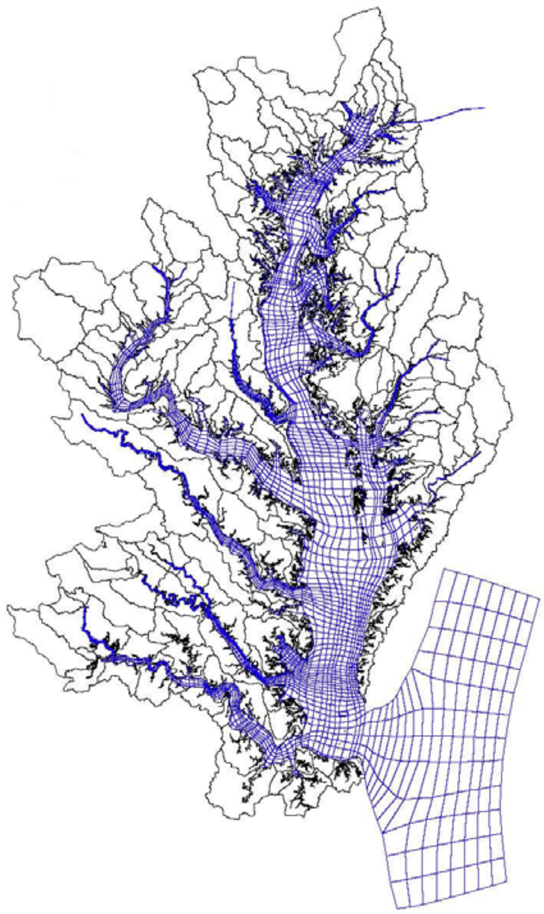
Final report of the Chesapeake Bay Scientific and Technical Advisory Committee's workshop:

Modeling in the Chesapeake Bay Program: 2010 and Beyond



January 17-18, 2006
Radisson Hotel, Annapolis, Maryland

Sponsored by the Scientific and Technical Advisory Committee
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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 on measures to restore and protect the Chesapeake Bay. As an advisory committee, STAC reports periodically to the Implementation Committee and annually to the Executive Council. Since it's 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 conferences and workshops, and (5) service by STAC members on CBP subcommittees and workgroups. In addition, STAC has the mechanisms in place that will allow STAC to hold meetings, workshops, and reviews in rapid response to CBP subcommittee and workgroup requests for scientific and technical input. This will allow STAC to provide the CBP subcommittees and workgroups with information and support needed as specific issues arise while working towards meeting the goals outlined in the *Chesapeake 2000* agreement. STAC also acts proactively to bring the most recent scientific information to the Bay Program and its partners. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

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The Scientific and Technical Advisory Committee (STAC)

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July 5, 2006

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EXECUTIVE SUMMARY

The Scientific and Technical Advisory Committee (STAC) of the Chesapeake Bay Program (CBP), with the support of the CBP Modeling Subcommittee and the Chesapeake Community Modeling Program (CCMP), sponsored a workshop in early 2006 to discuss future directions for modeling in the CBP. The genesis of the workshop was the realization that the CBP modeling program is at a crossroads following a recent series of news articles and external reviews and facing a future focused on TMDLs in parts of the Bay and its watershed. STAC determined that a broad overview of modeling and its roles in the CBP was most appropriate for this workshop, rather than detailed examinations of individual component models. The objectives of the workshop included exploring the challenges and opportunities likely to face CBP modeling efforts in the next 5-10 years, and formulating recommendations to help the CBP plan for the future and maximize the utility, scientific rigor, and openness of its modeling efforts.

The workshop was held on January 17-18, 2006 at the Radisson Hotel in Annapolis, MD. It was attended by 54 participants from academic institutions, consulting companies, federal agencies, state agencies, and non-profits. Presentations and open discussion addressed many topics relevant to the workshop objectives over the course of two days, in both plenary sessions and breakout working groups. Working group topics were discussed in plenary and voted upon by all of the participants each day. The first day focused on broader, big-picture issues, while the second day focused on more specific, application-oriented issues.

After the workshop, the steering committee distilled the reports of the various working groups (see Appendix) into a set of primary recommendations, which are described in detail in the body of the report text. These are further summarized and listed below by topic, with the most important recommendations in bold.

Accessibility of CBP Models and Model Data
CBP model codes, model predictions, model forcing data, and model loading data should be made more accessible to the Chesapeake Bay modeling community. Better documentation and improved access to the model codes is needed, especially if, as many workshop participants requested, a nested modeling capability for enhanced local simulations is to be developed. A more important immediate goal for CBP modeling should be to provide straightforward access to CBP model predictions, model forcing data, and model loading data for calibrated simulation periods.

Restoring Living Resources
Restoring living resources is the ultimate goal of the CBP, beyond improving water quality in the watershed and the estuary. In their present forms, CBP models are only marginally helpful in this regard. **Living resources modeling must be given the same level of attention and support as watershed and water quality modeling, and the programs must be integrated. The next big challenge for CBP modeling is to model not only a restored Chesapeake Bay, but the recovery trajectory to a restored Bay. It is quite likely that CBP models will need to be able to predict ecosystem "tipping points" in order to predict ecosystem recovery trajectories.**

Better integration of modeling and monitoring

1. **Running a version of the CBP modeling system in near-real time hind cast mode, updated with monitoring data as it becomes available, would have significant benefits for the CBP.** It could be used to improve interpolation of the monitoring data, to evaluate the placement and frequency of monitoring stations, to enhance the presentation of information to the public, to assess the influence of major weather events, or to aid in seasonal forecasts.
2. **Archived monitoring data should be used to independently "post-audit" model predictions (e.g., 1985-94 model with 1995-2004 forcing and data).** Such a post-audit would add credibility to the overall modeling effort and would help to inform ongoing research and development efforts.
3. **The CBP monitoring program should be enhanced as necessary to better support linkages between water quality models and living resource models.** Potential strategies for modifying or supplementing the current monitoring program include nested designs with fine time and space sampling over relatively small areas to address specific aspects of water quality-living resource linkages.
4. **A plan for modeling shallow nearshore zones and incorporating CBP Shallow Water Monitoring Program (SWMP) data should be developed**, with a timeline and estimates of future resources needed to complete the task; this is essential for the long term goals of the CBP, especially with regard to SAV and marsh restoration.

TMDLs

Total Maximum Daily Loads (TMDLs) are currently being developed for local areas within the Bay watershed and tributaries, and will almost certainly be required for specific pollutants in broader reaches of the Bay after 2010. It would be helpful to the states if the CBP were to incorporate remaining TMDL pollutants (toxics, pH, pathogens) into the models, compiling necessary loadings in the process. More importantly, **development of a nested modeling capability on some level is critical for addressing local TMDLs at scales smaller than those resolved by the CBP models. Provision of archived large scale model predictions at the boundaries of local domains (e.g., exchange rates between tributary and main Bay for nutrients, DO, chlorophyll, etc.) and local forcing factors (e.g., insolation, wind, rainfall, etc.) would be almost as valuable.**

Multiple Models

Multiple models of the same phenomenon or situation are routinely used in weather and climate forecasting to provide estimates of prediction uncertainty. However, **workshop participants could not agree whether or not adoption of the multiple models approach was appropriate for CBP modeling.** Supporters of the multiple models approach noted that when different models agree on a prediction, confidence in that prediction is much greater, and vice versa. In addition, forcing a single model towards greater and greater complexity in order to resolve all scales and all processes can be very inefficient for addressing specific issues. Opponents of the multiple models approach felt that, while there were clear advantages to multiple models from a scientific or forecasting point of view, from a regulatory and practical point of view multiple models are not appropriate for the CBP. For TMDLs, multiple models are potentially counterproductive, inviting court cases and delays. **The issue merits re-examination in a more focused forum. Alternate approaches to resolving the multiple models issue should also be**

explored, such as using the timing of new CBP model development to allow old-new model comparisons, and encouraging alternate model development by others in the scientific and forecasting communities. The latter would be facilitated by provision of CBP model input data and sponsorship of model intercomparison exercises.

Structural changes in the CBP

There is no apparent need to change the existing structure of the CBP modeling groups and advisory committees. However, in general **CBP modelers need more interaction with the broader CB modeling community.** This can be achieved through increasing the accessibility of CBP model codes, predictions, and input data fields, through transitioning to modern, modular, open source models, and through working with existing groups such as the Chesapeake Community Modeling Program. **A key recommendation is that the CBP should allocate some percentage of its annual modeling budget specifically for strategic development, documentation, dissemination, and investigation.**

Improvements to the Watershed model

The next watershed model (2010-2015) should be modular with the ability to communicate with other models and data sources through standardized formats. Improved process simulations in specific areas also are needed. Watershed monitoring will support modeling efforts best by adopting integrated observing systems, with complete data suites collected in small watersheds/stream reaches that represent different landscape settings.

Improved estimates of meteorological forcing and atmospheric deposition

Ongoing efforts to integrate national air quality and atmospheric deposition models with CBP models are commendable and should be continued. **An additional, potentially valuable collaboration with NOAA/NWS weather modelers should be pursued to improve recent past and future wind field predictions.** Recent advances in weather modeling could provide greatly improved wind stress fields for the Bay hydrodynamic model, which could have important local impacts on circulation and water quality predictions. In addition, the wave modeling capability being added to the hydrodynamic model would greatly benefit from improved wind fields over water.

Improvements to the Hydrodynamic and Water Quality models

Present CBP hydrodynamic and water quality models are sufficient to meet the primary water quality management goals of the CBP. However, present model codes are overly difficult to access, understand, modify, or utilize by others. **Many workshop participants (but not enough to proclaim a consensus) recommended future, parallel development of a new, modern, modular, open source hydrodynamic and water quality CBP modeling system circa 2010-2015. The issue merits re-examination in a more focused forum.** In either case, improved process simulations in specific areas are needed.

Improved ocean boundary conditions

There was no consensus that presently unrepresented processes outside the Bay mouth were a significant influence on circulation, water quality, or living resources within the Bay. The importance of some of these processes should be investigated further, including nitrogen variability in the nearshore coastal ocean, nitrogen transport into the Bay, and fisheries recruitment and migration issues. **In the long term, the CBP should consider coupling the current continental shelf ROMS model to the CBP hydrodynamic and water quality models.**

Forecasting
The CBP should not attempt regular short term (days to weeks) forecasts, which are beyond its purview. However, running a version of the CBP modeling system in near-real time hindcast mode would enhance the CBP's ability to produce seasonal ecological forecasts by allowing forward projection of different seasonal scenarios, starting with present conditions. Most importantly, **CBP models should be used to investigate the impacts of longer term changes in population, land use, and/or climate change. Land use change is most important in the near term.**

Model Complexity
Trends towards increasing complexity and spatial resolution are likely to continue as long as computing power continues to increase, even though this is not always the best course of action. These **tendencies towards greater complexity must be tempered by the need to rigorously explore model performance and behavior. Additional focus is needed on analyzing and quantifying model performance, assessing model sensitivities, considering model uncertainties, and optimizing model parameter selection.**

Conclusions
In conclusion, all participants thought that the workshop was very successful, bringing together representatives of almost all parties interested in modeling in the Chesapeake Bay and its watershed and airshed. Presentations were informative and provocative, plenary discussions were open and inclusive, and working group breakout sessions were lively and balanced.

There were several recurring themes and areas of clear consensus. The strongest was the first one listed above – that CBP model codes, model predictions, model forcing data, and model loading data should be made more accessible to the Chesapeake Bay modeling community. More attention needs to be paid to documentation, independent verification, and sensitivity testing, as well. These issues were deemed important enough to recommend that the CBP identify specific budget resources and time for addressing them. There was also clear consensus that living resources modeling should be a very high priority, not only for analysis of past and present conditions, but also for predicting both a restored Bay and the trajectory by which it may be reached. There was a consensus that more effective interactions between monitoring and modeling were needed in specific areas, some involving new modeling efforts and some involving changes to the monitoring programs to better support modeling needs. A clear vision for development of the next major version of the watershed model was presented, interactions with meteorological and atmospheric transport models were encouraged, and modeling the effects of long term changes in population, land use, and/or climate change was strongly recommended.

There were also several unresolved issues from the workshop. These should be considered further in a series of focused workshops, communications, or other forums, working toward consensus recommendations on each issue. These issues include: (1) how to implement living resources models and coordinate with other modeling efforts, (2) whether and how to support development of multiple models, (3) how to integrate modeling and monitoring more effectively (especially for living resources and shallow water environments), and (4) establishing a consensus vision for the future of the hydrodynamic and water quality models.

BACKGROUND

For more than 20 years, numerical modeling has been an integral part of the Chesapeake Bay Program (CBP), one of America's premier watershed restoration partnerships. Models have helped the CBP to understand and interpret observed patterns of flow, water quality, population dynamics, and ecosystem interactions in the Bay and its watershed. Models have also been used to help define restoration goals, and to predict the outcomes of proposed regulatory and restoration activities. Over this period, the scope and complexity of CBP modeling have grown tremendously, and numerical modeling has become a central tool for evaluating restoration options and assessing trends.

The CBP modeling program now appears to be at a crossroads. Recent reviews of CBP component models, while generally positive, have identified scope for enhancement and improvement. Public perceptions of the role and reliability of CBP model predictions have been damaged by recent news stories. A recent GAO review recommended that the CBP develop a more integrated assessment approach and improve its communication of the status and trends of the restoration effort. Meanwhile, rapid growth of the open-source community modeling concept has challenged the more focused and traditional approach of CBP modeling while offering exciting new opportunities. The likelihood that TMDLs will be required in parts of the Bay and its watershed after 2010 presents new management and modeling challenges. Innovative changes in monitoring approaches and capabilities also offer significant new challenges and opportunities for modelers.

For these reasons, the Scientific and Technical Advisory Committee (STAC) of the CBP, with the support of the CBP Modeling Subcommittee and the Chesapeake Community Modeling Program (CCMP), sponsored a workshop to discuss future directions for modeling in the CBP. The workshop was held on January 17-18 at the Radisson Hotel in Annapolis, MD.

WORKSHOP OBJECTIVES AND FORMAT

The broad objectives of the workshop included:
(1) Exploring the challenges and opportunities likely to face CBP modeling efforts in the next 5-10 years, and (2) Formulating recommendations to help the CBP plan for the future and maximize the effectiveness and openness of its modeling efforts.

The workshop was attended by 54 participants from academic institutions, consulting companies, federal agencies, state agencies, and non-profits. Presentations and open discussion addressed many topics relevant to these broad objectives over the course of two days. The first day focused on broader, big picture issues, while the second day focused on more specific, application-oriented issues. Each morning's session began with a series of plenary talks, followed by an open discussion about topics for the afternoon breakout groups.

Plenary talks on the first day included:

1. Larry Sanford, *Introduction to the Workshop and Charge to Participants*
2. Lewis Linker, *An Overview of Modeling in the CBP: Past, Present, and Future*
3. Mike Haire, *The Looming Challenge of TMDLs*

4. Mike Kemp, *Science Modeling, Engineering Modeling, and Management Needs*
5. Tom Gross, *Building a Chesapeake Research Community through Open Source Modeling*
6. Bill Dennison, *Ecological Forecasting and Integrative Ecosystem Assessment*

Plenary talks on the second day were:

7. Robin Dennis, *New Capabilities in Airshed Modeling*
8. Chris Duffy, Challenges *for Integrated Modeling and Monitoring in the Watershed*
9. Bob Wood, *Challenges for Integrating Monitoring and Modeling in the Estuary*
10. Harry Wang, *Advances in Modeling the Chesapeake Estuary*
11. John Wilkin, *Modeling the Continental Shelf of the Mid-Atlantic Bight*

The plenary talks provided an excellent basis for further discussion and were all well conceived and presented. All but one of the talks are posted on the STAC web site at http://www.chesapeake.org/stac/2010Modeling.html.

For organizing the breakout groups, an attempt was made to follow a modified Open Space Meeting (http://www.openspaceworld.org/) format, in which the participants select discussion topics and parallel groups self-organize. The nomination and selection process for topics took place following the plenary talks. Topics were not limited to those covered in the plenary talks, though the general themes of group discussions on each day followed the general themes of the plenary talks on that day. This was intended to provide an opportunity for all participants to express whatever thoughts they may have had on the future of Modeling in the Chesapeake Bay Program. This idea was only moderately successful, however, such that a small sub-group had to combine disparate ideas into a set of workable topics during the lunch break of the first day. On the second day, a more directed selection of topics was compiled prior to the open discussion, which worked better under the circumstances. The Open Space concept remains an attractive alternative for future workshops, but the logistics of making it work need more thought.

Breakout group topics and leaders are summarized in Table 1. The groups were numbered 1A-D and 2A-C on day 1, and 3A-C and 4A-C on day 2. The deliberations and recommendations of the breakout groups form the primary basis for the conclusions and recommendations of the workshop, as summarized in the following sections. Detailed summaries of the deliberations of each group are provided in The Appendix.

SUMMARY OF DISCUSSION AND RECOMMENDATIONS

The workshop participants generally expressed admiration for CBP modeling efforts to date. The CBP watershed, hydrodynamic, and water quality models in many ways define the state of the art for regulatory modeling, and the CBP is well positioned to address future issues such as TMDLs. The focus of the workshop was how to make CBP modeling even better, how to maximize the utility of all available resources, and how to facilitate community interactions.

Better integration of modeling and monitoring

There are many different ways of combining models and observations, ranging from relatively simple qualitative comparisons to complex, computationally intensive formal procedures for blending model simulations with observations or for adjusting model parameters. The CBP has focused on the use of data for model calibration and validation in hindcast mode, which should

Table 1. Breakout Group Topics and Discussion Leaders

Group	Discussion Leader	Discussion Topic
1A	Denise Breitburg	What is the potential role of modeling in setting restoration goals and informing implementation plans for a restored Bay?
1B	John Klinck	Using models to integrate diverse data for assessment and forecasting
1C	Kevin Sellner	Integrating science modeling, engineering modeling and management needs, the role of community modeling, and how to make it work.
1D	Carl Cerco	Development of long-term modeling strategies for the CBP.
2A	Tom Jordan	What questions need to be addressed in the next generation of CBP models to complete Chesapeake Bay TMDLs and start implementation?
2B	Peter Claggett	How can management modeling deal with uncertainties associated with long term changes in land use, technology, and climate change?
2C	Mike Kemp	Should the CBP encourage development of multiple models for addressing different questions in the Bay and its watershed? How should the complexity and scale of these models be adjusted to address specific questions?
3A	Robin Dennis	Does CBP modeling need improved estimates of meteorological forcings and atmospheric deposition, and if so, how can they be implemented?
3B	Gary Shenk	What future developments are needed for the CBP Watershed Model? What continuing or new data needs should accompany these model developments?
3C	Tom Gross	What future developments are needed for the CBP Hydrodynamic and Water Quality Estuary Models?
4A	Vic Bierman	Should the CBP be involved in forecasting, and if so, for what purposes and on what time scales?
4B	Carl Hershner	What structural changes in the CBP hierarchy (if any) will be required to build and support next generation models and model products?
4C	Carl Cerco	Do CBP Estuarine models need improved ocean boundary conditions? If so, how might this be achieved?

be continued. However, there are additional combinations of models and observations that should be explored that might have significant benefits for the CBP.

1. There would be significant benefits to running a version of the CBP modeling system in near real-time hind cast mode, using observed forcing factors as soon as they are available to update the models and using observed response variables to nudge predictions back towards reality. For example, the model could be used to dynamically interpolate monitoring data (enhancing or replacing the present static interpolator); the model could be used to tune the number, placement and/or frequency of long term monitoring stations; the model could be used to enhance the presentation of information to the public (e.g., as done by the NWS); and the model might be used to enhance or improve seasonal forecasts.
2. Archived data should be used to independently "post-audit" model predictions, which is not currently done. For example, monitoring data from 1995-2004 should be compared to model predictions for the same period, but using the model configuration and model parameters derived from the 1985-1994 calibration, as an independent verification of model performance. Such a post-audit would add credibility to the overall modeling effort and would help to inform ongoing research and development efforts with newer versions of the model.
3. The CBP monitoring program should be enhanced as necessary to better support linkages between water quality and living resource modeling. In order to restore and protect the Chesapeake Bay ecosystem, we need to understand how plant and animal populations are linked to manageable processes, such as land use and fishing. Current monitoring programs of the Chesapeake Bay Program provide both an effective description of the state of the Bay and databases that support water quality modeling activities. However, the existing monitoring program is often insufficient for addressing linkages between water quality and living resources, which will be critically important for restoring the Bay. Potential strategies for modifying or supplementing the current monitoring program include nested hierarchical sampling designs with fine time and space sampling in relatively small areas to address specific mechanisms, processes, or water quality-living resource linkages.
4. A plan for modeling shallow nearshore zones and incorporating SWMP data should be developed, with a timeline and estimates of future resources needed to complete the task. At present, there is a mismatch between CBP modeling plans and the large and growing data base of the CBP Shallow Water Monitoring Program (SWMP). The SWMP is a huge 10-20 year investment in shallow water monitoring for ascertaining water quality criteria attainment, with collections across >60 Bay segments. Models of the shallow littoral zone are equally important for extrapolating in time and space and predicting the effects of management actions, but there are no present plans within the CBP for explicit modeling of these shallow nearshore areas. Development of such models with appropriate use of the SWMP data is essential for the long term goals of the CBP, and should be pursued actively. Shallow water modeling may be important for the SWMP as well, since models often identify sensitivities or missing factors that need to be explored further in the field. Recent attempts to incorporate subgrid depth partitioning for modeling SAV in nearshore cells of the water quality model are promising, and should be expanded if successful. Complementary, nested nearshore model(s) to interact with the large scale model for specific problems may also be needed.

Forecasting
The CBP should not attempt regular short term (days to weeks) forecasts, which are beyond its purview. However, running a version of the CBP modeling system in near-real time hindcast mode would enhance the CBP's ability to produce seasonal ecological forecasts by allowing forward projection of different seasonal scenarios, starting with present conditions. CBP models should also be used to investigate (forecast) time lags between management actions and water quality response. Most importantly, CBP models can and should be used to explore the impacts of longer term changes in population, land use, and/or climate.

While climate change will certainly be a major factor in the long term, in the intermediate 20-30 year time frame population changes and land use changes will be the major drivers of changes in the Chesapeake Watershed and Estuary. Thus, investigations of changes in land use and loading due to population growth and development should be given the highest priority. Economic analyses should be incorporated into these models. Because land use planning is local, CBP land use change models should be provided as tools to GIS staff and planners within local governments. Land use and land cover change models should be actively used to inform local communities where to grow and where not to grow rather than just passively used to inform jurisdictions that their current strategies will or will not achieve anticipated nutrient reductions.

TMDLs
Total Maximum Daily Loads (TMDLs) are currently being developed for local areas within the Bay watershed and tributaries, and will almost certainly be required for specific pollutants in broader reaches of the Bay after 2010. Relative to many other jurisdictions in the US, the CBP and local and state governments around the Bay are well-positioned to develop TMDLS, but there are several actions the CBP can take now that will facilitate TMDL development in the future. Toxics (metals and PCBs), pH, and pathogens are not computed in the present CBP models. It would be helpful to the states to incorporate these remaining TMDL pollutants into the models, compiling necessary loadings in the process. More importantly, development of a nested modeling capability on some level is critical for addressing local TMDLs at scales smaller than those resolved by the CBP models. Ideally, the local modeling studies would be able to use the same modeling framework as the larger scale CBP model. However, provision of archived predictions at the boundaries of local domains and local forcing factors (e.g., insolation, wind, rainfall, etc.) over the domain are most important. This would avoid the need to run the entire modeling system for each local TMDL.

Multiple Models
Multiple models of the same phenomenon or situation are routinely used in weather and climate forecasting to provide estimates of prediction uncertainty. When different models agree on a prediction, confidence in that prediction is much greater, and vice versa. In addition, forcing a single model towards greater and greater complexity in order to resolve all scales and all processes can be very inefficient for addressing specific issues. For these reasons, a large number of the workshop participants felt that the CBP should move towards the use of multiple models. Within the suite of models developed, a range of scales, as well as a range of model and food web complexities should be included so that the consequences and benefits of scale and simplification can be evaluated. In addition to multiple models that allow specific issues to be

approached from a variety of perspectives, this group envisioned a suite of restoration models including models of climate change, economics and human behavior, watershed processes, atmospheric processes, coastal ocean processes, and estuarine processes. Even if the CBP decides to continue use of a single integrated modeling system for making management decisions, the value of and need for an ensemble of smaller simpler models for understanding and diagnosing dynamic behavior of various components of the integrated system remain.

However, other workshop participants felt that, while there were clear advantages to multiple models from a scientific or forecasting point of view, from a regulatory and practical point of view multiple models are not appropriate for the CBP. A succinct statement of this opinion is as follows, focusing specifically on the TMDL issue: If there are multiple models for a TMDL then court cases are invited. It can be a very contentious process. Another issue is time. TMDLs are almost always deadline driven, usually by agreements between the courts and the States. Development of multiple models for TMDLs thus is often impractical and potentially counterproductive from a regulatory point of view. A third issue is cost. It is more expensive to develop and analyze multiple models than to focus on a single approach.

Another aspect of multiple model development is programmatic. The CBP is so completely invested in utilization of the existing watershed/water quality model package, that there is little probability of significant commitment to development of alternatives in the near term. In the absence of Bay Program partner dissatisfaction with the existing models' performance, there is really little motivation for investment in alternatives.

In the end, workshop participants did not reach a consensus on the issue of multiple models. The issue merits re-examination in a more focused forum. Alternate approaches to resolving the multiple model issue might also be explored. For example, parallel development and phasing in of new, modular hydrodynamic, water quality, and watershed models in the 2010-2015 timeframe would allow for old-new model comparisons while both were available and operational. In addition, increased ease of access to CBP model codes, forcing, loading, and predictions would enable other modelers in the scientific and forecasting communities to explore multiple model comparisons on their own, with encouragement and modest support from the CBP.

Accessibility of CBP Models and Model Data
While there was no consensus on the use of multiple models within the CBP, there was an overwhelming consensus that existing CBP model codes, model predictions, model forcing data, and model loading data should be made more accessible to the Chesapeake Bay modeling community. Aspects of this recommendation appear in the notes from many discussion groups. Three related types of accessibility were encouraged:

1. Better documentation and improved access to model codes. One group noted that the CBP water quality and hydrodynamic models are cumbersome and are not easily viewed, understood, or modified by non-CBP programmers, which is a major impediment to their adoption, use, and exploration by other modelers. Another group noted that ease of use of the watershed model is becoming increasingly desirable as local TMDLs are being developed, because it would be logistically simpler and much better in a regulatory sense to use the same codes at both large and small scales.

2. A nested modeling capability. Models developed to address local issues often need much higher resolution than is practical for models of an entire region. Development of the capability to nest higher resolution sub-domains within the coarser resolution large scale CBP models would enable exploration of local issues without modifying the large scale grid. It would also avoid the necessity of running the large scale model repeatedly, as long as feedbacks from the small scale to the large scale were not required.
3. Ready access to CBP model predictions, model forcing data, and model loading data. Access to archived CBP model information for calibrated time periods would alleviate some of the short-term pressure to release or support the codes themselves, or to include nesting capabilities within the CBP models. Modelers focusing on local issues could then use CBP model predictions at the edges of their local domains as boundary conditions, and could use appropriately scaled forcing and loading as needed. Developers of alternate models could use the same forcing, boundary conditions, and loading to drive their models, and could compare their results to CBP model predictions with greater confidence as a result. Scientists and managers could "mine" the model predictions data base to explore important relationships and statistics that are beyond the scope of the CBP modeling mandate, or to compare to independently collected data.

Increased accessibility will facilitate interactions between management and research modelers, and potentially increase the 'exercising' of CBP models (sensitivity studies, parameterization studies, etc.). The above goals will be facilitated if the CBP works more closely with the Chesapeake Community Modeling Program.

Model Complexity

Over the years, CBP models have become increasingly complex in terms of both the number of state variables and processes represented, and spatial resolution. Workshop participants generally recognized that this trend toward increasing complexity has occurred largely because of increasing computational capabilities. In a practical sense, model complexity and resolution are limited largely by what can be calculated overnight on existing computer platforms, so that there is a direct correlation between model complexity and computational capabilities. Participants also recognized that the trends towards increasing complexity and spatial resolution are likely to continue as long as computing power continues to increase.

However, the natural push towards more complexity and greater resolution must be tempered by the need to explore parameter sensitivities, consider model uncertainties, and optimize model precision. Increasing model complexity generally adds realism to a model structure. However, increased complexity tends to reduce model generality (i.e., its applicability to a broad range of situations). A guiding rule of model development is that, while systematic bias (lack of realism) tends to decline with increasing complexity, measurement error (e.g., parameter uncertainty) tends to increase and propagate upward as model complexity is increased. Thus, maximum model precision (skill at simulating observed dynamics) tends to occur at intermediate model complexity. To some extent, more powerful computing capabilities would be better utilized in exploring these issues, rather than further increasing complexity and resolution.

Restoring Living Resources

Restoring living resources is the ultimate goal of the CBP, beyond improving water quality in the watershed and the estuary. In their present forms, CBP models are only marginally helpful in this regard. Interactions between water quality and stationary benthic resources such as oysters, SAV, and microphytobenthos are now included in the water quality model, though population dynamics effects such as recruitment, interspecies competition, and mortality are not well represented at present. Spatially aggregated ecosystem models with interactions between multiple trophic levels, including fish, are coming online in the CBP, but linkages between these models and the circulation and water quality models are at best tentative. Living resource modeling must be given the same level of attention and support as watershed and water quality modeling, and the programs must be integrated.

The next big challenge for CBP modeling is to model not only a restored Chesapeake Bay, but the path by which we arrive there. Because the same trajectory followed during system degradation may not be followed during system recovery, modeling a restored Bay may not be the same as modeling Bay restoration. Beyond threshold levels of change, ecosystems may respond differently to restoration efforts as well as to continued stress from human activities, and may provide qualitatively as well as quantitatively different ecological services. Feedback mechanisms and nonlinear responses often characterize these thresholds of change, called “tipping points”, which need to be both better understood and better modeled. It is quite likely that CBP models will need to be able to predict ecosystem tipping points before they can predict ecosystem recovery trajectories.

Improvements to the Watershed model

Workshop participants thought that the next generation of the watershed model, to be developed circa 2010-2015, should be modular with the ability to communicate with other models and data sources through standardized formats. The modularity allows for the ability to test different modules and data sets, and to work on many scales. For example, a modular design would allow a user to swap out the HSPF agricultural simulation for a SWAT agricultural simulation or possibly the entire groundwater simulation for a more explicit one. Localities would also be able to use the model for small-scale water quality assessments more easily, by swapping out Bay-scale model segments for a distributed local model in a particular geographic area. To accomplish this modularity, standardized data models and formats would have to be agreed upon prior to starting work. These formats would ideally conform to national standard data models, such as ArcHydro.

While there are many needs for improved process simulation in watershed model(s), priority issues for the next CBP watershed model include improved simulation of the transport of sediments and phosphorous, the impact of denitrification on nitrogen transport and occurrence, ground water and associated nutrient transport, and the effectiveness of management actions in different landscape settings. Improved information on these processes is needed, especially at finer scales. Integrated observing systems are recommended, where all of these data are collected in small watersheds/stream reaches that represent different landscape settings.

Improvements to the Hydrodynamic and Water Quality models

Workshop participants generally acknowledged that the present CBP hydrodynamic and water quality models are sufficient to meet the primary water quality management goals of the CBP, especially after recent and ongoing improvements have been completed. However, a significant number of participants also thought that the present model codes are overly difficult to access, understand, modify, or utilize, which has hampered their adoption by other modelers. As a result, the models have been under-utilized and under-exercised, especially for conducting sensitivity and mass balance analyses, determination of prediction uncertainty, and post-auditing. Their complexity also hinders the development of alternative process modules and nesting capabilities, which likely will be needed to address local-scale TMDLs. In addition, it would be useful to apply formal parameter optimization methods for model components toward the goal of improving model performance and making it more objective.

A significant fraction of the workshop participants, though not enough to proclaim a consensus, recommended the future, parallel development of a next generation, state-of-the-art hydrodynamic and water quality modeling system. This new modeling system would be fully complementary and compatible with the current CBP WQ model, which it would someday replace (e.g., by 2015). The new modeling effort should adopt modern modular programming practices and the code should be open source. This approach will ensure the transparency needed to engage a much broader critical user group. It will also ensure much more rapid and robust model development and evolution. The development of this new modeling system could be based upon existing, readily accessible modular models such as ROMS or ELCIRC.

Whether a new hydrodynamic and water quality modeling system is developed or the present system simply continues to evolve, the group recommended that several new processes or issues should be addressed during the next 5-10 years. These include:

- Incorporation of additional living resources component models, including higher trophic levels, or construction of workable links to separate living resources models.
- Incorporation of living resource feedback mechanisms, e.g., the effects of marsh restoration or top-down foodweb control on water quality.
- Development of modeling capabilities for toxics, pH, and water clarity.
- Development of strategies to incorporate shallow water (< 5' depth) processes (or their effects) into the system-wide model, as well as data from the ongoing shallow-water monitoring program.
- Investigation of the effects of processes outside the Bay mouth on internal Bay processes.

Improved ocean boundary conditions

There was no consensus on the potential importance of presently unrepresented continental shelf processes on circulation, water quality, or living resources within the Bay. Absent this consensus, the group focused on steps the Bay Program could take to investigate and establish the importance, if any, of processes outside the Bay mouth. The most significant of these centered on questions of nitrogen variability and its causes in the nearshore coastal ocean, and associated variability of nitrogen transport from the continental shelf into the Bay. Fisheries recruitment and migration issues were also highlighted. Over the long term, the CBP should consider coupling of the current continental shelf ROMS model and the CBP hydrodynamic and water quality models. This would require two-way nesting of model grids.

Improved estimates of meteorological forcing and atmospheric deposition

Ongoing efforts to integrate regional and national air quality and atmospheric deposition models with CBP models are commendable and should be continued. An additional, potentially valuable collaboration that should be pursued is with NOAA/NWS weather modelers. Recently improved capabilities for nested mesoscale weather modeling could provide greatly improved wind stress fields for the Bay hydrodynamic model. Resolving the wind field at approximately 1-2 km would improve the model's ability to simulate Bay breezes, which can have important local impacts on circulation and water quality. In addition, the wave modeling capability being added to the hydrodynamic model would greatly benefit from improved wind fields over water, which can be quite different from those measured at land-based weather stations. Meteorological models of winds over and around the Bay would benefit from this coupling, as well. While reconstruction of mesoscale wind patterns may be possible for hindcast modeling, high resolution wind analyses archived after 2004 are readily accessible. As implementation of national air quality standards decreases the influence of deposition from remote sources, identification and control of local sources will become both feasible and important. Increased resolution of local wind fields will be important in this effort.

Structural changes in the CBP for implementation of these recommendations
In general, the present structure of the CBP modeling groups and advisory committees appears to work reasonably well and will likely continue to serve in the foreseeable future. There were, however, two areas identified in which significant change may be required.

1. Past interactions between CBP modelers and the research community have primarily been *ad hoc* for specific management identified needs. Although this has resulted in effective development of several subcomponents of the model via input from specific researchers (e.g., SAV, sediment diagenesis, benthic invertebrates, oyster filtration), the larger community has generally not been involved. This approach has also perpetuated development of a single model of ever increasing complexity, adding new processes and finer resolution on a piece-by-piece basis. The recommended CBP efforts to increase accessibility to model codes, predictions, and input data fields will engage more of the community. Transitioning to modular, open source models will also let CBP modelers tap into the considerable community expertise that supports these models. These efforts will proceed more efficiently and effectively if the CBP works with existing regional consortia such as the Chesapeake Community Modeling Program. In addition, it is likely that some investment of CBP funds will be needed to drive future inclusion of researcher modeling in CBP efforts. The CBP should plan for this commitment beyond 2010.
2. In the future, time-critical management demands on CBP modelers should be balanced with strategic investment needs. Examples of such needs are documentation of model computer codes, experimental data, and pre- and post-processing software, and community sharing of these resources in user-friendly and accessible forms. Many of the other recommendations of this report may also be considered strategic investments. To address these recommendations and other strategic needs that will appear in the future, it is recommended that the CBP allocate some percentage of their annual modeling budget and modelers' time specifically for strategic model development, documentation, dissemination, and investigation. By setting aside these resources apart from continuing, pressing management needs, the CBP will go a long way towards ensuring the future viability of its modeling programs.

CONCLUSIONS

In conclusion, all participants thought that the workshop was very successful, bringing together representatives of almost all parties interested in modeling in the Chesapeake Bay and its watershed and airshed. Presentations were informative and provocative, plenary discussions were open and inclusive, and working group breakout sessions were lively and balanced.

There were several recurring themes and areas of clear consensus. The strongest was that CBP model codes, model forcing data, model loading data, and model predictions should be made more accessible to the Chesapeake Bay modeling community. Access to the model input data sets, loadings and predictions would facilitate addressing many of the other issues raised in the workshop, even if it is done by investigators funded by resources outside the CBP. Access to the codes themselves would facilitate development of nested modeling capabilities, a need voiced by several working groups. More attention needs to be paid to documentation, independent verification, and sensitivity testing, as well. These issues were deemed important enough to recommend that the CBP identify specific budget resources and time for addressing them.

There was also clear consensus that living resources modeling should be a very high priority, not only for analysis of past and present conditions, but also for predicting both a restored Bay and the trajectory by which it may be reached. There was a consensus that more effective interactions between monitoring and modeling were needed in specific areas, some involving new modeling efforts and some involving changes to the monitoring programs to better support modeling needs. A clear vision for development of the next major version of the watershed model was presented, interactions with meteorological and atmospheric transport models were encouraged, and modeling the effects of long term changes in population, land use, and/or climate change was strongly recommended.

There were also several unresolved issues from the workshop. These should be considered further in a series of focused workshops, communications, or other forums, working toward consensus recommendations on each issue. These issues include: (1) how to implement living resources models and coordinate with other modeling efforts, (2) whether and how to support development of multiple models, (3) how to integrate modeling and monitoring more effectively (especially for living resources and shallow water environments), and (4) establishing a consensus vision for the future of the hydrodynamic and water quality models.

APPENDIX A

WORKSHOP ATTENDEES LIST

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APPENDIX B

WORKSHOP AGENDA

January 17, 2006 – THE BIG PICTURE

8:30 Gathering and Continental Breakfast (provided)

9:00 – 9:20 Greeting and Introduction to the workshop – Larry Sanford

9:20 – 11:15 Plenary talks and discussion – a series of 20 min talks, moderated by Larry Sanford, with a 15 min break at 10:20

An overview of modeling in the CBP, past, present, and future – Lewis Linker
The looming challenge of TMDLs – Mike Haire
Science Modeling, Engineering Modeling, and Management Needs –Mike Kemp
The Chesapeake Community Modeling Program – Tom Gross
Ecological Forecasting and Integrative Ecosystem Assessment – Bill Dennison

11:15 – 12:00 Nomination of and Voting on Discussion Group Topics - Ben Hilliard

12:00 - 12:45 Lunch (provided)

12:45 –3:15 Discussion Groups (up to 3 groups at a time, up to 3 separate time slots, for a total of 3-9 discussion groups)

3:15 – 3:30 Break

3:30 – 5:00 Discussion Group reports and Plenary Discussion, moderated by Larry Sanford

5:00 – adjourn

September 18, 2006 – THE DIFFERENT 'SHEDS

8:30 Gathering and Continental Breakfast (provided)

9:00 – 9:20 Summary of First Day's Proceedings and Charge for 2nd day – Tom Gross

9:20 – 11:15 Plenary talks and discussion – a series of 20 min talks, moderated by Tom Gross, with a 15 min break at 10:20

New capabilities of macroscale airshed models – Robin Dennis
Challenges for integrating monitoring and modeling in the watershed – Chris Duffy
Challenges for integrating monitoring and modeling in the estuary – Bob Wood
Advances in the Modeling the Chesapeake Estuary – Harry Wang
Modeling the Continental Shelf of the Mid-Atlantic Bight – John Wilkin

11:15 – 12:00	Nomination and Voting on Discussion Group Topics – Ben Hilliard
12:00 - 12:45	Lunch (provided)
12:45 –3:15	Discussion Groups (up to 3 groups at a time, up to 3 separate time slots, for a total of 3-9 discussion groups)
3:15 – 3:30	Break
3:30 – 5:00	Discussion Group reports and Plenary Discussion, moderated by Tom Gross
5:00 –	adjourn except for steering committee and discussion group leaders/reporters
5:00 – 6:00	Meeting of steering committee and discussion group leaders/reporters, decide on report responsibilities and writing assignments
6:00 – 8:00	Dinner for steering committee and discussion group leaders/reporters (provided)

APPENDIX C

WORKSHOP BREAKOUT SESSION REPORTS

RECOMMENDATIONS OF BREAKOUT GROUP 1A: What is the potential role of modeling in setting restoration goals and informing implementation plans for a restored Bay?

Participants: Denise Breitburg, Gary Shenk, Larry Sanford, Tom Jordan, Carl Hershner, Arthur Butt, Robert Wood, Xinsheng Zang

The breakout group was in agreement that modeling can play a critical role in predicting the benefits of a variety of restoration strategies and testing the results of alternate restoration and management actions. In order to be most useful, both direct effects of living resources management, and indirect effects mediated through human influence on the environment (water quality, habitat and climate) should be included.

The most valuable application of modeling for restoration is to test the effects of regulations and human behavior on both the stressors reaching the Bay and its watershed, and on the consequences to water quality and living resources. Coupled models of drivers (human behavior, including economics) and outcomes are critical tools that can help predict the likelihood of achieving quantitative water quality criteria as well as more qualitative goals of sustainable populations of living resources and fisheries. Optimizing our ability to reach multiple goals and testing the relative efficacy of alternative management approaches requires coupled, appropriately scaled models. Economic as well as ecological costs and benefits of management strategies and environmental degradation should be modeled, with a strong emphasis on spatially explicit modeling of both mechanisms and outcomes.

The need to predict and understand tipping points was highlighted repeatedly. To be useful, models will need to include appropriate feedback mechanisms and have the ability to predict nonlinear responses. Beyond threshold levels of change, systems may respond differently to restoration efforts as well as to continued stress from human activities, and may provide qualitatively as well as quantitatively different ecological services. Because the same trajectory followed during system degradation may not be available or followed during system recovery (i.e., hysteresis may be an important feature processes of interest), modeling a restored Bay may not be the same as modeling Bay restoration. It will be important to identify the processes that need to be incorporated in order to capture potential restoration trajectories.

The group strongly endorsed the use of multiple models that focus on temporal and spatial scales appropriate to the specific questions asked. Within the suite of models developed, a range of scales, as well as a range of model and food web complexities should be included so that the consequences and benefits of scale and simplification can be evaluated. Complex models inclusive of a variety of physical and biotic processes should be developed in coordination with, and should complement simpler targeted models. In addition to multiple models that allow specific issues to be approached from a variety of perspectives, the group envisioned a suite of restoration models including models of climate change, economics and human behavior, watershed processes, atmospheric processes, and important features of the coastal ocean, as well as Chesapeake Bay, itself.

Finally, a strong emphasis was placed on validating model predictions and mechanisms with data. Both field measurements and experimental studies will be required.

***RECOMMENDATIONS OF BREAKOUT GROUP 1B*: Using models to integrate diverse data for assessment and forecasting.**

Participants: John Klinck, Ming Li, Louis Linker, Robin Dennis, Marjy Fredrichs, Ping Wang, Liejun Zhong, John Billet, Steve Rogowski, Vic Berman, Jian Shen, John Wilkin, Brendan Peloquin, Bill Boicourt, Xinsheng Zhang, Carey Graff, Bill Dennison

The discussion ranged over topics of how models and observations are blended, how this information is used, who would be interested in these results and how a customer base can be developed for these results.

Several types of products were distinguished. Observations are typically information over time from a sensor (e.g., water level) or an area measurement at a fixed time (e.g., surface temperature from satellite). Analyses are products developed from observations that involve interpolation or extrapolation based on empirical rules. Data assimilation blends observations with a numerical model based on conservation rules. Forecast models use only the model dynamics to estimate the future model state. Process studies also use forecast models to project future model states under the influence of initial and forcing conditions. Model results can also be used to evaluate observation or forecast uncertainty.

Models results and observations are used for a variety of purposes. Observations verify model veracity. Verified models can make predictions over weeks or seasons. Model simulations can identify poorly understood or missing processes. Various scenarios of changes in climate or other environmental conditions (e.g., nutrient loading) can be tested as to their effect on various part of the ecosystem. Model results can also be used to analyze processes and determine simpler relationships between parts of the natural system.

Formal mathematical procedures are available for blending a model simulation with observations or for adjusting model parameters to better compare to observations. These methods are complex and require considerable computer resources.

All of these products are used to evaluate ecological or physical processes or to design more efficient sampling procedures. However, model or analysis results need to be put in a form that is accessible to the general public or that provide specific information of public interest. Possible products are forecasts of harmful algal blooms, surface waves, water clarity, water temperature and the like.

The National Weather Service was identified as an activity with non-technical products of great interest to the general public. The Bay program should use public outreach or focus groups to develop similar products in response to customer needs. These products should be made available to media outlets or web sites for greater distribution. Furthermore, NWS stores all of its products for later use by researchers. The Bay program should make a similar effort to make observations and analyses available to the research community.

***RECOMMENDATIONS OF BREAKOUT GROUP 1C*: Integrating science modeling, engineering modeling and management needs; the role of community modeling and how to make it work.**

Participants: Maio-Li Chang, Jim Collier, Tom Gross, Raleigh Hood, Mike Kemp, Dave Potsiadlo, Kevin Sellner, Howard Townsend

Major Points:

1) History of CBP model development

To a large extent, interactions with research community have been ad hoc for management-identified needs/elements for the CBP model. Although this has resulted in effective development of several subcomponents of the model via input from specific researchers (e.g., SAV, sediment diagenesis, benthic invertebrates, oyster filtration), the larger community has generally not been involved. This approach has also perpetuated development of a single model of ever increasing complexity. These problems are exacerbated by the fact that there are few funding agencies that support scientific involvement in management-identified modeling projects. There is no long-term funding for the modeling community to develop and apply models for management. Therefore, it is likely that management funds and requests will be needed to drive future inclusion of researcher modeling in CBP efforts. CBP should plan for this commitment beyond 2010.

2) Facilitating management and research collaboration

For effective researcher involvement in management-focused modeling, there must be open dialog and communication between researchers and managers. Researchers must seek and understand the details and realities of management needs, and managers must understand the strengths and limitations of alternative models and how current scientific understanding and approaches can improve model performance. There are many alternative modeling approaches, and not all are appropriate for addressing a specific management problem or question.

3) The CBP needs to develop alternative models for the future

The CBP water quality and physical circulation models are cumbersome and are not easily viewed, understood, nor modified by non-CBP programmers. This "opacity" is a major impediment to broad scrutiny, use, and adoption of the CBP codes by other modelers including those in the research community. Moreover, the relatively inflexible structure of the CBP circulation model is a significant impediment to application at tributary scales for more local management problems. At present, to address local needs, the entire Bay model must be run which constitutes a substantial computational burden. It is important to develop a modeling capability that enables local explorations or tributary analyses. This implies a modular capacity and/or grid nesting capability that is not available in the current CBP model. This working group unanimously recommends that a complementary modeling effort should be set up and funded in parallel with the current CBP modeling effort to begin the development of the next generation, state-of-the-art modeling system for application to both science and management questions in Chesapeake Bay. The idea is that this new modeling system would be fully complementary and compatible with the current CBP WQ model, which it could someday replace (e.g., by 2015).

This complementary modeling effort should adopt modern modular programming practices and the code should be open source. This approach will ensure the transparency needed to engage a much broader critical user group. It will also ensure much more rapid and robust model development and evolution. Modularity provides a starting point for development of new models applied to new or local applications. The current CBP model and its subcomponents are not easily disaggregated or scaled down to provide either local application capability or employment of alternative model formulations. The development of this new modeling system can be based upon existing, readily accessible modular models like ROMS; potential models to be explored include ROMS, ELCIRC, among others. This alternative model system should be implemented, developed, and run in parallel with the current CBP models. It is unclear who would be the caretaker of a second or third Bay circulation or Water quality model. It is envisioned, however, that WES and other CBP management modelers would have these models available for use in appropriate management applications. In the near term, this work might be focused more on smaller tributary systems and application to local problems, especially as they relate to the development of TMDLs for Chesapeake Bay.

4) Using multiple models to inform management decisions

The use of multiple models for increasing confidence in model output is strongly recommended. In principle, multiple models would expand the scope of research and management modeling applications. In global change research and hurricane forecast modeling, this approach is referred to as an "ensemble" modeling. Using multiple models allows managers to assess the confidence limits of their model predictions, i.e., as defined by the envelope of solutions, and it also allows modelers to consider if a particular model is producing outlier results, which might be incorrect, in either case identifying further focus and analysis. Continued research and analysis of model output by research (and management) modelers will ensure progress and improvement over time in model development.

This working group, however, recognizes that managers have the real-world constraint that they must make decisions in a well-defined time frame. Moreover, they have the real-world dilemma that having different answers from multiple models enhances the potential for litigation. Indeed, in the near term, one model's output may have to be selected for the decision-making process. However, a post-decision request to the scientists for interpreting model output and assessing why different model solutions diverge should be encouraged to help identify applications where some models are more appropriate than others. Finally, we note that using multiple models will ultimately increase confidence, but this does not eliminate the absolute necessity for routine model error estimations and skill assessment as products for all CBP model runs.

***RECOMMENDATIONS OF BREAKOUT GROUP 1D*: Development of long-term modeling strategies for the CBP.**

<u>Participants</u>: Carl Cerco, others

Where do we want to be in 2015? What will the role of modeling be?

This session was an "eye-opener" for the moderator. His expectation was that the session would revolve around strategies for the water quality model of the Bay and tributaries. Instead the session focused almost exclusively on the watershed model. Prevalent themes were

- Make the watershed model easier to use.
- Make the watershed model applicable on the local scale on which plans are developed and management is implemented.

There was also some expression of the idea that multiple models should be available. Either to encourage competition or because one tool cannot do it all. That is, a model appropriate to the entire Chesapeake Bay watershed may not incorporate processes that are significant on the local scale. The sentiment for multiple models was not universal, however. Ease of use and local applicability were more in demand.

Participants were asked to respond to three questions. The questions and responses are summarized below.

Question 1. Provide one idea you would like to see in the Bay Model

- Watershed model that accurately represents transport of nutrients and sediments.
- Better description of small-scale processes such as denitrification at the soil-stream interface.
- Watershed model simulations at the "community association" scale so that community organizations can use the model.
- A watershed model appropriate for multiple scales.
- A suite of model tools with different complexities to suit different uses.
- A watershed model that functions as a "decision support" tool with a user interface that allows the user to select the right tool.
- Ability to model water quality impairments for the Bay by loading source category.
- Obtain a better idea of cost/benefit ratios for watershed management. What are effects and benefits of voluntary versus regulatory action?

Question 2. What should the Bay Program do to implement your idea?

- Implement "continuous quality improvement" in forums similar to this one.
- Determine the state of the art in watershed modeling.
- Identify current data gaps and model limitations. Issue "RFP's" to address limitations.
- Undertake a formal evaluation of alternatives to current models.
- Survey managers and ask them to describe what decision-making tools they want.

- Assess available data to improve small-scale processes. Take steps to fill in data gaps.
- Compile information on "non-traditional" point sources e.g. combined sewer overflows.

Question 3. The Bay Program will start a program to collect one piece of data. What should they measure?

- Sediment delivery in small watersheds.
- Selective implementation of four watershed test beds for water quantity, dissolved substances, and sediment.
- Nitrate concentrations in the shallow aquifer across the entire Chesapeake Bay watershed.
- More data on discharges from coastal plain watersheds, especially urban areas.
- Measure multiple species of nitrogen, phosphorus, and carbon loading.
- High-resolution land use and cover change.
- More detailed atmospheric deposition data.

The Water Quality Model

Several participants and the moderator were interested in the receiving water quality model. Ideas for improvements included

- Incorporate models of higher trophic levels. Provide a multi-species fisheries management component to the water quality model.
- Incorporate living-resource feedback mechanisms. e.g. the effect of marsh restoration on water quality.
- Develop ability to address potential TMDL's aimed at toxics, pH, and water clarity.
- Collect fisheries-independent fish population data across the tidal tributaries for 25 species.
- Provide a consistent Bay-wide estimate of the current oyster population.
- Develop a strategy to incorporate ongoing shallow-water monitoring program into system-wide model.
- Investigate effect of processes outside the Bay mouth on internal Bay processes.

***RECOMMENDATIONS OF BREAKOUT GROUP 2A*: What questions need to be addressed in the next generation of CBP models to complete Chesapeake Bay TMDLs and start implementation?**

Participants: Tom Jordan, others

Because TMDLs can be developed for water bodies of various sizes, the models need to be as spatially detailed as we can manage. The spatial scale of the current water quality model under development is on the order of 57,000 cells, and that's enough for the water quality standards of DO, clarity, and chlorophyll, but we need more for the PCB TMDL in Maryland, Virginia, and the District. For the Potomac PCB TMDL, the current model can provide boundary conditions, but it was not detailed enough to have the Virginia embayments and that's not sufficient for the TMDL decisions that are needed.

Toxics, pH, PCBs and pathogens are not computed in the CBP models. These need to be computed in the CB model in order for the States to complete their TMDL efficiently. The Anacostia is an example where one TMDL model is used for CSOs, and another TMDL model is used for storm water, but decisions in the CSO TMDL affect the storm water TMDL, and the other way around. One affects the other. PCBs are related to sediment, and sediment loads influence PCB dynamics and a water body's assimilative capacity for PCBs.

It would be better to have all the TMDLs planning decisions working from the same model so we could see the tradeoffs among the different management solutions. The Chesapeake Bay models don't recognize TMDLs underway now in the watershed. For example, what if acid mine drainage was controlled for a pH TMDL? Then more phosphorus is released in that watershed as the pH drops and that in turn affects the nutrient TMDL. This is not efficient management decision-making. We need to get away from a single solution approach.

We may use some modular methods to simulate what's needed for these TMDLs. For example, we could use the CB models with a pathogen module developed throughout the model domain, but only turned on where needed. Another approach we could use would be a nested approach for spatial detail where needed, like in the Virginia embayments for PCBs

A good start would be to have the Chesapeake Models compute the remaining TMDL pollutants, and to get the all the loading needed. Loads from all CSOs would be needed, but we don't have CSO loads from Harrisburg, and we don't have it from Richmond, and not from any other city other than DC. Other needs are a good groundwater module and a good coastal model too. With the coastal model we'd need to be sure we add the atmospheric deposition loads of Hg, NOx, and acid equivalents, just as we need them for the Bay tidal waters and for the watershed. Models need to connect atmospheric sources to receptors.

In the end, TMDLs are regulatory, and if there are multiple models for a TMDL then court cases are invited. It can be a very contentious process. Another issue is time. The TMDLs are almost always deadline driven, usually with deadline agreements between the courts and the States which is another problem for using multiple models for TMDLs.

The group briefly discussed modeling needs to support implementation of practices to achieve TMDL objectives, especially in controlling NPS pollution. Models are needed to support decisions about investments in BMPs (e.g. riparian buffers vs. cover crops) to control NPS discharges. However, it was noted that there are currently economic, social, and legal barriers to targeting investments in BMPs for NPS pollution. Also, some felt that targeting tools are now available, while others felt that more model development was needed to support BMP targeting.

Economic models may also be needed to determine the economic feasibility of TMDLs, to analyze costs and benefits of alternate scenarios, and project future land uses.

***RECOMMENDATIONS OF BREAKOUT GROUP 2B*: How can management modeling deal with uncertainties associated with long term changes in land use, technology, and climate change?**

Participants: Robin Dennis, Rich Batiuk, Peter Claggett, Kevin Sellner, Bill Dennison, Bob Wood, Carl Hershner

This discussion focused on how land use and land cover change and climate change can be best incorporated into Chesapeake Bay community modeling efforts. While all acknowledged that climate change is a very important long term variable for evaluating future watershed and Bay health, it was viewed as a second order parameter in the 20-30 year timeframe compared to land use and land cover changes. Complex interactions exist between land use and water and air quality. Thresholds and other non-linear water quality and hydrologic responses to land use change occur which reinforce the need to prioritize the incorporation of land use change into both watershed and atmospheric deposition modeling efforts. Furthermore, land cover types like impervious surfaces impact the delivery ratios of nutrients to the Bay. Impervious surfaces are particularly relevant to Bay restoration since over the 1990's impervious surfaces increased 40% compared to only an 8% increase in population.

Climate should not be ignored. Feedbacks exist between land use and climate. Examples include changes in hazard risks due to an increased frequency and severity of storm events, changes in the effectiveness of Best Management Practices and land suitability for particular agricultural commodities due to a future warmer and wetter climate, and change in local evapotranspiration and precipitation rates around urbanizing areas. Bob Howarth has stated that N export will increase by 17% on average by the year 2030 due to climate change indicating that future year Phase 5 Watershed Model runs should be based on a wetter than average hydrologic year.

Land use and land cover change models should be actively used to inform local communities where to grow and where not to grow rather than just passively used to inform jurisdictions that their current strategies will or will not achieve anticipated nutrient reductions. The models should also reflect how unplanned development impacts water quality and how local actions like Low Impact Development can make a difference. Economic analyses should be incorporated into land change models (e.g., escrow accounts could be developed to deal with future nutrient reductions). Because land use planning is local, our land use change models should be provided as tools to GIS staff and planners within local governments.

To further educate the public and decisionmakers, we need a tool like a "SIMChesapeakeBay" model which could be used to examine the cumulative impacts of individual decisions on the ecosystem and to test the effects of economic and regulatory controls for managing development. We also need well accepted ecosystem/quality of life indices to provide alternatives to standard economic development indices.

***RECOMMENDATIONS OF BREAKOUT GROUP 2C*: Should the CBP encourage development of multiple models for addressing different questions in the Bay and its watershed? How should the complexity and scale of these models be adjusted to address specific questions?**

<u>Participants</u>: Mike Kemp, others

Model Complexity

(1) The maximum complexity (number of variables) for any model is constrained by the availability of data. Formal methods (including adjoint data assimilation) can be used to determine the maximum number of variables that are supportable by existing data bases for a given model.

(2) These methods can also be used for parameter optimization (selecting sets of parameter values that maximize the fit between model and observation), and for analysis of model uncertainty and sensitivity. It is advantageous to apply such formal methods for parameter selection because this process reduces the subjectivity in model building, and it helps the modeler to achieve the best model-data fit efficiently. However, there are limitations.

(3) Although parameter optimization methods provide an objective approach to model building, this approach is complicated in estuaries with strong environmental gradients, many of which follow the estuarine salinity distribution. In this case, it may be logical to apply different coefficients in different regions to represent real differences in chemistry and organism physiology for the same biogeochemical processes.

(4) Formal parameter optimization methods are limited in their ability to improve model skill, because the selection of the model's functional relationships tends to be a subjective procedure. Actual model equations are selected from among a range of possible conventional and non-conventional formulations. Often more than one formulation is defensible based on data and experience. There is no formal process for selecting the best set of equations. Unlike hydrodynamic models, ecological models do not have the benefit of being built from "first principles." Comparative parameter optimization could be used for different alternative sets of equations.

(5) Increasing model complexity generally adds "realism" to the model structure. However, increased complexity tends to reduces model "generality" (i.e., its applicability to a broad range of situations). For example, for Chesapeake Bay water quality models, adding complexity may help to capture some specific characteristics of the main-stem Bay; however, these processes may not be important (or may not correctly represent dominant dynamics) in smaller, shallower Bay tributaries.

(6) Furthermore, a guiding rule of model development is that, while "systematic bias" (lack of realism) tends to decline with increasing complexity, "measurement error" (e.g., parameter uncertainty) tends to increase and propagate upward as model complexity is increased. Thus, maximum model precision (skill at simulating observed dynamics) tends to occur at intermediate model complexity.

Spatial Resolution of Models

(1) During model development and diagnostic analysis, there is a clear advantage in using models with aggregated spatial resolution. Certain research and management applications would also benefit from using spatially simpler, more tractable models. Dynamic responses in spatially aggregated models are easier to interpret because effects of biogeochemical versus hydrodynamic processes are readily separated.

(2) In principle, computations of hydrodynamic flux should improve with increased spatial (and temporal) resolution. This is because of the non-linearity of transport calculated as the product of velocity (and/or turbulent mixing) fields and concentration fields. The quantitative importance of associated aggregation errors is, however, seldom tested in computing ecological fluxes across relevant ranges of estuarine spatial scales.

(3) A recent paper (Cerco, C. 2005, J Env. Eng., ASCE) documents that little if any improvement in model skill (model-data match for chlorophyll, O2 and other variables) has occurred as a result of four decreases in grid scale (increases in spatial resolution) for the Chesapeake Bay water quality model over the last decade.

(4) The network of water quality monitoring sites in the main-stem of Chesapeake Bay includes approximately 50 stations. Obviously, this data base alone does not support the use of any more than 50 horizontal grid cells for the water quality model (certainly, not the current model's 1,200 surface cells). Formal analysis of auto-correlation and covariance for water quality properties among these sampling stations would certainly conclude that even fewer spatial cells are justified by data trends and gradients.

(5) In the past, it has been suggested that decisions to use finer and finer spatial resolution models are based on management or science questions that are being posed. However, this trend toward increasing spatial resolution is probably motivated in part by the simple fact that the growing computational capability of computers makes it possible to do so. It has been suggested that model complexity and resolution are limited only by what can be calculated overnight on existing computer platforms. For example, the model code and computer on which it is run must be able to complete a diagnostic model run (such as an annual cycle) in 8-10 hours.

(6) It has been documented that many ecologically important process occur on micro-scales (mm to m), where for example phytoplankton bloom patchiness influences behavioral patterns of zooplankton and forage fish. These process are, however, controlled by hydrodynamics and ecological interactions at sub-grid scales (i.e., scales much finer than the resolution of the model grid). Although model structures could use a nested grid configuration (where finer scale grids are used to simulate important micro-scale processes in one area and these are numerically linked to the whole-Bay computation at a coarser grid), this approach is rarely used in water quality models.

Model Complexity and Resolution: General Points

(1) When increasing complexity and resolution leads to increased uncertainty, further increases are unwarranted for management modeling. Model skill is one measure of uncertainty but there are other effective approaches. Regardless of the complexity and scale of a model, for use in

most science and management applications, the model needs to be validated, skill-tested, and analyzed for uncertainty.

(2) Uncertainty is probably best portrayed in terms of confidence limits around model forecasts. These model errors can be generated from Monte Carlo or other diagnostic methods, where the model is run over and over using sets of parameter values randomly selected from empirically derived frequency distributions. When more that one model is available to be used for simulating management scenarios, each should be run with displays of uncertainty using confidence intervals around model forecasts. This ensemble modeling approach has been used effectively by the IPCC in their application of atmospheric science modeling for management questions.

(3) An important advantage to simple aggregated models is that their dynamics are readily analyzed and understood using more formal methods (optimization, uncertainty, sensitivity). The scientific understanding underlying the structure of management models must be sound and beyond reproach simply because of the severe economic, social and ecological consequences of management decisions based on model output. A model is obviously too complex when its users no longer understand its behavior.

(4) Generally, scientific understanding of processes tends to be well ahead of descriptions used in contemporaneous models. Sometimes, however, the science lags behind the management model needs. It such instances, models should employ simple empirical relationships (preferably based on observations made in the system being modeled) rather than unconfirmed complex mechanistic equations.

(5) Scientific and management models are fundamentally similar in terms of equation structure and data application. Ideally, they should be interchangeable and applied equally well to research and management problems. Use of open source-codes in the development of these models encourages continual improvement and forward evolution. Model developers and users all have a vested interest in producing models with improved performance. To be effective the community's shared use of open source-code models requires one or more "clearing house" with the responsibility to maintain, update and check multiple versions of evolving models.

(6) The present CBP approach supporting a single, evolving model for each system domain (watershed, airshed, estuary) is limiting and inefficient. No single model can be designed to address all relevant questions. A more efficient approach would involve using an ensemble of models with different structures, complexities and scales.

***RECOMMENDATIONS OF BREAKOUT GROUP 3A*: Does CBP modeling need improved estimates of meteorological forcings and atmospheric deposition, and if so, how can they be implemented?**

Participants: Robin Dennis, others

Ongoing efforts to integrate regional and national air quality and atmospheric deposition models with CBP models are commendable and should be continued. An additional, potentially valuable collaboration that should be pursued is with NOAA/NWS weather modelers. Recently improved capabilities for nested mesoscale weather modeling could provide greatly improved wind stress fields for the Bay hydrodynamic model. Resolving the wind field at approximately 1-2 km will resolve bay breezes, which can have important local impacts. In addition, the wave modeling capability being added to the hydrodynamic model would greatly benefit from improved wind fields over water, which can be quite different from those over land. Meteorological models of winds over and around the Bay would benefit from this coupling, as well. While reconstruction of mesoscale wind patterns may be possible for hindcast modeling, high resolution wind analyses archived after 2004 are readily accessible. As implementation of national air quality standards decreases the influence of deposition from remote sources, identification and control of local sources will become both feasible and important. Increased resolution of local wind fields will be important in this effort.

***RECOMMENDATIONS OF BREAKOUT GROUP 3B*: What future developments are needed for the CBP Watershed Model? What continuing or new data needs should accompany these model developments?**

Participants: Gary Shenk, others

The main point that the group wanted to push forward was the idea that the watershed model had to be modular with the ability to communicate with other models and data sources through standardized formats. The modularity allows for the ability to test different modules and data sets, and to work on many scales. For example, a modular design would allow a user to swap out the HSPF agricultural simulation for a SWAT agricultural simulation or possibly the entire groundwater simulation for a more explicit one. Localities would also be able to use the model for small-scale water quality assessments more easily, by swapping out Bay-scale model segments for a distributed local model in a particular geographic area. To accomplish this modularity, standardized data models and formats would have to be agreed upon prior to starting work. These formats would ideally conform to national standards, such as ArcHydro.

The group came up with several probable priorities for the watershed model to be developed starting between 2010 and 2015. The most important are likely to be data-related, such as better BMP efficiencies, better agricultural data, and measurements of coastal plain pollutant flux to tidal water. Likely important upgrades to the model structure would be more physically-based process simulations and a more distributed model. The group felt that studying small watersheds by heavily instrumenting them and doing detailed modeling was important as well. Priorities are likely to change and new priorities may be established. The priorities should be set by using the current watershed model should to test the sensitivity of management-related findings to the proposed improvements in the model and data.

There were several future issues/needs that included:
-Addressing additional TMDL's for the Bay and its watershed which would be greater than just the current water-quality standards for dissolved oxygen, water clarity, and chlorophyll. Some of the additional TMDL's must address contaminants and pathogens, therefore additional (or enhanced) models are needed for these parameters.

-More accurately represents processes controlling the transport of nutrients and sediment.
-More accurately represents nutrient movement in the ground water and inter-relation with surface water.
-Forecast impacts of human population growth and behaviors on water quality and quantity.
-More accurately represents effectiveness of management practices for nutrient and sediment reductions (especially how the effectiveness of management action may vary in different watershed landscapes).
-Better target or optimize where to implement management actions to improve water quality. However, there was a wide range of opinions on “targeting” which included: (1) we should not do it, (2) States already have what they need in the tributary strategies, (3) States and local governments do not want to be told what to do, (4) we need the full degree of implementation of management actions everywhere so there is no cost benefit to targeting, (5) there is a need for a science-based approach to target management actions for maximum water-quality benefit.
-Improve integration with monitoring data to assess change in water quality over time.
-Are more physically based to simulate the effect of different watershed landscapes on water, nutrient, and sediment movement.

Some suggestions/recommendations of what needs to be done to address the issues/needs that included:
-Encourage development/linkage of multiple models to addresses the above at different spatial scales. However, for development of specific TMDL’s there was concern that potentially different answers from multiple models could lead to confusion and litigation.
-Construct a “data model” which contains information and associated metadata about the watershed. The “data model” would provide a common source of information for multiple investigators to develop models at different scales and for different purposes.
-Consider a modular modeling system that provides tools to link (1) results from different models, and (2) modules to address different processes in a model (or system of models).
-While there are many needs for improved watershed model(s), priority issues include improved simulation of:
(a) Transport of sediment and phosphorous
(b) Impact of denitrification on nitrogen transport and occurrence,
(c) Ground water and associated nutrient transport,
(d) Effectiveness of management actions in different landscape settings.
-Improved information on these processes is needed, practically at finer scales. There was recommendation to have “integrated observing systems” where all of these data would be collected in small watersheds/stream reaches that represent different landscape settings.

***RECOMMENDATIONS OF BREAKOUT GROUP 3C*: What future developments are needed for the CBP Hydrodynamic and Water Quality Estuary Models?**

Participants: Tom Gross, others

The future developments of the CBP Estuarine/Water Quality model were discussed largely in the context of what needs the current model satisfies, and whether those needs will change enough to alter the use of the modeling system. It is recognized that building a new model for the sake of newness is not a valid course to follow. The modeling system can be a regulatory model, a science investigation model or a collection of tools made ready for unanticipated future needs. Presently it is a regulatory model, which does the job of providing TMDL information. This is the need CBP built the model around. The fact that it does the TMDL job while not providing the other capabilities can be considered an asset in terms of cost effectiveness of support and targeted ability to solve problems. There are certainly numerous science questions and active research which could benefit from the development of better modeling and analysis tools. Is it the role of CBP to serve these needs by providing the tools through the current modeling system? Would an effort to alter and update the existing model be worthwhile, and if so should that be CBP's role?

There are needs of the CBP which remain unmet by the present modeling system. Most of these are in the realm of living resources modeling. The bottom-up food web control paradigm of the present system does not serve the living resource modeling community. Methods to model fisheries, oysters and the like are needed. Toxics are not well modeled at present. Toxic effects are manifest in the food chain and are not well modeled by simply following advective pathways.

Coupling the CBP model with a fisheries model, like EwE, will be complex. Maybe not worth the trouble, or necessary if EwE can benefit from the CBP model through one-way coupling. It was pointed out that the two-way effect of detritus coupling and top-down foodweb control might prove to be extremely important. However it is asked, once again, if these concerns will have an effect on the TMDL modeling. It is not thought so. Therefore the living resource modeling can be delayed. In the mean time fisheries questions and oyster distribution and restoration modeling are proceeding without benefit of the CBP model.

Modularity:

Modularity provides a tool to choose between alternative modeling methods within one system by providing plug and play alternatives for process testing. Modularity uses the scientific method of putting a process model at "risk" by testing an alternative within an identical testbed environment. Modularity is not the description of the best Estuary model. It is a tool, which may or may not lead to a better, more usable modeling system.

Modularity is not an end in itself. When discussed, the aim of most researchers is to be able to apply the modeling system easily. Sometimes that means applying the model in higher spatial resolution, sometimes it means simplifying the model to isolate modeling assumptions for understanding, control and clarification. Suggested uses were in small embayments for local regulations, including TMDLs and for chemical response studies of the effects and pathways of single toxins. Spatial refinement and simplification are not modularity. In theory, the CBP model can be spatially refined and processes can be dropped out and simplified. But researchers perceive the model as far too complex and difficult to manipulate, for anyone, but a few, to work with.

Retrofitting modularity to the existing CBP model will be extremely hard. A modular system will set communication protocols and data structures for process modules and enforce standards. Software systems exist and are being developed to tackle these tasks. For instance Regional Ocean Modeling System consists of numerous coupled components. In a sense, so does CBP WQM. Processes which have only one-way coupling are easy, and most of the CBP model consists of these. A great task will be building the alternative process modules within the frameworks to provide meaningful testing opportunities.

Recommendations:

Living resource modeling must be brought up to the same level of attention and support as that enjoyed by the TMDL based estuarine modeling program.

Feedback from living resource modeling must be integrated into the estuarine model.

Future models must be capable of nesting or subgridding, to resolve processes at the level of small embayments (100's acres).

A modular modeling system will be a research science tool. The existing CBP WQM model is fully adequate for the task of calculating TMDLs. Asked restrictively, in the context of TMDL calculation, there is no need to change the CBP model to a modular system.

An easier to use model system is needed. A hierarchical, modular system could aid this goal.

***RECOMMENDATIONS OF BREAKOUT GROUP 4A*: Should the CBP be involved in forecasting, and if so, for what purposes and on what time scales?**

<u>Participants</u>: Vic Bierman, others

- The opinion of the group was that the CBP should move into forecasting. It was recommended that the CBP not attempt to conduct short-term forecasting (days to a week), but to focus on longer time periods, depending on the particular model. For example, the watershed model could be used to forecast the time evolution of BMP effectiveness on reducing delivered nutrient and sediment loads to the Bay. The Bay water quality model could be used to forecast the impacts of decadal-scale population growth and climate variability on water quality.

- It was noted that the CBP is already conducting forecasting at some level. Examples are the ecological forecasts produced in 2005 by the Monitoring and Analysis Subcommittee (MASC) for dissolved oxygen in the mainstem Bay and harmful algal blooms in the Potomac.

- It was recommended that linkages be made between forecast results and the impacts of management actions. For example, an ozone forecast model could provide a regulatory "hammer" in terms of "GO RED" days on which public transportation service would be free of charge. Similar linkages should be developed for ecological forecasts.

- The opinion of the group was that modeling of flows, residence times, temperature and salinity could have value for forecasting the likelihood of oyster disease.

- The opinion of the group was that the current Bay water quality model has been under-utilized and under-exercised. The group recommended that the Bay water quality model be exercised by conducting sensitivity and mass balance components analyses, determination of prediction uncertainty, and post-auditing.

- It was recommended to determine the prediction uncertainty of the Bay water quality model. The calibration uncertainty of the 13K Bay model (1985-1994) is known, but the prediction uncertainty of the model has never been determined. The simulations conducted with the calibrated 13K model were all forecast scenarios of responses to assumed changes in solids and/or nutrient loadings to support the C2K Agreement.

- To determine the prediction uncertainty of the Bay model, it was recommended to conduct a post-audit with the 13K model by running the 1985-1994 calibration with actual 1995-2004 loadings and external forcing functions. This would provide back-to-back 10-year periods, the first of which would be the calibration and the second of which would be a post-audit. Results from the post-audit could be compared directly with experimental observations because both the model and the observations would have been driven by the same loadings and forcing functions. The group believed that such a post-audit would add credibility to the overall modeling effort and help to inform ongoing research efforts with the 57K model.

- It was recommended that outputs from the calibrated 13K Bay water quality model (1985-1994), along with the experimental observations used in the model calibration, should be provided as a community resource. The same information should be provided from the calibrated 57K Bay water quality model, when available. Researchers in the Chesapeake Bay community could "mine" this resource to better understand the overall system and attempt to find empirical relationships between stressors and responses. Such relationships could have potential benefits to ecological forecasting.

- It was recommended that time-critical demands on the CBP be balanced with strategic investments. Examples of such investments would be documentation of model computer codes, experimental data, and pre- and post-processing software, and community sharing of these resources in user-friendly and accessible forms.

***RECOMMENDATIONS OF BREAKOUT GROUP 4B*: What structural changes in the CBP hierarchy (if any) will be required to build and support next generation models and model products?**

Participants: Carl Hershner, others

It was the consensus of the discussants that the CBP was so completely invested in utilization of the existing watershed/water quality model package, that there was little probability of significant commitment to development of alternatives in the near term. This situation is a result of both the long-term development and utilization of the existing models, and the pressing need to inform near-term management decisions. In the absence of Bay Program partner dissatisfaction with the existing models' performance, there is really little motivation for investment in alternatives.

The group noted that while the Bay Program has made significant investments in development/refinement of the water quality model over the past decade, similar investments have not yet been made in the watershed model. The group felt that as the Bay Program continues to evolve toward tributary and sub-tributary management strategies, specialized needs for local watershed process simulations may lead to utilization of alternative models. At the scale of individual states, the challenges of TMDL development are anticipated to be a major incentive for model diversification. The important factor will be the emergence of a real need for alternatives, whether for ease of use, reduction in uncertainty, or simulation of additional processes.

Development of data models is a current focus of Bay Program modelers. These structured data sets are designed to support multiple model applications. Absent significant new resources to support an institutional commitment to new model development, data models may be a reasonable alternative. By making the information necessary to run alternative models readily available, the Bay Program at least facilitates independent efforts to diversify the toolbox.

***RECOMMENDATIONS OF BREAKOUT GROUP 4C*: Do CBP Estuarine models need improved ocean boundary conditions? If so, how might this be achieved?**

Participants: Carl Cerco, others

No consensus existed that processes outside the Bay mouth were a significant influence on circulation, water quality, or living resources within the Bay. Absent this consensus, the group focused on steps the Bay Program could take to investigate and establish the importance, if any, of processes outside the Bay mouth. Recommended steps included:

- Investigate the time series of nitrate concentration at the Bay mouth. Is there a correlation between temperature and nitrate? If so, this may indicate the influence of shelf water on nitrogen at the Bay mouth.

- Conduct a sensitivity run with the current ROMS model of the continental shelf. Does the model show sensitivity to atmospheric nitrogen loading? If so, management of air quality may change boundary conditions at the Bay mouth.

- Examine current computed nitrogen transport at the Bay mouth relative to upland loading. Order-of-magnitude comparisons may show whether transport from the shelf is worth worrying about.

- Conduct a sensitivity run with the current ROMS model of the continental shelf to coastal nitrogen loads. Examine computed conditions at the mouth of the Bay. This run may help illuminate whether development or management actions along the coastline will influence Chesapeake Bay.

- Examine an existing menhaden model (run by Jerry Ault) for the magnitude and implications on migration into and out of the Bay.

- Examine sensitivity of the Bay model to boundary conditions. By how much do they have to change to significantly influence water quality in the Bay?

- Obtain NOAA surface velocity CODAR data. Compare to model near the Bay mouth. Look for patterns.

There was consensus that the current ROMS model of the shelf lacks resolution to answer some persistent questions such as “Does nutrient export from Delaware Bay affect conditions at the mouth of Chesapeake Bay?” Aside from resolution, the ROMS model also requires examination and refinement of physical processes near the Bay mouth. Over the long term, the Bay Program could consider coupling of the ROMS model and the Bay model. This would require two-way nesting of model grids. A post-doc could be sponsored to carry out the effort.