Executive Summary

The U.S. Army Corps of Engineers, Baltimore District (USACE), and the Maryland Department of the Environment (MDE) partnered to conduct the Lower Susquehanna River Watershed Assessment (LSRWA). This report presents assessment efforts and documents findings.

The purpose of this assessment was to analyze the movement of sediment and associated nutrient loads within the lower Susquehanna watershed through the series of hydroelectric dams (Safe Harbor, Holtwood, and Conowingo) located on the lower Susquehanna River to the upper Chesapeake Bay. Critical components of this watershed assessment included: (1) use of hydrologic, hydraulic, and sediment transport models to link incoming sediment and associated nutrient projections to in-reservoir processes at the dams and to estimate impacts to living resources in the upper Chesapeake Bay; (2) identification of watershed-wide sediment management strategies; and (3) assessment of cumulative impacts from sediment management strategies on the upper Chesapeake Bay ecosystem. This assessment represents an increase in understanding that may be used to inform stakeholders undertaking efforts to manage the lower Susquehanna River watershed and restore the Chesapeake Bay.

Environmental History

The Chesapeake Bay ecosystem is substantially degraded today from historic conditions by human activities. Erosion of farmland, mined land, and logged areas in the watershed delivered immense quantities of sediment to rivers. Bay sediment loads peaked in the late 1800s and early 1900s, and then subsequently declined. Some increase in algal blooms and reduction in water clarity began to occur in the Bay at about the time of peak sediment loads. Following World War II, nutrient loads increased substantially (largely from fertilizer) causing eutrophication, and Bay oxygen levels underwent a precipitous decline. Over the last several decades, between 15 and 25 percent of the Bay water volume has severely low levels of oxygen annually in warm water months, greatly reducing its quality as habitat for aquatic life.

Oyster populations which formerly filtered Bay waters are reduced to less than 1 percent of historic levels from overharvesting through the 19th and 20th centuries, and mortality from exotic diseases that began in the 1950s (NOAA, 2015). Diminished oyster populations no longer produce sufficient shell to maintain oyster beds, which then are gradually buried by sediment and become unsuitable for oyster reestablishment. Loss of oyster filtration contributed to worsening of water clarity. Oysters are naturally vulnerable to impacts of large freshwater inputs to the Bay from major storms.

Submerged aquatic vegetation (SAV) declined in the 1960s accompanying worsening water clarity from eutrophication and oyster loss, and then underwent dramatic decline from impacts of Hurricane Agnes in 1972. The timing of Hurricane Agnes was particularly devastating, as its massive influx of freshwater occurred during the growing season for the aquatic grasses. SAV recovered somewhat in subsequent decades to occupy between about 20 to 50 percent of its historic bottom area in accompaniment with Bay and watershed environmental management efforts. SAV shows substantial interannual variation driven by variation in precipitation and nutrient and sediment loading.

Watershed is the Principal Source of Sediment

Sediment and associated nutrients from the lower Susquehanna River watershed have been transported and stored in the areas (reservoirs) behind the dams over the past century. The dams have historically acted as sediment traps, reducing the amount of sediment and associated nutrients reaching the Chesapeake Bay. The Chesapeake Bay ecosystem is impacted both physically and biologically by the delivered sediment load from the Susquehanna River basin. These impacts are exacerbated by large storm and flood events which scour additional sediment and associated nutrients from behind the dams on the lower Susquehanna River and adversely affect the Chesapeake Bay ecosystem.

However, while the impacts of all three dams and reservoirs on the Chesapeake Bay ecosystem are important, this assessment estimates that the majority of the sediment load from the lower Susquehanna River entering the Chesapeake Bay during storm events originates from the watershed rather than from scour from the reservoirs. But, storm characteristics are highly variable and variations in track, timing, and duration can alter the amount of sediment entering the system from both the watershed and from behind the dams. Consequently, the relative proportion of sediment originating from reservoir scour versus from watershed contributions also varies. Additionally, the proportion of sediment sources is not universal to all storms, but the estimate described below provides a good sense of magnitude.

It was estimated that during a major storm event, that is, one that occurs on average every 4 to 5 years, approximately 20 to 30 percent of the sediment that flows into Chesapeake Bay from the Susquehanna River is from scour of bed material stored behind Conowingo Reservoir, and the rest is from the upstream watershed (which includes scour from behind Holtwood and Safe Harbor Dams). During lower flow periods, the three reservoirs act as a sediment trap and, in essence, aid the health of the Bay until the next high-flow event occurs. Given the often smaller contribution of the sediment load to the Bay from Conowingo Reservoir scour in comparison to the watershed (under most hydrologic conditions), the primary impact to aquatic life in the Bay is from sediment and nutrients from the Susquehanna River watershed and the rest of the Chesapeake Bay watershed. However, both sources of sediment and nutrient loads, reservoir scour and watershed load, should be addressed to protect aquatic life in Chesapeake Bay.

The seven Chesapeake Bay watershed jurisdictions (Delaware, District of Columbia, Maryland, New York, Pennsylvania, Virginia, and West Virginia) have developed watershed implementation plans (WIPs), which detail how each of the Bay watershed jurisdictions will meet their assigned nitrogen, phosphorus, and sediment load allocations as part of the Chesapeake Bay total maximum daily loads (TMDLs), and achieve all dissolved oxygen (DO), water clarity, SAV, and algae (measured as chlorophyll) levels required for healthy aquatic life. Implementation of the WIPs was estimated to have a far larger influence on the health of Chesapeake Bay in comparison to scouring of the lower Susquehanna River reservoirs.

Modeling done for this assessment estimated that currently more than half of the deep-channel habitat in the Bay is frequently not suitable for healthy aquatic life. However, it was estimated that even with full implementation of the WIPs and subsequent achievement of the reduced nitrogen, phosphorus, and sediment loads documented in the Chesapeake Bay TMDL (which should yield 100 percent suitable habitat for aquatic life), DO levels required to protect aquatic life in the Bay's deeper northern waters will not be achieved (in 3 of the 92 Bay segments). An increased frequency of scour and the amount of scoured sediment and associated nutrients from behind the dams on the lower Susquehanna River is a major contributor to these results.

Loss of Long-Term Trapping Capacity

Since the 1990s, scientists raised concerns over impacts to Chesapeake Bay from the lower Susquehanna River dams filling to capacity, and consequent increased delivery of sediments and associated nutrients to the Bay. These concerns were founded on the large total quantities of sediments and nutrients that would be transported. This scientific information supported a widely held view among government agencies, academics, and the public that once Conowingo Dam filled to capacity, severe downstream impacts to Chesapeake Bay would occur. These concerns served as the impetus for conducting this assessment. Only limited consideration was given to the relative bio-availability of nutrients contained in these riverine sediments versus the nutrients delivered to the Bay in other forms in these earlier risk analyses. Findings of this assessment, and other recent scientific investigations referenced in the report, reexamine these earlier scientific views.

This assessment concludes that each of the three reservoirs' sediment trapping capacity is greatly reduced and that each reservoir has reached an end state of sediment storage capacity. The evaluations carried out through this assessment demonstrate that Conowingo Dam and Reservoir, as well as upstream Safe Harbor and Holtwood Dams and their reservoirs, are no longer trapping sediment and the associated nutrients over the long term. Instead, the reservoirs are in a state of dynamic equilibrium.

In this dynamic equilibrium state, sediment and associated nutrients will continue to accumulate in the reservoirs until an episodic flood (scouring) event occurs. That is, there is no absolute capacity or point at which the reservoir is "full" and will no longer trap sediment and associated nutrients. Storage capacity will increase after a scouring event, allowing for more deposition within the reservoir in the short term. This state is a periodic "cycle" with an increase in sediment and associated nutrient loads to the Bay from scour also resulting in an increase in storage volume (capacity) behind the dam, followed by reduced sediment and associated nutrient loads transported to the Chesapeake Bay due to reservoir deposition within that increased capacity.

Dynamic equilibrium does not imply equality of sediment inflow and outflow on a daily, monthly, or even annual basis, or similar time scale. It implies a balance between sediment inflow and outflow over a long time period (years to decades) defined by the frequency and timing of scouring events. Sediment and associated nutrients that accumulate between high-flow events are scoured away during storm events, whereby accumulation begins again. Over time, there is no net storage or filling occurring in the reservoirs.

The reservoirs are trapping a smaller amount of the incoming sediment and associated nutrient loads from the upstream watersheds, and scouring more frequently in comparison to historical amounts. For example, upon comparing 1996 bathymetry data to 2011 data, this study estimated that the decrease in reservoir sediment trapping capacity from 1996 to 2011 (within the Conowingo Reservoir) resulted in a 10-percent increase in total sediment load to the Bay (20.3 to 22.3 million tons), a 67-percent increase in bed scour (1.8 to 3.0 million tons), and a 33-percent decrease in reservoir sedimentation (6.0 to 4.0 million tons) over the period of analysis. These additional loads, due to the loss of sediment and associated nutrient trapping capacity in the Conowingo Reservoir, are causing adverse impacts to the Chesapeake Bay ecosystem. These increased loads need to be prevented or offset to restore the health of the Chesapeake Bay ecosystem.

Nutrients, Not Sediment, Have the Greatest Impact on Bay Aquatic Life

Modeling work completed for this assessment estimated that the sediment loads comprised of sand, silt, and clay particles from scouring of Conowingo Reservoir during storm events, are not the major threat to Chesapeake Bay water quality and aquatic life. For most conditions examined, the sediment scoured from the reservoir behind the dam generally settle out on the bottom of the Bay within a period of days to weeks and generally before the period of the year during which light levels in the Bay's shallow waters are critical for the growth of underwater bay grasses or SAV. If a storm event occurs during the SAV-growing season, burial and light attenuation impacts could occur causing damage to SAV.

Conversely, the nutrients associated with the scoured sediment were determined to be more harmful to Bay aquatic life than the sediment itself. The particulate nutrients settle to the bottom and are recycled back up into the water column in dissolved form and stimulate algal production. Algal organic matter decays and consumes oxygen in the classic eutrophication cycle. As a consequence, DO in the Bay's deep-water habitat is diminished following Conowingo scour events.

Additionally, increased algal growth (living and then dead) create murky waters that impede water clarity limiting growth of SAV. The primary impact to Bay aquatic life from the Susquehanna River watershed and the high river flows moving through the series of dams and reservoirs is lower dissolved oxygen concentrations and reduced water clarity from increased algal growth. It is the nutrients associated with the sediment that are the most detrimental factor from scoured loads to healthy Bay habitats and aquatic life versus sediment alone. Study findings are in accordance with scientific developments recognizing the effects of nutrients and algae upon suspended sediments (and water clarity) in the Bay, and emerging consensus that excess sediment independent of nutrients is a lower level stressor to the Bay than was previously thought (CBP STAC, 2007; CBP STAC, 2014).

Sediment Management Strategy Analysis

This assessment included a survey-level screening of management strategies to address the additional loads to Chesapeake Bay from scour. Sediment management in aquatic environments is a USACE agency mission activity. The focus was managing and evaluating sediment loads with the understanding that there are nutrients associated with those sediment loads; thus, in managing sediment, one is also managing nutrients. Potential sediment management measures were formulated in accordance with long-established concerns over potential impacts of excess sediments from the Susquehanna River impacting Chesapeake Bay, as described previously.

A variety of sediment management strategies were considered to reduce the amount of sediment available for a future storm (scour) event. Sediment management strategies were broadly divided into: (1) reducing sediment yield from the Susquehanna River watershed (reducing sediment inflow from upstream of the three reservoirs above what is required for the jurisdictions' WIPs); (2)

minimizing sediment deposition within the reservoirs (routing sediment around or through the reservoir storage); and (3) increasing or recovering volume in the reservoirs.

Additional management strategies for reducing sediment yield from the Susquehanna River watershed beyond the WIPs appear to be higher in cost, and ultimately, have a low influence on reducing the amount of sediment available for a storm event. This is because the majority of the effective lower cost opportunities to manage sediment are already being pursued in Pennsylvania, New York and Maryland's WIPs to meet the Chesapeake Bay TMDL mandated by the U.S. Environmental Protection Agency (USEPA, 2010a).

Sediment bypassing (minimizing sediment deposition behind the dams), defined here as routing sediment around reservoirs and downstream, appears to be lower in cost in comparison to other management strategies, but ultimately increases the total sediment and associated nutrient loads to the Bay and has high adverse impacts to the Chesapeake Bay ecosystem. As a result of the continuous discharge of nutrients associated with the bypassed sediment, conditions with lower DO concentrations would be produced. Increased algae levels are roughly 10 times greater than the benefits gained from reducing future scour from the Conowingo Reservoir.

Increasing or recovering storage volume of reservoirs via dredging or other methods is possible, but the Chesapeake Bay ecosystem benefits are minimal and short-lived, and the costs are high. When sediment is strategically removed from the reservoirs behind the dams, there was a predicted minor influence on scour load (reduction) and sediment deposition (increase); there was also a predicted minor reduction in adverse impacts to Chesapeake Bay ecosystem health for a future similar storm event. Scour events would still occur, but lower amounts of sediment and associated nutrients were estimated to be mobilized during these events.

However, Chesapeake Bay ecosystem benefits from sediment removal are short-lived due to the constant deposition of sediment and associated nutrients that originate throughout the Susquehanna River watershed in this very active system, as well as the unpredictable nature of storms (i.e., it is impossible to reduce all impacts from all storm events and it is unknown exactly when the next storm will occur as well as the magnitude of that storm). Sediment removal would be required annually, or on some similar regular cycle, to achieve any actual net improvement to the health of the Bay. This positive influence is minimized due to sediment loads coming from the Susquehanna River watershed during a flood event.

The estimated cost range for the suite of sediment management strategies evaluated was $5 to $90 per cubic yard of sediment removed. The removal of the specific amount of 3 million cubic yards (an estimated 2.4 million tons) of sediment which is estimated to be slightly more than what deposits and is temporarily stored behind the dams entering the Conowingo reservoir on an annual basis (average for 1993-2012), would cost $15 to $270 million annually (all strategies considered). For the dredging strategies investigated, the cost was estimated to be $16 to $89 per cubic yard, or $48 to $267 million annually for removal of 3 million cubic yards (an estimated 2.4 million tons) of sediment. Costs for reductions in sediment yield from the watershed were on the order of a one-time cost of $1.5 to $3.5 billion which is estimated to annually prevent approximately 117,000 cubic yards (an estimated 95,000 tons) of sediment from reaching the Chesapeake Bay.

The conclusion that the primary impact to living resources in Chesapeake Bay from reservoir scour was from nutrients associated with the sediments and not the sediment itself, was not determined until late in the assessment process. Further study on this is warranted. Management opportunities in the Chesapeake Bay watershed to reduce nutrient delivery are likely to be more effective than sediment reduction opportunities at reducing impacts to the Chesapeake Bay water quality and aquatic life from scour events, but these management opportunities were not investigated in detail during this assessment. The relative importance of nutrient load impacts from the lower Susquehanna River reservoirs is a finding that indicates that nutrient management and mitigation options could be more effective and provide more management flexibility, than solely relying on sediment management options only.

It should be noted that the LSRWA effort was a watershed assessment and not a detailed investigation of a specific project alternative(s) proposed for implementation. That latter would likely require preparation of a NEPA (National Environmental Policy Act) document. The evaluation of sediment management strategies in the assessment focused on water quality impacts, with some consideration of impacts to SAV. Other environmental and social impacts were only minimally evaluated or not evaluated at all. A full investigation of environmental impacts would be performed in any future, project-specific NEPA effort.

Future Needs and Opportunities in the Watershed

Based on these LSRWA findings, specific recommendations were identified to provide state, federal, and local decision makers with the additional information needed to take further actions to protect water and living resources of the lower Susquehanna River watershed and Chesapeake Bay.

1. Before 2017, quantify the full impact on Chesapeake Bay aquatic resources and water quality from the changed conditions in the lower Susquehanna River's dams and reservoirs.

2. The U.S. Environmental Protection Agency (EPA) and the Bay watershed jurisdictional partners should integrate findings from the LSRWA into their ongoing analyses and development of the seven watershed jurisdictions' Phase III WIPs as part of the Chesapeake Bay TMDL 2017 midpoint assessment.

3. Develop and implement management options that offset impacts to the upper Chesapeake Bay ecosystem from increased sediment-associated nutrient loads.

4. Commit to enhanced long-term monitoring and analysis of sediment and nutrient processes in the lower Susquehanna River and upper Chesapeake Bay to promote adaptive management.

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