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Cost and Performance Analysis of a Sediment Removal and Processing System for the Lower Susquehanna River Dams

Saqib Qureshi[1], Raymond Fontaine[2], Samuel Saleeb[3], and Joel Stein[4]

[1-4]George Mason University, Department of Systems Engineering & Operations Research (SEOR)

Corresponding Author's Email: squres14, rfontain, ssaleeb2, jstein7@gmu.edu

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Abstract: A series of three major dams and reservoirs located along the Lower Susquehanna River have historically acted as a system of sediment and nutrient pollution traps. However, episodic pulses of these pollution loads are released following short-term extreme storm events, affecting subaquatic vegetation, benthic organisms, and the overall water quality in the Upper Chesapeake Bay. In addition, all reservoirs have reached a state of near maximum storage capacity termed as dynamic equilibrium. Based on prior research, this study seeks to regain the trapping capacity of the dams through a sediment removal and processing operation, and thereby reduce the ecological impact of major storms. A set of regression curves and a stochastic lifecycle cost model were used to evaluate the resulting effect on storm scour and the economic feasibility of processing and dredging amount alternatives. Results indicate that a Cement-Lock processing plant at moderate dredging is the most cost-performance effective solution.

Keywords: Lower Susquehanna River, Environment Restoration, Decision Analysis, Life-cycle Cost Analysis

1. Concept Definition

The Susquehanna River flows from New York through Pennsylvania and Maryland where it empties into the mouth of the Upper Chesapeake Bay. It is the largest freshwater tributary of the Chesapeake Bay, providing nearly 50 percent of the total share of freshwater (Chesapeake Bay Program, n.d). The Lower Susquehanna River includes a series of three major dams and reservoirs that form from Pennsylvania to Maryland which include the Safe Harbor, Holtwood, and Conowingo dams. The Safe Harbor Dam is the northernmost dam and has a sediment storage capacity of 92.4 million tons, followed by the Holtwood Dam with the smallest capacity of 15.6 million tons, while the Conowingo is the southernmost dam with the largest capacity of 198 million tons. These dams, collectively referred to as the Lower Susquehanna River (LSR) Dams, provide hydroelectric power generation, water storage, and recreation for the surrounding areas (Langland, 2009).

The LSR Dams have also been acting as a system of sediment and nutrient pollution traps for the past 80 years; retaining and thereby preventing large amounts of sediment and associated nutrient pollution from entering the Upper Chesapeake Bay. From 1929 to 2012, roughly 430 million tons of sediment was transported down the Susquehanna River and through the LSR Dams, with roughly 290 million tons trapped by the dams, resulting in an average trapping capacity of 65 percent. However, all three reservoirs have reached a state of dynamic equilibrium in terms of trapping ability; this means the reservoirs have reached near maximum storage capacity and fluctuate asymptotically from near 100 percent capacity. Although the reservoirs still trap sediment to some degree in the dynamic equilibrium state, their trapping ability is reduced significantly (Langland & Koerkle, 2014).

The greatest danger of the diminished trapping capacities of the LSR Dams is the risk of short-term extreme storms known as scouring events. Scouring events are major storms, hurricanes, or ice melts which cause the river flow rate to exceed 400,000 cubic feet per second (cfs). This leads to extensive flooding in the reservoirs which releases episodic loads of sediment and attached nutrients into the Upper Chesapeake Bay leading to major ecological damage. These effects can be seen in historical case studies of major scouring events such as Tropical Storm Lee in 2011, Tropical Storm Ivan in 2004, and Hurricane Agnes in 1972 (U.S. Army Corps of Engineers, 2014; Langland, 2015).

The Total Maximum Daily Load (TMDL) regulation was established by the US Environmental Protection Agency (US EPA) in 2010, to aid water quality restoration of the Chesapeake Bay to safe ecological standards by 2025. The TMDL for sediment to be met by 2025 for the Lower Susquehanna River is 985,000 tons of sediment annually. Although scouring events occur on average every 5 to 60 years depending on the streamflow, it is estimated that scouring events with streamflows from 400,000 to 1 million cfs can transport from 1 to 13 million tons of sediment over the span of upto 23 days, equating to an increase from 1.5 to 1200 percent above the annual TMDL limit (U.S. EPA, 2010).

1.1 Previous Research and Need for Current Study

Previous research was conducted by the U.S. Army Corps of Engineers (US ACE) from 2011 to 2014, and George Mason University (GMU) from 2013 to 2014, evaluating the feasibility of various sediment management techniques for the Conowingo Dam during high flow scouring events (US ACE, 2014; Ain, Cazenas, Gravette, & Masoud, 2014). The strategies evaluated include: minimizing sediment deposition through bypassing sediment using flow diverters or an artificial island, and recovering sediment trapping volume through removing sediment and placing it in quarries, or reusing the sediment to make beneficial products. The studies concluded that sediment bypassing is lower in cost to the other alternatives, however will conversely have adverse effects on the Bay's ecosystem due to constant increases in sediment and nutrient loads. The US ACE study concluded that for dredging to be effective, it must operate annually or on a continuous cycle. The GMU study concluded that reusing sediment to make glass slag via Plasma Vitrification may yield a positive return on investment, however a more detailed economic assessment needs to be conducted. In addition, the GMU study suggested to evaluate sediment reuse strategies for the dams north of the Conowingo, namely Holtwood and Safe Harbor.

Therefore, there is a need to develop a sediment removal and processing system to reduce the sediment buildup in the Lower Susquehanna River Dams, and thereby reduce the ecological impact of future scouring events.

1.2 Stakeholder Analysis and Tensions

The primary stakeholders comprise of six groups: Hydroelectric Power Companies, Riverkeepers, Residents of Maryland and Pennsylvania, Private Environmental Organizations, State and Federal Regulatory Bodies, and Maryland and Pennsylvania State Legislatures. The current operators for the Conowingo, Holtwood, and Safeharbor dams are Exelon Generation, Pennsylvania Power and Light, and Safe Harbor Water Power Corporation, respectively. Private environmental organizations such as the Chesapeake Bay Foundation (CBF) and the Clean Chesapeake Coalition (CCC) lobby for environmental regulations with the support of riverkeepers such as the West/Rhode Riverkeeper. Maryland and Pennsylvania residents residing within the Lower Susquehanna River basin use the Susquehanna River for agriculture and recreation, as well as receiving hydroelectric power from the dams. Several state and federal regulatory bodies are involved with regulation regarding the Lower Susquehanna River watershed. Two notable agencies are the Maryland Department of the Environment (MDE) and the Federal Energy Regulatory Commission (FERC), which are responsible for licensing hydropower projects as well as regulating transmission of electricity, natural gas, and oil. These regulatory bodies work together with Maryland and Pennsylvania state legislatures to enact laws to improve and promote environmental restoration of the Chesapeake Bay and the Lower Susquehanna River.

While every stakeholder has an interest in the removal of sediment from behind the dams, no single organization has accepted responsibility for the pollution collected in the reservoirs. The Clean Chesapeake Coalition believes that Exelon Generation should take responsibility and pay for the expensive removal process. Exelon Generation however, believes that the responsibility falls on those living in the Susquehanna River watershed, and if required to pay for the sediment mitigation may want residents to pay more in utilities to cover the cost.

2. Concept of Operations

In order to address the need to reduce the sediment buildup in the LSR Dams, a sediment removal and processing system is proposed. The Concept of Operations describes the proposed system and the design alternatives evaluated.

2.1 Operational Scenario

The sediment removal and processing system consists of three components: sediment removal through dredging, sediment transport to the processing plant site, and sediment processing to make a sellable product. The sediment will be removed through a hydraulic dredging operation which removes and transports sediment in slurry form through pipelines connected directly to the processing plant. The removal and processing will be a steady-state operation that will continuously dredge sediment from each of the reservoirs lasting for a lifecycle of 20, 25, or 30 years. In addition, it is assumed that the operation will be funded by a government bond if implemented.

2.2 Design Alternatives

The design alternatives consist of sediment processing techniques which convert dredged sediment into products which can be marketed and sold to minimize the total cost of the operation. An exhaustive survey of dredged sediment processing techniques was conducted, of which Plasma Vitrification and Cement-Lock were chosen to be further evaluated.

Plasma Vitrification is a process piloted by Westinghouse Plasma Corp. in which dredged sediment is exposed to plasma torches reaching temperatures of 5000 deg. C destroying nearly all toxic organic and microbiological contaminants. This produces a glass slag product which can be sold as a replacement for glasphalt, roofing granules, coal slag, or as a three-mix glass substitute (McLaughlin, Dighe, Ulerich, & Keairns, 1999). Cement-Lock is a thermo-chemical process developed by the Gas Technology Institute and Unitel Technologies, in which dredged sediment is placed through a rotary kiln reaching temperatures between 1315 and 1425 deg. C. During the combustion process, the contaminated sediment is mixed with a set of chemical feed materials, after which the end product is finely grounded to produce EcoMelt. EcoMelt is a pozzolanic material that can be used as a 40 percent replacement for Portland cement used in concrete production (Mensinger, 2008). In addition, a Quarry/Landfill alternative was evaluated to serve as the control for this study. It is essentially removing the dredged sediment and placing it in a deposit site. Although this alternative may cost less than the processing alternatives, there is no decontamination that takes place, thus there is a risk of potential environmental degradation in the future.

Other processes that were considered included: Soil Washing, Thermal Desorption, Fluidized Bed Treatment, Glass Furnace Technology, Electrochemical Remediation, and Solidification/Stabilization (Great Lakes Commission, 2001).

3. Method of Analysis

The sediment removal and processing system provides a solution to address the retained sediment buildup in the LSR Dams. However, two important questions remain: How does dredging a certain amount affect sediment scouring potential? Also, what will be the return on investment for dredging various amounts of sediment to process into glass slag or EcoMelt products? The Scour Performance Curves, are a set of regression curves derived from a hydraulic model which are used to approximate sediment scouring potential from amounts of dredged sediment, while the Processing Plant Lifecycle Cost Model is a Monte Carlo Simulation used to simulate the lifecycle costs of a sediment removal and processing operation.

3.1 Scour Performance Curves

A hydraulic model was developed in the GMU study to simulate the sediment scouring potential resulting from dredging 1, 3, and 5 million cubic yards of sediment annually from behind the Conowingo Dam over a 20 year time frame (Ain et al., 2014). The model calculated scouring based upon numerical changes to river bathymetry and velocity profiles. The model also simulated three future water flow rates using the hydraulic record from 1967 to 2013: a ‘dry world’ with a maximum flow rate of 400,000 cubic feet per second (cfs), a ‘future is the past’ world matching historical data with a maximum flow rate of 700,000 cfs, and a ‘wet world’ with a maximum flow rate of 1 million cfs. Using the simulation data, a correlation between dredging and the percent of scouring reduced was derived, and extrapolated to a time frame of 30 years for each dredging amount. Figure 1 below shows the relationship between dredging 1, 3, and 5 million cubic yards (cy) annually and the percent of scouring reduced using the average of the three future water flow test cases.

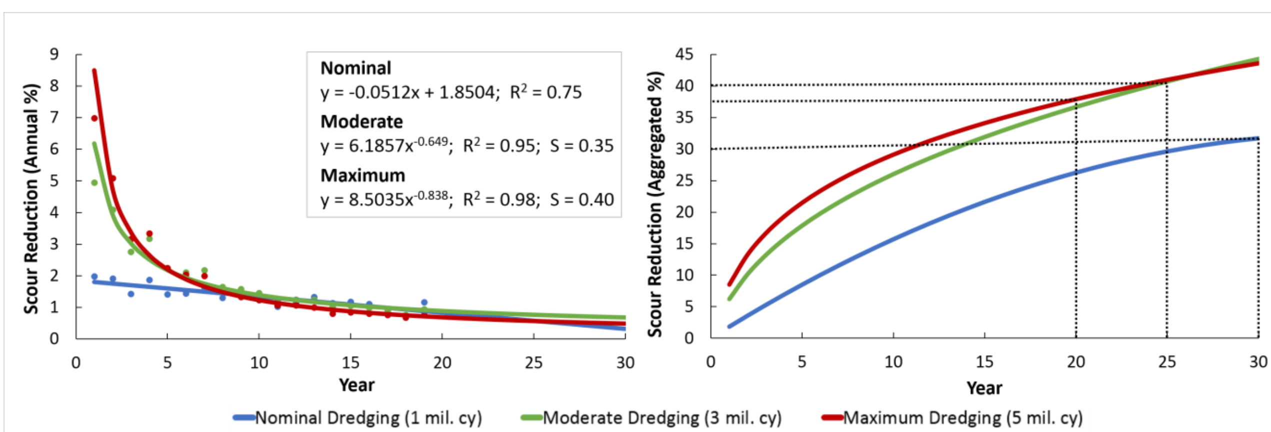

Figure 1: Scour Performance Curves (Annual and Aggregated Scour Reduction)

The annual regression curves indicate that there is a trend of diminishing returns in regard to sediment scouring reduction as the dredging amount increases. The benefits of dredging 1 million cubic yards annually decreases at a constant rate, while the benefits of dredging 3 and 5 million cubic yards decreases substantially after the first several years. The aggregated regression curves shows the total percent scouring reduction for each dredging amount over 30 years, and the dredging amount lifecycle chosen for each amount based on the optimum reduction and practical industry considerations.

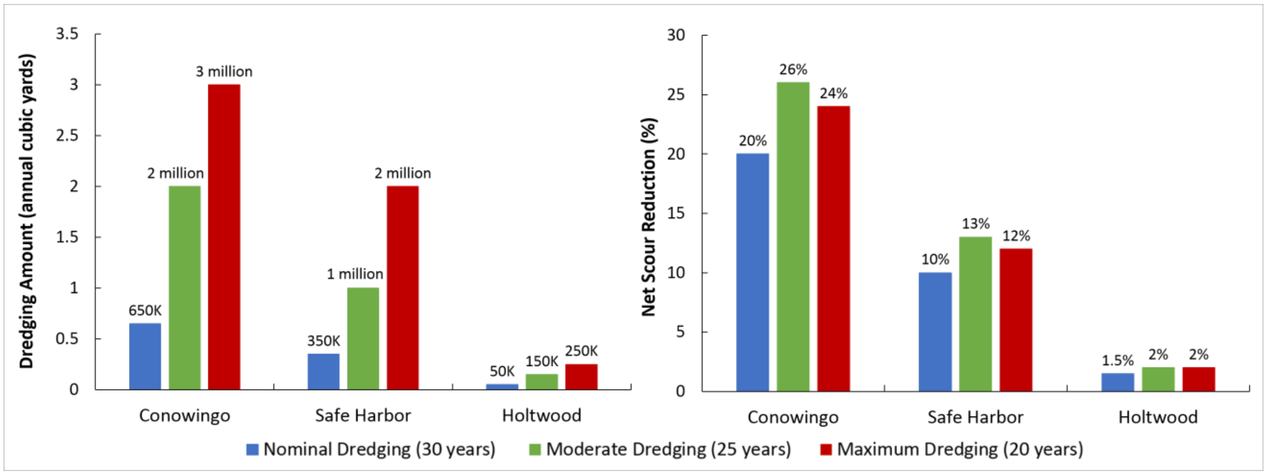

Figure 2: Annual Dredging Amounts and Scour Reductions for Conowingo, Safe Harbor, and Holtwood

From the correlation, nominal, moderate, and maximum dredging amounts were derived for the Conowingo, Holtwood, and Safe Harbor dams for 30, 25, and 20 years respectively, shown in Figure 2 above. Since the GMU study only simulated the Conowingo Dam, the weights for the dredging amounts were prorated from the capacity of the specific reservoir over the combined total capacity of all three reservoirs. Figure 2 also shows the respective scour reductions from the Conowingo, Holtwood, and Safe Harbor dams from the three dredging cases. The results indicate that the Conowingo Dam would result in the greatest scour reduction, followed by Safe Harbor, while Holtwood has the least.

3.2 Processing Plant Lifecycle Cost Model

The inputs to the lifecycle cost model include the dredging amount, the costs, revenue, and other variables associated with the processing plant operation, the cost of the dredging operation, and the cost of land. Using a series of cost, revenue, and production formulas, the model outputs a probabilistic estimate of the net present value for each plant and processing alternative. Baseline cost estimates were obtained for each variable in the lifecycle cost model and were extrapolated for cases specific to this study, in addition to normal and triangular distributions used to model the uncertainty associated for each cost variable. Market research was conducted for glass slag and EcoMelt replacement products (coal slag and Portland cement) from which it was assumed 70 to 85 percent of the replacement product's average selling price can be met. The table below provides an overview of the lifecycle costs and inputs associated for each plant and processing alternative, along with their parameters and modeled distributions.

Table 1: Inputs for the Processing Plant Lifecycle Cost Model

Variable	Parameter	Distribution	Plasma Vitrification	Cement-Lock	Quarry /Landfill
Plant Capital	Plant capacities from 50,000 to 3 million cy/annual	Triangular with +-15% tails	$50 - $825 million	$43 - $715 million	N/A
Net Processing Cost/Tipping Fee	Energy cost from 8-10 cents/kWh, and $4-$6/million Btu	Triangular with +-5% tails	$155 - $205 per ton	$60 - $90 per ton	$5 - $40 per ton

Dredging Capital	Dredging amount from 1 to 5 million cy/annual	Triangular based on low and high bids	$6 - $16 million	$6 - $16 million	$3 - $7 million
Dredging Transport	Distance from 0 to 15 miles	Triangular based on low and high bids	$15 - $30 per ton	$15 - $30 per ton	$30 -$130 per ton
Land Costs	Average land cost per acre for each geographic area	Triangular based on low and high bids	$15K to $40K per acre	$15K to $40K per acre	N/A
Revenue Prices	Average market price for replacement product	Triangular: 70 to 85% of market price	$140 - $170 per ton	$75 - $90 per ton	N/A
Sediment to Product Ratio	Tons of sediment required to product one unit of product	Normal of pilot studies	2.5 tons	1.5 tons	N/A
Interest Rate	Municipal Yield Curve	Normal of 2014	2.7 - 3.5%	2.7 - 3.5%	2.7 - 3.5%

In total, the lifecycle cost model consisted of 27 unique test cases (three reservoirs, two product alternatives, and three dredging amount alternatives). The average net present value from 100,000 simulation iterations, along with their respective 95% confidence intervals is shown in Figure 3 below. The results indicate that a dredging and processing sediment, or placing it in quarries/landfills is a very expensive operation ranging from millions to billions of dollars, of which none of the alternatives evaluated resulted in a positive net present value. The results also indicate that the Cement-Lock alternative results in the least cost, lower than both Plasma Vitrification and the Quarry/Landfill control case. This indicates that Cement-Lock may be the most viable option among the design alternatives evaluated.

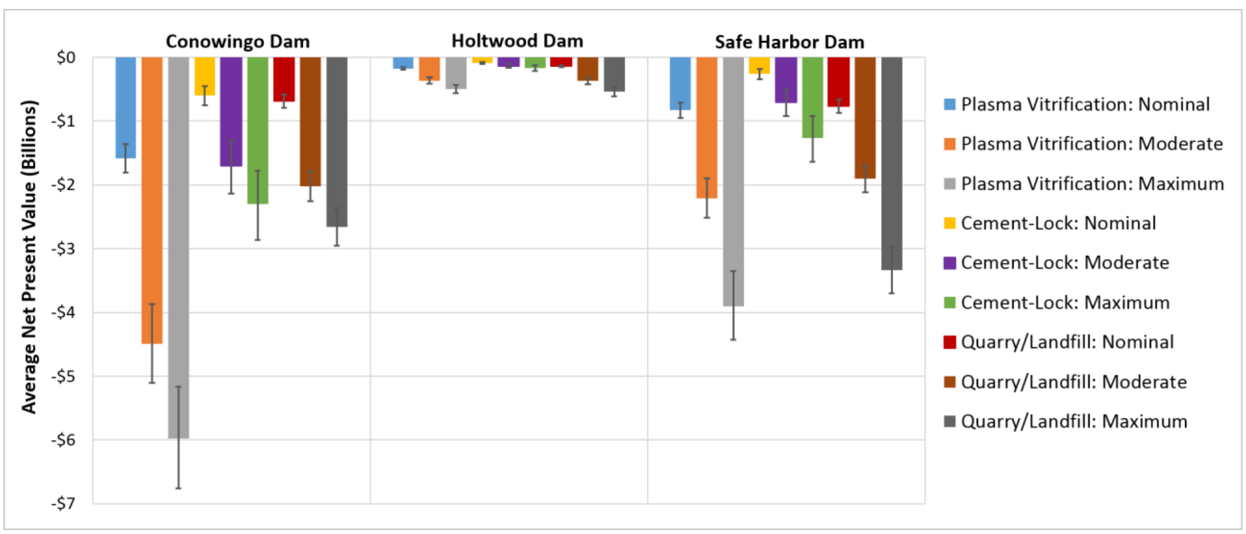

Figure 3: Average Net Present Value for Each Dam and Processing Alternative

4. Utility Analysis and Recommendations

The utility analysis consists of the following factors: time of the processing plant lifecycle which is either 30, 25, or 20 years, product suitability which is the percent of contaminants removed from the sediment, and the percent of scouring reduction potential. In Figure 4 below, each point represents the utility for each processing alternative and dam combination. The weights for the utility were determined through discussion with the project sponsor, the West/Rhode Riverkeeper, Inc.

$$U(x) = 0.10 * Time + 0.30 * Suitability + 0.60 * Performance \quad (1)$$

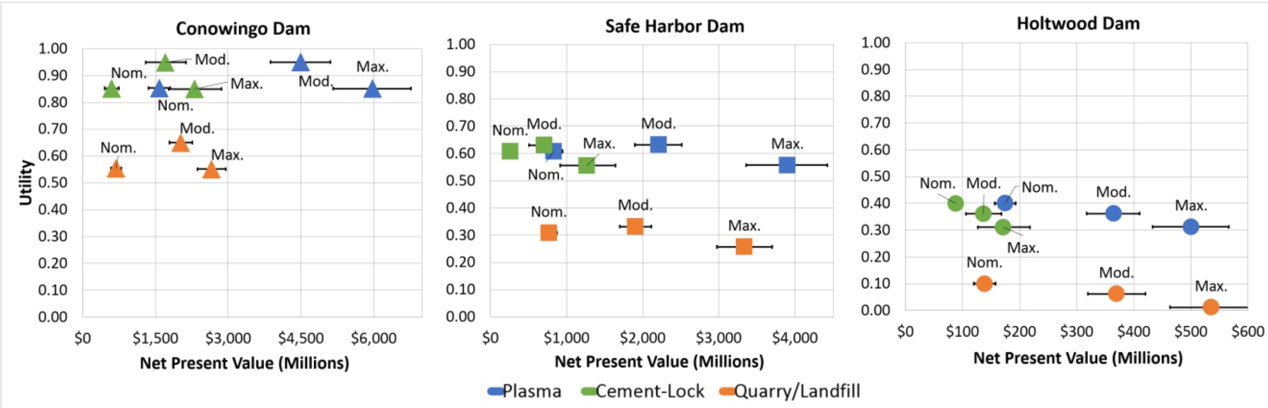

Figure 4: Utility vs. Cost Analysis

Based on the utility analysis, the most cost-performance effective solution among the design alternatives is a Cement-Lock processing plant at moderate dredging for the Safe Harbor and Conowingo Dams. A processing operation at Holtwood is not needed due to its low scour reduction potential.

However, the Scour Performance Curves treat the reservoirs as static. In other words, if a reservoir is dredged and its sediment capacity is reduced, this may subsequently reduce the water velocity flow into the following reservoir, and therefore the resulting sediment scour. This dynamic interaction may be considerable or negligible during major scouring events ranging from 400,000 to 1 million cfs. Before such a system is implemented, it is recommended that further study be conducted by a system dynamics or hydrological model, to determine if the dynamic interaction between the dams during major scouring events is negligible or considerable. If it is considerable, then a processing plant operation may only be needed at one dam which can act as a dynamic trap, thus reducing the resulting cost of the system significantly. Secondly, since it is the nutrients attached to the sediment which primarily cause long term environmental degradation, it is recommended that an exhaustive survey of nutrient management strategies be considered before implementation of a large scale processing operation. Lastly, if nutrient management is not more cost-performance effective, it is recommended that the patent holders of Cement-Lock, Volcano Partners LLC, be contacted for a pilot study on the cost and suitability of Cement-Lock technology for processing Lower Susquehanna River sediment.

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