Response of the Modeling Subcommittee to the Second STAC Review of the Phase 5 Community Watershed Model

January 28, 2009

Overall Comments

We thank STAC and the reviewers of the Phase 5 Watershed Model for an insightful and knowledgeable review of the Phase 5 Community Watershed Model. We appreciate the experience and knowledge of the reviewers, and their recognition of the difficulties and limitations, especially of observed data, in a simulation of the entire Chesapeake watershed.

The reviewers have kept in mind during this review the perspectives of the key customers of the Phase 5 Model analysis, i.e., the State, Federal, and Local users of this nutrient and sediment tracking tool. These users and decision-makers will be applying Phase 5 in a large-scale watershed wide TMDL of the Chesapeake, while some State and Local model practitioners and decision-makers will be using Phase 5 for portions of small-scale TMDL analysis in the watershed. For both the large and small-scale applications, this usually involves working with limited resources, often to court imposed deadlines, while contending with a high degree of uncertainty due in large part to sparse observed data covering wide heterogeneous landscapes. The reviewers have taken this into account and have provided insights and suggestions which have made the STAC Phase 5 Model review a valuable guide for the Chesapeake Bay Program, providing both long- and short-term follow-up actions and activities.

Much use by Phase 5 has been made, and will be made, of the Chesapeake Research Consortium's Chesapeake Community Modeling Program. The CCMP and its associated web site is where the Phase 5 documentation, input data, calibration and validation information, and ultimately scenario results will reside and be distributed to the broader CBP community. The Phase 5 model was designed from the bottom up as a community model, and the vision and mission of the CCMP has contributed much to our community model work. For the Phase 5 Model, model developers from the USGS, University of Maryland CES, University of Pennsylvania, CRC, ICPRB, EPA, NRCS, MDE, Virginia Tech and other CBP agencies, universities, and departments collaborated with the CBP monitoring and nutrient communities to together develop this community model. To the extent Phase 5 is successful it will be due to the efforts of the collaborative Phase 5 community team.

The STAC sponsored review was completed on February 20, 2008. Since then the Modeling Subcommittee has completed the first calibration of the Watershed Model (Version 5.0) and also completed a Phase 5.1 version which includes implementation of some of the recommendations from this independent peer review. The Modeling Subcommittee has been charged with the responsibility for completing the Phase 5.2 Watershed Model for management scenarios by March 2009 and for linking the Phase 5.2 Watershed Model inputs to the Water Quality and Sediment Transport Model. Over the next several years of the Phase 5.2 Model application period the Modeling Subcommittee and Phase 5 Modeling Team will continue to pursue work in response to the review panel's recommendations, though many of the recommendations, including the long-term recommendations, can only be implemented in the next generation of the CBP Watershed Model.

The long-term model development guidance provided by the reviewers was requested by the Bay Program, and the reviewers have taken a long look forward in order to give us a projected path ahead. The Modeling Subcommittee looks forward to providing STAC with periodic updates, as requested, on our continued progress on the recommendations of the review.

Response to Specific Points

Page 3, 1a) Completion of model calibration, validation, and documentation.

Calibration for the first and second versions of the Phase 5 Watershed Model have been completed and a third version, intended in part to implement some of the recommendations of this peer review, is underway and scheduled for completion in March 2009. A draft version of the complete Phase 5 Community Model documentation is also planned for completion by the summer of 2009. Validation procedures as recommended by the review team have been implemented in this Phase 5.1 version as discussed in more detail below.

Page 3, 1b) The need for uncertainly analysis.

We agree that an uncertainty analysis is important and desirable, and would like to implement the process but we continue to be dogged by the limitation in methods currently available to assess uncertainty in these large watershed models. The question of uncertainty is further compounded the more than 200 hydrology calibration stations and 7 key water quality parameters calibrated at more than 130 water quality observation stations, as well as thousands of calibrated rate parameters.

We wonder if a successful approach to this difficult task would be to assess the uncertainty of the effects of major input categories, such as BMP efficiencies, or rainfall directly on the TMDL water quality standards of estuarine dissolved oxygen, chlorophyll, and clarity, or perhaps on the specific decisions being made, such as allocations of pollutant control effort. This has the advantage of addressing uncertainty at the level of CBP decision-making. We‘ll continue to look into these and other methods, but suspect that with the current state of the science this may be just beyond the grasp of our current limited resources.

Nevertheless, as we've said in the previous Phase 5 review, "Uncertainty analysis requires automated calibration and data analysis methods, as well as large computing resources. Many of the techniques for large-scale Watershed Model uncertainty analysis were recently developed and are areas of ongoing and active research. While we've been unable to provide estimates of uncertainty in the past due to theoretical and practical constraints, we believe these constraints have decreased with the new tools now available and we welcome the opportunity to pursue this analysis." With the automated calibration procedures of Phase 5 and with ever increasing computation power coming available, we have at least the initial conditions we need to consider initiating an uncertainty analysis. We anticipate beginning to explore the uncertainty analysis at the close of the Phase 5.2 Model calibration.

Page 4, 1c) Representation of BMPs in the Model.
We agree that the BMPs simulated with an efficiency factor fail to conserve mass, such as in a vegetated filter strip which could trap and store sediment under most conditions, but subsequently release accumulated sediment during more extreme events. A key problem here is adequate research to describe at what hydrologic point and to what degree these BMPs fail under extreme hydrologic conditions. To address this uncertainty we've asked the CBP Watershed Technical Workgroup to provide estimates of hydrologic failure points in their BMP analysis. We expect to apply the BMP efficiency estimates under different hydrologies in the Phase 5.2 version, and the CBP will continue to examine BMP efficiencies under different hydrologic conditions as we develop our future BMP assessments and research.

To address the uncertainty of BMP efficiency overall, we've asked the Mid-Atlantic Water Quality Program to provide a range of efficiencies rather than a single number as part of their re-evaluation of BMPs.

Page 4, 1d) Overbank deposition and other unsimulated loss mechanisms.
We agree with the reviewers that the unsimulated loss mechanisms that have to do with the interaction of the model's river modules and the land modules should be tackled in the next generation of the CBP watershed model. In HSPF (Hydrologic Simulation Program – Fortran), the open source public domain model that Phase 5 is based on, the land is first simulated which then in a serial fashion provides the hydrology and loads for the river reach simulation. Using this linear simulation structure, the interaction of the rivers and the landscape, such as in the cases of overbank deposition or of wetlands nutrient uptake, is difficult in HSPF applications.

Page 4, 1e) Failure to account for streams with annual flow less than 100 cfs.
We agree that this is a structural problem of all lumped parameter watershed models. Lacking a distributed simulation, the lumped parameter HSPF approach must at some spatial scale have a level of aggregation. We chose the 100 cfs point for the river-segment aggregation largely due to computational constraints, as this gave us more than a thousand river-reach segments or about an order of magnitude improvement in scale from

the previous Phase 4.3 version of the model. Of course, in the case of a distributed model advocated by the reviewers, the level of aggregation shrinks further than a thousand model segments to a very small spatial scale, ideally to a point. To contend with the limitations of a lumped parameter HSPF structure we've added elements like a sediment delivery factor that's scaled to the average distance a land use is from a simulated reach. To some extent the segment level adjustment factor for nutrients provides the same function.

Page 4, 1f) Approaches to model validation.
The recommended approaches for validation seem to us to be sound and we've applied the recommended suggestions. We've adopted the suggested approach which is to select a subset of calibration sites that have adequate data for validation and withhold the most recent 25% of the observations with the extra provision that observations between 1991 and 2000 are held within the calibration data set. This extra provision is to allow for the most accurate calibration for the selected 10-year scenario hydrologic period that will be used for the Bay TMDL. If insufficient observations can be found after 2000, observations from the1985-1990 period are used for validation. If there are still too few observations for validation then observations within the 1991-2000 period are withheld.

Page 5, 1g & 1h) Coupling with a full groundwater model.
A fully developed groundwater model coupled to the Phase 5 Watershed Model is beyond the scope of currently available resources and time. We note that there are regional groundwater models under development in the Chesapeake region and believe a winning strategy is to couple a future version of the CBP watershed model with one of these models once development is complete. Even with the current HSPF Phase 5 simulation though we do have a full mass balance accounting of nitrogen and note that about 50% of the total nitrogen simulated in the reach is from the HSPF representation of groundwater. Still, we readily concede that the HSPF representation of groundwater is simplistic and falls well short of a regional groundwater model, especially with regard to lag time, and agree that a coupled watershed and regional groundwater model is a worthy long-term objective.

Page 5, 2a & b) Application at local watershed scale of Phase 5 Model structure and use of community modeling framework for local-scale applications.
The reviewers correctly point out that key data used as inputs to the Phase 5 Model are at the county level, such as the estimates of the different cropland types and associated estimates of manure and fertilizer inputs. On average this means that key land use input data estimates for county areas of about 250 square miles can only be proportionally used for model segments of river areas of about 66 square miles, which are equivalent to rivers with a mean annual flow of about 100 cfs. We concur that in some cases, the best approach for a local TMDL exercise would be to use appropriate elements of the Phase 5 Model with augmentation of local-scale land use and monitoring data when this is available or can be set up. As the reviewers have correctly pointed out, the use of CRC's

Chesapeake Community Modeling Program website to list the more detailed Phase 5 data sets that may be used at the local-scale would be an asset to more detailed modeling at smaller scales. The CBP Modeling Team will work to add these detailed data sets to the CCMP Phase 5 data library.

On the other hand, small-scale modeling is time and resource intensive and this must be weighed against the time and resources available. For example the benefits for the specific use of the Phase 5 Model in a consistent manor in local TMDLs can outweigh any benefits of using available information inconsistently on a finer scale.

While the Phase 5 was developed primarily for estimating nutrient and sediment loads to the Bay, the refinement of spatial scale from Phase 4 to Phase 5 allows Bay Program States to consider its use in localized TMDLs. An advantage of using the same model for local and Bay TMDL development is that it's a consistent method to compare the loading rate required to meet local water quality as compared to downstream tidal water quality.

The Phase 5 Watershed Model development process considered all available data at the finest consistent scale possible within the Bay watershed. Consistent is defined here as comparable level of accuracy for all watersheds, where these data include precipitation and landscape characteristics such as slope, land cover, land use, nutrient applications, monitoring data, etc. So that while it can be said that the Phase 5 Model accuracy improves with aggregation and increased spatial scale, the use of Phase 5 for local TMDLs has the merit of the best available information consistently applied at the local scale. The alternative local scale approach is incorporation of additional local data at a more localized scale into a separate model, but that has the tradeoff of inconsistent analyses among different local jurisdictions   Given the tradeoffs of the relative merits of the two approaches, we believe that local allocations should be evaluated on a case by case basis, and this is what our State partners are doing.

For example, in Maryland, the unit of TMDL assessment is at a watershed scale the same size or larger than the Phase 5 river-segments, and the Phase 5 river-segments were designed to facilitate representation of the Maryland watersheds (the so called "8-digit" watersheds). As part of its contribution to the Phase 5 development, the Maryland Department of the Environment collected monitoring data to calibrate Phase 5 at the scale of the 8-digit watersheds. Consistency of the scale of analysis among local TMDLs and between local TMDL and the regional Bay TMDL is considered to be an important advantage.

Page 5, 3a) Data inputs on a regional scale.

We agree that BMP efficiencies structured to be dependent on flow and county level soil test data for nutrient pools are two areas where the Phase 5 Model can be improved. The BMP efficiencies will be structured to be dependant on flow to the extent data allows in the Phase 5.2 version nearing completion and soil nutrient pool information will be examined for application in the next major version of the CBP watershed model.

Page 6, 3b) Potential oversmoothing of precipitation inputs by low-order meteorological interpolation.

We believe this concern has merit and agree with the reviewer's recommendation for incorporation of NEXRAD data when a sufficient period of record is available
At the same time, we've tested various versions of our rainfall model and used the versions that lead to the best hydrologic calibration. We have also tested the USGS model against the NARR dataset (since the review) and the Phase 4.3 Theissen polygon approach we applied in the last version of the model, and found that the USGS rainfall model outperformed both.

Page 6, 3) Response for local-scale application.

See response to ***Page 5, 2a & b.***

Page 6, 4a) Long-term decadal mass balance simulation.

We agree with this recommendation. When we consider that the next generation of Chesapeake watershed model supported by CBP may not start development until after 2011 and be completed by about 2015, the next model will have the potential to simulate at least three decades of continuous simulation. In this case, consideration of a long-term decadal mass balance becomes even more important to our modeling success.

Page 7, 4b) The need for process-oriented distributed modeling

We fully concur that we should strive for a distributed watershed model in the next major phase of CBP model development. See also response to ***Page 4, 1e.***

Page 7, 4c)   Small scale, first principle distributed modeling.

See response to ***Page 4, 1e.***

Page 7, 4d)   Incorporation of an ecosystem approach that fully couples carbon and nutrients.

We concur that the next generation watershed model should consider the incorporation of a dynamic ecosystem approach that integrates and fully couples carbon and nutrients in the soil and water cycles. While the modular nature of HSPF is attractive for simple simulations of, for example, a phosphorus only simulation using the hydrology and the PQUAL modules, the failure of a linkage anywhere in HSPH among carbon, nitrogen, and phosphorus provides many opportunities for bugs, errors, and a potential problem for properly achieving a mass balance in a simulation at the scope and scale of Phase 5. We've been as vigilant and rigorous as we can in properly linking the simulated nitrogen and phosphorus pools, but a proper carbon based ecological simulation as proposed by the reviewers would be a vast improvement.

Page 7, 4e) Use of parallel computer process by next generation CBP watershed Model.
We agree and continue to look toward further application of computer clusters, vectorized code, and more efficient computational approaches to watershed simulation.

Page 7, Immediate Needs 1) A much higher level of resources is needed for model development, calibration, and validation.
We fully concur. A higher level of resources would more fully integrate the CBP modeling, monitoring, and research and would advance Bay restoration and contribute to advancing the field of applied watershed restoration and research.

Page 8, Immediate Needs 2) Model documentation, calibration, and validation must be completed and distributed in a way that allows full review by the scientific and user community.
We agree that the documentation and information on model calibration and validation needs to be readily available, transparent, and continually updated as appropriate. The use of CRC's Chesapeake Community Model Program site has helped us tremendously in this regard. We plan to have a first draft of the complete Phase 5 Model documentation up on the CCMP site by August and to have full presentation of the calibration and validation material hosted there as well. As we have a community model approach to the Phase 5 effort, we'll look toward continual improvement f the calibration and documentation as the user community responds and suggests changes and improvements in the Phase 5 Model tool.

Page 8, Immediate Needs 3) Staffing of the modeling team should be increased and members cross-trained.
Staffing increases are dependent on additional funding and it's unlikely that we will be able to significantly increase the CBPO staff. We do have access to, and have been involving, CBP personnel and partners to expand our team using the community model rubric of collaboration. For example, we regularly call on CBP urban and agricultural nonpoint source experts for provision of Phase 5 inputs and information. We agree, however, that optimally we would have a larger team with direct input and cross training. Cross training of the model development team will be implemented as suggested.

Page 8, Immediate Needs 4) Monitoring to support CBP Watershed Model development, calibration, and validation should be improved.
We look forward to the time when continuous sediment and nutrient monitoring sensors are deployed in the watershed and will look for opportunities to actively encourage their deployment. We've found that the three continuous sediment monitoring sites we've had in the Chesapeake watershed have been especially useful for calibration, and look

forward to having, for the first time, the opportunity to use continuous monitoring data for nutrient calibration.

Page 8, Immediate Needs 5) Further exploration of automated calibration procedures encouraged.

We appreciate the enthusiastic support for our work to automate calibration procedures, an approach that in any case was an imperative in the Phase 5 Model development and calibration due to the more than 300 land segments, 20 land uses and 1,000 river segments in Phase 5. We'll continue to push toward expansion of this approach as recommended.

Page 8, Immediate Needs 6) Major software engineering needs to be completed for streaming code, and making input and output processing more efficient.

The Fortran code of HSPF is indeed getting long in the tooth. Much of the HSPF structure is due to computational constraints from the early seventies that are no longer operative today. The input/output (I/O) is one glaring example of HSPF inefficiency. Correcting this, however, would be a major undertaking well beyond the available CBP expertise. Generally, we've found it difficult to fund advances in model code with CBP funds as our budgetary decision-makers see this task as something the national EPA or USGS programs should be supporting.

We like several of the potential solutions suggested by the reviewers as they are somewhat grass roots and can be done in-house. We are continuing development of our web-based interface to modeling input and output. The CBP also recently hired a full time linux administrator who should be able to help with the Phase 5 operational efficiency and some files will be converted from simple binary to netCDF in the near future as suggested by the review.

Page 8, Immediate Needs 7) Calibration and validation can be improved by using a variety of additional tools in temporal aggregation/disaggregation, smoothing, and space-time principal components analysis.

We believe the suggested temporal aggregation tools be used along with the current calibration approaches. Aggregations are currently made in the hydrologic calibration in that we calibrate to average recession rate and overall baseflow fraction, for example, rather than calibration to individual data points. An overall aggregation to a concentration CFD is made in the simulated and observed comparisons for the purposes of calibration as suggested by the first STAC review. The reviewers have a very good point in that measures of calibration skill are then taken against daily flow and water quality concentrations rather than against these calibration metrics. We would like to incorporate more temporally aggregated measures into the water quality calibration and are currently completing a literature review to determine appropriate methods for Phase 5.2

Page 8, Immediate Needs 8) The need for uncertainty analysis.
See response to ***Page 3, 1b.***

Page 9, Immediate Needs 9) Need to develop a cleanly thought-out scenario process.
As the Phase 5 Model scenarios are developed the results of the scenarios will be placed on the CCMP website. Plans are already underway to accept these scenario results and the web page already has some of its "landscape" set up for this purpose. Once a library of these scenario results have been developed we've found in the past that extrapolation between the model runs is often possible, providing useful information without the need for additional model runs. We believe the CCMP site will be best for this purpose as the information will be most widely disseminated to the broadest audience from this site.

Page 9, Immediate Needs 10) An assessment needs to be made of the use of county level data from state soil testing labs to set initial soil nutrient levels.
We agree and will look into the availability of county level soil testing data. This will be of particular us in correctly establishing estimated initial conditions of nutrient pools in the soil and in determining where phosphorus saturated soils may be contributing to a greater export of phosphorus in the simulated land uses.

Page 9, Immediate Needs 11) New land uses need to be added to directly simulate BMPs rather than use of efficiency factors.
In the process of moving from Phase 4.3 to Phase 5 we've gone from 9 to 24 land uses mainly for the purpose of directly simulating more BMP types. We agree with the reviewers and would like to push this further in the next version. We are currently limited by data availability and computational resources.

Page 9, Immediate Needs 12) Procedures should be developed to simulate the dynamic nature of BMP response to extreme events.
See response to ***Page 4, 1c.***

Page 9, Immediate Needs 13) Continued development of the CBP Geodatabase is needed.
Work is underway and the CBP is committed to completion and continual updating of the CBP Geodatabase including the incorporation of key Phase 5 Model spatial attributes into the Geodatabase. We have migrated published CBP geospatial data to SDE (Spatial Database Engine), and will continue to do so as new data is generated. Plans for the spatial enablement of CBP relational databases of point source, water quality, and living resources are underway with plans to complete the point source and water quality spatial data before the end of the year.

Page 9, Intermediate Needs 1) The model should be used to identify subwatersheds that deliver disproportionate sediment and nutrient loads.

This will be part of the TMDL allocation process and at a relatively large-scale. We are also currently using SPARROW and Phase 4.3 output in a process to determine the highest loading watersheds for targeting within Maryland.

Page 9, Intermediate Needs 2) An applied research program should be established by the CBP to improve our understanding and ability to model key processes in the fate and transport of nutrients and sediment in the watershed.

We realize that proposing this is no more audacious than modeling a 64,000 square mile watershed, and we deeply appreciate the boldness, as well as the "rightness" of the concept of an applied research program on the fate and transport of watershed nutrients and sediment.

Page 9, Intermediate Needs 3) Improved representation of channel erosion, scour, and deposition is needed.

The HSPF simulation of the riverine fate and transport of sediment is weak as it simulates essentially an infinite source and infinite sink of scoured or deposited sediment depending on the scour and erodiblity parameters set by the modeler. We agree that in future phases of the watershed model this should be improved, particularly as we move from large basin scale to smaller scale simulations

Page 9, Intermediate Needs 4) A proactive approach should be taken to identify and consider future threats to water quality in the Chesapeake watershed.

We agree with this recommendation and are applying this approach with the examination of increased ethanol production from corn grown in the Chesapeake watershed by the Chesapeake Bay Commission and an analysis of climate change on hydrology and water quality that's ongoing (Linker et al, 2007a; 2007b). The community model approach also facilitates the work by other groups interested in examining future water threats to the region as the Phase 5 Model is hosted on the CRC Chesapeake Community Model Program website and is there to be used by the community in the proactive way suggested by the reviewers.

Page 10, Long-Term Needs 1)   Adequate funding must be provided for integrated modeling and monitoring.

We enthusiastically agree with the reviewers and while we'd like to see this recommendation implemented immediately, believe it's wise to keep hope alive by considering this to be a long-term goal to be seen and admired from afar by those that tend the CBP coffers.

Page 10, Long-Term Needs 2)   A new generation of CBP watershed model.

We agree that we should work toward a next generation CBP watershed model that's process-oriented and distributed. We also agree with the reviewers that one of the main obstacles to this objective is the sparsely sampled, highly heterogeneous landscape watershed models must simulate. We believe the strategy we need to apply is to continue to encourage the advancement of remote sensing, and to apply these products in watershed simulation as they mature, as suggested by the reviewers.

Final Thoughts

In this review there was broad agreement among the reviewers and the Phase 5 development team on the next hurdles and challenges in the field of watershed modeling generally, and in the next phases of CBP watershed model development specifically. It's interesting to speculate that this may be due to the watershed modeling field's maturity, as there's broad recognition in the modeling community that integration of modeling, monitoring, and research must be pushed further, and that the spatial scale in watershed modeling must be pushed down to provide information at local government levels where key land use decisions are actually made. All of this leads to integration of models of airsheds, watershed, and ground water as suggested by the reviewers, and at distributed scales as this review suggests. These directions have computational consequences such as the need for parallel processing (as this review recommends).

In the coming years the Phase 5 modeling community looks forward to beginning to tackle these challenges and to making further contributions to the field. The Modeling Subcommittee again thanks the reviewers for the application of their knowledge and experience in the Second Phase 5 Watershed Model Review. We look forward to working with STAC and the CCMP as we continue to apply and develop the Phase 5 Community Watershed Model.

References

Linker, L.C., T. Johnson, J. Kittle, Jr., G.W. Shenk, 2007a. Evaluating 2030 Climate Change in the Chesapeake Watershed. American Water Research Association Annual Conference, November 12-15, 2007, Albuquerque, NM.

Linker, L.C., T. Johnson, G.W. Shenk, C.F. Cerco, P. Wang, 2007b. Evaluating 2030 climate change in the Chesapeake Bay watershed and estuary. 19th Biennial Conference of the Estuarine Research Federation, November 4-8, 2007, Providence, RI.