Determining the effects of legacy sediment removal and floodplain reconnection on ecosystem function and nutrient export

Presenters: Vanessa B. Beauchamp & Joel Moore
Towson University

Co-authors: Patrick Baltzer, Patrick McMahon, Melinda Marsh, Kyle Bucher, Ryan Casey, Chris Salice
Acknowledgements

• Funding
  • Chesapeake Bay Trust (#13974), Towson University

• Logistical support – Ecotone, Inc.

• Landowners – Henry and David Pitts, Rigdon Family, Edwards Family, Harford County, City of Bel Air

• Students – Patrick McMahon, Patrick Baltzer, Ginny Jeppi
What are the goals and desired outcomes of restoration? What’s the end point?

**Shifting Waterways**

Researchers are studying how dams and milponds alter stream flow.

**PRE-SETTLEMENT**

Before European settlement, stream valleys in the Middle Atlantic states were typically marshy, with shallow channels of water flowing in sheets over gravel stream beds.

*Source: LandStudies*
What are the goals and desired outcomes of restoration? What’s the end point?

**Shifting Waterways**
Researchers are studying how dams and millponds alter stream flow.

**PRE-SETTLEMENT**
Before European settlement, stream valleys in the Middle Atlantic states were typically marshy, with shallow channels of water flowing in sheets over gravel stream beds. *Source: LandStudies*

**SETTLEMENT**
In the 18th and 19th centuries settlers built dams by the thousands. Trapped sediment runoff from logging and farming slowly filled in the millponds. If a dam failed another dam might be built on top of it, or just downstream.
What are the goals and desired outcomes of restoration? What’s the end point?

Shifting Waterways
Researchers are studying how dams and millponds alter stream flow.

PRE-SETTLEMENT
Before European settlement, stream valleys in the Middle Atlantic states were typically marshy, with shallow channels of water flowing in sheets over gravel stream beds.  
Source: LandStudies

SETTLEMENT
In the 18th and 19th centuries settlers built dams by the thousands. Trapped sediment runoff from logging and farming slowly filled in the millponds. If a dam failed another dam might be built on top of it, or just downstream.

TODAY
After hundreds of years the valley floor might be covered with 3 to 20 feet of sediment. Once a dam is gone, faster-flowing water cuts deep channels in the silt, eroding down toward the stream’s historic elevation and leaving horizontal layers of sediment visible along the stream banks.
Mill dam, Lancaster County, PA

>5–10 mill dams / 10 km² in north-central Maryland
Likely outcomes & questions about Legacy Sediment Removal and Floodplain Reconnection

• Vegetation
  • Increased dominance of hydric vegetation
  • Change in community composition
  • Response to disturbance? Invasives?

• Water chemistry
  • Decrease in N, P and TSS due to increased overbank events and longer residence time
  • Relationship with drainage area? Impervious cover? Project length?
Study sites

6 restored watersheds, 3 others

- 4 agricultural watersheds
  - 3 row crop

- 2 (sub)urban watersheds
  - + 1 larger scale watershed

- 2 (mostly) forested watersheds
Study sites

6 restored watersheds, 3 others

- 4 agricultural watersheds
  - 3 row crop
- 2 (sub)urban watersheds
  - + 1 larger scale watershed
- 2 (mostly) forested watersheds
Study sites

6 restored watersheds, 3 others

- 4 agricultural watersheds
  - 3 row crop
- 2 (sub)urban watersheds
  - + 1 larger scale watershed
- 2 (mostly) forested watersheds
- All <8.2 km²
- Agricultural: 0 – 73%
- Impervious: 0 – 56%
- Restored length: 1240 – 5230 ft
- Restoration age: 1 – 5 years
First Mine Branch
Vegetation: Sampled in spring and fall for two years

Three sites:
- Reference: Sampled in spring and fall for two years
- Restored: Sampled in spring and fall for one year before and one year after restoration

Post-restoration:
- Reference: Sampled in spring and fall for two years
Woody vegetation: Decrease in area, mixed on diversity

- 81% decrease in basal area
- 20% decrease in species richness
- Areas *within* a site become more diverse
- But differences *between* sites decrease. Biotic homogenization?

\[
z = -2.201, \ p = 0.028
\]
Woody vegetation: Decrease in area, mixed on diversity

- 81% decrease in basal area
- 20% decrease in species richness
- Areas *within* a site become more diverse
- But differences *between* sites decrease. Biotic homogenization?
- Similar species composition in unrestored and restored reaches
- No significant indicator species changed in importance due to planting

![Graph showing basal area comparison between pre-restoration/unrestored and post-restoration/restored](image-url)
Herbaceous vegetation: More hydrophytic, other improvements

- Post-restoration is more hydrophytic (decrease in Wetland Indicator Score)
- Sites become more different from each other (upstream/seedbank contribution?)
Herbaceous vegetation: More hydrophytic, other improvements

• Post-restoration is more hydrophytic (decrease in Wetland Indicator Score)

• Sites become more different from each other (upstream/seedbank contribution?)

• Slight increases overall in quality, richness, & diversity

• Sites that start with low quality vegetation improve, but sites with high quality vegetation decrease in quality

• 74% loss of skunk cabbage – slow regeneration?
Sampling approach

Three sites

Upstream

Downstream

**Pre-Restoration**

*Direction of streamflow*

\[ \text{Flux/load} = \text{Downstream} - \text{Upstream} \]
Sampling approach

Flux/load = \textit{Downstream} – \textit{Upstream}
Sampling approach

Pre-Restoration

Three sites
Upstream

Direction of streamflow

Downstream

Post-Restoration

Flux/load = Downstream – Upstream
Biggest control for baseflow N: land use

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Pre-restoration baseflow N differences across reaches

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Pre-restoration baseflow N differences across reaches

No substantial change post-restoration

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Baseflow N concentrations quite similar after restoration

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Baseflow N concentrations quite similar after restoration, fluxes higher

Higher fluxes driven by discharge 2018 *highest* precip on record

McMahon et al. (2021) *Environmental Research Letters*
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Carbon availability appears to be limiting denitrification.

Similar dissolved organic carbon concentrations pre- & post-restoration

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Carbon availability appears to be limiting denitrification.

Similar dissolved organic carbon concentrations pre- & post-restoration.

McMahon et al. (2021) *Environmental Research Letters*  
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Carbon availability appears to be limiting denitrification

Similar dissolved organic carbon concentrations pre- & post-restoration

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Carbon availability appears to be limiting denitrification

At Big Spring Run in PA, denitrification was not observed in groundwater (not even stream) until 5–6 years after restoration. McMahon et al. (2021) Environmental Research Letters https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Hints of downstream mitigation based on difference in event loads

FMB: Most ag site

Daily baseflow

\[
\text{N load} \quad 6300 \text{ g/km}^2
\]

McMahon et al. (2021) *Environmental Research Letters*

https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Hints of downstream mitigation based on difference in event loads

FMB: Most ag site

**Daily baseflow**

- 7/11/2019
- 1/12/2020
- 2/05/2020

**N load**

- 6300 g/km²

**Upstream > downstream**

McMahon et al. (2021) *Environmental Research Letters*

https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Hints of downstream mitigation based on difference in event loads

FMB: Most ag site

Daily baseflow
- 7/11/2019
- 1/12/2020
- 2/15/2020

N load: 6300 g/km²

Upstream > downstream

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Hints of downstream mitigation based on difference in event loads

FMB: Most ag site

Daily baseflow
- NO3 (g/km², difference)
  - Upstream > downstream

N load
- 6300 g/km²

Upstream > downstream

Integrated reductions:
- 10–37%

For all parameters:
- Peak reductions:
  - 5–19%

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Preview on temperature: First Mine Branch (most ag site)

**First Mine Branch – Upstream**

- **Daily max**
- **Daily mean**
- **Daily min**

June – Aug. **76%**

Time <20°C
Preview on temperature: First Mine Branch (most ag site)

- **First Mine Branch – Upstream**
  - Daily max
  - Daily mean
  - Daily min

- **First Mine Branch – Downstream**

**June – Aug.**

- Time <20°C: 76%
- Time <20°C: 59%
Preview on temperature: First Mine Branch (most ag site)

June – Aug.  Time <20°C  76%  59%
Preview on temperature: First Mine Branch (most ag site)

First Mine Branch – **Upstream**

First Mine Branch – **Downstream**

Baisman Run – **70% forested, 1-2% imperv.**

June – Aug.
Time <20°C  
76%

59%

47%
Summary - Water

• Weather (2018) made the study “interesting”

• Agricultural land use is the biggest driver of N concentrations

• Denitrification appears to be limited by carbon

• No significant difference in N after restoration

• During stormflow
  
  o Hints of slightly lower fluxes on downstream end

  o Of interest: storm N shifts with more ammonia & dissolved organic N (or NO$_3^-$ decreases more than total dissolved N)
What does this mean for me?

• The wet year of 2018 obscured some results in research
  • Nutrients, Sediment, and Temperature inconclusive
  • Why no dilution in higher discharges?

• Land Use of Watershed has dominant impacts
  • Are urban loads correlating with Bay Model?

• Legacy Sediment Removal increases hydrophytic vegetation establishment and decreases invasives at these sites – at least initially

• Majority of herbaceous vegetation established was not planted, majority of woody vegetation was planted
What does this mean for me?

What do I take from this if I am a practitioner:

• What is optimal selection of floodplain access elevation? Significance of baseflow versus flood flow nutrient and sediment fluxes?
• Siting of projects relative to land use
• Planting plan strategies
• Look for ways to create more storage or increase retention time for storm flows

What do I take from this if I am a regulator:

• Temperature fluctuations may be negligible but additional data in normal year needed
• Lower risk of invasives – at least initially
• Higher likelihood of self mitigating wetland impacts with hydrophytic vegetation quickly established?
Extra background slides
What are the goals and desired outcomes of restoration?

Meandering
What are the goals and desired outcomes of restoration?

Meandering

Anastomosing
Natural Piedmont Stream Valley

Connectivity between rooting zone, groundwater, and stream flow

- Roots extend to groundwater
- Floodplain Soils – Shallow, Peaty, Organic, & Porous
- Cobble/Gravel Bed (Groundwater)
- Bedrock
Mill density in mills/sq-km (number of mills)

- 0
- > 0 to 0.02 (5909)
- > 0.02 to 0.05 (14370)
- > 0.05 to 0.10 (22377)
- > 0.10 to 0.20 (12291)
- > 0.20 to 0.61 (1217)

State boundaries in 1840

Scale: 0 to 500 km
Summary - Vegetation

• Decrease in woody vegetation
  • Removal of trees
  • Near-complete elimination of vines
  • Community similarity among sites increases

• Increase in hydrophytic, native vegetation
  • Loss of species (like skunk cabbage) that don’t disperse/regenerate well from seed
  • Loss of forest understory species
  • Increase in graminoid species (grasses, rushes, sedges)
    • Response to hydrology and light
## Study sites – for questions

<table>
<thead>
<tr>
<th>Site</th>
<th>Drainage Area (km²)</th>
<th>Forest (%)</th>
<th>Impervious surface cover (%)</th>
<th>Restoration length (linear ft)</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTRD</td>
<td>6.55</td>
<td>14.5</td>
<td>1.26</td>
<td>5320</td>
<td>Reforesting / Retired Agricultural</td>
</tr>
<tr>
<td>BTRU</td>
<td>6.03</td>
<td>13.3</td>
<td>1.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMRD</td>
<td>3.88</td>
<td>26.4</td>
<td>1.26</td>
<td>2400</td>
<td>Row crop with (former) forested buffer</td>
</tr>
<tr>
<td>FMRU</td>
<td>2.93</td>
<td>22.5</td>
<td>1.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSRD</td>
<td>2.25</td>
<td>37.7</td>
<td>6.14</td>
<td>2600</td>
<td>Pasture / Active cattle farm</td>
</tr>
<tr>
<td>NSRU</td>
<td>1.83</td>
<td>43.8</td>
<td>7.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABD</td>
<td>4.97</td>
<td>7.92</td>
<td>13.7</td>
<td>1340</td>
<td>Row Crop &amp; Retired pasture</td>
</tr>
<tr>
<td>CABU</td>
<td>4.40</td>
<td>10.7</td>
<td>14.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCBD</td>
<td>8.18</td>
<td>21.6</td>
<td>21.6</td>
<td>3675</td>
<td>Suburban / Retired Agricultural</td>
</tr>
<tr>
<td>BCBU</td>
<td>7.07</td>
<td>21.9</td>
<td>21.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PTRD</td>
<td>0.96</td>
<td>5.01</td>
<td>56.4</td>
<td>1240</td>
<td>Dense urban</td>
</tr>
<tr>
<td>PTRU</td>
<td>0.88</td>
<td>3.29</td>
<td>54.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Beetree Run (2016)
First Mine Run (2017)
North Stirrup Run (2015)
Cabbage Run (2014)
Bear Cabin Branch (2018)
Plumtree Run (2017)

Baltimore City
INGREDIENTS FOR A MEANDERING RIVER

- Gravel, sand, and water come in from upstream
- Vegetation slows erosion
- Cuts into bank
- Point bar
- Stream deposits gravel...then sand
- Fine sediment helps block off chutes
- Downstream
- Over time stream wanders

http://www.berkeley.edu/news/media/releases/2009/10/images/invitro1_h.jpg
Extra site description slides
WARNING
DO NOT PLAY, SWIM OR FISH

SEWAGE OVERFLOW
EXPOSURE TO WATER MAY CAUSE ILLNESS.

TOWNSHIP OF BEL AIR
DEPARTMENT OF PUBLIC WORKS
330 CHESTERTOWN ROAD
BEL AIR, MARYLAND 21014
443-327-8665
(443) 905-8700 (9 a.m. to 4:30 p.m)

After Hours:
Contact Police Department
(443) 905-4112
Extra riparian vegetation slides
Average 81% DECREASE in basal area and 20% decrease in woody species richness

**Basal area**

$z = -2.201, p = 0.028$

**Species Richness**

$t = 2.99, df = 5, p = 0.03$

**Weighted Wetland Indicator Score**

$t = 2.20, df = 5, p = 0.08$
Woody Layer Beta Diversity

Within-Site Beta Diversity

Pre-restoration/Unrestored  Post-Restoration/Restored

Among-Site Beta Diversity

Pre-restoration/Unrestored  Post-restoration/Restored

$z = -2.201, p = 0.028$

$t = 2.44, df = 10, p = 0.035$
Woody Vegetation NMDS
Change in composition of important species (high indicator values)
## Change in Indicator Value

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Un/Pre Restored IV</th>
<th>Restored IV</th>
<th>Change</th>
<th>Planted Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salix purpurea</em></td>
<td>purpleosier willow</td>
<td>0</td>
<td>67</td>
<td>67</td>
<td>3</td>
</tr>
<tr>
<td><em>Viburnum prunifolium</em></td>
<td>blackhaw</td>
<td>19</td>
<td>60</td>
<td>41</td>
<td>2</td>
</tr>
<tr>
<td><em>Aronia arbutifolia</em></td>
<td>red chokeberry</td>
<td>4</td>
<td>37</td>
<td>33</td>
<td>1</td>
</tr>
<tr>
<td><em>Salix nigra</em></td>
<td>black willow</td>
<td>31</td>
<td>63</td>
<td>32</td>
<td>5</td>
</tr>
<tr>
<td><em>Quercus velutina</em></td>
<td>black oak</td>
<td>2</td>
<td>29</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td><em>Acer platanoides</em></td>
<td>Norway maple</td>
<td>46</td>
<td>1</td>
<td>-45</td>
<td>0</td>
</tr>
<tr>
<td><em>Lonicera japonica</em></td>
<td>Japanese honeysuckle</td>
<td>50</td>
<td>0</td>
<td>-50</td>
<td>0</td>
</tr>
<tr>
<td><em>Celastrus orbiculatus</em></td>
<td>oriental bittersweet</td>
<td>71</td>
<td>14</td>
<td>-57</td>
<td>0</td>
</tr>
<tr>
<td><em>Rubus occidentalis</em></td>
<td>black raspberry</td>
<td>60</td>
<td>2</td>
<td>-58</td>
<td>0</td>
</tr>
<tr>
<td><em>Rubus phoenicolasius</em></td>
<td>wineberry</td>
<td>63</td>
<td>1</td>
<td>-62</td>
<td>0</td>
</tr>
</tbody>
</table>
Woody Vegetation

• Large decrease in basal area and species richness
• Areas within a site become more diverse, but differences between sites decrease. Biotic homogenization?
• Similar species composition in unrestored and restored reaches
• No significant indicator species – *Salix purpurea* (purple osier or basket willow) importance increases due to planting

https://www.willowsvermont.com/purbl.html
Herbaceous Layer Vegetation

**Pre-restoration/Unrestored**
- Weighted Wetland Indicator Score: 3
- Among-Site Beta Diversity: 0.6

**Post-restoration/Restored**
- Weighted Wetland Indicator Score: 2
- Among-Site Beta Diversity: 0.7

Statistical Tests:
- $z = -2.201, p = 0.028$
- $t = 20.79, df = 10, p < 0.001$
Herbaceous vegetation – Change in composition, sites maintain identity

Reference
Pre-restoration
Post-restoration
Restored
Bear Cabin Branch
First Mine Run
Plum Tree Run
Cabbage Run
North Stirrup Run
Bee Tree Run

Axis 1
Axis 2

Axis 1  $r^2 = 0.626$
Axis 2  $r^2 = 0.233$
Number of species

<table>
<thead>
<tr>
<th></th>
<th>Unrestored</th>
<th>Restored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-restoration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-restoration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coefficent of Conservatism

<table>
<thead>
<tr>
<th></th>
<th>Unrestored</th>
<th>Restored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Restoration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-Restoration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

p = 0.004
## Indicators of unrestored reaches

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Common Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alliaria petiolata</td>
<td>garlic mustard</td>
</tr>
<tr>
<td>Rosa multiflora</td>
<td>multiflora rose</td>
</tr>
<tr>
<td>Symplocarpus foetidus</td>
<td>skunk cabbage</td>
</tr>
<tr>
<td>Parathelypteris noveboracensis</td>
<td>New York fern</td>
</tr>
<tr>
<td>Polystichum acrostichoides</td>
<td>Christmas fern</td>
</tr>
<tr>
<td>Arisaema triphyllum</td>
<td>Jack in the pulpit</td>
</tr>
<tr>
<td>Circaea alpine</td>
<td>enchanters nightshade</td>
</tr>
<tr>
<td>Carpinus caroliniana</td>
<td>hop hornbeam</td>
</tr>
<tr>
<td>Persicaria virginiana</td>
<td>Virginia jumpseed</td>
</tr>
<tr>
<td>Clematis virginiana</td>
<td>virgin's bower</td>
</tr>
<tr>
<td>Geum canadense</td>
<td>white avens</td>
</tr>
<tr>
<td>Viola sororia</td>
<td>blue violet</td>
</tr>
<tr>
<td>Lindera benzoin</td>
<td>spice bush</td>
</tr>
<tr>
<td>Amphicarpaea bracteata</td>
<td>hog peanut</td>
</tr>
</tbody>
</table>
Average 74% DECREASE in skunk cabbage cover
Indicators of restored reaches

70 species identified

Herb/Graminoid = 96%
Obligate/FACW = 50%
Native = 70%
Planted = 13%

Majority of dominant/indicator species were NOT PLANTED

Evidence for seed bank or downstream dispersal?
Extra water quality slides
Elevated baseflow discharge (& fluxes) in 2018 & 2019
Elevated baseflow discharge (& fluxes) in 2018 & 2019
Biggest control for baseflow N: land use
Biggest control for N: land use – *C also but generally opposite*
Pre-/Post-restoration: no significant difference (yet)
Decrease in N, increased P & TSS during storm events at FMB (most ag.)

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Decrease in N, increased P & TSS during storm events at FMB (most ag.)

Baseflow $N = \text{NO}_3^-$
Stormflow $N \neq \text{NO}_3^-$

McMahon et al. (2021) *Environmental Research Letters*
Decrease in N, increased P & TSS during storm events at FMB (most ag.)

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Decrease in N, increased P & TSS during storm events at FMB (most ag.)

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Decrease in N, increased P & TSS during storm events at FMB (most ag.)

McMahon et al. (2021) Environmental Research Letters
https://iopscience.iop.org/article/10.1088/1748-9326/abe007
Restoration not detectable downstream (restoration 15% of watershed)

*N via baseflow, TSS (&P) via stormflow* downstream of most urban site

Factor of 2 difference
Restoration not detectable downstream (restoration 15% of watershed)

N via baseflow, TSS (&P) via stormflow downstream of most urban site

Factor of 2 difference

Factor of >5 difference

Event driven