Legacies lost and found:
Improving stream restoration practices

Big Spring Run
Restoration
Monitoring
Experiment

EPA-STAC Workshop
March 21, 2023

Big Spring Run

Restoration
Monitoring
Experiment

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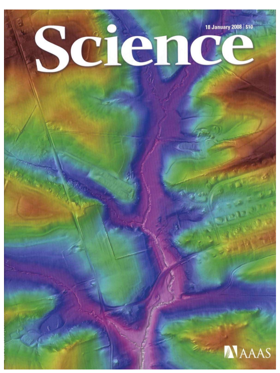
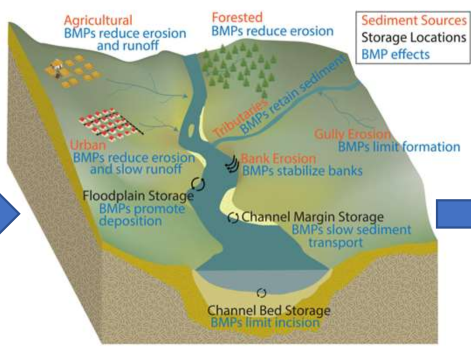
Topics

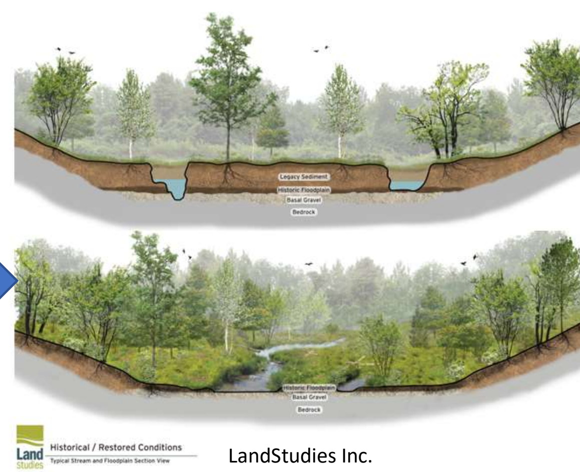
- Diagnosing the Problem
- Regulatory Landscapes
- Restoration Design & Goals
- Monitoring Results
- Scaling Up - Discussion



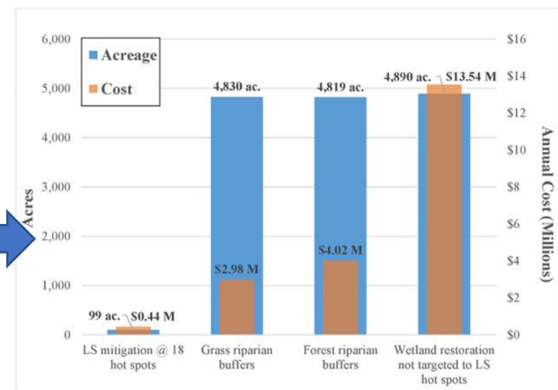
Walter and Merritts, 2008



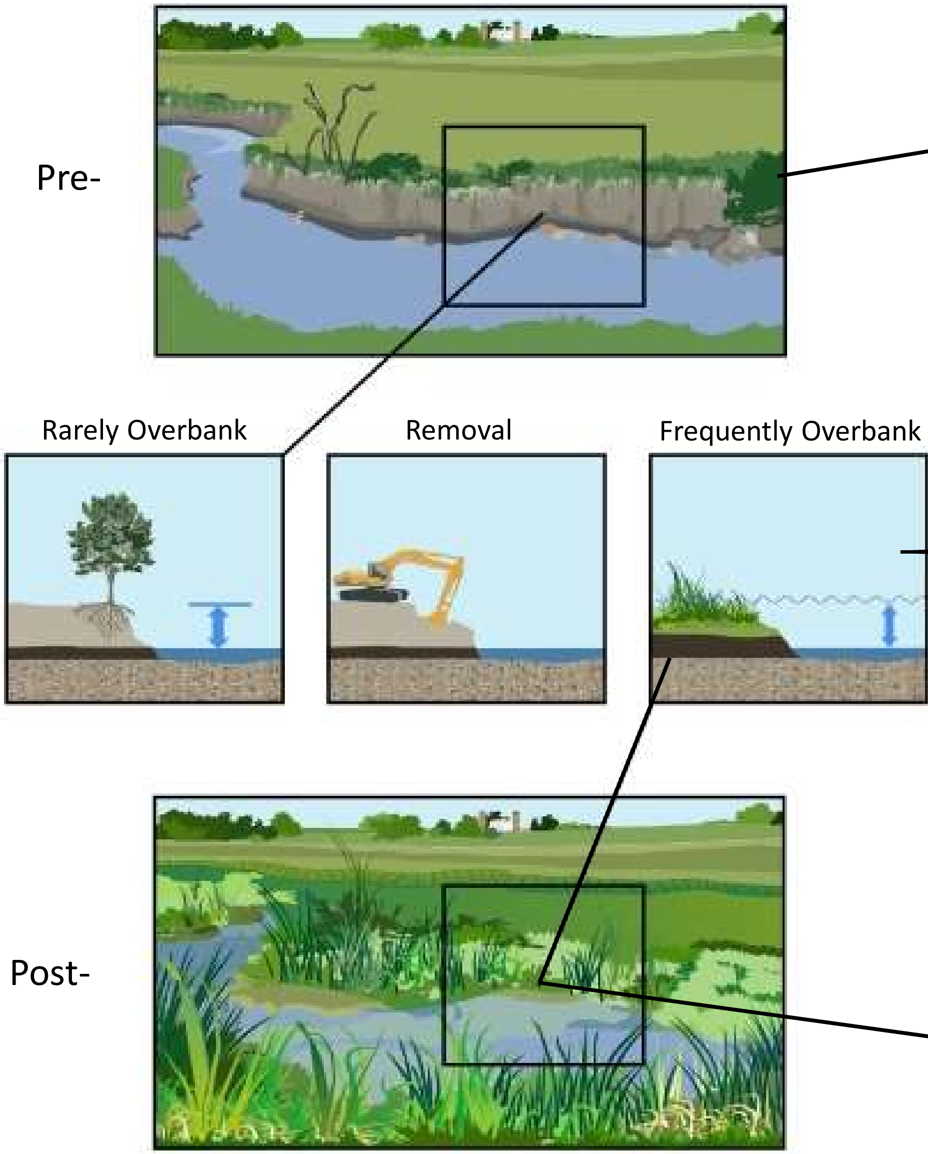
Noe et al, 2019



LandStudies Inc.



Fleming et al 2019



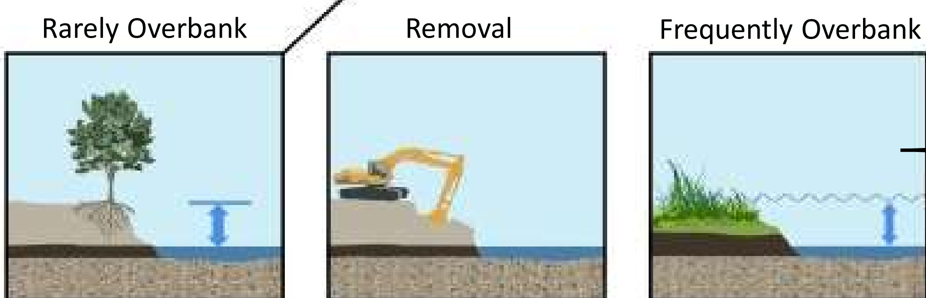
BSR Floodplain-Wetland Restoration Experiment Rationale

1. Mid-Atlantic streams with high banks are not natural, and they are sources of sediment and nutrient loads.
2. Legacy sediments typically bury Pre-Settlement wetlands.
3. Buried wetland soils bear evidence for stable and resilient wetland conditions for the last 10k years.
4. Removing legacy sediments reduces a prominent source of suspended sediment and nutrients to streams:
5. Removal creates the hydraulic conditions necessary to restore the buried wetland ecosystem.
6. It also creates an accommodation space for frequent flooding to interact with emergent wetland vegetation.
7. These are optimal conditions for carbon and nutrient retention, including and especially denitrification.
8. The restoration target is the buried wetland soil.

Walter and Merritts, 2008; Forshay et al., 2022

BSR Floodplain-Wetland Restoration Experiment Rationale

Pre-



Post-

1. Mid-Atlantic streams with high banks are not natural, and they are sources of sediment and nutrient loads.
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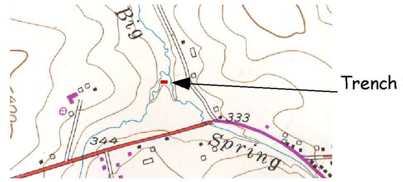
Big Spring Run - Our First Look at the Pre-Settlement Hydric Soil

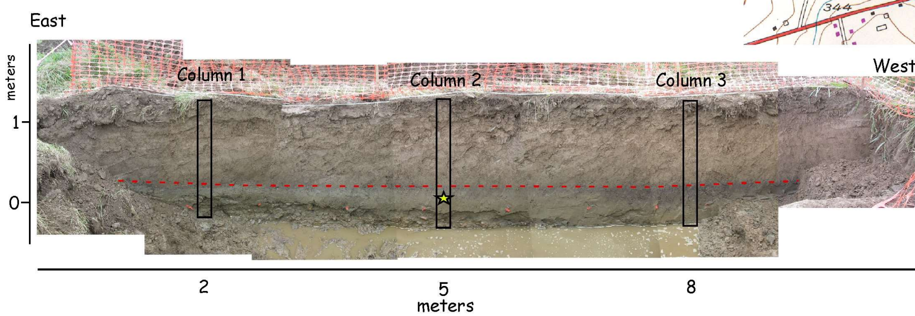
Big Spring Run - Our First Look at the Pre-Settlement Hydric Soil

10/15/14

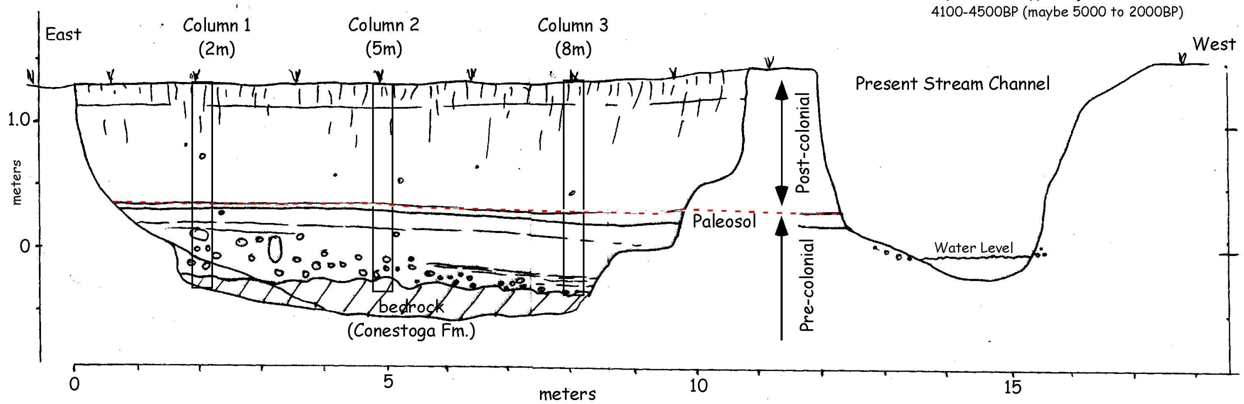
Big Spring Run - Our First Look at the Pre-Settlement Hydric Soil

Big Spring Trench 2





Poplar Island Type Projectile Point
4100-4500BP (maybe 5000 to 2000BP)



10/15/14

Floodplain-Wetland Restoration Policy Implications

Natural Floodplain, Stream, and Riparian Wetland Restoration Best Management Practice

Definition and Nutrient and Sediment Reduction Efficiencies For use in Phase 5.0 of the Chesapeake Bay Program Watershed Model

Recommendations for Formal Approval by the Nutrient Subcommittee's Watershed Technical Workgroup, the Modeling Subcommittee and the Nutrient Subcommittee's Sediment Workgroup

This document summarizes the recommended definition and nutrient and sediment reduction efficiencies for the Natural Floodplain, Stream, and Riparian Wetland Restoration Best Management Practice. The Tributary Strategy Workgroup, the Modeling Subcommittee, and the Sediment Workgroup were asked to consider and review the proposed practice at their meetings on March 5, 2007, April 3, 2007, and April 26, 2007, respectively. Attached to these recommendations is a full accounting of the Chesapeake Bay Program's discussions on this practice and how these recommendations were developed, including data, literature, data analysis results, and discussions of how various issues were addressed.

PA DEP 2007

BSR Restoration

1. Based on a better understanding of the mechanisms responsible for the origin and stability of natural landscape patterns.

2. This landscape-scale experiment enables PA DEP to assess whether this new restoration approach will optimizs ecosystem function and restores ecosystem services.

3. Long-term monitoring will determine whether restoring floodplains and riparian wetlands will improve hydro-geomorphic conditions, ecosystem services, and water quality.

Hartranft et al., 2011

BSR Design Criteria

Began September 2011

1. Flows greater than normal spring base flows will be conveyed through the floodplain.

2. Woody material will be placed within the channel to increase the water surface elevation during base flow.

3. Legacy sediments will be excavated and removed from the valley bottom.

4. Channel plan form will be based on increasing flow retention and flow exchange from the channel into the adjacent hyporheic zone and across the valley bottom.

5. Stumps and woody material will be placed frequently within the channel and floodplain to provide additional denitrification potential, habitat and base-flow grade control.

BSR Design Objectives

Completed November 2011

1. **Objectives**: Restore the ecological potential at Big Spring Run.

2. **Maximize Stream Stability**: Based upon the pre-settlement valley geomorphology and stratigraphy, modern bed material analysis, watershed area, and other hydrologic and hydraulic design considerations, the allowable boundary shear stress within the channel will be less than 0.3 lbs per square ft. Therefore, the design depth from base flow water surface to floodplain will vary between 0.3 and 0.7 feet, depending upon the local water surface slope.

BSR Design Objectives and Goals

Completed November 2011

3. Maximize Nutrient Reduction:

Nitrogen – (a) increasing the amount and availability of carbon based material, (b) increasing the retention time and flow contact with the carbon based material and (c) increasing the base flow channel water elevation to promote hyporheic exchange and increase hyporheic zone ecosystem function

Sediment and phosphorus –(a) removal of the main source (legacy sediment removal); (b) frequent overtopping of channel flows into the floodplain and (c) increase floodplain area and roughness to increase flow retention time.

Stream Restoration Objectives* Applied at Big Spring Run

i. Reduce suspended sediment & total P loads

ii. Increase surface water retention time on floodplain

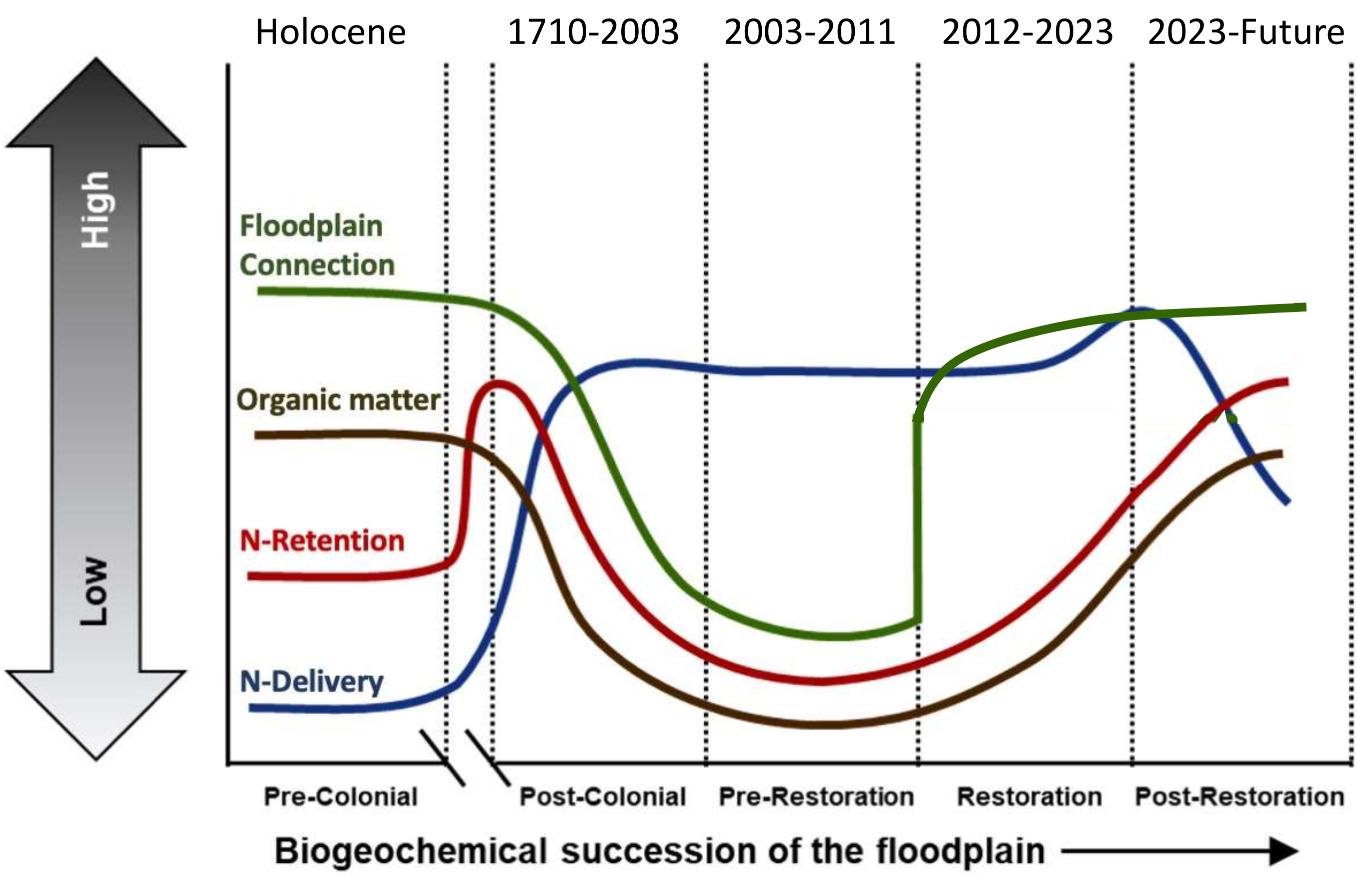
iii. Add Dissolved Organic Carbon (DOC) – enable frequent overbank flow

iv. Attenuate flows – slow water velocity

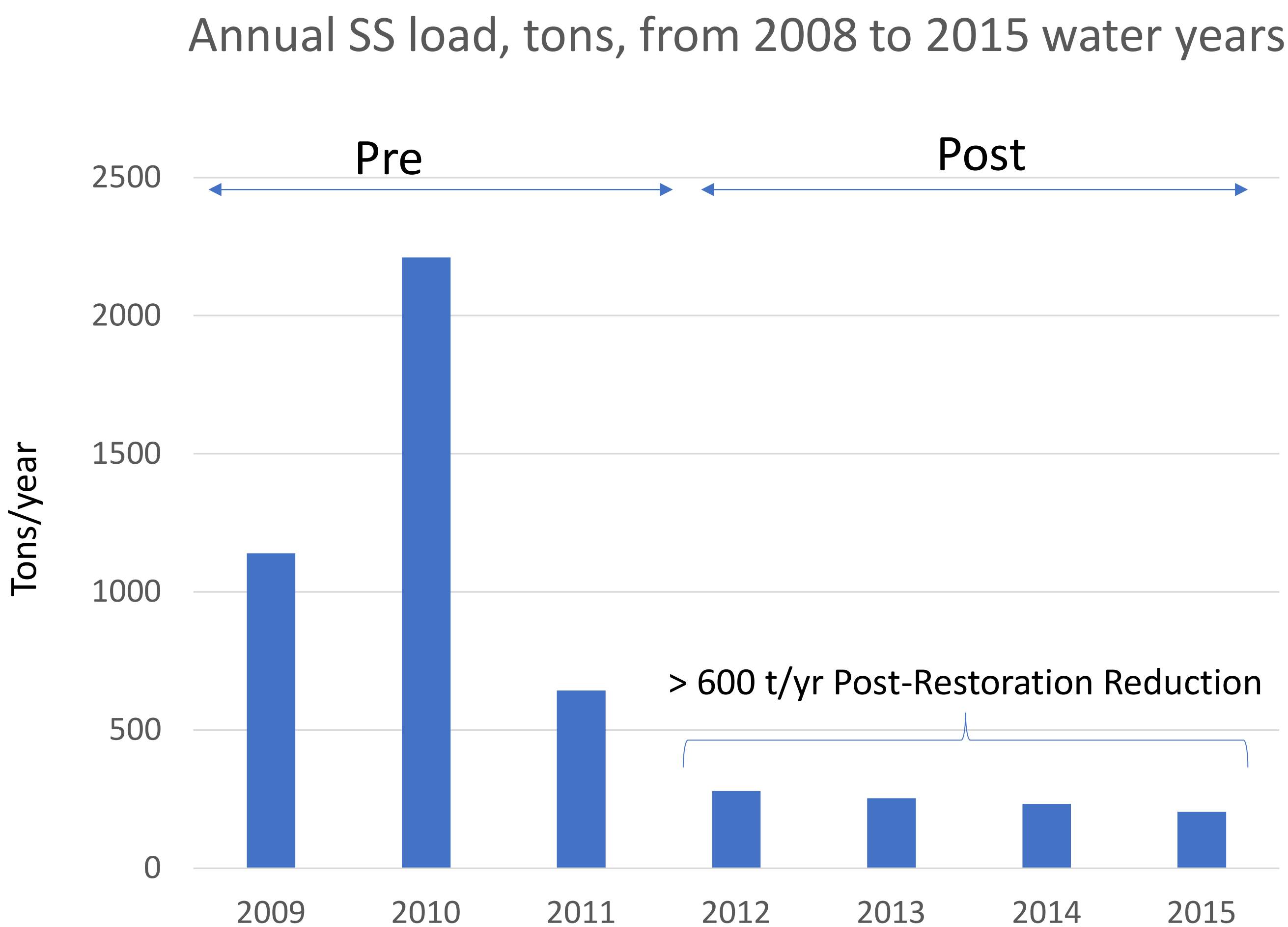
v. Reconnect floodplain wetlands with surface water and groundwater – enable denitrification of NO_3-N (via ii, iii, and iv)

*Recommendations of EPA/CBP Expert Panel on Stream Restoration (2014) Sections 3.2 and 3.3

Conceptual Model for Pre- and Post-Restoration Carbon & Nitrogen Changes

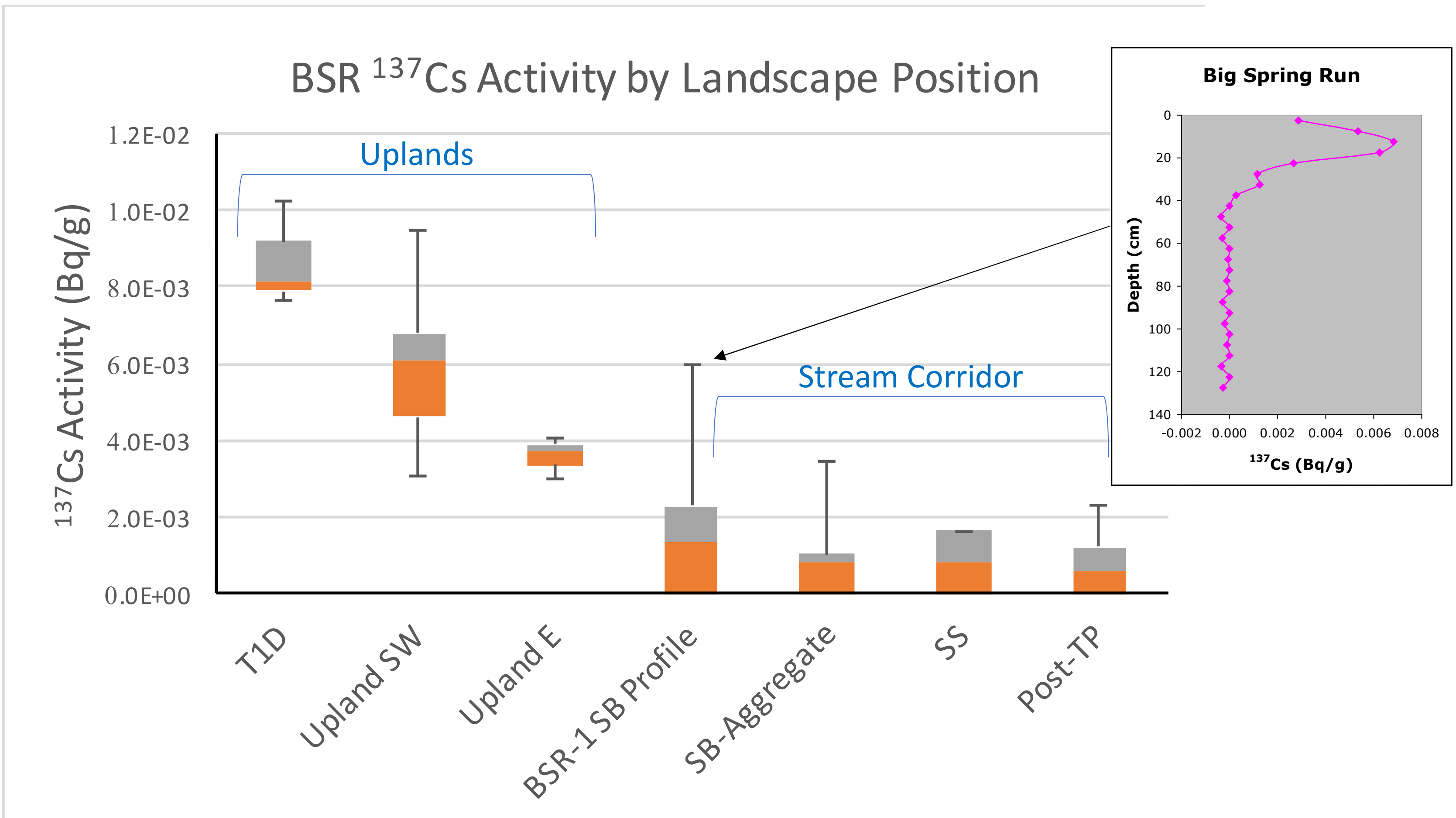


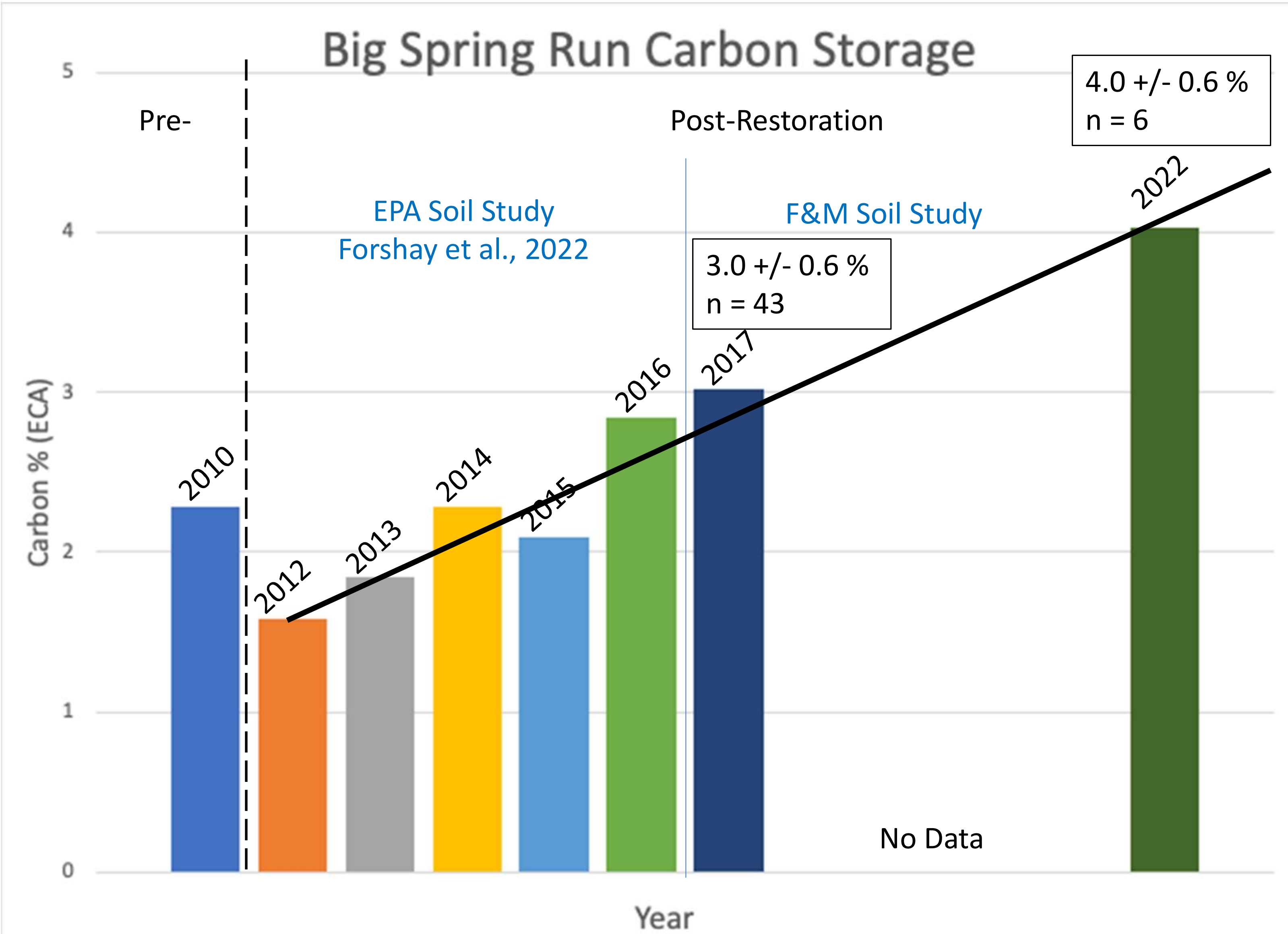
Modified from Forshay et al., 2022

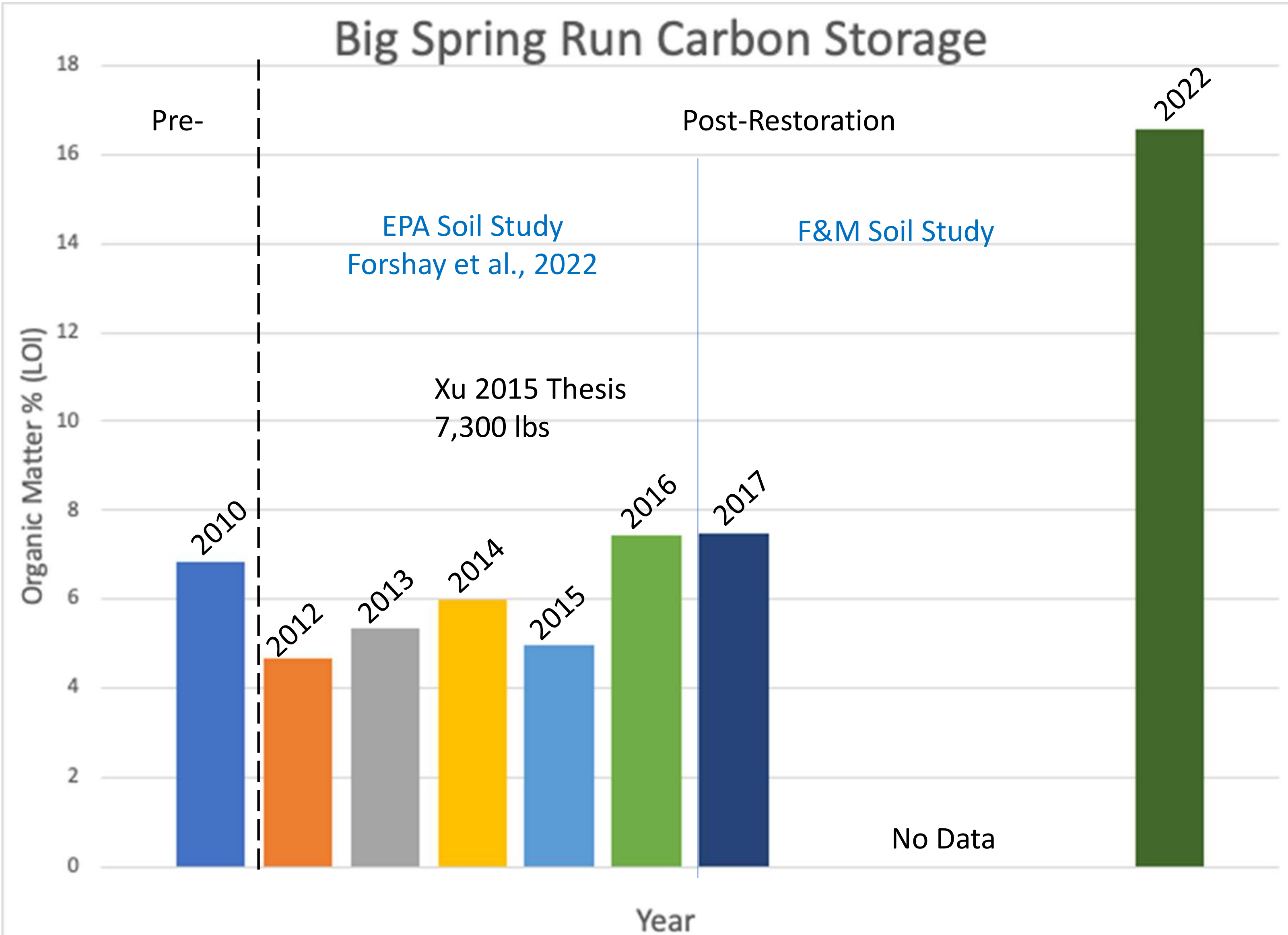


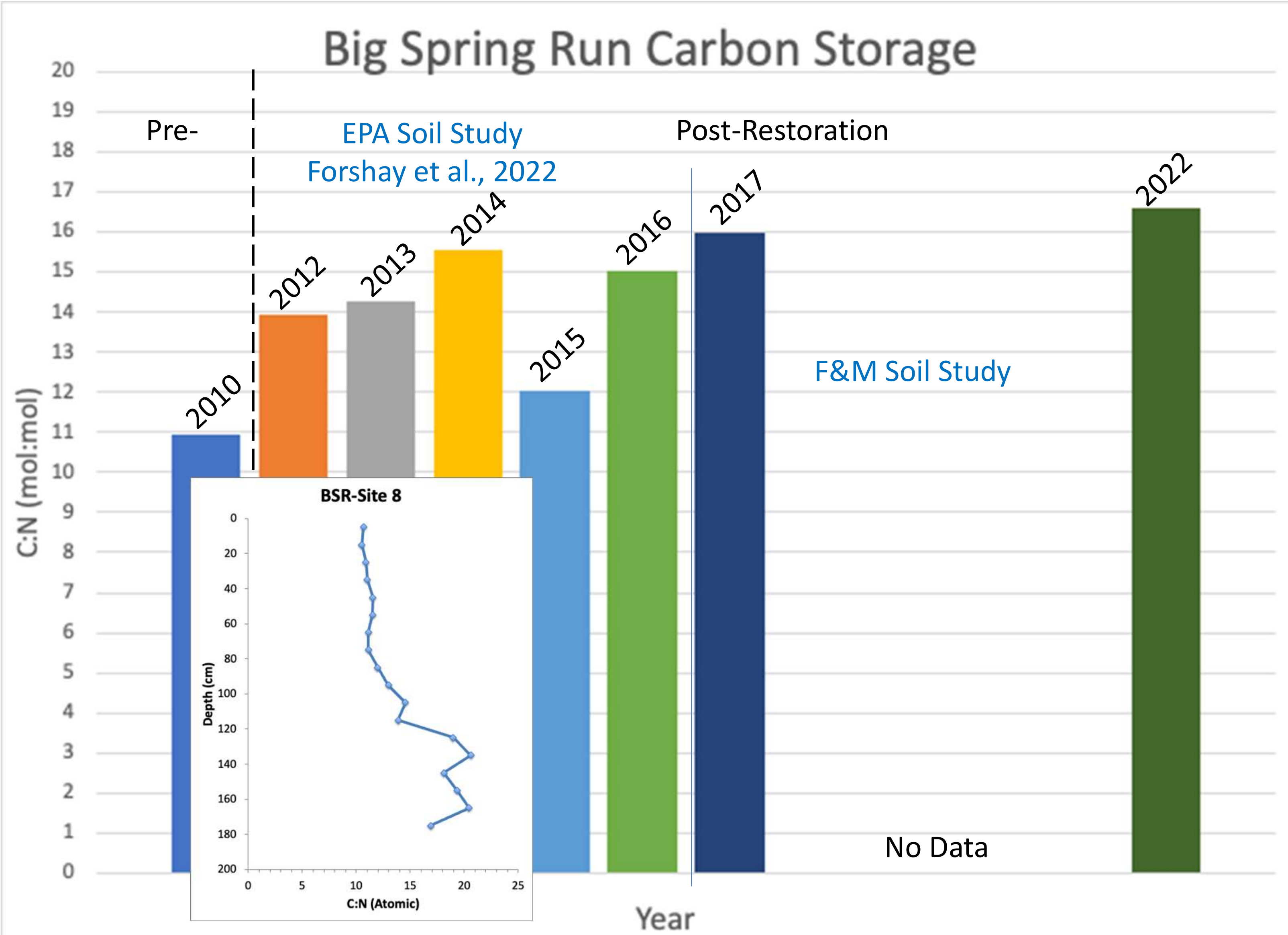
Langland 2020 USGS Report

BSR ^{137}Cs Activity by Landscape Position




Big Spring Run Carbon Storage
Pre-
Post-Restoration
EPA Soil Study
Forshay et al., 2022
F&M Soil Study
3.0 +/- 0.6 %
n = 43
4.0 +/- 0.6 %
n = 6
2010
2012
2013
2014
2015
2016
2017
2022
No Data
Carbon % (ECA)
Year
0
1
2
3
4
5


Big Spring Run Carbon Storage
Organic Matter % (LOI)
18
16
14
12
10
8
6
4
2
0
Pre-
Post-Restoration
EPA Soil Study
Forshay et al., 2022
F&M Soil Study
Xu 2015 Thesis
7,300 lbs
2010
2012
2013
2014
2015
2016
2017
2022
No Data
Year



Big Spring Run Carbon Storage
C:N (mol:mol)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Pre-
EPA Soil Study
Forshay et al., 2022
Post-Restoration
2010
2012
2013
2014
2015
2016
2017
2022
F&M Soil Study
No Data
Year
BSR-Site 8
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
C:N (Atomic)

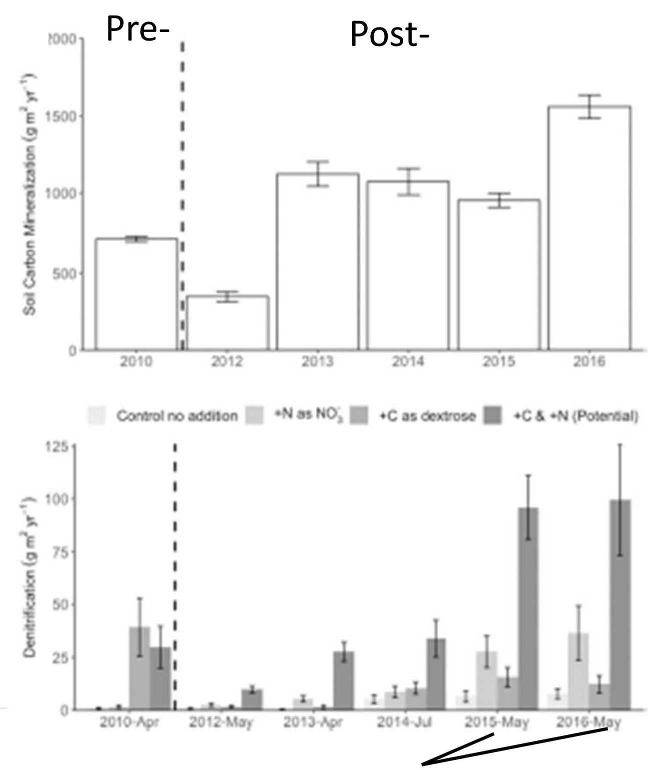
Biogeochemistry
https://doi.org/10.1007/s10533-022-00975-z

Unearthing a stream-wetland floodplain system: increased denitrification and nitrate retention at a legacy sediment removal restoration site, Big Spring Run, PA, USA

Kenneth J. Forshay · Julie N. Weitzman · Jessica F. Wilhelm · Jeffrey Hartranft · Dorothy J. Merritts · Michael A. Rahnis · Robert C. Walter · Paul M. Mayer

- The site dramatically shifted from a system starved of organic C to a sediment matrix capable of denitrifying excess NO^3
- The observations made at BSR support the hypothesis that when organic matter accumulates over time and interacts over a biogeochemically active plant-sediment matrix, restoration can drive a system to shift past a state of excess NO^3-N with low organic C, to lower NO^3-N with higher C:N due to higher processing rates under conditions of higher C availability.
- Based on these observations, one should expect similar results in similar situations.

Increased Soil Carbon Mineralization



Increased de-N Potential

BSR Key Monitoring Outcomes

- **Sediment Removed:** ~21,955 tons (LandStudies)
- **Sediment Source**: 85-100 % from banks (F&M/USGS)
- **Sediment Load Reduction:** 600 tons/yr (71% USGS/F&M)
- Total P Removed: ~50,500 lbs (F&M) (79% - USGS)
- Total N Removed: ~63,600 lbs (F&M)
- Increase de-N Potential: Shift from carbon-starved to high C:N denitrifying microbial ecosystem (EPA)
- Nitrate Reduction: 12-23% (EPA)
- Total SRP Reduction: 37% (EPA)
- Carbon Storage: OM doubled in 10 years (F&M)
- Surface Water T: Temperature modulation (F&M)
- Biological Indicators: Shift from upland, invasive dominated to aquatic ecosystem dominated plant communities. Other indicators – fish, birds, diatoms, amphibians show increased species richness and diversity (Johns Hopkins, Drexel, Elizabethtown, PA DEP).
- Cost Effectiveness:, LS removal reduces S and TP loading rates at a substantial cost savings compared to standard practices, and it is competitive for TN.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doi:10.2489/jswc.74.4.67A

FEATURE

Legacy sediment erosion hot spots: A cost-effective approach for targeting water quality improvements

Patrick M. Fleming, Dorothy J. Merritts, and Robert C. Walter

As federal and state governments seek to address nonpoint source (NPS) water pollution, billions of dollars will be spent to implement conservation practices known to reduce sediment and nutrient runoff. Nonpoint source pollution has proven to be a "wicked" challenge for policymakers, characterized by uncertainty and complex interactions among socioeconomic, hydrologic, and other geodynamic systems along multiple dimensions (Shortle and Horan 2017). A recent summary of research indicates, in fact, that the adoption of conventional NPS conservation practices is not directly linked to measurable pollution reduction in most streams in the Chesapeake Bay watershed (Keisman et al. 2018). A primary reason cited for this disconnect is the temporal dynamic by which water quality improvements are delayed or offset by the ongoing effects of legacy pollutants in soils and groundwater (Keisman et al. 2018). (Legacy pollutants are those that remain in the geosphere decades to centuries after the pollution occurred.)Innovative approaches to NPS pollution reduction may be needed to address these legacy pollutants, and thereby meet goals for improved water quality, such as the Chesapeake Bay total maximum daily load (TMDL).

One such approach that has received increasing attention is legacy sediment (LS) mitigation. As shown in the research of Walter and Merritts (2008), LS and associated nutrient pollution accumulated for decades (and sometimes centuries) behind milldams and other historic stream impediments. As these impediments are removed, intentionally or otherwise, long-term elevated pollution loads have been left behind along numerous stream systems in the mid-Atlantic region. These loads are concentrated at LS "hot spots," characterized by near-vertical stream banks carved into the previously accumulated sediment (figure 1). (Here, we consider LS erosion hot spots as stream lengths that produce above 0.05 tn ft^{-1} yr^{-1} [0.15 Mg m^{-1} y^{-1}] of sediment erosion over at least a span of 2,000 ft [610 m]). Subsequent research has shown that LS mitigation—through removal of sediment to restore the wetland or other aquatic ecosystem long buried behind historic stream impoundments (Hartranft et al. 2011)—is a highly effective form of sediment, phosphorus (P), and nitrogen (N) abatement when implemented at identifiable LS erosion hot spots (Sharpley et al. 2013; Inamdar et al. 2017). However, less is known about the cost-effectiveness of LS mitigation projects in terms of their cost per unit of pollution reduced, especially in comparison to other NPS reduction practices.

In this article, we summarize the results of a recent study of the cost-effectiveness of LS mitigation in the Chesapeake Bay watershed in comparison to agricultural practices that are commonly considered low-cost forms of abatement, such as cover crops and grass and forest riparian buffers. We then describe two broader policy implications of these findings, using recently available technology to identify hot spots at a landscape scale. The importance of legacy pollutant sources has long been recognized—from P in soils, to nitrates (NO_3) in groundwater, to LS and nutrients along stream banks (USGS 2003; Garnache et al. 2016). As technology increasingly allows policymakers to identify LS erosion hot spots, we emphasize that greater awareness of LS mitigation should be promoted as a cost-effective tool in the suite of options available to reduce NPS water pollution.

LEGACY SEDIMENT MITIGATION

The problem of LS impaired waters is ubiquitous in the mid-Atlantic United

Figure 1
Erosion of legacy sediment following breach of Strobers Dam in Pennsylvania in 2011. Bank sediments are upstream of the breached dam, and the top of the bank matches the top of the dam.

Dam
Historic sediment

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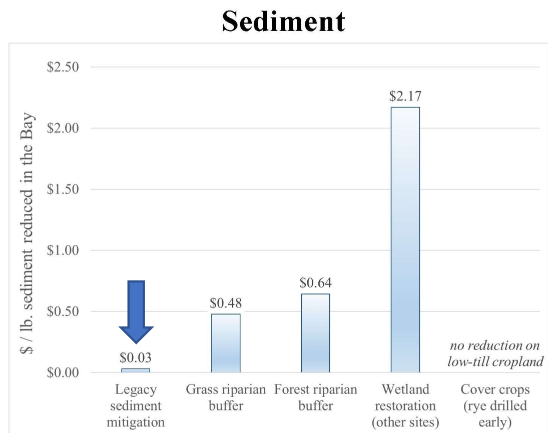
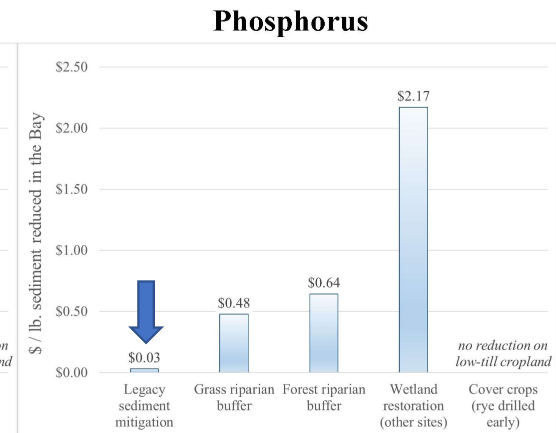
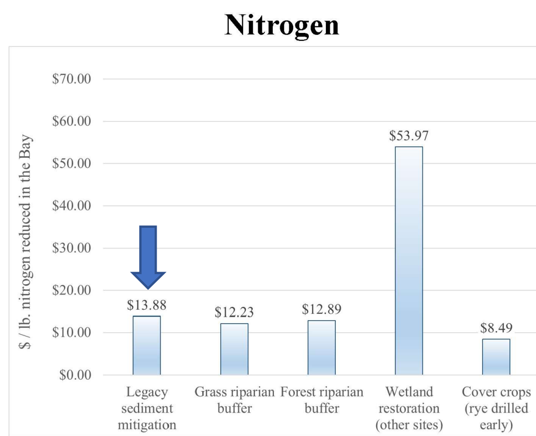
Economic Efficiencies







Legacy sediment mitigation retains a substantial cost advantage for sediment and P reduction, and is competitive for N abatement, in comparison to low-cost agricultural practices.

Fleming et al., 2019:
http://www.jswconline.org/content/74/4/67A.extract#

Carbon Benefits

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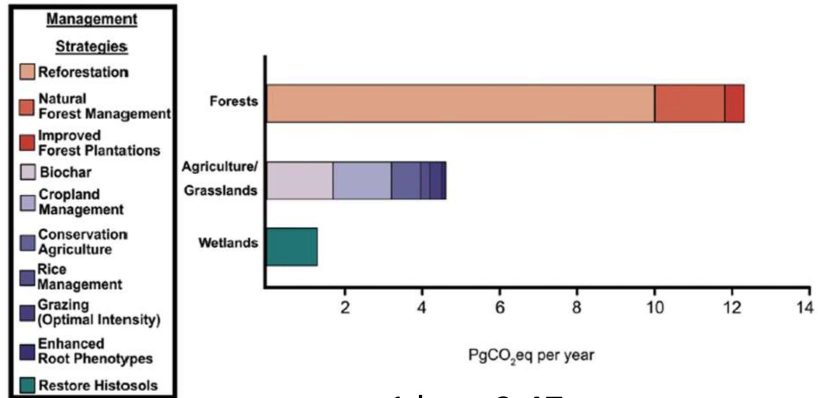
What's Soil Got to Do with Climate Change?

Todd Longbottom, Leila Wahab, Dept. of Life and Environmental Sciences, University of California Merced, Merced, California 95343, USA; Kyungjin Min, Dept. of Life and Environmental Sciences, University of California Merced, Merced, California 95343, USA, and Center for Anthropocene Studies, Korea Advanced Institute of Science and Technology, Daejeon, South Korea; Anna Jurusik, Dept. of Life and Environmental Sciences, University of California Merced, Merced, California 95343, USA; Kimber Moreland, Atmospheric, Earth, and Energy Division, Lawrence Livermore National Laboratory, Livermore, California 94550, USA; Manisha Dolui, Touyee Thao, Melinda Gonzales, Yulissa Perez Rojas, Jennifer Alvarez, Zachary Malone, Jing Yan, Teamrat A. Ghezzehei, and Asmeret Asefaw Berhe, Dept. of Life and Environmental Sciences, University of California Merced, Merced, California 95343 USA



1 ha = 2.47 acres

TABLE 1. CLIMATE MITIGATION POTENTIALS OF VARIOUS LAND USE PRACTICES ACCORDING TO POSSIBLE AREA OF PRACTICE ADOPTION

Practice	Climate Mitigation Potential ($Pg\ CO_2\ eq\ yr^{-1}$)	Area of Practice Adoption (Mha)	References	
Forests				
Reforestation	10	3665		9,052 ac
Natural forest management	1.8	3665	1, 2	
Improved forest plantations	0.5	204		
Agriculture and Grasslands				
Biochar	1.7	2000–3000		
Conservation agriculture	0.8	750–2000		
Grazing—Optimal intensity	0.4	500–2000	2, 3	
Cropland management	1.5	750–2000		
Rice management	0.3	20–50		
Enhanced root phenotypes	0.1	1000–2000		
Wetlands				
Restored histosols	1.3	10–15	2, 3	247 ac

[1]Siry et al., 2005
[2]Griscom et al., 2017
[3]Paustian et al., 2016

Wetlands are 32x more efficient at storing carbon that forests

Big Spring Run Before Legacy Sediment Removal & Wetland Restoration

Typical Existing Conditions (April 2005) – Three Years of Pre-Restoration Monitoring (2008 to 2011)

Big Spring Run Immediately After Restoration

Restoration Completed, November 2011 –On-Going Post-Restoration Monitoring (2011 to Present)

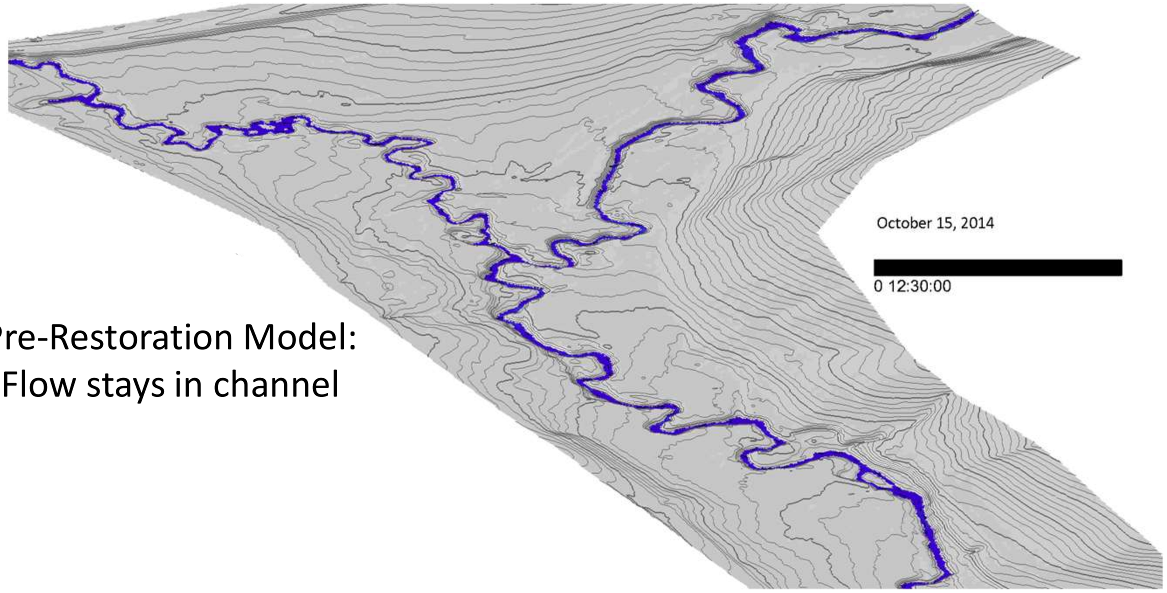
Big Spring Run Seven Months After Restoration

June 2012 – Beginning of first growing season, seven months after restoration

J.B. SPEED SCHOOL OF ENGINEERING — Art Parola

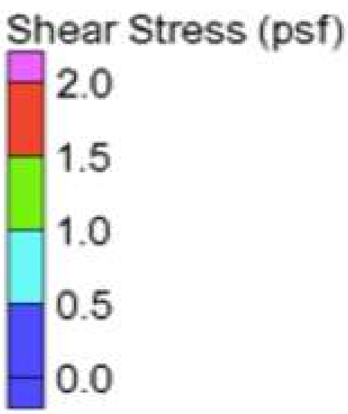
LandStudies — Ward Oberholtzer

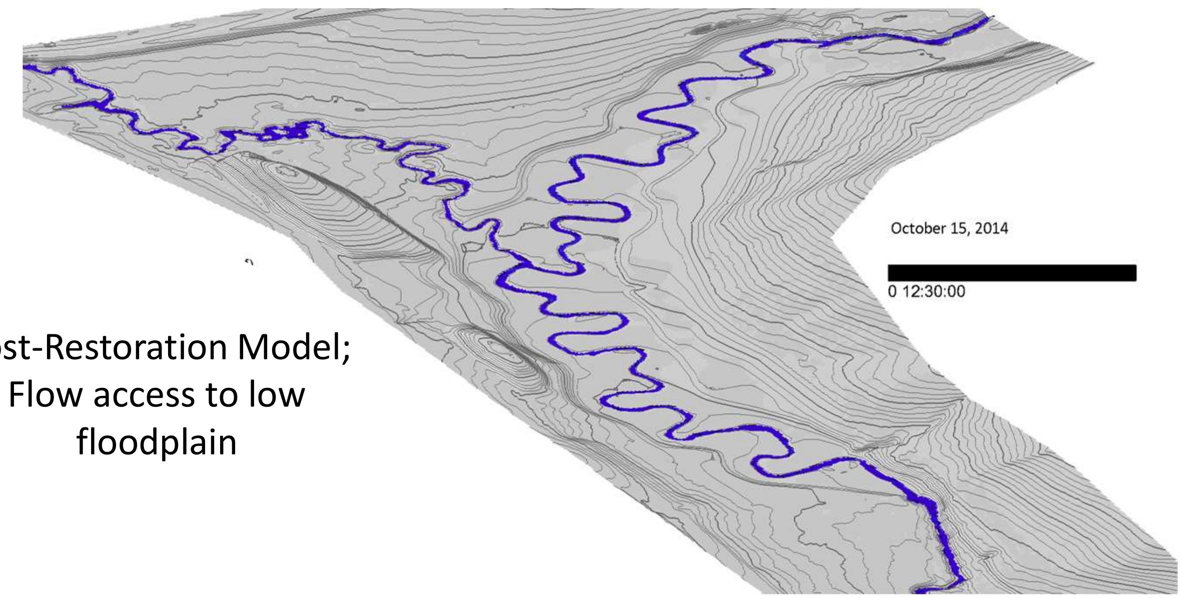
FRANKLIN & MARSHALL COLLEGE — Dorothy Merritts



Pre-Restoration Model:
Flow stays in channel

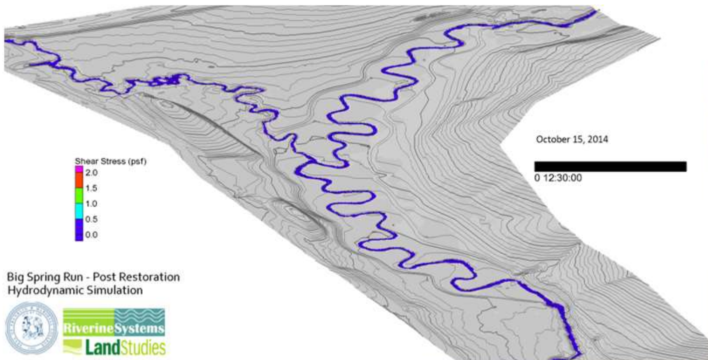
Input data from same storm, modelled to the pre- and post-restoration topographies.





Post-Restoration Model;
Flow access to low floodplain

Big Spring Run Floodplain Wetland Restoration



Storm of 18 September 2012

Big Spring Run Drone Aerial Video (9/6/18):
From downstream (unrestored) to upstream (restored)

Conclusions

- Stream bank erosion is a major source of high suspended and nutrient loads.
- The restoration experiment at BSR shows substantial reductions in suspended sediment and phosphorus loads, and improvements in carbon storage and denitrification potential.
- Additional benefits include: (a) improved aquatic ecosystem services, frequent overbank flow across a broad, low wetland floodplain; (b) flood attenuation; (c) groundwater recharge; (d) surface water temperature modulation; and (e) economically sustainable and cost-effective.
- These benefits will continue to improve as the wetland ecosystem matures.

Funding Agencies

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

National Science Foundation
WHERE DISCOVERIES BEGIN

Chesapeake Bay Commission
Policy for the Bay

Franklin & Marshall College

United States Environmental Protection Agency

Richard King Mellon Foundation

Publications by our Group Relevant to BSR

Forshay, K.J., et al., 2022. Unearthing a stream-wetland floodplain system: increased denitrification and nitrate retention at a legacy sediment removal restoration site, Big Spring Run, PA, USA. Biogeochemistry, 161(2), pp.171-191.

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Research Timeline