CHESAPEAKE BAY PROGRAM OFFICE

410 Severn Avenue, Suite 109 Annapolis, MD 21403 (410) 267-5700 or 1 800 YOUR BAY

February 4, 2000

Dear Dr. Jachowski:

The Modeling Subcommittee was tasked by the Implementation Committee to develop a water quality model of the three Virginia tributaries to determine what, if any, pollution control measures were needed to restore water quality and living resources in those tributaries. A series of workshops were held to consult with leading scientists and devise a work plan for the lower tributary modeling effort. In close consultation with the Bay scientific community, the Bay model used for the 1991 reevaluation was reconfigured with new segmentation and new enhancements such as submerged aquatic vegetation. The Modeling Subcommittee and the Model Evaluation Group reviewed the model in 1999, and by roll-call vote, agreed that the three tributaries were adequately calibrated and reflected the conditions of the three estuaries in sufficient accuracy to make management decisions. The Subcommittee stands behind this decision.

In the meantime, the Executive Council signed Directive 97-1 which called for a more rigorous analysis of the rest of the Bay, and at the request of the Implementation Committee, STAC formed a Model Review Team to review the water quality model. Attached are the Subcommittee's comments and consensus response on the STAC report. Individual responses from Virginia, Pennsylvania, and MEG are also enclosed.

Due to this sequence of events, the Model Review Team reviewed a work in progress. The Modeling Subcommittee has not completed the calibration of the rest of the Bay and has made no representation concerning the adequacy of a final, calibrated main-Bay model. When the calibration of the Bay is complete, the Modeling Subcommittee will again, by roll-call vote, approve or disapprove model application in the Bay. This judgement will be made after extensive review of model processes, structure, and function, in open public meetings, and with meaningful participation by the scientific community.

With the current emphasis upon delisting the Bay so that a formal TMDL will not be required, we are looking at different end uses of the model than were originally conceived and then modified by Directive 97-1 when the main-Bay calibration began. It is clear at this time that the new model will be a significant advancement in the representation of water quality in the Chesapeake Bay. It is also clear that there are still many processes and interactions in the Bay that are not well understood and consequently are not well represented in this newer model.

The Modeling Subcommittee believes that we have worked long and diligently with Bay scientists to incorporate new findings into the model pertinent to the management issues to be addressed, and with time and budget constraints. The Modeling Subcommittee has just finished a series of workshops with the scientific community to plan the development of the next generation of ecosystem models and probable approaches to solve the technical problems that will be encountered. The scientific community was most helpful, as they have always been in the past. We believe that continued work together will complete the best calibration of the current model, as well as the development of future ecosystem extensions of the water quality model that will assist in the ultimate goal of restoring the Bay.

Sincerely,

James R. Collier, P.E.
Chairman, Modeling Subcommittee

cc: Modeling Subcommittee members
W. Matuszeski
R. Batiuk

MODELING SUBCOMMITTEE RESPONSE TO THE STAC REPORT: REVIEW OF THE WATER QUALITY MODEL

The Consensus of the Modeling Subcommittee
Members and MEG

February, 2000

Summary

This is to provide the consensus response of the Modeling Subcommittee to the STAC Report: *Review of The Water Quality Model.* As described below, in many areas the Subcommittee is in agreement with the STAC report. In other areas, we believe the data does not support the report's conclusions. Overall, the comments on the model's shortcomings are not surprising to those who have confronted them directly. The modeling team of Subcommittee members, MEG, and model practitioners have a good sense of the times and places where the model does not approximate the calibration data. But recognizing the model's shortcomings need not equate to discarding it or suspending its use. Many analytical methods that are not 100% efficient are used nevertheless, because the shortcomings are understood and can be considered when interpreting results.

A realistic goal for the modeling effort has been to reduce uncertainty about how the estuary may respond to management actions over decadal time-scales. The model meets this criterion. Moreover perfect prediction, which seems to be a criterion implicit in the MRT report, even with a perfect model requires perfect forecasting of precipitation years into the future. If perfection needs to be the criterion, then no calculation will measure up until flawless weather forecasting is a reality.

Historically to reduce uncertainty, decision-makers in the Chesapeake area and beyond have used calculations that were much less capable than the present water quality model to evaluate management alternatives and to influence decisions. Until simulations that more closely mimic nature are developed, this water quality model should continue to be used for model-to-model comparisons between a base case simulation and cases simulating management actions.

Certainly, the modeling effort needs to reflect the state of the science. As the MRT report alludes, the water quality model has evolved from a much simpler 2-D calculation to the more complex 3-D version that is now operating. Judicious improvement and innovation have been characteristic of the program from its outset. This positive trajectory should continue with improvements to the existing model as suggested in the MRT report, or its replacement with a system better able to handle ecosystem calculations, including greater details of geometry, geology, physics, and biology in the estuary.

We acknowledge that primary production computed in the model is less than observed in the Bay. Computation of primary production is not a common performance goal of eutrophication models and under-estimation of primary production is not unique to the Chesapeake Bay model. Rather, under-estimation of primary production is characteristic of almost all eutrophication models. We are placing a high priority on revising the primary production computations. In the meanwhile, we believe the present model is well-suited for computation and management of conventional variables such as chlorophyll, nutrients, and dissolved oxygen.

The review of the salinity results was somewhat selective in its findings. We accept that no model is perfect, and that models by their nature are infinitely perfectible. When a system-wide model is applied over a ten-year period, times and locations will always exist in which results are less than ideal. We are attaching the full set of salinity material we provided to the reviewers in Appendix A.

The first draft of the review contained a section on the influence of reported salinity errors on computed filtration by benthic organisms. At an August 1999 meeting, we explained that the model does not link filtration rate to salinity. Despite our explanation, the material on influence of purported salinity errors on filtration remains in the final report and should be corrected.

Observed and modeled phytoplankton exhibit a "preference" to exhaust available ammonium before taking up nitrate as a nutrient source. Apparently the observed preference is stronger than modeled. This property of the model can be easily remedied. We disagree with the reviewers' statement that the difference in preferences has profound impact on the ecosystem. As presently formulated, modeled phytoplankton use ammonium and nitrate interchangeably. The real limitation on phytoplankton is dissolved inorganic nitrogen which is the sum of computed ammonium and nitrate. The use of one versus the other has no implications for the ecosystem. Obviously, if there were major implications for the ecosystem, the Bay Program should have an ammonia load goal, a nitrate load goal, etc., rather that the total nitrogen load reduction goal applied in the Chesapeake and in all other managed eutrophic estuaries.

Introduction

The initial portion of this document consists of point-by-point responses to review team comments. Comments from the review team are identified and briefly quoted *in italics*. Our response follows. When necessary, figures and citations are included as portions of the response. More detailed responses to reviewers' Appendices are included as corresponding appendices from the modelers.

Page 2, third paragraph, "To our knowledge, there doesn't exist a written formulation of Bay Program management needs."

Management goals for the bay were spelled out in the 1987 Chesapeake Bay Agreement. The goals are too extensive to repeat here. The initial phase of the model study, 1987-1992, was conducted to aid in understanding and implementing the forty-percent nutrient reduction commitment in the 1987 agreement. Expectations for the first phase of the model were spelled out in the workplan (Dortch et al. 1988). These were reiterated by Cerco and Cole (1993). Expectations included:

1) Project response of water column and benthic sediments to management activities.
2) Perform short-term (annual) and long-term (decades) simulations.
3) Determine effect of spring runoff events on summer anoxia.
4) Address lateral variations in water quality.
5) Determine response of Bay to area-specific nutrient control strategies.
6) Predict the response time of the Bay to management actions.
7) Evaluate frequency of critical water-quality events.
8) Evaluate historical changes in anoxia.

The grid employed in the first phase of the study did not provide sufficient resolution in the Virginia tributaries. Consequently, a second phase of tributary refinements was conducted from 1993- 1998. Expectations for the second phase of the model were spelled out in the workplan (Cerco 1994). Among these were:

1) Provide a more accurate simulation of the fate and transport of nutrients in the tributaries.
2) Simulate the effects of light attenuation by suspended sediment and nutrients on submerged aquatic vegetation.
3) More accurately simulate dissolved oxygen concentrations in the tributaries.
4) Provide the basic modeling framework for future toxics modeling.
5) Provide a more detailed hydrodynamic structure that can be applied to the simulation of oil spills in the James, York, and Rappahannock

Page 2, Programmatic 1, "The modeling program and the monitoring program should be more closely coordinated."

First, we have to recognize the Monitoring program does not exist solely to provide data to the modeling program. Modeling is only one of many uses of the monitoring data. Other important uses include trend detection, load quantification, and interpretation of environmental events. We have to realize that resource constraints mean the monitoring program cannot fulfill every desire of the modeling team. We feel the present monitoring program is one of the best in the world. Moreover, the monitoring program has been responsive to requests from the modelers. Among the special requests the monitoring program has fulfilled are:

1) Enhanced sampling of Virginia point sources,
2) Sampling of water quality parameters on the continental shelf,
3) Sampling of particulate inorganic phosphorus, and
4) Sampling of particulate biogenic silica
5) Sampling of the littoral and channel regions of tributary rivers
6) Enhanced sampling of sediment fluxes

Page 2, Programmatic 1, "There has been little effort to compare model performance with rate measurements..."

Model output is regularly compared with sediment oxygen and nutrient exchange rates collected as part of the SONE program. Comparisons from the first phase of the study were published in the sediment model report (DiToro and Fitzpatrick 1993) and in the model report (Cerco and Cole 1993). Comparisons from the second phase have been regularly presented and reviewed as part of the model development process and were provided to the review team in April 1999. In the second phase of the study, we made comparisons of observed and computed carbon fixation rates a regular component of all time-series presentations. These comparisons were viewed by the review team in December 1998.

On occasion, we have compared additional, independent observations to modeled processes. We must be reasonable in expecting these comparisons to be performed and in expecting agreement between observations and model: 1) the observations may be unpublished or obscured by time, 2) independent observations are not conducted with the model in mind and may not be directly comparable to modeled processes, 3) the observations may have been conducted outside the period of model simulation, and 4) the observations may be at isolated locations and not generally applicable.

Page 2,Programmatic 2, "The culture of the bay modeling community has not been one of merit review."

Before its latest application, the model was reviewed by representatives of the regulatory community (e.g. the Environmental Protection Agency, Virginia, Pennsylvania, and Maryland), and representatives of the regulated community (e.g. Virginia Association of Municipal Water Agencies) as well as by the Model Evaluation Group. On multiple occasions, panels of bay-area scientists were invited to hear presentations on the Submerged Aquatic Vegetation and benthos components and to comment on the models. Comments from all parties were addressed to the fullest extent possible.

In addition, we list below major awards that have been presented to the model team by government agencies and professional societies:

1) Department of the Army Decoration for Meritorious Civilian Service (1991)
2) Outstanding Planning Achievement, US Army Corps of Engineers North Atlantic Division (1991)
3) Department of the Army Research and Development Achievement Award (1992)
4) American Society of Civil Engineers Wesley M. Horner Award (1995)
5) Smithsonian Achievement in Information Technology Award (1995, 1996)
6) United States Environmental Protection Agency Science Achievement Award, presented in conjunction with Society of Environmental Toxicology and Chemistry (1999)

Page 2, Programmatic 2, "The larger modeling community ...has not had many opportunities to review model results."

Aside from the open meetings mentioned above, the model team has undertaken extensive efforts, inside and outside the Bay community, to explain and publicize the model. The full efforts are far too lengthy to list here. We list below some efforts we have undertaken in the last two years:

1) November 1997 - Six lecture hours and computer lab conducted at Virginia Institute of Marine Science. Topic was the diagenetic sediment component of the Chesapeake Bay eutrophication model.

2) October 1998 - Presentation on "The Chesapeake Bay Experience" at Fifth International Conference on Estuarine and Coastal Modeling, Alexandria VA.

3) October 1998 - Presentation on Chesapeake Bay SAV model at workshop "Subtropical and Tropical Seagrass Management Ecology" Ft. Meyers FL.

4) November 1998 - Modeling Workshop in Richmond VA. Topic was preliminary findings of the water quality modeling of Virginia's lower tributaries.

5) 1998 - Presentation on hydrodynamic model at "Ocean Community Conference Celebrating 1998 International Year of the Ocean," Baltimore MD.

6) March 1999 - One-hour lecture at Virginia Institute of Marine Science on formulation and results of the Chesapeake Bay Environmental Model.

7) March 1999 - Invited presentation on Chesapeake Bay model at Society of Industrial and Applied Mathematics Conference, San Antonio TX.

8) April 1999 - Seminar at University of North Carolina, Chapel Hill. Simultaneously broadcast to five additional campuses of UNC system

Page 3, Model Performance 1, "The model overestimates the salinity gradient...which can significantly affect the filtration rates and respiration rates of benthic organisms."

We believe the model provides reasonable and reliable computations of bottom salinity (Appendix A). In August 1999, we explained to the Model Review Team that the benthos portion of the model is not coupled to salinity. As formulated, salinity computations in the model CANNOT affect benthos in any way and corrections remain to be made to this section of the MRT report.

Page 3, Model Performance 2, "The fundamental processes, primarily primary production and respiration, are underestimated in several areas of the Bay..."

We agree that primary production is usually under-computed and agree this problem requires correction before we move further into computation of higher trophic levels. We do not believe the under-computation compromises work that has been completed to date. A more detailed look at the primary production issue is included in the response to Appendix B.

Page 3, Model Performance 3, "The model does not reflect the degree of preference for ammonium over nitrate. This has profound implications for the ecosystem."

As presently formulated, modeled phytoplankton use ammonium and nitrate interchangeably. The real limitation on phytoplankton is dissolved inorganic nitrogen which is the sum of computed ammonium and nitrate. The use of one versus the other has no implications for the ecosystem.

Page 3, Documentation 1, "Documentation ....is not been readily available."

We are developing plans, based on web based distribution of model documentation, to ensure more complete, timely documentation is available in the future.

Page 3, Documentation 2, "The model has not been subjected to peer review through published scientific papers."

We list below the peer-reviewed articles that have resulted from the Bay model application:

1) Dortch, M., Chapman, R., and Abt, S. 1992. Application of Three-Dimensional Lagrangian Residual Transport. *Journal of Hydraulic Engineering*, 118(6): 831-848.

2) Cerco, C. and Cole, T. 1993. Three Dimensional Eutrophication Model of Chesapeake Bay, *Journal of Environmental Engineering*, 119:1006-1025

3) Johnson, B., Kim, K., Heath, R., Hsieh, B., and Butler, L. 1993. Validation of a Three-Dimensional Hydrodynamic Model of Chesapeake Bay. *Journal of Hydraulic Engineering*, 199(1):2-20.

4) Cerco, C. 1995. Simulation of Long-Term Trends in Chesapeake Bay Eutrophication, *Journal of Environmental Engineering*, 121:298-310.

5) Cerco, C., 1995. Response of Chesapeake Bay to Nutrient Load Reductions, *Journal of Environmental Engineering*, 121:549-557.

6) Linker, L., Stigall, C., Chang, C., and Donigian, A. 1996. Aquatic accounting: Chesapeake Bay Watershed Model Quantifies Nutrient Loads. *Water Environment and Technology*, 8(1):48-52.

7) Hood, Raleigh R.,Wang, Harry V., Purcell, Jennifer E., Houde, Edward D., and Harding, Lawrence W., Jr. 1999. Modeling Particles and Pelagic Organisms in Chesapeake Bay: Convergent Features Control Plankton Distributions. *Journal of Geophysical Research*, 104(C1):1223-1243

8) Linker, L., Shenk, G., Dennis R., Sweeney, J., 2000. Cross-media Models of the Chesapeake Bay Airshed and Watershed. *Journal of Water Quality and Ecosystem Modeling.* In press.

9) Cerco, C., and Meyers, M. 2000. Tributary refinements to the Chesapeake Bay model. *Journal of Environmental Engineering.* In press.

10) Cerco, C. 2000. Phytoplankton Kinetics in the Chesapeake Bay Eutrophication Model. *Journal of Water Quality and Ecosystem Modeling.* In press.

Page 8, second paragraph, "...the MEG is not now effectively serving that [technical review] purpose."

The MEG's role did change over time from one of critical review to include problem-solving towards achieving optimum results within the temporal, technical, financial, and political realities that have existed over the life of the program. Even so, MEG's criticisms of the model structure or performance were not withheld. When the tools were available to make adjustments within constraints of time and resources, MEG insisted the adjustments were made.

The usual interaction between the model team and the Model Evaluation Group (MEG) takes place at quarterly Modeling Subcommittee meetings. A full review includes presentations of one hour or more on major portions of the model e.g. hydrodynamics, water column, benthos. Questions from the MEG are welcomed during the presentations. A "question and answer" session open to the MEG and to the Subcommittee follows each presentation. At the end of each day, time is allocated for the MEG to comment on the presentations and make recommendations for correction and future direction. MEG members often expand on their recommendations as a follow-up to the meeting. We do not recall that the review team witnessed a full presentation by the model team to the MEG and subsequent interactions with the MEG. As a consequence, the review team's impression of the MEG role may not be an accurate one.

Page 8,General Findings 2 , "...planning of the modeling and monitoring efforts are not closely coordinated, making ...validations difficult and questionable."

The monitoring program does not exist solely to satisfy the needs of the modeling program. We believe, nonetheless, that the monitoring data provides an excellent basis for validation of the model. We disagree that validations of the model are questionable. The monitoring program conducts twenty surveys per year in the bay, tributaries, and major embayments. The modeling team processed ten-years' observations of temperature, salinity, solids, chlorophyll, multiple forms of carbon, multiple forms of nitrogen, multiple forms of phosphorus, dissolved oxygen, particulate and dissolved silica, two forms of zooplankton, benthos number and biomass, SAV abundance, sediment-water interactions, and more. Model and data were compared along axes of the Bay and major tributaries, at individual stations, as aggregates in Chesapeake Bay Program Segments, as scatter plots, and in additional formats. We believe no other model has been subject to as much validation as the Chesapeake Bay model.

Page 8, General Findings 3, "Documentation... has not kept pace with model development."

We are developing a plan to place draft documentation, as it develops, on the web for review and comment.

Page 8, General Findings 4, "Very little of the bay model has been published and apparently none has been published recently."

Nine articles have been published or are in press. One article was published in 1999 and three are scheduled for publication in early 2000. Copies of the in-press manuscripts were provided to the STAC team prior to publication of their report.

Page 8,General Findings 5, "Comparisons of modeled and measured results are based upon visual evaluations...."

No generally-accepted statistical methods for examination of model results exist. Nor are optimization algorithms suited for evaluating model parameters. No substitute exists for the experience and judgement of the modelers and reviewers in determining the "calibration of the model". We do endeavor to provide summary statistics after the model is calibrated. Summary statistics are printed as part of every scatter plot and "probability plots" are the primary method of calibrating the benthos sub-model.

Page 8,General Findings 6, "Interactions between the model development community and the research community have been inadequate."

We actively solicit input from Bay area scientists. Modeling Subcommittee meetings are open and individual scientists are specifically invited when their input is essential. We have held several special meetings to solicit input from SAV and benthos scientists. In 1993, the Bay program and Corps sponsored four workshops to plan the Tributary Refinements phase of the model. Every year since 1992, the Bay Program has sponsored annual Ecosystem Modeling Workshops in St. Michaels MD. In 1999, the Bay program and Corps sponsored four additional workshops to plan the next phase of the model effort. Nevertheless, we agree we can do more to engage Bay area scientists, and are expanding our model review team to include 14 principal investigators in the Chesapeake.

Page 8, Q1.1. "The WQM cannot provide accurate predictions unless it: a) ... e)."

The review team has listed a very formidable set of model requirements. We note these are not the objectives that were spelled out in the workplan. Workplan objectives were formulated in concert with engineers and scientists from inside and beyond the Bay area who participated in workshops intended to design the model. We are placed in an impossible position when we are required to meet standards developed after our work was completed. We know of no model that presently fulfills all the requirements listed by the review team. We are working towards many of these goals but completion of such a model is years away. We do not believe implementation of models to aid in management of the bay should cease until all these requirements are met.

Page 9, Q1.2. "The hydrodynamic model does not always accurately reproduce bottom salinity which could represent an important discrepancy when biology and oxygen are concerned."

The data demonstrates that bottom salinity and dissolved oxygen are accurately computed. Examples of computed bottom salinity and dissolved oxygen along the Bay axis during the crucial summer anoxic period are provided in Figure 1.

Page 9, Q1.3. "For those areas where we were shown light attenuation predictions and measurements, the discrepancies were considered to be significant."

The water quality model computes light attenuation as the sum of attenuation from color, fixed solids, and organic matter. Attenuation is computed on a three-dimensional, time-varying basis. This computation is extremely demanding. Solids loads and transport must be correct. Loading of nutrients, transport of nutrients, and uptake of nutrients in the creation of organic matter must be correct.

Assignment of color to locations in the bay and assignment of attenuation coefficients to two classes of solids must be correct. We have compared computed and observed median light attenuation during the SAV growing season at 28 stations in the bay, tributaries, and major embayments (Figure 2). The model clearly captures the magnitude of observed attenuation and also system properties such as turbidity maxima in the mainstem and tributaries. Median absolute difference between computed and observed attenuation is 0.19 m or 13% of the observed values. We know of no other, superior attempt to compute light attenuation on a three dimensional basis in an estuary.

Page 9, Q1. 4. "The water quality model markedly underpredicts phytoplankton photosynthetic rates...."

We acknowledge the model often under-computes primary production, and are aware this problem must be remedied before advancing into simulation of higher trophic levels. We do not believe previous results obtained from the model are compromised, nor do we believe employment of models to aid in management of the bay should cease until the problem is remedied.

Page 9, Q1. 5. "The seasonal cycle of oxygen concentration/depletion is superficially well represented.... However, most of the cycle is a simple function of temperature."

Bay water temperature annually cycles between 0 and 28 C. Corresponding saturation dissolved oxygen concentrations, at 15 ppt salinity, are 14.6 and 8.1 mg/L. Any computation resulting in dissolved oxygen less than 8.1 mg/L is not driven solely by temperature. The demand to pull dissolved oxygen below 8.1 mg/L must be computed correctly. Since the model regularly computes bottom dissolved oxygen concentrations near zero (Figure 1), the model must be computing oxygen demand. The review team's contention that most of the cycle is a function of water temperature is without merit.

Page 9, Q1. 6. "The plankton food-web structure is crudely represented."

We plan to improve the representation of the food web. We caution, however, against introducing too much complexity, too soon. When we started the model effort, we formulated a model with heterotrophic bacteria, three phytoplankton groups, microzooplankton, and mesozooplankton. The model could not be calibrated. Wild oscillations and crashes in functional groups resulted. All those functional groups could not be taken on at once. Consequently, we eliminated the bacteria and zooplankton and concentrated on phytoplankton. Following delivery of the first version of the model, we re-instituted the two zooplankton groups. The model required a full re-calibration which took two years. Now we are preparing additional incremental improvements including improved representation of nutrient recycling. These improvements will take time and require, no doubt, extensive additional programming and calibration. We do not recommend wholesale replacement of the model kinetics with alternate kinetics nor do we think employment of the model should be deferred until all the recommendations regarding food-web structure are met.

Page 9, Q1. 7. "Sediment transport is not currently well represented in the model."

We recognized the desirability of a suspended sediment transport model at the completion of the first phase of the model, circa 1992. Advances in the state of the art indicate a fully-predictive, three-dimensional sediment transport model of the bay is now feasible. Consequently, we plan such a model for the next phase of the study.

Page 9, Q1.8. "Some important properties predicted by the model have not been compared with observations. In some cases, the relevant observations do not exist."

We wish the review team had been more specific about the important properties. We find it difficult to compare unidentified properties with non-existent observations.

Page 9, Q1.9. "Primary emphasis in the model has been with the state variables and less attention to rate variables."

We have, indeed, emphasized state variables over processes. Until recently, we were largely concerned with comparing model output with habitat criteria. Computed dissolved oxygen was compared to criteria for fish and benthos. Computed chlorophyll and nutrient concentrations were compared to criteria for SAV. We are aware of no management criteria for primary production or respiration. We are aware that we must improve representation of processes before advancing the model into higher trophic levels and we plan to do so.

Page 9, Q1. 10. "The benthos model, which the Modeling Subcommittee believes is not working properly, is still [being used]."

The statement "the Modeling Subcommittee believes the benthos model is not working properly" is incorrect. We believe the benthos model provides the best estimates currently available of grazing on phytoplankton and of incorporation of material into the bottom sediments. We are not confident of the credibility of the benthos model response to extreme nutrient reductions. Consequently, we have discounted results from the benthic model under nutrient reduction scenarios.

Page 9, Q1.11. "The models were intentionally designed not to handle event-scale occurrences."

We have carefully searched workplans for both phases of this study and found no statement that the models will be designed not to handle event-scale occurrences. We have attended planning sessions for twelve years and we have never heard anyone say "Let's design a model that will not handle event-scale occurrences." The review team's statement that the model was "intentionally designed not to handle event-scale occurrences" is incorrect. In fact, the opposite is true. In one of the original planning workshops, a test of the hydrodynamic model was devised. The test was to simulate a September 1983 de-stratification event. Observations from that period indicate that, in a matter of days, the entire bay was de-stratified by wind mixing. Meeting this test was a requirement for approval of the model by the original Model Evaluation Group. Subsequent to passing the examination by Model Evaluation Group, results of the event-scale simulation were published in a peer-reviewed journal (Johnson et al. 1993.)

Page 10,Q2.1 "The Watershed Model and the Water Quality Model are generally run sequentially as one integrated model, making it difficult to determine which [contributes to observed problems]."

The Watershed and Water Quality models are not run sequentially as one integrated model. The models are run fully independent of each other. Multiple Watershed Model runs are conducted by the watershed team with no concurrent Water Quality model runs. At intervals, following careful inspection and review of Watershed Model results, the output is communicated to the Water Quality team.

Page 10, Q2.2. "The coupling of the coastal ocean to the Bay ....does not appear to be modeled in sufficient detail ....with regard to nutrients."

We have a lengthy history in dealing with the ocean boundary condition of the water quality model. In the earliest phases of the model, we specified boundary conditions at the Bay mouth based on observations. Although this was a reasonable simulation, we wanted to allow conditions at the Bay mouth to change in response to nutrient load reductions. Consequently, a mass-conservation boundary condition, in which conditions at the Bay mouth were free to respond to load reductions, was developed. In the Tributary Refinements phase of the study, we extended the boundary to the continental shelf, to an extent at which we felt boundary conditions could not be influenced by the Bay. Since key data did not exist at the edges of our new grid, the Monitoring Subcommittee, in cooperation with EPA Region III, collected necessary observations during one year. The review team must realize that detailed observations of processes, concentrations, and biota on the shelf simply do not exist. Nor is it within the resources of the Bay Program to monitor these on a regular basis. We will work to improve the representation of the boundary conditions but expectations must be consistent with available resources particularly with respect to coastal shelf monitoring.

Page 10, Q4.1. "Improve the coastal ocean model by adapting one of the existing models...."

We already employ a coastal ocean model, the ADCIRC model, as an aid in specifying hydrodynamic boundary conditions. Water quality boundary conditions are much more problematic. We recently hosted a workshop on formulating a coastal ocean model to couple with the Chesapeake Bay model. The workshop was attended by scientists and engineers with interests in the coastal ocean from Maine to Georgia. We viewed presentations on models of the Gulf of Maine, Massachusetts Bay, and Long Island Sound. We viewed presentations on models of the circulation on the continental shelf and of the Gulf Stream. We did not see any evidence of an existing water quality model suited for the shelf outside Chesapeake Bay, nor did we hear any mention of such a model during the extensive discussion sessions held each day.

Page 10, Q4.2. "Develop state of the art biological models.... "

We are endeavoring to improve the biological functions of the model. Within constraints imposed by time, budget, observations, and computational capability, we recommend cautious, incremental improvements. Employment of the model should continue while these improvements are taking place.

Page 10, Q4.3., "Update the light/primary production component of the [model]."

We believe the present model of light attenuation is the state of the art, a representation already well beyond the standard in most eutrophication models. Nevertheless, improvements are planned. The eventual development of a sediment transport model will provide improved computations of suspended solids. We will ask the Monitoring Subcommittee for help in measuring the optical properties of the water and suspended sediments. We will be addressing the shortfall in primary production as the first priority in additional modeling efforts.

Page 10, Q4.4. "Include suspended sediments as a dynamic variable in the model."

Suspended sediments are already a dynamic variable in the Water Quality Model. What is necessary, however, is an independent model of multiple classes of cohesive sediments. This model will be developed in the upcoming model effort. Sediment concentrations computed by this model will be input to the Water Quality Model which will compute the environmental effects of suspended sediments.

Page 10, Q4.5, "Devise a method to handle event-scale processes."

The models are already capable of handling event-scale processes. The hydrodynamic model operates on an intra-tidal basis using time steps of three minutes or less. The hydrodynamic model is forced by winds specified on a four-hourly basis and by observed flows specified on a daily basis. The water quality model operates on an intra-tidal basis using time steps of fifteen minutes. Runoff-induced loads are calculated by the Watershed Model on an hourly basis, and provided to the WQM on a daily basis. Events driven by tide, wind, and load perturbations on the scale of days are routinely represented by the models in the course of the ten-year simulation including a 100-year storm on the Potomac (November, 1985) which is included in the 1985 to 1994 ten-year simulation period.

Page 10, General Recommendation 1, "Review the role of MEG as an objective quality review *mechanism."*

We plan to supplement the MEG with "expert teams" with advisory and review roles in appropriate features of the model.

Page 10, General Recommendation 2, "Redesign and re-implement the Monitoring and Model programs to function as coordinated, mutually supporting elements of the overall Bay Program."

We agree that the two subcommittees, while currently complementary, can be better coordinated. While the greatest level of coordination can be effected through structural change, we advise caution in directly combining the two subcommittees, in light of the overall success and effective communication that already exists in the two programs.

Page 10, General Recommendation 3, "A documentation library of the model, validation procedures, analyses, and results should be maintained so that future reviews will have a written database to review."

We agree, and are developing web distributed model documentation.

Page 11, General Recommendations 4, "...demands were put on the staff to produce a vast array of scenarios before credibility of the model could be established."

Every effort was made to establish credibility of the model before commencing scenarios. First, extensive runs were made with the hydrodynamic model to examine effects of boundary conditions at the mouth, boundary conditions at the head, and local bathymetry. Once the hydrodynamics were complete, over 100 water quality calibration runs were made to tune and improve the model. Interim results were reviewed and suggestions were provided by the Model Evaluation Group, by representatives of the federal, state and local governments, by representatives of the dischargers, and by invited scientists. Within the constraints of time and resources, we could not have done more to establish the credibility of the model before starting this important task.

Page 11, General Recommendations 5, "Greater attention should be directed to objective analysis and sensitivity analysis."

Before commencing scenarios, we conducted 139 Water Quality Model calibration runs. Each of these was, in fact, a sensitivity analysis. In each run, a load, a parameter value, or a formulation was changed and the effect on the model results was examined. We realize the results of each of these runs were not available to the review group. Sadly, we all must realize the impossibility of describing and publishing the results of over 100 model runs. Although the review team may not have seen them, we can provide assurances that we already place great emphasis on sensitivity runs.

Page 11, General Recommendations 6, "While there is an ongoing interaction between the Modeling Subcommittee and the research community, there have not been many joint or cooperative efforts and much of the current university based research is not reflected in the model"

We agree and are interested in developing more of an open, "community model" to be used by the larger research and environmental decision making community. An example is the work by Dr. Navar, who is using the Bay watershed and water quality models with a climate change model to examine increased flows and loads due to climate change over the next 50 years.

Page 12, Future Directions 1, "The current trend is to use data assimilative techniques."

The employment of data assimilation techniques is not at all suited to the predictive models we develop. We could readily substitute observations into portions of the model. Two problems prevent the extensive employment of data assimilation. First, the observations aren't always available. In the case of water quality boundary conditions on the shelf, for example, there are few data to assimilate. A second problem arises when we go to predictive model. How do we change the observations to reflect the influence of load reductions and similar management actions?

Page 12, Future Directions 2, "Consider major changes to the structure of the hydrodynamic model along the lines of finite element techniques that have become the preferred approach in the university."

To date, finite element techniques find only limited application in water quality modeling. The major problem is that finite element techniques do not conserve volume locally, in individual model cells. This shortcoming was acknowledged in a discussion that followed presentation of a finite element model at the Coastal Processes workshop we convened. A second major problem is computation time. Computational demands of finite element techniques render them infeasible for the long-term simulations we require. Personnel at the Waterways Experiment Station are currently using a two-dimensional finite element model to drive a water-quality simulation of Florida Bay. A three-month hydrodynamic simulation of Florida Bay using two-dimensional finite elements, consumes 18 days of CPU on a SGI workstation. By contrast, simulation of a full year of Chesapeake Bay in three dimensions using CH3D consumes only 20 hours on the same device.

CH3D uses non-orthogonal curvilinear coordinates to simulate the complicated geometry of Chesapeake Bay. The hydrodynamic model conserves volume and is computationally efficient. We see no reason or need to replace it now or in the future with a finite-element model. We wish to note, also, that finite elements are not necessarily the preferred approach in the university community. Researchers at some universities, including Notre Dame, University of North Carolina, and Dartmouth College, favor finite elements. Researchers at other universities, however, including University of Florida and University of Rhode Island, continue to work within the framework of boundary-fitted grids and finite difference methods. The choice between finite element and finite difference models often is made based on the purpose of the study. Much of the finite element work is focused on computing things such as storm surges along coastlines rather than on long-term simulations to drive water quality models.

Page 12, Future Directions 3, "Improve interaction with the research community (staff and students) so the research will be better coupled into the model and so the academic community can better benefit from the knowledge gained from the model. Graduate thesis involving both model and monitoring results could be encouraged."

We welcome the opportunity to work with STAC to increase the interaction of the research and modeling groups in shaping a community model. We are particularly interested in working with STAC to encourage graduate theses which would use the modeling tools and the monitoring data base.

Citations

Dortch, M., Cerco, C., Robey, D., Butler, L., and Johnson, B.,1988, Work Plan for Three-Dimensional Time-Varying, Hydrodynamic and Water Quality Model of Chesapeake Bay, Miscellaneous Paper EL-88-9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cerco, C. and Cole, T. 1993. Three Dimensional Eutrophication Model of Chesapeake Bay, *Journal of Environmental Engineering*, 119:1006-1025

Cerco, C., 1994, Workplan for Tributary Refinements to Chesapeake Bay Eutrophication Model Package, Miscellaneous Paper EL-94-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cerco, C., and Cole, T. (1994). "Three-dimensional eutrophication model of Chesapeake Bay," Technical Report EL-94-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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

Johnson, B., Kim, K., Heath, R., Hsieh, B., and Butler, L. 1993. Validation of a Three-Dimensional Hydrodynamic Model of Chesapeake Bay. *Journal of Hydraulic Engineering*, 199(1):2-20.