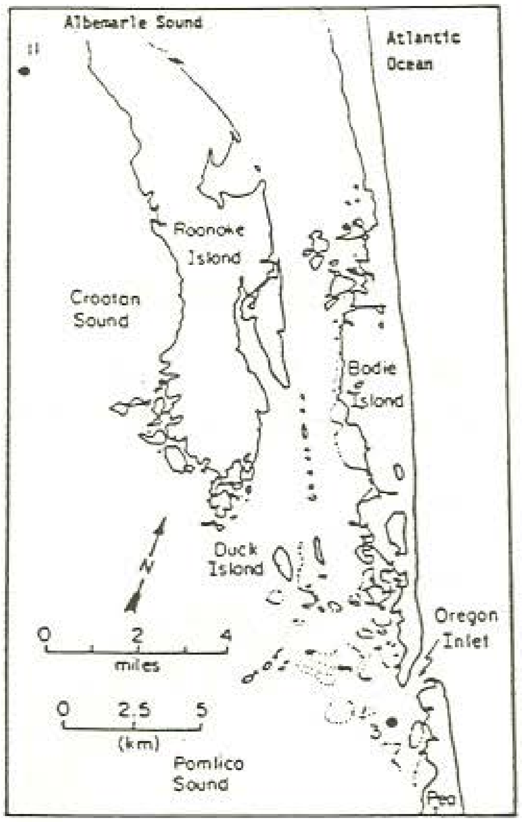

Figure 2a. Location of station 11, in north Pamlico Sound, and station 3, on the sound side of Oregon Inlet, during a study of currents recorded by bottom mounted current meters during period 1/3-3/3, 1974. Field study conducted by Singer and Knowles (1975).

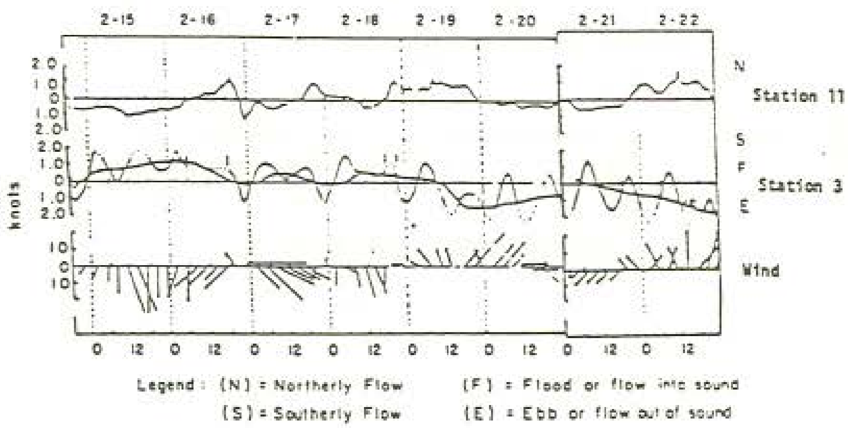

Figure 2b. Currents and winds at stations 3 and 11 near Oregon Inlet as shown in figure 71. Station 3 shows both a tidal signal as well as subdiurnal frequency currents.

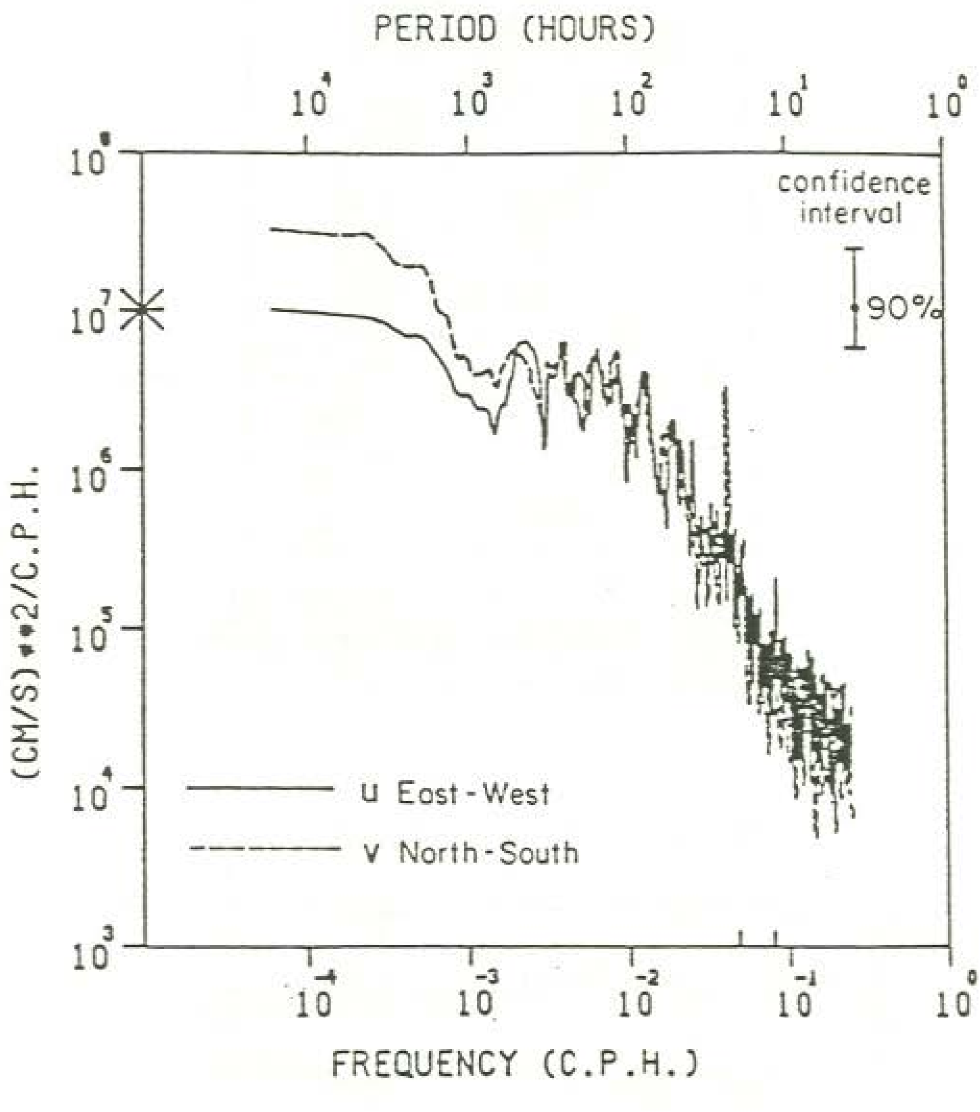

Figure 3 . Energy density spectra for averaged New Bern and Cape Hatteras wind velocity component time series for 1978.

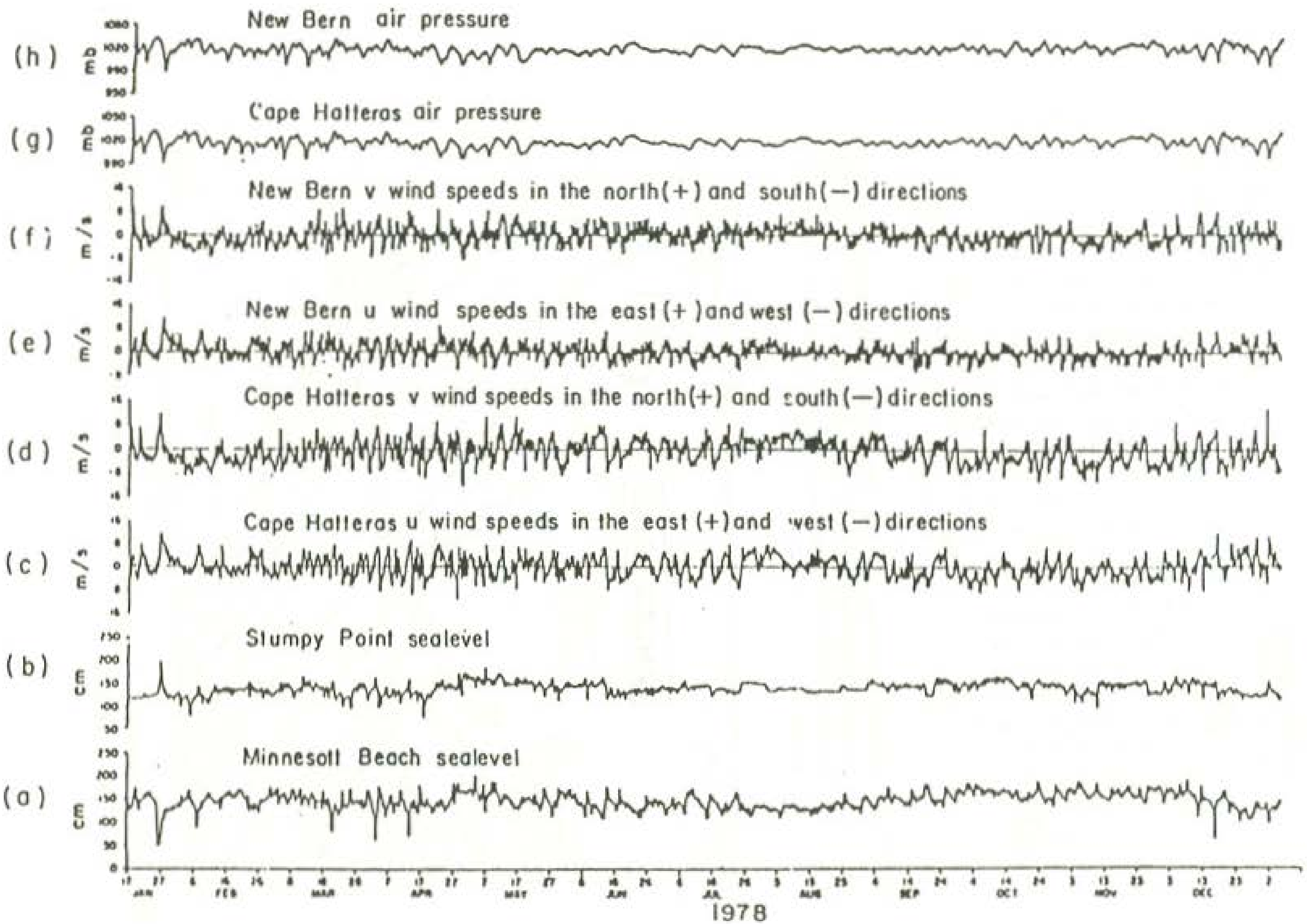

Figure 4. Time series of data collected during North Carolina State University 1978 Pamlico Sound study.

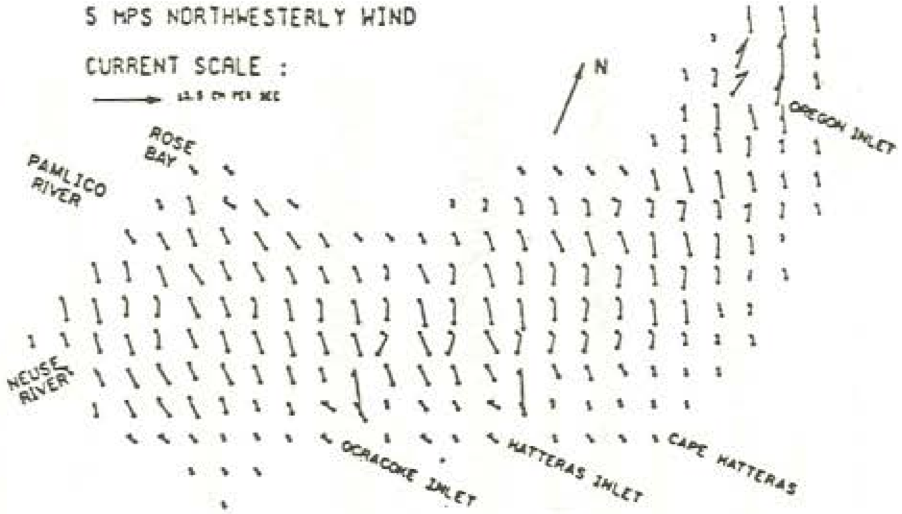

Figure 5a. *Surface (long arrow) and near-bottom (short arrow) model current-vector velocities throughout Pamlico Sound in response to a 5 m s⁻¹ northwesterly (southeastward) wind. Bottom velocities are computed 1 meter above the bottom.*

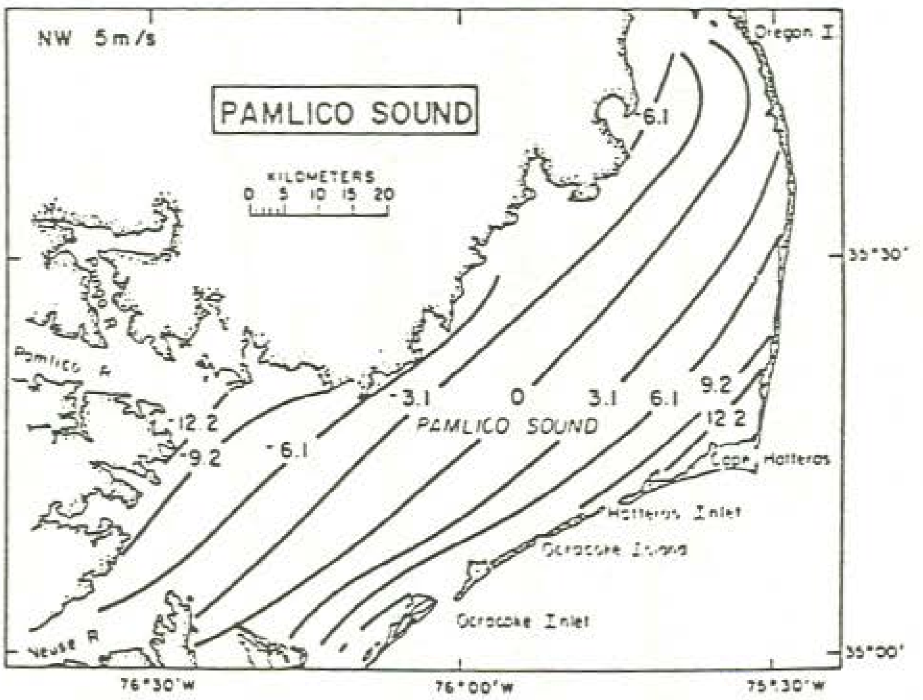

Figure 5b. *Model sea level distribution in Pamlico Sound in response to a 5 m s⁻¹ southeastward wind.*

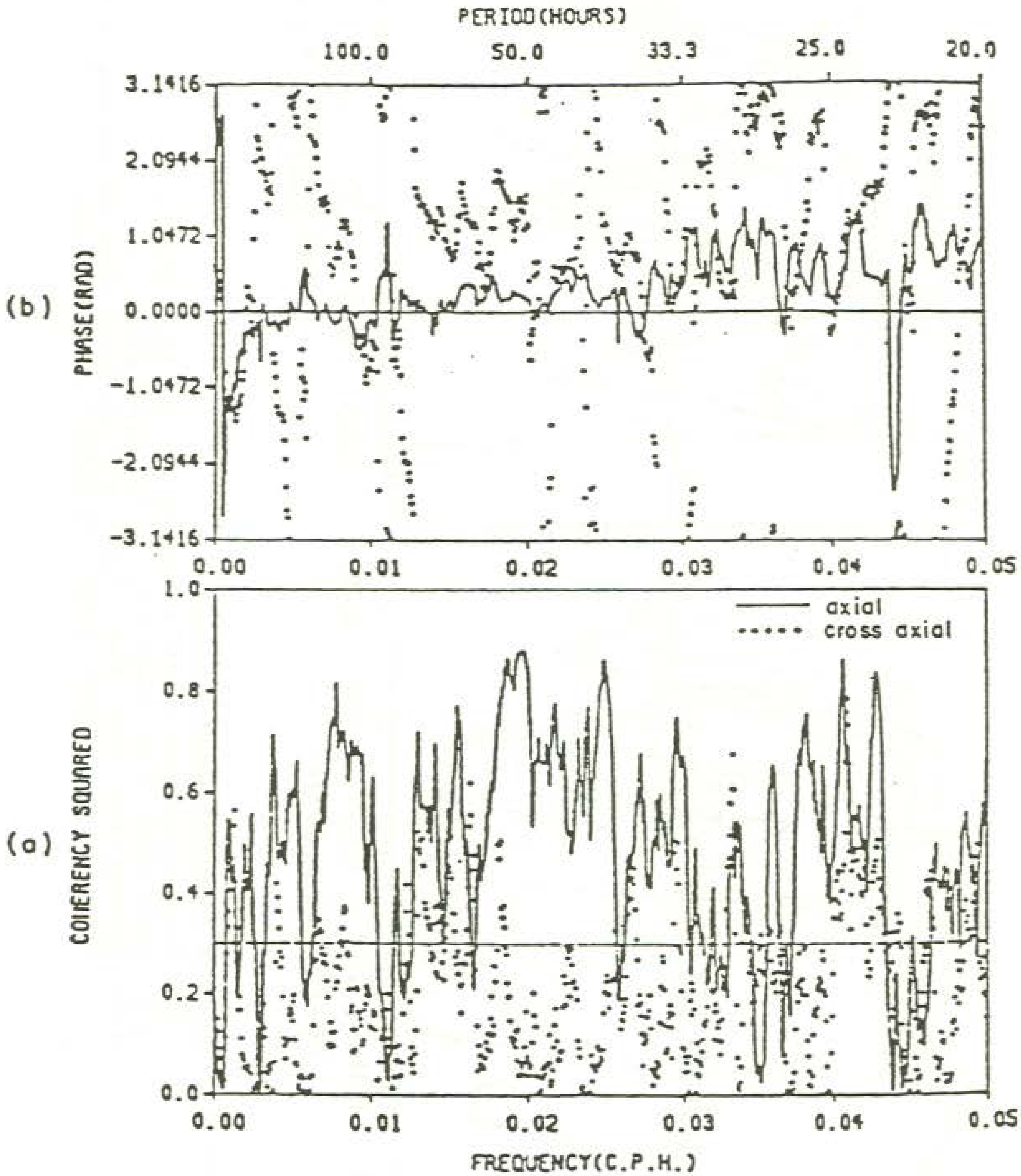

Figure 6. Coherency squared and cross-phase between axial and cross-axial wind stress components of Stumpy Point sea level during North Carolina State University 1978 study.

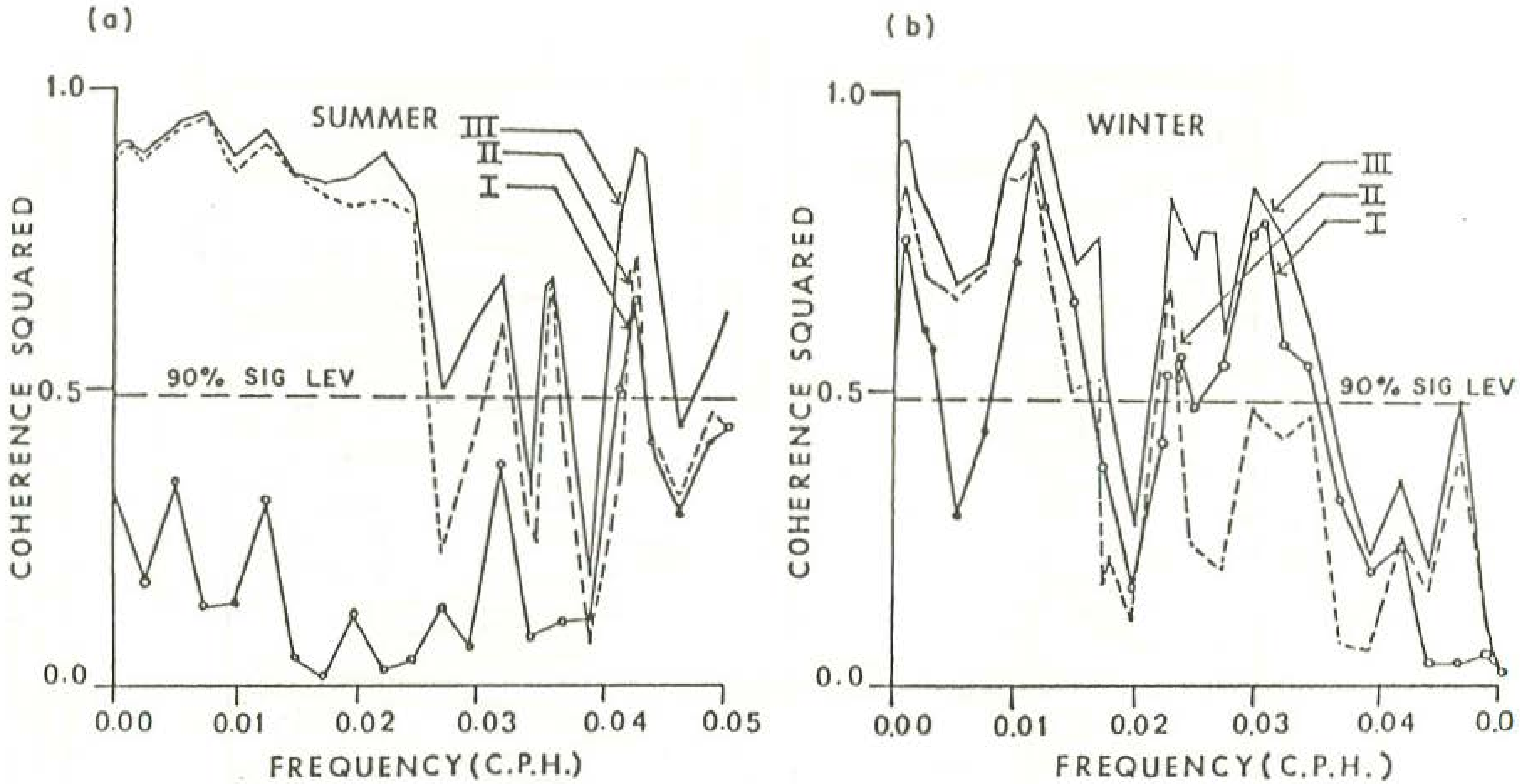

Figure 7 . Multiple coherence squated between:
(I) Cross-axial wind stress component and sea level slope;
(II) Axial wind stress component and sea level slope;
(III) Between total wind stress vector and sea level slope during North Carolina State University 1978 summer and 1978/79 winter studies.

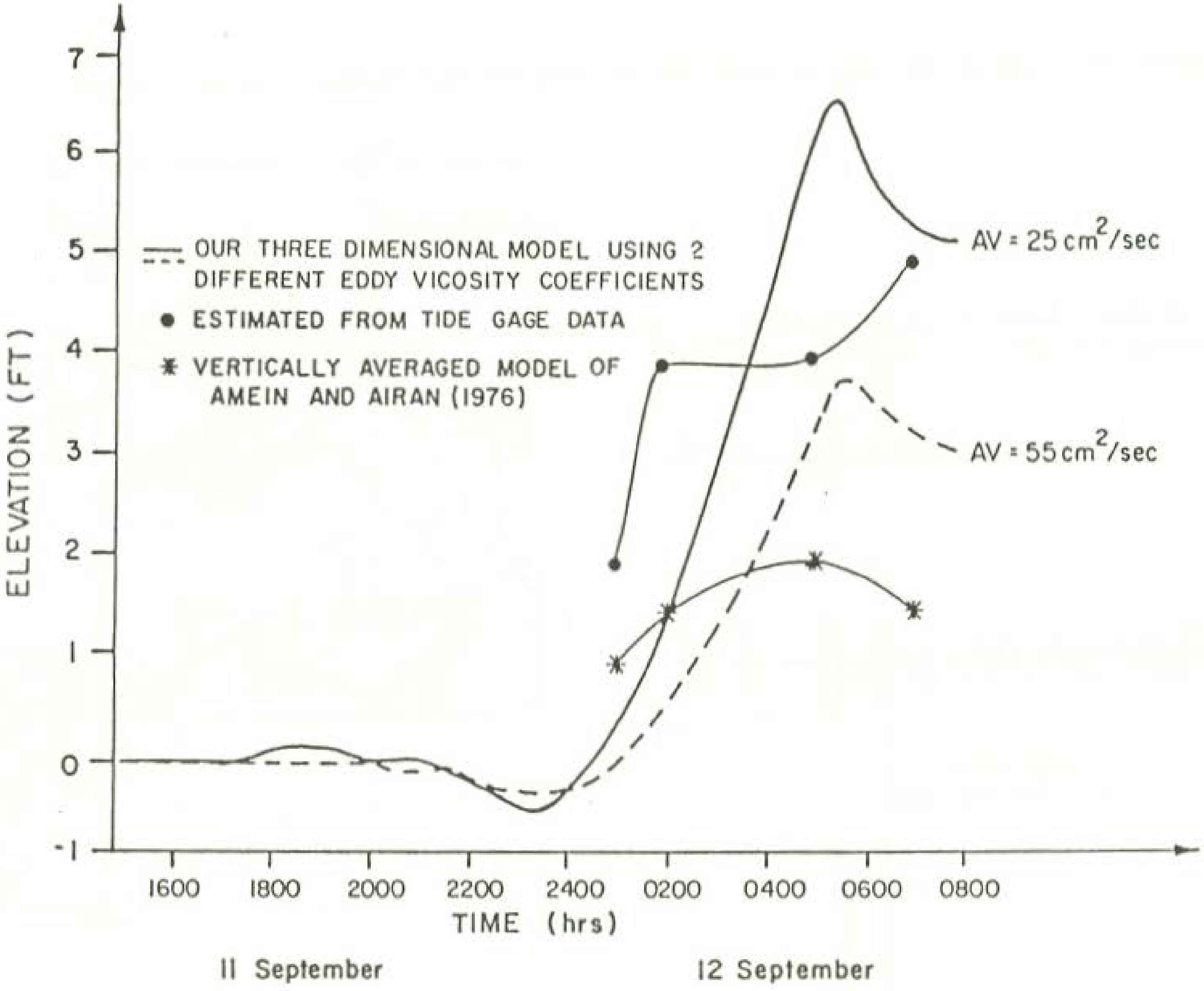

Figure 8. Measured and predicted sea level time series at the Oregon Inlet tide gage during the passage of Hurricane Donna.

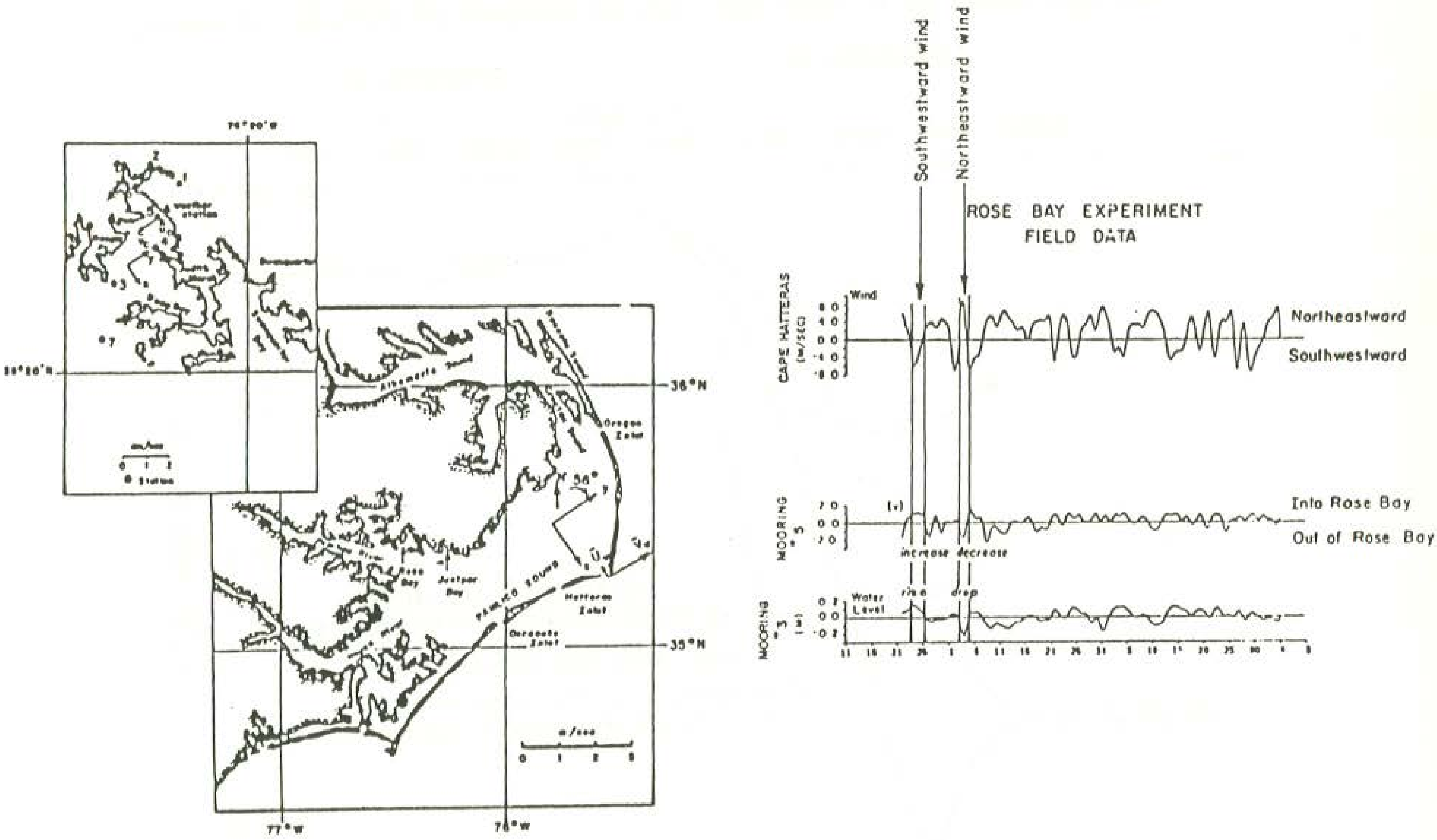

Figure 9 . Winds, currents and sea level at the mouth of Rose Bay in the south basin.

Curtis Richardson

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My dicussion is centered on land/water interactions, with an emphasis on Pocosin development. The importance of wetlands ecosystem level studies cannot be emphasized enough. We need some controlled watershed studies, to look at the functional value of freshwater wetlands in coastal N.C.

The Albermarle-Pamlico research effort needs to establish one or two watershed level studies to address the effects of land development on coastal water quality. It is important to look at nutrients, carbon and pesticide loadings in terms of estuarine ecosystem response. The question centers on how freshwater ecosystems function when disturbed.

For example, the state water management plan guidelines for the peat mining activity proposed for White Tail, asked several questions. What are natural water output conditions? How does development effect water quality? Do we have to regulate freshwater flow on a monthly basis to maintain normal ecosystem functions?

A hydrologic model has been developed to project what would happen under alternative land uses. This model needs to be refined but it could act as the basis for developing research on watershed studies on the coastal plain, especially if it was combined with a transport model. Finally we need to look at loading rates and determine nitrogen and phosphorus mass loadings (output as a function of input) under different land use patterns and under different management alternative.

Recommendations for future research includes:

1. Selection of wetland watersheds that we can manipulate and can be coupled with existing or proposed land use activities. (ie. forestry, peat mining).
2. Selection and development of models to predict outputs of water and materials from natural and developed pocosins. We need, studies designed to look at the effects of forestry, agriculture and peat mining development on water quality in the coastal plain of North Carolina.

An example of how modeling could be coupled with planned land use activities to predict potential freshwater output is shown in the attached document entitled peat mining. This example estimates the effects of different land uses on water quality and is from the White Tail Farm Water Management Plan submitted to the State of North Carolina. A complete field study on nutrients needs to be combined with this modeling effort to accurately predict mass outflows.

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PEAT MINING
EXAMPLE CASE STUDY

A. Modeling

1. Modeling techniques

We reviewed several hydrology simulation models for possible utilization in our peat mining simulation. The Minnesota hydrology model required extensive alterations and validation for WTF and thus was not chosen.

The computer model DRAINMOD was developed as a tool in the design of water management systems for shallow water table mineral soils (Skaggs, 1978) and has been modified and tested for peat soils by Gregory et al. (1984). This model was specifically tested for pocosin peatlands and was used to simulate the hydrologic and water quality impacts of peat mining in Dare and Hyde Counties in North Carolina (Gregory et al. 1984, CEIP 1984). The model has been described in detail in Skaggs (1978) and Gregory et al. (1984) and thus we will only briefly present the salient features as they pertain to our simulation of WTF conditions.

After preliminary analyses of the model, we assessed the availability of input parameters and the compatability of FCF soil parameters for WTF. We analyzed peat profiles and soil physical characteristics at WTF (See section IID for an analysis of soil physical characteristics at WTF) including bulk density, percent ash and moisture content (129 samples were analyzed at WTF by Ingram (1984) and compared this to the extensive data set at FCF (Skaggs et al. 1980, Gregory et al. 1984). As mentioned earlier (Section IID) lab analysis of natural, disturbed, and agriculture soils at Duke indicated that specific WTF peat soils and their physical, chemical and hydrologic properties were nearly identical to specific FCF soils properties. White Tail Farm soils were then matched with FCF sites in terms of peat depth, vegetation type, amount of disturbance, and drainage conditions. This cross-matching of soils, hydraulic conductivity and land use conditions allowed us to utilize some of the previously developed parameters and soil coefficients in our simulations. Rainfall inputs for 20 years were taken directly from the HISARS data file. This is the same procedure that was followed by Gregory et al. (1984) in their analysis of peat mining effects.

2. Model background

This field scale model has the capability of simulating on a day-to-day, hour-by-hour basis, the surface runoff, subsurface drainage, evapotranspiration, soil water content, and water table position as a function of climatological data, soil properties and under both natural and assigned water management plans (Gregory et al., 1984). The model is based on a soil water balance for a column of soil which extends from the impermeable layer to the surface where the water balance for a given time frame is as follows:

$$Va = D + ET + DS - F$$

where Va is the change in the air volume, D is the drainage from the column, ET is the actual evapotranspiration, DS is the deep seepage and F is the infiltration entering the section in time t. All values have units of cm^3/cm^2 or cm (Skaggs et al. 1980). The surface runoff and surface storage are computed with the following water balance equation:

$$RO = P - F - S$$

where RO is the surface runoff, P is the precipitation, F is the infiltration, and S is the change in surface storage during time t. All values are in cm and the time increment used in the calculation is one hour. For a more complete description of the model and details of field tests and validation see Skaggs et al. (1980) and Gregory et al. (1984).

3. Inputs and Key Parameter Estimates

a. Precipitation

Hourly rainfall data must be used as the driving function for DRAINMOD simulations. The meteorological data utilized for a 20 year simulation of peat mining effects was taken from Elizabeth City, North Carolina. These data were available from the computer storage system HISARS (Wiser, 1975). These data were carefully checked for missing data and errors and the final inputs utilized in the simulations were from 1955 to 1978. Excluded were years with incomplete data sets of partial hourly records (1968, 1970, 1971,and 1973). This site was chosen due to the fact that it is the closest complete hourly record set on the coast of North Carolina and it has been validated against regional records. Our records have shown this data set to be quite similar on a daily basis to local rainfall events.

b. Infiltration

Infiltration was determined from the Green and Ampt equation (1911) for each soil profile from:

$$f = A/F + B$$

where f is the infiltration rate, F is the accumulated infiltration and A and B are parameters that are dependent on the soils properties such as bulk density, and air space etc. These values for each soil at WTF were determined by land use type (See IID) and the parameters used are presented in appendix C for each simulation.

c. Hydraulic conductivity

This soil parameter varies with depth and surface conditions. Highest rates are at the top few cm in undisturbed profiles and decrease as soil bulk density increases and large pore space decreases with depth. Values for hydraulic conductivity by soil type and vegetation cover have been developed for the pocosin peats by Bard (1978) and Polisinsit (1982). These values were also predicted from bulk density curves values following Boelter (1969) and are given in section IID. Analysis of WTF soil profile characteristics at the Duke soils lab permitted us to correlate hydraulic conductivity values with physical characteristics for each site condition or disturbance (See Section IID). This procedure was also utilized by Gregory et al. (1984) in their simulation procedures. Values for each simulation condition are given in appendix C.

d. Evapotranspiration

The determination of actual evapotranspiration (ET) by the model is a two step process where potential evapotranspiration (PET) is calculated from climatological data over 12 daytime hours. Next, the ability of the soil water to supply PET is determined and if it is not limiting then PET is set equal to ET. If it is limiting then ET is set equal to the upward flux value. PET in DRAINMOD is calculated by the Thornthwaite (1948) method which was proven to be suprisingly accurate over the growing season at the coast (Mohammad 1978). The Thornthwaite method is known to underestimate winter ET and thus estimated runoff would be higher than actual unless correction factors were added to the final solution. Conservation correction values were determined from the NOAA Evaporation Atlas (1982), the Gregory report (1984) and Thornthwaite and Mather (1957). Actual calculations and units outlined earlier in section IIE were utilized in the modeling.

4. Potential errors of assumptions

Drainmod has been tested (Skaggs et al.1980, Gregory et al. 1984, CEIP 1984) for pocosin peatlands, agricultural areas, peat mining conditions, forestry and pine plantations and the parameters have been estimated. We did field and lab tests to verify and refine input parameters for all the conditions being simulated. As mentioned in earlier sections we compared soil physical conditions with these earlier studies by cover type and found nearly identical conditions in terms of bulk density, hydraulic conductivity, total N and P, and ash content. This cross correlation allowed us to utilize a number of existing soil input parameters.

Major canals that have existed at WTF for decades are found at a density of every 3/4 miles. This fits within the general guidelines of a density of no greater than one per mile by one per 1/2 mile. An accurate determination of undrained conditions is not possible without the utilization of canals drainage points under the present configuration of existing wetland models. That is diffuse flow (surface and subsurface) across a broad surface area has not been accurately modeled in vast peatland areas.

Data inputs were also subjected to sensitivity analysis for each of the sites following the method of Purisinsit (1982). We simply ran simulations with input values altered by a 50% increase or decrease in value. We looked at evapotranspiration as estimated by the thornthwaite method, hydraulic conductivity, surface storage depth to impervious layer, and effective root zone depth. The only input values which altered annual runoff volumes by more than 10% were evapotranspiration and effective root zone depth. For example, increasing PET by 50% decreased annual runoff by approximately 20%. Our results closely followed Purisinit's (1982) findings and further support our contention that DRAINMOD input parameters from earlier studies were appropriate for WTF. Extra care was taken to quantify the two input parameters of greatest sensitivity: PET (Section IIE) and effective root depth (field measurements). For example, we have selected a conservative estimate of PET for forestry and will thus overestimate runoff. During the first few years of forestry operation we have calculated a lower ET and a 11% higher runoff value (See Section IIE). It is known that pine plantations do in fact transpire at a rate considerably higher than native vegetation due to high planting density and year round physiological activity (See section IIE, and Kramer, 1983). This strongly suggests that the forestry reclamation alternative will significantly improve runoff conditions. Extensive storm events (e.g. hurricanes) will result in runoff that will exceed the canal runoff predicted by our modeling projections.

This is to be expected since the entire area will be under water with or without the presence of mining. We have planned for consecutive storm conditions under our water management section and have discussed alternative plans of action.

We also plan to utilize DRAINMOD to aid in the water management of WTF. We will initially set flashboard risers and control structures to match DRAINMOD values. Simulations will be run and checked against field values on a monthly basis. Error adjustments will be made in the model if necessary and the model will be used to aid in the control management of each specific area in terms of outflow conditions.

5. Conditions modeled

We utilized DRAINMOD to simulate hydrologic conditions of runoff and evapotranspiration. Runoff in this document is total runoff and combines both surface runoff and subsurface runoff. We simulated conditions for hourly, daily and monthly hydrologic flux utilizing a twenty year period of hourly rainfall input from Elizabeth City, North Carolina. Yearly, seasonal, and monthly conditions, as well as large storm events and sequential storm events were simulated during different stages of the project and during each reclamation phase.

It should be noted that under present conditions (without mining) annual runoff from the site is 3808 million gallons per year (MGY) (Table 9). That is to say that canals and ditches (many of which have been present for decades) are currently releasing large volumes of uncontrolled runoff. The portions of the area that are disturbed (natural vegetation removed and ditched) are currently releasing nearly 19 inches or nearly 40% of the annual rainfall of 48 inches.

We have utilized natural conditions with mature natural vegetation as our baseline or target in terms of runoff levels. been completed for natural conditions, during mining, and forestry (loblolly pine) plantations following mining.

a. Natural conditions

The premining natural conditions are based on mature natural vegetation which is found on deep peats (> 1m) in the pocosin areas of North Carolina. The dominant species include pond pine (Pinus serotina), fetterbush (Lyonia lucida), titi (Cyrilla racemiflora), sweet bay (Magnolia virginiana), red maple (Acer rubrum), red bay (Persea borbonia), and loblolly bay (Gordonia lasianthus) etc. We utilized a peat depth of 6 feet (183 cm) and present canal conditions of 3/4 of a mile. This density of canals closely matches the 1 by 1/2 mile density noted in the guidelines (14 million versus 15.5 million ft^2 of area). (The parameters utilized in this simulation are shown in Appendix C.

b. During Mining

The parameters utilized during mining are presented in Appendix C. Drains were placed 165 feet apart (5029 cm) and simulations were done for one foot removals of peat. The peat was not removed when ash content rose above 20%. Subsurface drainage was natural since tiles were not employed.

c. Forestry

Parameters used in this simulation are found in Appendix C. One foot of peat was left and the drainage ditches were at 150 feet. Seasonal evapotranspiration was increased after 3 years over natural vegetation because of higher annual transpiration output from fast growing dense loblolly pine plantations (Campbell and Hughes 1981; Kramer, 1983).

6. Results of modeling

a. Precipitation (P) and evapotranspiration (ET)

The average rainfall for the WTF region is 48.3 in. (123 cm) over the last twenty years (Wiser, 1974). The monthly distribution of rainfall is shown in

Figure 6. On average (20 year simulation)the wettest months are July and August. Evapotranspiration exceeds rainfall only during June, but is close to rainfall in both July and August. A plot (Figure 7) of the average monthly rainfall compared to ET shows that 31.5 inches (80 cm) of the annual input of 48 inches (123 cm) leaves naturally vegetated pocosin sites as ET. Thus, nearly 66% of annual rainfall leaves a natural pocosin ecosystem as ET and 34% leaves as runoff, or groundwater losses, or is stored in the peat.

b. Ground water discharge (GWD)

The organic histosols of the North Carolina coastal plain are underlain by impervious subsurface layers of clay and sand. Ground water discharge rates representative of the region are very low and have been estimated to be approximately 0.5 inches per year (Heath 1975, Daniel 1981). Ground water losses are <1% of the annual water budget of pocosins and play an insignificant role in the annual water flux (See our section IIIF for groundwater information).

c. Runoff (RO)

An analysis (20 year simulation) of rainfall, ET, and runoff for a natural (mature) pocosin ecosystems is shown in Figure 8. Runoff is highest during the winter months and lowest during the summer months (<1 inch). A representative water profile (1955) shows that the water table remains near the surface 10-15 cm (4 to 6 inches) except during the summer months and during extreme dry periods (Figure 9). Water tables for the entire 20 years of the simulation are shown in Appendix D. Given the previous hydrologic values, runoff from natural pocosin areas can be calculated to be:

$$RO = P - ET - GWD$$

$$RO = 48 - 31.5 - 0.5$$

$$RO = 16 \text{ Inches/Year}$$

The annual variation in hydrology over a 20 year period shows that runoff varies

MONTHLY RAIN AND ET SIMULATIONS

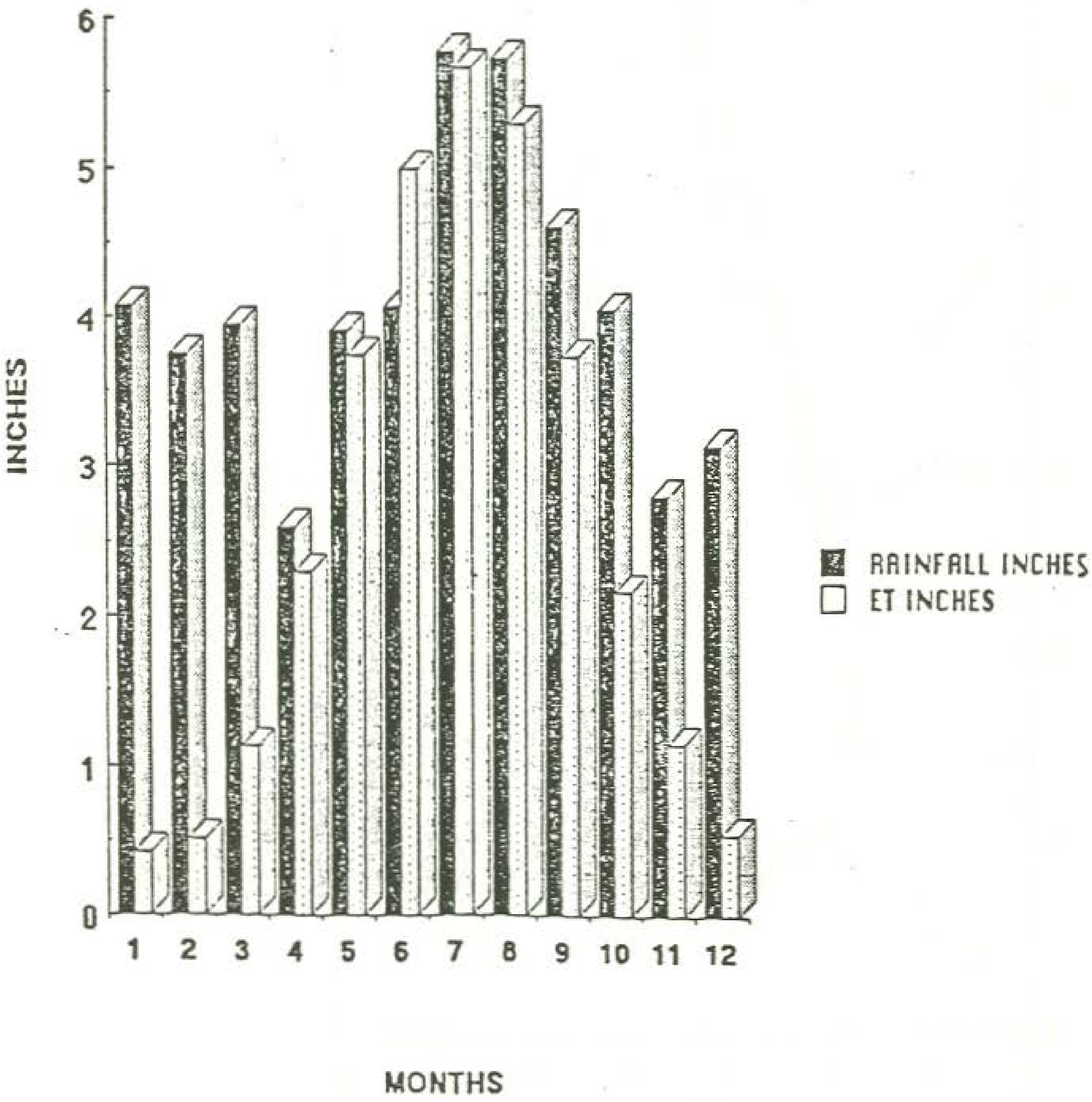


Figure 6. Monthly hydrologic conditions for mature natural vegetation site at White Tail Farm as simulated by DRAINMOD over a 20 year period.

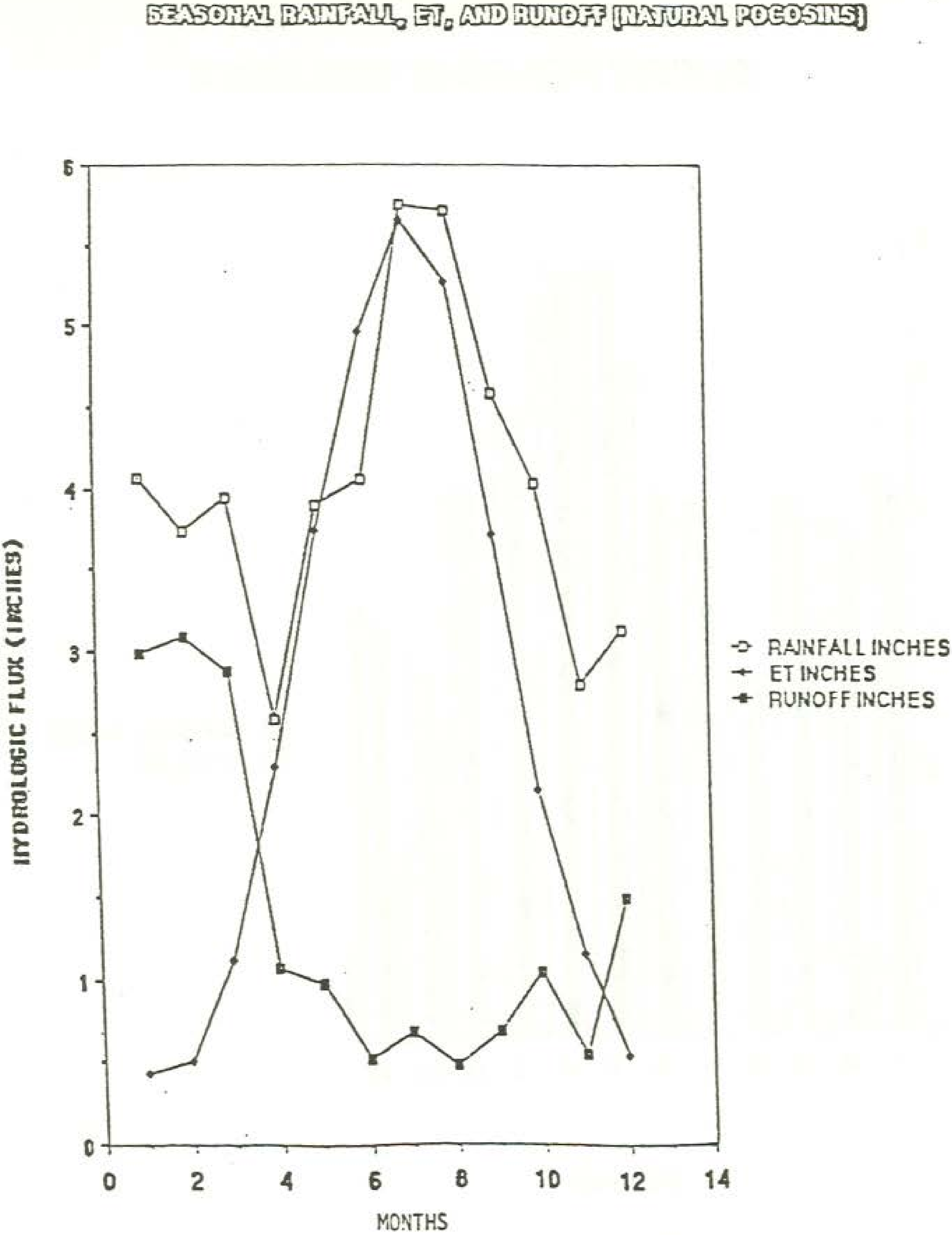


Figure 7. Seasonal rainfall. evapotraspiration (ET) and runoff from mature natural vegetation sites at White Tail Farm. Values represent monthly means from a 20 year simulation with DRAINMOD.

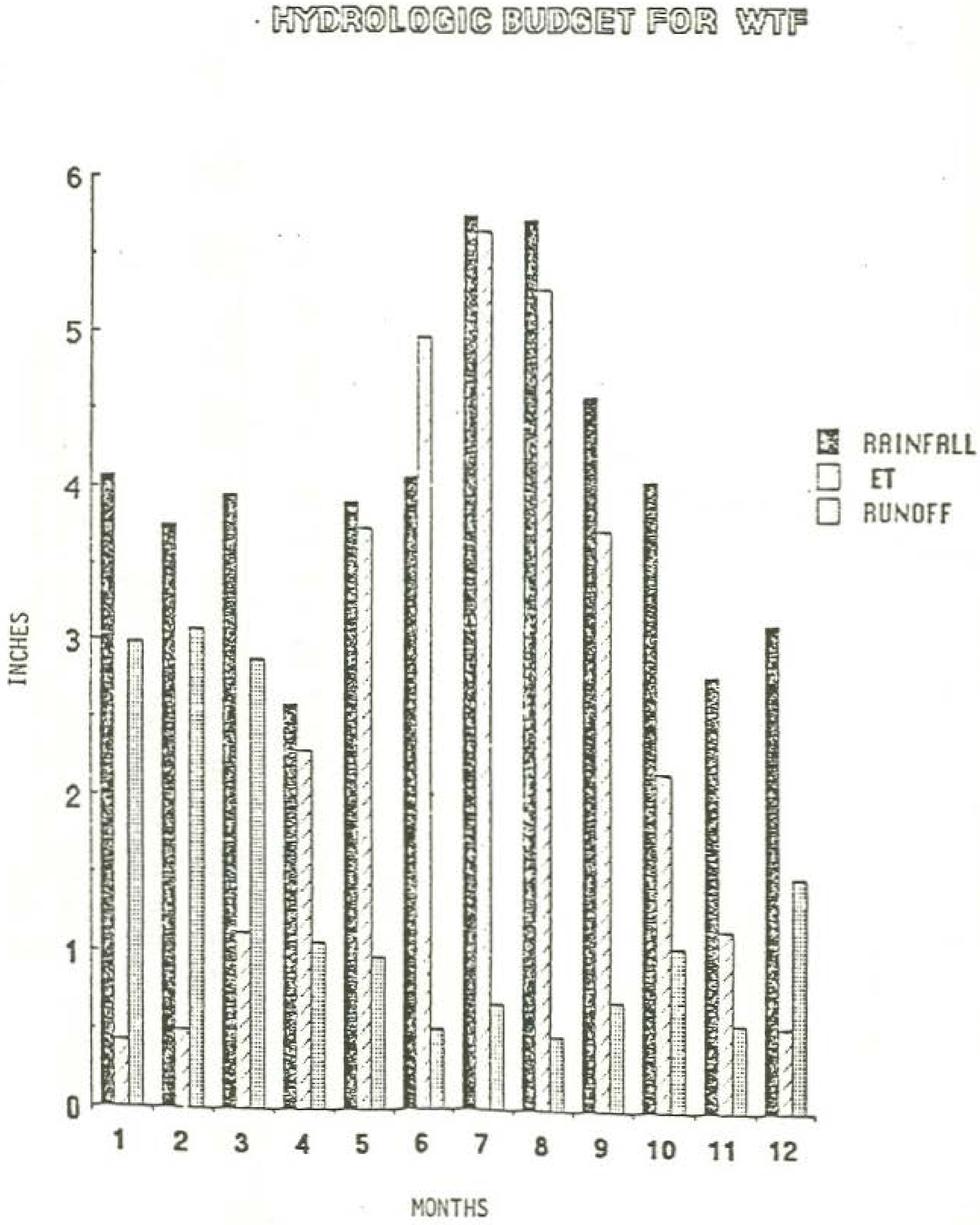


Figure 8. Monthly rainfall, ET, and runoff from natural sites at White Tail Farm. Mean values are from a 20 year DRAINMOD simulation.

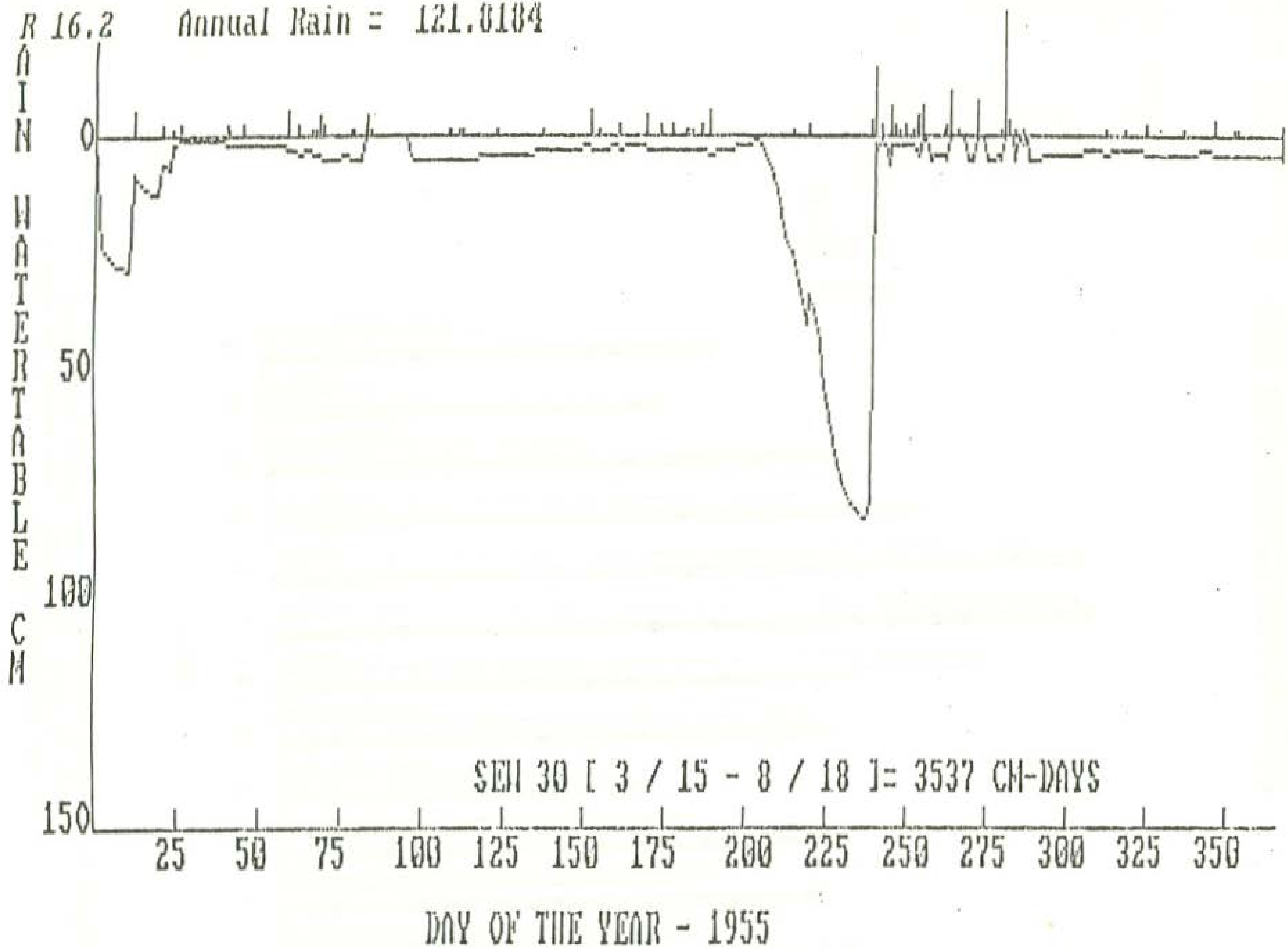


Figure 9. A DRAINMOD simulation of water table depth at WTF for a natural site with mature natural vegetation in 1955.

from mean conditions only during periods of extreme rainfall or drought (Figure 10). The annual runoff from a 1000 acre tract of natural WTF peatland can be calculated as follows:

$$\frac{16 \text{ in} \times 43{,}560 \text{ ft}^2 \times 1000 \times 7.48 \text{ gal/ft}^3}{12 \text{ in} \times 1{,}000{,}000} = 434 \text{ MGY}$$

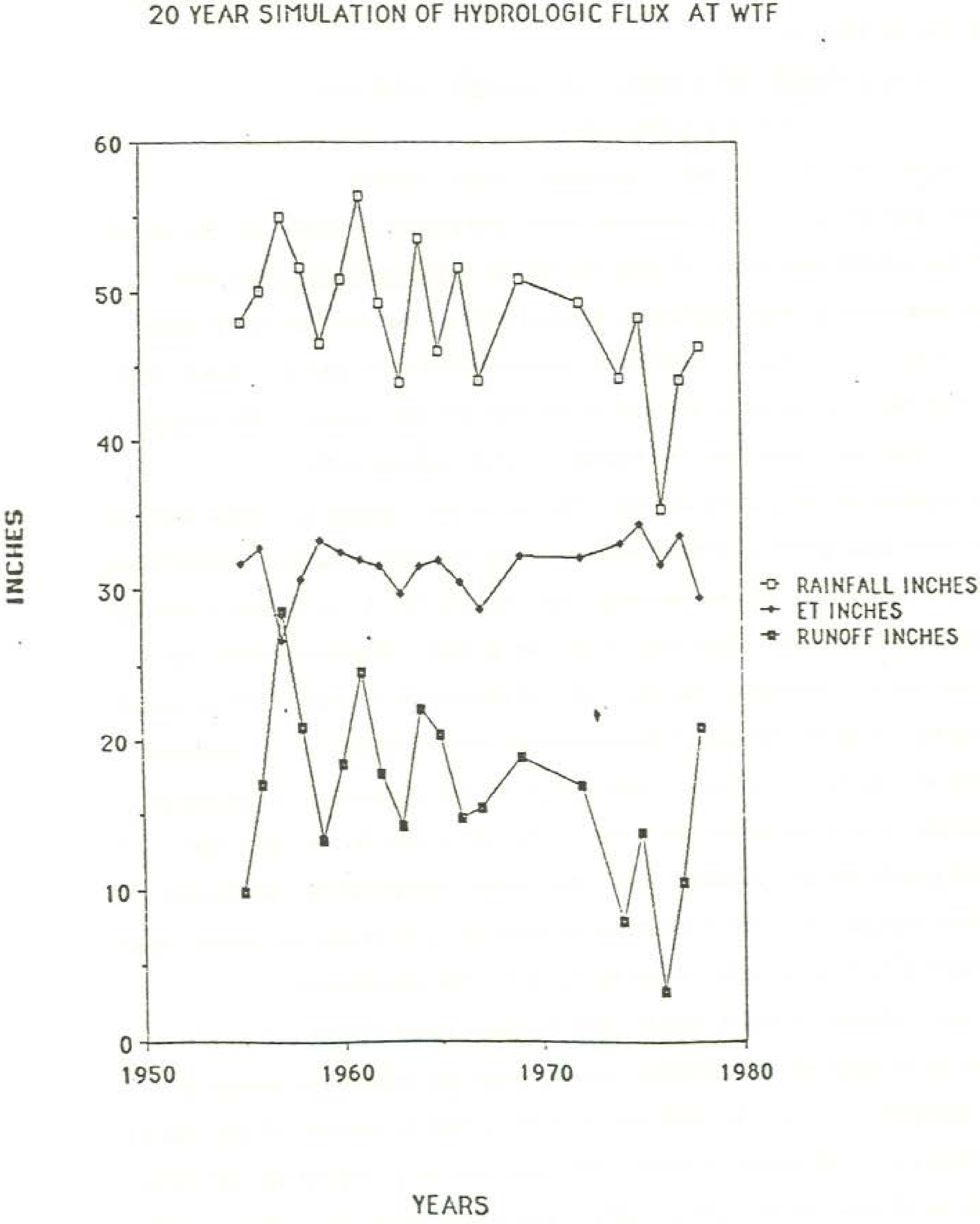
d. Disturbed and reclaimed conditions (Annual runoff)

Utilizing the previously described model (DRAINMOD) we simulated the annual runoff for a 1000 acre block of land at WTF for pre-mining disturbed (the present condition of WTF) peatlands, during mining, and forestry (both early years 1-3 and later growth conditions). Evapotranspiration was calculated from meteorological data as noted earlier in section IIE and annual runoff for the cypress filter pond area was determined as noted earlier (IIE).

The highest annual runoff was 657 MGY/1000 acres (Figure 11) which was the water output during the period of active mining. We simulated runoff conditions for one foot intervals of peat removal (i.e. removal of 1, 2, 3, and 4 feet of peat) during each mining phase over a 20 year period . Runoff averaged 24.7 $\pm$ 0.2 inches for all removals. The low standard deviation indicate that continued peat removal would not result in any increased runoff above initial measured increases at one foot of removal. This is due to the similarity in hydraulic conductivity conditions below the 1 foot level and a similar ET value for disturbed peatlands. Our proposed water management system (discussed later) would also reroute all water outputs in accordance with our stated project goals of reducing runoff to natural levels as noted in the introduction.

The next highest level of runoff, 508 MGY/1000 acres (Figure 11) is from land that is classified as disturbed (i.e. ditched and vegetation partly or totally removed). Currently, sections G, (962) acres) H (895 acres) part of I (1481 acres), J (1160 acres), K (970 acres) and part of E (418 acres) are in a disturbed or altered state. This totals nearly 6400 acres and current runoff

Figure 10. A 20 year DRAINMOD simulation of mean annual rainfall, evapotranspiration (ET), and runoff for a mature natural area at White Tail Farm.



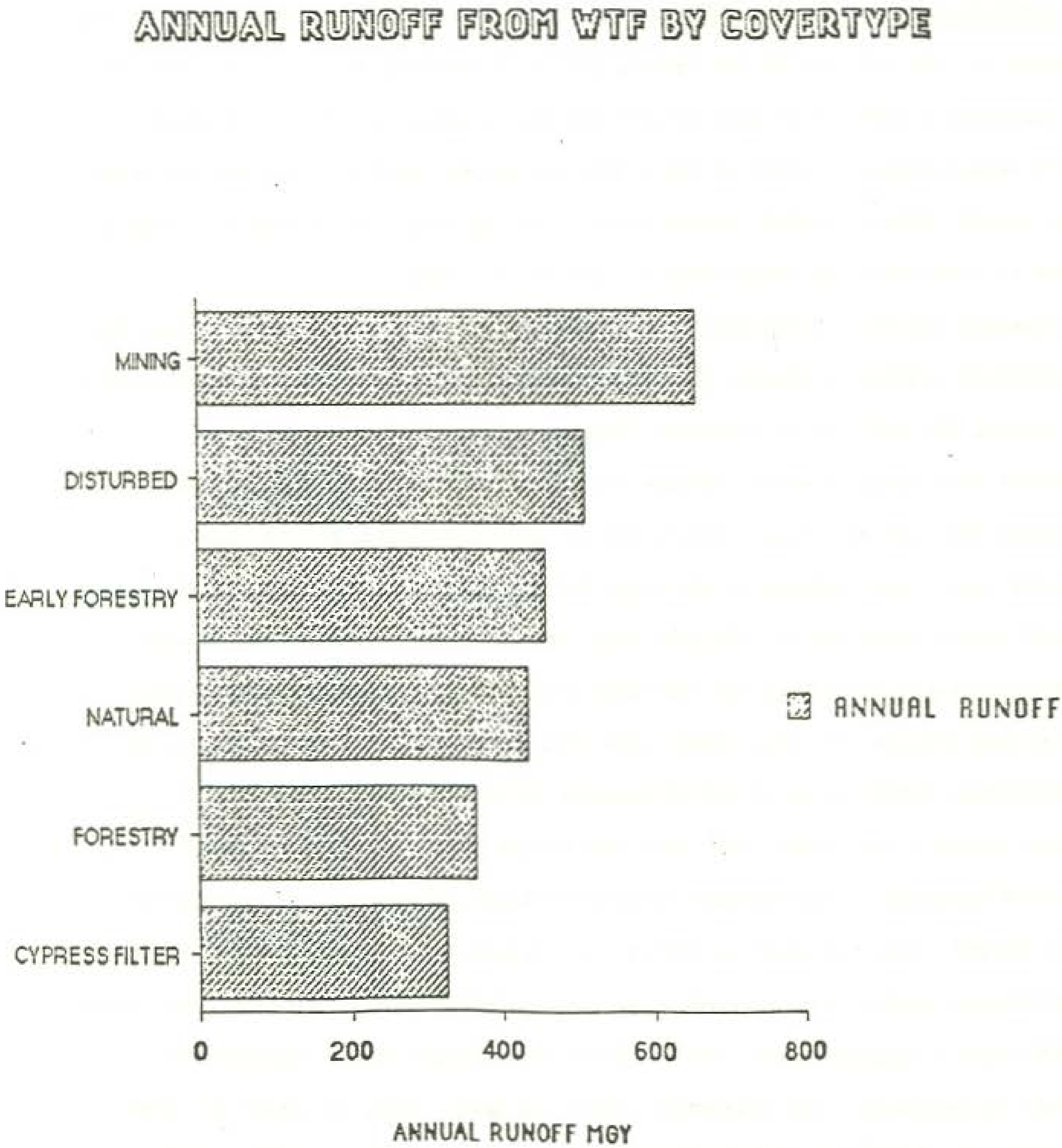


Figure 11. Annual runoff from a 1000 acre block of land at WTF for several land use types as simulated for a 20 year period via DRAINMOD. Note: runoff for the cypress filter was calculated by difference (see section IIF).

from this area alone would be 3,282 MGY.

Agriculture is no longer planned for any of the mined areas and thus was not included in this version of the report. It is interesting to note that most of the surrounding land is in agriculture and that a prior simulation of this runoff (wheat/soybean rotation) for a 20 year period resulted in a 489 MGY/1000 acres runoff. This exceeded natural levels and agricultural runoff is usually higher in nutrients and pesticides (Skaggs et al. 1980).

Forestry (silvicultural plantings of loblolly pine) runoff was analyzed for both initial conditions during the first 3 years of growth (low cover percentage and reduced ET) and during increased biomass and cover conditions (i.e. increased ET). Early forestry (Figure 11) runoff of 456 MGY/1000 acres was only 5% higher than natural runoff levels of 434 MGY/1000 acres, but by year 4 forestry runoff was reduced to 364 MGY/1000 acres. Thus, silvicultural plantings reduced runoff from WTF by 16% (per acre) compared to natural runoff levels.

Runoff levels were only 326 MGY/1000 acres for our constructed cypress filter area (Figure 11). This cover type will be constructed after mining on approximately 2,700 acres of WTF (discussed in detail later). The use of cypress serves 3 functions. One, this cover type will result in a 25% reduction in runoff compared to the natural conditions found in typical mature pocosin areas. Second, this reclamation effort will result in the development of 2,700 acres of high quality wetland type with high wildlife value. Finally, the water quality from a cypress stand will improve as a result of the significant removal of sediments, and nutrients (Ewel and Odum 1984). It should be noted that cypress wetlands have been sucessfully used in Florida to remove high nutrients levels from wastewater (Ewel and Odum 1984).

e. Monthly runoff comparisons by land use type

The hydrologic budgets for a 1000 acre tract of WTF under various land use conditions (natural, disturbed, mining, early forestry, more mature forestry, and cypress holding ponds) can be compared in terms of ET and runoff (Figure 12). The outputs are based on 20 years of simulations under measured weather conditions for the coastal plain and these values represent average predicted output values. The major point from these figures is that forestry and cypress pond conversions on WTF will result in a significant drop in runoff. This will be due to increased ET from holding ponds and forestry plantations. This information (Figure 12) was used in the water management plan along with storm data to develop holding pond capacity and pumping capacity requirements.

A comparison of monthly runoff levels for 1000 acre blocks of land from WTF for natural, during mining, and silviculture is shown in Figure 13. The highest runoff (> 3 inches/month) for all land use types occurred during the winter months and the lowest runoff (< 1 inch/month) was during the summer months. The highest runoff in the winter months was from the mining land. However, runoff from mining was only 0.5 inches per month above natural sites during this period. The lowest runoff (< 1 inch per month) for most of the year was in the silviculturally reclaimed areas. This suggests that the reclamation of mined areas with forestry would result in a significant reduction in total monthly and annual runoff. The next best land use type in terms of reduced runoff was the natural pocosin areas (Figure 11). The highest runoff during the summer months was from the mining sites where ET was significantly reduced. The relatively high runoff during mining requires that the excess water over natural conditions be managed via our water program. (See section IIIB).

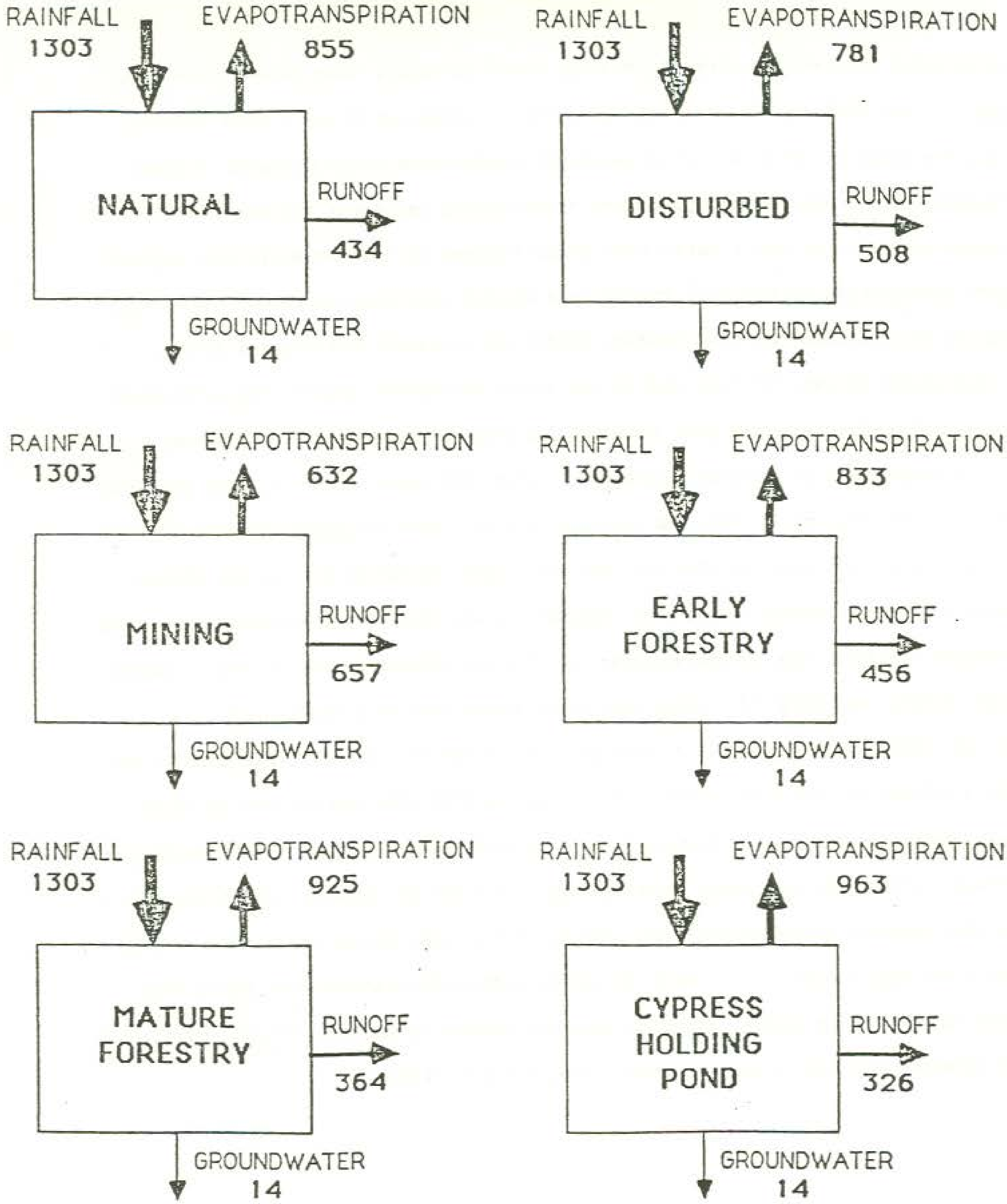


Figure 12. Hydrologic budget for 1000 acre tracts of WTF under various land-use types (million gallons/year (mgy)

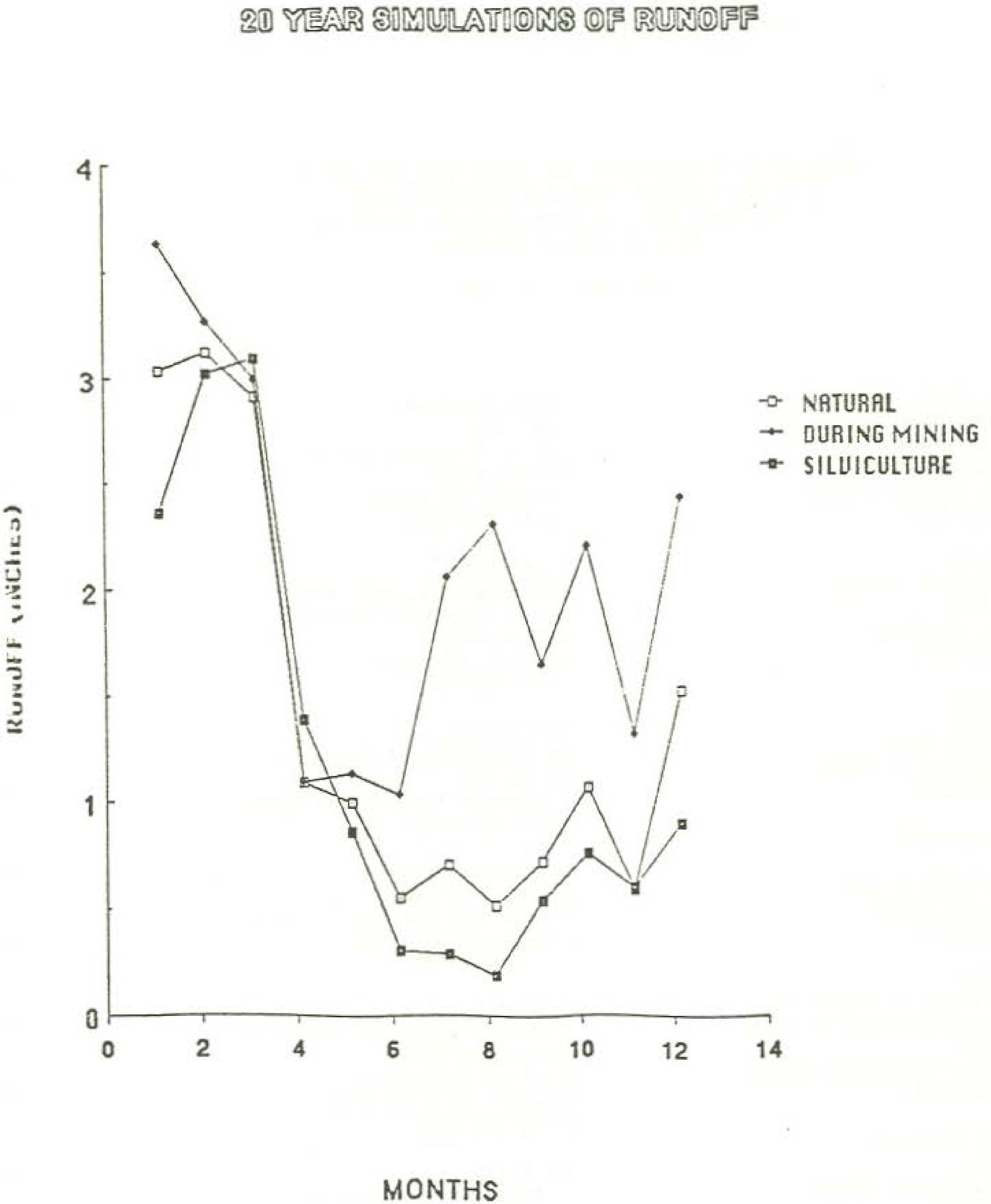


Figure 13. A monthly comparison of runoff values from a 1000 acre block at WTF. Data are from a 20 year simulation from DRAINMOD.

WORKSHOP ATTENDEES & PARTICIPANTS

WORKSHOP ON HYDRODYNAMIC AND WATER QUALITY MODELS
FOR THE ALBEMARLE-PAMLICO ESTUARINE STUDY
Ground Floor Hearing Room, Archdale Building
Raleigh, North Carolina

September 3-4, 1987

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