

## Understanding the Effect of the Conowingo Dam and Reservoir on Bay Water Quality

### Background

The Susquehanna River has a major influence on Chesapeake Bay water quality. The Susquehanna watershed is 43% of the land area in Chesapeake Bay watershed and provides about 47% of the freshwater flow to the Bay. With respect to nutrients and sediments, the Susquehanna delivers to the Bay about 41% of the nitrogen, 25% of the phosphorus and 27% of the sediment.

A large influencing factor in sediment and nutrient loads from the Susquehanna River watersheds to the Chesapeake Bay are the dams along the lower Susquehanna River, which historically have retained large quantities of sediment and associated nutrient in their reservoirs. The three major dams and their associated reservoirs along the lower Susquehanna River are the Safe Harbor Dam (Lake Clark), Holtwood Dam (Lake Aldred), and the Conowingo Dam (Conowingo Reservoir).

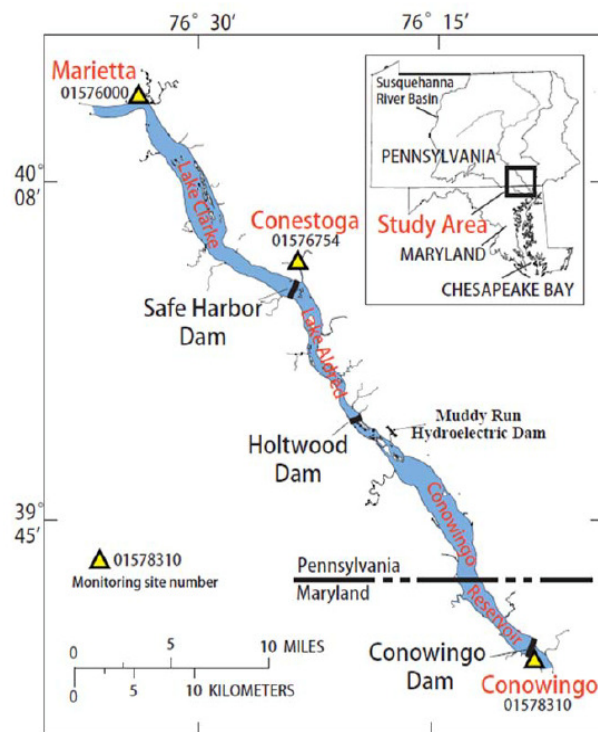


Fig 1 – Lower Susquehanna Reservoirs. Holtwood Dam was constructed in 1910 and reached dynamic equilibrium at about 1920. Safe Harbor Dam was constructed in 1931 and reached dynamic equilibrium at about 1950. Conowingo Dam was constructed in 1928 and in 2012 was reported to be at or near dynamic equilibrium.

The two most upstream reservoirs, Lake Clarke and Lake Aldred, have no remaining sediment trapping capacity and have been in long-term equilibrium for 50 years or more. Long-term equilibrium was assumed for these two reservoirs in the 2010 Bay TMDL. The Conowingo Reservoir was assumed to have some long-term trapping capacity remaining, but now current research has documented that that trapping capacity no longer remains.

A significant amount of monitoring and research has occurred between 2011 and 2016. In response to the Army Corps of Engineers Lower Susquehanna River Watershed Assessment (LSRWA) study recommendations for enhanced Conowingo monitoring and modeling, Exelon, owner and operator of the Dam, funded ~ \$3.5 million in enhanced Conowingo monitoring and modeling efforts between 2015 and 2016 to be used to help inform the 2017 Midpoint Assessment. In January 2016 a Scientific and Technical Advisory Committee (STAC) Workshop was held with the purpose to 1) compile the state of the science on the influence of Conowingo Reservoir infill on tidal Chesapeake Bay water quality and 2) advise the development of the Midpoint Assessment modeling tools. The workshop concluded with a general consensus with findings of the LSRWA study that the Conowingo Reservoir is essentially at a condition of “dynamic equilibrium” with regard to discharge of fine sediments and particle-associated nutrient loads. More specifically, there was recognition among the scientific community that on-going changes in the net trapping efficiency and sediment storage capacity of the reservoirs in the lower Susquehanna River Basin, primarily changes in Conowingo Pond, has impact on nutrient delivery to the Chesapeake Bay, which could limit progress in achieving the water quality and ecosystem goals of the Bay Agreement and Total Maximum Daily Load (TMDL).

Since the completion of the Bay TMDL, current scientific understanding is that the net reservoir trapping capacity is now at or near zero and as a result increasingly greater fractions of the total upstream load of total nitrogen (TN), total phosphorus (TP), and suspended sediment (SS) are now reaching the Bay when compared to reservoir conditions assumed in the Bay TMDL. Recent research, supported by first principles, indicates the loss of trapping has more influence on phosphorus and sediment. This means that relatively more phosphorus is likely to pass through the Conowingo Reservoir, when compared to historic rates, thereby increasing the Susquehanna River’s influence on main Bay dissolved oxygen (see Figure 2). There is a need to factor in how these changes influence water quality and habitat in the Bay because under full 2025 WIP implementation and a “dynamic equilibrium” Conowingo Reservoir condition the Chesapeake Bay water quality standards are estimated to be in nonattainment. The magnitude of the estimated nonattainment is currently being quantified with new information. The increased sediment load to the Bay, especially during high flow events, has been shown to have a short-term impact on water clarity, but does not appear to impact the attainment of the Bay water clarity standards.

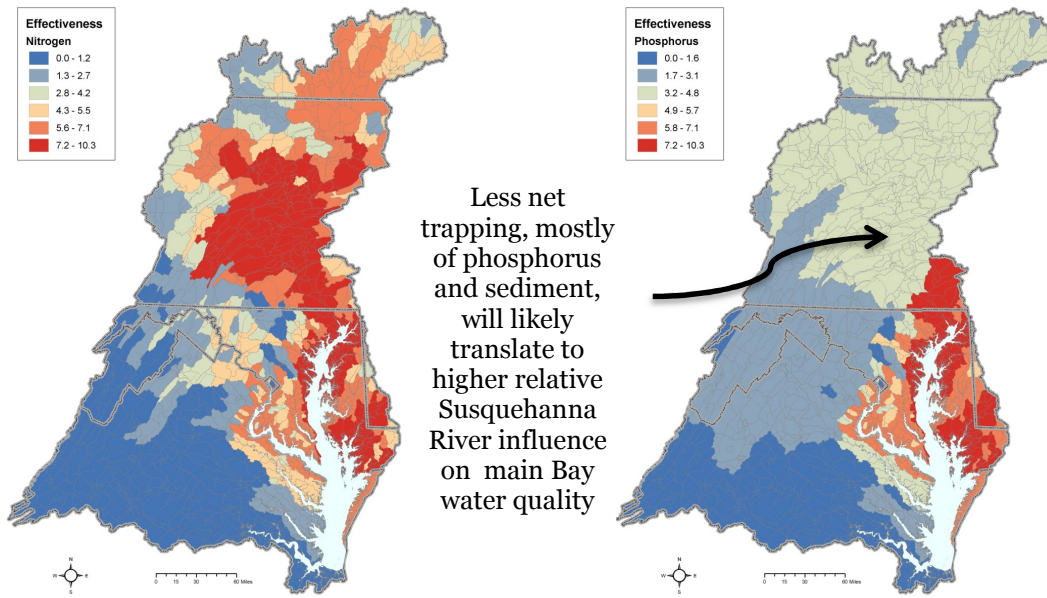


Figure 2 – The relative effectiveness (influence) of the Susquehanna River on main Bay dissolved oxygen is expected to increase as a result of diminished reservoir net trapping capacity.

### STAC Workshop on Conowingo Infill Modeling

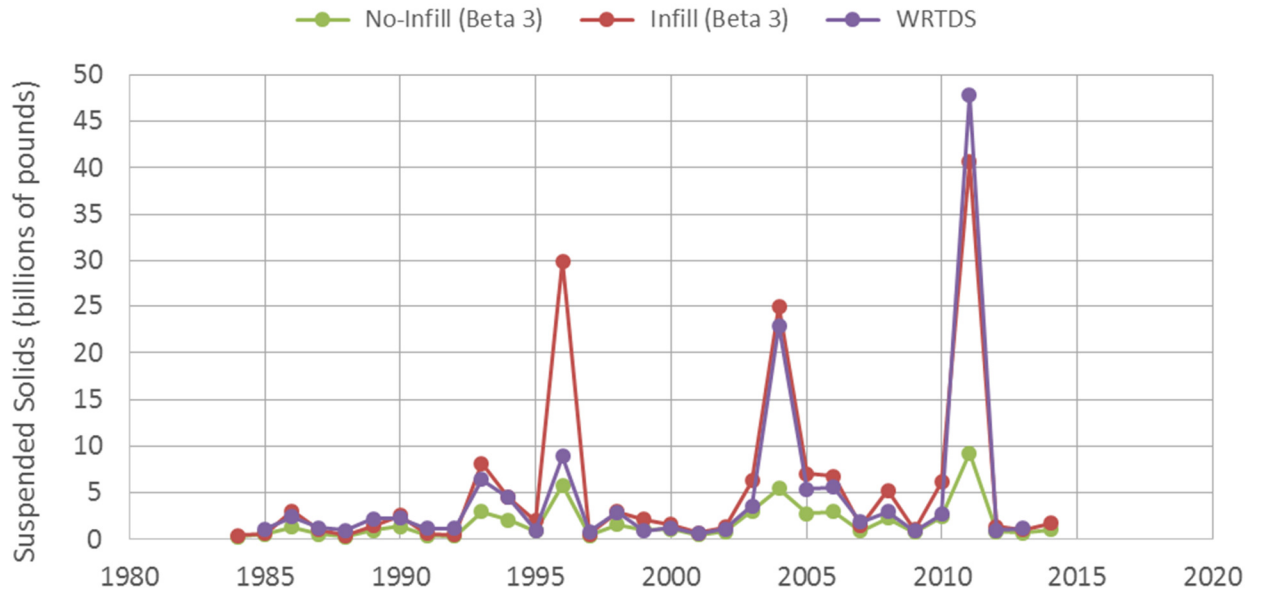
In January 2016 a STAC Workshop was held with the purpose to compile the state of the science on the influence of Conowingo Reservoir infill on tidal Chesapeake Bay water quality. There was recognition among the scientific community that on-going changes in the net trapping efficiency and sediment storage capacity of the reservoirs in the lower Susquehanna River Basin, primarily in the Conowingo Reservoir, could have substantial impact on nutrient delivery to the Chesapeake Bay, which could limit progress in achieving the water quality and ecosystem goals of the Bay Agreement and TMDL. Relative to the first nine decades since the Conowingo Dam completion, increasingly greater fractions of the total upstream load of total nitrogen (TN), total phosphorus (TP), and suspended sediment (SS) are now reaching the Bay.

The STAC workshop report recommended that to quantify the influence that Conowingo infill has on Chesapeake Bay water quality, the following processes must be considered in the Conowingo Reservoir:

- Increased sediment and nutrient loads from scour during relatively rare extreme events;
- Decreases in the scour threshold during moderately high flow events;
- Loss of trapping capacity during low and moderate flow; and
- A variety of biogeochemical processes that influence the mobility, fate, and bioavailability of the nutrients present in the reservoir be represented.

## Modeling Approach

The Modeling Workgroup is using the multiple new sources of information including: 1) published statistical model results based on Weighted Regressions on Time, Discharge, and Season (WRTDS) modeling including Hirsch (2012) and Zhang et al. (2014, 2016), 2) physically based models such as HEC-RAS2 models of Lake Clark and Lake Aldred, 3) the sediment transport and diagenesis simulation of the Conowingo Pool Model (CPM), and 4) historic water quality observations and measured bathymetry/infill. A simulation of the of Conowingo infill including all of the elements (except for the only recently completed CPM) is now fully operational in the *Beta 3* calibration of the Phase 6 Model (Figure 3).



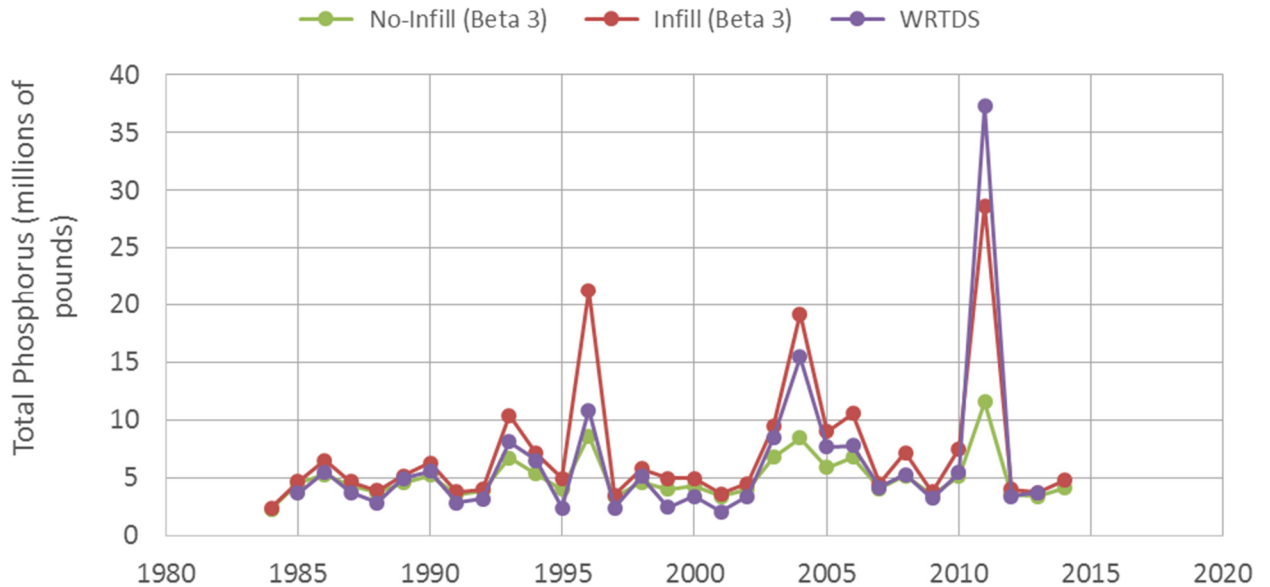


Figure 3. The estimated Phase 6 *Beta 3* sediment and phosphorus discharges from Conowingo are simulated under Conowingo no-infill conditions and Conowingo infill conditions with the Phase 6 *Beta 3* Watershed Model. As a comparison, the WRTDS estimated sediment and phosphorus loads first most closely follows the no-infill conditions (green line) in the early period of simulation but then more closely approximates the infill simulation (red line) in the later period as expected.

The Phase 6 simulation of the Conowingo Reservoir captures reservoir behavior under various flow & infill conditions through the adjustment in the calibration of increased scour and decreased settling as infill increases in the Conowingo. In addition, the biogeochemical reactivity of Conowingo Reservoir scoured material that is delivered to the tidal Bay is represented

Peer review of the Modeling Workgroup representation of the Conowingo infill will be through separate STAC peer reviews of the Phase 6 and Bay Model simulations as well as a Chesapeake Research Consortium (CRC) peer review of the HES-RAS2 and CPM simulations.

### **The 2010 Chesapeake Bay TMDL Position Regarding Potential Infill**

The 2010 Chesapeake Bay TMDL documented that EPA's intention with respect to the reservoir infill was to assume the trapping capacity would continue through the planning horizon for the TMDL (through 2025). The decision was based upon science available at that time which indicated that the Conowingo Reservoir was anticipated to reach a steady state in 15 – 30 years, depending on future loading rates, scour events, and trapping efficiency. The steady state condition was estimated to be at the limits of the planning horizon for the TMDLs (2025) and, depending on conditions, could be well beyond the planning horizon.

Under these assumptions, the basin-jurisdiction targets were established based on the Phase 5.3.2 modeled conditions at the dam. This has been determined to be about a mid-1990's infill condition. This also means that future diminished trapping capacity behind the Conowingo Dam, or a near full condition, was not considered in developing of the basin-jurisdiction targets.

The 2010 Bay TMDL Appendix T stated that if future monitoring shows the trapping capacity of the Conowingo Dam is reduced, then EPA would consider adjusting the Pennsylvania, Maryland, and New York 2-year milestone loads based on the new delivered loads. The adjusted loads would be compared to the 2-year milestone commitments to determine if the states are meeting their target load obligations.

Finally, the TMDL stated that future increases in sediment and phosphorus downstream of the dam can be minimized by making implementation activities above the dam a management priority. This will decrease the overall loads of sediment and phosphorus, and extend the time until trapping capacity is reached. Ultimately, the states should work together to develop an implementation strategy for the Conowingo Dam and take the opportunity to work with the Federal Energy Regulatory Commission (FERC) and Maryland State Agencies during the Exelon relicensing process for Conowingo Dam.

### **WQGIT Policy Considerations**

Based upon the STAC feedback, recent scientific information, and the likely need for additional nutrient and sediment reductions beyond those currently in the Bay TMDL, there are three policy considerations. The first two are to reaffirm that the both the hydrologic averaging period and critical period are sufficient to address the primary water quality impacts as a result of the infill conditions. The third policy consideration is how to assign additional load reductions.

#### **Reaffirm the Hydrologic Averaging Period**

The 10-year hydrologic averaging period for modeling and reporting purposes represents a typical or representative long-term hydrologic condition for the waterbody. The hydrologic averaging period is used for expressing average annual loads from various sources. It is important that the hydrologic period be representative of the long-term hydrology. The Bay TMDL defined the hydrologic period as the 10-year period from 1991 to 2000.

#### **Reaffirm the Critical Period**

The 10-year hydrologic averaging period is different from the 3-year critical period, which defines a period of high stress. In the Chesapeake Bay, EPA has found that as flow and associated nitrogen and phosphorus loads increase, DO and water clarity levels decrease (Officer 1984). Therefore, EPA bases the critical period for evaluation of the

DO and water clarity WQS on high-flow periods. Those periods were identified using statistical analysis of flow data as the 3-year period of 1993-1995.

The Chesapeake Bay Program's Water Quality Goal Implementation Team decided that the critical period would be selected from the previously selected hydrologic period 1991–2000 because that time frame is representative of long-term hydrology, is within the model calibration period, and would facilitate modeling operations (see Sections 6.2.1 and 6.5.1 and Appendix F). A 3-year period was selected to coincide with the Chesapeake Bay water quality criteria assessment period (USEPA 2003).

The Water Quality Goal Implementation Team also agreed that the critical period should be representative of an approximate 10-year return period. The team believed that 10 years was a good balance between guarding against extreme events (greater than 10-year return frequency) and ensuring attainment during more frequent critical events (occurring within less than a 10-year period). The selection of a 10-year return period was also based on the commonly applied 10-year return period for application of the 7Q10 low flow conditions. Finally, the 10-year return period is also consistent with the critical periods selected for other TMDLs developed and published by the Chesapeake Bay watershed jurisdictions. The critical period was selected as 1993 through 1995.

### **Assigning Responsibility to Increased Nutrient and Sediment Loads**

Recent estimates indicate nutrient and sediment loads from the Susquehanna River to the Chesapeake Bay are now higher than previously reported because of Conowingo infill, meaning additional reductions will be required.

A fundamental question for the partnership is how to allocate the additional nutrient and sediment loads coming over Conowingo Dam due to the Conowingo Reservoir reaching its capacity to trap nutrients and sediments. In order to inform this process, the following list of options has been developed. The options should be considered as a full array, recognizing that some options may be deemed non-viable upon closer consideration.

Table 1 – Menu of options to assign additional reduction responsibility as a result of Conowingo reservoir now in dynamic equilibrium.

Option	Description	WIP Implementation Considerations	Equity Considerations	Technical Considerations
<i>#1: Assign additional reductions to all jurisdictions</i>	Reallocate state-basin planning targets using the Bay TMDL allocation methodology but assume that the Conowingo Dam and Reservoir are now in a state of dynamic equilibrium.	This option will likely result in an explicit increase in the level of effort required to meet the states' CB water quality standards. The decision to select this option will require consideration of how changes to relative effectiveness will impact equity, and the ability of jurisdictions to reach the new Phase III WIP planning targets by 2025.	<p>Is consistent with current Bay TMDL allocation methodology and principles and is a comprehensive way of addressing additional loads from Conowingo.</p> <p>Could increase level of effort for jurisdictions not directly responsible for increased loads from an infilled Conowingo Dam and Reservoir.</p> <p>All jurisdictions have directly (improved Bay water quality) or indirectly (higher allocations) benefitted from the trapping capacity of the reservoir system since the Dam's completion in 1928</p>	The decision support tools exist to implement this option in sequence with other decisions related to development of the Phase III WIP planning targets.
<i>#2: Assign additional reductions to upstream (Susquehanna) jurisdictions</i>	Reallocate state-basin planning targets using the Bay TMDL allocation methodology assuming that the Conowingo Dam and Reservoir are in a state representative of the Bay TMDL (mid-1990s). Determine the additional reductions necessary to offset the effect of the Conowingo at dynamic equilibrium and assign additional reductions to the	This option will likely result in an explicit increase in the level of effort required by jurisdictions upstream of the Conowingo Dam to meet the states' CB water quality standards.	<p>Is consistent with the proposed principle of upstream responsibility outlined in Appendix T of the 2010 Bay TMDL.</p> <p>Places an increased burden on the three upstream states, viewed as a inequity and could hinder partnership buy-in.</p> <p>Assumes the three upstream states are responsible for the filling of the reservoir system, and should be held accountable, but does not recognize the</p>	The decision support tools exist to implement this option in sequence with other decisions related to the development of the Phase III WIP planning targets.



Option	Description	WIP Implementation Considerations	Equity Considerations	Technical Considerations
	three upstream jurisdictions—MD, PA and NY—using the allocation principles. .		benefit Conowingo has had on other States targets.	
<i>#3: Exchange reductions between nitrogen and phosphorus</i>	Balance the level of effort required to meet nitrogen and phosphorus targets assuming the Conowingo reservoir is in dynamic equilibrium. This allows for the exchange of nitrogen for phosphorus and phosphorus for nitrogen loads, all while ensuring water quality standards are achieved. The rationale is that nitrogen and phosphorus move through the dam/reservoir system differently and as a result of decreased trapping capacity, phosphorus loads have increased proportionally more than nitrogen.	This option would require consideration of how a nutrient exchange would impact/help jurisdictions' abilities to meet their nutrient and sediment reduction targets. For example, according to 2015 Progress results, Pennsylvania is currently on trajectory to meet their planning targets for P by 2025, but is not on trajectory to meet their planning targets for N. Establishing a phosphorus for nitrogen load reduction exchange may help PA to achieve a higher phosphorus load reduction (benefiting local Susquehanna waters) and lower nitrogen load reduction. This option could be combined with several of the other described allocation methodologies.	Individual states' local waters, not just the tidal waters of the main Bay, might benefit more from higher nitrogen or phosphorus loading reductions while, again, still ensuring Bay water quality standards are achieved.  Provides a degree of flexibility to balance the level of effort between N and P in meeting the targets	Any recommended N:P exchanges would need to be confirmed to still lead to achievement of the states' CB water quality standards.  At this point in time, the Phase 6 suite of Partnership models' N:P exchange rates are unknown. The CBP Modeling Workgroup plans to update the Phase 5 N:P exchange rates using the Phase 6 suite of models once the final versions of those models are approved by the Partnership in May 2017. Until that time period, the partners can use the Phase 5 N:P exchange rates as reasonable surrogates for planning purposes.
<i>#4: Apply special cases</i>	Reallocate state-basin planning targets using the Bay TMDL allocation methodology assuming that the Conowingo Dam and	This option will likely result in an explicit increase in the level of effort required to meet the CB water quality standards. The decision to	Is consistent with the current Bay TMDL allocation principles. This option will increase responsibility on to downstream states.	The tools exist to implement this option in sequence with other decisions related to the Phase III WIP planning targets. Consideration for how special

Option	Description	WIP Implementation Considerations	Equity Considerations	Technical Considerations
	Reservoir are now in a state of dynamic equilibrium. Apply special case adjustments for the upstream states consistent with those applied in the Bay TMDL.	select this option will require consideration of how special cases would be determined and quantified.		cases would be determined is needed.
<i>#5: Resource optimization or cost minimization</i>	Allocate the additional required reduction, as a result of the Conowingo infill, using a least cost solution with no consideration of political boundary. Then, divert financial resources to the areas of the watershed with additional assigned reductions	<p>While additional reductions are considered, it is unknown as to which jurisdictions would be impacted more and the type of funding that could be redirected.</p> <p>Also, significant consideration would need to be given to establishing a process that would ensure additional resources be diverted to areas of the watershed with the greatest increase in level of effort, while also ensuring that other regions do not have their implementation efforts negatively impacted.</p>	<p>This option would provide a cost-effective, pollutant load reduction solution for addressing increased loads from the infill Conowingo Dam and Reservoir.</p> <p>This option would likely increase the level of effort in specific concentrated regions across the watershed.</p> <p>A process would need to be established to ensure that financial resources are diverted to areas requiring additional reductions.</p>	<p>Technical ability to implement this option at this time is very low. The development of the Phase 6 BMP optimization tool is just beginning and is not scheduled for operational application by the partners until late 2017.</p> <p>This option would require constraints to be clearly defined for the optimization scenario which have not been determined at this time.</p>
<i>#6: Allocate with deferred implementation</i>	Assume that the Conowingo Dam and Reservoir are now in a state of dynamic equilibrium and quantify the projected impacts to the jurisdictions. However, additional loads from Conowingo will not be explicitly factored into	<p>The 2025 Target would be set under Conowingo trapping capacity assumed in the Bay TMDL. Additional reductions would be required sometime after 2025.</p> <p>Selecting this option would mean that the Phase III WIP</p>	This option would establish the partnership's commitment to addressing additional load reductions from the infilled Conowingo Dam and Reservoir but provide more time beyond 2025 planning horizon to address impacts, which was the time horizon under the Bay TMDL.	The tools exist to implement this option in sequence with other decisions related to the Phase III WIP planning targets.

Option	Description	WIP Implementation Considerations	Equity Considerations	Technical Considerations
	Phase III WIP 2025 planning targets. Instead, partners would establish a timeframe, beyond 2025, by which the additional nutrient and sediment loads resulting from infill of the Conowingo Dam and Reservoir reaching a state of dynamic equilibrium would be addressed.	2025 planning targets would not result in attainment of the states/ CB water quality standards.	Consideration would need to be given to an appropriate timeframe for addressing additional loads from the infilled Conowingo Dam and Reservoir, and how those additional loads would be allocated among the jurisdictions.	
<i>#7: Establish Phase III WIP planning targets with deferred implementation</i>	Reallocate state-basin planning targets using one of the allocation methods described in Options 1 and 2. Phase III WIP would include plans for achieving all necessary reductions, but could also establish a timeframe, beyond 2025, by which the additional loads resulting from Conowingo reaching a state of dynamic equilibrium would be addressed.	Selecting this option would likely mean that the implementation level come 2025 would not result in water quality standards attainment. Consideration would need to be given to an appropriate timeframe for addressing additional loads from Conowingo. Could be used in combination with options 3 and 4.	Consideration would need to be given to an appropriate timeframe for addressing additional loads from the infilled Conowingo Dam and Reservoir.	<i>Pro:</i> This option would establish the partnership's commitment to addressing loads from Conowingo but provide more time to assess impacts and understand and develop response options. <i>Con:</i> Implementation level come 2025 would not result in water quality standards attainment. <i>Technical Feasibility:</i> The tools exist to implement this option in sequence with other decisions related to the Phase III WIP planning targets.

A final consideration is how Maryland's 401 Water Quality Certification and the Federal Energy Regulatory Commission relicensing will factor into assigning responsibility for the water quality impacts. Exelon has been a willing participant and a financial contributor in the Conowingo Dam enhanced monitoring and modeling efforts. Determining Exelon's responsibility in

addressing excess sediments and nutrients delivered to the Bay now that the Dam has reached a state of “dynamic equilibrium” is a key component of the relicensing process.

## **Timeline**

### **2016**

- January 13-14 – STAC Conowingo Workshop
- March 2016 – Release of Army Corps of Engineers Lower Susquehanna River Watershed Assessment final report.
- August 9 -10 – Modeling Workgroup Quarterly Review. Review modeling revisions and data incorporation. Beta 3 release.
- August 24 – Conowingo synthesis meeting with key experts (Bob Hirsch, Jeff Cornwell).
- Late August – Release of STAC Conowingo report
- October 4-5 – Modeling Workgroup Quarterly Review. Initial presentations on Conowingo infill and preparation for WQGIT
- October 20 – Midpoint Assessment - CBP Conowingo Infill Webinar in preparation for WQGIT
- October 24-25 – WQGIT. First presentation to partnership policy makers
- November 2016 – CBP Management Board meeting decision on recommendations to the Principals’ Staff Committee regarding allocation of additional loads
- December 2016 – CBP Principals’ Staff Committee meeting decision on allocation of additional loads

### **2017**

- January 2017 TBD 2017 – CBP Modeling Workgroup Quarterly Review meeting with presentations of the simulation of the reservoir system at infill
- February 27, 2017 – CBP Water Quality Goal Implementation Team meeting briefing by CBP Modeling Workgroup co-chairs on findings from further analyses of the effects of the Conowingo Reservoir infill on upper Bay water quality
- March TBD 2017 – Webinar on findings from further analyses of the effects of the Conowingo Reservoir infill on upper Bay water quality

- April 10 2017 – CBP Water Quality Goal Implementation Team meeting decision on recommendations to the Management Board on how and when to fully offset the additional nutrient and sediment loads due to the Conowingo Reservoir infill
- April 13 2017 – CBP Management Board meeting decision on recommendations to the Principals’ Staff Committee on how to fully offset the additional nutrient and sediment loads due to the Conowingo Reservoir infill
- May TBD 2017 – CBP Principals’ Staff Committee meeting decision on how to fully offset the additional nutrient and sediment loads due to the Conowingo Reservoir infill
- June 2017 – Release of Phase 6 Model
- June 2017 – EPA releases the draft Phase III Watershed Implementation Plans planning targets
- December 2017 – EPA releases the final Phase III Watershed Implementation Plans planning targets