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Work Plan for a Water Quality Model of Florida Bay

by Mark S. Dortch, Carl F. Cerco, Allen M. Teeter, Robert T. McAdory

Prepared for U.S. Army Engineer District, Jacksonville

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Final report

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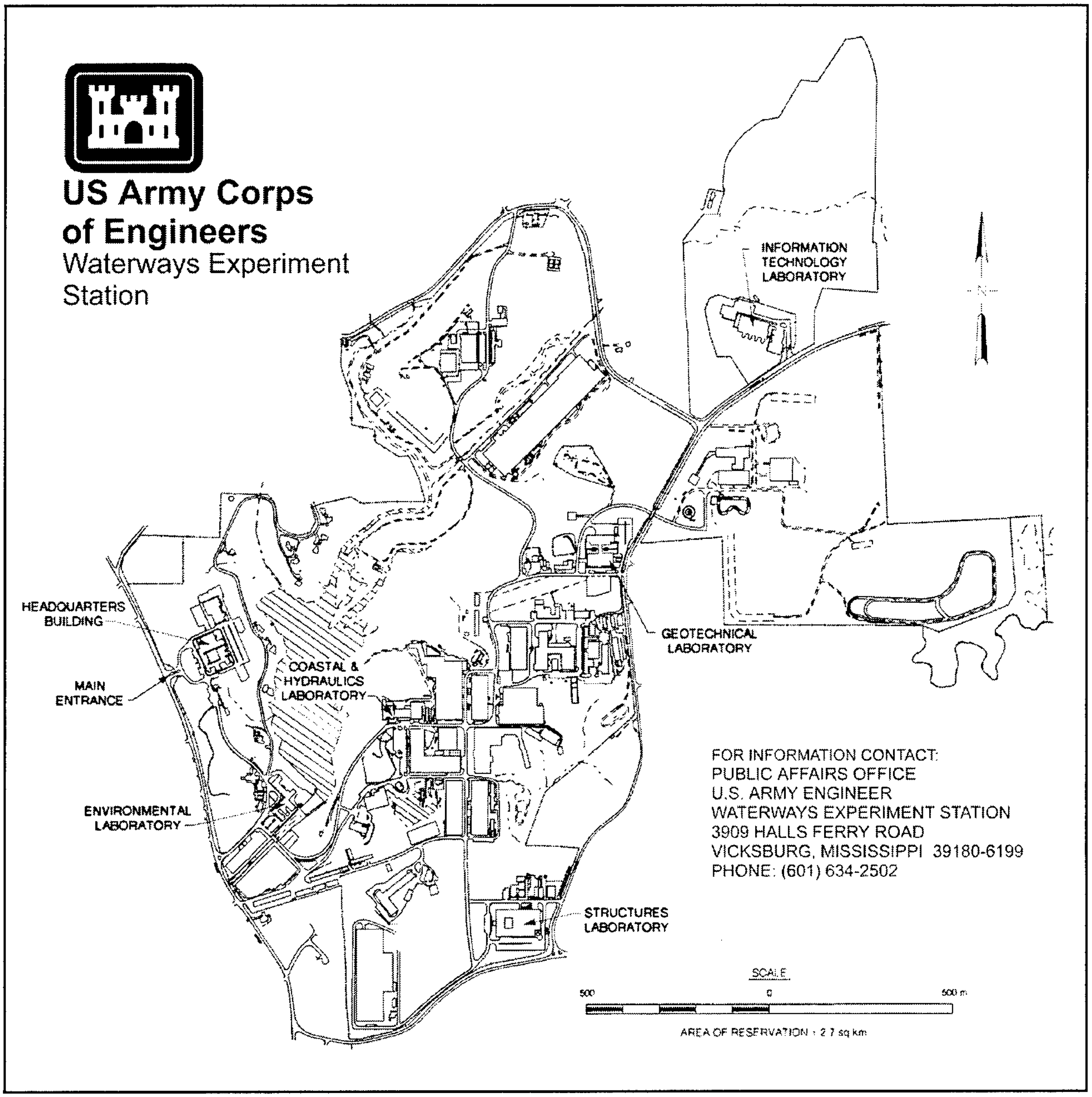

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Preface

The U.S. Army Engineer Waterways Experiment Station (WES) was requested by the U.S. Army Engineer District, Jacksonville, to prepare this report. The Jacksonville District is a partner in the Florida Bay Science Program. This report was prepared by Dr. Mark S. Dortch of the WES Environmental Laboratory (EL) with contributions from Drs. Carl F. Cerco, EL, and Robert T. McAdory of the WES Coastal and Hydraulics Laboratory (CHL), and Mr. Allen M. Teeter, CHL. Dr. Jeffery P. Holland, CHL, served as the overall WES point of contact for south Florida environmental model studies. This effort was coordinated through the Environmental Modeling, Simulation, and Analysis Center (EMSAC) of WES. Drs. John W. Barko and Holland are co-directors of EMSAC. Dr. Dortch served as team leader for work plan development.

The development of this work plan would not have been possible without the valuable information and insights on Florida Bay provided by various Bay scientists. The contributions of the Bay scientists are acknowledged and appreciated.

This report was prepared under the general supervision of Dr. John Harrison, Director, EL, and Dr. James R. Houston, Director, CHL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

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1 Introduction

Background

Concern for the ecological health of Florida Bay has increased dramatically in recent years. Symptoms of ecological degradation include die-off of sea grass beds, increases in algal blooms, increases in turbidity, deterioration of aquatic habitat, and decreases in the diversity and abundance of aquatic living resources.

Bay scientists have found that sea grass coverage has decreased substantially in the last decade. A major die-off of *Thalassia* occurred around 1987 following several years of dry, hot conditions that may have promoted disease. Various factors could have lead to plant stress, such as hypersaline water, high temperatures, and buildup of sulfide in bottom sediments. There was a second stage die-off around 1991 that the scientists think may have been caused by increased turbidity resulting from the loss of sea grass during the first stage of die-off. Wetter years have followed 1991, and sea grass die-off appears to have slowed some.

The concern for Florida Bay has lead to the formation of the Florida Bay Science Program to facilitate coordination and focus various State and Federally funded monitoring and research studies of the Bay. The general goals of the Florida Bay Science Program are to understand the Florida Bay ecosystem and guide its restoration. The program is directed by a Program Management Committee (PMC), which is composed of members from various State and Federal water resource agencies.

In addition to sea grass die-off, one of the primary issues surrounding Florida Bay is nutrient input, especially from freshwater sources. Thus, one of the elements of the Bay studies is associated with quantifying nutrient sources, fate, and effects. Nutrient related questions posed by the PMC include the following:

a. To what extent will increased freshwater flows into Florida Bay increase loadings of phosphorus and nitrogen?

b. What are implications for nutrient inputs to Florida Bay of shifting some of the distribution of freshwater flows from Shark River Slough to Taylor Slough?

c. What is the relationship of regional hydrological restoration to the quality of water reaching Florida Bay?

d. What is the relative importance of exogenous and endogenous nutrient sources in Florida Bay, and how is this likely to change with restoration?

e. To what extent are changes in nutrient loadings related to observed changes in sea grass and water column productivity?

f. What is the spatial pattern in nutrient limitation across Florida Bay and the causes and consequences of the differences?

g. What is the likelihood that increased freshwater flow into Florida Bay will adversely affect coral reefs?

A Florida Bay nutrient workshop was held on July 1-2, 1996, in Key Largo, FL, to exchange information and evaluate databases, research, and monitoring for deriving inferences about nutrient enrichment and how it might change as freshwater inflows increase in association with hydrological restoration of South Florida. A primary recommendation of the Science Oversight Panel convened for this workshop was that a numerical circulation-water quality model of Florida Bay should be developed to systematize data, pose hypotheses, and anticipate the effects of different water management scenarios. Specifically, the oversight panel recommended the model include the following:

a. Coupled hydrodynamic-nutrient-phytoplankton-water quality variability.

b. Suspended sediments and their influence on turbidity.

c. Sea grass populations and their influence on sediment resuspension, nutrient cycling, and geochemistry (Florida Bay Science Oversight Panel (FBSOP) 1996).

To respond to the need for a Florida Bay water quality model, the U.S. Army Engineer District, Jacksonville, requested the U.S. Army Engineer Waterways Experiment Station (WES) to assist with model technical scoping. This work plan is the result of the Jacksonville District's request to WES. A workshop on design and specification for a Florida Bay water quality model was held during October 22-24, 1996, in Key Largo, FL, to facilitate the model scoping effort (See Appendix A for workshop agenda). Recommendations from the October workshop are incorporated into this work plan and are also presented in Appendix A. This work plan has been written to address the recommendations provided by the Model

Evaluation Group for the October workshop (Appendix A). The tasks and schedule for the study completion of the modeling project components are provided in Appendix B. Following the first draft of the work plan, the PMC and various Bay scientists reviewed and commented on it. The review comments are provided in Appendix C. This final version of the work plan contains revisions based upon the review comments. The manner in which each comment was addressed is described in Appendix C.

Objectives

The objective of this report is to formally articulate the plans and specifications for development and application of a Florida Bay water quality model. The work plan also suggests specific field and laboratory studies needed to support model development.

The overall objective of the proposed model is to evaluate the impact of human actions and natural events on Florida Bay water quality. Water quality for Florida Bay should not be limited to nutrients and phytoplankton interactions, but it must also include the effect of water quality on sea grasses and vice versa. However, the focus of the model is on water quality issues rather than living resource issues. This model will be used to investigate various questions posed by the Florida Bay Science Program and its PMC, such as the following:

- How will alterations in freshwater flows affect Bay water quality and sea grass?
- What is the relative importance of various nutrient loading sources on Florida Bay water quality?
- How is sea grass related to changes in nutrient loadings?

The model can be used to investigate the relationship of sea grass to water quality conditions and vice versa, but it may not be able to simulate species competition and succession. Other types of models may be more suitable for these purposes. The model can potentially be used to explore die-off factors related to salinity, thermal, and sulfide stress, nutrient enrichment, and increased turbidity associated with sediment resuspension. However, the model should not be expected to determine the cause of die-off, especially when it might be disease-induced. Although the model can be used to determine the export of nutrients through the Keys towards the reef track, the model cannot be used to evaluate the impacts of nutrients on coral. In general, models such as this have a variety of uses and benefits as shown in Table 1. Specifically, the model must have the capabilities listed by the October workshop Model Evaluation Group (MEG) in paragraphs 1 and 2 of the Summary and Recommendations, Appendix A.

Table 1 Model Uses and Benefits
Developing an improved understanding of the system
Investigating the fate of nutrients, e.g., export to the reef track
Conducting sensitivity tests on various questions
Investigating the impacts on circulation, water quality, and sea grass of various management options
Investigating the impacts of varied hydrology and meteorology on water quality and sea grass
Investigating the relative importance of biogeochemical processes
Fostering synergism with other studies of the system
Focusing data needs and monitoring design

The components of this modeling project include the following:

- Hydrodynamic model.
- Wave model.
- Sediment transport model residing within the water quality model.
- Model linkages.
- Water quality model, including its submodels (water column, benthic sediments, and sea grasses).
- Model application, including calibration/confirmation, sensitivity testing, uncertainty analysis, and scenario testing.
- Technology transfer.

Each of these components is discussed in their respective chapters of this report along with tasks and schedule for the study completion (see Appendix B).

Specific models are discussed in this work plan so that rather definite recommendations and plans can be formulated. It is difficult to provide meaningful plans without a firm understanding of the capabilities of models to be potentially used for a study. Two hydrodynamic models are discussed, RMA10-WES and CH3D-WES. The presumed water quality model for use in this study is CE-QUAL-ICM (ICM). These models provide most of the required capabilities. Other models could be used as long as they possess the same capabilities and meet the requirements of the study. However, for the sake of discussions, these models are referred to throughout this report.

2 Overall Strategy

Study Procedure

In general, the procedures in a numerical water quality model study are as follows:

a. Conceptualize the model (i.e., determine general model features, attributes, and processes that are required).

b. Develop and/or modify the model code to include any new features and processes.

c. Establish and test model linkages, such as linkage to the hydrodynamic model if it is external to the water quality model code.

d. Prepare data for model input.

e. Estimate and set model parameters (e.g., model rate coefficients).

f. Test/verify any new model features to ensure proper implementation.

g. Calibrate the model.

h. Confirm the adequacy of the model using different conditions from those used for calibration.

i. Assess the accuracy of the model (i.e., skill assessment).

j. Conduct sensitivity tests and possibly evaluate model uncertainty.

k. Conduct scenario tests to evaluate management alternatives or other issues.

l. Transfer technology by providing briefings, written reports, documentation, videos, training, and software.

The above procedures will apply to this study. Additionally, many of the above procedures also apply for other model components, such as the hydrodynamic model that is used to drive the transport terms of the water quality model. Although not shown explicitly above as a modeling procedure, it should be recognized that the degree of success realized in any water quality model study depends heavily on frequent scientific exchange and dialog between the modelers and the local scientists studying the bay.

Model Conceptualization and Components

Comprehensive water quality models generally include water column state variables and processes for a wide range of constituents, such as salinity, temperature, suspended solids, light climate, dissolved oxygen, various forms of carbon, nitrogen, phosphorus, and silica, and multiple phytoplankton groups. With the development of benthic nutrient and carbon diagenesis models, such as the model developed by DiToro and Fitzpatrick (1993), the water column can be dynamically coupled to benthic nutrient and carbon cycling, and sediment oxygen demand can be predicted rather than specified. Additionally, various models of sea grass biomass with coupling to light, temperature, nutrients, sediments, and epiphytes have been developed and implemented within water quality models. A Florida Bay water quality model should include water column, benthic, and sea grass components, as well as suspended sediment and its effect on light. Since the sediments of Florida Bay are composed predominately of calcium carbonate as described by Halley and Prager at the model scoping workshop (October 1996), it was recommended by the workshop participants that carbonate chemistry, including the calculation of pH, be included in the model. It was also recommended that benthic algae be considered for the model.

Sea grasses are of central concern. However, detailed physiologically based models of the various sea grass species known to be present now or in the past are not appropriate at this initial stage of modeling. It was agreed at the workshop that two generic types of sea grasses should be modeled that represent the slowly spreading *Thalassia* and the rapidly spreading *Halodule*. The model formulations will be rather generic, but tolerance to salinity, temperature, and pore water sulfide concentration will be included. However, the disease-related start of die-off will be externally imposed on the model if necessary to reproduce observations. The sea grass models should also have dependence on water column and benthic nutrients, temperature, and light as impacted by depth, dissolved and suspended matter, self-shading, and epiphyte shading.

Resuspension and deposition of sediment are important since sediment affects water clarity, which affects sea grass growth, and phosphorus transport. Thus, it will be necessary to provide suspended solids resuspension and transport with its effect on light attenuation, in addition to other substances that can affect light, such as phytoplankton, detritus, and dissolved organic carbon. Thus, a suspended sediment modeling component will be required. It is not intended that the sediment transport component compute changes in the morphology of the Bay or the effects of hurricanes on reinitializing the system. For this model to be successful, it is only necessary to reproduce suspended solids concentrations with the associated effects on light extinction and phosphorus availability. Modeling suspended solids will require simulating particle resuspension, transport, and deposition.

Bottom shear stresses for sediment resuspension due to currents and wind-driven waves will be computed. The hydrodynamic model can provide information on currents, and a wind-wave model can be used to develop the wave climatology. Since currents, waves, and sediment resuspension are influenced by sea grass coverage as discussed at the workshop (Koch), a method for factoring in these interactions will be required.

In summary, the following model components will be required:

- Hydrodynamic model (HM).
- Wave model.
- Water quality model (WQM), including water column and benthic components.
- Sediment transport model (SM) within the WQM.
- Sea grass model within the WQM.

The linkages of these various components are discussed in the next section, and the details of each are covered in following chapters.

Challenges

There are several aspects of Florida Bay that create challenges when considering development of a model. The physical features and bathymetry of the Bay's keys, mud banks, channels, and submerged lakes (or basins) present a significant challenge to describe with a numerical model grid or mesh. The spatial scale of these features vary from the order of meters to kilometers. It is difficult to attain enough resolution to describe these features while maintaining a computationally manageable number of grid cells.

The interrelationship of hydrodynamics, wind-driven waves, sediment resuspension, and sea grass coverage presents a modeling challenge. As mentioned above, sediment is resuspended by currents and waves. Suspended sediment affects light which affects sea grass growth. Sea grass coverage affects currents, waves, and sediment resuspension. As an extreme case, one could envision hydrodynamic, wind-wave, sediment transport, and sea grass models all dynamically linked with feedback from one to another. However, such a complex dynamic coupling could quickly render the model too unwieldy for practical application. The key for creating a usable, reliable model is to determine what processes are of primary importance and provide those dynamic linkages only where necessary.

Changes in benthic sediments and sea grass occur gradually over years, so long-term simulations will be required to evaluate the effects of management strategies. It is anticipated that it will be necessary to run the model for approximately decadal periods to evaluate management impacts. The requirement for long-term simulations imposes additional complexity and computational demands on an already complex model.

Data limitations and inadequate understanding of some processes and parameters also present a technical obstacle to development and application of such a model. A key to successful development of the model rests in the ability to integrate modeling with data collection, monitoring, and process-level investigations. Model sensitivity and uncertainty analyses must also be included in studies such as this.

Each of the above technical challenges must be addressed for the Florida Bay model and are discussed in this work plan. However, it must be realized that the complexity of this system makes it impossible to specify a priori all of the best model features and design. A certain amount of testing and evaluation will be required to determine the best approach for some components.

Model Linkages

If all of the above model components are considered to interact, then the model linkages shown in Figure 1 would exist. The WQM of Figure 1 contains the water column component integrated with the benthic sediment and sea grass components, which all interact together. The HM provides currents for the WQM and the SM. The wave model provides the wave climatology to the SM. With currents and wave conditions, bottom shear stresses can be calculated for sediment resuspension in the SM. Suspended sediment information is provided by the SM to the WQM. Feedback on changes in sea grass coverage computed within the WQM is provided to the HM and wave model for the next iteration. The dynamic feedback linkages of Figure 1 constitute a complex and unwieldy model package, especially when considering the need to conduct long-term simulations.

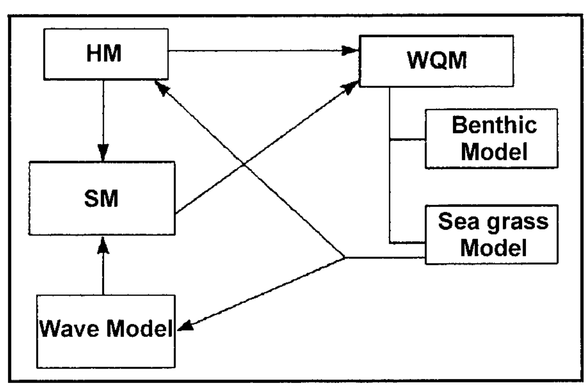

Figure 1. Schematic of comprehensive model system

Three simplifications to Figure 1 can be explored. The first simplification is to embed the SM within the WQM so that all dynamic feedback interactions related to suspended sediment, water quality, light, and sea grass are taken care of within the same code during execution. The second simplification is to assume that changes in currents due to predicted changes in sea grass coverage have an insignificant impact on water quality and sediment transport. This assumption can and should be tested for self consistency as explained in Chapter 5. It is suspected that currents have a minor effect on sediment resuspension when compared with erodibility caused by waves. If this second simplification is justified, then feedback from the sea grass model to the HM can be eliminated. The third simplification calls for eliminating the feedback from the sea grass model to the wave model by building a linkage from the sea grass model directly to the SM, both of which would be dynamically linked within the WQM. The wave model is still required to provide basic information on wave conditions. However, the wave effects on sediment resuspension as influenced by changes in sea grass coverage must be accounted for within the SM, resident within the WQM. The approach for this third simplification is discussed further in Chapter 5.

The three simplifications discussed above results in the model linkages shown in Figure 2. For this configuration, all feedback linkages are handled within the WQM, which greatly simplifies the model package. It is pointed out that wind climate information must feed the HM and wave climate model.

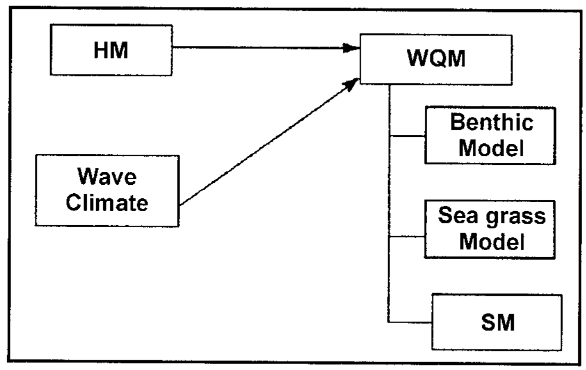

Figure 2. Schematic of simplified model system

Dimensionality and Domain

The model must include at least the two planform dimensions. There are questions as to whether the third (vertical) dimension is required. The general consensus is that vertical discretization is not required due to the shallowness of the Bay. Little or no vertical stratification is observed over most of the Bay. There is some vertical stratification in the western part of the Bay where the water is deeper, but this is considered to have a minor impact on circulation and water quality over the remaining portions of the Bay. Thus, the plan is to use a vertical-averaged two-dimensional modeling approach. The hydrodynamic and water quality models recommended for this study have the capability to run in three dimensions if required.

The model domain should be bounded by the Everglades on the north, the Gulf of Mexico on the west, and the Keys from the northeast to the southwest. The domain should actually extend beyond the Keys slightly to provide an open ocean boundary condition rather than conditions at the passes to the keys. The westward boundary should extend far enough west to allow flow from the western coast of Florida southeastward toward the Bay. The suggested model domain is shown in Figure 3.

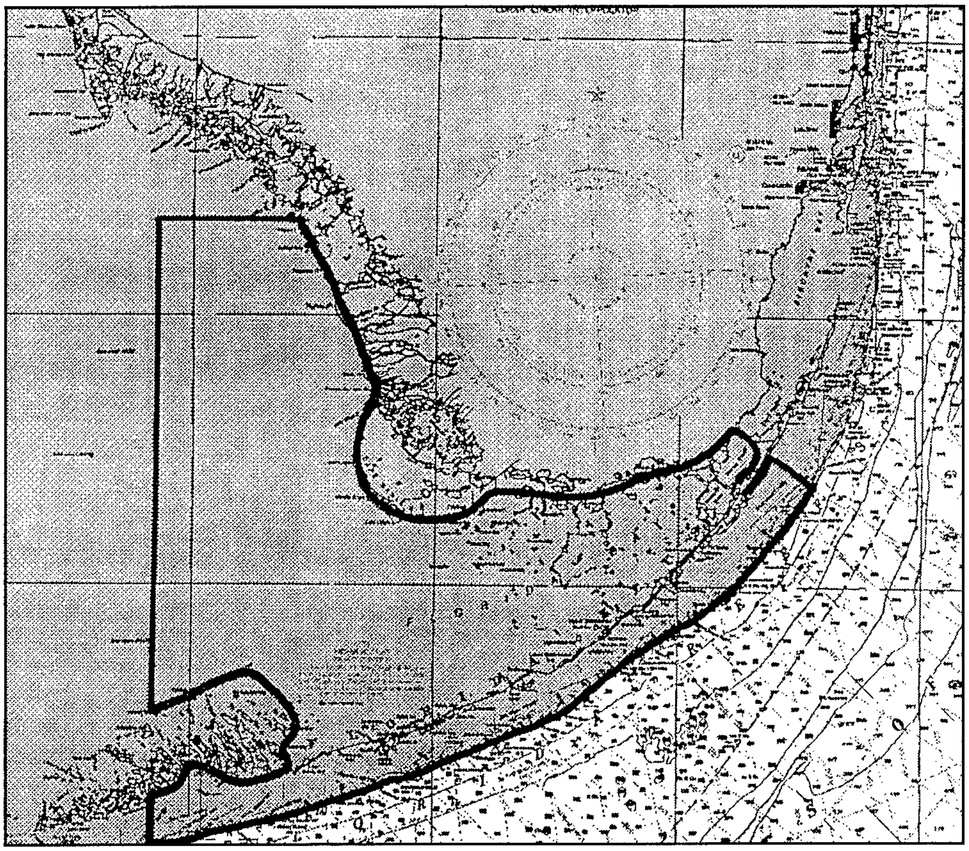

Figure 3. Suggested Florida Bay model domain

With the recommended domain, freshwater flows and nutrient loadings from the Everglades into the Bay will be treated as model loading input rather than a part of the model simulation. The mangroves will not be treated as part of this model. Thus, it will be necessary to accurately quantify the freshwater sources as modified by the mangroves through other means, such as using measurements coupled with regression models or possibly an Everglades simulation model. Atmospheric and groundwater inputs from the mainland and the keys will also be treated as loading input.

3 Hydrodynamics

General Approach

Water quality modeling of Florida Bay requires hydrodynamic circulation with which to advect system constituents that are of interest to understanding biological and chemical processes in the Bay. Results provided by a verified HM are also important for gaining insight into fundamental questions regarding the circulation and salinity regime of the Bay. Because the Florida Bay system possesses unique features, the HM must provide adequate detail of the complex system geometry of basins, channels, and emergent and submerged mudbanks. Horizontal salinity gradients are significant and can influence Bay hydrodynamics and water quality; thus, salinity must be modeled and coupled to hydrodynamic baroclinic pressure terms through water density. In addition to baroclinic pressure terms, the HM must also include evaporation, flooding and draining, subsurface and surface delivery of fresh water to the system, and all other necessary boundary conditions.

The structured grid, finite difference hydrodynamic model CH3D-WES is recommended for developing flow fields to drive the Florida Bay WQM. The initial application of the model will be with one layer throughout. If vertical resolution is determined to be necessary, the model can easily be extended to multiple layers. Successful application of the WQM requires linkage of the HM and WQM: flow rates (cubic meters/second), water depths, surface areas, and water volumes for all WQM cells must be provided from the HM calculations. The ICM WQM has been successfully linked to CH3D-WES in many other model studies to provide high quality results on which sponsors could base sound engineering and planning judgments. CH3D-WES has been successfully verified and applied in a wide variety of WQM efforts and has been proven to be a reliable production tool for the study of estuarine water quality (WQ) issues. The CH3D-WES model verification results will be assessed against predefined criteria to judge its acceptability for this study.

As part of a separate study, the RMA10-WES finite element HM is being applied by WES for the Jacksonville District to determine the effects of freshwater flow alterations on Florida Bay salinity. This ongoing study will be used in support of the CH3D-WES hydrodynamic and salinity modeling effort. This RMA10-WES Florida Bay model utilizes a high-resolution, unstructured grid and will be used to guide grid refinement and application of the CH3D-WES hydrodynamic modeling in the WQ effort as envisioned in this work plan. Though research is now underway to make finite element hydrodynamic and salinity results such as those in the RMA10-WES study available for use in WQ models such as the ICM model (Carey et al. 1997; Carey, Bicken, and Carey 1997), the current state of the art requires a CH3D-WES type model for hydrodynamic calculations. As new technical resources become available, however, they will be reviewed for possible application in the WQ effort to ensure the best possible study products.

Since the RMA10-WES study is available, it will be used specifically for general guidance of the modeling effort since elements of unstructured grid models like RAM10-WES can be placed in any fashion, thus providing modelers with the ability to use high resolution where required without being forced to carry that resolution throughout other grid regions. Such an unstructured grid scheme thus makes it relatively easy to resolve irregular features, such as mudbanks and cuts. Use of the existing RMA10-WES model will, then, provide much insight into the need for detailed resolution of the geometric features of the system and will provide a comprehensive database for evaluating attempts to reduce resolution within the structured grid CH3D-WES model. In addition to providing a comprehensive hydrodynamic database with which to guide the construction of the structured grid CH3D-WES model, the existing RMA10-WES model can be used to provide broad-scale circulation fields during early phases of water quality model development (e.g., for the initial nutrient budget analysis) and to provide insights regarding sensitivity of circulation/transport to boundary conditions and resolution of particular system features.

Considerable computational resources will be required to conduct long-term (e.g., 10 years) simulations of Florida Bay. Major efforts are presently underway at WES and elsewhere to convert models to massively parallel computers to meet computational demands for studies such as this. Study progress can be facilitated further by making every effort to reduce computational requirements. For this reason, it would be wise to relax the HM grid resolution as much as possible. The determination of the minimum acceptable level of grid resolution for CH3D-WES will be guided, in part, through analysis of the existing fine-grid RMA10-WES model results, as discussed above. In the past, the same grid resolution has generally been used for the CH3D-WES and the ICM grids. New projection tools under development, however, will allow projection of hydrodynamic results from one computational grid to another in such a way that mass conservation and other attributes of the original grid are preserved (Carey et al. 1997; Carey, Bicken, and Carey 1997). Such a tool could be used to allow a higher density hydrodynamic grid to pass accurate hydrodynamic results to a lower density WQM grid. Such resolution reduction is also possible through a careful choice of overlying grids. However, it is envisioned that a one-to-one HM-WQM grid correspondence will be used at the outset of this study.

Numerous studies involving Florida Bay modeling and field data have been performed or are underway to shed light on the complex modeling needs of the system. Information on a large sampling of these studies can be found as part of the "Florida Bay Abstracts" on the Florida Bay web page http://flabay.saj.usace.army.mil/abstract.htm. Of particular interest from the modeling perspective are entries by Galperin, Luther, and Haines (1995); Nuttle et al. (1995); Sheng, Davis, and Liu (1995); Wang and Monjo (1995); Wang and Lee (1995); Lee and Johns (1995); Roig and Richards (1995); and Roig (1996). Additionally, Sheng and Davis (1996) report on the results of modeling efforts in Florida Bay. These and other resources will continue to be reviewed for insights and help in modeling the complex Florida Bay system.

Model Descriptions

CH3D-WES (Curvilinear Hydrodynamics in 3 Dimensions - WES version), as detailed in Johnson et al. (1991, 1993), makes a combination of one-dimensional (1-D), 2-D, and/or 3-D free-surface flow computations in virtually all types of water bodies. The use of nonorthogonal curvilinear (boundary-fitted) coordinates in the horizontal plane allows for a better representation of boundary geometry and internal features such as channels and islands. An example of a boundary-fitted grid of Upper Chesapeake Bay and Delaware Bay is provided in Figure 4. Sufficient resolution yields an accurate replication of system geometry/bathymetry.

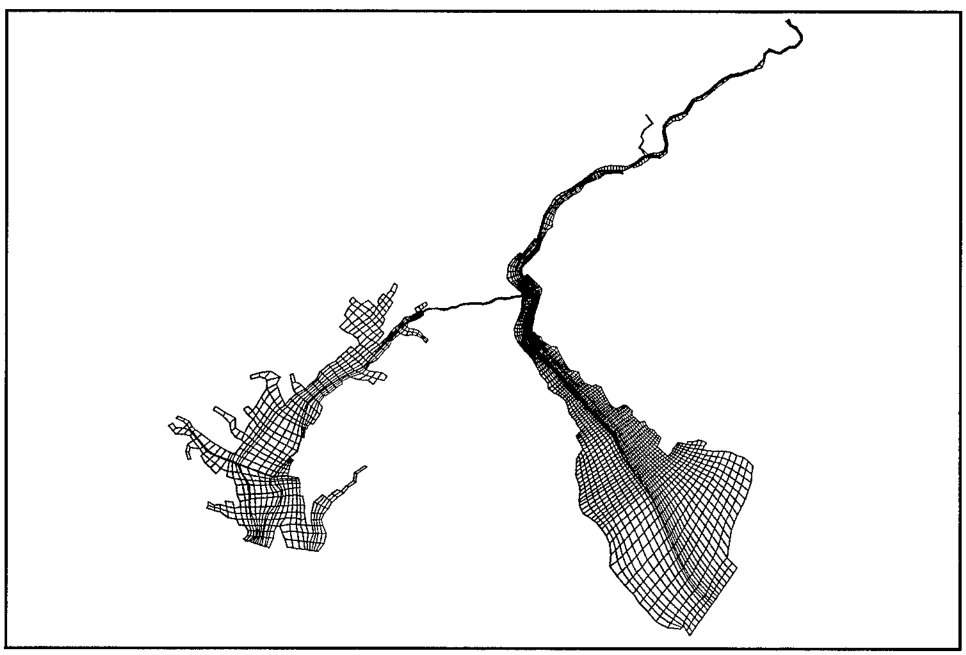

Figure 4. Boundary-fitted planform grid of Delaware Bay

Density effects due to salinity and temperature are fully coupled with the developing flow field in CH3D-WES calculations. Thus, advective diffusion equations for salinity and temperature are solved along with the conservation of mass and momentum equations for the flow field. An equation of state relates the water density to the salinity and temperature fields. Surface heat exchange is modeled through the concept of an equilibrium temperature. Turbulence is modeled through the concept of eddy viscosity and diffusivity. Vertical coefficients are determined through the modeling of the growth and decay of turbulent kinetic energy, i.e., a k-, model. A Smagarinsky formulation is incorporated in the horizontal plane.

The numerical solution scheme is a split mode one. An external mode makes computations for the water surface that is then used to compute the barotropic contribution of the horizontal pressure gradient in the internal mode 3-D computations. The external mode computations are made using an implicit factored finite difference scheme. In the internal mode, only the vertical diffusion terms and the bottom friction are treated implicitly. All computations are made on staggered grids, and mass is absolutely conserved over each individual cell. For 2-D depth-averaged applications, only the external mode is used. CH3D-WES has been successfully applied with the CE-QUAL-ICM water quality model in many different studies over the past 7 years. Examples of these include Los-Angeles and Long Beach Harbors (Hall 1990), Chesapeake Bay (Dortch, Chapman, and Abt 1992; Johnson et al. 1993; and Cerco and Cole 1993), lower Green Bay (Mark et al. 1993), New York Bight (Hall and Dortch 1994), Indian River - Rehoboth Bay, Delaware (Cerco et al. 1994), and Newark Bay (Cerco and Bunch 1997).

The RMA10-WES model (Norton, King, and Orlob 1973; Thomas and McAnally 1990) is a finite element, unstructured, 1-D, 2-D, and 3-D hydrodynamic and salinity surface water model. The application in Florida Bay uses the model in 2-D, depth-averaged mode, and with coupled hydrodynamics and salinity to account for horizontal density effects. As with the CH3D-WES model, RMA10-WES can be extended to 3-D as necessary. The RMA10-WES model is based on a finite element representation of the physics of shallow water tidal phenomena, incorporating the Reynolds averaged Navier-Stokes equations, the continuity equation, and an advection-diffusion equation for salinity. RMA10-WES is one of a suite of WES multidimensional models capable of performing hydrodynamic, salinity, and sediment modeling with capabilities such as wetting and drying and evapotranspiration. The model suite has been applied to well over a hundred sites and is supported by a sophisticated graphical user interface (GUI) for simplifying model setup and displaying solutions. This GUI is also being improved to allow use with CH3D-WES and ICM solutions. The RMA10-WES modeling effort described earlier is part of a comprehensive water resource management study of south Florida. The grid being used for the Jacksonville District Florida Bay circulation/salinity study is shown in Figure 5. The model is being validated against two field data sets in Fiscal Year 1997.

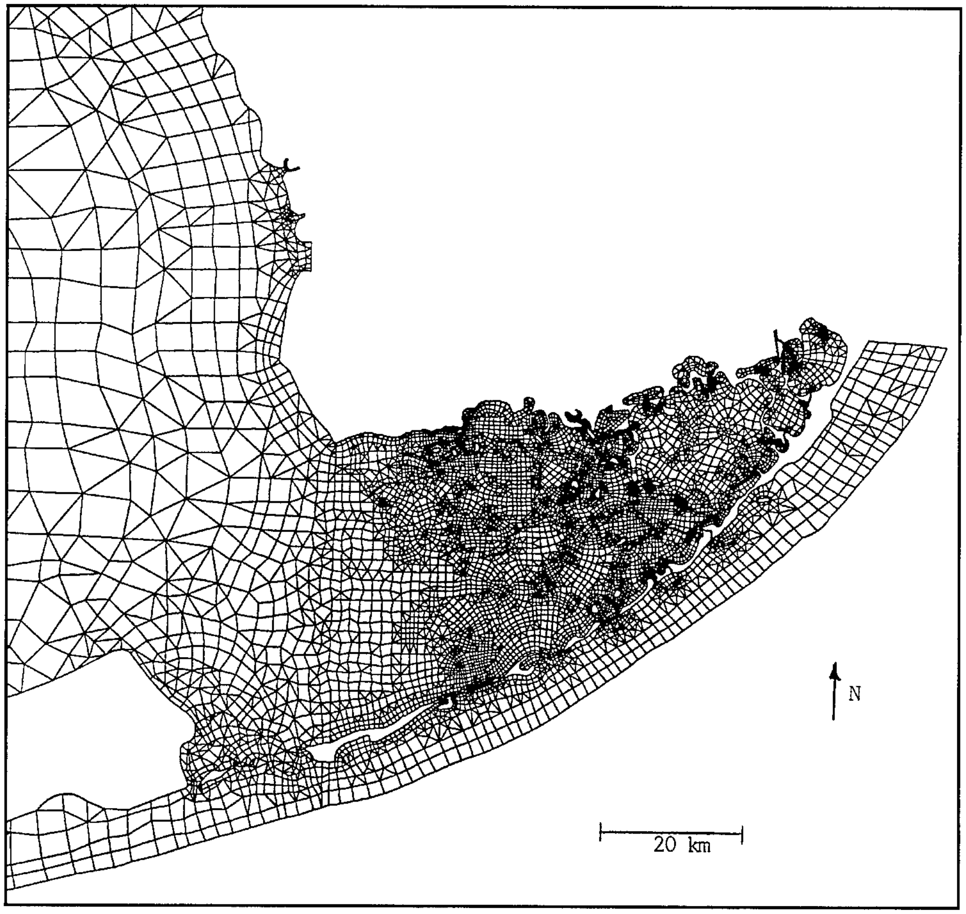

Figure 5. Mesh of the existing Florida Bay hydrodynamic model

Grid

The CH3D-WES HM grid will not have the high degree of resolution along the cuts and mudbanks that is provided by the existing RMA10-WES model grid, which has about 13,000 elements, due to the more evenly distributed cells associated with a structured grid. Sheng and Davis (1996) applied a version of CH3D to Florida Bay for tidal circulation using a 98 by 75 grid with a minimum resolution of 100 m. They were able to capture reasonably well the coamplitude chart of the M_2 tidal constituent. The Sheng model indicated that perhaps more resolution was needed in the eastern bay to properly represent the dissipation caused by the mudbanks. Sheng's model had approximately 5,000 active surface layer (i.e, planar) cells, and it is anticipated that the grid for the Florida Bay water quality modeling project must have at least this amount of resolution.

It is not possible to say a priori how many grid cells will be required for this study, although grid density will be greater in the eastern and central bay than in the western bay and gulf. Additionally, smaller grid cells will be required to resolve cuts through the keys. It is questionable how well individual channel cuts through the mudbanks can be resolved, however, so it may be necessary to use the RMA10-WES model to guide adjustment of CH3D-WES model roughness over the banks to pass the proper amount of water among the basins.

A grid of 5,000 or more cells does not present an excessive computational challenge for long-term hydrodynamic and water quality modeling using CH3D-WES and ICM. For example, 10-year simulations are being conducted on Chesapeake Bay with these two models where the grid is approximately 10,000 cells and is 3-D (multilayered). Considerably less computer resources will be required if Florida Bay can be modeled in 2-D, rather then 3-D. Three-dimensional resolution may be required in the western bay to preserve the variations in salinity and currents over the depth. This need will be explored.

Model Verification

The term model verification is used here to refer to the process of making model adjustments and comparing model results against observations to judge the level of model accuracy achieved. This process has also been referred to as model skill assessment, model confirmation, and model validation. The RMA10-WES HM of Florida Bay will be verified during the ongoing study for the Jacksonville District. Verification to field data involves a succession of comparisons and model adjustments to match field data for tides, current velocities, and salinity, as well as qualitative behavior indicative of the estuarine system, so that the features of the physical system deemed important to the study goals are reproduced sufficiently well for good engineering and planning decisions to be made from a use of the model to make base and plan type comparisons.

The CH3D-WES HM for Florida Bay will be adjusted during the water quality model study using the same verification data used for the RMA10-WES model. Verification will follow the patterns set out in other studies such as, for example, the Chesapeake Bay effort by Johnson et al. (1993) or the Galveston Bay effort by Berger, Martin, and McAdory (1995) and Berger et al. (1995). Verification results from the Florida Bay effort will be compared with these and other relevant verification efforts. Results from the fine-grid RMA10-WES model will be consulted to aid in the verification process.

Synoptic data sets such as that provided by Pratt and Smith (in preparation) will be used, along with National Park Service data sets for the same time period from stations in Florida Bay, in the verification process. The Pratt data are being analyzed further by Smith (1997a,b,c), and these analyses will also be used in the verification process. The web site mentioned above also contains information on numerous data-collection and analysis efforts in Florida Bay, such as Maul (1995); Smith (1995); Vargo, Ogden, and Humphrey (1995); and Wang and Lee (1995). Information on groundwater, hydrology, freshwater inflows, meteorological forcing, and Florida Bay flows and interactions with surrounding waters is also presented at the web site.

Following model verification, CH3D-WES results will be evaluated against explicit criteria to judge if successful verification has been achieved. Relative mean absolute error (RMAE) will be used for these criteria. RMAE is computed as the mean of the absolute errors (i.e., difference in predicted and observed values) divided by the mean of observed values; thus, it is the mean absolute error relative to the observed mean. RMAE is especially useful in computing performance between variables of different magnitude or performance of models of different systems.

The following criteria will be used to determine if successful HM verification has been achieved. Water surface elevations and velocities will be decomposed into their major harmonic constituents, e.g., the M2 constituent. The RMAE of the amplitudes of the major constituents of the water surface elevations must bee less that 0.10, with similar RMAE for the phases. With point velocities generally being more difficult to reproduce in a finite size numerical grid, the amplitudes of the major constituents must have an RMAE less that 0.20, with an RMAE for the phases being less that 0.10. The RMAE for the salinity will be less than 0.10.

4 Sediment Resuspension

This chapter describes data compilation and modeling related to sediment resuspension. Florida Bay water quality and submersed aquatic vegetation issues are related to water column turbidity and particulate resuspension. To address water quality and sea grass issues, simulations of sediment resuspension will be required. To perform this modeling, new capabilities will be added to the WQM, and information on winds and waves will be assembled for model input. Transport and resettling of resuspended sediment can be handled within the WQM similar to other constituents. The sections to follow describe background information on resuspension; development of wind climate for use by the HM and resuspension module; wave information at offshore stations and development of wave climate within the Florida Bay study area; the resuspension model module; and resuspension module adjustment and verification.

Background

Sediment resuspension and transport are important to water quality in Florida Bay mainly as they impact water clarity and light penetration to sea grasses. Areas bare of sea grass are prone to resuspension that can appreciably decrease water clarity and may prevent sea grass establishment or cause further sea grass decline. On the other hand, sea grass beds slow water movement, damp waves, and trap and hold sediments. Thus, there are feedbacks between the presence of sea grass, water clarity, and the establishment of new sea grass. These interactions are shown schematically in Figure 6.

Resuspension is driven by bed shear stress generated by tidal and wind-driven currents and by wind waves. Tidal currents are generally weak except through bank cuts and passes. Wind-forced currents with subtidal periods may be very important to circulation and flushing. Winds commonly move larger volumes of water than do tides in the interior of Florida Bay (Enos 1989), and 85 percent of alongshore velocity variance on nearby West Florida Shelf is in the subtidal frequency band (Mitchum and Sturges 1982).

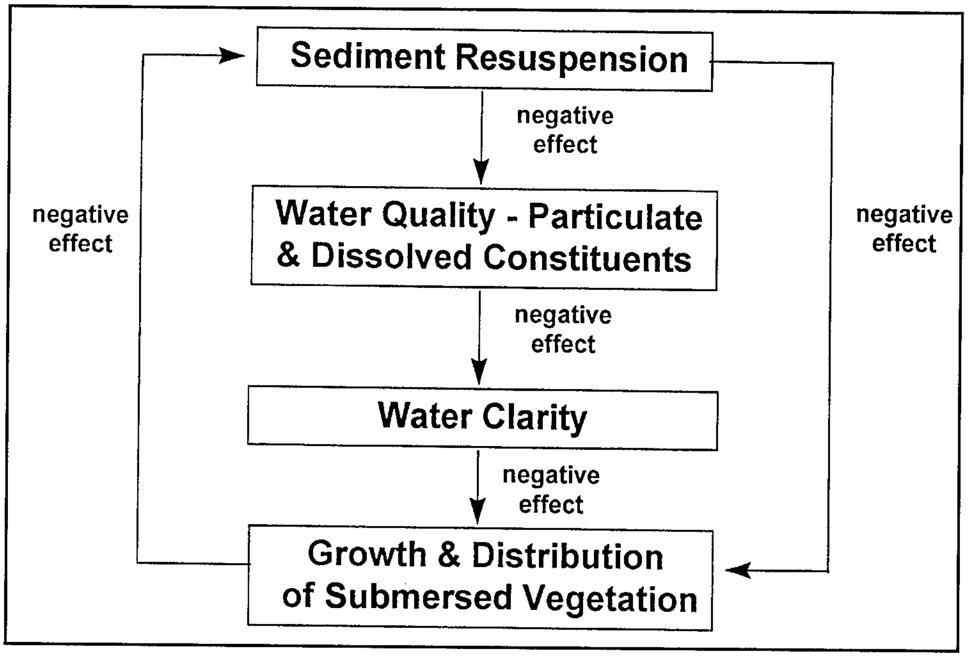

Figure 6. Sediment resuspension, water quality, and aquatic vegetation

Wind-generated currents and waves both create bed shear stresses that can resuspend bed material and mix it throughout the water column. Wind-generated currents transport salt, heat, and chemical constituents throughout the bay. Wind-wave resuspension is reported to be important to total suspended solids (TSS) levels in the water column and therefore to turbidity. Phlips, Lynch, and Badylak (1995) made observations and sampled at 17 stations in Florida Bay monthly over a 1-year period. Tripton (TSS minus algal biomass) levels ranged from 8 to 30 ppm, with higher values in the western bay. They reported that tripton was responsible for 54 to 92 percent of the water column light attenuation, with chlorophyll-containing particles the next most important contributor.

Florida Bay is a 1,500-sq km lagoon system consisting of largely interconnecting banks and associated islands which semienclose shallow "lakes." Banks are shallow, restrict flows and flushing, and affect waves. The Bay has 237 islands greater than 100 sq m that have a mean area of 0.11 sq km, median area of 0.02 sq km, and maximum area of 1.68 sq km (Enos 1989). Islands constitute 1.73 percent of the total Bay area. The entire Bay is underlain by pleistocene limestone at roughly 2 to 5 m depth deepening east to west. Florida Bay bed sediments are predominantly biogenic carbonate that vary considerably in texture from place to place. Windward (north and east) edges of islands and banks are mostly erosional and are composed primarily of sand- and gravel-sized material. Leeward (south and west) edges of banks are depositional and have finer sediment texture.

Lake bottoms are primarily carbonate mud with sand- and gravel-sized components. Sediments migrate from lake bottoms, where most are produced, onto relatively stable banks or out of the system (Bosence 1989). The northeastern or interior portion of the Bay is sediment starved, with thin banks and some bare rock bottom (Bosence 1989). Thicker sediment beds occur in the central bay. The western portion of the Bay contains a relatively deep (18-m) area called the "sluiceway," which has a rock and shell bottom and is reported to be frequently scoured (Schomer and Drew 1982).

Previous, rather sparse, sampling indicated that, overall, Bay sediments are 52 percent finer than 62 μm and on average a bi-modal mix of sand, silt, and clay-sized material. A new study is analyzing 600 samples from the Bay and will provide improved description of sediment characteristics in the near future (Prager, Halley, and Hansen 1996).

Shallow water carbonate sediments are relatively rare, and few studies have reported on the erodibility of sediments such as those that occur in Florida Bay. While erodibility information is not yet available for these sediments, studies are ongoing and results will be available soon (Prager, Halley, and Hansen 1996). Calcareous silt from the deep ocean, which might be similar to some fine sediments in the Bay, has been previously found to be eroded by low near-bed current speeds. Erodability of Florida Bay samples will depend on sediment characteristics as well as the nature and quantity of algae and other organic materials that generally reduce the erodibility of sediments.

Large, shallow water bodies such as lakes, estuaries, and lagoons are often subject to resuspension by wind waves. Resuspension model studies of such systems have used wave measurements or results from wave models driven by winds to provide wave parameters for use in calculations of bottom shear stresses and have been reasonably successful at simulating TSS levels (Luettich, Harleman, and Somlyody 1990; Hawley and Lesht 1992; Sheng, Eliason, and Chen 1992; and others). In the case of Florida Bay water quality modeling, simplifying assumptions such as a single grain class and independent erosion and deposition processes can be made (similar to the previous studies cited) to reduce resuspension model complexity and computational burden, as long as changes to sediments and depths are not varied for plan tests.

As mentioned earlier, sea grass and macrophytes in general reduce wind wave resuspension (James and Barko 1994; Hamilton and Mitchell 1996). Sea grass reduces shear stress at the sediment bed below that which would occur on a bare bottom. At the same time, sea grass greatly increases total resistance to flow and wave damping, absorbing shear stress, and sheltering the sediment in sea grass beds. A number of studies have documented the effects of submersed aquatic vegetation (SAV) on total flow friction and on wind wave damping (for example, see the bibliography of Dawson and Charlton (1988) and Fonseca and Cahalan (1992)). Sea grass probably greatly affects resuspension in Florida Bay.

Wave orbital velocity is a critical parameter for resuspension of bed sediments. Short-period oscillatory currents forced by wind waves are more effective at developing bed shear stress than the same current magnitudes forced by tides due to boundary layer effects. Pejrup (1986) points out that, where wave heights and depths change appreciably, wind speed (being relatively constant over an area) may correlate better to TSS concentrations than wave height at a point. Analysis of TSS time series from a microtidal estuary indicated that wind alone, regardless of direction, had the best correlation to TSS levels (Pejrup 1986). Arfi, Guiral, and Bouvy (1993) tested an expression relating wind speed and water column buoyancy to calculate thresholds for resuspension and obtained results that were similar in magnitude to wave-based threshold estimators. Although wave characteristics are critical, large shallow lagoons and estuaries respond to winds at small hydrodynamic scales (for example, Langmuir circulation cells and buoyant eddy overturning) so that an overall model correlation to observed TSS levels is likely to be improved by considering winds as well as wind waves.

Wind Climate

It is important to know what wind conditions cause the resuspension events and to characterize them according to frequency of occurrence, magnitude, and duration. This component of the study will analyze existing measured and hindcast wind data to determine the wind climate over Florida Bay.

Measured wind data are available at six Coastal Marine Automated Network stations and two National Data Buoy Center buoys in the area. Station identifier, location, and availability of data are summarized in Table 2.

Table 2
Summary of Wind Measurements

Station ID	Station Name	Lat. Deg N	Long. Deg W	Data Availability
DRYF1	Dry Tortugas	24.10	82.15	12/92–Present
SANF1	Sand Key	24.08	81.15	1/91–Present
SMKF1	Sombrero Key	24.10	81.02	2/88–Present
LONF1	Long Key	24.13	80.15	11/92–Present
ALRF1	Alligator Reef	24.15	80.15	1/85–12/87
MLRF1	Molassas Reef	25.00	80.07	12/87–Present
42025	*			7/93–7/94
42037	*			3/94–Present

Note: * = Buoys are not assigned station names.

Hindcast wind data from the National Center for Environmental Prediction are available from 1979 to 1993. These data are located at four stations in the area: (25.71 deg N, 82.50 deg W), (25.71 deg N, 80.63 deg W), (23.81 deg N, 82.50 deg W), and (23.81 deg N, 80.63 deg W). These data are from the NCEP Re-analysis Project, which is a study to reanalyze meteorological data. The purpose is to use current technology to remove any trends in data due to changes in analysis schemes or numerical weather models over time and to use all possible data of acceptable quality. Wind speed and direction are available every 6 hr during the 15-year period at a height of 10 m above the sea surface. Additionally, Mattocks (1996) has developed a climate model that could be used to provide wind fields for Florida Bay. Both measured and hindcast data will be analyzed to determine the distribution of wind speed and direction as a function of space and time.

The wind data will be analyzed and selected to produce the most accurate representation of meso-scale wind distributions over Florida Bay for the WQM calibration and confirmation periods (approximately 1986 to present). Data assimilation schemes will be used where necessary to give weight to the measured data that may contain local-scale winds not represented in the larger scale hindcast winds. It is not clear at this time how much spatial and temporal variability in wind fields will be needed for the model; thus, the required temporal and spatial resolution will be evaluated, and the appropriate wind fields will be processed for model (HM, wave model, and WQM) use. The wind fields can be processed to provide 1-hr updates of spatially varying winds for various regions of the model domain if necessary.

Wave Climate

There are few previous wave measurements in the area, although wave data are presently being collected.[1] A search for all available measured wave data will be made. Hindcast wave data are available at locations near the area for the period 1956-1996 from the WES Wave Information Study. Data from these sites are acceptable as boundary conditions for waves entering the area, but do not represent local wave conditions in the Bay itself. Data from these stations will be analyzed to determine the nature of waves propagating toward the Bay and their percent occurrence. Since the area is sheltered from all but the westerly direction, this analysis will determine the influence of waves not generated in the area.

Waves generated locally in the area can be estimated with a shallow-water wave model (e.g., SWAN, Holthuijsen, Ris, and Booij 1996, or the HISTWAV model being applied by Prager[1]) for those events determined from the wind climate to result in combined wind/wave bottom shear stresses that resuspend bottom material. The HISTWAV model is a steady-state event model, and Prager[1] is using spatially invariant wind; she is using a 100-m grid resolution for Florida Bay. A time-varying wave model may not be required since waves respond rapidly to wind in shallow water. It is not clear at this time whether or not spatially varying wind will be required for the wave estimates.

The wind climate data and Florida Bay bathymetric and bottom-type data will be used with a simple wave model to generate first-order estimates of local wave conditions for the WQM calibration and confirmation period. The wave model will be verified against any available observational data.

Resuspension Model Description

To meet the needs of the Florida Bay water quality model, a new capability will be added to the ICM model to provide resuspension modeling. Wind and wave climate information, circulation model flows and water levels, and sea grass density will be used as input. The objective is to develop a simple, flexible tool for simulating resuspension levels in Florida Bay without substantially increasing the computational requirements of the model.

The ICM model, described in Chapter 6, uses suspended sediment as one component that factors into the calculation of diffuse light attenuation. For Florida Bay, the WQM will not address changes to inorganic sediment conditions in the bed. Rather, suspended sediment levels will

1 Personal Communication, 1997, E. J. Prager, U.S. Geological Survey, St. Petersburg, FL.

change as a result of winds and currents and changes in sea grass density. For the purposes of this study, it is not necessary to model bed sediment transport or bed morphology, bed shoaling, or uprooting of sea grasses. The model will allow resuspension and transport of inorganic and organic sediment, and one sediment size class of each will be provided. The proportion of inorganic and organic sediment resuspended will be based upon the fraction of organic sediment in the bed.

The resuspension algorithm developed for the ICM model will provide a time-varying bed flux of sediment that depends on currents, winds, wind waves, and sea grass density. The resuspension at each cell will be calculated based on a weighted sum of shear stress contributions from circulation, winds, and cell-centered hindcasted waves. HM and wave model shear stresses will be adjusted to include the proper frictional effects of existing grain, form, and sea grass roughness.

As described earlier and discussed by Evamaria Koch at the October 1996 workshop, the presence of sea grass alters velocity profiles and shear stresses imposed on the bed by currents and waves. Since the HM and wave model will not be dynamically linked to the resuspension model built within the WQM, it will be necessary to develop an indirect linkage formulation that accounts for the effect of time-varying sea grass density on total and bottom shear stresses, without having to rerun the HM and wave model. Shear stress calculations will include the effects of sea grass density, as well as grain and form roughness, such that the portion of shear stress acting to erode sediments will be differentiated from the total shear stress. The modified shear stress will be computed dynamically within the WQM along with temporally and spatially changing sea grass density. The detailed steps for the development of the modified shear stress formulation will be determined during the specification exercises at the initiation of the study. While some inaccuracies will result from uncoupling HM and wave models from changes in sea grass density, the proposed method will provide the proper direction of change in shear stress in response to change in sea grass density.

Even though winds are used as input to the HM, vertically averaged shallow water wave equations, as used in the HM, only portray to first-order accuracy bed shear stress generated by wind stress on the water surface. Therefore, winds will also be considered in the resuspension module to ensure that the effects of wind stress are fully taken into account.

Shear-stress thresholds for erosion and deposition, erosion rate parameters, and settling rates will be specified locally based on measurements being made by the U.S. Geological Survey (USGS), St. Petersburg (Prager, Halley, and Hansen 1996). The sediment bed will be represented by a single layer, initialized with a sediment bed mass per grid cell to limit resuspension and conserve the total sediment mass for the system. Settling and deposition processes will also be included as well as water column transport.

Note that threshold values for erosion (resuspension) and deposition will be set independently, thus allowing for the possibility of concurrent erosion and deposition. While experimental evidence for these processes acting concurrently is lacking, from a modeling standpoint, two independent threshold values can be used to reduce model complexity involved in representing the sediment bed while maintaining source limitation during erosion.

Model Adjustment and Verification

Initial model adjustment and verification will be performed in conjunction with other WQM components, such as particulate organic matter and algae as described in Chapter 6, on several areas within Florida Bay where the most complete data sets are available. The procedure will follow that of the WQM calibration as described in Chapter 6, including using reduced systems to facilitate calibration. Final calibration will be to a period of several years from the mid-1990s, when data are more abundant. Data from field studies of bed sediment characteristics and erodibility being performed by the USGS (Prager, Halley, and Hanson 1996) will guide selection of model parameter values, but, ultimately, model to prototype time series agreement will determine final model parameter values.

Measurements of TSS or related parameters such as turbidity will be used to verify model performance. Since a primary goal of the resuspension model will be to provide accurate radiative transfer to sea grasses, the most important statistical property to reproduce is the central portion of the TSS frequency distribution. Sea grass responds to normal, day-to-day light levels, and extreme values are of less importance. Thus model and prototype TSS levels from 10- to 90-percent deciles will be compared. Since a transfer function is applied to convert TSS to light extinction coefficient, it is more important to reproduce the slope of the TSS frequency distribution correctly than to reproduce say the mean or median value. Any error in the latter can be easily compensated for in the transfer function. The goal of the resuspension model will be to reproduce the central portion of the TSS frequency distribution such that model and prototype slopes in these distributions do not differ by more than 10 percent. Statistical measures of the goodness of agreement between the model and field observations will be presented.

5 Model Linkages

Hydrodynamics and Water Quality

The WQM will be indirectly linked to output saved from the HM. Indirect linkage means that the HM is first executed, and its output is saved and used later by the WQM whenever required. Based upon the arguments presented in Chapter 2, it is proposed that indirect linkage, without feedback, will provide a satisfactory modeling strategy.

There are two types of HM output that must be saved, time-invariant grid geometric information and time-varying hydrodynamic information. The grid geometric information consists of the grid cell locations with respect to each other and their numbering, initial volumes and facial areas, and distances between neighboring cell interfaces. The hydrodynamic information is provided at a specified update time interval and consists of flows through each cell face, averaged over the update interval, and cell volumes at the end of the update interval.

Linkage software and procedures are in place for the CH3D-WES and ICM models and have been used on numerous studies as mentioned in Chapter 3. However, if the RMA10-WES model has to be used for this study, there would be a need to further develop and test linkage software, although much progress towards this goal has been recently completed.

It is recommended that a one-to-one grid correspondence be used between the HM and WQM grids. This means that the same number of cells and their locations will be used for both models. If a one-to-one correspondence proves to be too restrictive on the allowable WQM time step, then grid overlay procedures for CH3D-WES and ICM exist and can be used.

Following linkage of the WQM to the Florida Bay HM grid, it will be necessary to show that the two models are correctly linked and transport is properly preserved. Various volume and mass conservation tests will be run to demonstrate that the models are correctly linked. Volume conservation can be checked in ICM by turning on the volume balance check switch. If a volume imbalance occurs, there will be a grid linkage error.

Additionally, mass conservation will be checked by turning on the mass conservation check switch for a conservative, nonreacting, tracer variable transported by the model. Both global and local mass balance tests will be performed to ensure that balances are achieved within acceptable tolerances. Transport tests will be performed by introducing conservative tracers in both the HM and WQM at the same locations and comparing tracer concentration contours from both models. The two results should compare closely except for possibly small differences caused by the numerical methods employed in the two models. Additionally, salinity will be simulated by both models providing an another verification of correct transport.

Hydrodynamic and Water Quality Model Self Consistency

As discussed in Chapter 2, the self consistency of the HM and WQM linkage must be tested. The need for this test arises from elimination of the dynamic feedback loop from the sea grass model to circulation to simplify model linkages. The circulation model will be run with a specified sea grass distribution observed near the beginning of the WQM confirmation period. The resulting circulation field is used for a WQM confirmation simulation. Next, the observed sea grass distribution at the end of the WQM confirmation period is used to adjust the HM roughness. Then this flow field is used for another WQM confirmation simulation. At this point, the results from the two WQM simulations are examined. If the results from the two simulations are similar, then self consistency exists, and feedback from the sea grass model to the HM is not necessary. If the results are significantly different, then a dynamic linkage between the HM and WQM/sea grass model will be required, or either additional iterations will be necessary to achieve self consistency. Hypothesis testing at the 95-percent confidence level will be used to determine whether the two simulations are significantly different.

Wind Wave Model, Sediment Transport, and Water Quality

A model linkage simplification calls for eliminating the feedback from the sea grass model to the wave model by building a linkage from the sea grass model directly to the SM, both of which would be dynamically coupled within the WQM. A wave model will be used to provide basic information on wave conditions as a function of local wind speed, water depth, and bottom friction. It will be necessary to develop a relationship between sea grass density and bottom shear stress. As current and wave information is provided to the WQM from output from the HM and the wave model, respectively, the associated bottom shear stresses will be calculated within the SM component of the WQM and modified based on local sea grass density predicted by the sea grass component of the WQM. The modified shear stresses will then be used to calculate resuspension rates within the SM component. Resuspended sediment will be transported and eventually redeposited by the water column component of the WQM. Thus, as predictions for sea grass coverage evolve, sediment resuspension predictions can change too as a result of local sea grass coverage without the need for feedback to the wave model. The difficulty lies in developing the algorithms to relate bottom shear stress to sea grass density.

6 Water Quality

The water quality model will consist of four interactive submodels: a model of water quality processes in the water column; a model of sediment resuspension, transport, and deposition; a model of sediment diagenetic processes; and a model of sea grasses (or submersed aquatic vegetation, SAV). Together, these four submodels comprise the CE-QUAL-ICM water quality model, which is discussed herein as a primary candidate for conducting this study. The current status of CE-QUAL-ICM and proposed modifications for Florida Bay application are described in subsequent sections of this chapter.

During the course of the study, the WQM variables and processes may be revised from those described below to better represent Florida Bay. To facilitate model conceptualization at the initiation of the study, it is recommended that three specification exercises be held to help refine specifications for the WQM. These exercises may take the form of exchanges through a Web site and e-mail and phone discussions with various scientists. Bay scientists, modelers, the MEG, and various other experts will be asked to review strawman proposals for the three specification exercises to address specific issues dealing with the four WQM components. Following the reviews and informal exchanges, a meeting (possibly in conjunction with the MEG briefings) or brief workshop may be held to conclude each specification exercise. The first specification exercise will address the suspended sediment module and related computations, including winds, waves, and resuspension as related to winds, waves, currents, and sea grass. The second specification exercise will address the water column and benthic sediment components of the WQM to refine the state variables and processes to be included. The third exercise will address the sea grass model component to refine the state variables, processes, and related mechanisms to include. The results of these three exercises will be documented and used to guide model development.

Water Column Processes

Current status

The CE-QUAL-ICM water quality model was developed as one component of a model package employed to study eutrophication processes in Chesapeake Bay (Cerco and Cole 1993; Cerco and Cole 1994; Cerco 1995a,b). Subsequent to employment in the Bay study, the model code was generalized and released for public distribution and use on other systems (Cerco and Cole 1995).

The foundation of CE-QUAL-ICM is a finite volume solution to the 3-D mass-conservation equation. CE-QUAL-ICM solves, for each control volume and for each state variable, the equation:

$$\frac{\partial (V_j C_j)}{\partial t} = \sum_{k=1}^{n} Q_k C_k + \sum_{k=1}^{n} A_k D_k \frac{\partial C}{\partial x_k} + \sum S_j \tag{1}$$

where

V_j = volume of jth control volume, m^3

C_j = concentration in jth control volume, g m^{-3}

t, x = temporal and spatial coordinates

n = number of flow faces attached to jth control volume

Q_k = volumetric flow across flow face k of jth control volume, m^3 sec^{-1}

C_k = concentration in flow across flow face k, g m^{-3}

A_k = area of flow face k, m^2

D_k = diffusion coefficient at flow face k, m^2 sec^{-1}

S_j = external loads and kinetic sources and sinks in jth control volume, g sec^{-1}

The central issues in eutrophication modeling are primary production of carbon by algae and concentration of dissolved oxygen. Primary production provides the energy required by the ecosystem to function. Excessive primary production is detrimental, however, since its decomposition, in the water and sediments, consumes oxygen. Dissolved oxygen is necessary to support the life functions of higher organisms and is considered an indicator of the "health" of estuarine systems. In order to predict primary production and dissolved oxygen, a large suite of model state variables is necessary (Table 3). The 22 model state variables include physical properties that impact eutrophication and components necessary to represent cycling of carbon, nitrogen, phosphorus, dissolved oxygen, and silica.

Table 3 Existing Water Quality Model State Variables	
Temperature	Salinity
Suspended solids	Cyanobacteria
Diatoms	Flagellates and other algae
Dissolved organic carbon	Labile particulate organic carbon
Refractory particulate organic carbon	Ammonium nitrogen
Nitrate + nitrite nitrogen	Dissolved organic nitrogen
Labile particulate organic nitrogen	Refractory particulate organic nitrogen
Total phosphate phosphorus	Dissolved organic phosphorus
Labile particulate organic phosphorus	Refractory particulate organic phosphorus
Chemical oxygen demand	Dissolved oxygen
Particulate biogenic silica	Dissolved silica

An effort has recently been completed to include higher trophic levels (microzooplankton, mesozooplankton, deposit-feeding benthos, and filter-feeding benthos) in the CE-QUAL-ICM framework. Addition of these components adds tremendously to the data requirements, calibration effort, and computational demands of the model. Initial indications are that addition of higher trophic levels does not increase the accuracy of the model. The addition is worthwhile solely if quantifying biomass and processes within higher trophic levels is a major study objective. Since the Florida Bay study is concerned primarily with SAV and the processes that affect SAV, inclusion of higher trophic levels within the model framework is not recommended.

Application to Florida Bay

The eutrophication framework presently incorporated in CE-QUAL-ICM is robust and should transfer readily to Florida Bay. Primary modifications will be in parameter evaluation and in model emphasis rather than in formulation. For example, the three algal groups presently comprise diatoms, freshwater cyanobacteria, and flagellates. These can be made to represent indigenous Florida Bay phytoplankton through adaptation of appropriate model parameters. Since anoxia is not a problem in Florida Bay, this phenomenon can be de-emphasized and attention devoted to more significant processes.

Major changes to the model will involve inclusion of the calcium carbonate system and interactions of calcium carbonate with phosphorus. The carbonate system will be represented through the addition of four model state variables: calcium, calcium carbonate, alkalinity, and total inorganic carbon (TIC). From these, pH and concentrations of carbonate species can be derived using well-known relationships (e.g., Faust and Aly 1981). Inclusion of these state variables will require modifying the model to incorporate calcium dissolution, settling and resuspension, and TIC production, consumption, and atmospheric exchange. Modeling calcium-phosphorus interactions will require the introduction of a calcium phosphate state variable too and representation of phosphorus sorption onto calcium carbonate.

Algorithms to compute the carbonate system and calcium-phosphorus interactions are widely available, e.g., Brown and Allison (1987). Public-domain codes are inefficient, however, and not suited to the magnitude of computations anticipated in Florida Bay (thousands of cells, time increments of minutes, and duration of years). Likely an efficient, specialized algorithm will have to be developed as part of the project.

There is one other modification that must be made to the water column component of the WQM. Wetting and drying of cells and proper handling of residual mass in dry cells must be added.

Sediment Transport

Current status

CE-QUAL-ICM presently contains an inorganic suspended sediment (ISS) variable that is transported within the water column, thus varying temporally and spatially. The model does not account for benthic inorganic sediments, nor does it presently contain resuspension. ISS enters the system through external loadings and can be lost from the water column through settling. Light attenuation is affected by ISS concentration.

Application to Florida Bay

The ISS module of CE-QUAL-ICM must be modified to include resuspension as described in Chapter 4. Additionally, organic sediments will be allowed to resuspend as explained in Chapter 4. A single inorganic sediment bed layer will be included, but bed transport and bed morphology will not be modeled.

Benthic Sediment Diagenesis Model

Current Status

Benthic sediments are represented as two layers with a total depth of 10 cm. The upper layer, in contact with the water column, may be oxic or anoxic depending on dissolved oxygen concentration in the water. The lower layer is permanently anoxic. The thickness of the upper layer is determined by the penetration of oxygen into the sediments. At its maximum thickness, the oxic layer depth is only a small fraction of the total.

The sediment model consists of three basic processes. The first is deposition of particulate organic matter from the water column to the sediments. Due to the negligible thickness of the upper layer, deposition proceeds from the water column directly to the lower, anoxic layer. Within the lower layer, organic matter is subject to the second basic process, diagenesis (or decay). The third basic process is flux of substances produced by diagenesis to the upper sediment layer, to the water column, and to deep, inactive sediments. The flux portion of the model is the most complex. Computation of flux requires consideration of reactions in both sediment layers, of partitioning between particulate and dissolved fractions in both layers, of sedimentation from the upper to lower layer and from the lower layer to deep inactive sediments, of particle mixing between layers, of diffusion between layers, and of mass transfer between the upper layer and the water column.

Subtidal benthic algae occupy a thin layer between the water column and the benthic sediments. CE-QUAL-ICM simulates these as part of the sediment diagenesis model. Biomass within the layer is determined by the balance of production, respiration, and losses to predation:

$$\frac{dB}{dt} = (G - R - P)B \tag{2}$$

where

B = algal biomass, as carbon, g C m^{-2}

G = production rate, day^{-1}

R = respiration rate, day^{-1}

P = predation rate, day^{-1}

Formulations of the production, respiration, and predation terms are similar to conventional models of algal dynamics in the water column. Key factors that determine these terms include light, nutrients, and temperature at the sediment-water interface.

A listing of sediment model state variables and computed sediment-water fluxes is provided in Table 4. Documentation of the diagenesis model is provided by DiToro and Fitzpatrick (1993). The benthic algal component is detailed in Cerco and Seitzinger (1997).

Table 4
Existing 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	
Dissolved silica	Silica flux
Benthic algal biomass	Dissolved oxygen, nutrients

Application to Florida Bay

The primary modification to the benthic sediment model will be adaptation to the carbonate sediments of Florida Bay. The adaptation will primarily affect sediment phosphorus cycling since phosphorus has a high affinity to sorb to sediment solids such as calcium carbonate. As presently configured, the model is adapted to iron-rich sediments such as those found in Chesapeake Bay. Precipitation and dissolution of iron and adsorption/desorption of phosphorus to solids are roughly represented through empirical solubility and sorption coefficients. The model will be improved through detailed representation of carbonate cycling between the water column and sediments and through improved representation of phosphorus partitioning between dissolved and particulate phases. An initial effort to incorporate carbonate cycling into the sediment model has already been completed as part of research on sediment iron and manganese modeling (DiToro, Fitzpatrick, and Isleib 1994).

State variables to be introduced into the sediment model will largely follow the modifications to the model of the water column, i.e., calcium, calcium carbonate, calcium phosphate, alkalinity, and TIC. Phosphate adsorption to calcium carbonate and formation of calcium phosphate will be represented. Computation of pH in sediments is a complex problem due to the enormous number of reactions that affect and are affected by pH. As a first approach, a simplification will be employed in which pH is determined by the carbonate system alone.

Incorporation of resuspension may require substantial modifications to the sediment model. As presently represented, solids deposited on the bottom stay there permanently. If resuspension is represented in detail, all sediment solids including particulate carbon, nitrogen, phosphorus, and silica must be considered. Modeling the introduction of resuspended solids and associated interstitial dissolved matter into the water column can be readily addressed. Modeling the reconstitution of benthic sediments upon deposition of resuspended material is not straightforward. Substantial effort will be required for this portion of the model study.

Sea Grass Model

Current status

The sea grass (i.e., submersed aquatic vegetation, or SAV) model builds on principles established by Wetzel and Neckles (1986) and Madden and Kemp (1996). Three state variables are computed: shoots (aboveground biomass), roots (below-ground biomass), and epiphytes (attached algae). Each state variable is computed as a density, e.g., gram shoot carbon per square meter of bottom area. The model is based on mass-balance principles expressed through differential equations that describe growth and loss of each state variable. For example, the basic equation governing shoot biomass is:

$$\frac{d}{dt}(C\,SH) = \left(1 - F_{psr}\right) P\,C\,SH \tag{3}$$

where

C = coverage, m^2

SH = shoot biomass, g C m^{-2}

F_{psr} = fraction of primary production transferred from shoots to roots

P = net production rate, day^{-1}

Production is computed as a function of temperature, light, and nutrients in water and sediments. Light at leaf surfaces is computed as a function of light at the water surface and attenuation within the water column. Attenuation is computed, in turn, as a function of concentrations of particulate and dissolved matter and depth. Self shading and shading by epiphytes, based on nutrient availability, are also included. The model is carbon based but incorporates SAV nitrogen and phosphorus through the use of fixed nitrogen-to-carbon and phosphorus-to-carbon ratios. Model SAV can extract nutrients from the sediments and water column.

Separate equations for shoot density (SH) and coverage (C) can be derived by applying chain rule differentiation of Equation 3 and separating both equations resulting in

$$\frac{d\,SH}{dt} = FD\left(1 - F_{psr}\right)P\,SH \tag{4}$$

$$\frac{d\,C}{dt} = (1 - FD)\left(1 - F_{psr}\right)P\,C \tag{5}$$

where *FD* is the fraction of total production that goes to increased/decreased shoot density. The fraction is determined by an optimization algorithm that minimizes the biomass required for SAV spread through spatial expansion on the bed or through increasing shoot density within the bed.

Root biomass is governed by

$$\frac{d(C\,RT)}{dt} = F_{psr}P\,C\,SH - R\,C\,RT \tag{6}$$

where

RT = root biomass, gm C m^{-2}

R = root respiration rate, day^{-1}

Epiphyte biomass is governed by

$$\frac{d(C\,EP\,SH)}{dt} = \left(G_{ep} - R_{ep} - PR - SL\right)C\,EP\,SH \tag{7}$$

where

E = epiphyte density, g epiphyte C g^{-1} shoot C

G_{ep} = epiphyte growth rate, day^{-1}

R_{ep} = epiphyte respiration rate, day^{-1}

PR = predation rate on epiphytes, day^{-1}

SL = sloughing rate of SAV shoots, day^{-1}

The model has been applied to two species at two sites in Chesapeake Bay: *Zostera marina* at the mouth of the York River and *Potamogeton perfoliatis* in Choptank River mesocosms. Application of the model system-wide is presently underway.

Application to Florida Bay

As with the water column model, application of the SAV component to Florida Bay largely amounts to applying parameters appropriate for indigenous species and local conditions. For example, the model presently depends on epiphytes as the major light-limiting factor. Sediment sulfide toxicity is incorporated in the code but not activated. Indications from the October workshop are that epiphytes may be less of a limiting factor than sulfide toxicity. A switch of the role of these limiting factors can be readily accommodated through selection of appropriate parameters.

Two species have been selected for simulation: *Thalassia testudinum* and *Halodule wrightii*. At present, the model does not represent the coexistence of two or more species. Rather, it simulates a single dominant species in each model cell. If *Thalassia* and *Halodule* coincide or compete, then modifications to the model are required, which are expected to be straightforward.

A second modification to the model involves incorporating potential TIC limitation to growth. Since TIC will be computed in the water column as part of the calcium carbonate system, addition of TIC to the present list of limiting factors (temperature, nutrients, and light) can be readily accommodated. It is recommended that a sea grass modeling workshop be held at the beginning of the project to refine the plans for the sea grass component.

Initial Nutrient Budget Analysis

It was recommended at both the July and October workshops that the WQM be applied to the Bay as quickly as possible to rapidly gain a better understanding of the Bay nutrient budget. It was suggested that a very coarse grid (approximately 20 to 40 cells) model application of the entire Bay be conducted to assess the relative importance of external nutrient loadings and internal nutrient cycling. The version of the WQM existing at the beginning of this project can be used for this application. This application should be conducted early into the project to help guide model development and further development of nutrient loadings. Broad-scale, seasonally averaged circulation fields can be derived from existing models, such as RMA10-WES HM or the Florida International University box model of Nuttle and Fourqurean, and provided to the WQM for the nutrient budget analysis. This application should consist of data from recent years. Consideration should be given to using the box model grid configuration of the Nuttle and Fourqurean box model.

Initial Calibration

Application of a complex eutrophication model to a system such as Florida Bay is a major task involving data assembly, model parameter evaluation, and model parameter calibration through comparison of predictions and observations. The study of Florida Bay will involve addition of new state variables, development of new model algorithms, and evaluation of unknown parameters. Under these circumstances, development and application are greatly facilitated through application of the model to a reduced system with a relatively limited grid. Development can be conducted rapidly on the reduced system without incurring the lengthy computer turn-around time involved in modeling the complete system.

Three reduced systems will be employed in the initial development and application of the Florida Bay model. Each will be one of the natural basins formed by the topography of Florida Bay. Basins will be selected to represent a range of conditions that occur in the Bay, such as a central, eastern, and western basin. A second criteria for selection will be data availability. The data should be representative of the variables and processes computed in the model and should extend over at least 1 year. Flows into and out of each basin may be derived from the currently available finite element model if results from the CH3D-WES model are not yet available; seasonally averaged flow fields will be employed from the RMA10-WES model in this case. Boundary conditions will be specified based on observations. Model simulation period and parameters will be selected in cooperation with Bay-area scientists. Existing data for 1 year will be used for initial model calibration and comparisons.

Final Calibration and Confirmation

Final calibration of the model will be conducted on the complete bay system using the full, detailed grid driven by the CH3D-WES HM (assuming it is determined to be acceptable). Final calibration will cover a period sufficient to demonstrate agreement between observed and computed changes in water quality and sea grass. A period of several years from the mid-1990s, when data are more abundant, should be used for final model calibration. Alternatively, if future monitoring efforts are modified to better reflect the needs of the WQM, and if results are provided within the time frame required for the model study, then monitoring data from a future period, rather than existing data, should be used to provide a more complete final model calibration.

Following final model calibration, the model will be confirmed over a longer period of time, within which sea grass conditions have changed substantially. (As mentioned in Chapter 3, the terms model verification or validation could just as well be used for confirmation.) Workshop discussions indicated that a major sea grass die-off occurred during 1987. Therefore, simulations will commence from about 1986, to encompass the die-off, and extend through 1996, to include recent sea grass and water quality surveys. The exact period for model confirmation will be developed through discussions with the study oversight committee, MEG, and Bay scientists.

Graphical plots and statistical analyses for computed and observed data will be used to assess the skill of model calibration and confirmation. Time series of computed and observed concentrations at stations will be plotted. Snapshot and/or time-averaged results will be used for planar contour plots to compare computed and observed 2-D data. Seasonal mean-, maximum-, and minimum-computed and observed data will be compared along longitudinal transect plots. Statistical analyses of computed and observed results will include mean error, mean absolute error, RMAE, root mean square error, and the cumulative frequency distribution of absolute error and relative absolute error.

WQM confirmation will be considered acceptable when the RMAE values shown in Table 5 are satisfied. The values in Table 5 are comparable with those of other similar water quality models. The RMAE criteria in Table 5 can be modified through recommendations by the MEG and study oversight committee early in the study.

Table 5
RMAE Values for Water Quality Model Acceptance

Variable	RMAE
Temperature	0.10
Dissolved oxygen	0.15
Chlorophyl *a*	0.30
Total organic carbon	0.30
Total nitrogen	0.20
Total phosphorus	0.25

7 Water Quality Model Application

This chapter deals specifically with the application of the WQM for sensitivity tests, scenario testing, and uncertainty analysis. Sensitivity analysis and scenario testing will also be conducted with the HM. Each WQM scenario test involving a change in the system physical features or hydrology and hydrodynamics will require application of the HM to generate the scenario circulation field.

Sensitivity Tests

Tests should be conducted to evaluate model sensitivity to various assumptions and input values. Obviously, it is not practical to test every model parameter and input value, but the more questionable input values, such as certain model rate coefficients and boundary conditions, should be examined to determine their relative significance to the modeling process. As an example, tests to determine the sensitivity of the model to various nutrient loading sources are commonly conducted. Sensitivity tests help to focus future data-collection efforts, process investigations, and model development. The specific details of sensitivity tests cannot be provided at this time, but such tests should be coordinated through the study oversight committee and MEG. The WQM calibration process results in a large number of computer runs where parameters are adjusted, thus providing much sensitivity information.

Scenario Testing

Following model calibration, confirmation, and sensitivity testing, the model will be used to evaluate various management scenarios. Each WQM scenario simulation should be conducted for approximately a 10-year period to allow sufficient time for the system to reach a new equilibrium. Water quality alterations affect sediment quality and sea grass conditions, which in turn affect water quality. For planning and budgeting purposes, six management scenarios are assumed. Management scenarios will generally involve various alternatives for freshwater flows and nutrient loadings. Structural modifications, such as opening new passes through the keys, can also be evaluated. The scenario specifications will be established by the study partners and the PMC.

Each scenario should be compared with a base condition. The base condition is usually existing conditions for loads, freshwater flows, and structural configuration. Historical conditions are usually used to construct the input conditions for the base condition and scenario tests. It is recommended that the 10-year WQM confirmation simulation be used for the base condition. This same period will also be used for the management scenarios, but the model input will be adjusted to reflect the particular management alternative. In addition to comparing each scenario against base conditions, model results can also be analyzed in various ways to assess differences in scenarios. For example, nutrient fates can be assessed and compared among the scenarios.

The HM must be executed for each scenario that involves flow or structural alterations. It will not be necessary to execute the HM for scenarios involving only changes in nutrient loads. It is planned that the HM will be executed for the entire 10-year scenario simulation period, and the output will be used to drive the WQM for the same period.

Uncertainty Analysis

Concern for the environmental health of Florida Bay has developed relatively recently. Thus, the Florida Bay database is not rich, and the scientific understanding of certain bay environmental processes is not mature. Additionally, Florida Bay is a relatively complex system. For these reasons, there will be uncertainty associated with any model projections of the Bay, as there is with any model study.

Using Monte Carlo simulation techniques, the confidence limits associated with stochastic inputs can be constructed. Ideally, it would be desirable to estimate the total uncertainty associated with all input values to provide confidence limits on model projections. However, it is infeasible to place confidence limits on long-term water quality model simulations when a large number of input variables are involved. The number of realizations that must be run are on the order of N^3, where N is the number of input variables included in the uncertainty analysis. When each run takes hours of CPU time on a supercomputer, it is easy to see why it is necessary to restrict N, thus the number of runs.

It is possible to conduct uncertainty analysis for a limited number of input variables. The sensitivity work should reveal which parameters and input conditions have the most effect on the model. The modeling process will also help focus the primary data limitations. This information can be used to design uncertainty analysis for the most sensitive model input values with the least information.

All uncertain input variables can be simultaneously perturbed randomly during each realization. It may be necessary to run hundreds of realizations. The preferred management alternatives will become evident from the scenario testing. The uncertainty analysis will be conducted for the most preferred management scenario. It will be necessary to constrain the limits of the uncertainty analysis within the bounds of computing resources available at the time of the study.

8 Water Quality Model Data Needs

The success of any water quality modeling study hinges heavily on the amount, type, and quality of field-monitoring studies. The Florida Bay water quality model will be able to utilize a substantial amount of data. Although there are a lot of data-gathering efforts being conducted in the Bay, not all of the model variables and parameters are being addressed. Furthermore, much of the data-collection efforts to date have not been designed for model use. The existing database is considered adequate to conduct water quality modeling, but additional data are recommended to provide a higher level of confidence for the comprehensive water quality model proposed herein.

The first section of this chapter describes all of the data that can be utilized by the water quality model if such data were available. The second section discusses potential data gaps and needs that are not being satisfied and that are considered important for maximizing confidence in a comprehensive Bay water quality model. Fulfilling the additional data needs will require resources and effort outside of the tasks planned for this study. An expanded data-collection program is required to maximize the success of this and other future studies of Florida Bay.

Data requirements are limited to the water quality model, including sediment modeling. Data required by the hydrodynamic model are not discussed since this modeling and associated data collection are well underway in other studies. Any new data collected in support of the WQM must be obtained within the first 2 years of this study to be of use during this modeling effort. If additional data were collected during the first 2 years of the study, it could be used for final WQM calibration and confirmation.

Data Utilized by the WQM

In general, water quality models utilize the following data:

- Computational grid and hydrodynamics.
- Boundary conditions for various loading sources, including freshwater flow boundaries, ocean boundaries, point source discharges, diffuse runoff and loadings (e.g., storm water and septic tanks), atmospheric fallout and rainfall, and groundwater.
- Meteorological data, including air temperature, dew point, wind speed, cloud cover, and atmospheric pressure.
- Model parameters (e.g., rate coefficients).
- Calibration data.

Of the above data needs, calibration data, process data for setting model parameters, and the boundary conditions or loadings can present the greatest problems. Each of these data requirements are discussed below.

Calibration data

Calibration data can be divided into three categories: (a) water column, (b) benthic sediments, and (c) sea grasses. Each of these is discussed.

Water column. Water column state variables are compared with water column observations during model calibration and confirmation. Since WQM confirmation will involve the period 1986-1996, available historical data from this period will have to suffice. However, model calibration can be conducted using new or recently available data. The water column observations appropriate for the Florida Bay WQM calibration are listed in Table 6. For dissolved and particulate constituents of the same type, such as dissolved and particulate phosphorus, either total and dissolved or total and particulate forms can be used by subtracting from the total to obtain the dissolved or particulate quantity. It is advisable to have measurements for each of the variables in Table 6. However, it is common to not have measurements for all state variables. In these cases, comparisons between model and observed cannot be made, thus reducing model confidence. If observations are missing for many state variables, either the model structure and interactions should be simplified to be consistent with available data, or additional data should be collected.

Observations are required over time and space for model calibration. The frequency of these observations can vary, but they should be on the order of every 2 weeks to monthly. The duration of monitoring is also highly variable. A minimum of 1 year of monitoring is required for model calibration, but 2 years is preferable. Some estuary/coastal programs extend their water quality monitoring efforts over many years. Spatial coverage is also highly variable, but for a system the size of Florida Bay, at least 20 to 40 stations should be routinely sampled.

Table 6
Water Column Observations Appropriate for Florida Bay WQM Calibration

Salinity	Particulate inorganic phosphorus
Temperature	Dissolved organic phosphorus
Inorganic suspended solids	Particulate organic phosphorus
Dissolved oxygen	Dissolved silica
Dissolved organic carbon	Particulate biogenic silica
Particulate organic carbon	Chlorophyll *a*
Ammonium nitrogen	Abundance of major algal groups (3)
Nitrate + nitrite nitrogen	Alkalinity
Dissolved organic nitrogen	pH
Particulate organic nitrogen	Total inorganic carbon
Dissolved inorganic phosphorus	Dissolved calcium
Light attenuation	Particulate calcium

Benthic sediments. Sediment-water fluxes and interstitial concentrations are used by the benthic sediment diagenesis model during calibration. For the Florida Bay model, these should include the variables listed in Table 7.

Table 7
Benthic Fluxes and Interstitial Water Concentrations Used for WQM Calibration

Ammonium nitrogen	Nitrate nitrogen
Dissolved inorganic phosphorus	pH (interstitial concentration only)
Sulfide	Dissolved silica
Total inorganic carbon	Dissolved oxygen
Dissolved calcium	

Also of use are particulate benthic concentrations for the following:

- Organic carbon.
- Organic nitrogen.
- Organic phosphorus.
- Biogenic silica.

- Inorganic phosphorus.
- Calcium.
- Sulfide.

The above benthic measurements should be collected at multiple stations with a frequency of at least seasonally (approximately four times per year) over the model calibration period. Spatial coverage should be adequate to describe the different regions of the Bay; approximately six to eight stations are appropriate.

Estimates of sediment accretion or burial are required for the sediment diagenesis model. These estimates should be available from the ongoing sediment dating studies.

Sea grasses. For the sea grass (or SAV) model, the following observations are required:

- Time-varying biomass (as grams C square meter) of shoots and roots.
- Accumulation of epiphytic material (organic and inorganic) on leaves.
- Areal distribution of SAV beds, including distribution of *Thalassia* and *Halodule.*

Process data

Many rate coefficients, i.e., model parameters, must be specified for the water column. Required model parameters are not listed here, rather they can be found in the CE-QUAL-ICM user manual (Cerco and Cole 1995). Parameters are adjusted during calibration within bounds based on experience from previous model studies and/or values found in literature. Site-specific measurements for these various parameters are not usually available, but such measurements help reduce model uncertainty. Since it is cost prohibitive to measure all model parameters, measurements are required for only the most sensitive or most suspect parameters as discussed below in the data recommendations section.

Loads to system and boundary concentrations

Water quality constituents enter the WQM via loads and boundary concentrations. Loads are quantities of mass per unit time that enter at specified locations. Boundary concentrations (mass per unit volume) can only be specified where there is a flow boundary defined by the HM. Both loads and concentrations can be specified at HM flow boundaries.

The WQM will require loading information for carbon, nitrogen, phosphorus, silica, and TSS (or ISS) from major sloughs entering the Bay and from distributed sources around the Bay. The distributed sources should account for local runoff, septic tank seepage, groundwater, and any other distributed sources. Additionally, loadings should account for any source/sink effects of mangrove fringes since these will not be modeled. Loadings from any point-source discharges must be included. Also, atmospheric nitrogen and phosphorus (wetfall and dryfall) must be included. Ideally, loads should be partitioned into species to be employed by the model as listed in Table 8.

Table 8
Loading Data Required by the WQM

Total or inorganic suspended solids
Dissolved organic carbon
Particulate organic carbon
Ammonium nitrogen
Nitrate + nitrite nitrogen
Dissolved organic nitrogen
Particulate organic nitrogen
Dissolved inorganic phosphorus
Particulate inorganic phosphorus
Dissolved organic phosphorus
Particulate organic phosphorus
Dissolved silica
Particulate biogenic silica

In the absence of data on the above species, assumptions must be made regarding the partitioning of C, N, P, and Si into species for loadings.

Boundary concentrations, rather than loadings, should be specified for all HM flow boundaries where heat and mass can enter via bi-directional transport, such as the open gulf boundary. Boundary concentrations must be entered at tributaries for those constituents that are not entered as loads. The Florida Bay WQM should be able to allow specification of boundary concentrations for the constituents listed in Table 9. This list is inclusive; for example, it may not be necessary to measure chlorophyll *a* and abundance of major algal groups for the tributaries. As with loads, missing information on boundary concentrations must be generated or synthesized.

Table 9
Boundary Concentrations Required by the WQM

Salinity	Particulate inorganic phosphorus
Temperature	Dissolved organic phosphorus
TSS or ISS	Particulate organic phosphorus
Chlorophyll *a*	Particulate biogenic silica
Dissolved organic carbon	Dissolved silica
Particulate organic carbon	Dissolved oxygen
Ammonium nitrogen	Alkalinity
Nitrite and nitrate nitrogen	pH
Dissolved organic nitrogen	Dissolved calcium
Particulate organic nitrogen	Particulate calcium
Dissolved inorganic phosphorus	Abundance of major algal groups

Monitoring for loadings on tributaries should be conducted frequently enough to characterize the variability. This usually requires sampling at weekly, or more frequent intervals. Tributary sampling should include base flows and storm events. During storm event sampling, frequent sample collection (e.g., every few hours or less) is required to characterize how water quality varies with discharge. The duration of tributary sampling should be long enough to allow development of meaningful loading regression models that account for variations in flow and time of the year. Typically, tributaries should be sampled each season to include multiple base flow samples (at different flow rates) and several storm events.

Open ocean boundaries can be sampled at about the same frequency as that used for other water column observations. Sampling frequency can be seasonally for septic tank seepage and groundwater flows. Point source discharge information is usually available on a monthly basis. Atmospheric deposition measurements should cover seasonal variation as well as events.

Potential Data Gaps and Needs

Special monitoring and process investigations are recommended below if they meet two conditions: (a) they are considered important for supporting the model, and (b) there is reason to believe that they are either not presently being undertaken or the present data-collection plan may need to be expanded. The authors of this work plan are not fully knowledgeable of the details of all existing data-collection efforts. Thus, there may be some gray areas concerning the data-collection needs. It is beyond the scope and funding of this work plan to develop a data-collection plan that might be undertaken to support the model since developing such plans is a major effort. For these reasons, a task for data review and recommendations is suggested at the initiation of the study (see Appendix B, Task 1b) to plan a future data-collection effort to better support modeling needs. However, this modeling project should not be expected to fund and execute future data-collection activities.

The recommendations that follow can be used to immediately gain a rough picture of future data collection and process investigation needs. These recommendations are presented in terms of calibration observations, process investigations, and loadings/boundary conditions.

Calibration observations

Water column. Based upon a listing of water column variables presently being collected by Florida International University (FIU), the following additional water column measurements should be considered (along with the current list of FIU variables) at each station throughout the Bay for a period of at least 1 year on approximately a bi-weekly basis for use in model calibration:

- Total suspended solids.
- Inorganic suspended solids.
- Particulate organic carbon.
- Total dissolved phosphorus (TDP).
- Total inorganic phosphorus (TIP) (reactive and acid-hydrolyzable).
- Dissolved inorganic phosphorus (DIP) (reactive and acid-hydrolyzable).
- Particulate biogenic silica.
- Dissolved silica.
- Light attenuation.
- pH.
- Alkalinity.
- Total inorganic carbon.
- Dissolved and particulate calcium.

From ongoing monitoring of total phosphorus and the addition of TDP, TIP, and DIP, it will possible to determine dissolved and particulate organic phosphorus by difference. Spatial coverage should be sufficient to capture the marked water quality gradients that exist in the Bay. Existing FIU sampling stations should suffice. A logical approach would be to expand the FIU sampling program to include additional parameters. It may also be advantageous to conduct some diel measurements at select locations. Diurnal tidal fluxes of nutrients through passes in the keys are being measured.[1]

Sediment flux data. Ongoing sediment flux studies are being conducted by the Florida Department of Environmental Protection (FDEP) and the University of Miami (UM) through the National Oceanic and Atmospheric Administration's South Florida Ecosystem Restoration Prediction and Modeling program. Principal Investigators for this project are Paul Carlson, Larry Brand, and Alina Smant. This project includes in situ flux chamber measurements of ammonium, nitrite, nitrate, dissolved inorganic phosphorus, dissolved silica, dissolved oxygen, and dissolved sulfide.[2] The chamber flux measurements are being conducted at six sites three times a year. In addition, sediment-water fluxes of TIC and dissolved calcium should be measured.

At the same time as the flux measurements, FDEP/UM are also measuring pore water profiles of dissolved inorganic N and P using peepers.[2] The peeper measurements should coincide with the constituents listed in Table 7. Additionally, twice a year FDEP/UM collect cores from 24 sites and analyze them for pore water concentrations of nutrients, pH, and sulfide, as well as solid concentrations of nutrients and organic carbon.[2] The following quantities should be measured from the core's interstitial water (if not presently being measured in the FDEP/UM study):

- Dissolved oxygen.
- Dissolved sulfide.
- Ammonium nitrogen.
- Nitrate and nitrite nitrogen.
- Dissolved inorganic phosphorus.
- Silica.
- TIC.
- Sulfide.
- pH.
- Dissolved calcium.

Sediment core particle composition analyses should be conducted for the following:

- Particulate organic nitrogen.
- Particulate organic phosphorus.
- Particulate organic carbon.
- Particulate inorganic phosphorus.

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1 Personal Communication, 1997, J. N. Boyer, Florida International University, Miami, FL.

2 Personal Communication, 1997, Paul Carlson, Florida Department of Environmental Protection, St. Petersburg, FL.

* Particulate biogenic silica.
* Particulate calcium.
* Acid-volatile sulfide.

Composite dissolved and particulate concentrations of the upper 10 cm of sediment cores are sufficient.

The FDEP/UM are conducting most of the above analyses already or can accommodate the above needs, except for perhaps biogenic silica.[1] Some data on sediment particle size and particulate phase nutrients will come from the USGS research efforts being conduct by Ellen Prager and Bill Orem. Sediment flux data are also being collected by the South Florida Water Management District,[2] but these data are only being collected along the north boundary of the Bay.

Process data

Nitrification, primary production, and respiration. At the workshops, there was discussion over the high ammonium and low nitrate values that have been observed, suggesting low nitrification rates. Thus, a site-specific study of nitrification may be warranted to estimate the rates and to determine causality of any unusual rates. Other useful water column process measurements include primary production and respiration rates.

Light attenuation. Information is required to define the effect of various dissolved and suspended matter on light attenuation. Turbidity and light attenuation data have been collected. Additionally, Phlips, Lynch, and Badylak (1995) have contributed to the information available on the effects of various components to the total optical attenuation of Florida Bay. However, these studies are not sufficient to model light penetration. The model will compute suspended sediment, phytoplankton, detritus, and dissolved organic carbon, all of which affect light attenuation. Parameters are used to relate each of these components to light attenuation. These parameters are known for other systems, but they may be different for Florida Bay. Thus, a study is recommended to relate phytoplankton, detritus, suspended sediment, and dissolved organic carbon to light attenuation. Additionally, there is a need to relate turbidity to light attenuation since an abundance of turbidity measurements exist.

Phosphorus partitioning. Inorganic phosphorus can partition between water and sediments in both the water column and sediment bed. Partitioning of phosphorus is dependent on a number of factors, such as pH

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[1] Personal Communication, 1997, Paul Carlson, Florida Department of Environmental Protection, St. Petersburg, FL.

[2] Personal Communication, 1997, Dave Rudnick, South Florida Water Management District, West Palm Beach, FL.

and iron, aluminum, calcium carbonate, clay, and organic carbon content. There are no universal methods for estimating the partitioning parameters from these variables. Thus, it will be necessary to conduct site-specific adsorption-desorption experiments using native sediments to determine the partitioning parameters for phosphorus in various sediment-water mixtures of varying sediment types.

The adsorption-desorption experiments should be conducted to determine parameters described by Reddy at the October workshop, which include equilibrium phosphate concentration (EPC, milligrams/liter), native adsorbed phosphate (NAP, milligrams/gram sediment), phosphate sorption capacity (PSC, milligrams/gram), and the linear adsorption coefficient (k, liters/gram). The NAP will provide an approximation of the total exchangeable P pool. Various bound P fractions (e.g., iron-bound, calcium-bound, and aluminum-bound P) and total iron in the sediments should be measured in conjunction with the adsorption-desorption experiments through sequential extractions with various extractants. This information will aid in determining controlling mechanisms for P release.

Sea grass parameters. It is recommended that the sea grass model be made dependent on various stressors, such as salinity, temperature, and pore water sulfide concentrations, as well as nutrients and light. Information on stressor tolerance levels for Florida Bay sea grasses will be required for the model. Additionally, nutrient uptake and light-growth information will be required. Some of this information can be obtained from the literature, but site-specific determinations would be valuable. The recommended SAV process information needed for Florida Bay include the following:

- Production versus light intensity curves for dominant species.
- Effect of temperature on production.
- Nitrogen and phosphorus content of shoots and roots.
- Half-saturation concentrations for nutrient uptake through shoots and roots.
- Sulfide and salinity toxicity.
- Half-saturation concentration for TIC uptake.
- Sediment nitrogen and phosphorus concentrations within and outside plant beds.
- Light attenuation measured at the leaf surface due to accumulation of periphyton and seston.

Ongoing studies are addressing some of these needs, and some of this information can be extracted from the literature. However, to avoid any omission, all SAV process data needs are identified. These data are needed for both *Thalassia* and *Halodule.*

Waves and resuspension. As noted earlier, the information on sediment properties and erodibility developed by the ongoing USGS study (Prager, Halley, and Hansen 1996) can be used to describe resuspension parameters in the resuspension module. The erodibility tests will cover low to moderate shear stresses sufficient to describe conditions important to sea grasses. Information on settling rates are also desirable. Settling rate estimates can be obtained from time series suspended sediment (or turbidity) data collected over a period of hours during and after high shear stress events, or by field settling tubes.

The USGS study is also collecting wave information for verification of their wave hindcast model. The comparison will provide a measure of accuracy of the hindcast information for the locations and times data exist. Additionally, spatial wave measurements can be compared with sea grass maps to relate sea grass effects on wave energy. Point measurements of a direct nature, for example pressure gauges, provide the most accurate information, but limit the spatial coverage. An experimental high-frequency radar technique provides large spatial coverage, but is not as accurate as pressure gauges.

Resuspension effects. Concurrent with wave measurements and resuspension events, other point measurements should be made for the nitrogen and phosphorus series, TSS, ISS, and optical properties. Automated water samplers can used to obtain composite water quality samples collected over short time intervals (e.g., 2 hr). Additionally, continuous recordings of turbidity and light attenuation at several locations are useful for characterizing the magnitude and duration of resuspension events. These water quality measurements would be conducted over relatively short time periods characteristic of wind events. The ongoing USGS study is also addressing some of these needs.

Information on changes in soluble nutrients and light in the water column during sediment resuspension events are useful for model evaluation. As an alternative to or in conjunction with field measurements, changes in soluble nutrient concentrations due to sediment resuspension can be easily monitored in the laboratory using a resuspension devise (i.e., a shaker or oscillating grid) to resuspend sediments. This information is important for evaluating the role of sediment resuspension in controlling soluble nutrient concentrations.

Loads and boundary concentrations

Based upon information presented at the nutrient workshop in July 1996 and the modeling workshop in October 1996, it appears that there are data, or ongoing studies, to develop much of the loadings and boundary concentrations. There will be limitations and uncertainty associated with the loading data even though loading information continues to be collected. There are a number of studies that could be instituted or enhanced to better define the loadings.

Other types of models, such as an Everglades (including the mangroves) water quality model, would improve the understanding of nutrient transformations in freshwater flows prior to entering the Bay. Groundwater models can be used to gain a better understanding of nutrient loadings via subsurface flow. However, the use of models to define loadings may not be possible within the time required for use in this Florida Bay water quality modeling effort. Such models may be suitable for future Florida Bay model enhancements.

FIU monitoring stations are being expanded further out onto the western shelf between the Dry Tortugas and Cape Romano,[1] which will help define open-water boundary conditions.

Atmospheric loadings of nutrients have been monitored in the Everglades National Park (ENP) by the U.S. Environmental Protection Agency as part of the National Atmospheric Deposition Program (NADP) and by Florida State University (FSU) through funding from FDEP and the Electric Power Research Institute (EPRI) as part of the Florida atmospheric mercury deposition study. The FSU ENP site is near the NADP site and consists of data on nitrate, ammonium, and total phosphorus, whereas phosphorus was not collected at the NADP site.[2] Almost all of atmospheric deposition of phosphorus is inorganic. The FSU ENP data extends from about 1993-1996; the NADP data covers a longer time period. FSU has also collected atmospheric deposition of N and P in the Bay area at two other sites, Little Crawl Key (just north of Marathon, FL) and Key Biscayne. The FSU sampling consists of monthly integrated measurements of both wet and bulk deposition. FSU also has about 6 months of daily measurements at selected sites. Landing[2] feels that there are sufficient data on atmospheric deposition for Florida Bay to obtain at least first- order monthly estimates of N and P atmospheric deposition (within about a 20-percent error band). However, should additional funding become available, Landing would recommend operating multiple stations in and around Florida Bay to collect both wet and bulk N and P deposition. An expanded network of collectors would decrease the uncertainty of deposition rates and provide improved spatial correlation. Precautions would be required to prevent P contamination of bulk collectors from bird droppings. Monthly integrated sampling would suffice unless it is necessary to determine where the deposition is coming from; then weekly integrated sampling would be required.

Studies are ongoing to define tributary loadings and concentrations. The constituents being sampled in these studies may need to be expanded based upon the list of constituents presented in Table 9. Additionally, efforts are underway to estimate loadings from septic tanks in the Keys. Concern has been expressed over the contributions of nutrients (primarily phosphorus) via groundwater flows. It is recommended that a study be

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1 Personal Communication, 1997, J. N. Boyer, Florida International University, Miami, FL.

2 Personal Communication, 1997, William Landing, Florida State University, Tallahassee, FL.

initiated to better define the groundwater contributions of nutrients from the mainland. Although there are studies being conducted to quantify groundwater flow beneath the Keys and groundwater inputs to the Bay, there appears to be a need for more focus on groundwater contributions of nutrients from the mainland, especially the "river of sand" theory (Brand 1996) discussed at the Annual Florida Bay Science Conference in December 1996.

9 Technology Transfer

Technology transfer is an important component of a large model study such as this. The Florida Bay model should be a joint asset among the various Bay study partners, as well as other interested scientists working in the Bay. To be truly useful, the technology associated with this asset must be transferred to the Bay community.

Technology transfer basically involves three components:

a. Transfer of results.

b. Transfer of computer data and codes.

c. Training for model use.

Results should be transferred in three forms: written and oral progress reports, written documentation reports, and video reports. Written progress reports should be submitted quarterly and include accomplishments during the reporting period, plans for the next reporting period, and cost summaries. Oral presentations on progress should be presented quarterly to the Modeling Committee (MC) and the MEG at a sight in south Florida designated by the partners and the PMC. The quarterly progress meetings should also be open to interested Bay scientists. The functions of the MC and MEG are explained in the next chapter. Various written reports must be prepared to document model development, calibration/confirmation, and scenario testing. Additionally, a video production is recommended to illustrate through computer graphical animation the results of the most preferred management scenario. It is also anticipated that a number of referred journal papers will result from this study.

Following completion of the study, all model codes, supporting software, and databases must be transferred to the study partners and the Florida Bay Science Program. Training on model use should be performed at that time for modelers designated by the partners and the Florida Bay Science Program. The study partners will determine the training site.

10 Partnering, Oversight, and Collaboration

The Jacksonville District has stated that it requires funding partners in order to obtain partial funding for this model study. It is appropriate for several partners to fund this effort given that various agencies are already cooperating in studying Florida Bay and planning its future. The funding partners could form or use an existing interagency agreement to execute this study. Participating partners might contribute through direct funding or through in-kind services.

After a study partnership has been formed, each partner will need to designate members to serve on a Florida Bay MC for water quality. The PMC should also have representatives on the MC. The MC should meet quarterly with the modeling team conducting the study to review progress, provide oversight, and make recommendations. The MC is also responsible for reporting back to the partnering agencies and the PMC. The MC oversight should be guided by an MEG, a panel of three to five professionals with expertise in various aspects of hydro-environmental modeling, measurement, and assessment. The MEG must also attend each quarterly progress meeting. The partners, MC, and the PMC should be responsible for nominating and selecting MEG members.

Specific data needs are addressed in Chapter 8. Only through collaboration by the various agencies working in the Bay can these many varied data needs be satisfied. Collaboration among modelers and scientists is critical for the success of an effort such as this. Collaboration may consist of sharing of information stemming from studies that are already funded and would be conducted whether or not this study is conducted. Collaboration must occur on a voluntary basis without additional funding from the model study. Sharing of monitoring data for model calibration/confirmation is a good example of such collaboration. Collaboration also involves providing model results to the bay scientists to obtain feedback. There may also be collaboration during future studies that are modified in some fashion to yield additional information useful for modeling. It should be the responsibility of the Florida Bay Science Program to identify, prioritize, and commission future monitoring and data-collection efforts. The MC should provide recommendations for data collection useful to the model study.

Most of the model development and calibration/confirmation should be conducted within a single centralized model team to avoid errors. However, it is possible and sometimes advantageous to have specific model components developed and tested from outside the central model team and later incorporated into the full model. Additionally, many aspects of the model database can be handled from outside the central modeling team. For example, nutrient loadings are often developed better by those that are more familiar with the data.

11 Summary

This work plan specifies the approach for development and application of a numerical water quality model of Florida Bay. The model package will consist of an HM indirectly linked to the WQM. The WQM will contain components for the water column, sediment resuspension and suspended sediment transport, benthic sediment diagenesis, and sea grasses. Additionally, output from a wave model will be used to develop the wave climate that feeds into the WQM for sediment resuspension.

A structured-grid, finite difference HM (CH3D-WES) will be applied to Florida Bay to develop detailed circulation fields for the WQM calibration, confirmation, and scenario simulations. The existing, unstructured-grid, RMA10-WES finite element HM being applied to the Bay for the Jacksonville District will be used to provide a comprehensive database for guiding the adjustment of the CH3D-WES model. Additionally, the RMA10-WES model will be used to provide aggregated, coarse-scale circulation for the early phases of WQM application on simple grids while the CH3D-WES model is being adjusted and verified. The WQM will be indirectly linked to the HM, meaning that circulation fields will be developed, saved, and used later in WQM runs. Indirect linkage of the HM and WQM implies that there will be no feedback from the WQM to the HM. The adequacy of this assumption must be tested.

The suspended SM component will allow resuspension of inorganic and organic sediment, and one sediment size class of each will be provided. For the purposes of this study, it is not necessary for the model to address changes to inorganic sediment conditions in the bed. Rather, resuspension of suspended sediment will vary as a result of spatially and time-varying current, wind, and wave conditions and changes in sea grass density. It will also not be necessary to model bed sediment transport, changes in bed morphology, shoaling, or uprooting of sea grasses. The resuspension algorithm will be developed within the WQM and will provide a time-varying bed flux of sediment. Shear stress calculations will be modified to include the effects of sea grass density. The sediment bed will be represented by a single layer. Settling and deposition processes will also be included as well as water column transport.

The benthic sediment diagenesis model of DiToro and Fitzpatrick (1993) will be modified for Florida Bay. The model will include carbonate cycling between the water column and sediments and improved representation of phosphorus partitioning between dissolved and particulate phases. State variables to be added include calcium, calcium carbonate, calcium phosphate, alkalinity, and TIC. Phosphate adsorption to calcium carbonate and formation of calcium phosphate will be represented. Computation of pH in sediments will also be added.

An existing sea grass model with the CE-QUAL-ICM model will be used for simulation of *Thalassia testudinum* and *Halodule wrightii.* The model will be modified to incorporate TIC limitation to growth, and salinity and sulfide toxicity effects will be activated. Additionally, if *Thalassia* and *Halodule* coincide or compete, then modifications to the model are required for competition.

WQM development will be guided by three specification exercises to be conducted during the first 6 months of the project. These exercises will provide an opportunity for Bay scientists and other experts to review the detailed strawman proposals for model variables and processes and make suggestions for improvements that will yield a more accurate characterization of Florida Bay.

The existing WQM will be applied on a coarse grid (approximately 20 to 40 cells) at the beginning of the project to obtain an early understanding of the Bay nutrient budget to help guide model development and further development of nutrient loadings. Model development and calibration will be facilitated through initial calibration to a reduced system of three basins representing a range of conditions that occur in the Bay. This initial model calibration will use 1 year of data collected during the mid-1990s. Final WQM calibration will be conducted on the complete Bay system using the detailed CH3D-WES grid. Final calibration will use data for a period of several years from the mid-1990s to present. However, if future monitoring is modified to better represent needs of the WQM, and if the new data can be provided in time, then the new data will be included for final model calibration. Additional data needs to support the model have been identified herein.

Following final model calibration, the WQM will be confirmed over a longer period extending from approximately 1986 through 1996, or even present (or a period decided through consultation with the MC, MEG, and Bay scientists). This period includes the beginning of major sea grass die-off and extends into recent years of some sea grass recovery when data are more abundant. Additionally, this period contains nearly extreme conditions for wet and dry hydrology.

Model application will involve sensitivity testing, scenario testing, and uncertainty analysis. The model will be applied to evaluate six management alternatives. Each scenario will be run with a 10-year simulation to yield near equilibrium conditions using data from the confirmation period (approximately 1986 - present) for loadings and boundary conditions. Results from each scenario will be compared with the baseline scenario results, which will be the confirmation simulation. WQM uncertainty analysis will be conducted for the most preferred management scenario. Monte Carlo simulation techniques will be used to develop confidence limits associated with stochastic perturbations of the selected input data.

WQM data requirements have been identified herein. Additionally, potential data gaps are discussed. There may be a requirement for developing and executing a future data-collection plan to better fulfill model data requirements. If the future data-collection plan is not drafted by the PMC before the initiation of the water quality modeling study, then the first funded task of the model study should include preparing the plan.

Technology transfer will include quarterly progress reports and briefings, model documentation and application reports, a scenario documentation video, and model transfer and training. Extensive partnering and collaboration will be required for this project to be successful. The overall time frame for conducting this study is 4 years.

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Appendix A
Model Scoping Workshop

Workshop on the Design and Specifications for the Florida Bay Water Quality Model
22-24 October 1996
Key Largo, FL

Workshop Moderator, Dominic DiToro, HydroQual, Inc.

Tuesday, 22 Oct

Background and Overview - Facilitator, MEG Chairman

9:00 Introduction and purposes of model and workshop - David Rudnick, SFWMD

9:15 Modeling Water Quality in Complex Estuaries: Lessons Learned - DiToro

9:45 Discussion

10:15 Break

10:30 Overview of Proposed Modeling Strategy - Mark Dortch, WES

11:00 Discussion

12:00 Lunch

Hydrodynamics and Linkage to Water Quality - Facilitator, Mark Dortch

1:15 Update on the Florida Bay Hydrodynamic Model - Lisa Roig, WES

1:30 Hydrodynamic and Water Quality Model Linkage Strategy - Charlie Berger, WES

1:45 Discussion

2:15 MEG comments

Sediment Transport - Facilitator, Kirk Ziegler, HydroQual, Inc.

2:30 Florida Bay Sediment Characterization - Ellen Prager, USGS

2:50 The Influence of Sea Grass on Hydrodynamics and Sediment Resuspension - Evamaria Koch, Univ. of Maryland, Horn Point

3:15 Break

3:30 Sediment Transport Modeling Strategy - Allen Teeter, WES

4:00 Discussion

5:00 MEG comments

5:15 Adjourn

Wednesday, 23 Oct

Sediment Chemistry, Diagenesis and Fluxes - Facilitator, David Rudnick, SFWMD

8:30 Source and Formation of Calcium Carbonate in Florida Bay - Bob Halley, USGS, St. Petersburg

8:45 The Interaction of Calcium Carbonate and Phosphorus - Ramesh Reddy, U. FL

9:00 Modeling Strategy for Benthic Diagenesis and Chemical Flux - Dominic DiToro

9:30 Discussion

10:15 MEG comments

10:30 Break

Water Column Water Quality Processes - Facilitator, Joe Boyer, FIU

10:45 Modeling Water Column Eutrophication Processes - Carl Cerco, WES

11:15 Discussion

12:00 MEG comments

12:15 Lunch

Sea Grasses - Facilitator, Chris Madden, SFWMD

1:30 The Status of Florida Bay Sea Grasses - Mike Durako, Florida Marine Res. Inst.

1:50 Sediment Resuspension, Water Quality and Aquatic Vegetation - John Barko, WES

2:00 Approaches for Modeling Sea Grass - Carl Cerco, WES

2:30 Discussion

3:15 Break

3:30 Resume discussion

4:00 MEG comments

4:30 General discussions covering the last two days

5:15 Adjourn

Thursday, 24 Oct

External Loadings - Facilitator, Dan Childers, FIU

8:30 Sources and Quantities of Nutrient Loadings to Florida Bay - Bill Walker, Consultant

9:00 Discussion

9:45 MEG comments

10:15 Break

Synthesis - Facilitator, Dominic DiToro

10:30 Discussion

12:00 Lunch

1:15 Consensus Summary

2:15 Break

2:30 MEG comments and recommendations

4:30 Adjourn

WORKSHOP ON THE DESIGN AND SPECIFICATIONS FOR THE FLORIDA BAY WATER QUALITY MODEL: REPORT OF THE MODEL EVALUATION GROUP

Workshop Moderator, Dominic M. DiToro

22-24 October 1996
Key Largo, Florida

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SUBMITTED TO THE

PROGRAM MANAGEMENT COMMITTEE FLORIDA BAY RESEARCH PROGRAM

SUMMARY AND RECOMMENDATIONS

The Florida Bay Program Management Committee (PMC) convened a workshop in Key Largo, Florida from October 22-24, 1996 to focus on the identification of model components and activities critical to the management of Florida Bay. A "Model Evaluation Group" (MEG) was impaneled to observe the workshop proceedings and make recommendations about future directions of the Florida Bay modeling effort. The MEG's major recommendations are given below.

1. Practical management alternatives and issues must motivate the modeling effort. The model must be able to:

- Provide managers with the necessary information to determine optimal freshwater flows and diversions.
- Determine any physical alterations necessary to manage water flow.
- Predict water quality changes to the extent possible.

2. Important issues to be explicitly addressed by the water quality model include:

- Source, fate, and distribution of nutrients.
- Trend and fate of seagrass populations as affected by nutrients, turbidity, and salinity.
- Resuspension of sediments and impacts on light penetration.
- Distribution and occurrence of planktonic algae blooms.
- Distribution of salinity, brackish water, and hypersalinity.

3. Development and early implementation of a hydrodynamic model to link to the water quality model is a high priority. The CH3D model has been linked to water quality and sediment transport models elsewhere; however, it will be very difficult to develop a linkage *ab initio* for the RMA2 model (Berger, workshop presentation). Accordingly, the MEG believes that in the long run, the CH3D model offers an important advantage over RMA2.

- Preliminary implementation of the CH3D model should begin before the RMA2 is finished.
- The CH3D model should be used in a 2D- or 3D-mode to simulate larger scale circulation between basins to insure that hydrodynamic and water quality model linkage is practical.
- The calibrated RMA2 model should be used to explore questions about fine scale circulation patterns occurring over mud banks, between basins, through the Keys, and at the western boundary, because difficulties will arise in implementing CH3D in such a shallow, irregular estuary.
- Projecting salinity distributions and freshwater impacts from the alteration of C-111 canal and other freshwater flows will likely require a coarser grid than the one currently under development.
- Reproducing measured salinity distributions at various scales is a critical task. Thus, a fine scale RMA2 simulation should be calibrated to existing salinity distribution data and a subsequent similation used to provide a more comprehensive data set for calibrating a coarser scale CH3D circulation pattern at critical times.

4. Expectations and goals should be explicitly agreed to by key players at the outset and be kept realistic by:

- Avoiding the inclusion of too many elements in the model.
- Starting simply, adding complexity *only as necessary.*
- Using auxiliary research models to address a few specific management issues.

It is vital that a simple, large box model be formulated prior to linkage of the hydrodynamics model as recommended by COE/WES (Dortch, workshop presentation). Preliminary models are crucial to confirm and further develop the initial mass balance calculations presented by Walker (workshop presentation); to gain an early appreciation of the behavior of the Bay; to facilitate development of detailed models; and to guide future data collection.

5. An elaborate modeling system cannot address all resource management issues. Some processes are not sufficiently understood at the present time, requiring special research investigations to define parameters and kinetic rates.

- Continued monitoring is necessary for model calibration, verification and refinement.
- A complex modeling effort, such as for Florida Bay, also requires the establishment of a separate budget for coordinated research and development.
- Research project selection should employ peer review and avoid conflict of interest.
- Supporting research should focus on improving vital parameters within the model, should improve process understanding, and should explore potential issues that cannot be quantified presently, but that may represent a significant ecological risk.

6. The members of the PMC and their agencies need to set priorities, coordinate effectively, and communicate goals and objectives clearly. Recommendations made by previous review panels with regard to organizational improvements for program management should be pursued without further delay.

INTRODUCTION

As part of the process of designing and providing specifications for the modeling effort on Florida Bay, a modeling workshop was convened by the Program Management Committee (PMC) from October 22-24, 1996 in Key Largo, Florida. A "Modeling Evaluation Group" (MEG) was impaneled to evaluate and guide the PMC's modeling efforts. This panel included Ted Callender, Chris D'Elia, Winston Lung, and Steve McCutcheon. The following report summarizes the meeting and gives the panel's recommendations for future directions.

Discussion at the outset of the workshop set the stage for the ensuing discussion by reviewing progress of the past several years. Accordingly, David Rudnick, who presented introductory comments, urged the group to frame modeling efforts in the context of the central questions that have been addressed by the previous PMC efforts, review panels and workshops (Table 1).

Table 1. The "central questions" of the Florida Bay interagency science program.	
1.	How and at what rates do storms, changing freshwater flows, sea level rise and local evaporation/precipitation influence circulation and salinity patterns within Florida Bay and influence the outflow from the Bay to adjacent waters?
2.	What is the relative importance of the input of external nutrients and internal nutrient cycling in determining the nutrient budget of Florida Bay? What mechanisms control the sources and sinks of the Bay's nutrients?
3.	What regulates the onset, persistence and fate of planktonic algal blooms in Florida Bay?
4.	What are the causes and mechanisms for the observed changes in seagrasses and the hard bottom community of Florida Bay? What is the effect of changing salinity, light and nutrient regimes on these communities?
5.	What is the relationship between environmental and habitat change and the recruitment, growth and survivorship of higher trophic level species?

While these organizing questions provide the framework for the entire Florida Bay effort, the present task is more constrained and pertains to issues discussed at workshops directed at hydrodynamics (April, 1996) and nutrients (June, 1996). The review panels at the previous workshops have made a number of substantive recommendations that should also be considered[1,2,3].

In its report[4], the review panel at the April, 1996 Hydrodynamics Workshop considered the following major topics: model appropriateness, system representation, boundary conditions, interfacing with water quality models, field measurements, and model and data collection evaluations groups. The panel's major recommendations are summarized in Table 2.

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[1] Armstrong, et al., 1996.

[2] Boesch, et al., 1996.

[3] Boesch, et al., 1995.

[4] Armstrong, et al., 1996.

Table 2. Key recommendations of the April, 1996 Hydrodynamics Workshop.
1. The 2-D RMA2 finite element model is appropriate for an initial exploration of Florida Bay hydrodynamics. The number of elements currently in the RMA2 model probably can be reduced.
2. A 3-D model may be required to deal with western regions.
3. Boundaries should be expanded northward and westward to include Shark River influence, as well as circulation along the west coast of Florida, and southward to include offshore of the Keys.
4. The review panel was concerned regarding linkage of RMA2 with sediment transport and water quality models.
5. Water quality modeling, including seagrasses and benthic exchanges, is an essential tool in the development of the restoration plan for Florida Bay.
6. A central repository for data and vigorous coordination of field measurement programs should be initiated.

In its report[5], the review panel at the Nutrient Workshop considered critical issues related to modeling that will be essential for the restoration of the ecosystem. (Table 3). Major topics considered by the review team were the adequacy of databases, research and monitoring programs, modeling needs, restoration objectives and strategies, and the Florida Bay science program management.

Table 3. Recommendations related to modeling from June, 1996 Nutrient Workshop.
1. Pursue the development of a coupled circulation-ecosystem model of Florida Bay as a tool to systematize data, pose hypotheses, and anticipate the effects of different water management scenarios.
2. Include as key features in the model: (1) coupled hydrodynamic-nutrient-phytoplankton-water quality variability [a "water-quality" model], (2) suspended sediments and their influence on turbidity, and (3) seagrass populations and influence on sediments, nutrients and geochemistry.
3. Critical questions to address in the model include: (1) What is the fate of nutrients discharged from the Shark River? (2) What is the biological availability of particle-bound P? (3) Why are the features of nitrogen cycling in Florida Bay apparently distinct from those in other coastal water bodies? (4) What are the mechanisms that trigger and sustain algal blooms in Florida Bay? and (5) What are the origins of turbid water?

The *ad hoc* review panel at the nutrient workshop further emphasized that certain essential state variables must be measured continually in a monitoring program, and that fundamental processes, such as mineralization of TOP and TON must be measured via experimentation. Furthermore, the panel observed that "the temptation to produce a model which answers all possible questions (e.g. regarding food webs and living resource production) should be avoided." The panel asserted emphatically that the restoration program should have more clearly stated goals, and that the Florida Bay Interagency Science Program program should make improvements in management in a number of areas.

CONSENSUS ON UNDERSTANDING AND MODELING FLORIDA BAY

[5] Boesch, et al., 1996.

Overall Progress on Understanding and Modeling Florida Bay

The MEG was impressed with the level of interest, commitment and activity that is now being shown by federal and state agencies, academic and government scientists, non-government organizations (NGO's), and the public for Florida Bay. Considerable progress has been made in understanding the structure and function of this unique resource and ecosystem, and several useful monitoring programs have been instituted at different times to provide important information on a regular basis about the Bay and its water quality.

The modeling workshop that this report addresses was highly successful and relevant to issues confronting the Bay. Attendees came well prepared and anxious to enter into a constructive dialogue. The workshop moderator, Dominic DiToro, did an exemplary job in keeping the focus of the group on achievable goals, while at the same time allowing sufficient latitude for fruitful scientific discussion at a more detailed level.

Consensus Reached by Workshop Participants

The open scientific dialog was intrinsically useful, but also meshed well with preparations by the Corps of Engineers, William Walker, and others in formal presentations (see the attached schedule of presentations). The result was a solid consensus on all of the important elements of an integrated water quality-sediment-sea grass model. At the end of the workshop participants explicity agreed that:

- Sea grasses must be included in the integrated modeling system.
- Two generic classes of seagrass — a longer-term stable species and shorter term opportunistic species — are required to adequately address management issues related to submerged aquatic vegetation (SAV).
- Nutrients cannot be adequately simulated without including SAV.
- The effect of SAV on nutrients is expected to be adequately described by treating SAV as biomass (as is done in current water quality models).
- Two classes of algae seem to be required — silicified and non-silicified groups.
- First-order, quadratic estimates of resuspension based on wind speed and water depth are expected to be adequate to simulate effects of turbidity on SAV and water quality.
- The simulations of SAV (based on two generic classes, light effects of resuspension, planktonic algae shading, nutrient distributions, and salinity distributions) may not be absolutely correct or fully predictive, because disease and other effects will not be explicitly included. However, the relative sensitivity analyses of the differences between simulations should be useful and accurate to define approximate maximum and minimum recovery conditions over 10-year time periods. This should winnow out some hypotheses about SAV behavior and narrow the management alternatives.
- Phase II (post disease impact) should be simulated for SAV recovery for at least ten years (ten years was considered the minimum period necessary to capture some of the natural cycle of SAV in Florida Bay).
- The finite element model RMA2 and finite difference or box water quality models like CE-QUAL-ICM are too difficult to link adequately (although it is agreed that this is theoretically possible).

- The RMA2 model will be used by the Jacksonville COE to explore the effects of freshwater diversions between the C-111 canal and Taylor Slough on salinity distributions (including hypersalinity), and to determine flows through cuts between the Keys.
- In parallel, the CH3D (in a 2D- or 3D-mode), or similarly compatible finite-difference, model will be calibrated over a grid on the order of 1000 elements, using the RMA2 simulations extrapolated from salinity and current measurements and independent estimates of friction coefficients from the USGS investigations, to drive the water quality model.
- The new hydrodynamics model will be tested to determine the gross circulation in three basins — an eastern, a central, and a western basin.
- A preliminary coarse box model based on RMA2 water fluxes on the order of one or two boxes per basin or about 20 to 100 boxes will be implemented to address broader questions about nutrient and salinity transport and get preliminary estimates of fluxes between basins.

The workshop consensus was based on important points made during formal presentations first by David Rudnick on the management issues (covered in the Introduction above), and then by Mark Dortch of the COE, who stated that the purpose of the workshop was to develop a report that he would write and present at the December 1996 Annual Science Conference. The report is intended to be a general assessment that will define general modeling requirements to address a range of management issues. The report is not intended to be a work plan for a particular organization, nor to bias any peer-review and management selection of any group. However, Mark Dortch and the COE will clearly have an inside track based on experience in water quality modeling and preferred funding mechanisms through the Jacksonville COE. *Nevertheless, it is important for team building and managing the Florida Bay Program that any proposals from WES/COE, or anyone else invited to propose an integrated model, be thoroughly peer reviewed and assessed by the Florida Bay PMC.*

Based on the background of the meeting, the MEG generally agreed with the consensus, reaching essentially the same conclusions on the modeling framework in a separate meeting the night before, with only two exceptions. First, the unique system, consisting of a mantle of sediment over bedrock and largely discrete particles, seems ideally suited for mass balance modeling of sediment transport and dispersion. The key is whether sediment transport should be simulated or whether local resuspension and deposition occurs as was assumed in the workshop consensus. Second, the MEG lacked the experience and adequate information possessed by local scientists to reach specific decisions on the classes of SAV and phytoplankton to include in the model. Regardless, it is remarkable that an outside panel anticipated the wider consensus of experts knowledgeable of this unique system working in concert with modeling experts experienced with many systems. This is a tribute to the many investigators present who shared concisely, freely, and openly of their own experience in Florida Bay and of the advancing state of the art of modeling now conducted for many water bodies.

Key Issues of Concern to the Modeling Evaluation Group

In the same constructive spirit that guided this workshop and the April 1996 workshop on hydrodynamics, the present report both confirms the MEG findings that the workshop consensus is generally sound, and addresses potential problems and gaps in knowledge. In general, the Florida Bay investigation is well conceived and sensibly executed, but improvements are possible.

Sediment Resuspension and the Effect on the Light Field

The MEG believes that good modeling codes are presently available for calibration to simulate resuspension and deposition, whereas the workshop consensus was that light attenuation as influenced by local resuspension and settling, should merely be simulated descriptively. The MEG further believes that if phosphorus desorption kinetics are important in nutrient cycling, the model calculations should portray accurately different particle transport and residence times in the water column. The MEG is concerned that a simple conceptual model of resuspension, nutrient release and deposition on an unspecified time scale may not adequately address Florida Bay conditions.

Sediment resuspension is potentially important to P release from the sediments and to the subsequent resorption on the surface of resuspended material. Accordingly, sediment resuspension represents a potential source/sink of P in the water column and thus relates in a different way to light attenuation incorporated in the phytoplankton growth model. The conceptual model proposed by Reddy at the workshop related to P uptake by benthic periphyton and possible transfer to "leaf" organic matter, suggests that wind-generated resuspension events might translocate the $CaCO_3$-sorbed P to other parts of the pelagic system. This P, in turn, might be released to solution and available for rapid incorporation into organic matter. On the other hand, diagenetic release of P to interstitial water and the enrichment of sediment particles that reside in the benthos may provide a source of P to the water column when resuspension of these particles occurs, since sorbed P in resuspended sediment may subsequently become desorbed under the different physico-chemical conditions of the water column. One can only speculate at present, and there is need for much research on these topics.

Submerged Aquatic Vegetation (SAV) and Relationship to Water Quality

The whole area of growth, die-off, and decay of SAV species (*Thalassia* and *Halodule*) appears to be fundamental to the understanding of nutrient cycling in Florida Bay. Seagrasses are the most dominant biological system of Florida Bay; the canopy strongly affects the water column and 80% of the biomass resides in benthic sediment. It seems clear that there is limited understanding of the role of seagrasses in nutrient cycling.

The MEG suggests that the Program Management Committee (PMC) convene a group of experts with respect to seagrass ecology, seagrass dynamics, carbonate geochemistry, benthic processes, and water-quality modelers for the purpose of defining a conceptual model of nutrient cycling between the water column and benthic systems. The outcome of this exercise would be to identify critical research components that would yield quantitative information needed by the water-quality modelers. Then, the PMC could foster a few interdisciplinary studies to provide the necessary data.

Model Structure

Based on the discussions in the workshop, a consensus has been reached to develop a integrated modeling framework to address management questions for Florida Bay. The modeling framework should consist of the following components: a seagrass model, a water quality model, and a hydrodynamic model.

To keep the modeling effort to a manageable level and yet still robust enough to accurately quantify the seagrass effect on turbidity and nutrient recycling, two generic species of seagrass (i.e., fast growing and slow growing species) are recommended for the model. Model coefficient values should be derived from specific studies by local scientists. The water quality model will include a sediment benthic diagenesis module directly interacting with the water column kinetics. The pH-carbonate equilibria will be incorporated due to the unique geological characteristics of Florida Bay and the pH effect on phosphorus precipitation, adsorption, and desorption. Two phytoplankton species will be simulated in the water column. Another key element in the water quality model is the quantification of light attenuation in the water column, which is closely related to the suspended solids concentration. In lieu of a sediment transport modeling effort, a simplified approach is recommended: i.e., quantify bottom shearing stresses based on the wind speed and wind-generated waves on the water surface. The magnitude of the shearing stress therefore determines the resuspension flux of the solids. In areas covered with seagrass, resuspension rates are reduced, depending on the density of coverage.

While the fine, structured grid model, RMA2, is to be used to compute detailed circulation patterns and mixing in the Florida Bay, the total number of cells should be significantly reduced to make the computational effort reasonable. Reduced numbers of grid points will insure that the code is transferable to the COE Jacksonville District and the South Florida Water Management District (SFWMD). In the meantime, the structured grid hydrodynamic model, CH3D, should be configured for the study area. The advantage of the CH3D model is that it can be directly linked with the water quality model CE-QUAL-ICM, a technology that has been successfully demonstrated in previous studies by the COE/WES modeling staff. The disadvantage is that local morphological and topographic features of Florida Bay are less resolved than with the RMA2. The relative importance of morphological resolution on general water quality patterns needs further assessment.

Modeling Strategy and Steps

The workshop participants have identified and discussed three primary technical issues for this modeling study:

1. Linkage between the hydrodynamic and water quality model. The model linkage issue can be approached in the following manner. First, the fine, unstructured grid model, RMA2 will be run to match the measured salinity distributions in the Bay. Once the model is calibrated and verified, its results will be saved and serve as a data set for calibrating the subsequent mass transport modeling effort. In a dual-track effort, the structured grid hydrodynamic model, CH3D, will be configured and run to match the salinity results of the RMA2 model. Matching the salinity field is a key test for the hydrodynamic modeling effort. The calibrated mass transport can then be used to drive the water quality model. *It is important that both the CH3D and water quality models use the same spatial grid system for a direct linkage without any spatial averaging.*

2. Effect of seagrass die-off on turbidity and nutrient recycling in the water column. Seagrass die-off affects the turbidity and nutrient recycling in the water column. Accordingly, model sensitivity runs are recommended to quantify seagrasses' effects on the hydrodynamics and water quality.

3. Nutrient loads to the Florida Bay. Since data on nutrient loads from the mainland are limited, it is necessary to use a watershed model or other methodologies to develop the loads from the mainland to Florida Bay.

The MEG agrees, in priniciple, with the COE that CH3D and CE-QUAL-ICM are adequate models for Florida Bay. However, any work plan or proposal for water quality modeling should be peer-reviewed prior to initiation of funding. The PMC should be open to any alternative proposals applying similar models.

The Roles of Research and Monitoring

Both research and monitoring play crucial roles in support of the modeling and management effort for Florida Bay. As the original Florida Bay science report[6] observed, "we cannot overemphasize the need to provide sustained support for research, monitoring and modeling activities to provide managers proper information." Estuaries and coastal areas are notoriously "individualistic," and the modeling of estuaries has only in the last decade begun to develop adequate sophistication and technical reliability to be effective management tools. Although there are now excellent examples of coupled hydrodynamic-water quality models for estuaries, these have generally benefited by having identifiable support for research targeted to key needs, such as understanding nutrient and oxygen fluxes at the sediment-water interface. They also have intensive monitoring programs to provide baseline information about hydrographics, water quality, and natural variability.

There can be no doubt that Florida Bay possesses unique features that have yet to be included in any water quality model for an estuary. For example, the carbonate sediments in the Bay contrast markedly with the clastic sediments encountered in temperate estuaries such as Chesapeake Bay, Long Island Sound, and San Francisco Bay. The relationship between water column productivity and sediment oxygen demand/nutrient flux has never been sufficiently examined for a carbonate environment to provide information needed in the water quality model. Accordingly, we recommend that in addition to providing continued support for the Florida Bay monitoring program, that federal and state agencies join forces to establish an independent research fund for activities that provide information essential for development of the model. As the Florida Bay Science Review Panel has observed, "The Program Management Committee should commit to external peer review of proposals . . ."

Agency Coordination and Leadership

The members of the PMC and their agencies need to set priorities, coordinate effectively, and communicate goals and objectives clearly. Recommendations made by previous review panels with regard to organizational improvements for program management should be pursued as soon as possible.

We recognize that in most cases, individuals on the PMC are limited in their ability to commit their own agency to changes necessary to improve the management and coordination function. We also recognize that federal agencies do not have consistent and equivalent policies for managing research, funding extramural activities, and conducting peer review of scientific proposals. The recent comments of the Ad Hoc Committee on Nutrients[7] and Peer Review Panel on Hydrodynamic Modeling about ways to strengthen the management of the Florida Bay Science Program remain relevant. Particularly important will be to "hire or designate a full time program manager whose responsibility it will be to coordinate and track Florida Bay research and make appropriate recommendations to managers." We would supplement that statement with the further recommendation that the individual should also have a budget to service

[6] Boesch, et al. 1993, p. 23.

[7] Boesch, et al., 1996, pp. 11-12.

coordination functions (such as organizing and conducting workshops, paying travel expenses for panelists and advisors, preparing reports and communications to the public, etc.).

For necessary changes in management structure and function to be made, it may be wise to convene separately a meeting of responsible agency officials above the level of PMC principals. The PMC has wisely coordinated agency efforts, but it seems that more is possible. Given the dedication of the PMC, the responsible agencies owe it the effort to achieve even more effective cooperation.

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12/9/96

Appendix B
Task Descriptions, Milestones, and Schedule

Task Descriptions

Study tasks are separated according to model study components. A brief explanation of each task is provided.

1. Review and Planning - There is a need at the initiation of this study to review existing information and to plan future data collection needed to support modeling efforts.

1a. Literature and Data Review - Literature and existing data will be assimilated and reviewed to gain a better understanding of Florida Bay.

1b. Future Data Collection Plan Development - If prior initiatives of the Program Management Committee have not addressed this need by the time this study starts, then a work plan will be developed for collection of future water quality (and related) data to satisfy the needs of a comprehensive Florida Bay water quality model. This subtask will be initiated with a 2-day workshop to delineate additional data needs. The data-collection work plan will include collection locations, frequency, duration, analyses, quality assurance/quality control, and methods, along with estimated costs.

1c. Specification Exercises - Three specification exercises will be held at the initiation of the study to finalize the details of model specifications. These exercises will be used to lay out the best model framework, processes, and modeling approaches. Experts from around the country and Bay scientists will participate in these exercises along with Florida Bay modeling personnel, the Modeling Committee (MC) and Model Evaluation Group (MEG) members. Each exercise will be initiated with the posting of the strawman proposal for review on a Web site. Comments from reviewers will be considered through phone and e-mail discussions. The strawman will be revised and presented to the MC and MEG for approval. Each exercise may be concluded through a meeting or brief workshop if the MC/MEG deem necessary. Conclusions and recommendations from the exercises will be documented and used to guide model development.

The first exercise will deal with the material presented in Chapter 4 (main text) related to suspended resuspension and its linkage to wind, waves, and sea grass. Additionally, the first exercise will address the approach for developing wind wave information.

The second exercise will deal with state variables and processes of the water column and benthic sediment components of the water quality model (WQM). Decisions will be made regarding the addition of new state variables and processes and methods for prescribing new or revising existing processes.

The third exercise will refine the plans for the sea grass model component.

2. **Hydrodynamic Model** - There are a number of tasks associated with hydrodynamic model (HM) verification and production runs for WQM calibration and confirmation.

2a. Computational Grid Development - A CH3D-WES grid of Florida Bay will be developed with adequate resolution to preserve the proper circulation, transport, and salinity fields. Results of the Sheng Florida Bay HM (Sheng and Davis 1996)[1] will help in this determination. Additionally, the verified RMA10-WES HM of Florida Bay will be used to guide the grid resolution requirements for the system. Minimal resolution requirements for accurate reproduction of system behavior will be determined, while considering trade-offs between grid resolution requirements and computational speed. Boundary condition tests will also be made on the existing RMA10-WES HM to determine the sensitivity of the calculations to the specification of open ocean boundaries. Based on the results of these sensitivity tests, additional ocean/gulf boundary condition information will be developed if necessary.

2b. CH3D-WES Model Modification and Verification - Boundary condition files for the RMA10-WES verification will be transformed into appropriate CH3D-WES boundary condition file formats. In addition, wetting and drying will be added to the CH3D-WES code. Calculations will proceed using the enhanced CH3D-WES code and the verification boundary condition files to develop a verified CH3D-WES HM of the Florida Bay system. Results from the RMA10-WES model will aid in the verification process, e.g., adjusting roughness

[1] References cited in this appendix are listed in the References at the end of the main text.

over the mudbanks to provide the appropriate advection among basins. Verification will involve comparisons of the HM model with field data that contain a range of hydrologic and meteorological events. Grid resolution and time step size will be examined to ensure model consistency. Following model verification, the adequacy of verification will be assessed against predetermined criteria as described in Chapter 3, Verification section (main text).

2c. HM Application for WQM Calibration/Confirmation - It will be necessary to make HM production runs to develop circulation fields to drive the WQM for the calibration and confirmation periods. This task will involve development of boundary condition files and verification to the available salinity record for each production run. Results will be processed for use by the WQM in its calibration and confirmation simulations. In addition, this task includes developing and processing hydrodynamics from the RMA10-WES model for the initial nutrient budget analysis and the initial WQM calibration, both of which will use rather coarse, limited grids. Thus, in these cases, the HM output will have to be aggregated and processed for WQM use. For these coarse-scale, simplified WQM applications, the RMA10-WES model will be applied for either seasonally averaged or annually averaged hydrodynamic conditions.

3. Hydrodynamic and Water Quality Model Linkage - There are two tasks associated with developing and testing the linkage between the CH3D-WES HM and the ICM WQM.

3a. Linkage Files Setup - After the final HM grid is established, the HM-WQM map files must be built. These files provide information to the WQM on the location of all computational cells with respect to each other and their geometric attributes.

3b. Linkage Testing - Checks on volume and mass conservation and comparisons of transport results will be conducted to ensure correct linkage. The HM and WQM will be applied to the Florida Bay grid with a hypothetical conservative (i.e., nonreacting) mass tracer introduced into both model simulations. Transported tracer concentrations will be compared between the two models to ensure that HM transport is properly preserved from the HM to the WQM. Additionally, WQM mass conservation of the tracer will be examined to ensure correct linkage. Salinity will be modeled during WQM calibration and compared with both the HM and observed salinity data to provide a final test of proper linkage.

4. Resuspension Module - Current, wind, and wave conditions are required for the resuspension module of the WQM. The following tasks are required to develop the resuspension module and the required input data to drive it.

4a. Wind Climate Estimates - Wind data sources will be reviewed and selected to produce an accurate representation of meso-scale wind distributions over Florida Bay for the WQM calibration and confirmation periods (approximately 1986 to present). The required temporal and spatial resolution for wind fields will be evaluated, and the appropriate wind fields will be processed for model (HM, wave model, and WQM) use. The wind fields can be processed to provide 1-hr updates of spatially varying winds for various regions of the model domain if necessary.

4b. Wave Climate Estimates - The wind climate data and Florida Bay bathymetric data will be used with a simple wave model to generate first-order estimates of local wave conditions for the WQM calibration and confirmation period. The wave model will be verified against any available observational data.

4c. Resuspension Module Development - The resuspension module will be developed for the WQM to provide time-varying bed flux of sediment that depends on currents, winds, wind waves, and sea grass density. The resuspension at each cell will be calculated based on a weighted sum of shear stress contributions from circulation, winds, and waves. Shear stress calculations will be modified to include the effects of sea grass density such that the portion of shear stress acting to erode sediments will be differentiated from the total shear stress. Shear stress thresholds for erosion and deposition, erosion rate parameters, and settling rates will be specified locally based on measurements being made by the U.S. Geological Survey. The sediment bed will be represented by a single layer, initialized with a sediment bed mass per grid cell, to limit resuspension and conserve the total sediment mass for the system. Settling and deposition processes will also be included as well as water column transport for two suspended sediment classes, inorganic and organic sediment.

4d. Resuspension Module Adjustment and Verification - Model adjustment and verification will be performed in conjunction with other WQM components at several areas within Florida Bay where the most complete data sets are available. Measurements of suspended solids and turbidity (as related to solids) will be used to verify model performance.

5. Water Quality Model Development - The model recommended for this study, CE-QUAL-ICM, already exists in a highly developed state. However, there are several additional features that must be developed and tested.

5a. Physical Modifications - The ICM WQM has been adapted for wetting and drying during a previous study of the Cache River wetland where a link-node hydrodynamic model was used. There will be a need in this study to implement, in a fashion compatible with the CH3D-WES HM, wetting and drying algorithms into the latest version of ICM. Also, it will be necessary to modify the WQM to allow water evaporation and rainfall and the concurrent change in water quality concentrations. Since rainfall and evaporation will be included in the HM, it may be possible to simply read in this information from HM output files.

5b. Modifications for Water Column Processes - The WQM will be modified to include five new state variables and their associated processes: calcium, calcium carbonate, calcium phosphate, alkalinity, and total inorganic carbon (TIC). From these, pH and concentrations of carbonate species will be derived. An efficient, specialized algorithm will be developed to compute the carbonate system and calcium-phosphorus interactions.

5c. Benthic Diagenesis Model Modifications - The benthic diagenesis model will be adapted to the carbonate sediments of Florida Bay. The model will be improved through detailed representation of carbonate cycling between the water column and sediments and through improved representation of phosphorus partitioning between dissolved and particulate phases. State variables to be introduced into the sediment model include calcium, calcium carbonate, calcium phosphate, alkalinity, and TIC. Phosphate adsorption to calcium carbonate and formation of calcium phosphate will be represented. A simplification will be employed in which pH is determined by the carbonate system alone. Resuspension of solids and pore water will be added.

5d. Sea grass Model Modifications - The ICM code presently contains a fairly well developed sea grass model. However, several adaptations will be required to properly represent the sea grasses of Florida Bay. Two species have been selected for simulation: *Thalassia testudinum* and *Halodule wrightii*. Presently, the model simulates a single dominant species in each model cell. If *Thalassia* and *Halodule* coincide or compete, then modifications to the model are required. The model will be modified to include TIC limitation to submersed aquatic vegetation (SAV) growth and the transfer of TIC to/from SAV.

6. Water Quality Model Calibration and Confirmation - There are a number of tasks associated with preparing input data and calibrating and confirming Florida Bay WQM.

6a. Loading and Boundary Concentration Estimates - Mass loadings or boundary concentrations for nutrients and other WQM variables must be estimated for all possible entry points, including freshwater inflows, atmospheric loadings, septic tanks, storm water runoff, groundwater, and the ocean boundaries. Concentrations are required at open-water boundaries, whereas, loads (mass/time) are usually specified for other entrees. Loading and boundary concentration estimates will be required for WQM calibration and confirmation periods. Modifications to loadings for scenario testing will be handled under the scenario testing task.

6b. Model Setup - This task includes selecting and specifying model parameters; specifying locations and quantities for all boundary conditions and loadings; and processing and specifying meteorological data. This task must be executed for each WQM simulation condition, including the initial nutrient budget analysis, initial calibration, final calibration, and confirmation.

6c. Initial Nutrient Budget Analysis - This task involves conducting a coarse-grid (approximately 20 to 40 cells) model application of the entire Bay to gain a better understanding of the relative importance of external nutrient loadings and internal nutrient cycling. The application will also serve to gain an early start on modeling the Bay. This analysis will be conducted for relatively recent data, e.g., 1995 and/or 1996. Annually or seasonally averaged results from the existing fine-scale RMA10-WES HM will be spatially averaged, adjusted to ensure volume conservation, and used to provide circulation for this application. The purpose of this application is to quickly gain a better understanding of the Bay nutrient budget, not WQM calibration. The existing WQM will be used for this application.

6d. Initial Model Calibration - Following the initial nutrient budget analysis, the WQM will be calibrated against observations from three basins for a period spanning 1 year during the 90s. If available by this time, results from the CH3D-WES model will be used to provide circulation and flushing for each basin; otherwise, results from the RMA10-WES HM will be used. As with task 6c, spatial averaging of seasonally averaged flows may be employed for each basin. Local observations will be used for water quality boundary conditions for each basin. This approach will provide an effective mechanism for focusing on model evaluation and adjustment with relatively short turn-around times between model runs.

6e. Final Model Calibration - Final WQM calibration will be conducted for the entire Bay using the detailed WQM gird, driven by the CH3D-WES HM model, for a period spanning several recent years, e.g., mid-1990s. However, if future monitoring is modified to better represent needs of the WQM, and if the new data can be provided in time, then the new data will be included for final model calibration. Calibration results will be evaluated graphically and statistically for all model variables for which there are field observations.

6f. Model Confirmation - Long-term WQM confirmation will be performed for a period of approximately 10 years, starting with approximately 1986 conditions, just before the major sea grass die-off, and extending through the present. The confirmation will serve to demonstrate the ability of the model to capture changes in sea grass coverage as well as long-term water quality conditions. This skill of the model will be assessed graphically and statistically.

7. Model Application - Model application involves sensitivity analyses, scenario testing, and uncertainty analyses.

7a. Sensitivity Analyses - Based upon recommendations from the MC, tests will be conducted to evaluate WQM sensitivity to various assumptions and input values. Since it is not practical to test every model parameter and input value, a limited number of tests (on the order of 10) will be conducted to evaluate the sensitivity of the more questionable input values to examine the relative significance to the modeling process.

7b. HM Scenario Development - The HM must be applied to each 10-year scenario condition that involves changes in flow or circulation. The output will be processed and used to drive the WQM for the same scenario conditions. Six specific scenarios, as determined by the study sponsors, will be evaluated with the WQM, but not all may require recalculation of the hydrodynamics. For example, some scenarios may only involve loading reductions. HM scenarios will include assumptions about freshwater inflow amounts and distribution and other physical parameters as suggested by study sponsors. Forcing conditions, such as the overall hydrology, ocean boundary conditions, and meteorology, will come from the 10-year confirmation period.

7c. WQM Scenario Testing - The WQM will be applied to evaluate six management alternatives. Each scenario will be run with a 10-year simulation using data from the confirmation period (approximately 1986 - 1996) for general forcing and boundary conditions. Results from each scenario will be compared with the baseline scenario results. The confirmation simulation will serve as the baseline scenario.

7d. Uncertainty Analysis - WQM uncertainty analysis will be conducted following the completion of scenario testing. Uncertainty analysis is extremely difficult for models with a large number of input parameters and input conditions such as this model. The tremendous number of realizations that must be run can rapidly exceed computing capabilities. The analysis should be limited to the most preferred management scenario. It will not be possible to perturb all WQM input variables. Thus, a select few input variables should be considered for the analysis. Based upon results from the sensitivity study, the most sensitive parameters and input loadings and/or boundary conditions with the least certainty will be selected. The number of variables and simulation strategy will be designed and matched against existing supercomputing capabilities to ensure successful completion. Monte Carlo simulation techniques will be used to develop confidence limits associated with stochastic perturbations of the selected input data. Results will consist of model output with 95-percent confidence bounds.

8. Technology Transfer - Technology transfer will be conducted for both the HM and WQM. Progress reporting is included in this element.

8a. Progress Reports - Written progress reports will be submitted quarterly and will include accomplishments during the reporting period, plans for the next reporting period, and cost summaries. Oral presentations on progress and results will be presented quarterly to the MC and the MEG.

8b. HM Documentation Reports - A report will be produced detailing the application of the HM. Additionally, results from the various HM production runs, including the runs to support WQM calibration and confirmation and scenario testing, will be documented in another report.

8c. Sediment Transport Model (SM) Documentation Report - A report will be produced to document the SM development and testing.

8d. WQM Documentation Reports - Three reports will be produced to document the WQM activities. The first report will document the initial nutrient budget analysis. The second report will document developments and/or modifications to the WQM conducted during this study and WQM calibration, confirmation, and sensitivity analyses. The third WQM report will document results of scenario testing and uncertainty analysis. Additionally, peer-reviewed journal papers on model results will be encouraged to help build acceptance of the study.

8e. Video Documentation - A video will be produced to illustrate through computer graphical animation the results of the most preferred management scenario.

8f. Delivery of Models and Training - Following completion of the study, all model codes, supporting software, and databases will be transferred to the study partners and the Florida Bay Science Program. The models will be installed and made operational on computing platforms designated by the study partners. Training on model use will be performed at that time for modelers designated by the partners and the Florida Bay Science Program. The study partners will determine the training site.

Milestones

Major milestones are identified in Table B1. The schedule assumes that the study will start October 1997. If the study starts at a later date, then all dates must be shifted accordingly.

Table B1
Milestone Dates

Milestone	Completion Date (EOM)[1]
HM grid developed	March 1998
HM and WQM linked	September 1998
WQM modifications completed	September 1998
CH3D-WES verified	December 1998
Initial nutrient budget analysis completed	December 1998
Report on initial nutrient budget analysis	June 1999
HM development and verification documentation report	September 1999
HM production runs for WQM cal./conf. completed	September 1999
Initial WQM calibration completed	September 1999
SM documentation report	September 1999
Final WQM calibration completed	March 2000
WQM confirmed	September 2000
HM scenario runs completed	September 2000
WQM documentation and cal./conf. report	March 2001
HM production runs documentation report	March 2001
WQM scenario testing completed	March 2001
WQM scenarios documentation report	September 2001
Video documentation	September 2001
Model delivery and training	September 2001

[1] EOM = end of month.

Schedule

A time schedule for conducting each of the tasks is shown in Table B2.

Table B2
Task Schedule, by Fiscal Year (FY) and Quarter

Tasks	FY98				FY99				FY00				FY01			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1. Review and plan a. Lit/data review	■	■														
b. Data col. plan	■	■														
c. Specification exercises	■	■														
2. HM a. Grid develop	■	■														
b. CH3D-WES mods & verification	■	■	■	■	■											
c. HM applic. for WQM cal./conf.						■	■	■								
3. Model Linkage a. File setup			■													
b. Linkage testing				■												
4. Resuspension a. Wind climate	■															
b. Wave climate estimates		■														
c. Module development			■	■												
d. Module adjust & verification						■	■	■	■	■						
5. WQM develop a. Mods-physical	■															
b. Mods-water column processes		■	■	■												
c. Mods-benthic model		■	■	■												
d. Mods - sea grass model		■	■	■												
6. WQM cal./conf. a. Loads/BC est.	■	■	■													
b. Model setup	■				■		■			■						
c. Initial nutrient budget analysis		■	■	■	■											
d. Initial model calibration						■	■	■								

(Continued)

Table B2 (Concluded)

Tasks	FY98				FY99				FY00				FY01			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
e. Final model calibration																
f. Model confirmation																
7. Model applica. a. Sensitivity anal.																
b. HM scenario development																
c. WQM scenario testing																
d. Uncertainty analysis																
8. Tech transfer a. Progress report																
b. HM document. reports																
c. SM document. report																
d. WQM doc. reports																
e. Video documentation																
f. Model delivery & training																

Appendix C
Review Comments

The following section provides the comments made by reviewers of the first draft of the work plan. The comments are grouped where possible and numbered for reference. The last section in this appendix describes how each of the review comments were addressed.

Documented Comments

1. The MEG continues to have concern, as it has expressed before, that there are problems with the dual track application of RMA and CH3D models. We fully understand the HM-WQM model linkage dilemma that has led to this situation, but do not feel that it will be practical or cost effective to continue over the long term to support such a dual track approach. We suggest that the work plan include explicit criteria to evaluate CH3D. If the model cannot be used, then the study can return to RMA. At this time it is not clear that the RMA study will be fully useful.

2. The MEG feels that there was a lack of acknowledgment of several presentations, program reviews and other assistance that have helped modelers achieve their present understanding of Florida Bay and its special modeling requirements. Clearly, full acknowledgment of the open provision of data and advice by the science community is not a prerequisite, but credit should be more explicitly included as a courtesy to those who have contributed substantially. Overall, a broader review with more complete referencing should be undertaken to build up the credibility of the process and the resulting model.

3. Our panel believes that not enough effort has been made to cross-reference data needs with data availability or to define data costs. Do the authors believe, in general, that the scope of present monitoring and process-oriented measurements is sufficient? Will more resources need to be devoted to this effort? Are the limits of detection now extant likely to be sufficient? The present document seems to sidestep these issues. We understand that these issues are difficult to address in detail at this stage,

but feel that more is required nonetheless. The "bottom line" is that unless adequate data can be identified and obtained, it will be impossible to calibrate and verify a model with real world utility. The Jacksonville District should ask all members of the PMC to meet and review the data available and expected.

4. We did not cross-reference previous MEG recommendations with their actual treatment in the work plan, because of the way the present work plan is presented. Although it is our impression that most of our past concerns were covered satisfactorily (as for example, in the explanation of how seagrasses will be dealt with conceptually), we feel that it would help greatly to have the document address our prior recommendations on a point-by-point basis, perhaps in a table. The major exception to this is that we do not feel that the model linkage issue is satisfactorily treated.

5. In general, the plan lacks criteria to guide decisions and selections of alternative approaches. Defined criteria ensure quality and enhance credibility. Criteria indicate what levels of precision and uncertainty can be achieved to support decisions. Criteria serve as the important benchmarks that good managers like the Jacksonville District typically rely upon, and to which the PMC should also contribute.

6. In the section on the sedimentology of Florida Bay, the information presented is inaccurate and misleading, clearly someone has not done the appropriate literature review or does not understand the subject. Furthermore, reference is made to studies of deep-sea carbonates for comparison, this is inappropriate and could lead to inaccurate modeling. This whole section needs to be rewritten!

7. I am personally concerned regarding the wave modeling section, I believe that during the workshop I presented my wave modeling study which is currently underway. The wave model they propose to use will probably not do any better than the model I am using, and as described in the work plan, the Corps does not have the input or verification data which it needs to do this work (my study is not referenced at all here or the data I have collected). I am not sure what is going on, but at the workshop I thought that the recommendation was to use some of my results as input into the model or at least collaborate with me on this. Should an agency fund a duplicative study?

8. The work plan recognizes the problems with data gaps, both for input and verification, but the plan does not explain how these problems will be solved. This is a crucial issue and must be decided on before any attempt to model water quality is made. There also remain many topics which are not fully understood such as the benthic flux in a carbonate regime or water column flux during resuspension events. Some of this information will be available in the years to come following research, will it be timely enough for a water quality model to be completed by the time the results are needed for decision making? I think that the PMC needs to discuss these issues and really consider if a detailed, large scale water quality

model is possible given the time constraints, will it be verifiable, and could the huge amount of time and funding it will take to complete the project be better spent in other research areas and a simpler modeling effort (some type of box model combined with the hydrodynamic model).

9. Another concern is the feedback issue, I understand the complexities in modeling feedback and the problem of computational efficiency, but not having a loop between the seagrass, sediment, and water quality model except after long time periods (if my understanding of the plan is correct) is questionable. Also little emphasis seems to be placed on first trying a small scale version within one or two basins. This was the consensus from the workshop, given the problem of bathymetric complexity and the need for a high resolution grid. The problems with model linkages and grid complexity/computation efficiency appear to remain somewhat unresolved!

10. Overall, this is a very good plan. The few weak areas are covered below. These chiefly relate to the RMA2 model and the distortions in the plan to compensate for nature of a finite element model. There may be some cases where the planners failed to capitalize on workshop presentations and prior hydrodynamics work by Peter Sheng, Wang, and Boris Galphrin. To minimize these distortions due to trying to use the RMA2 model and the potential drain on resources, the Jacksonville District should require criteria in the plan that determine how CH3D will be evaluated for adequacy. Rather than a dual track evaluation, there should be a serial evaluation of CH3D in the early stages to see if the model can be calibrated adequately according to the criteria that the plan should define. In general, criteria are needed throughout that define how important decisions will be made. A few criteria, e.g., 0.1% mass balance errors, are given. Without evaluation criteria, a project normally flows along preconceived lines, rather than the most effective lines.

11. In general the plan is in tune with many activities ongoing for Florida Bay, but there are some apparent gaps. Knowledge of data collection activities is weak. Understanding of critical process studies like the USGS resuspension work and wave modeling does not come across. How clearly the plan takes advantage of the reviews like that of hydrodynamic interactions with SAV by Evamarie Koch and other workshop presenters could not be fully judged in the limited time available to read the plan. While there may be an over-reliance on the limited knowledge of WES coming into the October workshop, there has been some additional understanding of Florida Bay gleaned from the literature. I think the plan could be enriched by reviewing select presentations at workshops and touching base with the presenters like Evamarie Koch. Besides this hint of oversight, a glaring missed opportunity is a review and assessment of the hydrodynamic modeling projects undertaken of the Bay by Boris Galphrin, Peter Sheng, and Wang. The model selection process already suffers enough; the planners should take every opportunity to be sure that the plan builds on what work has been done for the Bay including the past preliminary hydrodynamic modeling. Presently, the plan seems to ignore

all other work except the RMA2 work. This bias undercuts the credibility of the plan.

12. I also disagree that a review of data collection needs is beyond the scope of the plan required. A sound modeling plan cannot be formulated without regard to data needs. We cannot make sound decisions about the plan and subsequent model selections without knowledge of the data collection needs. Generally, data collection is the major expense, not modeling analysis. In part the report authors did not have a good opportunity to hear about data collection at the October Workshop, but also, they do not seem to have attempted to determine what is available on their own. It would be appropriate that the Jacksonville District request a review of data available. It would seem to be in the best interest of the PMC to define what data are available, to see where and how additional data needs to be collected. Either the plan needs another iteration, or a phase to research the extent of data available. To fail to assess the quantity and quality of data available seems to imply that the planners view this as a modeling exercise, and not a first class study to provide quality information for decision making. (Which is not the impression I have from the various workshops.)

13. The redundant development of two hydrodynamic models does seem necessary but the plan needs to address better how this process should be managed. Rather than using the expected spring 1997 calibration of the RMA2 model and coarsening (as was recommended in April 1996 by the ad hoc panel on hydrodynamic modeling), it may be more effective to see if the CH3D model (2D mode) can be set up and calibrated on a coarser scale during the three basin calibrations. If CH3D cannot be calibrated easily, then come back and coarsen the RMA2 grid to provide a point of recalibration for the CH3D model. One strategy discussed during the October 1996 workshop on water quality modeling was to simulate representative basins. A coarse grid CH3D model could be set up for basins to see if this model has potential or not and if so, calibrate the model without regard to the RMA2 model. In fact, a good backup is needed in case the RMA2 model cannot be calibrated on the intense grid this spring. While the initial calibration of CH3D is attempted, the separate development of the RMA2-WQM linkage can proceed. Definite criteria should be stated in this report for when adequate RMA2-WQM linkage is achieved. Also, criteria should be defined in this report to say when the calibration of the CH3D model is adequate. This is one serious shortcoming of the current RMA2 simulation. There do not seem to be any criteria to define when the calibration is adequate and stops. As a result, the calibration effort may continue and continue until time and resources are no longer available and the calibration stopped without adequate definition of the accuracy of the calibrated model.

14. The RMA2 study is not set up to provide insight into the need for geometric resolution as I understand the project. The RMA2 model was set up on an intensive grid and no hypothesis testing related to geometric resolution has been presented over the time I have observed this project. It has

been stated several times that this might be done. Therefore, the WQM plan writers need to cite specific work plan passages where this is to be undertaken, or be clear that this must be done in this project.

15. Besides citing Luettich et al. 1990 and Hawley and Lesht 1992 it would represent an open approach to also cite the work by Sheng et al. 1992, p. 105, ASCE, *Estuarine and Coastal Modeling*, on Lake Okeechobee sediment resuspension by wind currents. (There was also a paper submitted to *JGR*. I do not know if the paper was published.) As a follow up to this suggestion, I wonder why the investigations of Wang, Sheng, and Galphrin were not cited and reviewed in this plan to build on what the PMC did in the past. If other PMC resources are needed, the plan should be sure it builds on past work by the PMC to provide a HM. These prior PMC studies demonstrate what coarse resolution can cannot achieve.

16. In the same paragraph on effects of SAV on hydrodynamics, it was not clear that the presentation on the topic by Evamarie Koch during the October 1996 was taken into account. Perhaps the same references she cited are cited here, but a more direct and specific acknowledgment would be useful. In fact, this report is wholly inadequate for its lack of acknowledgment of the members of the science community that have opened their books to give unpublished data, early insights, and the benefits of broad experience. The openness has been exceptional but will not continue with appropriate acknowledgment of that expertise and foresight in collecting the data that will make this modeling effort possible.

17. It was not clear if the SWAN model was consistent with the work underway by the USGS. This section should review the work underway by the USGS and clearly show that this plan builds on that approach, or show where a different approach is necessary and why.

18. This section is too vague and brief for the empirical nature of the model proposed to correlate turbidity with wind speed, direction, SAV density, and other parameters.

19. Progress is clearly being made on the linkage of RMA2-WQM but there needs to be detail given on how the accuracy of the RMA2 conversion to calculate flows and elevations at interfaces will be determined.

20. "Projection techniques are being used to allow WQM grids that are different from the HM grid . . ." The next paragraph says, however, this is not recommended. Be clear that the projection to use different grids is from the separate project.

21. ". . . Two simulations are similar, then self consistency exists, . . ." The degree of similarity should be defined numerically in this plan.

22. Before going to the problem of reformulating the WQM advection scheme, and dropping the state-of-the-art approach already available, the plan needs to clearly demonstrate that the CH3D model cannot be applied, then worry about going to the problems of linking RMA2.

23. The advice that an interagency agreement be formulated to fund this work seems premature. Until the PMC has accepted the plan and refined scope, and then a cost estimate made, it is not clear how the Jacksonville District knows it cannot afford the work. Obtaining the necessary cooperation by in kind services to collect the extensive data required may also be possible. Regardless, an MOU or some formal agreement would be prudent.

24. It seems that the current MEG may not be suitable to WES. Normally, selection of peer reviewers should be left to the management levels that must evaluate the results (the PMC here), or selected by an independent body like the Science Oversight Panel. The modeling committee is a good idea but for appearances, the modeling committee should not be involved in selection of peer reviewers, if a new panel is to be selected. They may make nominations.

25. Use exact model name throughout the work plan, not "HM." For example, always refer to the hydrodynamic model by its name (i.e., RMA2, or CH3D). If both hydrodynamic models are considered to be used, due to the dual track proposed in the work plan, for a specific task, then use both names (i.e., RMA2/CH3D).

26. In Equations 6.1 and 6.2 is it $\frac{\partial(\ )}{\partial t}$ or is it $\frac{\delta(\ )}{\delta t}$?

27. The use of the fine-grid HM model to gain insights regarding the sensitivity of the Florida Bay circulation and transport to boundary conditions and resolution of system features is an innovative idea that will insure the success of the Florida Bay modeling study. This paragraph clearly shows the benefits of using the HM fine-grid to assess the coarser-grid for structured and unstructured grid models and providing circulation fields during early phases of the water quality modeling effort. This paragraph, however, did not show how are we going to achieve these goals; in other words, how are we going "to assess the coarser-grid unstructured and structured grid models," and how the "fine-grid HM can be used to provide circulation fields during early phases of water quality modeling?" For example, a numeric criterion can be selected a priori, by the oversight and modeling team members, to determine acceptable and unacceptable structured model grid resolutions. Based on the preselected numeric criterion, we can objectively determine whether we accept or reject a model grid resolution.

28. The work plans included the use of the fine-grid HM to provide a circulation field during early phases of water quality modeling. Furthermore, in Appendix B, the work plan stated that the initial nutrient budget

analysis will be conducted for one- to two-year simulations using recent data. Annually or seasonally averaged results from the existing fine-scale RMA2 HM will be spatially-averaged, adjusted to insure volume conservation and used to provide circulation for this application. I am not quite sure that I can follow this: Are we running RMA2 HM for a year or two, averaging (temporally and spatially) the circulation field, and then providing this information to the WQM? If so, how long (CPU) would it take to run the RMA2 HM model for a year or two? Is it practical to use RMA2 HM for one- to two-year hydrodynamic model simulations, if the CPU time is large?; RMA2 CPU time to simulate one year in Florida Bay was estimated to be approximately one full month (Hydrodynamic Model Meeting, April, 1996).

29. The workplan did not specify how and what criteria will be used to determine which model to use with the WQM for this study.
Why does the decision on selecting a hydrodynamic model for use in conjunction with the WQM have to wait until the RMA2 is verified? Does verification mean that the RMA2 is calibrated and verified?
What about CH3D? Is it also part of the workplan to calibrate and verify the CH3D model before making a decision as to which model to use with the WQM?
Do we need to wait until both models are calibrated and verified? Or, is there another alternative and/or test that can help us decide, at an early stage of our plans, as to which model should be used with WQM? Where is this decision listed in Appendix B?
Which group/committee and what type (e.g., internal or external) will be involved in making such a decision?

30. Does either model (HM and/or WQM) have the capability to vary wind field spatially?

31. The workplan needs to state clearly "what other components" will be adjusted and/or verified? The workplan needs to define all "related parameters" that will be used in model verifications and what statistical measures will be used in model verifications (e.g., means, RMSE, R^2, . . . etc.) and why. If one or several statistical measures are selected, what numerical criterion will be used to determine the goodness of agreement (e.g., 15% error, $R^2 = 0.90$) between model predictions and the observed data.

32. "Software to create the HM-WQM grid map . . . By the spring of 1997, software will be developed under separate funding for converting RMA2 nodal velocities and water surface elevation to flows through ICM cell faces and cell volumes that are consistent (i.e., conservative). **Projection techniques are being used to allow WQM grids that are different from the HM grid, both of which can be unstructured.**"
What does the bolded sentence mean in the aforementioned paragraph?
"It is **expected** that the projected volume fluxes will satisfy WQM conservation within 0.1% or less. **Following this development, additional efforts will be required refine and test the new linkage capability.**"

Bolded sentence is not clear to me.
How did we arrive at the 0.1% expected conservation error? Over what period of time (minutes, days, months, or years)? How large of an area (a single model cell or the entire model domain) over which the volume fluxes was projected? One tenth of one percent of a large volume or flux is a large number that may not be ignored. However, if the projected volume fluxes were estimated over a two-year simulation period, then it can be ignored.

33. "Regardless of which HM is selected . . . **If a one-to-one correspondence proves to be too restrictive, then grid overlay procedures will have to be developed and tested.**" The ICM has a grid collapsing software (for example, see WES WQM model application to Delaware/Rehoboth Bay systems). Is the grid collapsing software, used in the Delaware-Rehoboth Bay modeling application, not applicable here? If yes, then how long would it take to develop and test the grid overlay procedure?

34. "Following linkage of the WQM to the Florida Bay HM grid, . . . Additionally, mass conservation will be checked by turning on the mass conservation check switch for a conservative, non-reacting, tracer variable transported by the **model.**"
The plan provided a good check on mass conservation. An additional check also would be necessary to determine the appropriate time-averaging period that can be used to average flow fields, generated by the hydrodynamic model, and required by the WQM to calculate the transport of a water quality constituent. For example, two time periods (e.g., three hours, six hours, and/or daily time steps) should be selected to reduce the storage requirements for saved output from the hydrodynamic model and to derive the WQM. The averaged output, from the hydrodynamic model, is then used with the WQM to verify that both model results are in agreement. First, we need to run the hydrodynamic model using a 3-hour averaging period or the 1-day averaging period. Results (time-variable transport, volumes, and concentrations) from the hydrodynamic model are then used to derive the WQM. Then time series at specific locations can be compared to see how well the two model results match. Furthermore, a series of contour plots also should be generated in order to see how well the two models compare spatially.

35. Let us assume that we conducted two model runs. During the first run, one cell was specified as an area with no seagrass, and during the second model run, the same cell was specified as fully vegetated with seagrass (assume no change in water depth). I expect that model results from these two runs at the selected cell (i.e., no seagrass in the first run and fully vegetated during the second run) to be different. If we want to follow this approach, then a numerical criterion should be determined, a priori, to either accept or reject the hypothesis (e.g., reject hypothesis, if model results are different by approximately 60% over the entire grid?).
A different approach to include seagrass effects on circulations is to use linear interpolations between two or several model results. For example,

linear interpolation between model results, from the aforementioned two model runs, at the selected cell (i.e., no seagrass in the first run and fully vegetated during the second run) can be used to generate a look-up table to include the seagrass effects on circulation as a function of biomass present. Model runs also should be expanded to include the effects of seagrass on circulation; the model domain need not be large for these simulations.

36. Initial Calibration: "Three reduced systems will be employed in the initial development and application in the Florida Bay model. . . . Flows into and out of each basin will be derived from the currently available **finite element** model of the system."
How long of a time period would this initial calibration of three reduced systems be? How different is the selected time period compared to ecological process dominant in the bay? Most importantly, how much computer time (CPU) and resources would it take for the finite element model (RMA2) to complete the proposed initial calibration runs to generate the flows for the WQM?

37. "Final calibration of the model will be conducted on the complete bay system using the detailed grid. Final calibration will cover **a period** sufficient to demonstrate agreement between observed and computed changes in water quality and **seagrass**."
We need to determine what are the most important parameter(s) that scientists consider to be measures of success for a calibrated water quality model in Florida Bay. I suspect that the seagrass community will be selected, unanimously, by the scientists as a measure of success of a calibrated water quality model of Florida Bay. I believe that scientists should also be asked to select the "sufficient time period" to demonstrate agreement between observations and model results. If seagrass is selected as the measure of success, and the Thallasia life cycle is more than a decade-long, then we should consider extending the time scale proposed for management scenarios to more than ten years.

38. "Graphical plots and statistical analyses for computed and observed data will be used to assess the skill of model calibration and confirmation."
The work plan did not determine the statistical analyses that will be used, on computed and observed data, to evaluate the success of model calibration and confirmation (e.g., means, RSME, . . . etc.), spatially and temporally.

39. "CH3D-WES Model modifications and Verification - **Boundary condition** files for the RMA2-WES verification will be transformed into appropriate CH3D-WES boundary condition file format."
What boundary conditions? Flows and fluxes (e.g., water volumes, loads)? How is this going to be accomplished? Is there any error in transferring boundary conditions generated using a finite element unstructured grid model to a finite difference structured grid model? How similar or different is the RMA2-WES groundwater coupling compared to the one that

will be added to the CH3D-WES model? If they are different, should we be concerned about verifying CH3D-WES using RMA2-WES results?

Responses to Comments

This section describes how each of the comments in the previous section were addressed. The numbered paragraphs below coincide with the numbered comments.

1. The work plan was modified in Chapter 3 and Appendix B to make it clear that the CH3D-WES model is targeted as the hydrodynamic model to use in this project. The RMA10-WES model will be used to provide insights towards the amount of grid refinement required for CH3D-WES and to provide fine-scale hydrodynamic information that can be used to guide adjustments of the CH3D-WES model. However, if the CH3D-WES model cannot be used for some unforeseen reason (such as properly resolving flows through the mudbanks), then the RMA10-WES model may have to be used. Explicit criteria to judge the success of hydrodynamic model verification has been added to Chapter 3.

2. The reviewers are absolutely correct that the Bay scientists should be acknowledged and appreciated. Any oversight by the authors was unintentional and hopefully has been rectified in this revised report. Acknowledgments have been added in several locations, including the Preface and other locations as throughout the main text. It must be kept in mind, however, that this document is not intended to provide a broad review with complete referencing of the various work being undertaken in Florida Bay, rather references are provided as needed to make specific points.

3. The authors agree with the reviewers that a plan for future data collection in Florida Bay is desperately needed. It is surprising that such action has not been undertaken already under the direction of the Program Management Committee (PMC). However, this need should not be made the sole responsibility of the Corps of Engineers. The development of a comprehensive data-collection plan will require a fairly significant effort with much coordination. It was not possible to develop such a plan with the modest funding provided for the development of this work plan. A good data-collection plan would result in a document of size comparable with the size of this document. Chapter 8 clearly describes all of the data required for a comprehensive water quality model of Florida Bay. Additionally, Chapter 8 provides a synopsis of potential data gaps and needs beyond existing data collection efforts. Thus, Chapter 8 provides a good starting point for planning future data collection. Costs for additional data needs cannot be addressed until a plan for that effort is drafted. If the future data-collection plan is not drafted by the PMC before the initiation of the water quality modeling study, then the first funded task of the model study should be to draft such a plan as now proposed in the revised plan.

4. It is not necessary and is not a good use of time to tie each Model Evaluation Group (MEG) recommendation to a specific point in the work plan since the work plan satisfies almost all of the recommendations of the MEG. If the entire work plan is read, it is relatively easy to determine which MEG recommendations were satisfied and which ones were not. The MEG recommendations that are not satisfied by the work plan are discussed below. The following recommendations are located within the section "Consensus Reached by Workshop Participants" of Appendix A.

- Two classes of phytoplankton were recommended, silicified and non-silicified. If data permit, we recommend that three phytoplankton groups be included in the model, diatoms, cyanobacteria, and other (e.g., flagellates).
- First-order, quadratic estimates of resuspension based on wind speed and water depth were recommended. It is anticipated that both wind and wind-generated waves are important for resuspension. Thus, it is recommended that resuspension be based on the wind and wave climate, rather than wind alone.
- The MEG recommended that the CH3D-WES model be calibrated on a grid of approximately 1,000 cells. It is our opinion that more grid cells than this will be required to produce reliable results. The model should probably have at least 5,000 grid cells.
- The MEG recommended that the structured-grid hydrodynamic model (CH3D-WES) be used to derive the gross circulation for the three basins employed for initial WQM calibration. To prevent unnecessary delays in study progress, it is recommended that gross, seasonal circulation for the three basins be extracted from the existing RMA10-WES model rather than waiting for a calibrated CH3D-WES model. This approach will allow faster progression to initial WQM calibration. The flows extracted from the RMA10-WES model for these three basins can be fairly easily spatially averaged and massaged to ensure conservative flow fields for the WQM. If the CH3D-WES model can be calibrated in time to provide the three basin circulation for initial WQM calibration, then results from it will be used instead.

5. Specific criteria have been added to guide decisions regarding success of model calibration/verification.

6. These comments have been addressed by revision of Chapter 4.

7. These comments have been addressed by revision of Chapter 4.

8. Meaningful modeling can be achieved with the existing data. However, more meaningful progress can be made if additional data collection and research are funded and integrated with the modeling. The plan now more clearly presents in Chapter 8 how existing and future data will be used in the study.

9. These comments reflect an incomplete reading of the work plan by this reviewer. The work plan previously satisfied these concerns. Sea grass, suspended sediment, benthic sediment, and water quality are all presently dynamically coupled within the same code and will be simulated together. Chapter 6 states that three basins will be modeled individually first to attain initial WQM calibration, just as the MEG and the workshop recommended. Issues of model linkage are not unresolved, rather they were and are explained within the work plan. The issue of grid resolution cannot be resolved until CH3D-WES model adjustment and verification are initiated.

10. This comment has been addressed through the changes made to the work plan to address Comment 1.

11. These comments are similar to those in Comments 6 and 7. Thus, these comments are addressed through changes to Chapters 3, 4, and 8.

12. We agree that data collection is a major part of all studies such as this, and data-collection costs greatly exceed modeling costs. We have made an attempt to determine what data are available and are being collected. A complete evaluation of data-collection needs is beyond the scope and funding provided for development of this work plan. A task has been added to address this need as referenced in the response to Comment 3. We never treat a modeling study as just "a modeling exercise." Modeling is a tightly coupled integration of observed data and modeling skill, and we regret any wording of the work plan that may have given the wrong impression.

13. This comment is very similar to Comment 1, thus it has been addressed through revisions made to address Comment 1. If for some reason the RMA10-WES model must be used to drive the WQM, then some effort will be required to further expand the robustness of the recently developed RMA10-ICM linkage procedures. However, great progress on the linkage of these two models has been achieved. The same tests used to prove proper linkage of the CH3D-ICM models will be used for the RMA10-ICM linkage should that linkage be necessary. These tests are described in Chapter 5.

14. The revised work plan does not call for varying the resolution of the RMA10-WES grid, rather the RMA10-WES model will be used as an additional data source for adjusting the CH3D-WES model. The CH3D-WES model grid will be refined as necessary to yield acceptable results as now stated in Chapter 3.

15. This comment has been addressed through revisions to Chapter 3.

16. We have made an effort to more completely reference in the revised work plan the work of others, including those presented at the October 1996 workshop.

17. This comment is similar to Comment 7 and has been addressed through revisions to Chapter 4.

18. This comment has been addressed to some extent through revisions to Chapter 4. However, we readily admit that relating wave resuspension parameters to sea grass density falls under the category of research and development, rather than model application. Thus, it is not possible to explicitly state at this time how the development of these relationships will evolve. Deciding the steps of this development will be accomplished during the specification exercises conducted during the first months of the study.

19. As suggested in the response to Comment 13, the linkage to RMA10-WES fine grid to the WQM will most likely not be necessary. However, should it be necessary, we anticipate that local-flow continuity can be achieved within machine precision at the expense of additional postprocessing.

20. Discussions that resulted in this comment have been removed. However, if the RMA10-WES model were to be linked to ICM, it is possible with the recently developed procedures to project flows from the RMA10-WES grid onto a different grid used for the WQM while preserving flow continuity locally.

21. The section in Chapter 5 related to self-consistency testing has been modified to reflect the use of hypothesis testing at the 95-percent confidence level to determine whether the two simulations are different.

22. This comment has been addressed through changes to Chapter 3 to address previous related comments.

23. It is not clear what is intended by this comment or how it should be addressed. However, Chapter 10 has been modified to reflect the possibility of using in-kind services to help fund the study.

24. This comment indicates that a portion of Chapter 10 may have been misinterpreted by this reviewer. We believe that the chapter already states what the reviewer is requesting. The PMC can decide how the MEG members are nominated or selected.

25. We believe that the use of the abbreviation HM for hydrodynamic model is appropriate as long as it is clear which hydrodynamic model we are referring to.

26. The partial derivative symbol is now used instead of the delta symbol.

27. This comment has been addressed through changes to Chapter 3 to address previous related comments.

28. Chapter 6 has been modified to address this comment. When the RMA10-WES model is used for the nutrient budget analysis and possibly the initial WQM calibration, then seasonally averaged flow fields will be generated for use by the WQM.

29. These comments have been addressed through changes to Chapter 3 to address previous related comments.

30. Both the CH3D-WES HM and the ICM WQM have the capability to use spatially varying wind fields.

31. Specific criteria for acceptance of all model verification/confirmation are now stated in Chapters 3, 4, and 6.

32. This comment is similar to Comment 20 (see response to Comment 20).

33. The ICM model can be used with existing linkage software to conduct an overlay grid of the CH3D-WES grid. However, we prefer not to use grid overlay if at all possible since overlays tend to lose hydrodynamic resolution and may require imposing corrective, but unrealistic, dispersion. The MEG for the October workshop recommended that a one-to-one HM to WQM grid correspondence be used if computationally practical.

34. We recommend averaging and storing HM information over 1- or 2-hr intervals for use in the WQM. With the supercomputers and mass storage centers that are available today, data storage requirements are not such a great issue as they were 10 years ago. We know from experience that averaging the hydrodynamics over 1 or 2 hr will produce perfectly acceptable WQM transport results. We have the capability to process hydrodynamics over tidal cycle intervals such that the Stokes drift residual currents are preserved along with the Eulerian residual currents, and the two are combined to produce mass conservative Lagrangian residual currents used to drive the WQM. If data storage requirements were a concern, then we could resort to the use of these methods. However, this will not be necessary if 1- or 2-hr averaging intervals are used.

35. We now propose to use hypothesis testing as stated for Comment 21 to test self-consistency. We do not believe it is possible to have look-up tables of circulation for interpolation between conditions with and without sea grass. Such an approach would produce inconsistent hydrodynamic fields that do not balance nor conserve volume flux.

36. This comment is similar to Comment 28 and has been addressed in Chapter 6.

37. We do not believe that there is a sufficient database to extend the WQM confirmation beyond about 10 years. However, it will certainly be the duty of the Modeling Committee and MEG to guide the model confirmation process and review criteria for confirmation success.

38. This comment is identical to previous comments and has now been addressed through revisions to Chapters 3, 4, and 6. Specific numerical criteria to evaluate the success of model calibration and confirmation are now described.

39. The statements relating to this comment simply refer to taking boundary condition information for RMA10-WES (i.e., water surface elevations, freshwater flows, open water salinity and temperature, and meteorological forcing) and reformatting for CH3D-WES input. This task has nothing to do with one model being finite element and the other being finite difference.

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13. ABSTRACT *(Maximum 200 words)*

This report describes the plans and specifications for a Florida Bay water quality model and provides tasks and schedules for its development and application. The model is required to address issues pertaining to nutrient inputs and associated impacts on water quality and sea grass, particularly as related to changes in freshwater inflows from south Florida through the Everglades and the Central and South Florida Flood Control Project. Modeling components discussed in the report include the hydrodynamic model; the water quality model, including submodels for the water column, benthic sediments, and sea grass; and the sediment transport model, which will also reside within the water quality model. Strategies for model calibration, confirmation, sensitivity analyses, and scenario testing are discussed. Data requirements and gaps are presented. Plans for technology transfer and partnering/collaboration are also discussed.

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