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Workplan for Tributary Refinements to Chesapeake Bay Eutrophication Model Package

by Carl F. Cerco

WES

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Prepared for U.S. Environmental Protection Agency
and U.S. Army Engineer District, Baltimore

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Final report

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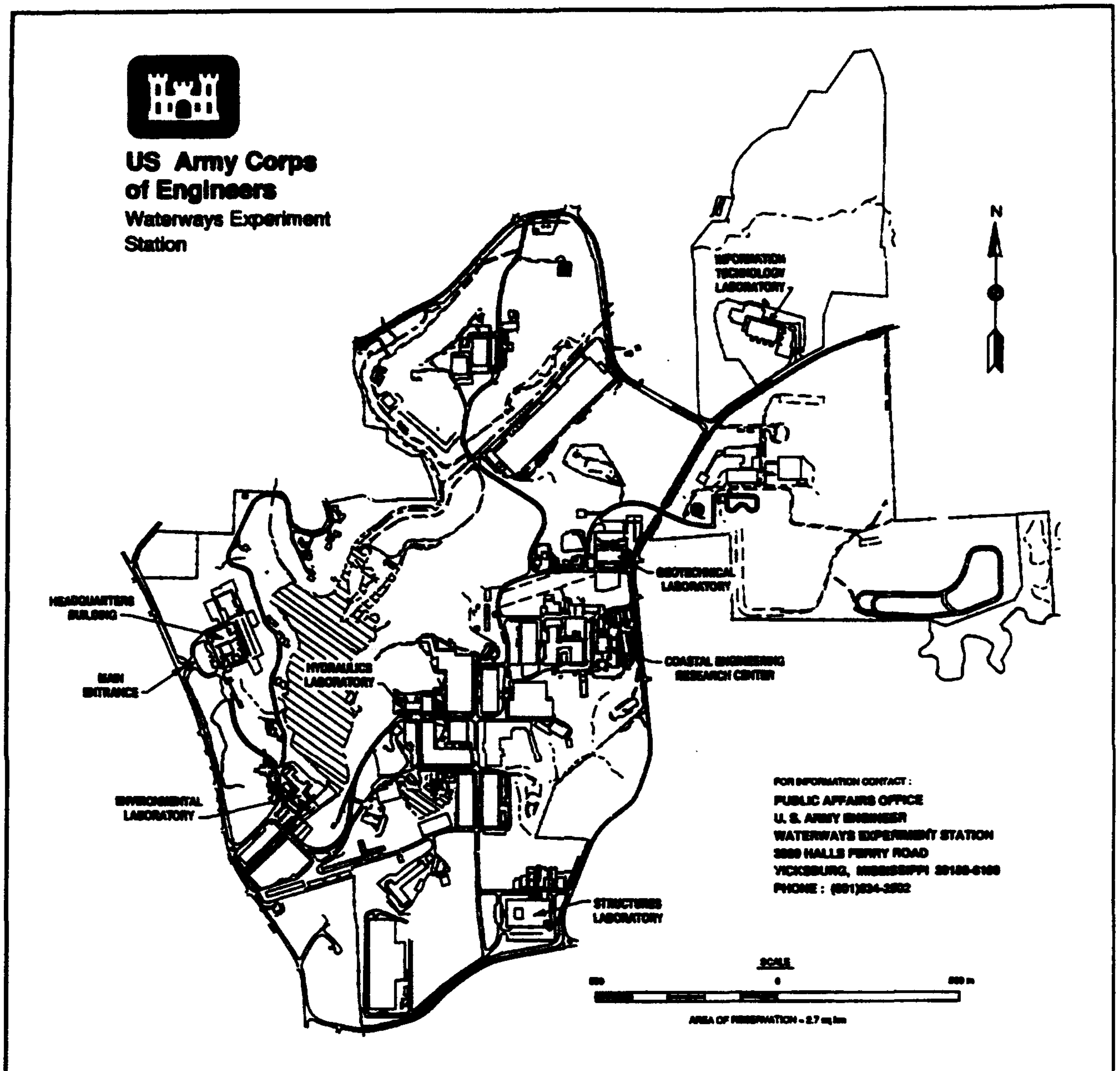

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Contents

Preface

The study reported herein was conducted as part of the Chesapeake Bay Three-Dimensional Model Study. It was sponsored by the Chesapeake Bay Program Office, U.S. Environmental Protection Agency, and the U.S. Army Engineer District, Baltimore.

The principal author of this workplan was Dr. Carl F. Cerco, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES). The chapter on Hydrodynamic Model Activities was formulated in cooperation with Dr. Billy Johnson, Waterways Division, Hydraulics Laboratory, WES. Technical review was provided by Mr. Ross Hall, WQCMB, and Dr. Mark Dortch, Chief, WQCMB.

Management was provided by Mr. Donald L. Robey, Chief, Environmental Processes and Effects Division, EL. Overall supervision was provided by Dr. John W. Keeley, Director, EL.

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Chapter 1
Introduction

The Corps of Engineers, in partnership with the USEPA Chesapeake Bay Program Office, recently completed a three-dimensional model study of eutrophication in Chesapeake Bay and tributaries. The model package applied included an intratidal hydrodynamic model (Johnson et al. 1991), an intertidal water-quality model (Cerco and Cole 1994), and a benthic sediment diagenesis model (DiToro and Fitzpatrick 1993). The Chesapeake Bay Program Office has proposed a series of tributary refinements to the existing model package. The refinements have the following goals:

> To provide a more accurate simulation of the fate and transport of nutrients in the tributaries.
>
> To simulate the effects of light attenuation by suspended sediment and nutrients on submerged aquatic vegetation.
>
> To more accurately simulate dissolved oxygen concentrations in the tributaries.
>
> To provide the basic modeling framework for future toxics modeling.
>
> To provide a more detailed hydrodynamic structure that can be applied to the simulation of oil spills in the James, York, and Rappahannock Rivers and Baltimore Harbor.

The existing model provides excellent representation of physical and eutrophication processes in the mainstem bay. Representation in the tributaries is uneven, however. A broad characterization is that model performance diminishes along with the size of the tributary and according to distance from the juncture with the mainstem. Consequently, representation of the larger tributaries, the James and the Potomac, is superior to lesser tributaries including the York, Rappahannock, and Patuxent. Model performance in the lower Potomac, adjacent to the Bay, is superior to performance in the freshwater Potomac, immediately below the fall line. In all cases, the existing model is unable to accurately quantify water-quality benefits of a proposed forty-percent reduction in controllable nutrient loads.

Starting points for improved representation in the tributaries have been identified (Cerco and Cole 1994). They are:

> Magnitude and composition of loads must be quantified with extreme accuracy.
>
> Phenomena near the limit of salt intrusion must be represented. These include flow convergence, accumulation of organic and inorganic particles, and occurrence of a chlorophyll maximum.
>
> Longitudinal and lateral resolution of the tributary grids should be improved.

At present, living resources are indirectly coupled to the model. Model predictions of dissolved oxygen, nutrient concentrations, and light extinction are compared to "living-resources criteria". The comparison indicates the effect of management activity on conditions favorable to living resources but does not quantify the living-resource response. Nor does the current framework compute feedback effects in which living resources impact water quality. At present, only the effects of water quality on living resources are quantified.

The present document comprises a workplan to improve tributary representation and to incorporate living resources directly into the model framework. Four tributaries have been selected by the Chesapeake Bay Program Office for emphasis under this tributary refinements program. They are the James, York, and Rappahannock Rivers, and Baltimore Harbor. The James, York and Rappahannock were specified because tributary-specific models are required to address water-quality and living-resource benefits to be derived from nutrient reductions. Baltimore Harbor was specified because it presents unique management problems, coupled with long-term toxics impacts, which cannot be addressed in the current model framework. The time scale for the project is four years from initiation to completion. Anticipated commencement is April 1, 1994.

Chapter 2
Workshop Summary

Three technical workshops were convened to assist in formulation of a technical approach for tributary refinements. The workshops were attended by members of government, academia, and private enterprise within and outside the Bay community. Conclusions of the workshops are summarized below. Complete proceedings are available in HydroQual (1993).

Workshop I: Tributary Models and Main Bay Model Linkage

The workshop was convened primarily to investigate methods by which fine-scale tributary models will interface with a larger-scale model of the mainstem bay. Among the topics discussed were grid resolution in the tributaries, interactions between the tributaries and mainstem, and target processes to be reproduced in the model. Significant recommendations included:

> Interactions between the mainstem and tributaries indicate that the tributaries cannot be modelled independently of the mainstem.
>
> The hydrodynamic model should accurately represent bathymetry to the 2 m contour, at least.
>
> Spatial resolution of nonpoint-source loads to the water-quality model should be refined.
>
> Target processes to be represented in the model include: tributary turbidity maximum, tributary chlorophyll maximum, tilting events at the bay-tributary interfaces, and three-layer circulation in Baltimore Harbor.
>
> Model application should be extended beyond the current 1984-1986 period.

The formulation of the open-mouth boundary condition should be reviewed. Extension of the grid outside the bay mouth should be considered.

Workshop II: Living-Resource Processes and Ecosystem Modeling

The workshop addressed the objectives in adding living resources to the model framework. Next, state variables and processes for addition to the existing water-quality model were suggested. Significant recommendations included:

The hydrodynamic model should resolve bathymetry to the 2 m contour. Volume within the 2 m contour should be modeled as a littoral zone treated as storage area by the hydrodynamic model.

Mechanistic representation of submerged aquatic vegetation should be added to the model package. The SAV submodel should include roots and rhizomes, leaves, epifauna, and grazers on epifauna.

Mechanistic representation of benthos should be added to the sediment submodel. Representation of benthos requires modeling of benthic algae, dissolved organic carbon, and two groups of macro-invertebrates.

Zooplankton should be added to the water-quality model.

Continuous salinity records should be collected at midchannel and in shoal areas of tributaries. The records will be used to verify modelled exchange between the littoral zone and channel conveyance area.

Workshop III: Suspended Sediments and Light Attenuation

The workshop considered the addition of suspended sediments to the model framework. The potential of a fully-predictive approach and of alternatives were considered. Effects of suspended sediments on light attenuation were examined and inclusion of the effects in the model were discussed. Significant recommendations were:

A fully-predictive suspended-sediment model, operating on the temporal and spatial scales of the hydrodynamic model, is desirable but not immediately feasible.

The first step in sediment modeling requires investigation of the sediment budget of the bay. The existing model framework should be used for this investigation.

Light attenuation can be successfully computed as a function of organic and inorganic solids, dissolved carbon, and chlorophyll 'a'.

Successful modeling of SAV in the littoral zone requires consideration of interactions between suspended sediments and light attenuation. Sediment resuspension by wind must be included in the representation.

Consideration should be given to special studies to determine the relationship between light and solids and to measure sediment resuspension as a function of wind velocity.

Chapter 3
Hydrodynamic Model Activities

The Hydrodynamic Model

Employment of the CH3D-WES (Computational Hydrodynamics in Three Dimensions - Waterways Experiment Station) hydrodynamic model will continue during tributary refinements. Model formulation is based on principles expressed by the equations of motion, conservation of volume, and conservation of mass. Quantities computed by the model include three-dimensional velocities, surface elevation, vertical viscosity and diffusivity, temperature, salinity, and density. Details of the model formulation and prior application to Chesapeake Bay are presented by Johnson et al. (1991).

Model Modifications

The CH3D-WES code will be modified to incorporate a littoral zone around the shoreline of the bay and tributaries. The littoral zone will extend from the land-water interface to the two-meter (at mean tide) depth contour (Figure 3-1). The "littoral zone" is a new name for a distinction between storage and conveyance area that has been employed for over twenty years (Thatcher and Harleman 1972) and is still useful in representing the geometry of bay tributaries (Park and Kuo 1993). The storage area fills and empties as surface level rises and falls at a channel cross section. Lateral exchange between the storage and conveyance area is computed according to continuity. Axial flow occurs in the conveyance area only and is computed according to the coupled momentum and continuity equations. The momentum equation employs the cross section of the conveyance area while the continuity equation employs the total cross section of the conveyance and storage areas.

A second modification to CH3D-WES will allow employment of only one cell in the vertical. At present, two cells are required which restricts the minimum depth represented in the model. Employment of one vertical cell depth and addition of the littoral zone will provide excellent representation of geometry and flows throughout the channel cross section.

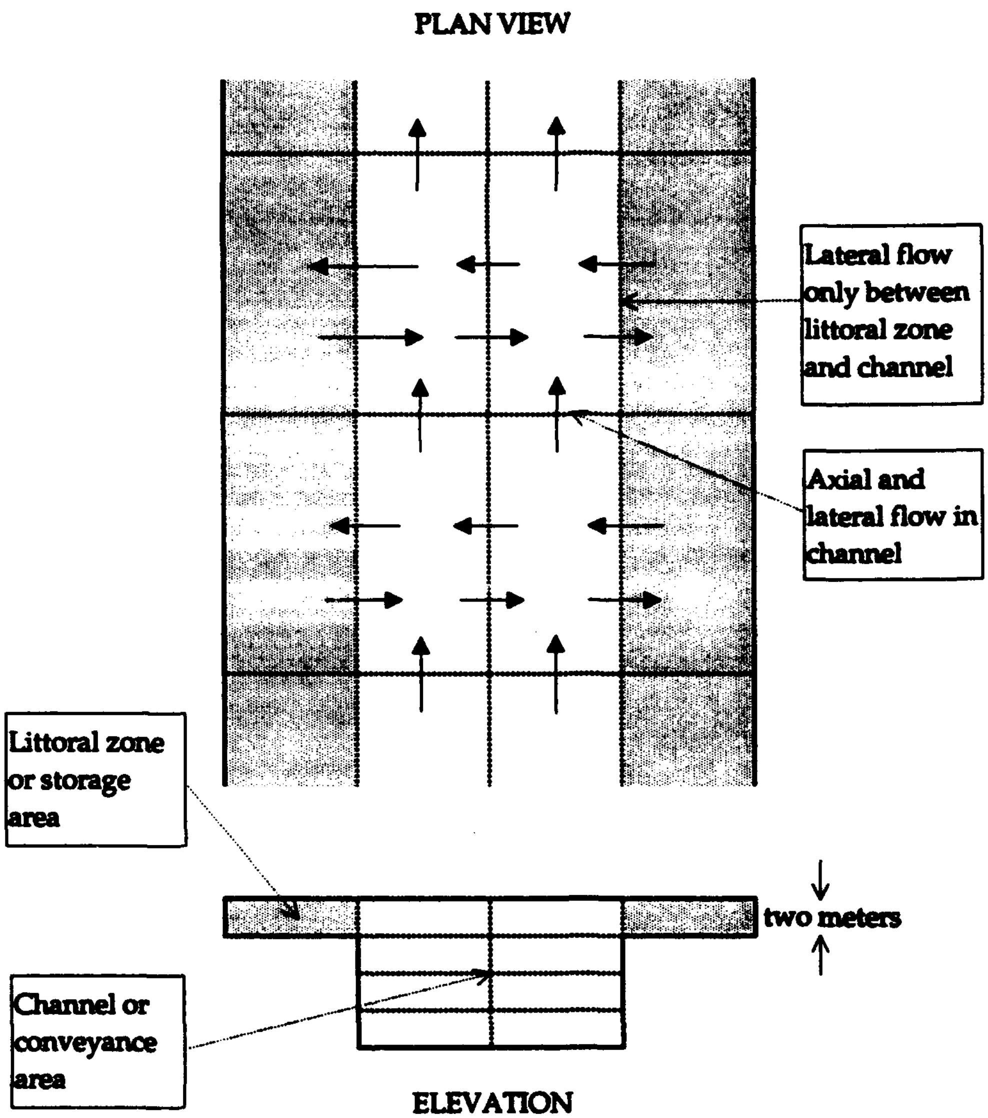

Figure 3-1. Schematic of Littoral Zone

Computational Grid

Virginia Tributaries

A unique system-wide grid will be constructed for each Virginia tributary. On each grid, present resolution within one tributary will be doubled along the longitudinal and lateral axes. Existing vertical resolution (surface layer ≈ 2m, all others ≈ 1.5m) will be maintained. Outside the tributary, resolution will gradually transition to an equivalent of the present grid. The strategy offers two advantages:

> Resolution in the tributaries is enhanced while total computational burden is minimized.
>
> Interactions of the tributary with the mainstem and other tributaries are represented.

Present grid size and approximate proposed grids are summarized in Table 3-1.

Table 3-1
Existing and Proposed Grid Size

	Existing Surface Cells	Existing Total Cells	Proposed Surface Cells	Proposed Total Cells
James River	42	139	168	556
York River	61	224	244	896
Rappahannock River	35	120	140	480
System Total	729	4,029	≈1,600	≈9,000
Baltimore Harbor	15	78	150	780

Baltimore Harbor

Baltimore Harbor (including the Patapsco and Back Rivers) is less extensive than the other tributaries selected for refinements. Detailed resolution of geometry in the harbor means that grid cells will be much smaller than elsewhere in the system. The diminutive cells present two problems. The first is transition between the harbor and adjoining bay. Large, discontinuous jumps in grid size are not permissible. Consequently, the fine grid will extend into the bay and influence grid scale throughout the system. The second problem is numerical time step. The time step forced by the fine grid spacing in the harbor will determine the time step throughout the system. The solution is to create a fine-grid model of the harbor and adjacent bay which will operate independently of the system-wide model. Approximate extent of the grid will be from the Susquehanna fall line to the Bay Bridge, near Annapolis. Information from hydrodynamics runs on one of the system-wide grids will be used to set boundary conditions at the open end of the Baltimore harbor grid.

Remainder of the System

Regridding the Virginia tributaries will force grid refinements throughout the system. System-wide refinements are required to avoid large discontinuous jumps in grid scale from the tributaries to the bay. Also, gridlines must be continuous from one boundary to the other. Consequently, lateral grid resolution at the mouth of the Rappahannock, for example, must be carried across the mainstem to the Eastern Shore.

As part of the regridding process, refinements will be made in the Potomac to rectify some existing problem areas. Notably, the right-angle bends at Mathias Point and Maryland Point will be smoothed. The littoral zone will be installed throughout the system including the Potomac, Susquehanna Flats, and Tangier Sound.

Open-Mouth Boundary Conditions

Good practice in predictive modeling is to place boundary conditions as far as possible from regions of interest. Downstream boundaries in the current grid, at the mouth of the bay, are close to the James River, a primary focus of the tributary refinements. Prospects for extending the boundary away from the James, out into the continental shelf, are cloudy, however. Among the concerns are:

Availability of hydrographic and water-quality observations,

Computational problems associated with specification of three open boundaries, and

Additional computational burden.

Opinions at the workshops were mixed as to the feasibility and desirability of extending the open boundary. At initiation of the study, a careful examination of the above-noted issues will be conducted before determination of the downstream boundary location. Examination will include an exploratory hydrodynamic model run with the grid extended $\approx$30 km outside the bay mouth. Duration of the run will be thirty to sixty days. One objective is to determine whether observed conditions at the bay mouth can be reproduced when boundary conditions are specified on the extended grid. Model performance at the bay mouth will be a primary consideration in determination of the location of the grid boundary.

Sequence to be Modeled

Virginia Tributaries

The York River is specified as the first to be modeled since it contains extensive littoral regions and living resources. Model runs on the York grid will provide the testing ground for code revisions and implementation of the littoral zone. The James and Rappahannock will be modeled simultaneously following initial efforts in the York.

Periods selected for model calibration within the tributaries will be specified following examination of available data. After calibration, production runs will be conducted for 1985-1987 and 1994. Additional verification of the model will be conducted using salinity data from the production years. Hydrodynamic production runs correspond to years selected for calibration and verification of the water-quality model.

Baltimore Harbor

Work on the independent, Baltimore Harbor model will commence following calibration of the Virginia tributaries. Delaying Baltimore Harbor until Year 2 of the project will allow for utilization of a system-wide grid to set downstream boundary conditions for the fine-grid harbor model.

Periods selected for calibration of the harbor model will be specified following examination of available data. Timely calibration and initial verification of the model require employment of data collected prior to the 1994-1995 surveys. After calibration, production runs will be conducted for 1985-1987 and 1994-1995. Additional verification of the model will be conducted using salinity data from the production years. Hydrodynamic production runs correspond to years selected for calibration and verification of the water-quality model.

We note that calibration to 1994-1995 within the time frame of the project will be problematic and may be impossible. Calibration requires observed salinity and tidal boundary conditions, meteorologic conditions, and freshwater runoff records. These may not be available within the time frame of the project. If the system-wide model is to be used to provide boundary conditions, an additional year, 1995, must be added to the four years of planned production runs. Data for the system-wide runs may not be available either.

System-Wide Model

A single system-wide grid, incorporating all refinements to Virginia tributaries, may be created following hydrodynamic model calibration on individual grids. Production runs on this grid, 1985-1987 and 1994, will be completed if required to accurately represent tributary interactions during nutrient load-reduction scenarios. Determination of the need for a single grid will be made following transport tests on individual grids.

Data Bases

Virginia Tributaries

Extensive observations of tides, currents, and salinity have been collected in the Virginia tributaries by the Virginia Institute of Marine Science (VIMS). Cooperation with VIMS will be solicited in employing this data base for model calibration. We will also seek advice for target processes that should be simulated, such as spring-neap stratification cycling and tributary-mainstem exchange processes. The VIMS data will be supplemented with salinity observations collected in the Chesapeake Bay Program monitoring program.

Baltimore Harbor

Our workshops revealed limited hydrographic data exists for Baltimore Harbor. The only known current observations were collected in 1979. Monitoring program stations are limited to one each in the Patapsco and Back Rivers. These data will be employed in initial development of the hydrodynamic model. Hydrographic data collected by the Maryland Department of the Environment in 1994 will be incorporated into the hydrodynamic model data base as it becomes available.

Linkage to the Water Quality Model

In the Chesapeake Bay Three-Dimensional Model Study, Lagrangian averaging (Dortch 1990) was performed on hydrodynamics prior to employment in the water quality model. A processor imbedded in the CH3D-WES code transformed velocities, surface elevations, and vertical diffusivities computed on a five-minute basis into tidal-average values output every 12.5 hours. Employment of the Lagrangian algorithm reduced the storage requirements for the hydrodynamic output by an order of magnitude. Expert consensus is the Lagrangian algorithm is not suited for use in the geometrically-confined tributaries. Consequently, intratidal (< 12.4 hours) rather than intertidal (> 12.4 hours) hydrodynamics will be used to drive the water quality model.

Averaging hydrodynamics up to a time scale more lengthy than the CH3D-WES time step should still be possible, however. A target of one- to two-hour hydrodynamic increments is desirable. Intratidal averaging of hydrodynamic output is employed to minimize the storage requirement of hydrodynamic input to the water-quality model. The water-quality model time step is not necessarily equal to the hydrodynamic averaging increment. The typical water-quality model time step employing the Lagrangian-average velocities was two hours. Larger, intratidal velocities and smaller grid spacing will likely force water-quality model time steps much less than two hours during tributary refinements.

During the Three-Dimensional Model Study, extensive experience was gained in coupling hydrodynamic and water-quality models and in testing the linkage. Tests focused on comparisons of transport of conservative substances in both models. Initial tests compared "dye dumps" in the hydrodynamic and water quality models. Secondary tests were examinations of salinity computed in both models. Similar testing will be conducted during tributary refinements to ensure correct and accurate transfer of information from the hydrodynamic to water-quality models.

Chapter 4
Water-Quality Model Activities

The Water-Quality Model

Employment of the CE-QUAL-ICM water-quality model will continue during tributary refinements. The foundation of CE-QUAL-ICM is the solution to the three-dimensional mass-conservation equation for a control volume. Control volumes in CE-QUAL-ICM correspond to cells in x-y-z space on the CH3D-WES grid. CE-QUAL-ICM solves the conservation of mass equation in each volume for each model state variable.

A suite of twenty-two state variables (Table 4-1) is currently employed to model eutrophication processes in the water column. Kinetic interactions affecting the state variables are described in over 80 partial differential equations that require evaluation of over 140 parameters. The kinetics describe carbon, phosphorus, nitrogen and silica cycles and the dissolved oxygen balance. Details of model formulation and prior application to Chesapeake Bay are found in Cerco and Cole (1994).

The Sediment Model

A unique feature of the eutrophication model package is coupling of the water-quality model with a predictive model of diagenesis in benthic sediments. The model is driven by net settling of organic matter from the water column to the sediments. In the sediments, the model simulates the diagenesis (decay) of the organic matter. Diagenesis produces oxygen demand and inorganic nutrients. Oxygen demand, as sulfide (in saltwater) or methane (in freshwater), takes three paths out of the sediments: export to the water column as chemical oxygen demand, oxidation at the sediment-water interface as sediment oxygen demand, or burial to deep, inactive sediments. Inorganic nutrients produced by diagenesis take two paths out of the sediments: release to the water column, or burial to deep, inactive sediments. A listing of sediment model state variables and predicted sediment-water fluxes is provided in Table 4-2. Details of model formulation are found in DiToro and Fitzpatrick (1993).

Table 4-1 **Water Quality Model State Variables**	
Temperature	Salinity
Total Active Metal	Cyanobacteria
Diatoms	Green Algae
Dissolved Organic Carbon	Labile Particulate Organic Carbon
Refractory Particulate Organic Carbon	Ammonium
Nitrate	Dissolved Organic Nitrogen
Labile Particulate Organic Nitrogen	Refractory Particulate Organic Nitrogen
Total Phosphate	Dissolved Organic Phosphorus
Labile Particulate Organic Phosphorus	Refractory Particulate Organic Phosphorus
Chemical Oxygen Demand	Dissolved Oxygen
Particulate Biogenic Silica	Available Silica

Table 4-2
Sediment Model State Variables and Fluxes

State Variable	Sediment-Water Flux
Temperature	
Particulate Organic Carbon	Sediment Oxygen Demand
Sulfide/Methane	Release of Chemical Oxygen Demand
Particulate Organic Nitrogen	
Ammonium	Ammonium Flux
Nitrate	Nitrate Flux
Particulate Organic Phosphorus	
Phosphate	Phosphate Flux
Particulate Biogenic Silica	
Available Silica	Silica Flux

Modifications to Water-Quality Model

Water-Column State Variables and Processes

Initial modifications to the water-quality model will be the addition of particulate inorganic phosphorus and zooplankton to the suite of state variables. Modifications will also be made to the model treatment of dissolved organic compounds and suspended sediment.

Particulate Inorganic Phosphorus. At present, little is known regarding the nature and availability of particulate inorganic phosphorus in the bay and tributaries. The phosphorus may be tightly bound in mineral complexes and largely unavailable to the water column or the phosphorus may freely exchange between fractions dissolved and loosely sorbed to inorganic particles. The model formulation will allow for both exchangeable and unexchangeable forms of particulate inorganic phosphorus. Initial guidance regarding these forms will be obtained from existing data. Further determinations will be conducted after data collected as part of the tributary refinements becomes available.

Zooplankton. One or two zooplankton groups will be added to the model. Determination of the number of groups will be made following review of available data and investigation of computational requirements.

Dissolved Organic Compounds. At present, the model represents labile and refractory fractions of particulate organic carbon, nitrogen and phosphorus. Dissolved organic substances are not divided into labile and refractory fractions, however. An area of concern in the next phase of the study is the potential refractory nature of nutrients entering the bay from the ocean. Present representation of dissolved organic matter will be revised to include labile and refractory fractions. The revision will allow improved investigation of the influence of oceanic boundary conditions.

Suspended Sediment. Suspended sediment will be represented in the water-quality model to account for interactions with particulate inorganic phosphorus and to account for the effect on light extinction. A suspended-sediment state variable is currently in the model. Suspended sediment is treated as a conservative substance that settles at a specified velocity. At present, the suspended-sediment state variable is employed to represent particulate iron and manganese that precipitate following autumn turnover of anoxic bottom water.

The mechanism for representing suspended sediment during tributary refinements will be determined as part of the study. Options include prediction by the CH3D-WES hydrodynamic model, specification based on observations, and prediction within the water-quality model. To provide for the first two options, the water-quality model code will be modified to allow suspended sediment concentration and transport to be read in, from external sources, or predicted, as in the present code.

Extension of Calibration. Initial modifications to the water-quality model will be performed prior to availability of hydrodynamics on refined tributary grids. Preliminary calibration of the modified model will be conducted on the existing grid using existing hydrodynamics and loads. Transition to the refined grids will be completed as soon as the revised hydrodynamics become available.

The Littoral Zone

The littoral zone will be treated as a distinct region in the water-quality model. To accommodate the littoral zone, the model code must be changed to allow one cell thickness along the shoreline and multiple cell depths elsewhere. No additional changes are required to account for transport in the littoral zone. Cell volume and transport across cell faces will come from the hydrodynamic model, modified to include the littoral zone as storage area.

Water column kinetics and state variables in the littoral zone will be identical to elsewhere. The major distinction in the littoral zone will be addition of a submerged aquatic vegetation (SAV) component. Consensus, expressed in the workshops, is that SAV cannot exist at depths greater than 2m, even under ideal circumstances. Definition of the littoral zone as water inside the 2m contour means that SAV need only be considered within the littoral zone. SAV will be modelled as a separate submodel which will interact with the models of the water column and sediments. Initial development of the SAV model will be in standalone mode with conditions in the water column and sediments specified as boundary conditions. Development in standalone model will focus on SAV kinetics without the complications and resource requirements of the coupled water-quality and sediment models. A pilot for this process was development of the sediment diagenesis model which operates in standalone or coupled mode.

Formulation of the SAV model will be determined following review of SAV models currently existing for the bay and elsewhere. Following the recommendations of the workshops, initial formulation of the SAV model will include as state variables: roots and rhizomes, leaves, epifauna, and grazers on epifauna.

Downstream Boundary Condition

Nature and location of the downstream boundary condition in the water-quality model depends upon the outcome of the tests conducted with the hydrodynamic model. If extension of the grid beyond the bay mouth is hydrodynamically feasible, the downstream boundary of the water-quality model will be at the limit of the grid. Concentration boundary conditions along edges of the grid will be specified based on observations and best estimates. If extension of the grid is not feasible, other alternatives will be examined for specification of the water-quality boundary condition. One possibility is addition of a few well-mixed cells outside the bay mouth.

Nitrogen and phosphorus concentrations at the bay mouth have decreased since collection of the 1984-1986 observations currently employed in the water-quality model. The origin and nature of the decrease are uncertain. Early in the study, sensitivity to the recent conditions will be examined in the existing model. The Monitoring Subcommittee will be requested to determine if the apparent decreases originate in laboratory methodology.

Modifications to Sediment Model

Tributary Refinements

Formulation and performance of the sediment model in tidal freshwater will be enhanced as part of the tributary refinements. In the present formulation, sediment model parameters are arbitrarily differentiated into freshwater and saltwater values at the 1 ppt isohaline. No other spatial differentiation in parameter evaluation is possible. No observations in tidal freshwater and few observations in Virginia tributaries are represented in the present calibration data base.

The minimum suite of revisions to the sediment model will allow for spatially-variable specification of parameter values. An attempt will be made to smoothly transition sediment processes from saltwater to freshwater instead of differentiating kinetics at an arbitrary isohaline. Particulate inorganic phosphorus that settles from the water column will be routed into appropriate components in the sediments. The model will be calibrated to observations collected in appropriate tributaries.

At present, the model of phosphorus cycling in the sediments is primitive. Phosphate produced by diagenesis sorbs to particles or is released to the water column. More detailed modeling of phosphorus cycling is desirable, especially in freshwater. Improved modeling requires addition of iron and manganese to the suite of sediment-model state variables. Iron and manganese addition will also improve prediction of sediment oxygen demand in freshwater. The feasibility of iron and manganese modeling will be examined and the two metals will be added to the model if possible.

Living Resources

Modeling of living resources also necessitates revisions to the sediment model. The workshops called for quantitative, mechanistic modeling of benthic macroinvertebrates. Two groups of macroinvertebrates, suspension (heads-up) and deposit (heads-down) feeders, will be added to the suite of sediment-model state variables. Inclusion of macroinvertebrates will provide direct quantification of the biomass of this important food source.

Representation of predation on algae and of bioturbation in the sediments will also be enhanced.

Other modifications to the sediment model will be addition of benthic algae and dissolved organic carbon to the suite of state variables and accommodation of nutrient uptake by rooted, submerged aquatic vegetation. These features are required to model the littoral zone.

Sequence to be Modelled

York River

The first application of the completely revised model, including the littoral zone, will be to the York River. Initial calibration will be on a sub-grid derived from the grid created for hydrodynamic calibration of the York River. The sub-grid will include only the York River and adjacent bay. Hydrodynamic boundary conditions at the open edges of the grid will be derived from the hydrodynamic model. Water-quality boundary conditions will be derived from observations. This procedure will allow a large number of runs to be made rapidly. The York River will be calibrated to 1985-1987 data in one continuous run. Following calibration, the model will be run on the complete system-wide grid to evaluate performance throughout the bay.

Verification of the York River model will be conducted employing observations collected in 1994. The verification will be an individual, one-year run. Model conditions at the end of 1987 will be employed as initial conditions for the 1994 run. If this procedure is unsatisfactory, consideration will be give to a simulation of 1985-1994. Determination of the grid extent during verification (York River sub-grid or system-wide grid) will be made following evaluation of model performance and computational requirements.

James and Rappahannock Rivers

Calibration of the James and Rappahannock Rivers will commence shortly after calibration of the York. Calibration activities for all three tributaries will overlap. As with the York, calibration will be on sub-grids for the years 1985-1987. Verification of each river will be a one-year run for 1994.

Baltimore Harbor

Initial calibration of the Baltimore Harbor model will be to 1985-1987 observations. The monitoring data is limited to one station in the Patapsco and one in Back River. Further calibration and verification will be conducted against the 1994-1995 data as it becomes available.

Application to 1994-1995 requires loads generated by a watershed model simulation of those years. The hydrodynamic model must be run on the system-wide grid to set boundary conditions for the independent model. Employment of the 1994-1995 observations within the time frame of this project depends upon the availability of watershed model output and of runoff, meteorological, and other data needed to force the hydrodynamic model. We recommend that steps be taken now to ensure required inputs are available. Delay in delivery of required inputs will result in increased costs and delayed completion of the project.

Visualization

The present model produces overwhelming quantity of output. Additional state variables and grid revisions will multiply the existing output volume. A postprocessing and visualization package is required and will be developed as part of model refinements. Early in the project, incorporation of the model into the Corps FASTABS system will be explored.

Scenarios

Twenty final scenarios, to be specified by the Modeling Subcommittee, will be run. During the Three-Dimensional Model study, decade-long runs were required for sediments to achieve steady state. More lengthy runs may be required in the tributaries based on tributary residence time and local sediment burial rate.

Procedures for running the scenarios remain to be determined. One option for scenarios in Virginia tributaries is to run scenarios in each river using the system-wide hydrodynamic grid with emphasis in the subject tributary. A second option is to combine the fine grids in the Virginia tributaries into a single system-wide grid with fine resolution in all tributaries. The first option represents system-wide effects with minimum computational requirements. The second option increases computational requirements but produces optimum resolution of interactions between tributaries. A third, fall-back option is to run scenarios on tributary sub-grids using boundary conditions specified from the current three-dimensional bay model. The scenario procedure will be determined following tests of mass-transport interactions between tributaries and evaluation of resources.

Baltimore Harbor scenarios will be run on the fine grid using results of system-wide scenarios to specify boundary conditions. If system-wide scenarios are not run, boundary conditions will be specified by an alternate method, perhaps employing the existing model.

The computational requirements to run decade-long simulations on the system-wide grid with all model modifications are immense. Exact time estimates cannot be made without benchmarking the revised model but order-of-magnitude increases in computation requirements over existing scenarios are feasible. Scenario execution time may easily increase from the present 30 hours CPU time on a Cray Y-MP to 300 hours. A combination of high-tech and low-tech alternatives to consumption of 6000 CPU hours (250 days) for twenty scenarios need to be investigated.

Faster Computers

We currently have available a Cray C-90 which executes forty-percent faster than the Y-MP. Three years from now, still faster computers will be available. Alternate computers may also be considered. Early in the project, investigation of current model performance on a massive parallel processor will be conducted.

Revised Code

One option to reduce computation time is to update kinetics and sediment fluxes at less frequent intervals than each time step. No need exists, for example, to recompute SOD every hour. Daily updates will likely suffice. The benefits of less-frequent updates will be investigated. A "fix" to speed up the sediment model time to steady state was proposed during the Three-Dimensional Model Study and may be implemented in tributary refinement scenarios.

Revisions described above can be implemented by the WQM team. WES will also solicit advice and services of experts in optimizing the code. Optimization will be conducted in two phases. One round of optimization will be conducted at commencement of the project. The optimized code will be nearly identical to the existing code. Revisions will follow the pattern set by consultants to the EPA who halved the execution time of the present model. A second phase of optimization will be conducte. prior to production scenario runs. At this phase, the optimized code will be close to the final code developed for tributary refinements.

Reduced Grid

The system-wide grid can be overlaid to reduce the number of cells away from regions of interest. Another alternative is to run scenarios on the James and Rappahannock employing the subgrids developed for rapid tributary calibration. Boundary conditions would be specified by runs on only one of the system-wide grids, e.g. the York River grid. Yet another alternative is to run scenarios on a grid which includes the lower half of the bay only.

Chapter 5
Suspended-Sediment Activities

Suspended-Sediment Budget

The first step in modeling suspended sediments will be investigation of the suspended-sediment budget of the system. The primary objective is to determine if sources of sediment are known sufficiently to allow for a more advanced, mechanistic sediment model. Additional objectives are to indicate the fraction of the sediment inputs that are manageable and to investigate the feasibility of employing the water-quality model as a suspended-sediment model.

The existing water-quality model will be employed in a mass-balance accounting. The accounting will indicate if observed suspended sediment concentrations can be computed based on known sediment loads. Fall-line loads will be alternately derived from regression on observations and from the watershed model. Below-fall-line nonpoint-source loads will be derived from the watershed model, if available. Other below-fall-line sources, notably bank erosion, will be derived from best available information. Oceanic boundaries will be obtained from observations. Net settling will be specified based on measures of long-term burial.

Two classes of sediment will be considered, organic and inorganic. Observed organic solids will be derived from observations of particulate organic carbon in the data base. Observed inorganic solids will be determined as observed total suspended solids less organic solids. Predicted organic solids will be determined from presently modeled particulate organic carbon. Predicted inorganic solids will be computed by mass balance using the existing model suspended solids state variable.

Concentrations and spatial distributions of predicted and observed solids will be compared in the mainstem and tributaries. Predicted concentrations will indicate our ability to "balance the budget". Spatial distributions will provide a first look at the feasibility of predicting phenomena such as the turbidity maximum using the water-quality model.

Wind Resuspension of Sediments

Investigations indicate that submerged aquatic vegetation (SAV) is sensitive to short-term fluctuations in light extinction induced by fluctuations in suspended sediment. A primary agent of sediment fluctuations is wind resuspension. Consequently, a mechanistic representation of wind resuspension of sediments will be incorporated into the model of the littoral zone. The resuspension model will be based on existing data, primarily collected by VIMS in the York River. The relationship of light extinction to suspended solids will be based on existing data and on observations collected during enhanced tributary monitoring. The sufficiency of these data bases for model calibration and verification is unknown. Additional studies to measure wind resuspension in Virginia tributaries and Baltimore Harbor and to examine the relationship of light and solids are under consideration. Data developed in these studies will be employed as it becomes available.

Chapter 6
Coordinating Efforts

Development and calibration of the refined tributary and living-resource models will be supported by data in the data base maintained by the CBPO, by output from the Watershed Model, and by observations conducted specifically for the project. The present chapter summarizes the coordinating efforts required for successful completion of the study.

Existing Data

Upon commencement of the study, a detailed request for data will be presented to the CBPO. Most significant information to be requested is listed below.

Monitoring Data

Observations collected in the mainstem, tributaries, and fall lines by the monitoring program will be supplied by the CBPO to WES in the form of SAS datasets. In the event SAS datasets cannot be supplied, another format compatible with WES computers will be provided. Data must be supplied for 1985-1987 and 1994-1995, at least. Provision of all monitoring data, 1984 to date, is preferable, however. The data will be available for potential model extension and for purposes other than model data comparison.

Zooplankton and Macrobenthos

Zooplankton and benthic macrobenthos are monitored by the CBPO but are not routinely provided as part of the monitoring data base. Observations will be provided to WES in SAS data sets or other compatible format. To be of use, observations must be in units of biomass, preferably as carbon. If observations are supplied as number of organisms, suitable conversion factors to biomass must be supplied as well.

Submerged Aquatic Vegetation

Submerged aquatic vegetation acreage and density will be provided for years of record. Information will be provided for each model cell based on cell coordinates supplied by WES to the CBPO. Since several grids will be employed, multiple data requests will be completed.

Watershed Model

Water-Quality Calibration Years

Application of the water-quality model to the years 1985-1987 requires execution of the watershed model for the same years. Prior linkage of the watershed model to the water-quality model employed loads specified on a bi-weekly or monthly basis. Below-fall-line loads were distributed uniformly along the length of each tributary. Both the Three-Dimensional Model calibration report (Cerco and Cole 1994) and the first workshop (HydroQual 1993) called for increased temporal and spatial resolution of loads to the water-quality model. Loads can be readily input to the model on a daily basis. The workplan for Phase III Watershed Model efforts calls for refined spatial detail but not in Virginia tributaries. As an alternative, loads in below-fall-line watersheds will be allocated into major sub-basins. Loads outside major sub-basins will be uniformly distributed along the length of each tributary. Allocation of load into sub-basins will be conducted by the CBPO. WES will assign sub-basin loads to appropriate model cells.

Water-Quality Verification Years

Application of the water-quality model to observations collected in 1994-1995 requires execution of the watershed model for the same years. In view of the time required to assemble watershed model input data, plans should be made immediately to acquire the data. Otherwise, alternatives to employment of the watershed model need to be developed.

The 1985-1987 loads will be initially produced by Phase III of the watershed model. The 1994-1995 loads will be produced by Phase IV of the watershed model. Calibrating the water-quality model to Phase III loads and verifying with Phase IV loads presents potential problems. Results from the Phase IV version of the watershed model should be carefully checked by the CBPO for consistency with Phase III. If substantial differences exist, 1985-1987 loads must be produced from Phase IV and input to the water-quality model.

Point-Source Characterization

As part of the effort to refine loading information to the model, effluent characteristics will be measured at 42 facilities in Virginia and 12 in

Maryland. Substances to analyzed in the effluent are presented in Table 6-1.

Table 6-1
Concentrations Measured at Point Sources

Particulate Organic Carbon	Dissolved Organic Carbon
Particulate Organic Nitrogen	Dissolved Organic Nitrogen
Ammonium	Nitrate+Nitrite
Particulate Phosphorus	Total Dissolved Phosphorus
Dissolved Phosphate	

Loads from each point source will be computed by the CBPO on a monthly basis for the model application period. Monthly loads will be supplied to WES as SAS datasets or in compatible format.

Supporting Observations

Observations beyond the routine monitoring program will be conducted in the tributaries and, to a lesser extent, in the mainstem and Potomac. Collection in Virginia tributaries, the mainstem, and Potomac will be conducted primarily in 1994. Collection in Baltimore Harbor will be in 1994 and 1995.

Virginia Tributaries

Additional Stations. Monitoring stations will be added along the longitudinal and lateral axes of the tributaries. Additional lateral stations will be located within the littoral zone, halfway between the 2 m contour and the shoreline.

Additional Substances. Particulate inorganic phosphorus and particulate biogenic silica will be added to the suite of monitoring variables. These will be analyzed in all fall-line samples. The additional substances will be analyzed at all in-stream stations but for only half the surveys.

SONE Measures. Measures of sediment oxygen demand and nutrient flux will be conducted in two of the tributaries, the James and York. Measures in tidal freshwater will be conducted in the James only. Measures will also be conducted that compare fluxes in the channel versus littoral zone. Littoral zone measures will be conducted in light and dark to evaluate effects of benthic algae.

Baltimore Harbor

Additional Stations. The number of monitoring stations in the Patapsco River will be increased from one to nineteen. Monitoring stations in the Back

River will be increased from one to four.

Additional Substances. Particulate inorganic phosphorus and particulate biogenic silica will be analyzed at all stations. Samples will be collected in only a portion of the surveys, however.

SONE Measures. Measures of sediment oxygen demand and nutrient flux will be conducted at three stations in Baltimore Harbor.

Sediment Resuspension. A program is proposed to collect sediment and hydrographic data required to develop and calibrate a fully-predictive suspended-sediment transport model.

Mainstem Bay and Potomac

Additional Substances. Particulate inorganic phosphorus and particulate biogenic silica will be analyzed at all mainstem stations and depths at which nutrients are analyzed in the monitoring program. Particulate inorganic phosphorus and particulate biogenic silica will be analyzed at three stations in the Potomac. In both systems, samples will be collected in only a portion of the surveys.

Potential Additional Observation Programs

The workshops and subsequent meetings indicated numerous data collection efforts of value to the tributary refinements. Resources available when the program of extended tributary monitoring was planned did not allow for all data requirements to be fulfilled. Other data needs were not obvious when the extended monitoring was planned. A list of recommended programs has been prepared by the CBPO and will be considered by the Monitoring Committee. These include:

Detailed study of the relation of light absorbance and scattering to dissolved and suspended solids.

Measurement of sediment resuspension by wind in existing and potential SAV locations.

Additional SONE measures in tidal freshwater.

Measure of labile and refractory portions of dissolve organic matter at the ocean boundary.

Collection of continuous salinity observations for validation of exchange between littoral zone and main channel.

Living-Resources Workshops

The Living Resources Subcommittee of the Chesapeake Bay Program has sponsored numerous data collection and ecosystem modeling efforts. Observations and knowledge developed during these efforts are invaluable to the living-resource modeling proposed for the present study. Annual workshops will be conducted to promote cooperation and information exchange between investigators sponsored by the Living Resources Subcommittee and participants in the present study. The workshops will be organized by the CBPO or one of its contractors.

References

Cerco, C.and Cole, T. (1994). "Three dimensional eutrophication model of Chesapeake Bay," US Army Engineer Waterways Experiment Station, Vicksburg, MS.

DiToro, D., and Fitzpatrick, J. (1993). "Chesapeake Bay sediment flux model," Contract Report EL-93-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dortch, M. (1990). "Three-dimensional, Lagrangian residual transport computed from an intratidal hydrodynamic model," Technical Report EL-90-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

HydroQual. (1993). "Summary report workshops 1-3: model interfacing, living resource and ecosystem process modeling, suspended sediments/light attenuation modeling," USCE0212, HydroQual Inc., Mahwah, NJ.

Johnson, B., Kim, K., Heath, R., and Butler, L. (1991). "Development and verification of a three-dimensional numerical hydrodynamic, salinity and temperature model of Chesapeake Bay," Technical Report HL-91-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Park, K., and Kuo, A. (1993). "A vertical two-dimensional model of estuarine hydrodynamics and water quality," SRAMSOE 321, Virginia Institute of Marine Science, Gloucester Point, VA.

Thatcher, M., and Harleman, D. (1972). "A mathematical model for the prediction of unsteady salinity intrusion in estuaries," Report 72-7, Massachusetts Institute of Technology, Cambridge, MA.

Appendix
Time Lines and Budget

Coordinating Efforts

Task	Estimated Cost (K$)	1994 Q1	1994 Q2	1994 Q3	1994 Q4	1995 Q1	1995 Q2	1995 Q3	1995 Q4	1996 Q1	1996 Q2	1996 Q3	1996 Q4	1997 Q1	1997 Q2	1997 Q3	1997 Q4
CBPO Efforts																	
Receive zooplankton data from CBPO				■													
Receive SAV data from CBPO				■													
Receive monitoring data, 1985-1987				■													
Execute Phase III WSM 1985-1987			■	■	■	■											
Enhanced sampling in mainstem		■	■	■	■												
Sampling in VA tribs		■	■	■	■	■	■										
Sampling in Baltimore Harbor		■	■	■	■	■	■	■	■								
Receive mainstem samples								■									
Receive VA tributary observations								■			■						
Compute point-source loads								■									
Execute Phase IV WSM 1994									■								
Receive 1994 monitoring data								■									
Receive Baltimore Harbor observations, 1994									■								
Execute Phaes IV WSM 1995													■				
Receive 1995 monitoring data												■					
Receive Baltimore Harbor observations, 1995												■					
Living-Resources Workshops				■				■				■				■	

Hydrodynamic Model Efforts

Task	Estimated Cost (K$)	1994 Q1	1994 Q2	1994 Q3	1994 Q4	1995 Q1	1995 Q2	1995 Q3	1995 Q4	1996 Q1	1996 Q2	1996 Q3	1996 Q4	1997 Q1	1997 Q2	1997 Q3	1997 Q4
Hydrodynamics																	
Modify CH3D for minimum 1-layer grid	25		■	■													
Add littoral zone to CH3D	25		■	■													
Evaluate open-mouth boundary condition	25		■	■													
York River grid, revisions elsewhere	50				■												
Calibrate York River	75					■											
York River production runs, 1985-1987	25						■										
York River production run, 1994	15								■								
Sediment resuspension in littoral zone	100							■	■								
James River grid	25					■											
Calibrate James River	75						■										
James River production runs, 1985-1987	25							■									
James River production run, 1994	15								■								
Rappahannock River grid	25					■											
Calibrate Rappahannock River	75						■										
Rappahannock production runs, 1985-1987	25							■									
Rappahannock production run, 1994	15								■								
Baltimore Harbor grid	25							■									
Calibrate Baltimore Harbor Hydro Model	75								■	■							
Baltimore Harbor production runs, 1985-1987	25										■						
Baltimore Harbor production run, 1994	25											■					
Baltimore Harbor production run, 1995	25												■				
Reports	150										■	■	■	■	■	■	
Total Hydrodynamics	945	Yr 1 = 125				Yr 2 = 545				Yr 3 = 200				Yr 4 = 75			

Water-Quality Model Efforts and Summary

Task	Estimated Cost (K$)	1994 1	1994 2	1994 3	1994 4	1995 1	1995 2	1995 3	1995 4	1996 1	1996 2	1996 3	1996 4	1997 1	1997 2	1997 3	1997 4
Water Quality/Ecosystem Model																	
Solids budget	50		■	■													
Test model on parallel processor	10		■	■													
Optimize code	20		■									■					
Couple model to FASTABS visualization package	25			■	■												
Investigate boundary conditions	15		■	■	■	■											
Modify WQM to read specified suspended solids	50		■	■													
Add zooplankton, PIP to WQM	50		■	■	■												
Modify WQM for minimum 1-layer grid	100				■	■											
Model of littoral zone water column (SAV etc.)	150				■	■	■	■	■								
Revised sediment model (benthos, freshwater etc.)	150				■	■	■	■	■								
Compute solids effects on light extinction	50								■	■							
Combine sediment, littoral zone models into WQM	100								■	■							
Calibrate York River Model	150									■	■	■	■				
Calibrate James River Model	150										■	■	■				
Calibrate Rappahannock River Model	150										■	■	■				
Scenarios on individual grids	200												■	■	■	■	
Calibrate Baltimore Harbor WQM, 1985-1987, 94	150												■	■	■		
Verify WQM with 1995 data	25															■	
Reports	250															■	■
Total Water Quality	1845	Yr 1 = 305				Yr 2 = 330				Yr 3 = 685				Yr 4 = 525			
Project Contingency	210	Yr 1 = 50				Yr 2 = 50				Yr 3 = 55				Yr 4 = 55			
Total Project	3000	Yr 1 = 480				Yr 2 = 925				Yr 3 = 940				Yr 4 = 655			

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The Corps of Engineers, in partnership with the U.S. Environmental Protection Agency Chesapeake Bay Program Office, recently completed a three-dimensional model study of eutrophication in Chesapeake Bay and tributaries. The model package applied included an intratidal hydrodynamic model, an intertidal water-quality model, and a benthic sediment diagenesis model. This report comprises a workplan to improve model representation of Chesapeake Bay tributaries and to incorporate living resources directly into the model framework. Four tributaries have been selected for emphasis under this tributary refinements program. They are the James, York, and Rappahannock rivers, and Baltimore Harbor. The James, York, and Rappahannock were specified because tributary-specific models are required to address water-quality and living-resource benefits to be derived from nutrient reductions. Baltimore Harbor was specified because it presents unique management problems, coupled with long-term toxic impacts, which cannot be addressed in the current model framework. The time scale for the project is 4 years from initiation to completion. Anticipated commencement is April 1, 1994.

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Eutrophication	Phosphorus

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