Review of the Exelon Three-Dimensional Sediment Transport Model of Conowingo Reservoir

Final Review Summary

By

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BACKGROUND

The Exelon Corporation contracted with HDR consultants to build, calibrate, and execute a three dimensional (3D) sediment transport model of Conowingo Reservoir on the lower Susquehanna River to evaluate sediment transport characteristics of the reservoir. The model was part of a suite of models designated as the Conowingo Pond Mass Balance Model (CPMBM). This 3D model was designed to be used in conjunction with the HECRAS model of the uppermost reservoirs Lake Aldred and Lake Clark previously developed by West Consultants under contract with Exelon. These models provide a system wide approach to evaluating sediment transport and water quality issues associated with the Susquehanna River and associated reservoirs, as well as sediment and nutrient loadings to Chesapeake Bay from the river system.

INTRODUCTION

Currently, estimates of nutrient and sediment loadings to Chesapeake Bay from the Susquehanna River system are provided by HSPF, a numerical model developed by the USEPA to route sediment and nutrients through the lower Susquehanna River to Chesapeake Bay. The current version of the model is for routing only and not moveable bed sediment transport modeling, and is, therefore, heavily dependent on measured flow, nutrient, and suspended sediment concentrations throughout the Lower Susquehanna River basin. In some cases, such as the reservoirs, these data are lacking, or there are significant data gaps due to infrequent large flow events that deliver substantial wash load and bed material load to the bay. To address these empirical data gaps, the United States Geological Survey (USGS) and Exelon have initiated a comprehensive sampling program for the Lower Susquehanna. In addition to this effort, Exelon has developed a system wide approach to modeling the lower reservoirs which builds on previous modeling efforts by the US Army Corps of Engineers (USACE) and the USGS. This system wide approach includes a one dimensional model of the upper two reservoirs that provide an inflowing sediment boundary condition for Conowingo Reservoir. The models were developed, calibrated, and executed to evaluate long term simulations of bed change and sediment loading to Chesapeake Bay.

REPORT REVIEW

The review of the modeling effort was guided by the following five questions concerning the design, construction, and application of the CPMBM.

1. **Is the modeling approach reasonable and credible to satisfy the goals defined in the Proposal for Lower Susquehanna River Reservoir System Model Enhancements in Support of the 2017 Chesapeake Bay TMDL Midpoint Assessment?**

The two upper reservoirs, Lake Clark and Lake Aldred, are considered to be in dynamic equilibrium in that there is no long term sediment storage. However, Conowingo Reservoir has some sediment storage capacity remaining although it appears close to an equilibrium condition. Analysis of this type of system requires a multi-dimensional model that can evaluate both spatial and temporal sediment erosion and deposition. The CPMBM model was appropriately designed and applied for this application. The model calibration procedures were rigorous and successful given the lack of measured flow and sediment data. The model application demonstrated its usefulness as a tool for evaluating management scenarios as well as for simulating both short and long term sediment transport events. Use of this model in conjunction with the HECRAS model of the upper two reservoirs will provide the best estimate of sediment loadings to Chesapeake Bay in lieu of a substantial and complete empirical data set which is not currently available.

2. **Do the Lake Clarke/Lake Aldred HEC-RAS Model (HEC-RAS Model) and Conowingo Pond Mass Balance Model (CPMBM) provide added value to the information available to the EPA Chesapeake Bay Program and the State of Maryland? Do they inform and advance the current science and understanding of the Lower Susquehanna River Reservoir System?**

   The system-wide modeling strategy implemented by Exelon is the correct approach to estimating sediment transport within the reservoirs and sediment loadings into Chesapeake Bay. Although suspended sediment measurements below Conowingo are available, there are relatively few data for the large flow events that not only deliver large quantities of sediments from upstream of Conowingo, but also have high potential for scouring and transporting sediments through the system. These high flow events not only change the morphology of the reservoirs but also significantly impact Chesapeake Bay water quality. The suite of models developed by Exelon provides the tool needed for better understanding the complexity of sediment transport through this system. As more and better empirical data become available, model predictions should improve accordingly. The end result is a useful tool for managing the watersheds and reservoirs and therefore can assist in determining the impacts of sediment and nutrient loads discharged into Chesapeake Bay.

3. **Given the data which were available to the modelers, evaluate the model results, input parameters, and modeling assumptions made to determine if the models perform reasonably.**

   The CPMBM modeling platform is well suited for modeling the lower Susquehanna River and its associated reservoirs. The construction, calibration, and application of the model represents an improvement over previous models applied to the system including the following:

   - A system-wide approach with movable bed sediment transport modeling in one, two, and three dimensions

- Development of a sediment boundary condition at Holtwood Dam from fully unsteady sediment transport simulations of the upper 2 reservoirs utilizing a 1D model calibrated to historical bed change in the reservoirs
- Enhancement of the cohesive sediment transport theory in the model by incorporating the relationship between clay content, plasticity, and cohesive erosion parameters, thus augmenting the existing SedFlume data
- Development of a multi-layered bed based on historical sediment cores including coal
- Calibrated the 3D model to bed change by performing a thorough analysis of historical bathymetry surveys
- Simulated the models as one system in fully unsteady mode to evaluate both long term and short term bed change and to evaluate the capability of the model to reproduce measured bed change and sediment loads and concentrations
- Demonstrated the applicability of the model as a management tool for evaluating base versus plan type scenarios

The calibration and modeling results were good considering the lack of sediment boundary condition data and the high uncertainty of historical reservoir bathymetric surveys and cohesive sediment erosion characteristics. Model results comparing computed and measured suspended sediment concentrations were quite good considering the substantial uncertainty generally found in suspended sediment data when evaluated as a function of discharge. This was particularly evident for the Tropical Storm Lee event in September 2011 in which very high concentrations were measured (>3000 mg/l).

The long term simulations of bed change produced reasonable results in terms of reservoir annual average deposition or scour. As expected there were some differences in spatial deposition and erosion patterns when comparing the change in survey elevations to computed elevations, however, the overall sedimentation trends were adequately depicted within the inherent range of uncertainty.

4. Are the modeling outputs developed under this study appropriate to help inform or guide the suite of Chesapeake Bay Program models (i.e. the Watershed Model and Water Quality and Sediment Transport Model)?

To date there has been a high degree of dependency of Bay Program models on the measured data set. Gaps in the measured data, particularly for Susquehanna River flows greater than 400,000 cfs, add to the uncertainty of mass balance calculations in terms of water quality impacts to the Bay. Curve fits have typically been applied to the data to extend the measured data set for predictive purposes. These curve fits tend to be poorly correlated and may significantly over-predict loads transported to the bay for high flows.

The CPMBM model provides a more representative system-wide approach for determining a mass balance through the reservoir system utilizing unsteady non-uniform sediment transport theory. Measured suspended sediment concentrations resulting from instantaneous grab samples provide only a point in time, whereas, a properly calibrated model can provide a continuous record based on unsteady non-uniform transport of sediment. Integration of the continuous flow and concentration model output will provide the best estimate for load delivered through the system.

In lieu of a comprehensive measured data set, the output from the CPMBM model represents the best sediment boundary condition data available to the Bay models, and thus should be utilized by the models in subsequent water quality / mass balance simulations.

5. While keeping the goals of the study in mind, could the models and outputs be improved? If possible, please identify specific areas of potential improvement (e.g., model input datasets/parameters, modeling assumptions, process description, other modeling systems or programs, etc.)

The development of a calibrated movable bed sediment transport model is critical for predicting morphology change in the lower Susquehanna River and the associated reservoirs as well as determining long and short term sediment loadings to the Bay. The linked models will provide a platform for not only evaluating impacts, but running management scenarios as demonstrated in the report. The accuracy of the models is highly dependent on boundary condition data such as measured sediment concentrations and cohesive bed material erosion and deposition properties. The on-going data collection efforts are critical for both understanding how the system works and the continued improvement of the models. Currently, the CPMBM model is calibrated to the best available data. As field data collection progresses, the model should be continually updated and validated using the up-to-date boundary condition data, thus improving model prediction capability.

It is apparent from this and previous studies that further work is needed in two areas to better understand the sediment transport characteristics of the river and reservoir system. The relationship of bed sediment cohesive properties to erosion needs to be further explored. The SedFlume work as well as the clay plasticity relations presented in this report represent a good start to future studies. However, as stated in the report, there are cohesive bed sediments in areas of the reservoirs that appear to be stable even though computed shear stresses on the bed well exceed the erosion threshold. The role of bed sediment consolidation and resistance to erosion, particularly in areas that are subjected to high bed shear stresses, needs to be further evaluated. I recommend involving experts in this field of study to help design field and laboratory studies to clarify the reservoir cohesive sediment behavior and to help improve model capability in this area.

The dominant sediment process in the reservoirs is deposition. It is critical that this process be correctly represented in the models for both morphology change and mass balance calculations. All the models applied to the reservoir problem to date have had difficulty with replicating both spatial and quantitative deposition patterns. Typically, inflowing sediment size and concentration are adjusted to increase or decrease deposition when calibrating the model. Many models treat sediment as individual grains, assigning the fall velocity according to their size. In some cases, depending on the type of sediment and the settling environment, the particles may flocculate thus having a different fall velocity than the primary particle. Other factors that may influence sedimentation in the model are mesh resolution and how turbulence is represented in the model. I recommend further lab and numerical studies to improve the deposition process capability in the models.