

Review of the Exelon One-Dimensional Sediment Transport Model for Lake Clarke and Lake Aldred

Final Review Summary

By

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BACKGROUND

The Exelon Corporation contracted with West Engineering to build a one dimensional (1D) HECRAS sediment transport model of Lake Clarke and Lake Aldred on the lower Susquehanna River to evaluate sediment transport characteristics of the reservoirs. Lake Clarke, the uppermost reservoir, discharges into Lake Aldred, which in turn discharges into the lowermost Conowingo Reservoir. Flows through Lake Clarke are regulated through Safe Harbor Dam for hydropower production, while the un-regulated flows out of Lake Aldred are controlled by a dam that operates as a weir. Lake Clarke is approximately 11 miles in length (from Wrights Ferry Bridge to the dam) with Lake Aldred about 7 miles long. The uppermost reaches of both reservoirs are relatively wide compared to the lower 4 miles with the upper reach of Lake Clarke containing a higher percentage of sand sized sediments. The lower reaches for both reservoirs have higher percentages of silt and clay in the bed. The average discharge through the reservoirs is approximately 30,000 cfs, however, periodic large storms pass flows up to 600,000 cfs or greater. The United States Geological Survey (USGS) has conducted numerous studies on sediment transport characteristics of the Lower Susquehanna River to gain a better understanding of how sediment transports through the system and specifically how the trapping efficiency of the reservoirs is changing with time. To support their studies suspended sediment data are collected at Marietta, Pennsylvania above Lake Clarke and at the lowermost Conowingo Dam below Lake Aldred. Generally, a good suspended sediment data record is available for flows approximately less than 400,000 cfs at these locations. No suspended sediment data have been collected at Safe Harbor or Holtwood Dam until recently. For flows greater than 400,000 cfs, the river is highly turbulent and dangerous to either navigate or sample from a location on Conowingo Dam. The maximum flow sampled at Marietta (inflow to the reservoir system) is approximately 450,000 cfs, while a few samples have been taken at Conowingo Dam for flows ranging from 500,000 – 600,000 cfs. It is important to understand the sediment dynamics of these large storms because they potentially can discharge much more than the annual sediment load into Chesapeake Bay in a short period of time, thus possibly having a negative impact on water quality in the bay. If suspended sediment sampling were possible below all the lowermost dams through the full range of discharge, a sediment mass balance could be determined which would provide critical information on the quantities of sediment entering the system for large storms as well as quantities of sediment scoured from the bed. These data would then be used as a total sediment boundary condition for Chesapeake Bay water qualities models. Because these data were not currently available, sediment transport was simulated through the three reservoir systems by a number of numerical modeling efforts to better understand the potential sediment loads passing through the reservoirs for varying time periods and large flood events.

In 1995, Hainly et al of the USGS developed a HEC-6 sediment transport model of the three reservoir systems using flow and sediment boundary conditions that were available at the time. Their goal was to validate the model to bed change over time, using bathymetry surveys as a

comparison. To validate the model to bathymetry changes, they had to coarsen the inflowing load to encourage deposition thus the model was not further utilized. In 2012, Exelon used the Hainly USGS model and simulated a number of flow scenarios (Exelon 2012).

In 2009, the Lower Susquehanna River Watershed Assessment Study was initiated by the Baltimore District of the US Army Corps of Engineers (USACE). Two modeling efforts were conducted to evaluate sediment transport through the lower reservoirs. The USGS constructed a 1D sediment transport model based on the most current version of HECRAS created by the Hydrologic Engineering Center USACE (Langland 2014). This model was used to evaluate sediment transport through the three reservoirs for the time period of 2008-2011, including Tropical Storm Lee which occurred from September 7 – 16, 2011. The Engineering Research and Development Center (ERDC), Corps of Engineers, located at Vicksburg, Mississippi, developed a 2D model of Conowingo Reservoir using the Adaptive Hydraulics (AdH) modeling system developed at ERDC (Scott 2014). The purpose of this model was to evaluate sedimentation characteristics of Conowingo Reservoir for the time period of 2008-2011. The USGS model provided the flow and sediment boundary conditions for the AdH model for this time period. In addition to developing the 2D model, the ERDC collected a number of bed samples from Conowingo Reservoirs to determine the critical bed shear stress for erosion and erosion rate. The bed of Conowingo consists of a relatively high percentage of fine sediments (silts and clays), thus erosion processes are strongly influenced by the cohesive properties of the fines. To investigate this, the ERDC used the SedFlume, a laboratory scale flume to evaluate the erosion properties of the samples. The sediment cores were approximately 12 inches in depth, with SedFlume erosion characteristics evaluated along the length of the core. Generally, the less consolidated layers located at the top of the core have a lower critical shear stress with the more consolidated and dense lower layers more resistant to erosion. The SedFlume data were used by the AdH model to define the threshold of erosion over the entire area of the reservoir, and the rate that the bed erodes give the hydrodynamic conditions within the reservoir.

A number of scenarios were investigated with the AdH model: 1) The scour potential for large infrequent floods such as Tropical Storm Lee; 2) The effects of dredging the reservoir to restore sediment trapping capacity; 3) The feasibility of methodologies for moving sediment past the dam; and 4) Providing sediment discharge output to the Chesapeake Bay water quality model.

The USGS 1D model was validated based on the measured suspended sediment data below Conowingo Reservoir, and not on volumetric bed change within the upper two reservoirs. The model was adjusted to provide sediment discharge that would reflect the range of the measured concentrations below Conowingo Dam

INTRODUCTION

The Exelon Corporation is currently evaluating sediment transport through the reservoirs using an improved version of HECRAS which is fully unsteady, unlike the quasi-unsteady version of HECRAS used in the LSWRA study. The Exelon modeling philosophy is also different from the

USGS effort under the LSWRA study. Whereas the USGS validated the 1D model to measured sediment discharge below Conowingo Dam, the Exelon model was validated to volumetric bed change within the upper two reservoirs, much like the earlier 1995 study conducted by the USGS. Thus, the magnitude of sediment transport throughout the upper two reservoirs during the calibration and validation simulations is based on comparison of volumetric changes in the bed and not outflow of sediment through Conowingo Dam.

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

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?

Previous water quality models applied to the lower reservoir system were not movable bed models, and thus assumed the sediment and nutrients entering the upstream boundary transported through the reservoirs without interacting with the bed. The upper two reservoirs were assumed to be in dynamic equilibrium, thus assuming sediment pass through was considered a reasonable assumption. However, dynamic equilibrium suggests a long term stability of the bed (years or decades) and does not account for deposition and erosion occurring over shorter time scales. This model has the capability to account for temporal and spatial variations in sediment transport thus providing enhanced analysis capability.

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?

These models provide the capability to calculate a mass balance of sediment and nutrients through the reservoir system which is critical for assessing the impact of reservoir sedimentation on water quality in the Susquehanna River and ultimately Chesapeake Bay. The degree to which these models represent actual field conditions is highly dependent on input boundary condition data. Given sufficient high quality boundary condition data, the models will provide reasonable estimates of total sediment and nutrient loads throughout the reservoir system, thus providing a better understanding of how the system responds to not only average flow conditions, but also to flood events that periodically occur.

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 degree of certainty of modeling results is highly dependent on measured boundary conditions. The calibration procedures for the HECRAS model were adequate given the available hydrodynamic, sediment, and bed survey data. The flow and stage data sets provided by the USGS were complete for the simulation periods. However, suspended sediment data were lacking for discharges greater than 450,000 cfs, and thus it was necessary to extrapolate the data for higher flows at the upstream boundary (Marietta). Bed sediment grain size data were adequately represented in the model for both reservoirs. However, the erosion characteristics of the mixed sediment beds in the model were not measured, and thus were highly uncertain. Periodic bed surveys in both reservoirs provided adequate trends in bed change to enable an approximate volumetric calibration.

The model results indicate the system is net depositional even for a relatively large flow event such as Tropical Storm Lee (~600,000 cfs). Erosion of the bed mostly occurred in areas consisting of primarily sand, with minimal erosion of areas consisting of a mix of sand, silt, and clay. These mixed sediment areas occurred in channel reaches with the highest velocities and subsequent bed shear for the Tropical Storm Lee event.

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)?

The model provides the Chesapeake Bay program models with an input sediment boundary condition for Conowingo Reservoir. The modeling approach was appropriate and model results reflect sorting of the bed based on the volumetric calibration. However, the potential bed scour load range due to infrequent large storms should be represented by model simulations that vary the highly uncertain bed erosion coefficients. The Water Quality models used to rout sediment to Chesapeake Bay should consider this range of scour loads in their simulations.

This modeling effort represents a significant improvement over previous efforts in terms of how the model was applied and the calibration process. The USGS 1D model developed under the LSWRA study was calibrated to suspended sediment load data measured below Conowingo Reservoir. Approximately 98 percent of the measured data represented flows less than 400,000 cfs, with less than 1 percent representing flows on the order of 500,000 to 600,000 cfs. An exponential curve fit was applied to the data for predictive purposes. The result was that for the peak flow of the Tropical Storm Lee event, very high sediment loads were predicted to be discharged from Conowingo (5 million tons per day). The 1D modeling model was then calibrated to produce this sediment load at Conowingo Reservoir. To achieve this result either significantly higher sediment discharge entered the model upstream boundary at Marietta or and/or significant scour occurred in the reservoirs. The USGS model predicted approximately twice the load delivered to Conowingo Reservoir. The Exelon model results are based on

existing boundary condition data and calibration of bed change over time which is a more appropriate and meaningful approach. The Chesapeake Bay Program models should utilize the Exelon 1D model results for rating curve development below Holtwood Dam.

- 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 model results are only as good as the boundary conditions used to populate the model. Additional data collection activities are underway that should provide much needed information that will improve the quality of the simulations. Additional studies should be conducted on the erosion potential of mixed bed sediments in the reservoirs. Although general data are available in the literature, it is necessary to develop site-specific erosion coefficients for each reservoir.

The 1D model provides a useful and efficient method for evaluating sediment transport through reservoirs in series. However, these models have limitations in terms of representing flow distributions that vary laterally in channels and bed layer properties. A 2D model more thoroughly represents the physics of alluvial channels and may be more useful in evaluating site specific sediment transport.

The sediment transport models applied to the lower Susquehanna are limited by the inflowing sediment and bed sediment erosion data available. Until more definitive data become available, model sediment load output should be presented as a range of possible outcomes based on the uncertainty of variables in the model such as erosion coefficients.

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