Design of a Dam Sediment Management System to Aid Water Quality Restoration of the Chesapeake Bay

Rayhan Ain, Kevin Cazenas, Sheri Gravette, and Said Masoud
George Mason University, rain, kcazenas, sgravett, smasoud@gmu.edu

***Abstract* - The water quality of the Susquehanna River, a major freshwater tributary of the Chesapeake Bay, significantly affects the aquatic health of the Bay. Following major storms in which the river flow rate exceeds 300,000 cubic feet per second (cfs), nutrients and sediment stored in the Lower Susquehanna Reservoir are deposited into the Chesapeake Bay. These excess nutrients facilitate algae blooms that hinder the growth of sub-aquatic vegetation (SAV) and harm the Bay's aquatic species. The Conowingo Dam, on the Lower Susquehanna River, is estimated to be at 85% of its sediment capacity. To reduce the sediment backlog, three dam sediment management alternatives have been identified: (i) No Mitigation, (ii) removal of sediment by Hydraulic Dredging and (iii) removal of sediment by Hydraulic Dredging and increasing the bottom shear velocity to avoid sediment build-up. A utility analysis conducted using a fluid mechanics, ecological impact and business model indicates annual removal of sediment at 5,000,000 cubic yards to produce slag product, with the instantiation of a flow diverter to increase bottom shear stress to be the best alternative.**

Index Terms – Chesapeake Bay, Environment restoration, Sediment mitigation, Utility analysis

INTRODUCTION

The Lower Susquehanna flows from Pennsylvania into Maryland and empties into the Chesapeake Bay. It provides approximately 60% of the Bay's freshwater. Dams, power plants, and incinerators built during the 20^{th} century contributed to the waste, alteration of fish migration, the heating of the river, and the reduction in the river water's overall quality [1].

Four dams were built on the Lower Susquehanna River, with the Conowingo Dam being the southernmost dam and a hydroelectric power source. While Conowingo Dam currently traps sediment and nutrients from reaching the Chesapeake Bay (Fig. 1), a study conducted by the United States Geological Survey (USGS) suggests that the reservoir will reach capacity around 2030[2]. Once at capacity, Conowingo Dam will be completely silted up and no longer capable of retaining sediment [3]. At that point sediment will begin to reach the Bay at an increased steady-state, during which time it is estimated that sediment delivery to the Bay will increase by about 150% [4]. An increase in steady-state deposition further negatively impacts the Chesapeake Bay's aquatic ecosystem.

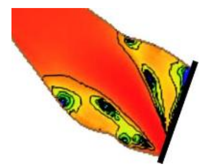

FIGURE 1
SEDIMENT AT CONOWINGO DAM (RIGHT BLACK BAR IS DAM LOCATION)

To initiate the restoration of clean water in the Chesapeake Bay, the US Environmental Protection Agency (EPA) has created the Chesapeake Bay Total Maximum Daily Load (TMDL). The Chesapeake Bay TMDL identifies the necessary pollution reductions for major sources of nitrogen, phosphorus and sediment for various Chesapeake Bay watersheds [5].

The biggest concern with respect to the sediment buildup at Conowingo Dam today relates to the adverse effects of the sediment on the Bay during major scouring events. Scouring events have been defined as storms that cause the flow rate of the river to exceed 300,000 cfs. Sediment erosion is enhanced due to the increased flow rates and constant interaction of water with the Dam. The Rouse number further defines how the sediment will act when there is an increase in river flow rates. The Rouse number expresses a concentration profile of sediment, which determines how sediment will be transported into flowing water. A low Rouse number coincides with moving sediment and an increase in flow rate tends to lower the Rouse number[2]. Numerous groups have sought, and continue to look for, ways to mitigate the effects of high scouring transient storms in order to promote and restore the health of the Chesapeake Bay.

STAKEHOLDER ANALYSIS

A. Lower Susquehanna Riverkeeper and Stewards of the Lower Susquehanna

The Lower Susquehanna Riverkeeper founded the Stewards of the Lower Susquehanna, Inc. (SOLS), a non-profit environmental advocacy organization that supports the licensed Riverkeeper. The association works with citizens and scientists to find solutions to environmental problems along the Lower Susquehanna River and the Chesapeake Bay Watersheds[6].

B. Pennsylvania and Maryland Residents

Residents of Maryland and Pennsylvania have varying objectives. The objective of some residents is to maintain healthy waters in the river for recreational purposes and overall water quality. The objective of other residents is to continue to receive power from the hydroelectric plant at Conowingo Dam without additional service charges.

C. Exelon Generation

Exelon Generation is the owner of the Conowingo Dam. The objective of Exelon Generation is to extend their licensing for ownership and usage of Conowingo Dam prior to the license expiration set to occur September 1, 2014. The relicensing, if granted by the Federal Energy Regulatory Commission (FERC), will allow Exelon Generation the ability to continue to provide power to some of the Lower Susquehanna Watershed residents until 2060.

D. Waste Treatment Plants

The instantiation of the Chesapeake Bay TMDL has set in place water quality standards that could cost waste treatment plants in the Chesapeake Bay watershed billions of dollars. The cost is derived from the upgrades required to meet the TMDL standards [7]. The objective of waste treatment plants is to minimize renovation costs while meeting required water quality standards.

E. Stakeholder Tensions

The Lower Susquehanna Riverkeeper, SOLS, and the residents of the Lower Susquehanna Watershed all desire that Exelon Generation accept some, if not most, of the responsibility for the sediment build up behind Conowingo Dam. To make a change these groups are urging FERC to implement greater regulations on Exelon Generation.

STATEMENT OF NEED

There is a need to reduce the environmental impact of scouring events on the Chesapeake Bay, by reducing the sediment and nutrients currently trapped behind Conowingo Dam. This is to be done while maintaining energy production at Conowingo Dam and satisfy the Chesapeake Bay TMDL regulations.

DESIGN ALTERNATIVES

Sediment deposition mitigation is paramount to the success of the Chesapeake Bay's water quality restoration. Three alternatives have been identified to meet the needs of our stakeholders.

A. No Mitigation Techniques

Taking no action at Conowingo Dam might seem to provide the best minimum short-term cost decision. Enforcing no sediment mitigation techniques imposes no direct financial costs on stakeholders in the form of equipment or labor expenses. Doing nothing with the sediment build up within the reservoir would allow for an asymptotic buildup at Conowingo Dam for the next 10-15 years, before capacity is met. Once this occurs all suspended sediment from upriver will simply flow from the reservoir into the Chesapeake Bay [8].

B. Hydraulic Dredging

Hydraulic dredging is a method in which a device on the surface moves over a particular area of water and removes the sediment below through a pipeline. The sediment is then transported onto land, where it can be moved and processed. Given optimal conditions, this alternative could remove up to 525 tons of sediment per hour per dredge[9].

The baseline alternative for the management of dredged sediment is to deposit and store the sediment in a quarry. This alternative involves the lowest initial capital investment costs and overall operational costs. The only expense is the cost of transportation of the sediment to the quarry site.

To help offset dredging costs, dredged sediment can be decontaminated and manufactured into various products. The goal would be to produce the largest amount of product to help minimize cost and maximize the sediment reusability.

An additional alternative for sediment reuse is low temperature sediment washing. It is a recycling and decontamination process in which as-dredged sediment can be screened and rigorously rinsed with a chemical washing agent. The separated sediment can then be reassembled into manufactured topsoil for use in various landscaping projects [10].

Another sediment reuse process considered is thermal decontamination via a rotary kiln. The kiln heats the material to cause thermal desorption and destruction of organic compounds. This process produces lightweight aggregate which greatly enhances thermal resistance and more than doubles the thermal insulation value of the final concrete end product it is normally made into [11].

The final process known as plasma arc Vitrification, turns dredged sediment into slag by the immobilization and glassification of any non-organic substances and contaminants. This process involves one of the most extreme technologically available applications of thermal energy in a safely reinforced and controlled reactor. The resulting output of this process is a vitrified, durable, and stable glass compound known as slag. The slag byproduct can be used to produce sellable products, with the most profitable being high and low-grade architectural tile [12].

C. Hydraulic Dredging and Artificial Island

This alternative looks at partial reuse of the processed sediment within the reservoir. Dredging and processing enough sediment to build an artificial island, within the reservoir, would help divert flow. Flow velocity around the island would increase, decreasing the Rouse number, or the ratio of sediment settling velocity to shear velocity, allowing for more sediment to pass through the dam during steady-state flow. This would aid in the reduction of the transportation costs and reduce the cost of continual maintenance dredging. A sample location of the reservoir is shown in Figure 2 [2].

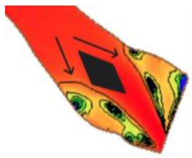

FIGURE 2
EXAMPLE ARTIFICIAL ISLAND LOCATION IN CONOWINGO RESERVOIR

This artificial island would be approximately diamond shaped with a set size and distance from the dam. A diamond was chosen because it is efficient enough to minimize the drag coefficient while maintaining feasibility with a simple shape for analysis. While this technique may remove a substantial amount of suspended sediment, not all of the sediment may be removed this way. Any unaffected sediment would still need to be dredged annually.

METHOD OF ANALYSIS

The method of analysis used to assess the alternatives included running a stochastic model over a span of 20 years with predetermined maximum flow rates and amounts of dredged sediment. This was done for 3 possible future 20 year scenarios. The models were defined as follows.

A. Sediment Mitigation Model

In order to calculate total scoured sediment loads, Conowingo Reservoir must be modeled in its entirety. To accomplish this, a fluid mechanics model was created which predicted scoured sediment based on flow rate and alternatives measures. The reservoir is divided into 400 sections, each with a corresponding average velocity and space dimensions (length, width, and depth)[13]. Length is about 0.5 miles for all sections, while width is 1/20 the width of the particular section of the reservoir. These characteristics update daily based on a stochastic flow rate.

The initial flow rate is set using a lognormal distribution fitted to daily historical data from 1967-2013 water years[14]. A seeded correlation is used to model every other day's flow rate. Differences between each day are measured, and then sectioned off into 67 intervals based on flow rate. Each data set is fitted to a lognormal distribution. Depending on where the previous day's flow rate lies within these intervals, the difference in flow rate for the next day is updated accordingly based on the corresponding distribution.

Each day velocity is adjusted from 700,000 cfs to the simulation flow rate, using cross-sectional area (width multiplied by depth) into (1) and solving the continuity equation. The Rouse number is then calculated using (2) for each section of the reservoir[15]. Particle fall velocity set as fixed throughout the entire reservoir, calculated using average feet per second fall rate for 72% silt, 20% sand, and 8% clay, and the von Kármán constant is set to 0.4, which accounts for the turbulence boundary layer[16]. Shear stress is calculated as one-tenth of the velocity profile using wall shear stress, assuming turbulent flow[17]. A correlation between flow rate and average Rouse number was found and then inserted into an equation correlating flow rate to total sediment scoured to find (3)[13]. Note that this equation multiplies total sediment scoured by the fractional surface area of the specific reservoir section. Total daily sediment scoured is calculated as the sum of all sections.

TABLE I
SEDIMENT MITIGATION MODEL VARIABLES

Symbol	Description	Units
L	Section length	ft.
W	Section width	ft.
D	Section depth	ft.
Q	Flow rate	ft./second
v	Velocity profile	ft.^{3}/second
A	Cross-sectional area (WD)	ft.^{2}
Z	Rouse number	
w_s	Particle fall velocity	ft./second
κ	von Kármán constant	
SS	Scoured sediment load	tons
SA	Surface area (LW)	ft.^{2}
V	Section volume (LWD)	ft.^{2}

$$Q = vA \tag{1}$$

$$Z = \frac{w_s}{\kappa\left(\frac{1}{10}v\right)} \tag{2}$$

$$SS_i = 0.000012\left(\frac{222197}{Z_i}\right)^{1.88623} * \left(\frac{SA_i}{SA}\right), i = 1, \ldots 400 \tag{3}$$

Reservoir bathymetry changes daily using (4), from sediment scoured from the previous day and new sediment redeposited from upstream. This is set to a fixed value of 4 million tons per year, which is distributed based on each specific reservoir section's volume (i.e. the smaller the section, the smaller the daily sediment load to that section)[18]. Note that (4) solves for specific cross-sectional area in feet, so values are first converted to ft^3 and then divided by length.

$$A_{i2} = A_{i1} - \left[\left(\frac{4000000*32.67*\frac{V_i}{V}}{L}\right)*\frac{1}{365}\right] + \left[\frac{SS_i*32.67}{L}\right] \tag{4}$$

B. Ecological Impact Model

Currently no information has been generated that associates a direct cost to the effects of scoured sediment on the Chesapeake Bay. The ecological impact model used surrogate data on waste treatment plant upgrade costs to estimate the monetary impact of scoured sediment levels on the Chesapeake Bay. The nutrients and sediment being treated at these plants directly correlates to the excess nutrients that facilitate algae bloom growth in the Chesapeake Bay [7]. An indirect correlation between the phosphorus within the scoured sediment and the cost to meet TMDL regulations for phosphorus in the Lower Susquehanna watershed allowed for a way in which to quantify ecological impact to the Bay in our utility function (to be described).Since scoured phosphorus has a correlation to sediment scoured, a linear trend between the two is assumed to produce an average remediation cost with respect to waste treatment plants' upgrade expenses to meet TMDL regulations.

The following equations were used in the ecological impact model to calculate the associated remediation costs. Equation (5) was used to determine the amount of phosphorus produced in tons (P_s) based on sediment scoured in tons (S_s). Equation (6) denotes phosphorus scoured during normal flow, where *rand* is defined as a random number between 0.002933 and 0.00132. The values in both equations were derived from empirical data on the amount of phosphorus scoured relative to the amount of sediment scoured. The input used for these derivations is found in Table II[19][20].

TABLE II
ECOLOGICAL IMPACT MODEL INPUT DERIVATIONS: LOWER SUSQUEHANNA TO CHESAPEAKE BAY

	Average ANNUAL Pollution Loads (tons)	Tropical Storm-Lee Related Pollution Loads (tons)
Phosphorus (P_s)	2,610 - 3,300	10,600
Sediment (S_s)	890,000 - 2,500,000	19,000,000
Ratio (P_s/S_s)	0.00132 - 0.0029	0.000558

$$P_s = 0.0005578 S_s \quad (5)$$

$$P_s = rand S_s \quad (6)$$

The following equations for the model use relations between the Lower Susquehanna TMDL limits and those of the Chesapeake Bay. Approximately 30% of the scoured phosphorus reduction for the Chesapeake Bay TMDL comes from the Lower Susquehanna TMDL. Accordingly, (7) denotes how the remediation cost, R, is calculated.

$$R = (LSRP_{TMDL} - P_s)(W_{cost}) \quad (7)$$

Within (7), $LSRP_{TMDL}$ is 1895 tons of phosphorus, or the Lower Susquehanna TMDL phosphorus limit, and W_{cost} is the average total waste treatment plant costs for upgrades due to the Chesapeake Bay TMDL as determined by surrogate waste treatment plant data on plants within the Chesapeake Bay watershed [7].

The final results of this model are normalized and used in the utility function as a surrogate 20 year period cost for remediation of scoured phosphorus from the Lower Susquehanna River into the Chesapeake Bay.

C. Business Reuse Model

The business model is a Monte Carlo simulation used to project the net cost of using the sediment removed from the river, by the production of product or the dumping of sediment into a quarry. The cost per cubic yard is multiplied by the amount of sediment removed/processed. The revenue per cubic yard of processed sediment is also multiplied by the amount of sediment processed. When the difference of cost and revenue are calculated, the result is a net cost per cubic yard of dredged sediment. The calculation was run 1000 times. Out of this simulation, we calculated the mean, standard deviation, and half width of the net cost, which are required to formulate a 95% confidence interval for the expected the net processing cost.

Table III shows the input for the values for each product alternative[21][22][12]. To account for uncertainty, the values were modeled using a pessimistically skewed triangular distribution to show a worst-case scenario for each alternative. Revenue was skewed "to the left" to simulate lower values for revenue more frequently and vice versa for cost. These values were derived from case studies performed mostly by companies looking to win a proposal for different dams and reservoir projects. The need to skew the values in a pessimistic way arises due to the concern that the companies may have exaggerated their values in order to win their respective contracts.

TABLE III
BUSINESS REUSE MODEL: COST AND REVENUE INPUT ($/CUBIC YARD)

	Revenue			Cost		
Product Alternative	Low	Mid	High	Low	Mid	High
Quarry	X	X	X	36	48	54
Topsoil	15	18	25	48	56	58
Light-Weight Aggregate	40	65	100	52	70	80
Slag – High Grade	200	250	290	150	180	220
Slag-Low Grade	193	209	219	150	180	220

The amount of product produced by each alternative is simply the ratio of the amount of sediment removed to the amount of sediment required to produce the product. Equation (8) is the net cost of producing a product after it has been processed and sold. This equation is the difference between the revenue and cost of an alternative multiplied by the amount of product produced.

$$T_i = (c_i + M_x - rev_i) * R_i \quad (8)$$

In (8), rev_i = revenue per unit product i, M_x = mitigation cost per cubic yard of sediment, and c_i = cost per unit product i.

RESULTS

Each alternative was tested against future 20 year scenario simulations, each with a maximum flow set to 400,000 cfs, 700,000 cfs, or 1,000,000 cfs. These flow sets were modeled against each alternative to find differing scour loads, bathymetry levels, remediation costs and product revenue. Annual dredging was conducted for each of the flow rates and removed sediment evenly 5 miles upstream from the dam (1, 3, and 5 million cy sediment), while no mitigation only involved scour and remediation costs. The dredging and artificial island alternative required 20 million cubic yards of wet sediment annually for eight years for the required 4,000,000 cubic yards of lightweight aggregate[21] needed to build the island. The entirety of the model was designed and used to extrapolate and make inferences based on relative comparison of the design alternatives.

A. Sediment Mitigation Model Results

The model results indicate that as more sediment is removed, transient scouring effects are reduced. For every 1 million cubic yards of sediment dredged, initially scour potential decreased by 2% and 0.4% at the end of the simulation with maximum dredging. Additionally, use of the artificial island reduces transient scour impact by scouring sediment into the Chesapeake Bay during lower steady-state flow rates.

Of the three maximum flow rate scenarios, using a seeded value of 700,000 cfs as the maximum flow rate, most accurately matched historical flow rate data. A comparison was made using the percentage decrease in sediment scoured for each alternative compared to the baseline alternative of no mitigation. Figure 3 shows this comparison as the average from three simulation runs with standard deviations for the error bars.

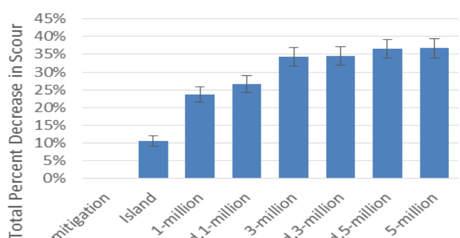

FIGURE 3
PERCENT DECREASE IN SCOUR POTENTIAL COMPARED TO NO MITIGATION

All data points show a decrease in scouring when compared to no mitigation, which may be supported by model bias; however, the biggest changes are shown when dredging 3 and 5 million cubic yards annually with both island and no island constructed.

B. Ecological Impact Model Results

The ecological impact model results projected the minimum ecological impact to occur when 5 million cy are dredged annually, after the creation of the artificial island. Table IV denotes predicted hypothetical average remediation costs for waste treatment water plants, for each alternative.

TABLE IV
BUSINESS REUSE MODEL: APPROXIMATE AVERAGE WASTE TREATMENT REMEDIATION COST

Alternative	Cost	Cost (Normalized)
No Mitigation	$16,9000	1
Dredge: 1 million	$11,700	0.57
Dredge: 3 million	$7,700	0.23
Dredge: 5 million	$6,000	0.09
Island: No Dredge	$11,900	0.58
Island: 1 million	$8,900	0.33
Island: 3 million	$6,100	0.10
Island: 5 million	$5,000	0.00

According to Table IV, the island alternative with an annual dredging of 5 million cy, is the best alternative with respect lowest waste treatment plant remediation expense.

C. Business Reuse Model Results

Table V shows the results of the business reuse model. These figures represent the total annual recurring costs of the five product reuse alternatives versus different amounts of sediment dredged annually, respectively. The result of most significance is the high-grade architectural tile from the plasma gas arc Vitrification process, as it is the only alternative that has the potential to result in a profit.

TABLE V
BUSINESS REUSE MODEL RESULTS

Average ($ millions)					
Cubic Yards Dredged Annually	Topsoil	LWA	Plasma low-grade	Plasma high-grade	Quarry
1 million	80	45	25	(18)	46
3 million	248	137	73	(49)	140
5 million	405	229	126	(88)	231
Standard Deviation ($ millions)					
Cubic Yards Dredged Annually	Topsoil	LWA	Plasma low-grade	Plasma high-grade	Quarry
1 million	5	14	16	23	4
3 million	15	43	48	69	12
5 million	25	73	79	117	20

A 95% confidence interval calculated for the high-grade architectural tile resulted in a profit ranging from $17 million to $95 million (NPV ranges from $306,000,000 to $670,000 at a 5% discount rate for 20 years), depending on the annual amount of dredged sediment. No other product alternatives showed potential for profit. It should be noted that the standard deviations for the high-grade architectural tile alternative are larger than the respective averages. Accordingly, the alternative is not guaranteed to turn a profit. This is not the case for the other alternatives, where the averages are larger than the standard deviations. While these results are a preliminary analysis, they show the slag product alternative may be best in terms of reducing the cost of sediment mitigation.

ANALYSIS AND RECOMMENDATIONS

In order to determine the best alternative combination (product alternative plus dredging amount, with or without the artificial island), two factors were analyzed using a utility function with two normalized values: reduction percentage of scouring potential, and average cost of remediation. The following formula was used to determine the utility of each alternative:

$$U_i = 0.5\frac{S_i}{S_5} + 0.5\frac{E_0 - E_i}{E_0 - E_{5s}} \quad (9)$$

In (9), U_i = utility of dredging alternative i, S_i = scour potential percentage decrease of dredging alternative i, S_5 = scour potential decrease percentage of dredging 5 million cy per year, E_0= normalized cost of remediation of no mitigation after a scouring event, E_i=normalized cost of remediation of dredging alternative i after a scouring event, and E_{5s}= normalized cost of remediation of dredging 5 million cy/yr with an artificial island. The most desirable option includes reducing the scouring potential and remediation costs, while minimizing the cost, in terms of net present value, of the respective product alternative(s).

The results of the utility analysis show that dredging 5 million cy/yr and using high-grade plasma gas arc vitrification to produce slag has a high utility and a negative cost (i.e. will have a positive NPV after 20 years). Table VI shows the dredging alternatives ranked according to utility.

TABLE VI
RESULTS OF DREDGING ALTERNATIVES WITH UTILITY

Alternative	Scour Potential Decrease (%)	Remediation Cost (Normalized)	Utility
Island,5-million	37	1	0.99
5-million	37	0.57	0.95
Island,3-million	34	0.23	0.92
3-million	34	0.09	0.85
Island,1-million	27	0.58	0.70
1-million	24	0.33	0.54
Island	11	0.10	0.35
no mitigation	0	0.00	0.00

ACKNOWLEDGMENT

The authors would like to acknowledge our sponsors: Michael Helfrich, Lower Susquehanna Riverkeeper, and Jeff Holland, West and Rhode Riverkeeper. The authors would also like to thank Dr. George Donohue, GMU Faculty Advisor; Dr. Lance Sherry, GMU Associate Professor; Paula Lewis, IPA FAA Assistant Administrator; and Jedidiah Shirey, GMU Graduate Teaching Assistant.

REFERENCES

[1] "Watershed History," *Lower Susquehanna Riverkeeper*, 2013. .

[2] S. Scott, "Evaluation of Uncertainties in Conowingo Reservoir Sediment Transport Modeling," 2012.

[3] R. Hirsch, "Flux of nitrogen, phosphorus, and suspended sediment from the Susquehanna River Basin to the Chesapeake Bay during Tropical Storm Lee," U.S. Geological Survey, 5185, 2012.

[4] "The Impact of Susquehanna Sediments on the Chesapeake Bay," Scietific and Technical Advisory Committee, May 2000.

[5] "Chesapeak Bay Total Maximum Daily Load (TMDL)," US Environmental Protection Agency, 2011.

[6] "Who We Are," *Lower Susquehanna Riverkeeper*, 2013. .

[7] K. McCraw, "Wastewater Treatment," *The Chesapeake Bay: An uncertain future*. [Online]. Available: http://chesapeake.academic.wlu.edu/wastewater-treatment/. [Accessed: 16-Feb-2014].

[8] M. Langland, "Bathymetry and Sediment-Storage Capacity Change in Three Reservoirs on the Lower Susquehanna River, 1996-2008," U.S. Geological Survey, 2009.

[9] C. Johnson, "Maximizing Profits by Understanding Hydraulic Dredge Efficiency," Dredging Supply Company, Inc.

[10] J. D. Derman and H. A. Schlieper, *Decontamination and Beneficial Reuse of Dredged Material Using Existing Infrastructure for the Manufacture of Lightweight Aggregate*. .

[11] Solena Group, "Plasma Arc Technology."

[12] D. F. McLaughlin, S. V. Dighe, and N. H. Ulerich, "Beneficial Reuse of Vitrified Dredged Estuarine Sediments - Phase III FInal Report," Westinghouse STC, Pittsburrgh, PA, 99-9TD0-NYSED-R1, Sep. 1999.

[13] S. Scott, "Lower Susquehanna River Watershed Assessment," 30-Apr-2012.

[14] "USGS 01578310 Susquehanna River at Conowingo, MD," *USGS*, 15-Mar-2014. [Online]. Available: http://waterdata.usgs.gov/nwis/dv/?site_no=01578310&agency_cd=USGS&referred_module=sw.

[15] K. Whipple, "Essentials of Sediment Transport." Sep-2004.

[16] V. Ponce, *Engineering Hydrology, Principles and Practices*. Prentice Hall, 1989.

[17] K. Whipple, "Flow Around Bends: Meander Evolution." Sep-2004.

[18] Lower Susquehanna River Watershed Assessment Team, "Lower Susquehanna River Watershed Assessment: Quarterly Team Meeting," Baltimore, MD, Team Meeting, Aug. 2013.

[19] "Backgrounder: The Conowingo Dam and Chesapeake Bay Water Quality." .

[20] "Changes in Sediment and Nutrient Storage in Three Reservoirs in the Lower Susquehanna River and Implications for the Chesapeake Bay," US Geological Survey, Mar. 1998.

[21] JCI Upcycle Associates, LLC, "Sediment Decontamination and Beneficial Use Pilot Project," New Jersey, Final Summary Report, May 2002.

[22] D. Pettinelli and H. D. Luce, "Purchsing Topsoil," *University of Connecticutt Home and Garden Education Center*, 2013. [Online]. Available: http://www.ladybug.uconn.edu/PURCHASINGTOPSOIL.HTM.

AUTHOR INFORMATION

All authors are Senior Undergraduates in the Department of Systems Engineering and Operations Research, George Mason University.