Design of a Sediment Removal and Processing System to Reduce Sediment Scouring Potential from the Lower Susquehanna River Dams

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Sponsor
West/Rhode Riverkeeper
Agenda

1. **Concept Definition**
   Context, Problem, Need, Scope, Stakeholder Analysis

2. **Concept of Operations**
   Requirements, Operational Scenario, Design Alternatives

3. **Method of Analysis**
   Performance Curves, System Dynamics, Lifecycle Cost Model

4. **Recommendations**
   Utility Analysis, Project Findings, Future Research
Project Overview

Three major dams located along the Lower Susquehanna River retain large amounts of sediment and nutrient pollution. Episodic pulses of these pollution loads are released into the Upper Chesapeake Bay during major storms leading to environmental degradation.

This project seeks to reduce the amount of sediment loads retained behind the Lower Susquehanna River Dams through a sediment removal and processing system, and thereby reduce the ecological impact of major storms on the Upper Chesapeake Bay.
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The Lower Susquehanna River (LSR) Dams

- Provide hydroelectric power, water storage, recreation
- Historically acted as a system of sediment and nutrient traps; trapping 55% to 80% of the annual loads from 1928-2012

Sources: USACE, USGS [1]
Sediment Storage Capacity of the Lower Susquehanna River Dams

**Conowingo** reached dynamic equilibrium in 2000’s; approx. 93% filled in 2011

**Safe Harbor** reached dynamic equilibrium in 1950’s; approx. 100% filled in 2008

**Holtwood** reached dynamic equilibrium in 1920’s; approx. 93% filled in 2008

Dynamic Equilibrium: a state of asymptotic fluctuation from near 100% capacity

Sources: USGS [2-4], USACE [5]
Sources: UMD-CES[6]

**Scouring Events:** Subaquatic Vegetation, Benthic Organisms, and Water Quality

- Episodic pulses of sediment and attached nutrients are released into the Upper Chesapeake Bay
- Enhanced erosion of sediment due to reservoir flooding
- Excess nutrients cause algae blooms, leading to oxygen dead zones
- Excess sediment blocks sunlight leading to subaquatic vegetation die off
- Silt deposition buries oyster beds and benthic organisms

**Scouring Events:** major storms, hurricanes, or ice melts which cause river flow rates above 400,000 cubic feet per second (cfs)

**Case Studies:** Tropical Storm Lee (2011), Tropical Storm Ivan (2004), Hurricane Agnes (1972)
Sediment Load for TMDL Limits, Annual Amounts, and Scouring Events

Scouring Events above 500,000 cubic feet per second surpass Susquehanna TMDL limits for the Susquehanna by 1 to 13 times.

Total Maximum Daily Load: Regulation to restore Bay by 2025

- Scouring Events below 300,000 cubic feet per second contribute up to 0.5 million tons of sediment

Sources: USGS [7], EPA [8-9], USACE[5]
Previous Sediment Mitigation Studies

The Lower Susquehanna River Watershed Assessment (LSRWA)
- U.S. Army Corps of Engineers; 2011-2014
- Evaluated: bypassing sediment, modifying dam operations, dredging and quarry, dredging and reuse through Lightweight Aggregate and island restoration

Results:
- Alternatives evaluated are not cost-effective sediment mitigation strategies; dredging needs to be done on a regular cycle

Gaps:
- Other processing alternatives
- Evaluate dams upstream of Conowingo

Design of a Dam Sediment Management System to Aid Water Quality Restoration of the Chesapeake Bay
- George Mason University; 2013-2014
- Evaluated: artificial island construction, dredging and reuse through topsoil, Lightweight Aggregate, and Plasma Vitrification; only for the Conowingo Dam

Results:
- Plasma Vitrification yielded a positive ROI
- Artificial island did not reduce sediment to a significant degree

Gaps/Recommendations:
- Evaluate dams upstream of Conowingo
- Re-evaluate feasibility of Plasma Vitrification

Sources: USACE[5], GMU[10]
**Problem Statement:** The Lower Susquehanna River Dams have acted as a sediment and nutrient trap for approximately 80 years. However the Safe Harbor, Holtwood, and Conowingo dams have reached near maximum sediment storage capacity. Due to the increased deposition, the predicted amount of harmful sediment that will enter the Upper Chesapeake Bay during a major scouring event will surpass TMDL limits, and significantly damage the Bay’s ecosystem more than previously.

**Need Statement:** There is a need to develop a sediment removal and processing system to reduce the sediment build up in the Lower Susquehanna River Dams, in order to reduce the ecological impact of future scouring events.
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   Utility Analysis, Project Findings, Future Research
<table>
<thead>
<tr>
<th>Mission Requirement ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR. 1</td>
<td>The system shall reduce sediment scouring potential from the Lower Susquehanna River Dams.</td>
</tr>
<tr>
<td>MR. 2</td>
<td>The system shall operate for a minimum lifecycle of 20 years.</td>
</tr>
<tr>
<td>MR. 3</td>
<td>The system shall remove at least 60 percent of the contaminants from the sediment.</td>
</tr>
<tr>
<td>MR. 4</td>
<td>The system shall facilitate achievement of Susquehanna River TMDL limits of 985,000 tons of sediment and 1,900 tons of phosphorous per year.</td>
</tr>
<tr>
<td>MR. 5</td>
<td>The system shall allow for continued hydroelectric power generation for the Lower Susquehanna River Dams.</td>
</tr>
</tbody>
</table>
Sediment Removal and Processing System Operational Scenario

- **Dams:** Conowingo, Holtwood, Safe Harbor
- **Lifecycle:** 30, 25, 20 years
- **Dredging Amounts:** 1, 3, 5, million cubic yards/year
- **Funding:** Government Bond
Dredged Sediment Processing Alternatives

Plasma Vitrification
Piloted by Westinghouse Plasma Corp. Uses plasma torches reaching 5000 deg. C destroying nearly all toxic and microbiological contaminants
Product: **Glass Slag**, replacement for coal slag, glasphalt, talc/feldspar, three-mix glass

Cement-Lock
Piloted by Gas Tech. Institute and Unitel Technologies. Thermochemical process involving a rotary kiln reaching temperatures from 1315 – 1425 deg. C.
Product: **Eco-Melt**, 30-40% replacement for Portland cement

Quarry/Landfill
Removing dredged sediment and placing it in deposit sites. Serves as the control/base case.
Product: **None**

Sources: ENDESCO[11], Westinghouse[12]
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Cost and Performance Analysis Overview

Performance: Scour Performance Curves
Fluid System Dynamics Model

Cost: Lifecycle Cost Model

GMU 2014 Model Results
Regression Model
Scour Performance Curves
Assumption Validation
Fluid System Dynamics Model
Percent of Scouring Reduction
Dredging Amount
Monte Carlo Simulation
Processing Plant Lifecycle Cost Model
LifeCycle Costs
Net Present Value for Each Alternative
Utility vs. Cost Analysis
Recommendations
Scour Performance Curves
GMU 2014 Hydraulic Model

Numerical simulation of the Conowingo Reservoir using bathymetry and velocity profiles

Simulated three flow rates (400K, 700K, 1 mil.) and three dredging amounts (1, 3, 5 million cubic yards per year)

Sources: GMU[10]
Scour Performance Curves
Annual and Aggregated Scour Reduction

Nominal
\[ y = -0.0512x + 1.8504; \quad R^2 = 0.75 \]

Moderate
\[ y = 6.1857x^{0.649}; \quad R^2 = 0.95; \quad S = 0.35 \]

Maximum
\[ y = 8.5035x^{0.838}; \quad R^2 = 0.98; \quad S = 0.40 \]
Scour Performance Curves
Annual Dredging Amounts and Scour Reductions for Conowingo, Safe Harbor, and Holtwood

<table>
<thead>
<tr>
<th>Location</th>
<th>Dredging Amount (annual cubic yards)</th>
<th>Net Scour Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conowingo</td>
<td>650K (1 million)</td>
<td>20%</td>
</tr>
<tr>
<td>Safe Harbor</td>
<td>350K (1 million)</td>
<td>26%</td>
</tr>
<tr>
<td>Holtwood</td>
<td>50K (2 million)</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>150K (5 million)</td>
<td>2%</td>
</tr>
</tbody>
</table>

Nominal Dredging (30 years): 1 million cubic yards/annual
Moderate Dredging (25 years): 3 million cubic yards/annual
Maximum Dredging (20 years): 5 million cubic yards/annual
Fluid System Dynamics Model Overview

**Historical Data Inputs:**
- Scouring Event Test Cases
- Historical Water Data
- Historical Sediment Data
- Reservoir Profiles

**Assumption Validation**

**System Dynamics Model**

**Fluid System Dynamics Model**

**Outputs:**
- Cumulative Sediment Deposition
- Sediment Scour Reduction

**Utility vs. Cost Analysis**

**GMU 2014 Model Results**

**Regression Model**

**Scour Performance Curves**

**Monte Carlo Simulation**

**Processing Plant Lifecycle Cost Model**

**Recommendations**

**Net Present Value for Each Alternative**

**Lifecycle Costs**

**Percent of Scouring Reduction**

**Dredging Amount**
System Dynamics Model

Approach

- System Dynamics Model for Sediment Transport in the Lower Susquehanna River
- Derive experimental coefficients with subset of historical data
- Validate model with subset of historical data

Test Cases:
- Scouring Events: 400,000 / 700,000 / 1 million cubic feet per second (cfs)
- Capacitance: 0 to 1, 0.10 increments for each dam
- Dams are analogous to hydraulic tanks storing water and sediment
- Mass leaving the first tank enters the second tank, mass leaving the second tank enters the third tank, empties into Chesapeake Bay
- Given: water flow rate into Safe Harbor (first tank)
The amount of sediment entering the first tank:

\[
\frac{dm_{in}}{dt} = \rho_{sediment} \times [Q_{in}]_{water}
\]

Where:
\[
\rho_{sediment} = 0.007 \times ([Q_{in}]_{water})^{0.9996}
\]

Based on the conservation of mass:

\[
\frac{dm_{out}}{dt} = \frac{dm_{in}}{dt} - \frac{dm_{cv}}{dt}
\]

Sources: USACE[1]
System Dynamics Model
Determining Sediment Behavior

Sediment within the tank is either deposited or entrained:

\[
\frac{dm_{cv}}{dt} = \frac{dm_{deposited}}{dt} - \frac{dm_{entrained}}{dt}
\]

Deposition or Entrainment is a function of velocity.

Velocity is determined by applying the continuity principle

\[ v = \frac{Q_{in}}{A} \]

Source: Z.Ji-2008 [13]
System Dynamics Model
Calculating Sediment Within Control Volume

\[ x_1 = \begin{cases} 1, & \text{if } v - v_{\text{resuspension}} \geq 0 \\ 0, & \text{if } v - v_{\text{resuspension}} < 0 \end{cases} \]

\[ x_2 = \begin{cases} 1, & \text{if } v_{\text{deposition}} - v \geq 0 \\ 0, & \text{if } v_{\text{deposition}} - v < 0 \end{cases} \]

\[ \frac{dm_{\text{entrained}}}{dt} = k_1 * x_1 * SA \]

\[ \frac{dm_{\text{deposited}}}{dt} = k_2 * x_2 * \frac{dm_{\text{in}}}{dt} \]
System Dynamics Model
Calculating Sediment Out of System

\[ m_{out} = \int (1 - k_2 \times x_2) \times (0.0007 \times Q_{in}^{1.9996}) + k_1 \times x_1 \times SA \, dt \]
System Dynamics Model

Results – Sediment Scoured

Results and Implications:
1. Dredging all three dams still results in the greatest scour reduction
2. The Conowingo results in the greatest scour reduction, followed by the Safe Harbor, while Holtwood has the least
3. Holtwood results in low scour reductions and should not be dredged
4. By implication, the most effective scour reduction would be dredging both Conowingo and Safe Harbor
5. The results agree in general with the Scour Performance Curves
Lifecycle Cost Model Overview

Lifecyle Inputs:
- Plant Capital
- Net Processing Cost
- Net Dredging Cost
- Land Cost
- Market Prices
- Sediment to Product Ratio

Monte Carlo Simulation

Output
- Probabilistic Estimate of Net Present Value (Average, 95% Confidence Intervals)

GMU 2014 Model Results

Regulation Model

Assumption Validation

Fluid System Dynamics Model

Percent of Scouring Reduction

Dredging Amount

Utility vs. Cost Analysis

Recommendations
<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Distribution</th>
<th>Plasma Vitrification</th>
<th>Cement-Lock</th>
<th>Quarry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Capital</td>
<td>Plant capacities from 50,000 cy to 3 million cy/annual</td>
<td>Triangular with +15% tails</td>
<td>$50 - $825 million</td>
<td>$43 - $715 million</td>
<td>N/A</td>
</tr>
<tr>
<td>Net Processing Cost / Tipping Fee</td>
<td>Energy Cost from 8-10 cents/kWh, and $4-$6/million Btu</td>
<td>Triangular with +5% tails</td>
<td>$155 - $205 per ton</td>
<td>$60 - $90 per ton</td>
<td>$5 - $40 per ton</td>
</tr>
<tr>
<td>Dredging Capital</td>
<td>Dredging Amount from 1 to 5 million cy/annual</td>
<td>Triangular based on low and high bids</td>
<td>$6 - $16 million</td>
<td>$6 - $16 million</td>
<td>$3 - $7 million</td>
</tr>
<tr>
<td>Dredging Transport</td>
<td>Distance from 0 to 15 miles</td>
<td>Triangular based on low and high bids</td>
<td>$15 - $30 per ton</td>
<td>$15 - $30 per ton</td>
<td>$30 - $130 per ton</td>
</tr>
<tr>
<td>Land Costs</td>
<td>Average land cost per acre for each geographic area</td>
<td>Triangular based on low and high bids</td>
<td>$15K to $40K per acre</td>
<td>$15K to $40K per acre</td>
<td>N/A</td>
</tr>
<tr>
<td>Revenue Prices</td>
<td>Average market price for replacement product</td>
<td>Triangular: 70 to 85% of market price</td>
<td>$140 - $170 per ton</td>
<td>$75 - $90 per ton</td>
<td>N/A</td>
</tr>
<tr>
<td>Sediment to Product Ratio</td>
<td>Tons of sediment required to product one unit of product</td>
<td>Normal from pilot studies</td>
<td>2.5 tons</td>
<td>1.5 tons</td>
<td>N/A</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>Municipal Yield Curve</td>
<td>Normal of 2014-2015 data</td>
<td>2.7 - 3.5%</td>
<td>2.7 - 3.5%</td>
<td>2.7 - 3.5%</td>
</tr>
</tbody>
</table>
## Processing Plant Lifecycle Cost Model
### Design of Experiment

<table>
<thead>
<tr>
<th>Dam</th>
<th>Products</th>
<th>Dredging Amounts (for each process)</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conowingo</td>
<td>Plasma</td>
<td>Nominal</td>
<td>Probabilistic Net Present Value for each Capacity, Plant, and Processing Combination</td>
</tr>
<tr>
<td></td>
<td>Cement-Lock</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quarry/Landfill</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Holtwood</td>
<td>Plasma</td>
<td>Nominal</td>
<td></td>
</tr>
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Processing Plant Lifecycle Cost Model
Average Net Present Value (by Dam)

Cement-Lock results in the least cost operation
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Value Hierarchy

Reduce Future Impact of Major Scouring Events

Time

Suitability

Performance

Time: lifecycle of the processing plant operation. 30, 25, or 20 years depending on the amount dredged.

Suitability: percent of contaminants contained for each processing technique. Cement-Lock and Plasma are around 80 to 99%, while Quarry is 0%.

Performance: the percent of scouring reduction potential from each dredging amount.

Weights:
Time: 10%
Suitability: 30%
Performance: 60%

*Weights were derived through discussion with the project sponsor, West/Rhode Riverkeeper
Utility vs. Cost Analysis

**Cement-Lock at Moderate Dredging**
Total NPV: -$2 to -$1.3 billion
Performance: 26 percent
Lifecycle: 25 years

**Cement-Lock at Moderate Dredging**
Total NPV: -$900 to -$500 million
Performance: 13 percent
Lifecycle: 25 years

*Note: net present value axis are NOT to scale*
Recommendations and Future Research

1. Detailed Hydrological Model
   - If desired, for more precise scour reduction estimates and to further test the dynamic interaction effect

2. Exhaustive Survey of Nutrient Management Strategies
   - Example: neutralizing the deposited sediment to remove nutrients and contaminants

3. Pilot Study for Cement-Lock Technology on Lower Susquehanna Sediment
   - Volcano Partners LLC are the patent holders

4. Further Research for an Integrated Plasma and Architectural Tile Processing Plant
   - Glass slag may be used as a substitute for three-mix glass, a material used in architectural tile production
Questions
References


References

[8] EPA, “Chesapeake Bay TMDL.” Internet: http://www.epa.gov/chesapeakebaytmdl/

[9] EPA, “Chesapeake Bay TMDL: Section 9 – Chesapeake Bay TMDLs.” Internet: http://www.epa.gov/reg3wapd/tmdl/ChesapeakeBay/tmdlexec.html


Appendix Slides
The Chesapeake Bay
- The largest estuary in the U.S.
- Spans from MD to VA
- Supports wildlife, recreation, commerce

The Susquehanna River
- The largest tributary to the Bay
- Supplies 50% of the freshwater
- Flows from NY to MD

Sources: Chesapeake Bay Program [1]
Subaquatic vegetation has declined by 140,000 acres (as of 2013) from 1937 levels.

On average, only 47% of the Bay has met acceptable benthic index levels for the past 16 years.

On average, only 31% of the Bay has met water quality standards for the past 27 years.

Attributed to: excess sediment and nutrient (nitrogen/phosphorous) loads.

Susquehanna contributes 27% of the sediment, 41% of the nitrogen, 40% of the phosphorous load annually into the Bay.

Source: EPA-2012 [5]
The Lower Susquehanna River (LSR) Dams

Safe Harbor
- Located in Manor Township, PA; 32 miles from the Bay
- Forms Lake Clarke; 10 miles long

Holtwood
- Located in Matric Township, PA; 25 miles from the Bay
- Forms Lake Aldred; 8 miles long

Conowingo
- Located in Conowingo, MD; 10 miles from the Bay
- Forms the Conowingo Reservoir; 14 miles long

- Provide hydroelectric power, water storage, recreation
- Historically acted as a system of sediment and nutrient traps; trapping 55% to 80% of the annual loads from 1928-2012
Normal Conditions
‘Steady-State Problem’

- Steady-state flow < 400,000 cubic feet per second (cfs)
- Average annual river flow: 40,000 cfs
- Dynamic Equilibrium creates a periodic cycle of scour and deposition, with scour occurring from 150,000 cfs – 400,000 cfs
- Scouring below 400,000 cfs can discharge up to 1 million tons of sediment

Sources: ACE/STAC-2011 [10], USGS-2012 [5]

Extreme Conditions
‘Transient Problem’

- Transient flow ≥ 400,000 cubic feet per second (cfs)
- Scouring Events: transient flow events such as major storms or hurricanes that release large amounts of pollution loads from the Susquehanna watershed and reservoirs of the LSR Dams, eventually discharging into the Upper Bay.
- Low Frequency, High Severity
- Ex: Tropical Storm Lee in 2011 discharged 4 million tons from the reservoirs; 300% of TMDL regulation
The Steady-State Problem

TEMPORARY STORAGE

SCOUR

SEDIMENT CYCLE

DEPOSITION
Scouring Event Frequencies

![Graph showing Sediment Scour Load and Recurrence Interval vs. Streamflow](image-url)
Gap Analysis: Predicted Average Sediment Loads from the Lower Susquehanna River Dams During Major Scouring Events

Sources: ACE-2014 [9]
Sediment Cores Study

Sediment consists of the following types of contaminants:

1. **Nutrients** – carbon, nitrogen, phosphorous

2. **Metals** – arsenic, cadmium, chromium, copper, iron, manganese, nickel, lead, zinc, silver, and mercury.

3. **Trace Organic Compounds** – polycyclic aromatic hydrocarbons (PAH’s), polychlorinated biphenyl (PCB’s), and other pesticides
Characterization of Sediment in the Lower Susquehanna Dams

- Nutrients attached to sediment causes environmental degradation
- Nutrient attached primarily to clay and silt, not sand
- During scouring events, 5% - 10% of the sand is transported in the scour load

Total Amounts of Clay and Silt:
- Lake Clarke: 67.45 million tons
- Lake Aldred: 5.69 million tons
- Conowingo Reservoir: 152 million tons

Sources: ACE-2014 [9]
Need Statement & Proposed Solution

There is a need to develop a **sediment removal and processing system** to **reduce sediment** build up in the Lower Susquehanna River Dams, in order to reduce the ecological impact of future scouring events.

Proposed Solution: Remove deposited sediment in the reservoirs via hydraulic dredging and process sediment into marketable products in a processing plant operation to offset the costs.
LSRWA Recommendations and Insight: Reservoir Scour

1. Scour should be reduced from both the Susquehanna watershed and the reservoir scour from the dams:

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 in 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 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.

Pg. 3 of Executive Summary

Link: http://mddnr.chesapeakebay.net/lsrwa/docs/report/ExecutiveSummary.pdf
LSRWA Recommendations and Insight: Nutrients and Sediment

2. Although the US ACE study concluded that nutrients are the main issue, they also stated that by conducting sediment management, we are also managing nutrients (since most of the phosphorous is attached to the sediment).

Sediment Management Strategy Analysis

This assessment included a survey-level screening of management strategies to address the additional loads to Chesapeake Bay from scour. 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.

Lower Susquehanna River Watershed Assessment, MD and PA

ES-3

October 2014

Pg. 3 of Executive Summary

Link: http://mddnr.chesapeakebay.net/lsrwa/docs/report/ExecutiveSummary.pdf
LSRWA Recommendations and Insight: Dredging

3. From our interpretation of the report, what the US ACE stated was that dredging would need to be done on a regular cycle or annually, to be performance effective, while keeping in mind that the costs would be very, very high. In addition, the US ACE mainly looked at dredging and placing sediment into quarries or lightweight aggregate, while we wanted to re-evaluate the plasma vitrification alternative, and see if any other product can give us a lower cost, or even result in a profit margin.

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 sudden reversal on concern about the impact of sediment held by O’Malley, the U.S. Geological Survey and numerous conservation groups was greeted with suspicion by the Hogan administration. “It was kind of surprising to us that all of a sudden the Army Corps was reversing their concern about the dam,” said Adam Dubitsky, policy director for Hogan.

Chip MacLeod, general counsel for the Clean Chesapeake Coalition of 10 rural farming counties such as Frederick, Cecil and Dorchester that support Hogan, thinks he knows why.

MacLeod said turning the focus away from sediment is the goal of a multibillion-dollar federal plan to clean up the bay by limiting nutrient pollution. Run by the Environmental Protection Agency and managed by states in the bay watershed, including Maryland, the “pollution diet” is supported by the Army Corps and regional environmental groups.

Link: http://www.pressreader.com/usa/the-washington-post/20150406/281513634666489/TextView
<table>
<thead>
<tr>
<th>Primary Stakeholder</th>
<th>Description</th>
<th>Objective(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West/Rhode Riverkeeper, Inc. (WRR)</td>
<td>• Non-profit organization&lt;br&gt;• Founded in 2005</td>
<td>• Protect watershed community&lt;br&gt;• Attempt to stop pollution&lt;br&gt;• Help authorities enforce environmental laws</td>
</tr>
<tr>
<td>Pennsylvania Power and Light (PPL)</td>
<td>• Licensed operator of Holtwood Dam&lt;br&gt;• Produce 230MW annually&lt;br&gt;• Privately owned</td>
<td>• Provide clean renewable energy&lt;br&gt;• Licensed through 2030</td>
</tr>
<tr>
<td>Safe Harbor Water Power Corporation (SHWPC)</td>
<td>• Licensed operator of Safe Harbor Dam&lt;br&gt;• Produce 114MW annually&lt;br&gt;• Privately owned</td>
<td>• Provide energy during peak demand&lt;br&gt;• Licensed through 2030</td>
</tr>
<tr>
<td>Exelon Generation</td>
<td>• Temporarily licensed operator of Conowingo Dam&lt;br&gt;• Produce 500 MW annually&lt;br&gt;• Privately owned</td>
<td>• Provide clean renewable energy&lt;br&gt;• Pending relicensing</td>
</tr>
<tr>
<td>Pennsylvania and Maryland Residents</td>
<td>• Farmers and residents around the Lower Susquehanna River Watershed&lt;br&gt;• Residents receiving power</td>
<td>• Ability to use the river for farming and recreation&lt;br&gt;• Receive power with no increase in cost</td>
</tr>
<tr>
<td>In Scope</td>
<td>Out of Scope</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Conowingo, Holtwood, and Safe Harbor Dams</td>
<td>York Haven Dam</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reason:</strong> low head dam, does not fully cross river, does not trap sediment to a significant degree</td>
<td></td>
</tr>
<tr>
<td>Sediment Deposition in Reservoirs</td>
<td>Sediment Loads from Watershed and Preventing Sediment Loads</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reason:</strong> addressed by TMDL</td>
<td></td>
</tr>
<tr>
<td>Nutrients Attached to Solid Sediment</td>
<td>Free Flowing Nutrients</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reason:</strong> addressed by TMDL/other regulations</td>
<td></td>
</tr>
<tr>
<td>Scouring Events (Transient Flow)</td>
<td>Normal Conditions (Steady-State Flow)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reason:</strong> episodic scouring is most detrimental, mitigating transient problem may help with steady state problem</td>
<td></td>
</tr>
<tr>
<td>Sediment Removal and Processing</td>
<td>Other Sediment Mitigation Techniques</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Reason:</strong> evaluated by Army Corps of Engineers and George Mason as infeasible</td>
<td></td>
</tr>
</tbody>
</table>
### Processing Alternative Evaluation

<table>
<thead>
<tr>
<th>Processing Technique</th>
<th>Product Produced</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Vitrification</td>
<td>Glass Slag</td>
<td>High cost, however recommended to be further evaluated by GMU Study due to high revenue</td>
</tr>
<tr>
<td>Cement-Lock</td>
<td>EcoMelt</td>
<td>Moderate cost and was not evaluated by prior studies</td>
</tr>
<tr>
<td>Particle Separation/Soil Washing</td>
<td>Topsoil</td>
<td>Low cost and revenue, evaluated prior by GMU Study</td>
</tr>
<tr>
<td>Thermal Desorption</td>
<td>Construction Aggregate</td>
<td>Similar costs to Cement-Lock, however lower revenue, evaluated prior by US ACE Study</td>
</tr>
<tr>
<td>Fluidized Bed Treatment</td>
<td>Agricultural products</td>
<td>Discontinued development due to high costs</td>
</tr>
<tr>
<td>Flowable Fill</td>
<td>Concrete Mix</td>
<td>Has not been used for contaminated dredged sediment</td>
</tr>
<tr>
<td>Glass Furnace Technology</td>
<td>Glass Slag</td>
<td>More cost-effective than Plasma Vitrification however discontinued development</td>
</tr>
<tr>
<td>Electrochemical Remediation,</td>
<td>N/A</td>
<td>Used only for sediment remediation, no product produced to offset costs</td>
</tr>
<tr>
<td>Solidification/Stabilization</td>
<td>N/A</td>
<td>Used only for sediment remediation, no product produced to offset costs</td>
</tr>
<tr>
<td>Base Catalyzed Decomposition</td>
<td>N/A</td>
<td>Discontinued development due to high cost, in addition is used only for sediment remediation</td>
</tr>
</tbody>
</table>
### Manufactured Top Soil Alternative

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Acceptable Levels (mg/kg)</th>
<th>Found Levels (ug/g)</th>
<th>Section of river max found in (1-38)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>abrev</strong></td>
<td><strong>element</strong></td>
<td><strong>Residential</strong></td>
<td><strong>Non-residential</strong></td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
<td>any</td>
<td>any</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
<td>any</td>
<td>any</td>
</tr>
<tr>
<td>S</td>
<td>Sulfur</td>
<td>any</td>
<td>any</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorous</td>
<td>any</td>
<td>any</td>
</tr>
<tr>
<td><strong>Metals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>Cadmium</td>
<td>3.9</td>
<td>51</td>
</tr>
<tr>
<td>Cr</td>
<td>Chromium</td>
<td>23</td>
<td>310</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
<td>310</td>
<td>41000</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron</td>
<td>5500</td>
<td>72000</td>
</tr>
<tr>
<td>Mn</td>
<td>Manganese</td>
<td>160</td>
<td>2000</td>
</tr>
<tr>
<td>Ni</td>
<td>Nickel</td>
<td>160</td>
<td>2000</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
<td>400</td>
<td>1000</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc</td>
<td>2300</td>
<td>31000</td>
</tr>
<tr>
<td><strong>Metal/Metaloid</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>Arsenic</td>
<td>0.43</td>
<td>1.9</td>
</tr>
<tr>
<td>Hg</td>
<td>Mercury</td>
<td>2.3</td>
<td>31</td>
</tr>
<tr>
<td>Se</td>
<td>Selenium</td>
<td>39</td>
<td>510</td>
</tr>
<tr>
<td>Ag</td>
<td>Silver</td>
<td>39</td>
<td>510</td>
</tr>
<tr>
<td>PCBs</td>
<td></td>
<td>0.32</td>
<td>1.4</td>
</tr>
</tbody>
</table>
## Potential Plant Sites

<table>
<thead>
<tr>
<th>Dam</th>
<th>Address</th>
<th>Coordinates</th>
<th>Description</th>
<th>Size (acres)</th>
<th>Distance</th>
<th>Acquirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conowingo Dam</td>
<td>2535 Silver Road, Darlington MD</td>
<td>39.640744, -76.171237</td>
<td>Farmland</td>
<td>184.15</td>
<td>3 miles</td>
<td>High</td>
</tr>
<tr>
<td>Holtwood Dam</td>
<td>162 Pinnacle Road W, Holtwood PA</td>
<td>39.846517, -76.331813</td>
<td>Farmland and some forest</td>
<td>199.85</td>
<td>3 miles</td>
<td>High</td>
</tr>
<tr>
<td>Safe Harbor Dam</td>
<td>Chanceford, PA</td>
<td>39.915838, -76.419359</td>
<td>Forest next to farmland</td>
<td>285.26</td>
<td>2 miles</td>
<td>High</td>
</tr>
</tbody>
</table>

![Map of Potential Plant Sites](image1)
![Map of Potential Plant Sites](image2)
![Map of Potential Plant Sites](image3)
Processing Plant Lifecycle Cost Model
Average Net Present Value (by Alternative)
HECRAS Hydrologic Model

• Hydrologic Engineering Centers River Analysis System (HEC-RAS)
• Developed by Army Corp of Engineers
• Utilized in LSRWA 2014

• Features
  • 1-D Steady/Unsteady Flow
  • Sediment transport, mobile bed, scouring
  • Varying bathymetry
  • Sediment grain size
  • Geospatial data
Utility Analysis (Combined)
System Dynamics Model
Results – Sediment Scoured (Normalized)

<table>
<thead>
<tr>
<th>Scouring Event</th>
<th>Sediment Scoured (Million Tons)</th>
<th>Reservoir Fill Capacity (normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400,000 CFS</td>
<td></td>
<td>0 100 200 300 400 500 600 700 800 900 1000</td>
</tr>
<tr>
<td>700,000 CFS</td>
<td></td>
<td>0 100 200 300 400 500 600 700 800 900 1000</td>
</tr>
<tr>
<td>1 Million CFS</td>
<td></td>
<td>0 100 200 300 400 500 600 700 800 900 1000</td>
</tr>
</tbody>
</table>

- All
- Conowingo
- Holtwood
- Safeharbor
### System Dynamics Model
#### Tabulated Results – Efficiency

<table>
<thead>
<tr>
<th>Scouring Event</th>
<th>Dam</th>
<th>m</th>
<th>b</th>
<th>R-Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>400,000</td>
<td>All</td>
<td>110,435,645.55</td>
<td>1,074,634.32</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Conowingo</td>
<td>105,265,667.60</td>
<td>48,690,236.50</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Holtwood</td>
<td>112,211,194.19</td>
<td>79,455,555.05</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Safe Harbor</td>
<td><strong>114,520,758.05</strong></td>
<td>100,068,657.73</td>
<td>0.79</td>
</tr>
<tr>
<td>700,000</td>
<td>All</td>
<td>109,913,166.73</td>
<td>2,681,511.27</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Conowingo</td>
<td>108,873,237.73</td>
<td>47,301,485.36</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Holtwood</td>
<td>129,674,538.56</td>
<td>76,241,721.23</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Safe Harbor</td>
<td><strong>144,892,893.00</strong></td>
<td>94,683,888.45</td>
<td>0.86</td>
</tr>
<tr>
<td>1,000,000</td>
<td>All</td>
<td>97,877,010.00</td>
<td>8,412,204.09</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Conowingo</td>
<td>102,265,471.86</td>
<td>47,911,141.50</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Holtwood</td>
<td><strong>113,328,781.38</strong></td>
<td>74,107,351.91</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Safe Harbor</td>
<td>102,807,319.07</td>
<td>94,746,797.27</td>
<td>0.94</td>
</tr>
</tbody>
</table>