

Peer Review:  
Conowingo Pond Mass Balance Model  
Exelon Generation Company, LLC  
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By:

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## **General Charge and Limits of the Review**

Exelon Generation Company, LLC (Exelon) submitted in January 2016 the “Proposal for Lower Susquehanna River Reservoir System Model Enhancements in Support of the 2017 Chesapeake Bay TMDL Midpoint Assessment.” That proposal outlined studies to be conducted in support of the 2017 Chesapeake Bay Total Maximum Daily Load Midpoint Assessment. Included in that proposal was the development of the Conowingo Pond Mass Balance Model (CPMBM). The (CPMBM) was intended to allow for an improved evaluation of the extent to which changes in sediment storage and nutrient bioreactivity within the Pond affect sediment and nutrient delivery to the Bay. That model was subsequently developed by HDR on behalf of Exelon and under management of Gomez and Sullivan Engineers, D.P.C. and consisted of coupled hydrodynamic, sediment transport, sediment nutrient flux and water quality mass balance models for Conowingo Pond. In addition to the model development, four external reviewers were selected through and in coordination with the Chesapeake Research Consortium (CRC) to provide independent reviews of the model enhancements.

The results of that model development are described in two reports produced in April 2017: “Conowingo Pond Mass Balance Model” and “Hydrodynamic and Sediment Transport Analyses for Conowingo Pond.” The charge for this review was limited to the sediment nutrient flux and water quality mass balance model for Conowingo Pond model.

## **Overview and General Comments**

The following represents this reviewers understanding of Conowingo Pond Mass Balance Model based on the subject report and prior information provided to facilitate the model development and review.

### *Data Sources and Analysis*

This section of the report provided the results on an in-depth review of historical sediment data as well as the University of Maryland Center for Environmental Science

(2015-2016) field and laboratory measurements. These data were used for model evaluation. In addition, the analysis of N was used to estimate diagenesis rates for G3. Commonly in diagenesis applications the diagenesis rate for G3 is assumed to be zero, but a non-zero rate was believed more reasonable for an application in which diagenesis of relatively deep sediments (with large G3 fractions) will be considered. This analysis was presented to the independent reviewers earlier in the study who agreed with the approach (e.g. memo dated 9 November 2016).

### *Model Overview*

The CPMBM was based on existing and widely accepted models which were applied by a highly respected and experienced modeling team. The hydrodynamic and sediment transport studies were based on the ECOM (Estuarine, Coastal, and Ocean Model) hydrodynamic framework along with its integrated SEDZLJS (SEDiment dynamics by Ziegler, Lick, Jones, and Sandford) sediment transport module, together referred to as ECOMSED. The application of ECOMSED is described in the report “Hydrodynamic and Sediment Transport Analyses for Conowingo Pond.” For the water quality mass balance model, ECOMSED provided the morphometry, changes in water elevation, advective flows and mixing. ECOMSED also provided changes in bed elevation based on deposition and erosion of sediments.

The water quality mass balance model was based on the Row, Column, and Advanced Ecological Simulation Program (RCA; Row-Column AESOP) water quality model developed by HDR. The RCA is a generalized water quality model capable of simulating the fate and transport of conventional and toxic pollutants in surface waters. For conventional pollution, state variables in RCA include dissolved oxygen, various forms of phytoplankton, dissolved inorganic nutrients, particulate organic nutrients, dissolved and particulate organic carbon.

RCA also includes a nutrient flux submodel developed for the USEPA Chesapeake Bay Program (DiToro and Fitzpatrick 1993) which simulates the deposition of organic matter to the sediment bed, the sequent diagenesis or decomposition and burial of this organic matter, and the resulting end-products of sediment oxygen demand and inorganic nutrient flux. The sediment flux model was originally described in Di Toro et al. (1990) and is also described in Di Toro (2001), Brady et al. (2013) and Testa et al. (2013). Versions of the sediment diagenesis submodel have also been incorporated into a variety of other models, such as the CE-QUAL-ICM, WASP, QUAL-2K and others.

The sediment flux (diagenesis) model (SFM) subdivides particulate organic matter (POM) into G classes, including G1 (labile; half-life of weeks to months), G2 (refractory; half-life on the order of a year), and G3 (inert components). The SFM model is driven by the flux of particulate organic matter (POM) from the water column in the form of

carbon, nitrogen and phosphorus (PON, POC, and PON) were the POM is subdivided into G1, G2 and G3 fractions based on an assumed reactivity (e.g. typically assumed to be 65 % labile or G1). Based on POM decomposition (diagenesis) in the sediments and anaerobic processes (nitrification, methanogenesis, etc.) the sediment model computes the distribution of POM among G classes as well as dissolved materials, which along with water column dissolved oxygen and dissolved nutrient concentrations are used to compute sediment oxygen demand and nutrient fluxes between the water column and sediment layer.

The original SFM (DiToro and Fitzpatrick 1993) was based on assuming a relatively thin (oxic) surface layer overlaying a somewhat thicker (approximately 10 cm) anaerobic sediment layer. That construction was adequate for the purpose of predicting sediment oxygen demand and nutrient fluxes. However that construct could not be used to predict the impact of deposition on the spatial distribution of POM in the sediments or scour on the sediment distribution and flux of sediments to the water column. Since the prediction of the deposition and scour of POM was a major goal of this study, HDR modified the SFM to include a “stack” of a series of layers (140 layers each 1 cm in thickness) overlying a deep bed layer (3 meters in depth). The construct was based on an existing sediment bed framework widely used in the toxicant model. The revised construct allowed estimation of the G-class distribution of POM and dissolved nutrients in each layer as well as the impact of the deposition and erosion of sediments (based on ECOMSED predictions). That modification allowed, for example, the prediction of the G-class composition of scoured POM which was critical to meet the objectives of this study. The modification is also considered to be a significant advancement in the SFM.

In addition to the coupled RCA and SFM, a stand-alone version of the original SFM was used in the analysis of historical data and data collected as part of this study. The stand-alone model did not include the impact of scour.

### *Model Application*

As this reviewer understands it, the model construct was designed largely to address two major questions:

- What is the reactivity (e.g. G1, G2, G3 carbon, nitrogen and phosphorus) of the material being scoured from the sediment bed and entering the water column?
- What is the composition (G1, G2 and G3 carbon, nitrogen and phosphorus) of the scoured nutrients entering the water column in Conowingo Pond and being transported out of Conowingo Pond into Chesapeake Bay?

As described above, ECOMSED provided the morphometry, changes in water elevation, advective flows and mixing to RCA. ECOMSED also provided the rates of

scour and deposition. Nutrient loadings entering Conowingo Pond were based on estimates from the watershed model (Phase 6, Beta 2) modified for Holtwood based on a computed flow balance from ECOMSED along with estimates of nutrient loads from ungauged sources. The ECOMSED application included inflows and the operation of the dam, which allowed variations in the water surface to be used as a check on mass balance. That analysis indicated that the inflows had to be recomputed to ensure a mass balance, which is not unusual in reservoir modeling studies.

The first model application was based on the stand-alone SFM. The boundary conditions for the application were based on the Chesapeake Bay watershed model (Phase 6, Beta 2) for Holtwood Dam (Lake Aldred), Muddy Creek, Broad Creek and Conowingo Dam (Conowingo Pond). For application in the stand-alone SFM these boundary conditions were converted to model input using the protocol developed for the Chesapeake Bay Program by Carl Cerco for use in the stand-alone SFM. As noted later (3.2 Calibration to Storm Event Data) the fractional split, such as between dissolved and particulate ON, were held constant regardless of flows (assumed 60% dissolved for the case of ON). The G-class splits (G1, G2, and G3) for phytoplankton were assigned based on DiToro and Fitzpatrick (1993), while the G-class splits for non-phytoplankton POM were estimated by model calibration (using the stand-alone SFM). However, as indicated, and given the lack of a multi-year calibration flux data set, there was some uncertainty as to which of the G-fraction splits provided the best calibration.

For the CPMBM the loads were first converted to concentrations and then applied with the revised flows (assumed by this reviewer to apply to all inflows) to compute loadings to Conowingo Pond, since the flows used (based on ECOMSED) varied from those from the Chesapeake Bay watershed model. It is also assumed by this reviewer that the protocols and splits as developed and tested, using the stand-alone SFM model (described above), were also utilized on the CPMBM.

Although RCA is capable of advanced eutrophication simulation, for this application water column nutrients were treated as non-reactive (conservative) and subject only to transport (advection and mixing) and settling. An exception was dissolved oxygen (DO) and aqueous CH<sub>4</sub>, where CH<sub>4</sub> oxidation represented a loss of DO in the water column. DO reaeration was also included. Predicted DO was then be checked against observations as an additional check of the application. The general approach was discussed during the course of the independent review process and is considered reasonable given the retention time of the system, lack of available water quality data in the surface water, and goals of the study.

The evaluation of the model application was based on comparing predictions to observations below the dam and in the sediment bed. The stand-alone model was first used while the ECOMSED model was in development. In the bed, comparisons were

only made for nitrogen and phosphorus. Comparisons with carbon fractions was problematic due to the presence and influence of coal. The model was run over an 18-year period from 1997-2015. Comparisons between observations and predictions were reasonable considering the lack of data to drive the model. Two management scenarios were then run to determine the impact of load variations on C, N, and P exported or trapped in the reservoir.

## Responses to Peer Review Questions

- 1. Question:** 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*?

**Response:** Yes.

In the above cited proposal the stated goal was to “enhance and complement the existing Phase 6 HSPF Watershed Model (HSPF) as well as the inputs to the Bay Water Quality and Sediment Transport Model (WQSTM).” To accomplish that goal, a two phased plan was developed, one phase of which was to develop a “coupled hydrodynamic, sediment transport, sediment nutrient flux and water quality mass balance model for Conowingo Pond – the Conowingo Pond Mass Balance Model (CPMBM).” As stated in the proposal this “model will allow for an improved evaluation of the extent to which changes in sediment storage and nutrient bioreactivity within the Pond affect sediment and nutrient delivery to the Bay. The output from this model combined with the results of the UMCES biogeochemical experiment being conducted as part of the Integrated Monitoring Program will allow for improved inputs to the WQSTM.”

This review dealt only with the water quality mass balance model (CPMBM), one component of the second modeling phase. That model was linked to the hydrodynamic model, which provided morphometric and transport information (advection, mixing). The sediment transport model provided erosion and sedimentation. The water quality portion of the model considers the fate and transport of dissolved and particulate nutrients within Conowingo Pond and its sediment bed. A key component of the water quality model was a sediment flux model enhanced to allow prediction of sedimentation and scour. That modeling system, along with data from the UMCES study, was used to develop estimates of the magnitude and composition of exports from the Conowingo Pond and the reactivity of those exports, in completion of the stated goals of the study.

- 2. Question:** Does the 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?

**Response:** Yes

The CPMBM effort produced a number of results/products that should be of added value, including:

- The data provided by the University of Maryland Center for Environmental Science (2015-2016) field and laboratory measurements conducted with funding provided by Exelon and under management of Gomez and Sullivan Engineers, D.P.C. These data should contribute to the understanding of the sediments and sediment dynamics in the Conowingo Pond.
- The information generated in the development and through application of the CPMBM, including:
  - An analysis of flows in order to achieve a water balance (from ECOMSED).
  - An analyses of the UMCES data and development of estimates of diagenesis rates.
  - An analysis of nutrient inputs entering Conowingo Pond from its upstream boundary from the USEPA CBP watershed model.
    - An analysis of the protocol used to partition those loads among model fractions (e.g. between dissolved and particulate ON).
    - An analysis of the G-class distribution of particulate-phase nutrients delivered to the Pond from the USEPA CBP watershed model.
  - An analysis of the confounding impacts of coal.
  - An analysis of spatial variations in Conowingo pond (e.g. decrease in sediment C, N, P along the length of the pond).
  - An analysis of the availability and quality of water column nutrient data in the surface water and sediment bed of Conowingo Pond.
  - Relationships between loads and nutrient exports from Conowingo Pond as a function of flow (e.g. such as during scour events).
  - An analysis of the nutrient trapping efficiency of Conowingo Pond (and changes in that efficiency with time and flows; e.g. maximum output/input about 2.5 during 2011).
  - The G-fractions for exported POM and changes in those fractions as a function of flow (e.g. higher G3, lower G1 and G2, during higher flows).

- The development of a suite of models which could and should be used and refined in subsequent studies as data become available to provide improved information to the watershed and bay models.

3. **Question:** 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.

### *Model Assumptions*

The models used in this study included ECOMSED, RCA (along with the coupled sediment flux model) and a stand-alone version of the sediment flux model. All of these models have all been widely used and accepted, so there was little reason to question the models or assumptions on which they were developed.

Then assumptions with regard to the HDR application include the grid geometry, inflows, dam controls (outflows), and sediment parameters discussed and reviewed separately. For the water quality mass balance model, the major assumption was that nutrients (dissolved and particulate) and phytoplankton acted as conservative materials, only subject to transport and settling. The exceptions were dissolved oxygen (subject to reaeration and depletion via methane oxidation) and methane (subject to oxidation). Given the residence time of the system and lack of data to support a more detailed eutrophication model, these assumptions seem reasonable.

### *Model Input*

#### Constants and Coefficients

The number of model input parameters was limited. The water quality mass balance model was driven by the hydrodynamic and sediment transport model, evaluated elsewhere. The linkage between the transport and RCA model is well established and has been used and tested in a wide variety of applications. Although the water quality model is capable of advanced eutrophication simulations, for this application simulated water quality constituents were only subject to transport and settling. Therefore, the only major input to the water column portion of the water quality mass balance model were the settling coefficients. The settling rates were based on a weighted-average of the clay and silt settling velocities provided by the sediment transport model, which seems reasonable. However, as noted in the water quality mass balance report, the settling rates resulted in excess settling in the upper portion of the pond, and hence while reasonable are a source of predictive uncertainty.

The majority of the input constants and coefficients impacting the water quality mass balance model were associated with the sediment flux model, both stand-alone and coupled with RCA. The sediment flux model requires specification of a relatively large number of rates and coefficients. However, the majority of these are considered constants and typically not altered in model applications (with possible exception of partition coefficients for phosphorus and a limited number of other coefficients). QUAL2K for example, does not allow user access to the rates and coefficients for the sediment flux model. The HDR modelers are also expert in the development and application of the sediment flux model. Therefore the assumptions and input for the sediment flux model are considered appropriate. One exception was the computation of the diagenesis rate of G3, commonly assumed inert with a decomposition rate of 0. However, since this application included deeply buried sediments it was reasonable to assume that a rate term should be utilized, which was derived from an analysis of the UMCES data.

### Model Parameters

Driving factors for the model application included flows and boundary conditions (or loads). A flow balance was achieved by the ECOMSED model, which adds some confidence to the flows. The nutrient and phytoplankton (as C) loads were obtained from the CB watershed model. While the only reasonable alternative, there was no way to test the inputs other than through their impact on reservoir exports and sediment concentrations.

In addition to estimates of external loads/concentrations, estimates were also required for converted the watershed model outputs to the forms of inputs simulated by the water quality mass balance model. The estimates were based on the protocols developed for the Chesapeake Bay model, which was reasonable. However, as stated in the CPMBM report, some of the ratios held constant should probably have been varied as a function of flow.

Finally, for external loads/concentrations, estimates of the split of the organic materials among G-classes was required. For phytoplankton, the estimates were based on commonly used values as originally proposed by DiToro and Fitzpatrick (1993). For non-phytoplankton OM, the splits were based on calibration using the stand-alone sediment flux model, which seemed reasonable.

### Model results

The determination of whether model performance is “reasonable” and the confidence that can be placed in model predictions is typically assessed by qualitative and quantitative statistical comparisons of model predictions and observations as described by Fitzpatrick (2009) in “Assessing skill of estuarine

and coastal eutrophication models for water quality managers.” The operative phase in this review question is “Given the data which were available to the modelers.” In this application, these comparisons were largely not possible due to the paucity of water quality data. For surface waters quality data were limited to temperature and dissolved oxygen data collected by Exelon during 1998-2000. Sediment data were limited to data collected by SRBC in 2000 and UMCES field efforts, both of which exhibited considerable spatial and sample variability. Model comparison were then limited to comparisons with the sediment data and observed water quality in the reservoir outflows from the Conowingo Dam. As a result the evaluation of the application and reasonableness of predictions has to be based more on a qualitative assessment. Confidence in the models and modelers lends credence to the model results, as well as hopefully the external expert reviews. Given the limitations of the model, as described in the Summary and Conclusions (Section 6), the CPMBM results are reasonable and support the stated conclusions.

4. **Question:** 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)?

**Response:** Yes

See response to questions 2-3

5. **Question:** 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.).

**Response:**

The CPMBM modeling framework is considered adequate given the goals of this study, particularly with the addition of multiple layers to the sediment flux model. No major deficiencies or improvements in the model structure (ECOMSED, RCA with the sediment flux model, or the stand-alone SFM) were noted. One improvement of the sediment flux model that could be considered would be the inclusion of iron as a state variable, along with iron speciation in order to more realistically capture the impacts of phosphorus sequestration in iron rich sediments.

The primary limitation of the model application to this study and potential future studies are the data that were available to drive the model and to evaluate model

predictions, both in the water column and bed. Given the relative importance of the export from this system the paucity of data available in Conowingo Pond is surprising to this reviewer. The development and implementation of a detailed monitoring plan to support further model development and application and the use of these data and models to develop a further understanding the processes in the Conowingo Pond and impacting its exports is recommended.