



CHESAPEAKE WATERSHED INITIATIVE

What Lies Beneath:
The Geological and Environmental Transition from
Holocene Wetlands to Historic Legacy Sediments

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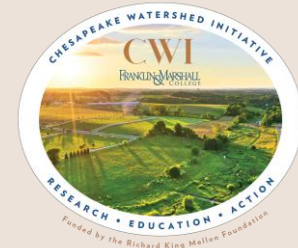
CHESAPEAKE WATERSHED INITIATIVE

...and How This Informs Restoration

2026 PA Aquatic Resource Restoration Conference
March 3, 2026

Robert Walter, Dorothy Merritts, Chris Williams, Adam Benfield, Julia Carr, Shuyu Chang,
Joe Galella, Jake Lamb, Mike Rahnis, Department of Earth and Environment

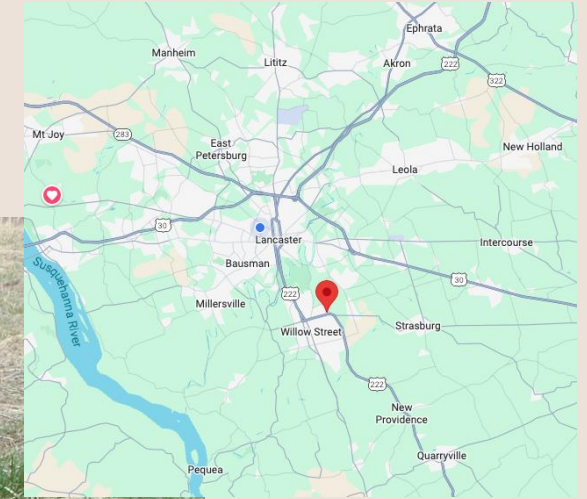
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How Do We Know What's Beneath?

I. Stream Bank Stratigraphy

Ergo, nothing is fluvial (Bill Dietrich)



2 m

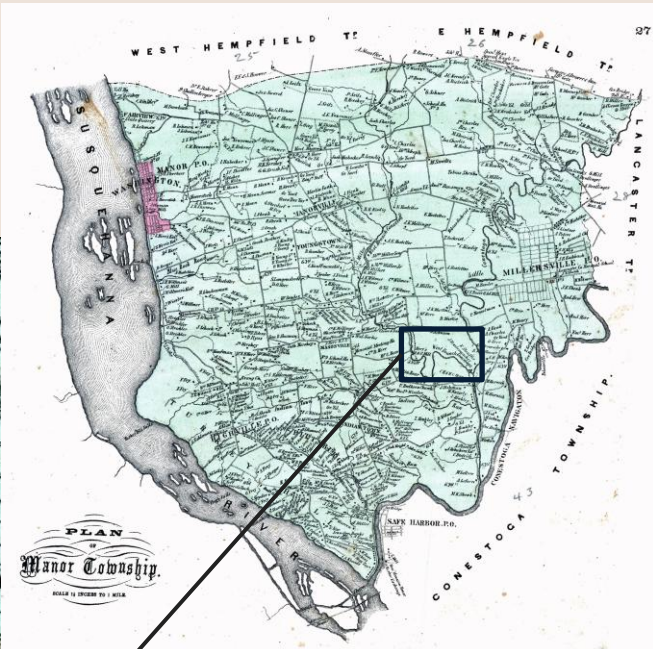
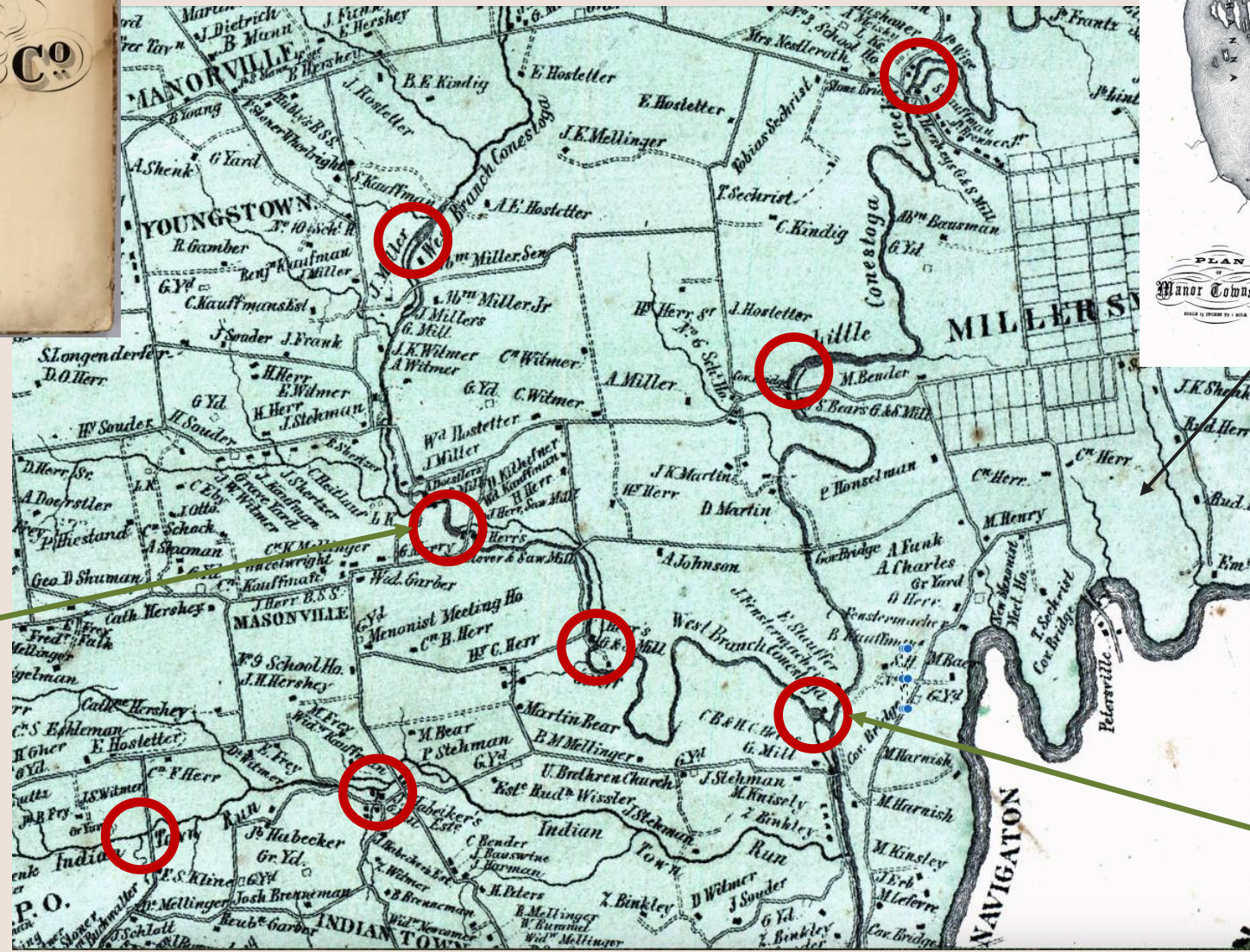
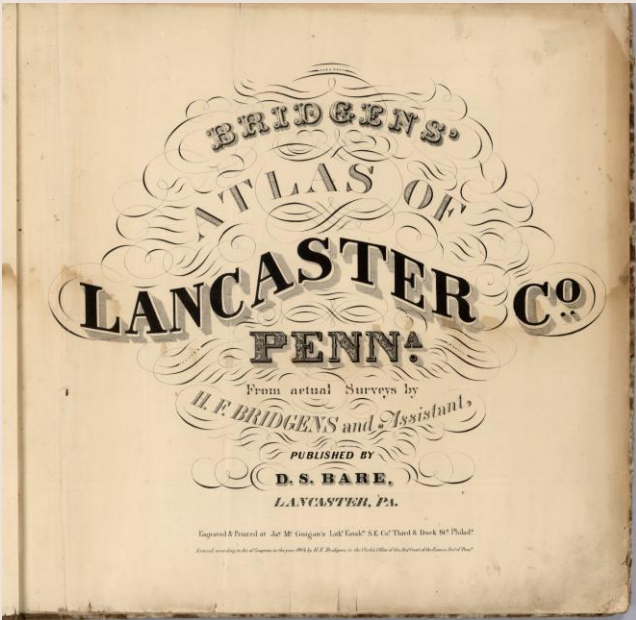
Big Spring Run, Lancaster Co (4/8/05)

II. Trenching



Big Spring Run, Lancaster Co. 10/15/04 (LandStudies)

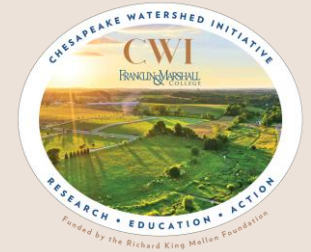
III. Historical Archives



Bender's Mill

Denlinger's Mill

1864 Bridgens' Atlas of Lancaster County



How Wide Spread Is It?

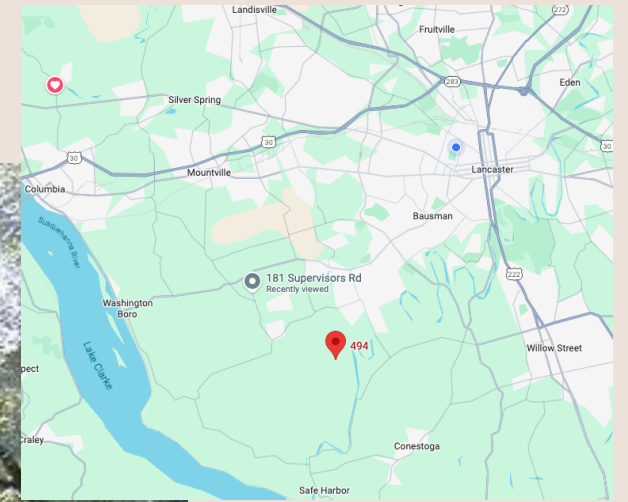
Stream Bank Stratigraphy

5 m



Legacy Sediment

Buried Wetland



Denlingers Mill, West Branch Little Conestoga, Lancaster Co. (6/6/03)

Stream Bank Stratigraphy

3 m



Buried wetlands are everywhere!

Benders Mill, West Branch Little Conestoga Creek, Lancaster Co. (4/30/07)

White Clay Creek, Chester County, PA



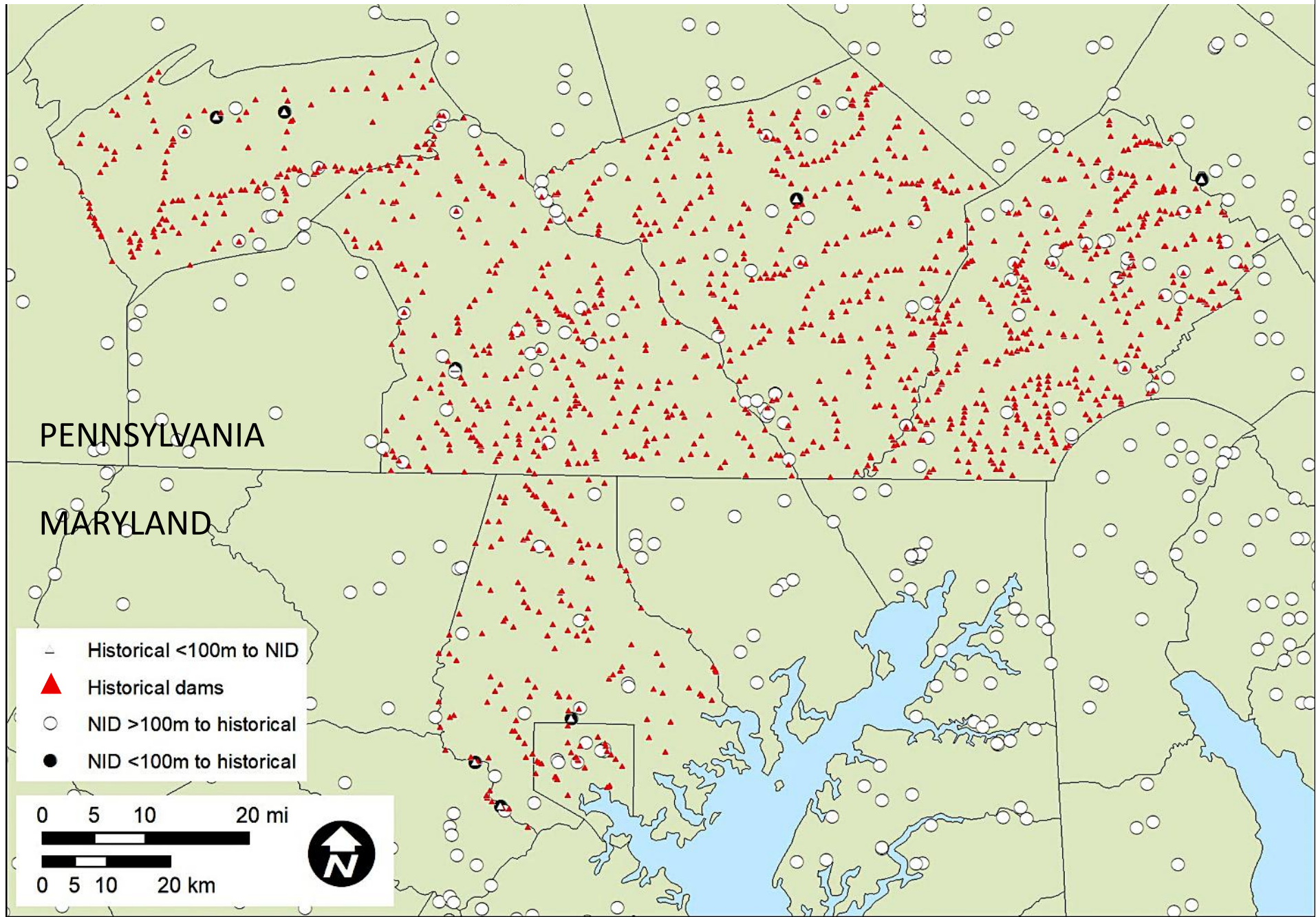
Collaboration
with PA DCNR
and LandStudies

Sam's Creek, Carroll County, MD



Collaboration with Ecotone

5 Counties: 1337 historical mildams

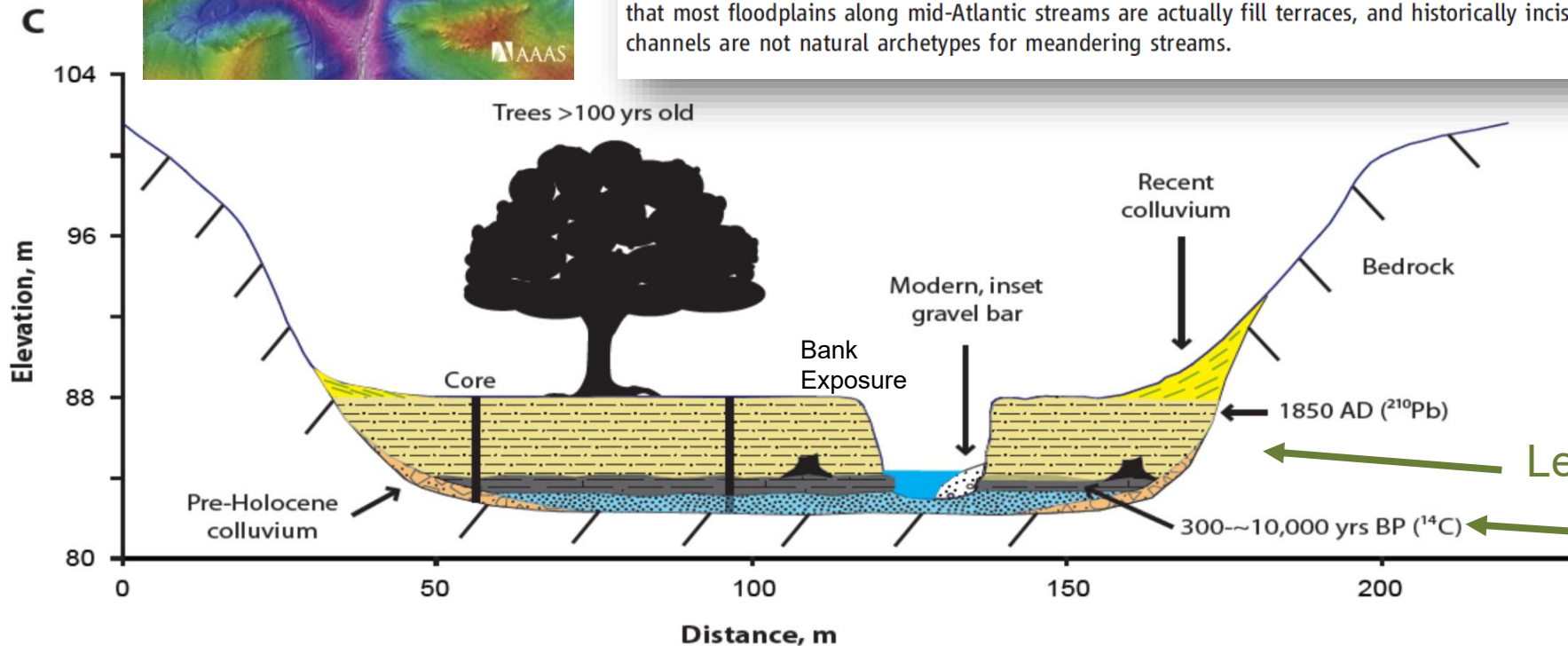




Natural Streams and the Legacy of Water-Powered Mills

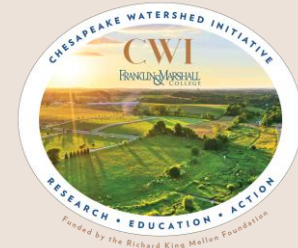
Robert C. Walter*† and Dorothy J. Merritts*†

Gravel-bedded streams are thought to have a characteristic meandering form bordered by a self-formed, fine-grained floodplain. This ideal guides a multibillion-dollar stream restoration industry. We have mapped and dated many of the deposits along mid-Atlantic streams that formed the basis for this widely accepted model. These data, as well as historical maps and records, show instead that before European settlement, the streams were small anabranching channels within extensive vegetated wetlands that accumulated little sediment but stored substantial organic carbon. Subsequently, 1 to 5 meters of slackwater sedimentation, behind tens of thousands of 17th- to 19th-century milldams, buried the presettlement wetlands with fine sediment. These findings show that most floodplains along mid-Atlantic streams are actually fill terraces, and historically incised channels are not natural archetypes for meandering streams.



“... tens of thousands of milldams buried the pre-settlement wetlands with fine sediment.”

Legacy Sediments
Buried Holocene Wetland



What happens to “base level” when lowhead dams are breached or removed?

What is Base Level?

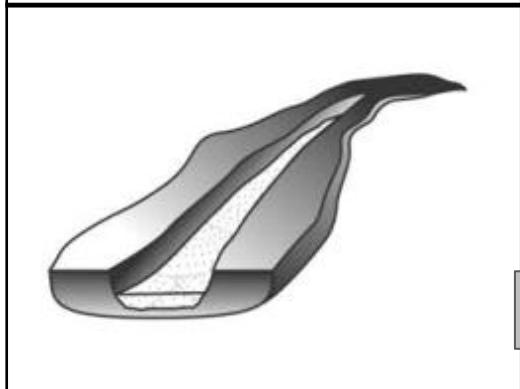
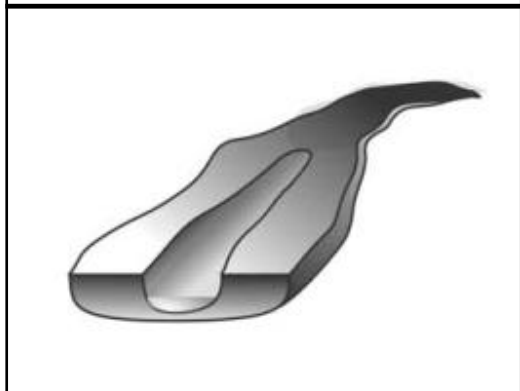
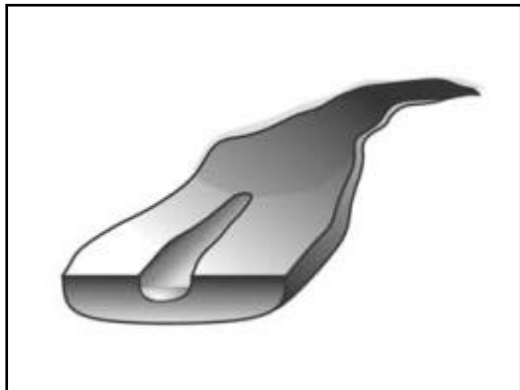
- Base level is the lowest point to which a river or stream can erode its channel, with sea level being the ultimate base level.
- Changes in base level—caused by tectonics and climate changes.
- Humans have now exceeded nature in our ability to affect landscape scale changes .
- Welcome to the Anthropocene!

**Conceptual
(Doyle et al, 2005)**

**Physical
(Cantelli, 2009)**

**Actual
(Beaver Creek)**

Time ↓



Laboratory Dam Failure

Exp. 9

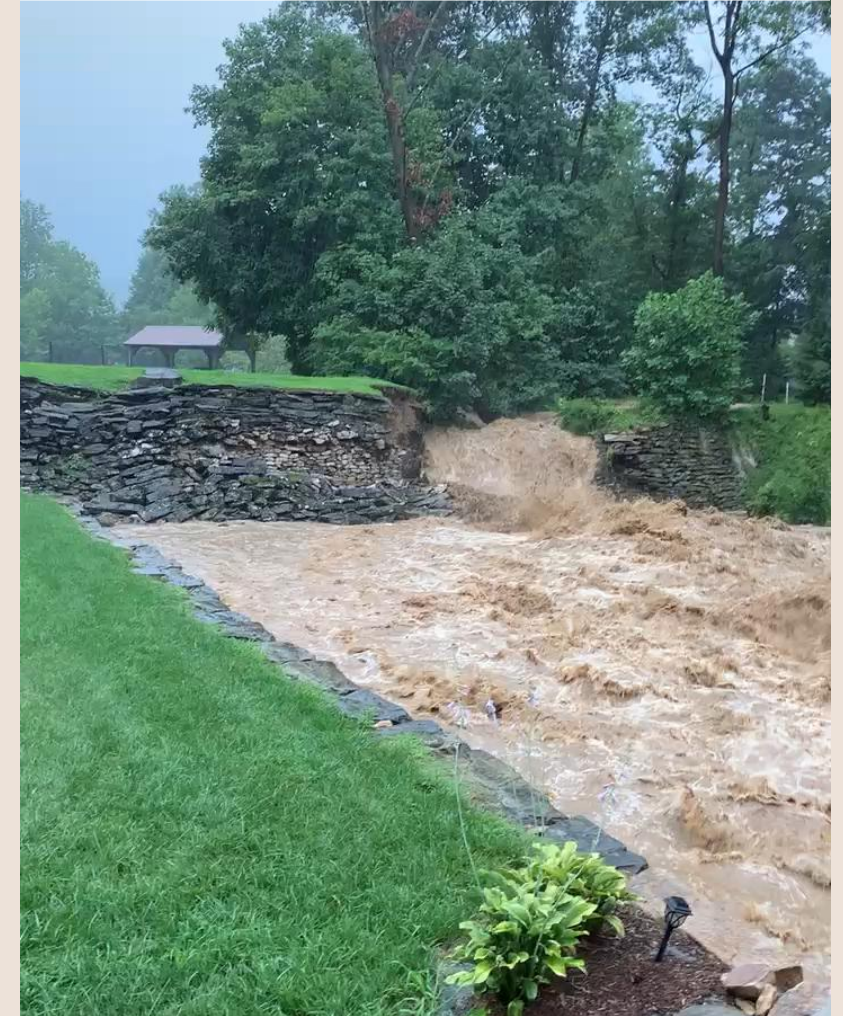
Processo di erosione

Vista da valle

**St. Anthony Falls
Laboratory
University of Minnesota**

Flume experiments and video footage from
Dr. Allesandro Cantelli, University of Minnesota

Natural Dam Failure Sides Mill



Realtime footage, 2020, from
the Hess Family, Strasburg, PA

Krady Milldam Removal - Chiques Creek Watershed



July 2018: Pennsylvania leads the nation in the removal of low-head dams.

View ~800 ft Upstream of Krady milldam



Before dam
removal

Feb 21, 2018

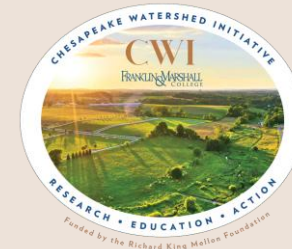


After dam
removal

Dam Removal
July 8, 2018

August, 2018

Roughly **2450 tons** of reservoir sediment erosion was measured along an 800 ft length of stream, within weeks after dam removal.



Why does this matter for restoration?

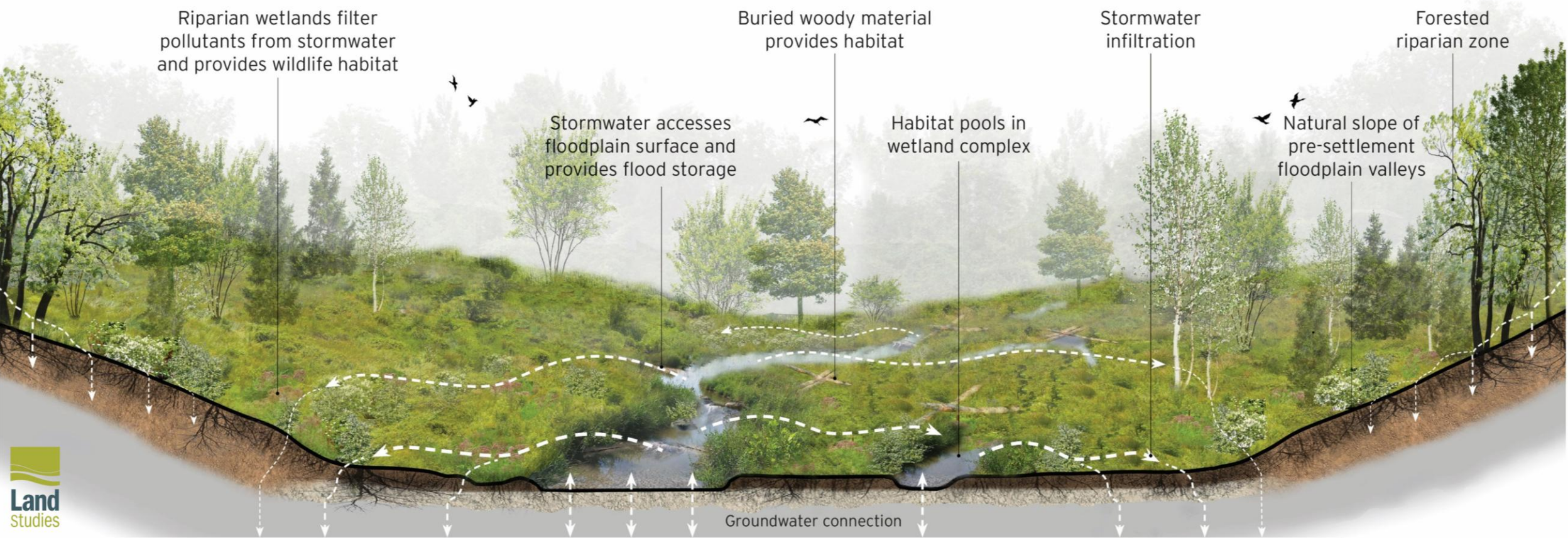


Illustration from LandStudies, Inc., Lititz, PA

What is Stream Restoration?

- Stream restoration is the reestablishment of the general structure, function, and self-sustaining behavior of a stream system and its floodplain to a close approximation of its condition prior to disturbance (U.S. EPA).
- How far back in time should we go to define a natural, stable and functional state? (recall Keynote talks by Profs. Wohl and Merritts)

Which Photo Shows a Natural, Stable Landscape?

A.



B.



Trick Question.... ~Same View - Before and After Restoration!

Before:
Winter, 2010



After:
June, 2013



Big Spring Run (BSR) Floodplain-Wetland Restoration, Completed November 2011

BSR Restoration - Legacy Sediment Removal (>20,000 tons)



Began September 2011

Big Spring Run Site 1

Same View



Before Restoration 9/13/11



After Restoration 9/28/11

Objective 1: Reconnect the groundwater and surface water with a low, hydric floodplain

Big Spring Run Site 1

Same View



Before Restoration 9/13/11



After Restoration 9/28/11

Objective 2: Remove the impairment... the eroding stream banks that contribute to high suspended sediment and nutrient loads (see my talk with Justin Spangler at 12:35 PM today).

River-Wetland Corridors and Their Value

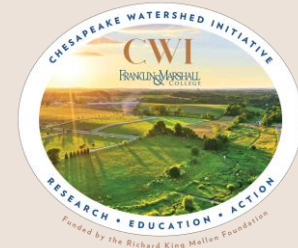


Banta Restoration (2004) on Lititz Run, Warwick Twp., Lancaster Co., PA

Ecosystem services they provide:

- Habitat for fish and wildlife
- Improved water quality
- Storing floodwaters
- Reducing flow velocities
- Denitrification

Objective 3: Rejuvenate the ecological function of the buried wetland.



Stream Restoration Objectives*

- i. Reduce suspended sediment & total phosphorus 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 $\text{NO}_3\text{-N}$ (via ii, iii, and iv)

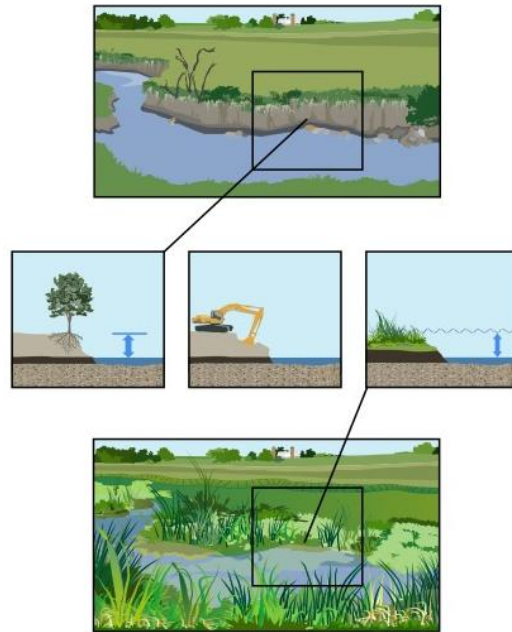
*Recommendations of EPA/CBP Expert Panel on Stream Restoration (2014)
Sections 3.2 and 3.3

i. Reducing sediment loads via legacy sediment removal (see Dr. Julia Carr's talk later today)

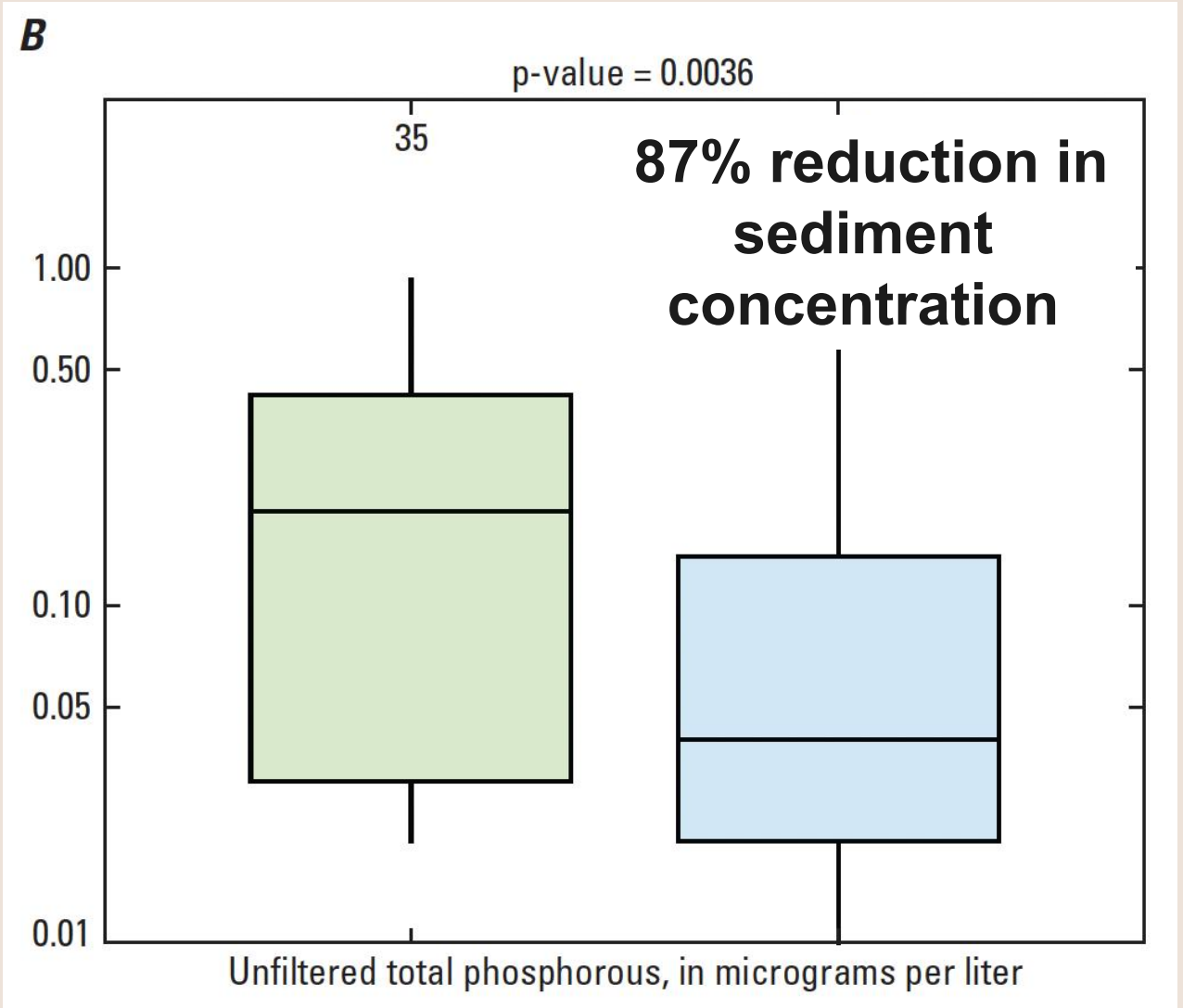


Prepared in cooperation with the Pennsylvania Department of Environmental Protection, and in collaboration with Franklin and Marshall College and the U.S. Environmental Protection Agency

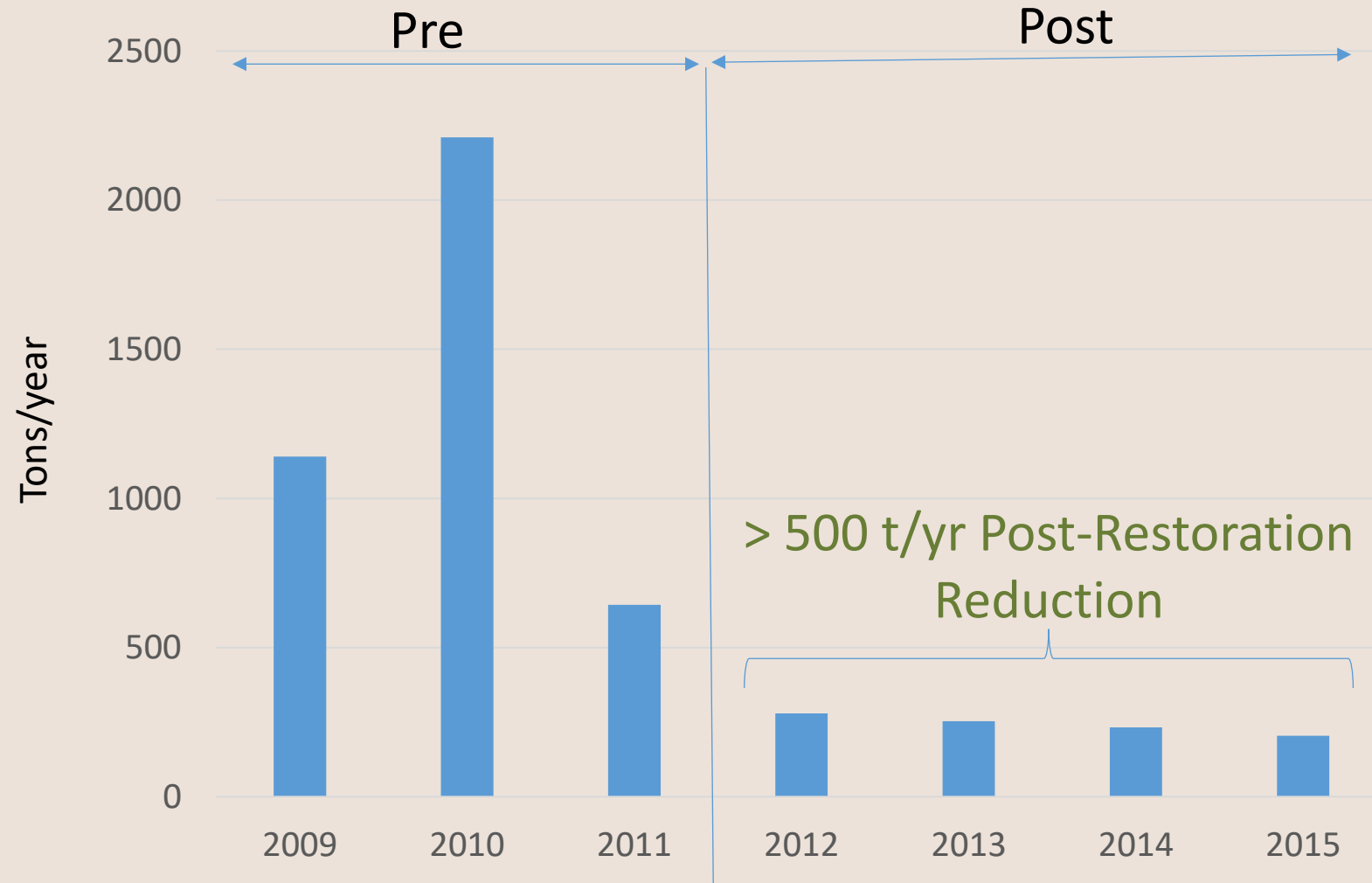
Effects of Legacy Sediment Removal on Nutrients and Sediment in Big Spring Run, Lancaster County, Pennsylvania, 2009–15



Scientific Investigations Report 2020–5031



i. Annual Suspended Sediment Loads - 2008 to 2015 water years

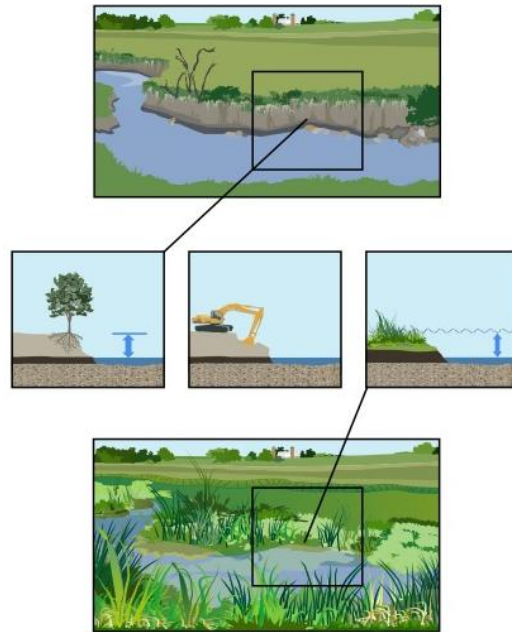


i. Reducing phosphorus loads via legacy sediment removal



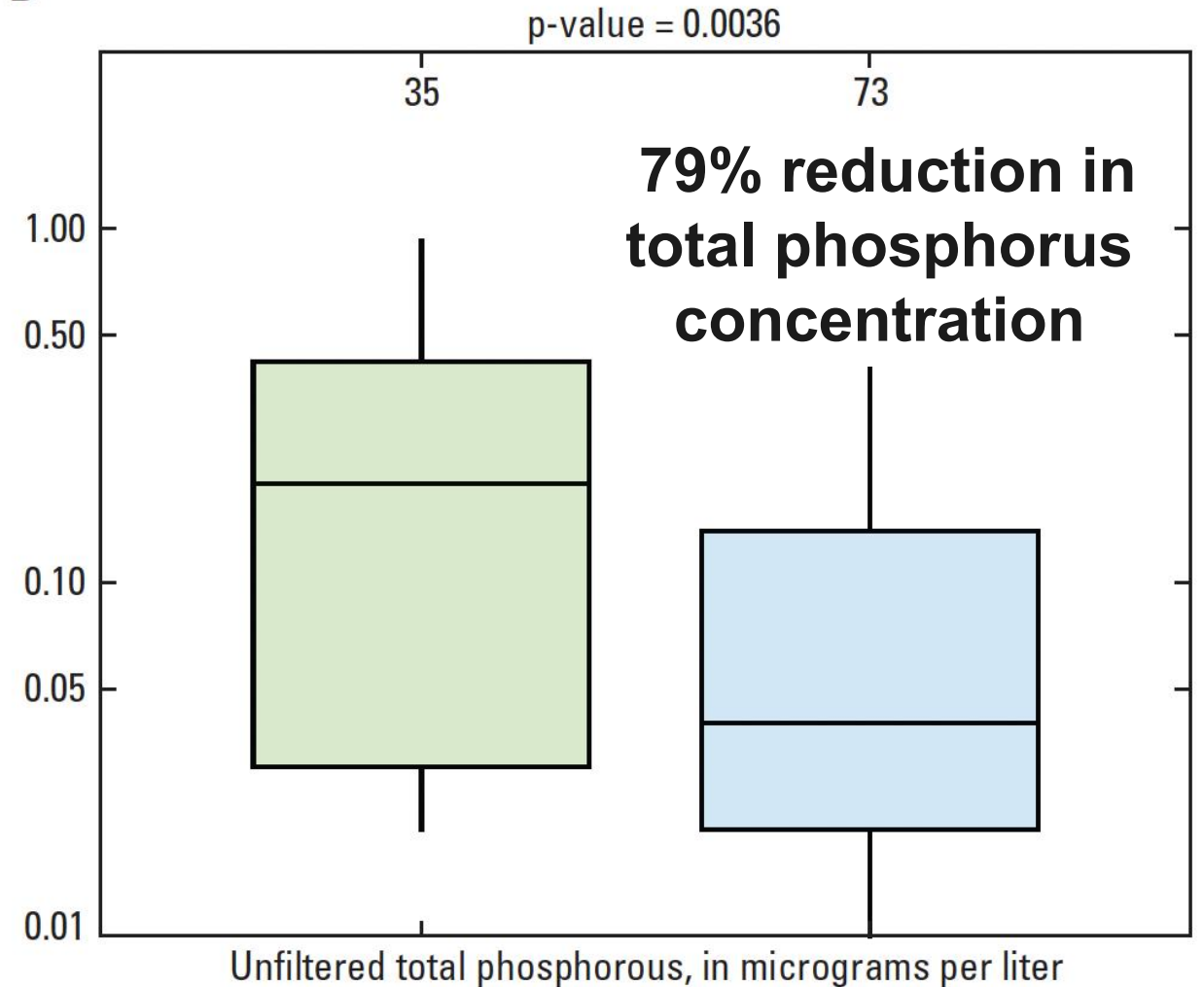
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Scientific Investigations Report 2020–5031

B



Sources of Bank Erosion - After Summer Storm Events



Big Spring Run 9/16/09

Sources of Bank Erosion - Needle Ice and Freeze Thaw Processes



Little Conestoga Creek - Woodcrest Villa 2/12/26

Sources of Bank Erosion - Needle Ice and Freeze Thaw Processes



Little Conestoga Creek - Woodcrest Villa 2/12/26

Freeze-Thaw Processes and Stream Bank Erosion

[AMERICAN JOURNAL OF SCIENCE, VOL. 257, MARCH, 1959, P. 204-216]

FACTORS INFLUENCING EROSION OF A COHESIVE RIVER BANK

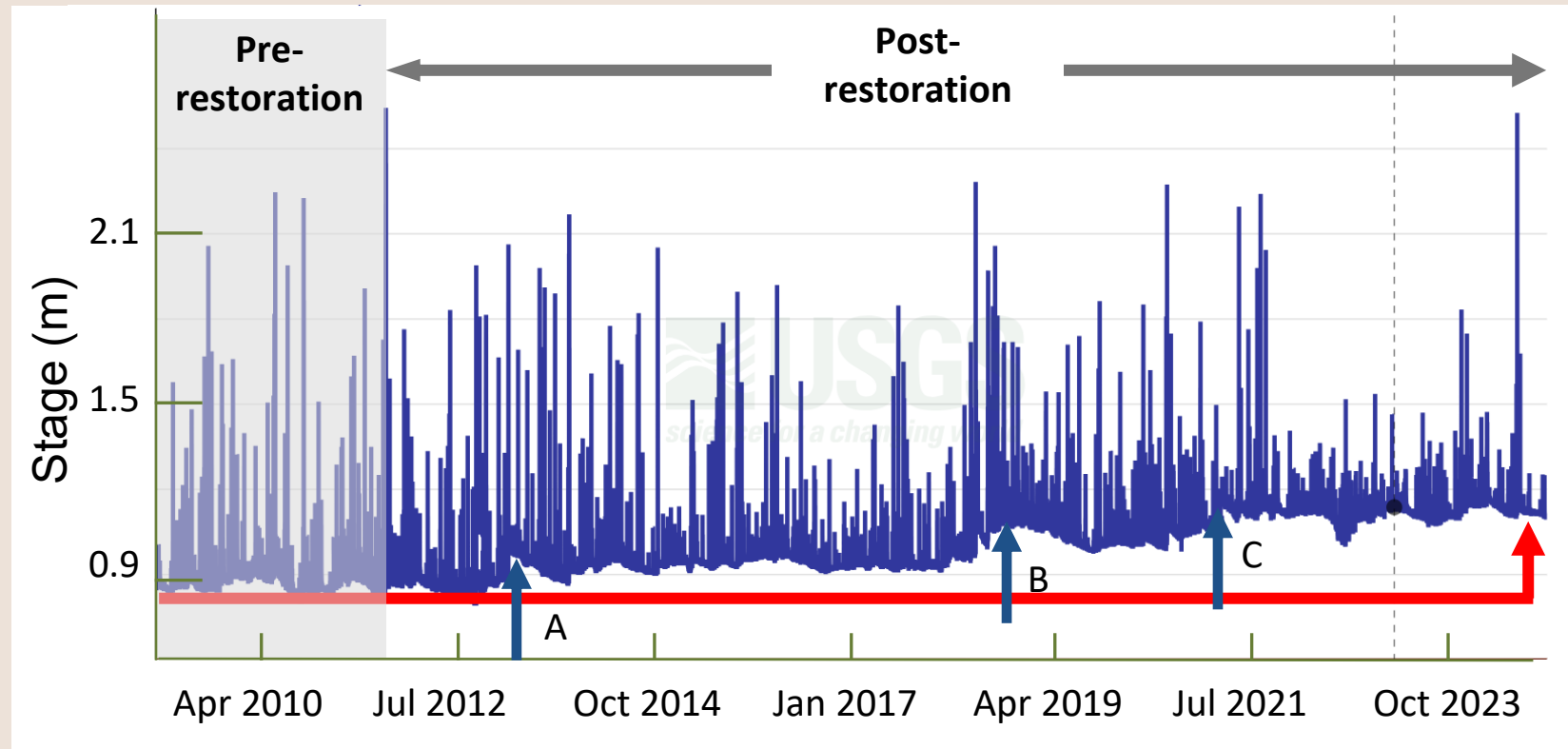
M. GORDON WOLMAN

Dept. of Geography, Johns Hopkins University, Baltimore, Maryland

ABSTRACT. The sinuous channel of Watts Branch in Montgomery County, Maryland, traverses a grassy meadow nearly devoid of trees. The creek has a drainage area of four square miles and the river bank is composed primarily of cohesive silt. Resurveys of cross sections during the five years 1953-1957 have revealed as much as seven feet of lateral erosion. Over the past two years, additional measurements of the amount of erosion around rows of steel pins driven horizontally into the bank have been made at frequent intervals. These observations indicate several combinations of factors primarily responsible for the progressive recession.

→ Approximately 85 percent of the observed erosion occurred during the winter months of December, January, February, and March. A thickness of as much as 0.4 feet of sediment was eroded from the bank at specific points in a period of several hours during which a bankfull flow attacked banks which had previously been thoroughly wetted. Erosion was most severe at the water surface. Little or no erosion was observed during the summer despite the occurrence of the highest flood on record in July, 1956.

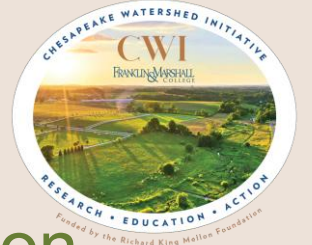
ii. Increase surface water retention on floodplain (see Dr. Shuyu Chang's talk later today)



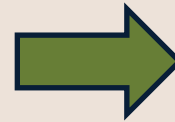
- Substantial, sustained jumps in base flow occur in (A) August 2012, (B) March 2017, and (C) June 2021.
- Base flow stage increased by 30 cm from 2012-2024.
- Consistent with groundwater recharge and greater hyporheic exchange.

USGS continuous gage station at downstream end of BSR restoration 2008-present (>16 years).

iii. Adding carbon to the floodplain (see Chris William's talk, up next).



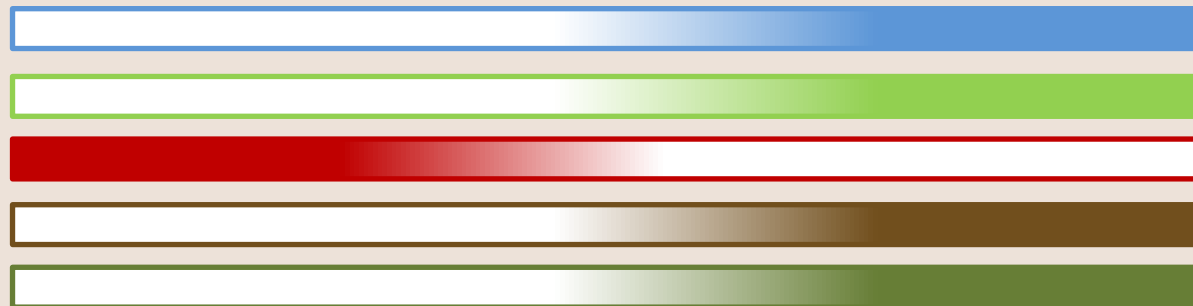
Pre-restoration condition



Post-restoration condition

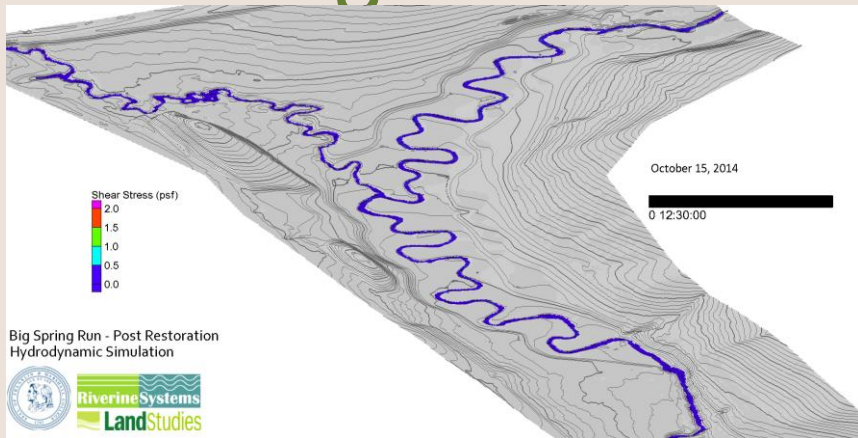


Degraded hydrology
Less plant biomass
More soil CO₂ emission
Lower C sequestration
Less stable carbon



Restored hydrology
More plant biomass
Less soil CO₂ emission
Enhanced C sequestration
More stable carbon

iv and v. Attenuate flows and reconnect floodplain with surface water and groundwater – enable denitrification.



Courtesy of Art Parola,
Univ. Louisville

Storm of 18 September 2012

Central Concept - Stratigraphy Provides the Restoration Target

Degraded Condition

vs.

Restored Condition

Legacy sediment is the impairment

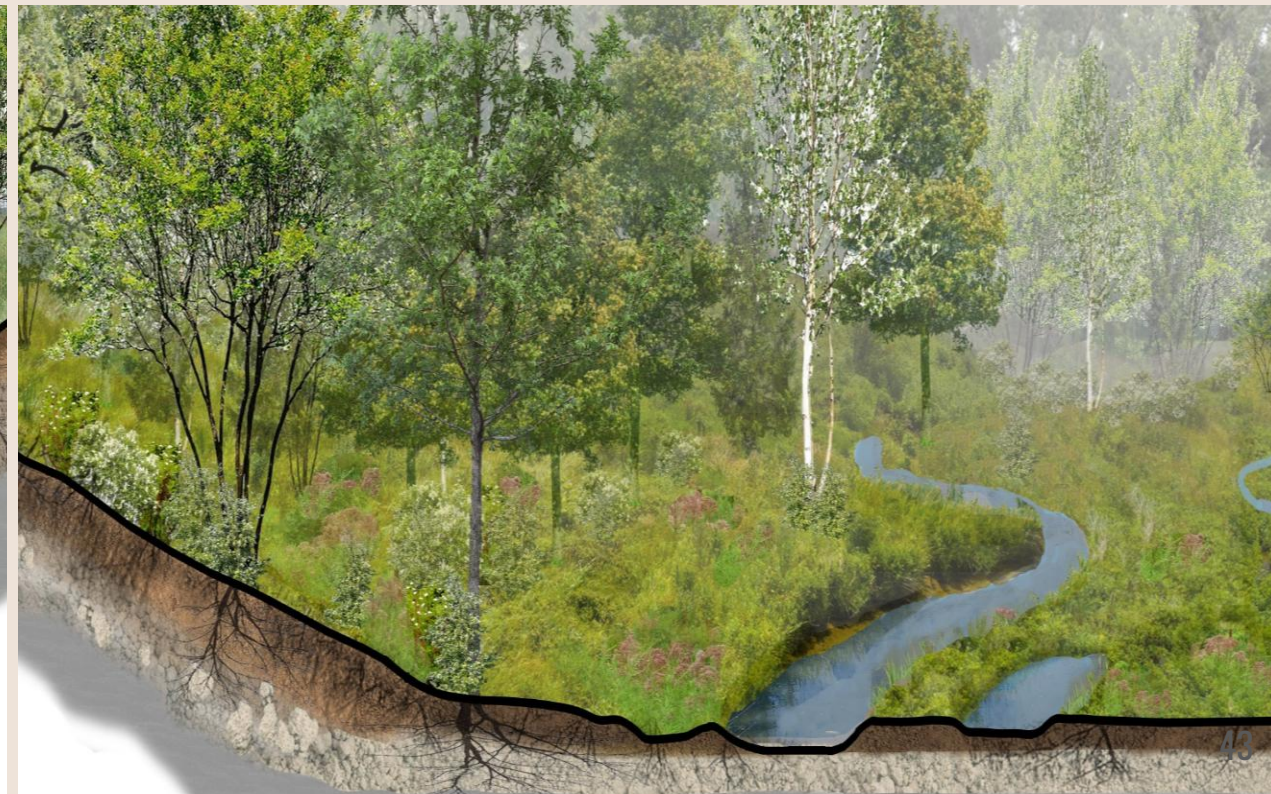
Buries pre-settlement wetland ecosystem (the reference condition).

Poor quality ecosystem

Remove legacy sediment

Re-establish hydrologic function of buried wetland

Restore aquatic ecosystem characteristics and functions similar to pre-disturbance condition





Summary

- The “deep time” evolutionary trajectory of valley bottom stream-wetland systems is important.
- This knowledge provides value to ecosystem restoration designs.
- Are buried wetlands everywhere? No, but they are ubiquitous.
- Are legacy sediments everywhere? No, but they are ubiquitous.
- Are legacy sediments always from millpond deposition? No, but it is the dominant mechanism in the much of region.
- Since restoration is meant to restore an altered ecosystem to a state that approaches its natural ecological functions, we must recognize that legacy sediments **are** the impairment and buried Holocene wetlands the restoration target.

Little Conestoga Creek Stratigraphy

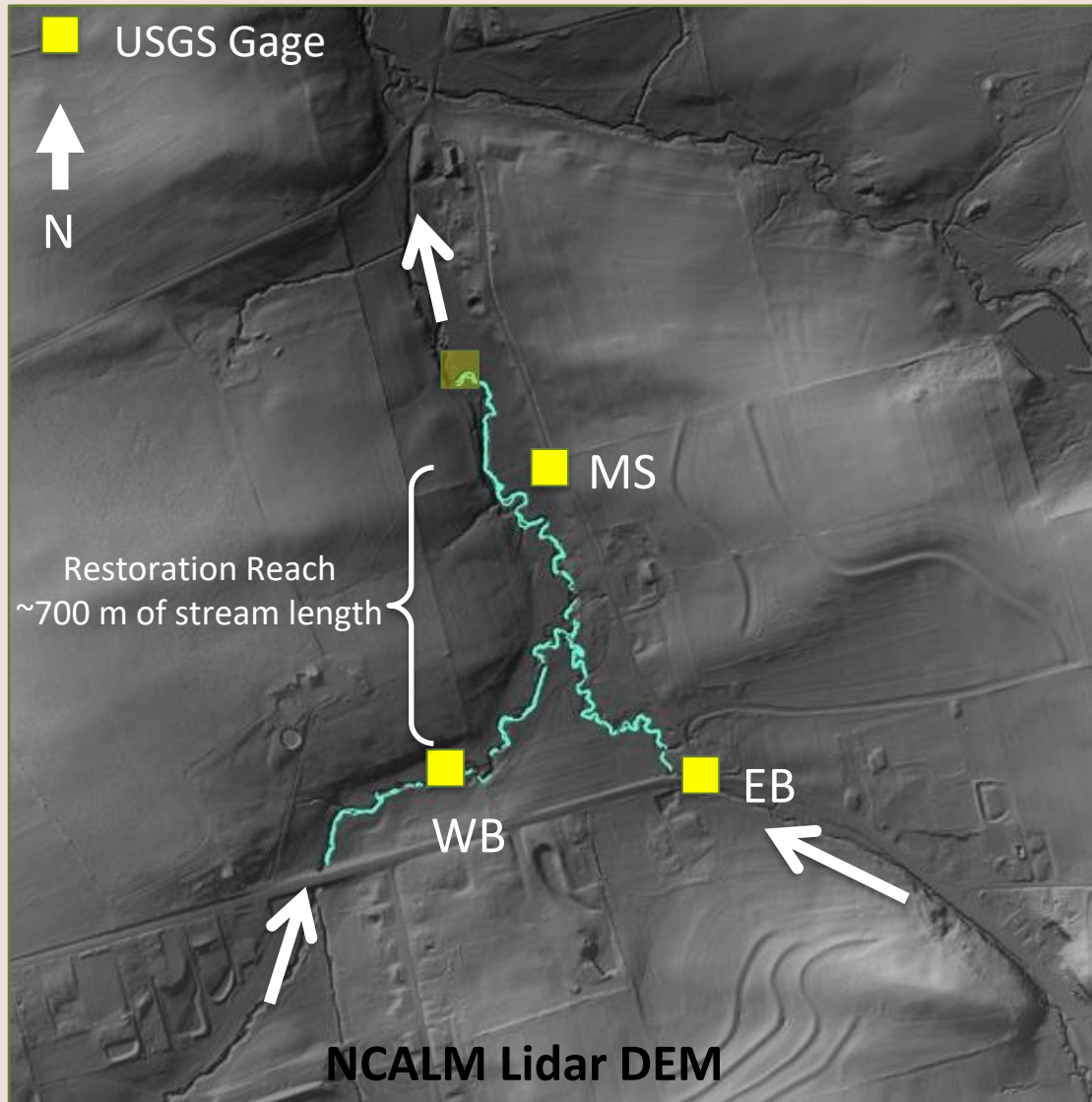


Woodcrest Villa Trench 2/13/23



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

Big Spring Run Floodplain-Wetland Restoration Outcomes (2008-2024)



For more information see: <http://www.bsr-project.org/>

- **Wetland Area Restored:** 2 ha
- **Sediment Removed:** 22,000 tons
- **Sediment Source:** 85-100 % from Banks
- **Sediment Load Reduction:** 500 tons/yr (70%)
- **Median Suspended Sediment Reduction:** 87%
- **Total P Concentration Reduction:** 79%
- **Nitrate Reduction:** 15% in base flow
- **Carbon Storage:** >3,000 kg/yr
- **Up/Down Peak Delay:** 17 min increase
- **Water Storage:** predicted increase
- **Summer Surface Water T :** decrease by ~6 C°
- **Biological Indicators:** Shift from upland dominated to aquatic ecosystem dominated floodplain species