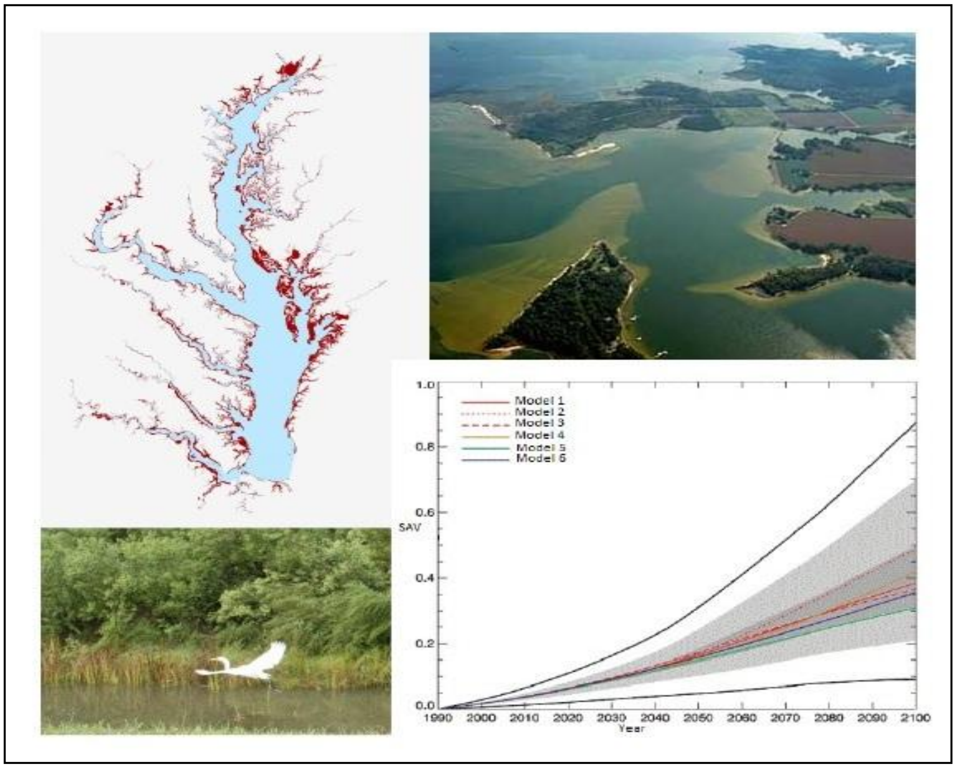
Using Multiple Models for Management in the Chesapeake Bay: A Shallow Water Pilot Project



STAC Workshop Report

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About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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Executive Summary

In early 2012, the Director of the Chesapeake Bay Program (CBP) requested that the Scientific and Technical Advisory Committee (STAC) convene an expert workshop to frame a shallow water, multiple model comparison pilot project that would provide the foundation for future modeling in the productive littoral areas of the Bay and would demonstrate the potential use of multiple models in routine CBP modeling activities. This workshop was held April 26-27, 2012 at the Virginia Institute of Marine Science (VIMS) in Gloucester Point, Virginia. Attendance was limited to 25 attendees, with the understanding that a second, larger workshop in the fall would foster a much broader discussion of the benefits and challenges of using multiple models in regulatory management. Workshop participants included coupled hydrodynamic-water quality modelers who were already running coupled models in the Bay or might do so in the near future. These participants unanimously agreed with the primary workshop recommendations:

A Shallow Water Multiple Model Pilot Project is key to the advancement of the CBP modeling program, and should begin as soon as possible.

The following recommended approach for conducting such a project is based on discussions held at the workshop.

Pilot Project Goal: The overarching goal of the Shallow Water Multiple Model Pilot Project is to improve Bay shallow water simulations of dissolved oxygen and water clarity in order to better understand the impacts of alternative management strategies on living resources in the tidal Chesapeake Bay (CB).

Rationale for New Shallow Water Modeling Efforts: Modeling Workgroup staff and subcontractors have identified limitations in the current CH3D-ICM hydrodynamic-water quality model in the shallowest, most productive depths of the Bay and its tributaries. Because dissolved oxygen and water clarity are water quality criteria that must be met to delist the Bay, the workgroup recently suggested that alternative or complementary modeling approaches need to be considered in these waters.

Rationale for Multiple Models: STAC believes that the routine comparison of output from several other models with the EPA regulatory model output will (1) help determine whether the regulatory model is as skillful as other models of the Bay, (2) enable effective adaptive management and accountability, and (3) build scientist, management, and stakeholder confidence

in the model. The pilot project outlined here provides an excellent opportunity for the CBP to address these issues by implementing a prototype multiple modeling strategy, as has been suggested in several recent CBP reports and reviews (e.g., NAS review; STAC LimnoTech review; STAC/CCMP Hydrodynamic Workshop report; STAC October 21, 2011 letter; STAC January 18, 2012 letter; see http://www.chesapeake.org/stac/stac_cor_pubs.php).

Pilot Project outcomes:

- Potential identification of new and improved models for shallow Bay waters, and/or suggested improvements to the existing regulatory model
- Confidence estimates for CBP shallow water simulations
- Demonstration of feasibility and utility of using multiple CB models

Pilot Project methods:

- Models of shallow water hydrodynamics and water quality will be sought for participation in a 1-2 year pilot project.
- Following identification of several study sites, each of 3-6 modeling teams will:
    - Utilize common forcing (bathymetry, winds, freshwater and nutrient inputs, open boundary conditions) to implement a 3-5 year base case run at specified shallow water sites
    - Provide daily distributions of variables relevant for submersed aquatic vegetation (SAV; e.g., temperature, salinity, dissolved oxygen, water clarity, nutrients) at the specified times and sites
    - Use the daily distributions as input to a specified empirical SAV model
    - Provide results as above after forcing the models with specified nutrient reduction scenarios
- A model comparison team will:
    - Use state-of-the-art metrics to assess the relative skill of the participating simulations, based on available CBP monitoring data (both inputs to empirical SAV model and outputs of SAV model)
    - Compare results of the modeled nutrient change scenarios
    - Analyze causes and impacts of differences among models

Pilot Project Funding Requirements:

- Workshop participants identified annual costs per modeling team per year at $100,000-$250,000, depending on the number of sites identified for simulation
- Workshop participants identified significant advantages for a multi-year project
- A mechanism to ensure participation of government research scientists is necessary (e.g., subcontract to a non-Federal entity, without salary support for government staff)
- Cost-sharing should not be required

Pilot Project Timing: Because of the approaching 2015 model implementation deadline (Modeling Workgroup Schedule), the pilot project should begin as soon as possible to have the most impact, preferably early in the 2013 calendar year.

Introduction

In response to a request by the Chesapeake Bay Program's Director, the workshop's steering committee brought together technical experts who could speak on a number of issues critical to the design of a shallow-water hydrodynamic modeling pilot project. The steering committee invited experts to: summarize a previously successful pertinent modeling project and describe how skill assessment was used to compare the project's model output to observations; describe the current state of Chesapeake Bay hydrodynamic modeling in the shallow water regions of the estuary; and discuss data availability and constraints within the estuary. Moderated discussion followed each presentation, and the steering committee devoted a substantial amount of time on the afternoon of the first day and the morning of the second day for discussing and brainstorming. Relevant points from the presentations are summarized below along with a thorough description of the workshop's discussions.

Presentations

Lessons learned from the IOOS Testbed – Marjy Friedrichs, Virginia Institute of Marine Sciences

Friedrichs described how the recent Integrated Ocean Observing System/Southeastern Universities Research Association (SURA) Coastal Modeling Testbed project, better known as the IOOS Testbed Project, used multiple models to improve operational and scenario-based hypoxia modeling in the Chesapeake Bay.

The project compared the skill of multiple models using hindcasting for parameters such as: salinity, temperature, stratification, and dissolved oxygen. Sensitivity tests were performed for each model to identify the factors that most affected each model's ability to reproduce the available CBP observations. Reviewers used "target diagrams" to illustrate total model-data misfit, which is plotted as the distance between each model symbol and the center of the plot. Thus the farther a model symbol is from the center or "bull's eye" of the target, the lower the reliability of that model. An example of this type of skill assessment applied to the total volume of hypoxic waters in the Chesapeake is provided in Figure 1 below.

By using these target diagrams and subsequently testing the models' sensitivity to a variety of parameters, the IOOS Testbed team has been able to determine model sensitivities to various parameters. Model predictions of stratification were not highly sensitive to wind forcing, river flow, grid resolution, and coastal boundary conditions, but were highly sensitive to turbulence closure parameterizations and advection schemes. These findings provide an example of how skill assessment of multiple models can provide managers with quantitative information to improve existing models and ultimately improve management decisions as well.

Friedrichs concluded her presentation with an announcement that four or five modeling groups are eager to participate in a shallow-water coupled hydrodynamic water-quality pilot project.

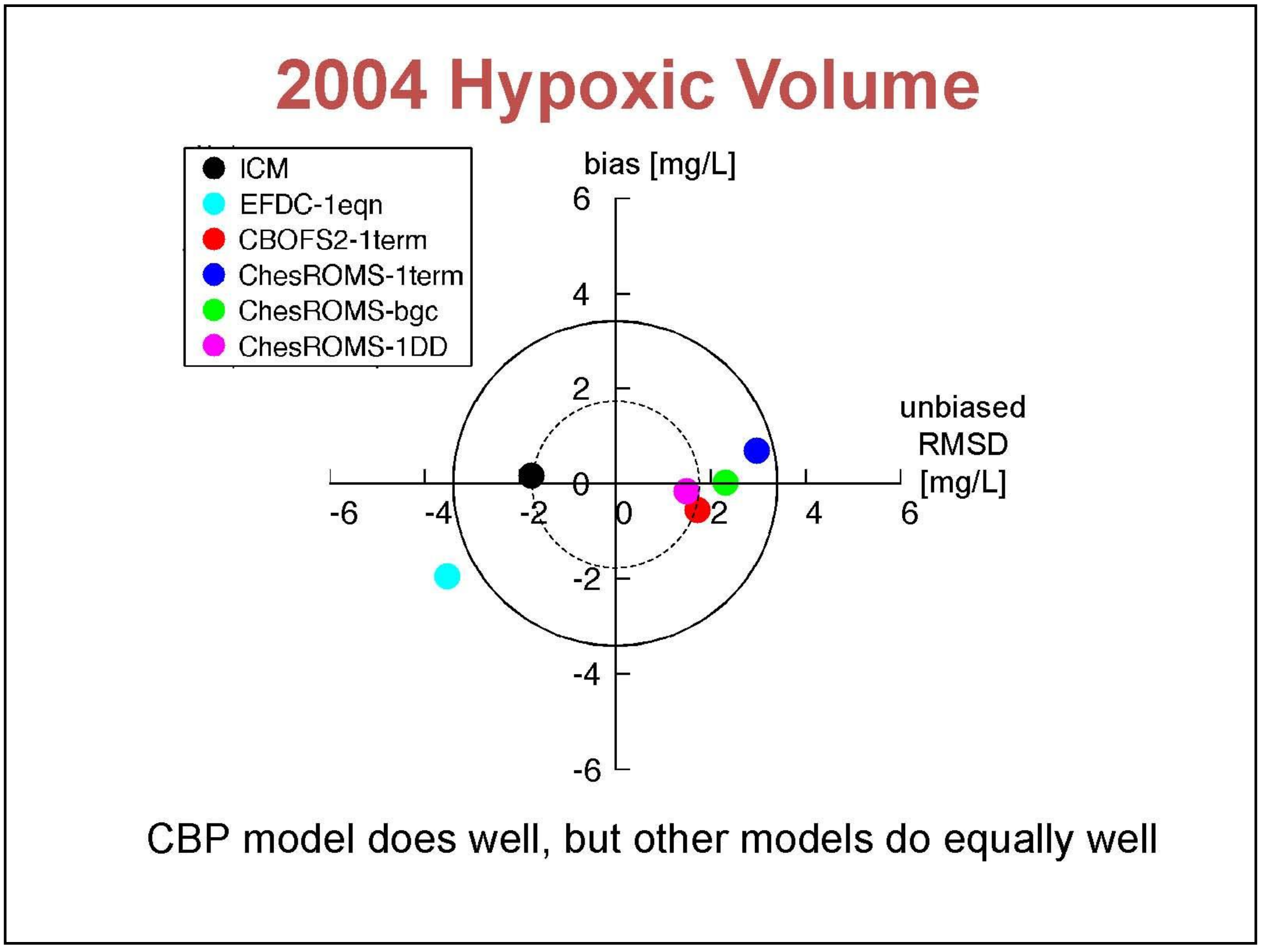

Figure 1. Model Skill Target Diagram of 2004 Hypoxic Volume in the Chesapeake Bay.(ICM = Integrated Compartment Model, results submitted by Ping Wang; EFDC = Environmental Fluid Dynamics Code, results submitted by Jian Shen; CBOFS2 = Chesapeake Bay Operational Forecast System, results submitted by Lyon Lanerolle; ChesROMS-1 term = Chesapeake Regional Ocean Modeling System, 1-term hypoxia model, results submitted by Malcolm Scully; ChesROMS-bgc = ChesROMS Biogeochemistry model, results submitted by Wen Long; ChesROMS-1DD = ChesROMS Depth Dependent Oxygen Code, results submitted by Malcolm Scully.)

Toward modeling and analysis tools for the 2017 midpoint assessment: The assessment of Chesapeake Bay shallow-water multiple management models – Lewis Linker, EPA-CBPO

Linker told participants that while the EPA is moving forward in implementing the TMDL using the current suite of models, the Chesapeake Bay Program and EPA are interested in investigating how multiple models could improve simulations in the shallow-water areas of the Chesapeake Bay. Regardless of which model or models is/are used to assess shallow-water criteria, all of these models must be operational by December, 2015 to be considered for the 2017 midpoint assessment of the Chesapeake Bay TMDL. Additionally, any shallow-water model that is included in this midpoint assessment must be able to assess water clarity (using light attenuation), SAV, and open-water DO.

**It should be noted that workshop participants later agreed that modeling teams should be required to provide water clarity as a model output, but not be required to directly simulate SAV. EPA would provide an SAV model based upon water clarity and other parameters to all teams for estimating potential SAV responses to a model's output.*

Linker went on to explain that the Chesapeake Bay's shallow water conditions were the most difficult to simulate with current models. This is due to a number of complicated interactions between the shallow waters, open waters, and land including shoreline erosion, waves, settling and re-suspension, biogenic solids production, boundary conditions, bathymetry, and watershed inputs. Linker also explained that the Bay Program could provide the boundary conditions and watershed inputs for the study sites once selected.

CH3D and modeling the shallow waters of the Chesapeake Bay – Carl Cerco, Army Corps of Engineers

Cerco explained to participants that the current hydrodynamic model, CH3D, has reached its limit of simulation ability. The current CH3D model contains approximately 57,000 cells and the model does well predicting DO and other water quality parameters in the Bay's open water; however, it does not do as well simulating processes in small embayments. To illustrate this point, Cerco pointed out that the small embayment of the Potomac River known as Gunston Cove could be simulated by only five cells in CH3D's structured grid while an unstructured grid model such as ADH or FVCOM simulates the embayment with tens or hundreds of cells thereby enabling much finer resolution of processes in these shallow areas. For this reason, Cerco suggested to participants that only an unstructured grid model would adequately simulate shallow-water living resource areas around the Bay.

Cerco went on to suggest a couple of options for modeling the shallow waters of the Bay. The first option would be to develop a "living resource ribbon model" that could model the Bay's shallow waters and feed its output into the existing CH3D open water model. A second option would be to develop one single hydrodynamic model that could model the open and shallow waters. Regardless of which option is selected, Cerco suggested the CBP modeling team and managers would learn much more from a pilot project that tested multiple models in different regions of the Bay. For example, the managers could select one site on the Lower Eastern Shore and another site in the Potomac River.

Cerco also cautioned the participants to be aware of the large number of variables and processes that are currently not well understood or documented in shallow waters. Perhaps the largest problem modelers and CBP managers will encounter is developing accurate bathymetry data for each site as depth will be extremely important in these shallow regions. In addition to depth, there is little known about resuspension of organic matter and sediment in shallow areas, what determines SAV success, benthic algae presence, and wave refraction. All of these problems will need to be considered by the modeling groups.

Quick overview of Maryland's intensive/shallow-water monitoring programs and Virginia's York River water quality monitoring data– Mark Trice, Maryland Department of Natural Resources and Ken Moore, Virginia Institute of Marine Sciences

Trice explained that Maryland has 30-50 operational, continuous water quality monitors deployed in the MD portion of Chesapeake Bay. Some of these monitors are deployed about 0.3 meters from the bottom. These monitors collect data once every fifteen minutes for the following parameters: DO, turbidity, chlorophyll, water temperature, salinity, pH, and depth. Additionally, all stations had complementary data including full suites of nutrients, sediment, chlorophyll, K_d, and light profiles prior to 2010. Due to funding constraints, most stations no longer have these additional data.

Trice went on to explain that most of the sites contained three consecutive years of water quality data with some sites having additional years. Monitoring stations are spread throughout the estuary covering various habitat types, bottom types, salinity ranges, etc. supporting exploration of model effectiveness at multiple sites with differing characteristics. The various regions might be the Upper Bay Susquehanna Flats, Lower Eastern Shore, Upper Eastern Shore, and a Western Maryland tributary such as the Patuxent or Potomac Rivers. Virginia's Moore concurred that with the amount of data available across a large number of sites with differing characteristics, a number of sites should be selected to study.

In a detailed description of one area, Moore described Virginia's extensive monitoring network in the York River, with 10 years of water quality monitoring data at six different stations within the river. Additionally, the York River has very different processes than other tributaries, and exhibits differences in processes, habitat type, bottom type, etc. from monitoring station to monitoring station in the system. Finally, the York River has documented areas of submerged aquatic vegetation (SAV) that could be studied.

Gunston Cove Study Overview – Chris Jones, George Mason University

Gunston Cove is a shallow-water embayment located in the tidal freshwater portion of the Potomac River approximately 20 km downstream of Washington, DC in Fairfax County, VA. The cove is unique compared to many other possible study sites. It is protected by tidal current velocities that dominate the Potomac River's main channel resulting in an unstratified water column that might be less representative of the majority of other Chesapeake Bay sites. Nonetheless, if managers chose to study Gunston Cove, they would have access to water quality data that was sampled twice per month from April through September since 1984. Monitors obtained the following parameters over that time period: water temperature, conductivity, DO, pH, nutrients, sediments, chloride, alkalinity, chlorophyll, light attenuation, turbidity, and Secchi depth.

**It should be noted that while Gunston Cove was originally selected as a good location to test multiple models, workshop participants agreed that many other locations with rich data histories may be more representative of the various shallow-water habitats across the Bay.*

Workshop Discussion

Following the presentations, participants were asked to envision what a successful pilot project would require. Specifically, participants were asked:

- How many sites should be selected? And what selection criteria should be used?
- What "forcing" data does the CBP need to provide to each modeling team?

- How should model skill be undertaken in the project?
- How many modeling teams should be allowed to participate in the project?
- How much would a pilot project cost? And how long should the project last?
- Which variables should models provide to managers?
- What will be the end contribution of the pilot project to the Chesapeake Bay Program?

Site Selection – How many? What Criteria?
The majority of the workshop's discussion on this topic involved developing a list of site selection criteria and debating an appropriate number of shallow water sites to study and developing a list of site selection criteria. Before determining those criteria, participants discussed the objective of the modeling effort. While it was not clear if the pilot project would result in the creation of a new Chesapeake Bay model to simulate living resources in every shallow water area within the estuary, participants agreed that the models should be capable of simulating SAV abundance indirectly by providing simulations of dissolved oxygen and water clarity, two parameters known to be crucial to the successful establishment and persistence of SAV beds.

With this requirement understood, participants agreed that the best pilot project would require modeling teams to simulate the following contrasting types of areas: **shallow water with present SAV abundance and known historical SAV abundance**; and **shallow water without present SAV abundance, but with known historical SAV abundance**. The CBP may also want to consider a third site category: **shallow water with no historical or present SAV abundance**. All sites should have 3-5 years of data including temperature, salinity, light/turbidity, chlorophyll, bathymetry, wave height, wave period, open boundary conditions, freshwater flows and loads, and where appropriate, SAV acres.
Out of these sites, workshop participants agreed that teams should be tasked to model contrasting, yet representative sites that would provide their models a chance to simulate a number of bottom types, salinity ranges, and weather and tidal forcing parameters. Contrasting sites should be selected using the following specific data:

- **Salinity** – predominantly freshwater site vs. brackish site.
- **Bottom type** – sandy site vs. silt-covered or muddy site.
- **Wave influence** – a site with moderate waves permitting SAV growth vs. a site dominated mainly by tides.
- **Input forcing variables** – a site influenced by locally forced conditions vs. a site influenced by mainly external factors
- **Nutrient levels** – a site with high levels of nutrients exhibiting eutrophic characteristics vs. a site with lower levels of nutrients exhibiting oligotrophic characteristics.

It is likely that modeling teams will only have the resources and time to develop their models for two, or three different sites. Thus, workshop participants recommended that the CBP choose two or three sites using the above selection criteria and incorporate as many of these contrasting conditions as possible in the two or three selected locations. Participants did not agree on whether the pilot project should specifically focus on two or three contrasting sites within a single, well-monitored tributary such as the York River, or should instead focus on two or three contrasting sites from around the entire estuary. Regardless of which method is chosen, it is important to pick sites that would be representative of a large number of areas throughout the estuary.

Forcing Data

It will be essential to provide necessary forcing data for each site to all modeling teams. Forcing data would include the following: bathymetry; shoreline boundary; shoreline erosion estimates; winds/fetch; freshwater and nutrient inputs from CBP model output up to 2011, including riverine and groundwater; and validation data.

Model Skill Comparison

The pilot project would need to include a single model comparison team, who would use state-of-the-art metrics to assess the relative skill of the various models. A number of traditional or new metrics could be used to compare model skill, including root mean squared difference, bias, variability and correlation. Regardless of the specific metrics used to assess model skill, the comparison team may need to withhold a portion of the data. This will assist in the assessment of each model's ability to reproduce data to which the models were not directly tuned. For this reason, the CBP should focus on sites with longer monitoring data records. Once model results are submitted, the model skill comparison team would then use the results as inputs to a single empirical SAV model. The team would then compare these results to identify feasible SAV growth. In a final portion of the comparison effort, each model's sensitivity to changes in nutrient loading scenarios will be assessed and compared in order to determine the range of effects expected for the specified changes in nutrient loading.

Pilot Project Costs

Workshop participants and STAC are cognizant of the current fiscal situations of many of the CBP partner agencies and jurisdictions. Models can be costly to develop and validate across a large ecosystem such as the Chesapeake Bay. However, STAC continues to believe that the current CBP modeling suite could benefit by the iterative testing and comparison of multiple models. Moreover, development of models to answer specific management questions such as, *Where are SAV and living resources likely to appear as a result of different nutrient input scenarios?* can be cost-effective, can enhance the current modeling suite, and can provide uncertainty estimates that give managers and the public a better understanding of the realities of large-scale ecosystem restoration projects. Hence, this pilot project appears to be a worthwhile investment to make prior to the mid-point assessment of the Chesapeake Bay Total Maximum Daily Load (TMDL) in 2017.

Participants suggested that each modeling team would require between **$100,000 and $250,000** each year, dependent upon the number of sites selected for the pilot project. Ideally, **3-6 teams** would be selected in addition to **one model comparison team**. Finally, participants agreed that while a one-year project might be suitable, a **two-year award** to each team would likely result in the best results for managers, allowing for an iterative process of model simulation, model skill assessment, model adjustments/improvements and additional model assessment. Additionally, considering that the results are directly beneficial to future CBP modeling code development, modeling teams should not be required to provide a cost share. Finally, participants agreed there should be a mechanism to ensure participation of governmental researchers through subcontracts to a non-Federal entity or other mechanism.

STAC is also well aware that the CBP's modeling deadlines approaching the 2017 mid-point TMDL assessment are stringent. All model implementations should be completed by 2015 in order to be incorporated and tested before the mid-point assessment. For this reason, STAC and the workshop participants urge the CBP to begin the pilot project as soon as possible and preferably early in the 2013 calendar year. If the project is delayed for any reason, STAC also urges the CBP to re-consider the 2015 modeling deadline so that the partnership can take advantage of the pilot project's eventual findings.

Requirements and Outcomes

All modeling teams should be required to utilize the common forcing and boundary conditions as specified above. The teams should also be required to provide daily distributions of: temperature, salinity, dissolved oxygen, water clarity, chlorophyll, nutrients, total suspended solids, and colored dissolved organic matter at the specific times and sites selected. These are the parameters that are needed as input for the existing SAV empirical model. It was the understanding of the workshop participants that while some teams may develop their own SAV model, this should not be a requirement, and a standard empirical model should be provided to all teams by the CBP. The teams will also provide the results of their models after forcing the models using nutrient inputs provided by the CBP for various nutrient reduction scenarios.

Following the development, execution, and skill assessment of the various models, the skill assessment team will provide confidence estimates for existing CBP shallow water simulations as well as sensitivity analyses of the new models' simulations. These outcomes will help to identify potential improvements to the existing model, demonstrate the feasibility of using multiple models within the estuary, and potentially identify a new model or models for use in the shallow water areas of the Chesapeake Bay.

Conclusion

STAC continues to believe that the current Chesapeake Bay modeling suite has used appropriate rigorous scientific expertise in its development. Future modeling should also include peer review and state-of-the-art science and modeling tools. Recent advances in modeling techniques and computing technologies now enable scientists to model ecosystems at a finer scale with multiple models and assess the uncertainty of each prediction. This multiple model pilot project will take advantage of these new improvements in science and technology so that the next generation of Chesapeake Bay Program models remain state-of-the-art. Well-reasoned demonstration projects such as the one described in this report move the Chesapeake Bay Program forward into the next phase of the TMDL with updated modeling tools, some estimate of uncertainty in model output, and therefore a justifiable increase in confidence in selection of best management practices (BMPs) to maximize costly load reductions. This demonstration project will provide Chesapeake Bay Program partners with improved simulations of SAV and living resources within the shallow water areas of the Bay and uncertainty estimates of the predictive capabilities of the existing model and others. To take advantage of such improvements, the Chesapeake Bay Program should act quickly to begin the pilot project by 2013 so that any lessons learned can be applied to the modeling suite for the 2017 TMDL mid-point assessment.