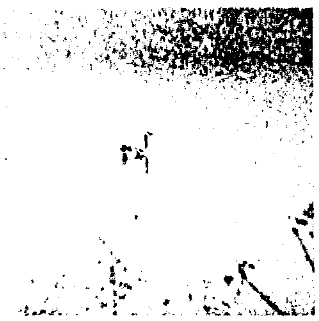

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WORK PLAN FOR THREE-DIMENSIONAL TIME-VARYING, HYDRODYNAMIC AND WATER QUALITY MODEL OF CHESAPEAKE BAY

by

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This report describes the Work Plan for development of a three-dimensional, time-varying, hydrodynamic and water quality model for Chesapeake Bay. The Chesapeake Bay Program is a cooperative effort between state and Federal agencies to restore the health and productivity of America's largest estuary. The report describes the technical work tasks, schedules, and study management. The developed hydrodynamic and water quality model will be an important component in the development of a strategy to address specific management issues.

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PREFACE

This report describes the Work Plan for development of a three-dimensional, time-varying, hydrodynamic and water quality model for Chesapeake Bay. The Work Plan was prepared in response to a request from the Chesapeake Bay Program Implementation Committee to the US Army Engineer District, Baltimore (NAB), and includes consensus recommendations of four scoping workshops described herein.

Funds for preparation and publication of this report were provided by the Headquarters, US Army Corps of Engineers, and the US Environmental Protection Agency (USEPA) through an Intra-Army Order for Reimbursable Services from the NAB.

The US Army Engineer Waterways Experiment Station (WES) gratefully acknowledges the direction and assistance of Messrs. Larry Lower and Robert Pace (NAB), Ms. Gale Mackiernan, formerly of NAB, and Mr. Charles App, USEPA.

The report was prepared under the general supervision of Mr. Donald L. Robey, Environmental Laboratory (EL). The report was prepared by Mr. Mark S. Dortch, Dr. Carl F. Cerco, and Mr. Robey, EL; Mr. H. Lee Butler, Coastal Engineering Research Center (CERC); and Dr. Billy H. Johnson, Hydraulics Laboratory (HL), WES. The Chief of EL was Dr. John Harrison, Chief of CERC was Dr. James R. Houston, and Chief of HL was Mr. Frank A. Herrmann.

COL Dwayne G. Lee, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

WORK PLAN FOR THREE-DIMENSIONAL, TIME-VARYING, HYDRODYNAMIC AND WATER QUALITY MODEL OF CHESAPEAKE BAY

PART I: INTRODUCTION

The Chesapeake Bay Program (CBP) is a unique cooperative effort between state and Federal agencies to restore the health and productivity of America's largest estuary. An important component is the development of a strategy to numerically model the hydrodynamic and water quality processes of Chesapeake Bay as a means of addressing specific management issues. This modeling effort complements other efforts, such as the long-term monitoring, data compilation and analysis, and planning, which support CBP activities.

The overall Chesapeake Bay modeling strategy consists of three phases. Phase I was the conversion and refinement of an existing Watershed Model for the Chesapeake Bay basin, and Phase II was the development of a steady-state (coarse grid) water quality model for the Bay. Phase III, development of a three-dimensional (3D) time-varying hydrodynamic and water quality model of the Chesapeake Bay, is described in the present document.

This document represents a detailed Work Plan (WP) for production of the 3D hydrodynamic/water quality model. It presents a brief background and chronology of the 3D modeling effort to date, and details technical work tasks, schedules, and supporting material for accomplishing the modeling effort. Model production and delivery will be the responsibility of the US Army Engineer District, Baltimore (NAB), using the expertise of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, as well as that of other agencies, research institutions, private contractors, and consultants.

The Administrator, US Environmental Protection Agency (USEPA) and Secretary of the Army signed a Memorandum of Understanding, dated 28 August 1987, committing the Department of the Army to develop the models described in this WP on a cost-shared basis. It is recognized because of the overall complexity of this study, revisions and subsequent course corrections may occur during conduct of this WP. Funds provided by the Corps of Engineers ($1.5 million) for the hydrodynamic portion of work cannot be exceeded in the conduct of the WP. Funds provided by the USEPA, $1.7 million, are for the conduct of water quality modeling and management scenario application as described in WP. Revisions to WP requiring additional funds and/or time will be negotiated with the CBP prior to commencing agreed upon work.

Background

Chesapeake Bay is one of the Nations's most valuable natural resources. It supports important commercial and recreational fisheries, transportation, industry, recreation, and tourism, and provides irreplaceable habitat for living marine resources and wildlife. However, the estuary has been subjected to increasing environmental stress in recent decades, and the productivity and beauty of the Chesapeake Bay have significantly declined. In 1983, the USEPA identified major contributing factors to the Bay's decline as inputs of nutrients and toxicants from point and nonpoint sources, changes in land use within the basin with resulting modification of the watershed and resource habitat, and concurrent impacts of natural events such as floods and droughts (USEPA 1983a, 1983b). Because population within the Bay drainage basin is still increasing, and development pressures will continue into the forseeable future, it is necessary that strategies are developed to reverse the present Bay decline and to accommodate future growth in an environmentally sound manner.

The CBP, established in 1983, provides a management structure through which the activities of state and Federal agencies, as well as that of private citizens, can be coordinated towards the goal of Bay restoration. A number of tools have been initiated by the CBP which will assist in the planning, implementation, and evaluation of these strategies. Among these are: a Bay-wide long-term monitoring program to determine water quality conditions and trends; a comprehensive Chesapeake Bay data base; and a series of numerical models to evaluate alternative control strategies and to guide the establishment of pollutant reduction goals. In June 1985, the CBP Implementation Committee approved a modeling strategy which called for phased development of these models. Phase I was the refinement, computer code conversion, and updating of the existing Chesapeake Bay Watershed Model which predicts the delivery of nutrients to the estuary from point and nonpoint sources above the fall line and nonpoint sources below the fall line. Additional refinements are presently being made to the Watershed Model. Phase II was the development of a steady-state (coarse grid) water quality model of the Bay to assess general response of the system to nutrients, and the relative importance of various processes. The third phase of the modeling strategy consists of a 3D, time-varying, hydrodynamic, and water quality model for the Bay and tributaries which can provide a detailed assessment of system's response to nutrient inputs and other parameters varied realistically over time and space.

The 3D model represents the means through which proposed management actions can be tested before implementation, allowing more cost-effective selection of appropriate strategies. In addition, the model will assist in development of quantitative pollution reduction goals or water quality standards for the Bay and tributaries. With proper initial planning, the model can also support future additions such as sediment transport and the fate of toxic materials.

The model will be used by the CBP to determine:

a. Relationship between nutrient loading and anoxia in Bay.

b. Critical nutrient(s) in control of eutrophication and anoxia.

c. Whether both point and nonpoint sources should be controlled.

d. The degree of control needed.

e. For greatest impact, where controls should be implemented first.

f. The length of time it will take for Bay water quality to improve once controls are implemented.

This level of analysis addresses management issues which are extremely costly, either financially or environmentally, and therefore requires the highest level of confidence in the technical tools. An example is the issue of need for nitrogen removal at sewage treatment plants. Additionally, such a model can address phenomena which are time-dependent, such as seasonally limiting nutrients, or frequency of occurrence of anoxic bottom waters. Finally, the 3D capabilities of the model will allow evaluation of issues which deal with localized or geographical (east-west) water quality events, such as evaluating the effects of controls applied to specific areas, or determining the changes in areal extent of anoxia under alternative control scenarios.

Objectives

The objective of the proposed work is to develop 3D, time-varying, hydrodynamic and water quality models for the Chesapeake Bay system. The purpose of this Chesapeake Bay Model Package (CBMP) is to address water quality management issues involving temporal and spatial variation. The CBMP will consist of a Hydrodynamic Model (HM), a Water Quality Model (WQM), linkage programs, and associated statistical and graphics software.

A HM will be used to drive a WQM; therefore, the two models must be compatible. The HM must be of sufficient temporal and spatial resolution to be able to simulate topographic effects and effects of time-varying forcings. The WQM must consider nutrient kinetics, oxygen dynamics and anoxia, point and nonpoint loadings, and sediment/water quality interactions at time scales compatible with transport processes determined by the HM.

The work proposed here deals primarily with construction, calibration, and verification of these models. Near the end of this effort, the CBMP will be applied to several management scenarios to demonstrate its utility. Following completion of this work, the model will be delivered to the CBP, and additional various CBP identified management scenarios will be tested by the WES. It is anticipated that a total of 25 scenarios will be evaluated with the model, subject to time and budget constraints.

The CBMP will provide a framework for including simulation of sediment transport and contaminant fate for future considerations. This WP calls for the initiation of work to develop sediment transport and contaminant fate capabilities during the latter part of the effort. Completion of full model development can be accomplished in a separate effort at a later date.

The general expectations of the 3D, time-varying, HM/WQM of Chesapeake Bay include:

a. Ability to simulate response of water quality and bottom sediment processes to point and nonpoint-source control actions.

b. Capability of short- and long-term simulations to adequately address management issues.

c. Determine effect of spring nonpoint source load.

d. Address lateral water quality variations.

e. Determine water quality response of area specific controls (sub-basin or zone).

f. Project overall response time of Bay.

g. Evaluate frequency of critical quality events.

h. Evaluate historical changes in anoxia.

PART II: FRAMEWORK

The Scope of Work (SOW) developed by the CBP was used as a basis for this WP. The approach outlined in this document uses the existing CBP structure and allows close coordination during model production. The CBP Modeling and Research Subcommittee (MARS) (Recently renamed as "Modeling Subcommittee") and its technical review panel, the Model Evaluation Group (MEG), will provide oversight on model development. The NAB, as a member of the MARS, will be responsible for delivery of the model within the agreed upon schedule, using technical WES resources, the resources of other agencies, research institutions, private contractors, and consultants.

General framework for model development is as follows:

a. The responsibility of defining the SOW for the 3D modeling effort was with the CBP. Specifically, this was accomplished by the MARS, advised by the MEG, and directed by the Implementation Committee.

b. This WP for the HM and WQM has been developed and approved within the above framework and provides the basis for the project described herein. Any revisions or modifications to the WP are subject to approval by the MARS.

c. The Corps of Engineers, as an active member of the CBP, has responsibility for delivering the completed 3D model to the CBP. Project coordination with the CBP will be accomplished by the NAB.

d. Overall development of models will be accomplished by the Corps of Engineers' Technical Modeling Team (TMT) at the WES. Coordination between the TMT and CBP will occur on a scheduled basis as outlined in Part V.

e. This WP will take advantage of the considerable technical expertise residing within the Bay community and will facilitate coordination of the Bay-wide modeling program with other ongoing, more regionally oriented modeling efforts. Selection of contractors and consultants will be coordinated with MARS.

f. A senior-level water quality contractor will be available throughout conduct of the study to make significant contributions on specific tasks and provide guidance and technical review on major decisions.

g. Four workshops were conducted to address specific issues and to identify the most recent information in areas important to successful conduct of the WP. Central topics for the four workshops included: selection of appropriate water quality state variables, layered sediment water quality modeling, HM/WQM interface, and long-term simulations. Results of these workshops, conducted November 1987-January 1988, have significantly influenced the technical approach described in Part III.

To ensure appropriate coordination and information exchange among CBP members and this work effort, monthly progress reports will be submitted to MARS for distribution to appropriate parties. Progress meetings between the TMT and CBP will be held on a quarterly basis. Details on these and other deliverables are included herein.

The approach described above will allow integration of appropriate expertise into model development and will facilitate involvement of concerned agencies throughout the modeling program. This should ensure that the work will be responsive to management, and resultant CBMP will address issues of concern to both decision-makers and technical staff. The involvement will help CBP members become knowledgeable about model algorithms, model assumptions and limitations, and model usage; therefore, they should be more confident in model results.

PART III: TECHNICAL APPROACH

To accomplish development of a 3D time-varying, HM/WQM of Chesapeake Bay, existing technology and models will be used to the fullest extent possible. Because of the scope of this effort, there are no completely "off the shelf" models and application approaches that will satisfy all of the requirements. The proposed approach is to use existing models; however, additional model development will be required to satisfy requirements of the original SOW and workshop recommendations.

The HM for the Chesapeake Bay and its tributaries will be based on the Coastal, Estuarine, and Lake Circulation Three-Dimensional model (CELC3D), an existing model available at the WES. This model was previously modified by the WES (using in-house research funds) to include boundary-fitted coordinates which allows more accurate simulation of the complex shoreline of Chesapeake Bay. This version is referred to as CH3D. CH3D will be linked to a water quality model based on a framework similar to USEPA's Water Analysis Simulation Program (WASP) (DiToro et al., 1983) and the completed steady-state (coarse grid) Bay water quality model, AESOP (HydroQual, 1987a). The WQM will include an interactive sediment/water quality component. Additionally, initial work is planned to establish a basis for later development of a toxics/contaminant model component. This would build on the interactive sediment/water quality work that will be a part of the WQM and upon improvements planned for the sediment transport code existent in CH3D.

The work on the AESOP model will be of great benefit in the development of the time-varying, 3D model. Much of the groundwork for reviewing data, selecting study years, compiling data, and filling data gaps has already been accomplished and will be valuable during the current effort. The AESOP model provided the following information:

a. Dissolved oxygen decline 1965-1985 was due to increased benthic oxygen demand and increased benthic nutrient fluxes.

b. Bottom sediments were the largest source of dissolved inorganic phosphorus and ammonia during 1984-1985.

c. Bay dissolved oxygen and algae are controlled largely by benthic oxygen demand and nutrient flux, and degree of vertical stratification.

d. Management strategies that decrease benthic oxygen demand and nutrient flux will result in significant improvements in Bay dissolved oxygen and algal levels.

This part of the WP describes the technical approach to be taken for the HM and WQM and interfacing of these models with each other and the Watershed Model. Approaches for initiating development of the sediment transport and contaminant fate models, conducting graphical and statistical analyses, scenario development, and conducting long-term simulations are included.

Hydrodynamic Model

Model selection

It has been acknowledged that water quality impacts in the Chesapeake Bay cannot be sucessfully assessed without an accurate description of hydrodynamic processes. The modeled processes should include at least the 3D flow circulation and the vertical turbulent mixing throughout the water column. Additionally, future modeling efforts may call for the capability to simulate entrainment and deposition of sediments at the bottom of the Bay. The 3D HM CH3D (with boundary-fitted coordinates) satisfies these requirements and will be used for hydrodynamic simulations in the Bay. This model was developed for WES by Sheng (1986).

Model description

CH3D is briefly described below. Sheng (1983, 1984, and 1986) provides detailed descriptions of the theoretical basis and computer program structure. The model solves the time-varying, 3D initial boundary value problem in which the governing equations are the continuity equation; the momentum equations; the conservation equations for salinity, temperature, and sediment concentration; and an equation of state.

The model allows several choices of the vertical turbulent eddy coefficients, including formulations derived from a complete second-order closure turbulent transport model with the assumption of the local equilibrium condition. The vertical turbulent diffusivity will be crucial to a successful simulation of stratification, destratification, and anoxia in the Bay. The boundary-fitted coordinates feature of the model provides enhancement to fit the deep navigation channel and irregular shoreline configuration of the Bay and permits adoption of an accurate and economical grid schematization. Sigma-stretching for the vertical grid is used to smoothly represent the bathymetry. A finite difference method using an alternating direction implicit scheme in the horizontal directions and a fully implicit scheme in the vertical direction is employed for numerical solution.

CH3D accepts hydrographical and meteorological forcings, such as freshwater inflow, tide, wind, and atmospheric pressure. Water temperature will be modeled by the HM. Model outputs are time-varying water elevation, 3D flow velocities, temperature, salinity, and water density. Freshwater flow discharges will be prescribed at the heads of each tributary. At the open Atlantic Ocean boundary, water surface elevation will be specified in terms of tidal elevation. Salinity will be prescribed during flood phase and an advection/dispersion condition for salinity will be employed during ebb phase. Appropriate Bay-area expertise will be consulted concerning the specification of salinity at the ocean boundary.

CH3D contains a sediment transport submodel which calculates sediment concentration in the water column and sediment entrainment and deposition at the bottom. However, the submodel does not include all desired mechanisms, sediment properties, and useful outputs. Code modification of the submodel is addressed in a later section on sediment transport modeling.

Grid resolution

To capture the important features of hydrodynamic processes and bathymetry in the Bay, grid resolution will be approximately 10 km longitudinal, 3 km lateral, and 3 m vertical. Major tributaries to be modeled are the James River, Potomac River, Patuxent River, York River, Rappahannock River, and Patapsco River (including Baltimore Harbor). Minor tributaries to be modeled are the Choptank River, Chester River, Back River, and Eastern Bay. The main Bay and the lower reaches of the major tributaries will be modeled fully 3D. Consideration will be given to using a 1D approach in the upper reach of all tributaries, and a laterally averaged 2D approach in the middle reach of the major tributaries and the lower reach of the minor tributaries. Other tributaries, such as the Nanticoke River, Wicomico River, Little Choptank River, Gunpowder River, Bush River, Magothy River, Severn River, Rhodes River, Piankatank River, Big Annemessex River, Bohemia River, Elk River, Great Wicomico River, Manokin River, Middle River, Miles River, Pocomoke River, Poquoson River, Tred Avon River, and Wye River and Mobjack Bay will be modeled as accurately as possible within resolution constraints. Most of these tributaries will probably be simulated as lateral inputs. To meet the horizontal resolution requirements, approximately 600 grid points will be needed. Ten variably spaced layers will meet vertical resolution requirements throughout the Bay, producing a total of approximately 6000 grid points. As is needed during model calibration or verification, mesh resolution may be increased to allow simulation of certain local phenomena.

Model calibration/verification

Various model sensitivity tests will be conducted with CH3D to address the significance of parameters and coefficients. These tests involve, but are not limited to, spatial/temporal resolution, wind response, initial and boundary condition representation, and turbulence formulation. A specific demonstration that the model conserves salt will be conducted on a simplified computational mesh of the main stem of the Bay. This mesh will have enough horizontal resolution (approximately 1000 grid points) to allow representation of all important bathymetry within the Bay and enough vertical resolution to simulate salinity intrusion.

A successful calibration/verification of the CH3D model requires sets of self-consistent field data. A preliminary study shows there are three data periods suitable for the model calibration/verification. They are: (1) the 1970 through 1974 data period compiled by Scheffner et al. (1981); (2) the July 1980 data period when USEPA sponsored a large field study; and (3) the 1981-1983 period when the National Ocean Survey circulatory study of the Bay was conducted. The 1970 through 1974 data have been used to verify the Chesapeake Bay Physical Model. The July 1980 data and summer 1983 data were used for model calibration/verification in the steady-state hydrodynamic studies (HydroQual, 1987a). Other data sources will be sought during the early phase of HM development. The September 1983 and spring 1983 data sets will be used during model calibration

Model calibration/verification against at least two sets of the aforementioned field data will be conducted using freshwater flows, tides, and winds measured during the periods of field data collection. Comparisons of time-varying water surface elevations, flow velocities, salinities, and dye concentrations (if available) from model calculations and field data will be made at multiple interior points throughout the main Bay and tributaries for the periods simulated. Sufficient data for model calibration/verification exist in major tributaries, e.g. the Potomac. In those tributaries where current and salinity data do not exist during the required time period, calibration and verification of the model will involve only water surface elevation and tidal currents which can be obtained from tide tables and tidal current tables. Because of a lack of synoptic data throughout the Bay and tributaries, initial calibration efforts may include a sectional approach. Sectional areas can be treated as submodels and calibrated to observed data. This process can reduce calibration costs but will not replace full grid calibration. Experience gained in calibrating the hydrodynamic model used for the completed steady-state modeling will greatly assist this portion of the study.

Minor code modifications and CH3D application to the Bay will require assistance from those knowledgeable of techniques and solution algorithms similar to that used in CH3D. Efforts for the HM will include appropriate consulting services as well as contract tasks for modifications that are needed in CH3D. These modifications allow (a) the number of vertical layers to be variable and (b) for the coupling of both 2D laterally averaged and 1D computations with the 3D computations. The changes are necessary for optimum storage and computational costs.

Production runs to support water quality simulations

The WQM will be driven by linked hydrodynamic data. It is anticipated that the WQM will be calibrated and verified to the 1984-1986 period. Therefore, hydrodynamic data for these years will be generated by the HM. Based upon discussions from the workshops, it is anticipated that long-term (up to 30 years) WQM runs will be driven by a sequence of hydrodynamic data generated for the 1984-1986 period representing wet, dry, and average year conditions, respectively.

Water Quality Model

Model variables

The workshop on selection of state variables indicated 19 state variables are necessary to model water quality in Chesapeake Bay. These are:

a. Diatoms

b. Cyanobacteria (including picoplankton)

c. Other phytoplankton

d. Dissolved organic phosphorus

e. Particulate labile organic phosphorus

f. Particulate refractory organic phosphorus

g. Dissolved inorganic phosphorus

h. Dissolved organic nitrogen

i. Particulate labile organic nitrogen

j. Particulate refractory organic nitrogen

k. Ammonium

l. Nitrate + nitrite

m. Available silica

n. Unavailable silica

o. Dissolved organic carbon

p. Particulate labile organic carbon

q. Particulate refractory organic carbon

r. Dissolved oxygen

s. Total zooplankton (to include preferential grazing)

The workshop recommended that multiple zooplankton groups and a bacteria variable should be considered for inclusion in the model. WES will incorporate these variables into the model code. After data availability and the results of sensitivity tests are considered, a decision will be made concerning the use of these variables in model calibrations.

Both the workshop on state variables and the workshop on sediment processes indicated release of reduced substances from sediments to overlying water may represent a significant oxygen demand. This demand must be incoporated into the existing state variables or else represented by an individual state variable. Sediment-released methane will be incorporated into the dissolved organic carbon pool. Sediment released sulfide will be represented by a new state variable, chemical oxygen demand. Addition of this state variable brings the total to 20:

t. Chemical oxygen demand (sulfide)

In addition to the above state variables, temperature, salinity, and inorganic suspended solids will also be included in the WQM, bringing the total number of state variables to 23. Particulate inorganic phosphorus will be computed via partitioning to suspended solids.

Spatial and temporal resolution

Space and time scales in the WQM will depend on the length of the period being simulated. The years 1984-1986 will be simulated on an intratidal time scale (e.g., 2 hr) with approximately 3,000 model segments. Longitudinal and lateral segmentation in the main Bay will largely be an overlay of segmentation in the HM. Hydrodynamic segments in the vertical may be combined into fewer water quality segments in shoal regions.

Longitudinal, lateral, or vertical combination of hydrodynamic segments into water quality segments may also be performed in the tributaries.

The long-term simulations will be conducted using a larger time scale, possibly an intertidal time scale (e.g., 12 hr), with coarser spatial resolution (e.g., approximately 1,500 segments). This coarser resolution is necessary to perform long-term simulations in a practical, cost-effective manner. The reduction in temporal and spatial resolution for the long-term model will be guided by experience with the finer scale model. A variety of tests will be performed to assure that transport and kinetic processes of the finer scale model are preserved in the coarser scale model.

Model formulation and testing

The WQM will be an integrated compartment (finite segment) model similar in formulation to the USEPA's WASP model and the steady-state Bay model, AESOP. The finite segment model framework will require substantial modifications for use in this study. Anticipated improvements include more accurate finite-difference formulations, more efficient use of computation time, and representation of the processes that affect the 23 state variables. In view of the significant effort required to modify WASP and/or AESOP, an early decision was made to rebuild the WQM with specific capabilities required for this study.

The state variables and processes proposed for use in the WQM are not all considered in models presently in use. Mathematical formulations to describe these state variables must be developed and incorporated into the model computer code. WES will formulate the appropriate equations in cooperation with an outside consultant. The overall project water quality contractor will review the equations to ensure they are appropriate and correct.

The WQM will be subjected to testing at several stages in its development. The model must conserve mass, be numerically stable, and minimize numerical dispersion. Tests will initially be conducted on a idealized system of limited extent and simplified geometry. Mass conservation will be examined for each state variable. Stability and numerical dispersion will be examined by comparing predicted transport of a conservative substance with analytical solutions of the advection-diffusion equation. A second series of tests will be conducted using the model representation of the Bay. Again, mass conservation will be examined. Since analytical solutions are not available for complex geometries, stability and numerical dispersion will be examined by comparing transport of conservative substances in the HM and the WQM.

Calibration and verification

It is anticipated that the primary data base for calibration and verification is the monitoring data collected by the CBP during years 1984, 1985, and 1986. The use of 1987 monitoring data for model calibration will be considered following a review of all data. If 1987 is selected for calibration purposes, it will replace either 1984, 1985, or 1986. Two types of calibration and verification are possible. The first is a comparison of predicted and observed state variables. The second is a comparison of predicted and observed processes. Comparisons of the first type are most common in modeling studies. Comparisons of the second type are less common, primarily because observations of processes are seldom available.

Observations of processes such as primary production, bacterial respiration, and particulate settling are available for some areas of the Bay. When the data permit, the WQM will be calibrated against both observations of state variables and processes.

Calibration and verification of 23 state variables throughout the Chesapeake Bay system for a 3-year period is a formidable task. Calibration and verification will be conducted in a series of steps. In each step, the number of variables, temporal extent, or spatial extent of predictions will be expanded. First, salinity, temperature, and inorganic solids will be modeled in a major tributary for one season. Next, the full suite of state variables will be modeled. When satisfactory model performance is obtained for one season, a full year will be modeled.

Following application of the model to one tributary, a second tributary will be modeled. Again a sequence of extending the number of variables and temporal extent of the model will be followed. Once the model is calibrated for several tributaries, the model will be expanded to the entire Bay system for a season and for a year. Additional calibration will be conducted using observations collected in a second year.

Verification is commonly regarded as testing model predictions against observations not employed in the calibration procedure. In this study, verification will be conducted in a simulation of the 3-year period (1984-1986). Two of the years will be used for calibration. If the agreement between predictions and observations in the third year is consistent with agreement for the first 2 years, the model will be considered verified. If agreement of predictions and observations in the third year is deficient, additional calibration will be conducted.

Parameter values

Prediction of previously listed state variables requires specification of the values of parameters in the mass balance equations that govern each variable. The parameters to be evaluated may number in the hundreds. Determination of parameter values through a trial-and-error calibration procedure will be a lengthy task. The possibility exists that different sets of parameter values will provide similar predictions. Specification of an appropriate and unique set of parameters requires minimum use of trial and error evaluation. Parameter values must be based on measurements whenever possible. A wealth of knowledge upon which to base parameter values exists for Chesapeake Bay, but not all of it is readily available. Cooperation of Bay-area scientists in providing published and unpublished observations is critical to the specification of model parameters and overall study success.

Sediment submodel

Inclusion of an interactive sediment component is essential to the success of the modeling effort. The workshop on sediment modeling identified three processes that must be represented in the sediment submodel:

a. Net deposition of organic matter

b. Diagenesis of organic matter

c. Flux across the sediment-water interface

All data necessary to model these processes are not available. The workshop on sediment modeling recommended a sediment data monitoring plan be developed by the CBP to provide all required information for model development and application. This has been accomplished by the CBP and will be implemented during 1988.

Initial development and testing of the sediment model will use the existing steady-state Bay model run in a time variable mode. An attempt will be made to predict net deposition with the WQM. The predicted rates and locations of particle deposition will be compared to deposition rates estimated from sediment cores collected in the Bay. Predicted deposition will be brought into agreement with observations through adjustment of settling velocity or a similar parameter. In the event that deposition cannot be represented by specification of settling rates, empirical transport velocities will be used in a bottom transport layer to move particles into regions of net deposition.

Diagenesis is the process by which organic matter in the sediments is converted to mineral form. Diagenesis will likely be represented as first-order decay of labile and refractory forms of organic matter (DiToro, 1986; HydroQual, 1987b).

Prediction of sediment-water flux is the most problematical portion of the sediment model. First, flux prediction requires predictions of deposition and diagenesis. Second, flux prediction requires quantification of the influence on flux of conditions in the water column and sediments. At least, fluxes of the following substances must be predicted for the WQM to be successfully calibrated:

a. Dissolved oxygen

b. Ammonium

c. Nitrate

d. Dissolved inorganic phosphorus

e. Silica

f. Methane

g. Sulfide

Fluxes of dissolved oxygen, ammonium, nitrate, methane, and sulfide can be related to the rate of diagenesis. A less mechanistic, more empirical approach may be required to model fluxes of phosphate and silica.

Presentation of results

Both qualitative and quantitative comparisons of model predictions and observations will be presented. Four types of qualitative comparisons are anticipated: (1) graphs of predictions and observations along the three major axes of the Bay, (2) graphs of the temporal behavior of predictions and observations at specified locations in the Bay, (3) scatterplots of predictions and observations and/or their deviations from each other, and (4) contour plots of deviations in predicted and observed data.

A wide variety of quantitative comparisons are available. Comparisons in this study will be selected to promote ease of interpretation. Most likely, comparisons are mean difference between predictions and observations, and root-mean-square difference between predictions and observations. These basic statistics can be applied to predictions grouped in numerous fashions (e.g., by station, by season, or by basin). The use of statistics in model calibration, verification, and application is discussed further in the section on statistics.

Model Interfacing

Because a different modeling framework will be used for the HM and WQM, proper interfacing of these models is very important and, thus, deserves special attention. Interfacing of the Watershed Model with these two models is also discussed in this section.

Hydrodynamic and water quality models interfacing

In most regions, the WQM will use the same grid resolution as the HM. There will be regions where the WQM will not require the same resolution used by the HM. For example, in the upstream reaches of the tributaries, the WQM grid may overlay multiple layers and/or lateral segments of the HM grid to reduce unnecessary computational expense while preserving required resolution. When more than one HM cell is overlain by a WQM segment, the flows for those cells will be combined in a manner to provide a single flow for each face of the WQM segment. Dispersion caused by spatial averaging will be examined and included, if necessary, in the WQM dispersion coefficient.

One interfacing task involves assigning WQM segments to HM cells such that all segments are properly connected. This type of task has previously been performed by WES and others and presents no technical difficulty. WES also has averaged output (averaged over time and space) from several different hydrodynamic codes and coupled it with the WASP code. In fact, flows from CH3D have recently been coupled successfully with WASP. Coupling requires that cell volumes, flows among cells, distances between cells, and the eddy diffusivities be output by CH3D to drive the WQM.

The WQM will use time steps larger than the HM. The fundamental interfacing problem consists of processing the hydrodynamic output so that advection and diffusion are accurately depicted in the WQM. Since the WQM will be run with two different time scales, two processing problems exist. The first is processing the hydrodynamic output, produced at approximately 0.25-hr intervals, into water quality input at about 2-hr intervals. Second is processing the hydrodynamic output into water quality input at approximately half-day intervals.

Since the 0.25-hr and 2-hr time steps are both intratidal, arithmetic averaging, over the WQM time step, of the flows and diffusion output by the HM will likely suffice for the intratidal simulations. Arithmetic averaging of intratidal hydrodynamic output into intertidal water quality input will not be successful, however. Arithmetic averaging of advective flows over a tidal cycle produces the Eulerian residual advection which can be much less than the net (Lagrangian) advection of a particle over the same period. The first order approximation for the difference between Eulerian and Lagrangian advection is "Stoke's drift" (Hamrick, 1987; Feng et al., 1986), a quantity that (in theory) can be calculated. Intertidal flows input to the WQM will be calculated by computing Stoke's drift and adding it to the Eulerian residual currents output by the HM. Presently, no principle analogous to Stoke's drift exists for combining intratidal diffusion into intertidal diffusion. Initially, intertidal diffusion will be computed as the average of intratidal diffusion.

Testing of the HM/WQM interfacing is required to ensure that transport predicted by the HM is maintained in the WQM. Tests will consist of comparisons of the transport of a conservative substance (salt or dye) in both. Tests will be performed for three time scales:

a. Comparison of transport with both models operating at the HM time scale.

b. Comparison of transport with both models operating at intratidal but different time scales (i.e., HM at 0.25 hr, WQM at 2 hr).

c. Comparison of transport with HM operating at an intratidal time scale and WQM operating at an intertidal time scale.

Initially, these tests will be conducted on a simplified grid under dynamic steady-state conditions. Next, the time scale tests will be performed on the fine Bay grid for varying conditions, such as the fall overturn period, September-October 1983.

The coarser spatial scale of the long-term intertidal model will also be tested to insure that the finer scale transport is preserved. If transport characteristics are lost during spatial averaging, then finer resolution will be retained. Mass conservation tests for the WQM also will be performed for each condition.

The possibility exists that the temporal averaging procedures described above will not succeed. Both theory and practice indicate computation of Stoke's drift near boundaries will be problematical. Arithmetic averaging of diffusion may not yield reasonable results. Several alternative methods exist and will be attempted if necessary. These include "flux averaging," or other procedures that directly compute a tidal dispersion coefficient, and smoothing or nonarithmetic averaging of HM diffusion.

The WQM solution for advection has recently been modified to reduce numerical diffusion. This was accomplished by incorporating a third order accurate advection differencing scheme referred to as QUICKEST (Leonard et al., 1978; Leonard, 1979). This scheme was selected because it possesses good phase and amplitude characteristics and is mass conservative (Hall and Chapman, 1982 and 1985). This improvement to the WQM transport will allow the effects of flows and diffusivities computed by the HM to be more properly realized in the WQM.

Watershed model interfacing

The WQM requires input loads at the fall-lines and overland runoff below the fall-lines of:

a. Dissolved oxygen

b. Nitrogen

c. Phosphorus

d. Silica

e. Organic carbon

f. Suspended solids

The spatial and temporal detail with which fall-line and overland loads are input to the model will be commensurate with spatial and temporal scales of water quality processes in the Bay and with spatial and temporal resolution of water quality observations. Overland runoff into each tributary will be distributed uniformly along the reach from the fall-line to the junction with the Bay. Overland runoff directly into the Bay will be partitioned into "eastern shore" and "western shore" and distributed uniformly from north to south. Fall-line inputs and overland runoff will be input to the WQM on a monthly basis for long-term simulations, and a biweekly or monthly basis for 1984-1986 simulations. Decisions concerning the frequency of model updates will be based on careful examination of observed data.

The data needed by the model and the way it will be used have been described. How will the data be obtained? For 1984-1986, fall-line observations are available. Gaps in the data can be filled by interpolation between the observations. Overland runoff can be specified as a fraction of fall-line loading. Prior to 1984, fall-line observations are scarce. Some sort of model is required to compute fall-line and overland loads. The existing watershed model is the obvious (but not the only) choice. Regression models of load versus flow can also be developed. The advantage of the Watershed Model is that it accounts for changes in land use. Regression models calibrated to 1984-1986 observations cannot account for alterations in land use.

The first step in deciding the employment of the Watershed Model is to assess its accuracy. Assessment will be performed by comparing predictions for 1984-1986 with fall-line observations. Predictions of daily runoff are required for this comparison. If agreement is satisfactory, the Watershed Model can be used to fill gaps in the 1984-1986 fall-line record and to predict overland runoff for that period. Additionally, the Watershed Model can confidently be employed to generate fall-line and overland runoff for prior years. If agreement between predictions and observations is unsatisfactory, interpolation or regression will be used to fill the 1984-1986 gaps. A decision will be required whether to use the Watershed Model or alternate methods to generate loads for long-term simulations.

The Watershed Model cannot predict all constituents required by the WQM. For those constituents not predicted by the Watershed Model, other techniques such as regression approaches will be used.

The CBP will be responsible for delivering output from the Watershed Model that is needed for the WQM. The data requirements, format, and details for data transfer will be agreed upon by the CBP and WES during the early stages of the study.

Long-Term Simulations

Two objectives of this study are simulation of water quality over the past 30 years and projection of water quality 30 years into the future. It could take years (or even decades) for water quality conditions to improve as a result of control strategies. Therefore, multidecade simulations may be required to adequately test control alternatives. Application of the model over the past 30 years is necessary to test the ability of the model to capture historical water quality trends and to better understand the reasons for the decline of Bay water quality.

Ideally, the past 30 years would be simulated using hydrodynamics produced by a 30-year record of tides, winds, and flows. Funding does not permit this approach. Neither is a 30-year hydrodynamic run absolutely necessary. Central importance lies not in the hydrodynamics but in the influence of hydrodynamics on water quality. The possibility exists that repetitive use of hydrodynamics from an average hydrologic year would result in the same trend in water quality as employment of a 30-year hydrodynamic record.

A compromise was recommended by the workshop on long-term simulations. Each of the past 30 years will be classified as "wet," "dry," or "average" and hydrodynamics appropriate to the hydrologic designation will be employed for that year. The hydrodynamics will be the same as used for 1984, 1985, and 1986, which were wet, dry, and average, respectively. Point-source and nonpoint-source inputs to the WQM will reflect as accurately as possible the inputs for each month of the past 30 years.

At least the hydrologic record for the past 30 years exists. How can hydrology be projected into the future? The "best-case" scenario is that hydrodynamics and water quality are not closely coupled so that average-year hydrodynamics can be employed for water quality projections. A test of this scenario is planned. Before water quality projections are performed, the model will have been calibrated and verified for the years 1984-1986. A WQM run will be performed using 1984-1986 inputs but average-year (1986) hydrodynamics only. If predicted water quality at the end of the 3-year simulation based on 1986 hydrodynamics resembles water quality predicted with 1984-1986 hydrodynamics, then evidence exists that multi-year water quality is not strongly dependent on hydrodyanmics. In this event, average-year hydrodynamics will be used for water quality projections. If the two, 3-year simulations yield significantly different results, an alternate approach to projections of the future is required. One possibility is the use of statistics to project the sequence of wet, dry, and average years expected in the next three decades.

The long-term simulation workshop participants recommended that a parallel approach be used to test the initial sediment submodel. The submodel will be developed and tested in the existing CBP steady-state model run in time-varying mode. Additional state variables beyond those in present version will not be included. This will provide initial test of the submodel and also an estimate of "sediment memory." It is possible that the sediment memory is on the order of years to a decade rather than multiple decades.

Modeling Scenarios

The SOW specifies that the proposal include 25 scenarios which can be evaluated with the calibrated and verified model. These scenarios would represent potential management alternatives, or comparisons of conditions under varying combinations of point and nonpoint source loads. The specifific details of the scenarios would be agreed upon at a later date by the CBP and the WES.

Five demonstration scenarios will be accomplished within the 36-month model development and testing period to demonstrate model utility to the CBP. The five demonstration scenarios will be selected by the TMT in consultation with MARS and MEG. It is felt that this number of initial scenarios will provide appropriate demonstration of the model, while allowing adequate time for model runs as well as interpretation and presentation of results. Additional scenarios will be addressed following the 36-month model development period with a completion date of March 1991. The selection of all scenarios must consider available funding and time constraints.

Graphical Output

Several pre- and postprocessing utilities previously developed at WES (such as those in the TABS system) (Thomas and McAnally, 1985), as well as commercially available software, will be used to present model output. Plots of predicted and observed values and their deviations will allow direct visual comparison of model accuracy. Output utilities permit plotting of velocity vector fields at selected model timesteps showing flow direction and magnitude. Contours of water surface elevations, velocity magnitudes, salinities, and water quality concentrations at selected model timesteps can be produced. Utilities can also produce shaded color contour plots. Time series plots of selected variables at specified grid points can be displayed. Various combinations of spatial and temporal dimensionality can be selected to display desired results. All plots can be produced on hard copy and on black and white or color film. It may be desirable to generate video of selected model results for presentation to management decision-makers.

Statistical Analyses

Statistical tests and comparisons will provide a rapid and efficient means of evaluating HM and WQM results. Such evaluations will be used during model calibration to aid in selecting coefficients, during model verification to measure model accuracy, and during scenario evaluation to help quantify the degree of effectiveness of various alternatives.

The statistical packages used at WES in the past include predicted and measured means, mean error and root mean square error of predicted and observed data, a Reliability Index (Leggett and Williams, 1981), paired T-test for means (Sokal and Rohlf, 1969), normalized mean error (Gordon 1981, see also Wlosinski, 1982), and coefficients for the linear equation for plotting observed and predicted values (Thomann, 1980). The WASP package also includes a Model Verification Program (MVP) to aid in the statistical analysis of model predictions and observed data. Other statistical approaches may also be identified and used during the study.

Sediment Transport Modeling

Sediments in the Bay are primarily cohesive and comprised of colloidal clay particles, fine silt, and a certain amount of organic materials including bacteria, detritus, benthos, and their fecal materials. Transport of sediments in the Bay is generally affected by a variety of mechanisms and properties. These include: the transport modes, including advection, turbulent mixing, and gravitational settling; the entrainment and deposition modes governing exchange between the suspended and bottom sediments; the properties of sediments including flocculation and particle-size distribution; and the physicochemical properties of the water, including salinity.

Comprehensive sediment transport modeling in the Bay is a challenge to investigators, particularly in modeling turbulent mixing, the flocculation process and particle-size distribution, entrainment and deposition at the Bay bottom with and without a vegetation bed, and the bed loads. The modeling also will be complicated in some ways by the transformation, production, and decay of water quality constituents. CH3D presently contains a sediment transport sub-model. However, the sub-model does not include all the mechanisms, sediment properties, and output forms useful for contaminants. Since time and funding resources are limited, the effort on sediment transport modeling will be concentrated only on additional code development and lay a framework for future sediment transport studies. Consideration will also be given to the extension and modification of existing sediment algorithms.

Contaminant Modeling

Contaminant models can generally be characterized as those intended for trace metals and those for trace organics. Although some models have been described as "generalized," the processes affecting these two groups are sufficiently different to require either extensive modification of a single model or the use of two separate models.

Toxic materials are often strongly associated with particles, and particle transport mechanisms may markedly affect a contaminant's fate. Contaminant modeling of the Bay logically follows development of a sediment transport model. The requirements for the contaminant model, in terms of sediment particle-size classes, must be a consideration in sediment transport modeling.

Models of trace organics are available which utilize the same finite segment model transport framework proposed herein, such as TOXIWASP or WASTOX. The prior application of a WQM based upon finite segment model framework would greatly facilitate the application of TOXIWASP or WASTOX. The TOXIcant Water Analysis Simulation Program (Ambrose et al., 1983) was developed by the USEPA by modifying, and in some cases simplifying, the kinetic structure from the EXAMS model and coupling these modifications to the transport framework of the WASP. A second version of the model called WASTOX was developed by HydroQual with participation of the group responsible for WASP (Connolly, 1982). TOXIWASP and WASTOX allow simulation of more dynamic transport and loading than the EXAMS model. They are suited to stratified lakes and reservoirs, large rivers, estuaries, and coastal waters.

Differences in speciation and sorption chemistry between metals and trace organics may preclude their being treated by the same contaminant model. Speciation of metals is usually determined by multiligand, multimetal equilibrium models, such as REDEQL2 (McDuff and Morel, 1973), WATEQ (Truesdell and Jones, 1974), MINEQL (Westall et al., 1976), GEOCHEM (Sposito and Mattigod, 1979), and NONEQUI (Fontaine, 1984). These models generally describe species distributions given concentrations of metals and ligands based on thermodynamic constants. They are generally equilibrium models and do not allow for simulation of kinetics or transport, with the exception of NONEQUI. These models may be of utility in estimation of steady-state distributions of trace metals.

The MEXAMS model is also a potential candidate for application to the Bay. This model (Felmy et al., 1984) was developed by USEPA by coupling MINTEQ, a geochemical model, to EXAMS, an aquatic exposure assessment model. It is a steady-state model that includes speciation effects on the adsorption and precipitation of metals assuming equilibrium conditions.

The development and application of a contaminant model to the Bay is beyond the scope of the present study. However, efforts are planned which will facilitate any future contaminant model development and application. These efforts involve three parts: review and selection of the appropriate model framework and basic approach; identify available data for model testing/evaluation/application; and identify and select most appropriate models/algorithms.

A contaminant modeling framework will be recommended that is compatible with the Chesapeake Bay WQM. Available data will be identified, compiled, and evaluated to determine if they are sufficient to support a contaminant modeling study. Appropriate model algorithms will be identified, selected, and implemented to the extent possible within time and funding constraints. It is emphasized that this is the initial step toward the development of a contaminant model for the Bay. Substantial work beyond this effort will be required to complete the model. A report will be prepared to document the contaminant model framework, recommendations/developments, and data review.

PART IV: TASKS, MILESTONES, SCHEDULES, AND PRODUCTS

The total cost of the efforts outlined in this WP will be approximately $3.2 million. This cost includes model development and application to evaluate the various agreed upon control scenarios. The cost also includes all technical manpower, administration, overhead, contracts, computer costs, travel, report preparation, documentation, management, and coordination throughout the study. It includes appropriate linkage with the Watershed Model. It does not include any costs for additional monitoring, field or laboratory investigations, or Watershed Model simulations, although these will be recommended to CBP if deemed necessary. Funds are included to initiate very preliminary work on sediment transport and contaminant model components, to ensure an appropriate framework for future toxics/contaminant modeling of the Bay.

The schedule for model production, and final delivery of the calibrated and verified CBMP is September 1990. Appendix A contains a description of HM and WQM tasks, milestones, schedules, and products (i.e., deliverables). It should be realized that due to the importance and complexity of this study, initial tasks will involve considerable organization and more detailed scoping. The four workshops, previously described, were the focal point for detailed scoping.

Monthly progress reports will be provided to MARS, with WES technical presentations and written material provided quarterly to combined MARS/MEG meeting. It is anticipated that Bay scientists and engineers will attend the quarterly MARS/MEG meetings. This will provide additional in progress review of interim study results.

Formal training sessions at a selected CBP site will be conducted after each component (i.e., HM and WQM) is installed on the CBP computer system. For the HM, training will take place in February 1990; for the WQM, training will be conducted in January 1991. The user's manuals will have been delivered prior to the training courses.

PART V: COORDINATION

Coordination with Chesapeake Bay Program

The MARS represent the point of contact for coordination between CBP and the Corps of Engineers. MARS and MEG will maintain oversight on progress of the model production, and will conduct periodic review of progress and deliverables. The Corps of Engineers will provide all information, documents, and deliverables to maintain coordination and ongoing review of the effort.

Coordination between the WES and the CBP will be accomplished by the MARS through the NAB (as the agency representative on MARS). NAB will have the responsibility for formal coordination with WES, and for maintaining complete communication with the CBP. NAB will have the responsibility of arranging periodic progress meetings with the MARS and WES, forwarding progress reports and documents for review, assisting in training and workshop arrangements, and all other areas of required coordination between CBP and the WES.

The MARS shall have the responsibility of arranging all technical review activities, including ongoing review by the MEG. MARS has the responsibility of arranging attendance of MEG (or any other reviewers) at the periodic progress meetings with WES. MARS also has the responsibility of maintaining communication with the CBP Implementation Committee on progress of the overall effort.

The CBP will be responsible for timely delivery to WES of all data and process-related information wherein Federal or state funds were provided for field, laboratory, or paper studies. The CBP will also be responsible for timely delivery to WES of all requested Watershed Model outputs and point-source data. Data that are not readily available (i.e., other than Federal or state-funded) would be the responsibility of WES to identify and obtain.

Throughout this study there will be opportunities for technology transfer and training. For the most effective and efficient transfer of information (other than formal reporting) and training, it is recommended that Bay-area personnel visit WES occasionally to personally experience model development and application and to exchange ideas. These people would be from the various state/Federal agencies involved with future model applications.

Because of the anticipated size and computational requirements of the proposed CBMP, it is recommended that the CBMP be installed on a super minicomputer or a mainframe supercomputer. The CBP will keep the WES apprised insofar as the computer for planned CBMP installation.

All changes to the schedule, or to the deliverables as described in this WP, must be agreed upon by all concerned parties (CBP, Corps of Engineers). All significant technical issues must be reviewed by the MEG. In the event of a technical difference of opinion concerning problem solution between MEG and the TMT, CBP guidance will take precedence. All changes or modifications in any aspect of the WP must be documented in writing, and copies distributed to all concerned parties. If any changes cause an increase in time or cost of the work to be performed, an equitable adjustment shall be negotiated between the CBP and the Corps of Engineers before beginning agreed-upon work.

Other areas of responsibility and coordination between CBP and the Corps of Engineers will be negotiated and clearly identified as required.

Project Management

Overall integration of the study will be through the umbrella of the existing CBP with the NAB representative on MARS serving as the WES point of contact for conduct of the work. The WES TMT is shown in Figure 1. The study will be conducted using appropriate expertise in three WES laboratories (i.e., Coastal Engineering Research Center, Environmental Laboratory (EL), and Hydraulics Laboratory). WES management considers the study to be of the highest priority, and therefore the WES Technical Director will be the Study Director with the three participating Laboratory Chiefs serving as members of an Oversight Group. The Study Manager is the Chief, Ecosystem Research and Simulation Division, EL, who will be directly responsible for day-to-day conduct of the study and the WES point of contact for the work. Senior level WES management and technical personnel will be directly involved in the study.

To date there has been broad agreement in the Bay scientific community that a 3D modeling effort, as proposed by the CBP, will have the best chance of success if hydrodynamic and water quality modelers work in close cooperation. WES completely agrees with this procedure and has assembled a TMT that has previously worked in close cooperation on other projects that required both hydrodynamic and water quality components. The HM and WQM Coordinators will work closely throughout the study to ensure that this coordination is accomplished.

The management approach presented ensures that the most knowledgeable WES people will be available to work throughout the study and that there is a total WES commitment to the success of the effort. The identified HM and WQM Team Leaders, Coordinators, and members are well experienced in their technical areas of expertise. The In-House Advisory Group is composed of other senior-level WES scientists and engineers that would be involved in an advisory/consultative capacity on an as required basis. At this time it is envisioned that three or four outside consultants will be hired to provide additional senior level water quality and hydrodynamic expert input to the WES in a manner similar to the way MEG assists MARS. This is done routinely at WES to obtain additional expertise on large, complicated studies. The Study Director, and Oversight Group will meet monthly with the Study Manager and HM and WQM Coordinators to review progress, discuss problem areas, if any, and check on milestone status. Biweekly technical meetings will be scheduled with the Study Manager, HM and WQM Coordinators, and Team Leaders to plan ongoing work and resolve technical issues. Quarterly meetings with MARS and MEG will be held to review technical progress and resolve any identified technical issues.

TECHNICAL MODELING TEAM
CHESAPEAKE BAY THREE DIMENSIONAL TIME-VARYING, HYDRODYNAMIC, AND WATER QUALITY MODELING STUDY

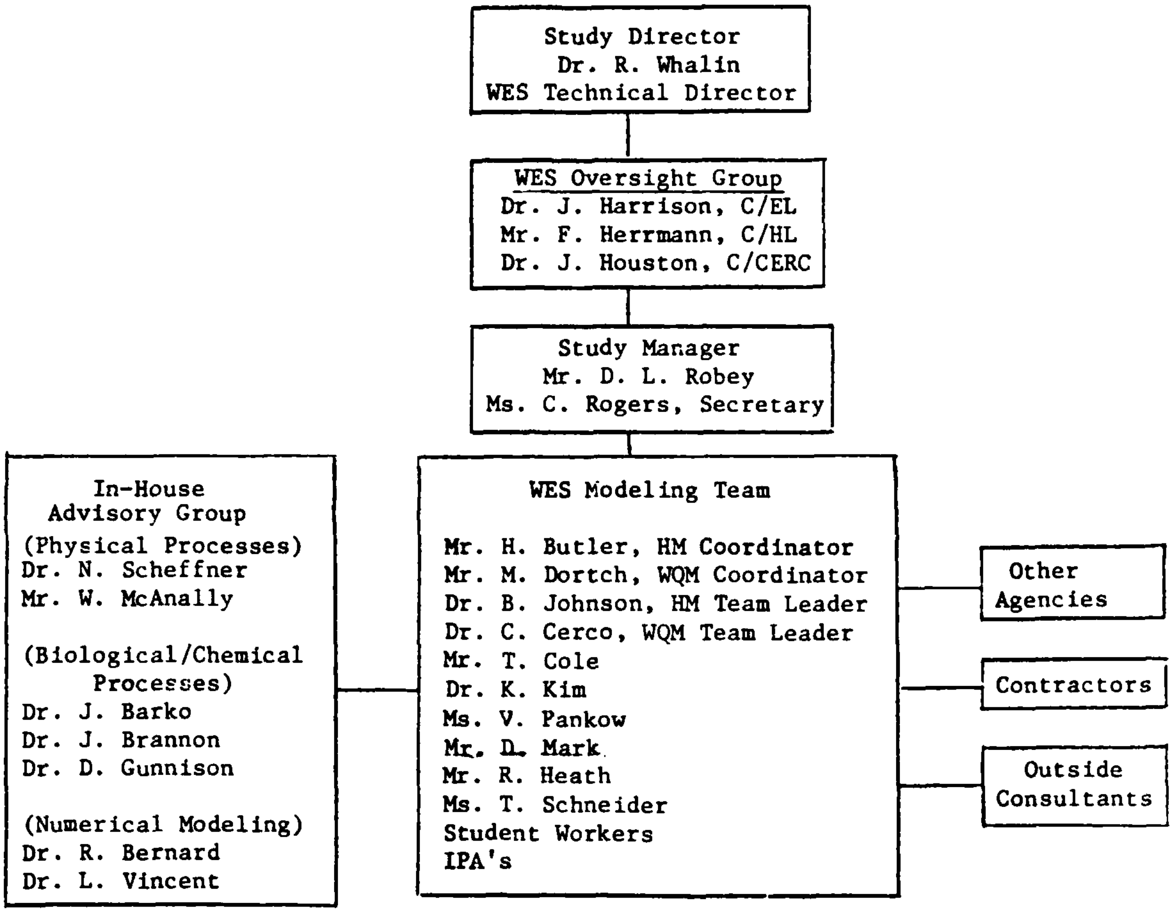

Figure 1. Technical Modeling Team

Contracting

The WES will have a senior-level water quality contractor and a senior-level hydrodynamic contractor throughout the conduct of the study.

Several contractural efforts are anticipated to accomplish various tasks or portions of tasks during conduct of the study. These may include but are not limited to:

a. Modifications to CH3D to handle fewer layers in shallows and coupling 3D, 2D, and 1D computations and grids.

b. Input data identification, acquisition, interpretation, evaluation , and preparation.

c. Workshop on WQM processes and variables.

d. Workshop, development, and initial testing of sediment/water quality module.

e. Workshop and some development on interfacing HM/WQM.

f. Workshop on long-term simulations.

g. Development, testing, and application of various aspects of the HM and WQM.

h. Modification of sediment transport module for CH3D.

i. Review and some developmental work associated with contaminant modeling framework.

j. Scenario application of developed models.

k. Technical review and guidance during conduct of study.

l. Conduct of training courses.

Agency Participation and Coordination

Preliminary discussions have been held with the National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS) participants in the CBP and with the USEPA Research Laboratories and several researchers in the Bay states. Discussions have not reached the point where definitive work efforts have been identified. However, it is anticipated that the USGS will provide monitoring and process oriented physical, biological, and chemical data and analyses previously accomplished but not resident on the CBP computer. NOAA has indicated an interest in potential involvement in the numerical modeling aspects of the study, particularly concerning the ocean boundary conditions and overall Bay wind fields. They have personnel experienced in 3D hydrodynamic modeling of the Bay and knowledgeable in data availability concerning physical processes. In addition, NOAA can provide assistance in obtaining data that are not on the CBP computer. USEPA, NOAA, and USGS participated in the four technical workshops and are interested in participating in future workshops.

PART VI: SUMMARY

This WP presents a technical description for the production of a 3D, time-varying, HM/WQM of Chesapeake Bay and its tributaries. The responsibility for development and delivery of the calibrated and verified CBMP rests with the NAB. The model production will use the technical expertise of the WES. Appropriate expertise from other agencies, research institutions, and private contractors and consultants will be incorporated where needed to provide the most appropriate technical team for the study.

The CBMP will utilize an existing HM, CH3D, and will adapt water quality coding based on the USEPA WASP and the steady-state Bay model. Although the HM and WQM will not be dynamically coupled, they will be appropriately interfaced. The models will accept output from the Chesapeake Bay Watershed Model as required. In addition, preliminary work to support later development of sediment transport and toxics models will be initiated as part of the model program.

Costs to complete the work outlined herein are estimated to be $3.2 million. The CBMP will be completed and delivered in September 1990. Products, in addition to delivery of the CBMP to the CBP computer, include user guides and verification reports on both the hydrodynamic and water quality components, various supporting reports such as conclusions and recommendations of workshops and contractor reports, and training on how to apply the CBMP. Simulation scenarios will be conducted during FY 91 to evaluate the various control strategies. Technical personnel at WES will be available (on a reimbursable basis), after completion of tasks described in the WP, to assist the CBP in future model updating, application, or interpretation.

Because the model will have potential for use for other agencies' programs in Chesapeake Bay, the final CBMP will reside fully in the public sector and will be available for use by state and Federal agencies and other institutions.

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APPENDIX A

TASK SUMMARIES, CHESAPEAKE BAY, 3D HYDRODYNAMIC/WATER QUALITY MODELING PROJECT

WORK TASK - H.1 Data Compilation

START DATE - Oct 87

COMPLETION DATE - Jan 89

PRINCIPAL INVESTIGATOR - Ms. Virginia Pankow

DESCRIPTION - Data sets are needed to calibrate/verify the HM model. Identify both physical model data (Hydraulic Model, Matapeake, MD) and appropriate field data from various collection efforts for the calibration/ verification of the HM model. Tidal elevations and velocities, salinity, river discharges, and meteorological data are required. Assemble selected data sets in HM model format.

APPROACH - Data collected on the Chesapeake Bay physical model will be identified and assembled for use in the initial HM model adjustment. Field data sets for final model calibration and verification of HM will be assembled from data collected by NOAA, EPA, CBI, USGS, VIMS, etc. Coordination with previous CBP contractors is planned in the compliation of these data. Data sets will be constructed to cover a range of events, e.g. freshwater inflows and wind influence.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Identify data for model calibration/verification		Oct 87	Mar 88
	A) Physical Model Data		Dec 87
	B) Field Data		Mar 88
Assemble data in HM format		Dec 87	Oct 88
	C) Physical Model Data		Feb 88
	D) Field Data-Calibration		Apr 88
	E) Field Data-Verification		Oct 88
Task summary		Oct 88	Jan 89
	F) Interim report		Jan 89

WORK TASK - H.2 Model Sensitivity Studies

START DATE - Oct 87

COMPLETION DATE - Nov 88

PRINCIPAL INVESTIGATORS - Dr. Keu Kim and Mr. Ronald Heath

DESCRIPTION - Before initiating calibration/verification of the numerical model, studies are required to assess model sensitivity and performance. Numerical tests are required to determine such things as model sensitivity to the grid and model coefficients. Applications to idealized problems possessing analytic solutions are also required to demonstrate model accuracy. In addition, verification of model physics, numerical techniques and coding are necessary. Linkage techniques between the HM and Watershed Model and the HM and WQM will be developed and demonstrated.

APPROACH - Comparison of model results and analytical solutions will be conducted in water basins of simplified bathymetry and geometrical configuration. Bay grids of varying resolution will be numerically generated with subsequent model applications on those grids to assess grid and coefficient sensitivity, salt balance, numerical properties, etc. A final Bay grid will be developed for use in Task H.4 and by the WQM team. Develop interface techniques for accepting watershed inflows and provide assistance in HM/WQM linkage. An intensive study of the numerical model's theoretical basis will be conducted.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Generate HM grids		Oct 87	Jun 88
	G) Preliminary Bay grid		Nov 87
	H) Final Bay grid		Jul 88
Conduct sensitivity tests		Oct 87	Oct 88
	I) Simplified basins (known solutions)		Apr 88
	J) Salt balance demo		May 88
	K) Grid/coefficients/physical parameters		Oct 88
Demonstrate linkage techniques		Jan 88	Nov 88
	L) HM/Watershed and HM/WQM		Nov 88

WORK TASK - H.3 Model Modifications

START DATE - Nov 87

COMPLETION DATE - Jan 89

PRINCIPAL INVESTIGATORS - Dr. B. H. Johnson, Contractor(s)

DESCRIPTION - Modifications of existing 3D hydrodynamic code (CH3D) are required for efficient/economical Bay simulations.

APPROACH - The existing 3D HM code, CH3D, will be optimized for efficient and economic application to the Bay by modifying the code to: a) treat variable layer resolution in the vertical, b) permit coupling of 2D-lateral (constant width) and 1D grids, and c) permit coupling of 2D-lateral (constant width) and 3D grids. The 1D/2D and 2D/3D grid couplings will be accomplished within the framework of block-structured grids for optimal storage and computation costs. The variable layer modification is necessary to efficiently represent the vertical structure over deep and shallow water areas and within tributaries.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Implement HM modifications		Nov 87	Dec 88
	M) Variable layers		Jul 88
	N) 1D/2D Coupling		Oct 88
	O) 2D/3D Coupling		Jan 89

WORK TASK - H.4 Model Calibration/Verification

START DATE - May 88

COMPLETION DATE - Jun 89

PRINCIPAL INVESTIGATOR - Dr. B. H. Johnson

DESCRIPTION - Data sets assembled in Task H.1 will be used to calibrate/ verify the HM model over a range of observed Bay conditions. Calibration will be initiated by making model adjustments for various bay sectional areas (e.g., tributaries) followed by a complete Bay grid calibration to observations. After calibration of the full Bay grid, the model will be verified for appropriate Bay conditions.

APPROACH - There are no known synoptic data sets on the complete Bay. However, detailed data (Task H.1) exist for segments of the Bay. These data include both Chesapeake Bay physical model data as well as field data. The physical model data will be the most complete data set for no wind conditions. Therefore it is anticipated model calibration will be initiated through a segmented approach, with the major tributaries being calibrated first. A coarse Bay grid and/or section grids will be employed when working with the tributary calibration. Model verification will be accomplished by employing separate data sets assembled in H.1 which cover a range of freshwater inflows and wind conditions.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Develop sectional approach		May 88	Jun 88
	P) Coarse Bay grid and sectional grids		Jun 88
Calibrate HM model		Jun 88	Mar 89
	Complete Bay tributary sections		Sep 88
	Complete full Bay model		Feb 89
	Q) Interim report		Mar 89
Verify HM model		Feb 89	Jun 89
	R) Interim report		Jun 89

WORK TASK - H.5 HM Production Simulations

START DATE - Apr 88

COMPLETION DATE - Jan 90

PRINCIPAL INVESTIGATORS - Dr. Keu Kim and Mr. Ronald Heath

DESCRIPTION - HM production runs are required to provide hydrodynamic input to the WQM. These inputs are water elevations, currents, and diffusivity coefficients.

APPROACH - Production runs will be conducted for the years 1984, 1985, and 1986. However, prior to supplying data for these years, additional results are required for testing the WQM. These HM simulations include a single tidal cycle simulation, a preliminary 60-day dye transport simulation, a final grid 60-day dye transport simulation, and preliminary results for initiating WQM calibration for 1985 conditions. The freshwater inflow of each tributary and nonpoint sources must be provided from output of the watershed model for the years 1984-1986.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Tidal cycle simulation		Apr 88	Apr 88
	S) Results (all in WQM format)		Apr 88
60-day dye transport runs		Jul 88	Feb 89
	T) Preliminary results		Jul 88
	U) Final grid model results		Oct 88
HM runs for WQM calibration		Mar 89	Jun 89
	V) Preliminary 1985 HM results (1 month)		Apr 89
	W) 1985 HM results		Jun 89
HM runs for WQM verification		Oct 89	Dec 89
	X) 1984 and 1986 HM results		Dec 89

WORK TASK - H.6 Sediment Transport Model

START DATE - Feb 89

COMPLETION DATE - Jun 90

PRINCIPAL INVESTIGATOR - Dr. B. H. Johnson

DESCRIPTION - Modeling of contaminants in the Bay is dependent upon being able to numerically model the transport of cohesive sediments and their exchange between the water column and the bed. Additional considerations in the development of a sediment transport model include turbulent mixing and sediment behavior properties such as flocculation and particle size distribution.

APPROACH - Much work in modeling cohesive sediment transport has been accomplished. However, WES experience indicates need for additional code development to lay the framework for future Bay sediment transport studies. Existing model technology will be reviewed and the most appropriate transport algorithms will be adapted within HM. Data for use in model development will be identified.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Review/identify data/code needs		Feb 89	Oct 89
Code development		Apr 89	Jun 90
	Y) Task report		Jun 90

WORK TASK - H.7 HM Technology Transfer

START DATE - Oct 87

COMPLETION DATE - Oct 90

PRINCIPAL INVESTIGATOR - Mr. H. L. Butler

DESCRIPTION - Contribute to monthly progress reports and make oral presentations to MARS quarterly. Prepare HM calibration/verification report, HM user guide, and deliver HM to CBP. Conduct training on HM use.

APPROACH - Monthly progress reports will be submitted to NAB. Each quarter an oral presentation on progress will be given to MARS. A report will document the calibration and verification of the HM. A separate HM user guide will be developed. A report on the HM production results for 1984-1986 will be issued. The final model will be delivered and installed on the CBP computer. A training course on HM model use will be held in the Bay area. Preliminary/intermediate reports are cited under other HM tasks.

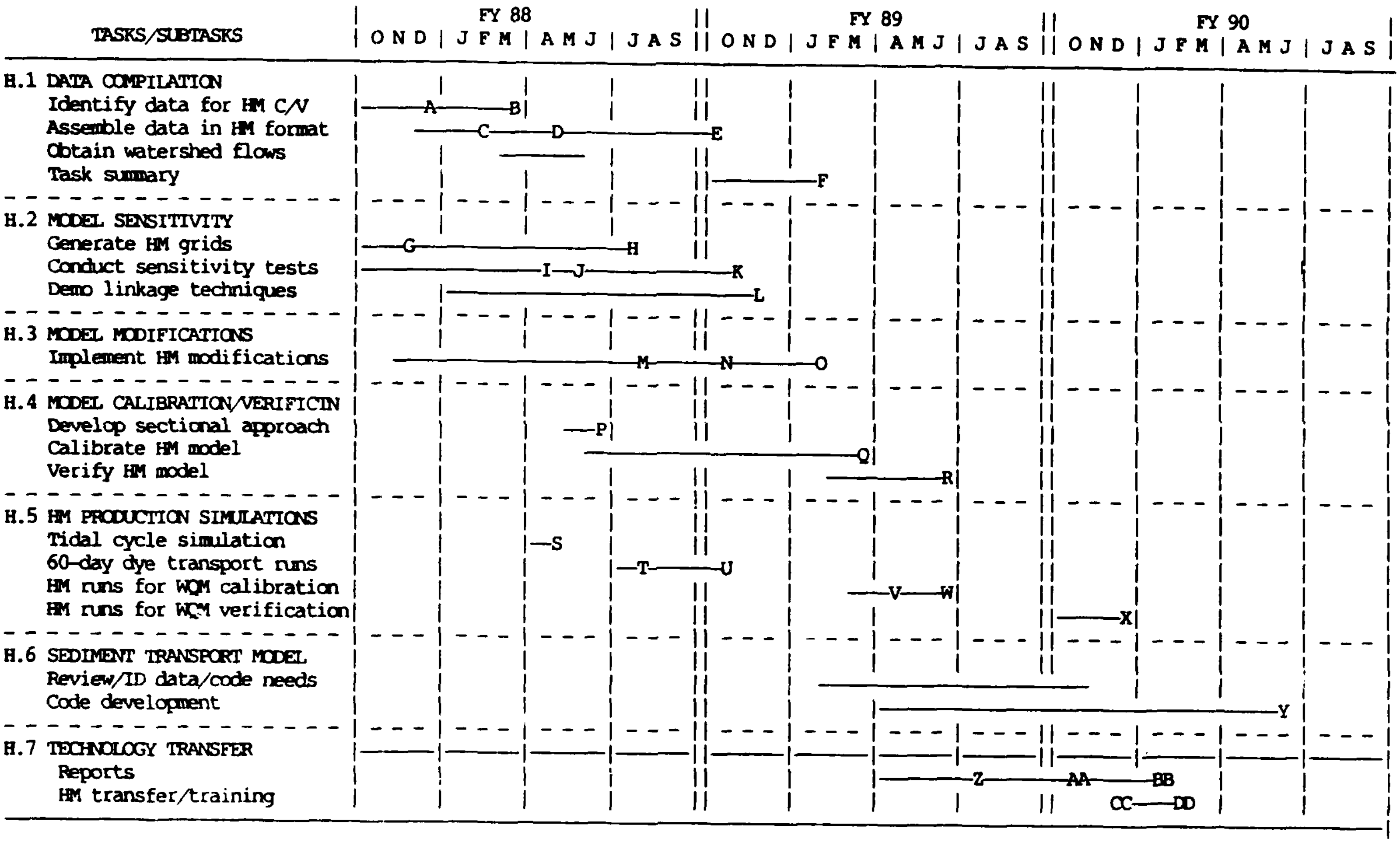
SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
HM reports		Apr 89	Jan 90
	Z) HM Calibration/verification		Jul 89
	AA) HM User Guide		Oct 89
	BB) HM Production Results		Jan 90
HM transfer/training		Dec 89	Feb 90
	CC) Install HM code on CBP computer		Dec 89
	DD) Conduct HM training		Feb 90

HYDRODYNAMIC MODEL PRODUCTS/MILESTONES

PRODUCT/MILESTONES	IDENTIFICATION	DATE
Preliminary Bay grid	G	Nov 87
Identify physical model data for HM cal/ver	A	Dec 87
Assemble physical model data for HM cal/ver	C	Feb 88
Field data ID for HM cal/ver	B	Mar 88
Simplified basins (known solutions) sensitivity (HM)	I	Apr 88
Tidal cycle simulation for WQM support	S	Apr 88
Field data assembles for HM calibration	D	Apr 88
Salt balance demonstration (HM)	J	May 88
Developed sectional grid approach for HM cal	P	Jun 88
Final Bay grid	H	Jul 88
Variable layers modification (CH3D)	M	Jul 88
Preliminary 60-day HM simulation	T	Jul 88
1D/2D coupling (CH3D)	N	Oct 88
Field data assembled for HM verification	E	Oct 88
Grid/model coefficients/physical parameters sens.	K	Oct 88
Final grid 60-day HM simulation	U	Oct 88
Linkage for HM/Watershed & HM/WQM demonstration	L	Nov 88
2D/3D coupling (CH3D)	O	Jan 89
Task H.1 interim report	F	Jan 89
Interim report on HM calibration	Q	Mar 89
Preliminary 1985 HM calibration (partial)	V	Apr 89
Verification of HM model-Interim report	R	Jun 89
Complete 1985 HM simulation	W	Jun 89
HM Calibration/Verification Report	Z	Jul 89
HM Model User Guide	AA	Oct 89
Complete 1984 and 1986 HM simulation	X	Dec 89
Code installation on CBP computer	CC	Dec 89
HM Production Results Report	BB	Jan 90
Training course on HM model use	DD	Feb 90
Task H.6-Sediment Transport Model Report	Y	Jun 90

HYDRODYNAMIC MODEL SCHEDULE



WORK TASK - W.1 Reconnaissance

START DATE - Oct 87

COMPLETION DATE - May 88

PRINCIPAL INVESTIGATORS - Dr. Cerco, IPA's, and Contractor

DESCRIPTION - Indentify and review water quality data of the Bay to be used in the model and make recommendations for future data collection efforts to support the model; review water quality model studies of the Bay to guide model development; review boundary condition data sources and data to establish any necessary runs for the watershed model; conduct four workshops and prepare recommendations report that will help guide the study.

APPROACH - This task will be conducted through literature reviews, study of the CBP and other data bases, and discussions/workshops with appropriate scientists. Available water quality data bases will be reviewed to ensure model formulations are consistent with available data, to identify any new data sources, and to make recommendations for direction of future data collection efforts to close any gaps. Other model studies on the Bay will be reviewed to ascertain the significance of various state variables, processes, and coefficients. Watershed Model runs needed to support the WQM must be determined early in the study to allow sufficient lead time. The four workshops will be used to obtain a technically sound consensus on approach for the following subjects: (1) model state variables and processes; (2) interactive bottom sediment water quality model; (3) developing and interfacing of HM output to support the WQM; and (4) long-term simulations. A report summarizing the conclusions of these workshops will be produced.

(continued)

Task W.1 (Continued)

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Data review		Oct 87	May 88
	1) Future data collection recommendation report		May 88
Model review		Oct 87	Feb 88
	2) Establish model variables		Feb 88
Review boundary conditions		Nov 87	Mar 88
	3) Establish Watershed Model runs		Mar 88
Workshops		Nov 87	May 88
	4a) Variables/processes		Nov 87
	4b) Sediment WQ		Dec 87
	4c) HM/WQM interface		Jan 88
	4d) Long-term simulations		Feb 88
	4e) Summary report of workshops		May 88

Note: A brief report of each workshop's conclusions will be available one month after the workshop.

WORK TASK - W.2 Input Data Compilation

START DATE - Mar 88

COMPLETION DATE - Jan 90

PRINCIPAL INVESTIGATORS - Dr. Cerco and Contractor

DESCRIPTION - Compile and format water quality data required for WQM calibration/verifications.

APPROACH - The Chesapeake Bay data base and other data sources will be accessed. The data sets to be assembled include both input data and observations and are basically broken down into 1985 calibration data, 1984-86 verification data, and the 30-year verification data. The assembled data will be transfered to the WES VAX computer.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Assemble data sets*		Mar 88	Jan 90
	5a) 1984 calibration data set		Jan 89
	5b) 1985-86 verification data sets		Sep 89
	5c) 30-year verification data set		Jan 90

* The assemblage of data sets is dependent upon receipt of appropriate data from the CBP, the Watershed Model, and other sources.

WORK TASK - W.3 Model Development

START DATE - Oct 87

COMPLETION DATE - Mar 89

PRINCIPAL INVESTIGATORS - Dr. Cerco, Mr. Cole, IPA's, and Contractor

DESCRIPTION - Install new state variables and WQM routines; install sediment water quality routines; make any necessary changes to numerical solution procedures or other algorithms; develop and test programs to link HM output and grid with WQM; overlay WQM grid on HM grid; implement graphics, statistical, and flux programs; and develop any necessary interface programs for Watershed Model.

APPROACH - Initial development and testing of the sediment water quality routines will be conducted with the steady-state model run in time-varying mode. Experience with the WQM, CPU and stability requirements will dictate any changes in the solution procedures. Computer programs will be used to facilitate linking the HM grid/output to the WQM. Several approaches for averaging of HM output for input to the WQM will be implemented and tested (see Task W.4). Other programs required for pre- and postprocessing and/or interfacing will be developed/implemented.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
HM/WQM interface procedures		Oct 87	Dec 88
New WQM routines and state variables		Mar 88	Oct 88
Sediment water quality routines		Mar 88	Feb 89
	6a) Implemented/tested in steady-state model		Dec 88
	6b) Implemented in time-varying model		Feb 89
WQM grid overlay		Jul 88	Aug 88
	7) WQM grid		Aug 88
Pre- and Postprocessors		Mar 88	Mar 89

WORK TASK - W.4 Model Testing, Calibration, and Verification

START DATE - Feb 88

COMPLETION DATE - July 90

PRINCIPAL INVESTIGATORS - Dr. Cerco, Mr. Dortch, and Contractor

DESCRIPTION - Test WQM conservative and non-conservative mass balance; test HM/WQM linkage and preservation of mass transport properties; calibrate the model on 1985 data; verify the model for the period 1984-1986; test the ability of the model to simulate changes that occurred over past 30 years; and test use of an average HM year to drive WQM for evaluation of future conditions.

APPROACH - Conservative and non-conservative mass balance tests can be conducted during model development. The various procedures for interfacing HM output will be tested for preservation of transport properties in the WQM. Initially the WQM transport will be tested against the HM using the same time step and the fine grid. Next intratidal (e.g., 2 hr) transport will be tested using the fine grid. Successful completion of these tests will constitute the fine scale WQM which will be used for the 1984-86 calibration/verification. HM output will be processed for larger WQM time steps (e.g., intertidal, 12 hr), and the WQM transport will again be tested using the fine grid and a coarser grid. Successful completion of these tests will result in the coarse scale WQM which will be used for all long-term (i.e., 30-year) simulations. The coarse scale (long-term) WQM will be run on 84-86 for comparison with the fine scale model to confirm its accuracy for both transport and kinetics. Following this confirmation, the long-term WQM will be applied to the past 30 years for long-term confirmation. The long-term WQM will be applied with 1984-86 loadings and average hydrology (1986 HM output used for each year) and compared with 1986 observations to test the adequacy of using average hydrology for evaluating future conditions.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Interfacing/transport tests		Feb 88	May 89
	8a) Intratidal, fine grid transport test		Sep 88
	8b) Intertidal, fine grid transport test		Dec 88
	8c) Intertidal, coarse grid transport test		Feb 89
	8d) Long-term model 60 day transport verif		May 89
Model calibration for 1985		Apr 89	Nov 89
	9) Calibration complete		Nov 89
Model verification for 1984-1986		Dec 89	Mar 90
	10) Verification complete		Mar 90
Long-term WQM tests/verification		Nov 89	Jul 90
	11a) Confirmation for 84-86		Apr 90
	11b) Confirmation for past 30 years		Aug 90
	11c) Test average HM year for future scenarios		Sep 90

WORK TASK - W.5 Scenarios

START DATE - Jul 90

COMPLETION DATE - Jul 91

PRINCIPAL INVESTIGATORS - Dr. Cerco and Contractor

DESCRIPTION - Conduct water quality model simulations to demonstrate model utility and to test effectiveness of various control strategies.

APPROACH - Five demonstration simulations will be conducted to demonstrate the model's utility for evaluating scenarios. Following the demonstration scenarios, a study will be initiated to evaluate the control strategies. This study will help to better understand cause and effect relationships, to determine effective control strategies, and to evaluate the effectiveness of control strategies. As originally envisioned by the CBP, about 25 different scenarios would be simulated. In general, these include varying reductions in point and/or nonpoint sources of phosphorus and nitrogen, both Baywide and in specified basins. The strategies need to be evaluated for low and high flow years (i.e. 1985 and 1984). It has also been suggested that a simulation be made to estimate the state of the Bay under "pristine" conditions. The details of the evaluation scenarios will determined later through input from MARS, MEG, and the involved agencies.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Conduct demonstration scenarios		Jul 90	Sep 90
Conduct evaluation study		Oct 90	Mar 91 *
	12) Complete evaluation report		Jul 91

* Time required depends upon details of the requested simulations. Results will be delivered as available.

WORK TASK - W.6 Contaminants Model

START DATE - Mar 89

COMPLETION DATE - Sep 90

PRINCIPAL INVESTIGATORS - Dr. Cerco and Contractor

DESCRIPTION - This task involves three parts: review and selection of the appropriate model framework and basic approach; indentify any available data for model testing/evaluation/application; and identify and select appropriate model algorithms.

APPROACH - A contaminant modeling framework will be selected such that it is compatible with the Chesapeake Bay WQM. The various mechanisms to be included in the model must be commensurate with contaminant concerns in the Bay and available data. Available data will be identified, compiled, and evaluated to determine if they are sufficient to support a contaminant modeling study. Appropriate model algorithms will be identified, selected, and implemented to the extent possible within time and funding constraints. It is emphasized that this is the initial step toward the development of a contaminant model for Chesapeake Bay. Substantial work beyond this effort will be required to complete the model. A report will be prepared to document the contaminant model recommendations/developments and data review.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Contaminant model review		Mar 89	Sep 89
Review contaminants data base		Oct 89	Mar 90
Algorithm selection/implementation		Oct 89	Sep 90
	13) Task summary report		Sep 90

WORK TASK - W.7 Technology Transfer

START DATE - Oct 87

COMPLETION DATE - Sep 91

PRINCIPAL INVESTIGATORS - Dr. Cerco, Mr. Dortch, and Contractor

DESCRIPTION - Transfer monthly progress reports; make oral presentations to MARS quarterly; prepare WQM documentation and calibration/verification reports; deliver WQM to CBP; conduct training on WQM use; prepare scenarios evaluation report; and prepare/furnish other miscellaneous reports related to other tasks.

APPROACH - Monthly progress reports will be submitted to NAB. Each quarter an oral presentation on progress will be given to MARS. A report will document WQM development and describe input requirements. WQM calibration and verification will be documented in a separate report. The final model will be delivered to the CBP computer. A training course on model use will be held in the Bay area. Other reports (i.e., workshops, contaminant model, scenarios evaluations, and data recommendations) cited under the other WQM tasks will be reproduced under this task. All travel associated with the WQM is covered under this task.

SCHEDULE

SUBTASKS	PRODUCTS	START DATE	COMPLETION DATE
Reporting		Oct 87	Sep 91
Final reports		Jan 90	Dec 90
	14) WQM doc/user guide report		Jun 90
	15) WQM cal/ver report		Dec 90
WQM transfer/training		Oct 90	Jan 91
	16) Deliver WQM to CBP		Sep 90
	17) Hold training on WQM		Jan 91

WATER QUALITY MODEL PRODUCTS/MILESTONES

PRODUCT/MILESTONES	IDENTIFICATION	DATE
Variables/processes workshop	4a	Nov 87
Sediment water quality workshop	4b	Dec 87
HM/WQM interface workshop	4c	Jan 88
Long-term simulations workshop	4d	Jan 88
WQM variables list	2	Feb 88
Watershed model runs specified	3	Mar 88
Future data collections recommendation report	1	May 88
Workshops' summary report	4e	May 88
WQM grid	7	Aug 88
Intratidal, fine grid transport test	8a	Sep 88
Intertidal, fine grid transport test	8b	Dec 88
Sediment WQ implemented/tested in steady-state model	6a	Dec 88
85 calibration data set assembled	5a	Jan 89
Sediment WQ implemented in time-varying model	6b	Feb 89
Intertidal, coarse grid transport test	8c	Feb 89
Long-term model 60 day transport verification	8d	May 89
1984-86 verification data set assembled	5b	Sep 89
1985 WQM calibration complete	9	Nov 89
30-year verification data set assembled	5c	Jan 90
1984-86 WQM verification complete	10	Mar 90
Long-term model confirmation for 84-86	11a	Apr 90
WQM documentation/user guide report	14	Jun 90
Long-term model confirmation for past 30 years	11b	Aug 90
Long-term model test with average HM year	11c	Sep 90
Contaminant model task summary report	13	Sep 90
Delivery of WQM to CBP	16	Sep 90
WQM calibration/verification report	15	Dec 90
WQM training	17	Jan 91
Scenarios evaluation report	12	Jul 91

WATER QUALITY MODEL SCHEDULE

TASKS/SUBTASKS	FY 88 O N D	FY 88 J F M	FY 88 A M J	FY 88 J A S	FY 89 O N D	FY 89 J F M	FY 89 A M J	FY 89 J A S	FY 90 O N D	FY 90 J F M	FY 90 A M J	FY 90 J A S	
W.1 RECONNAISSANCE													
Data review	—	—	1										
Model review	—	2											
Review boundary conditions	—	3											
Workshops	4a-4b	4c4d	4e										
W.2 INPUT DATA COMPILATION													
Assemble data sets		—	—	—	—	5a	—	5b	—	5c			
W.3 MODEL DEVELOPMENT													
HM/WQM interface procedures	G	—	S	—	L								
New WQ routines		—	—	—	—								
Sediment WQ routines		—	—	—	6a	6b							
WQM grid overlay				H—7									
Pre- and post-processors		—	—	—	—	—							
W.4 MODEL TESTING, CAL, VERIF													
Interfacing/transport tests		—	—	T—8a	U—8b	8c	8d						
Model calibration for 1985							V—W	—	9				
Model verif for 1984-1986									X	10			
Long-term WQM tests/verif										—	11a	11b11c	
W.5 SCENARIOS													
Conduct demo scenarios												—	
Conduct evaluation study													a
W.6 CONTAMINANTS MODEL													
Contaminant model review						—	—	—					
Review contam data base									—	—			
Algorithm select/implement									—	—	—	13	
W.7 TECHNOLOGY TRANSFER													
Reporting	—	—	—	—	—	—	—	—	—	—	—	—	b
Final reports										—	14	—	c
WQM transfer/training												16	d

a - Extends from Oct 90 through Jul 91, includes completion of scenario testing in Mar 91 and product 12 in Jul 91
b - Extends through FY 91
c - Extends through Dec 90, includes product 15 in Dec 90
d - Includes product 17 (Jan 91)

PRODUCT/MILESTONES	IDENTIFICATION	DATE
Preliminary Bay grid	G	Nov 87
Variables/processes workshop	4a	Nov 87
Sediment water quality workshop	4b	Dec 87
Identify physical model data for HM cal/ver	A	Dec 87
HM/WQM interface workshop	4c	Jan 88
Long-term simulations workshop	4d	Jan 88
WQM variables list	2	Feb 88
Assemble physical model data for HM cal/ver	C	Feb 88
Field data ID for HM cal/ver	B	Mar 88
Watershed model runs specified	3	Mar 88
Simplified basins (known solutions) sensitivity (HM)	I	Apr 88
Tidal cycle simulation for WQM support	S	Apr 88
Field data assembles for HM calibration	D	Apr 88
Salt balance demonstration (HM)	J	May 88
Future data collections recommendation report	1	May 88
Workshops' summary report	4e	May 88
Developed sectional grid approach for HM cal	P	Jun 88
Final Bay grid	H	Jul 88
Variable layers modification (CH3D)	M	Jul 88
Preliminary 60-day HM simulation	T	Jul 88
WQM grid	7	Aug 88
Intratidal, fine grid transport test	8a	Sep 88
1D/2D coupling (CH3D)	N	Oct 88
Field data assembled for HM verification	E	Oct 88
Grid/model coefficients/physical parameters sens.	K	Oct 88
Final HM grid 60-day simulation	U	Oct 88
Linkage for HM/Watershed & HM/WQM demonstration	L	Nov 88
Intertidal, fine grid transport test	8b	Dec 88
Sediment WQ implemented/tested in steady-state model	6a	Dec 88
2D/3D coupling (CH3D)	O	Jan 89
85 calibration data set assembled	5a	Jan 89
Task H.1 interim report	F	Jan 89
Sediment WQ implemented in time-varying model	6b	Feb 89
Intertidal, coarse grid transport test	8c	Feb 89
Interim report on HM calibration	Q	Mar 89
Preliminary 1985 HM calibration (partial)	V	Apr 89
Long-term model 60 day transport verification	8d	May 89
Verification of HM model-Interim report	R	Jun 89
Complete 1985 HM simulation	W	Jun 89
HM Calibration/Verification Report	Z	Jul 89
84-86 verification data set assembled	5b	Sep 89
HM Model User Guide	AA	Oct 89
1985 WQM calibration complete	9	Nov 89
Complete 1984 and 1986 HM simulation	X	Dec 89
Code installation on CBP computer	CC	Dec 89

HM Production Results Report	BB	Jan 90
30 year verification data set assembled	5c	Jan 90
Training course on HM model use	DD	Feb 90
1984-86 WQM verification complete	10	Mar 90
Long-term model confirmation for 84-86	11a	Apr 90
Task H.6-Sediment Transport Model Report	Y	Jun 90
WQM documentation/user guide report	14	Jun 90
Long-term model confirmation for past 30 years	11b	Aug 90
Long-term model test with average HM year	11c	Sep 90
Contaminant model task summary report	13	Sep 90
Delivery of WQM to CBP	16	Sep 90
WQM calibration/verification report	15	Dec 90
WQM training	17	Jan 91
Scenarios evaluation report	12	Jul 91