

A photograph of a person wading in a stream. The person is wearing a light-colored shirt, a hat, and a vest, and is holding a long, light-colored pole. The stream is murky brown. The background shows a steep, eroded bank with exposed roots and some vegetation. The sky is blue with some clouds.

Legacy Sediment and Stream Restoration

Reya Mertz
Conservation Technician
Otsego SWCD

What is “legacy sediment”?



[Sheldon Dick, photographer, 1938, for U.S. Farm Security Administration \(U.S. Library of Congress, public domain\)](#), Public domain, via Wikimedia Commons



Public domain, via Wikimedia Commons



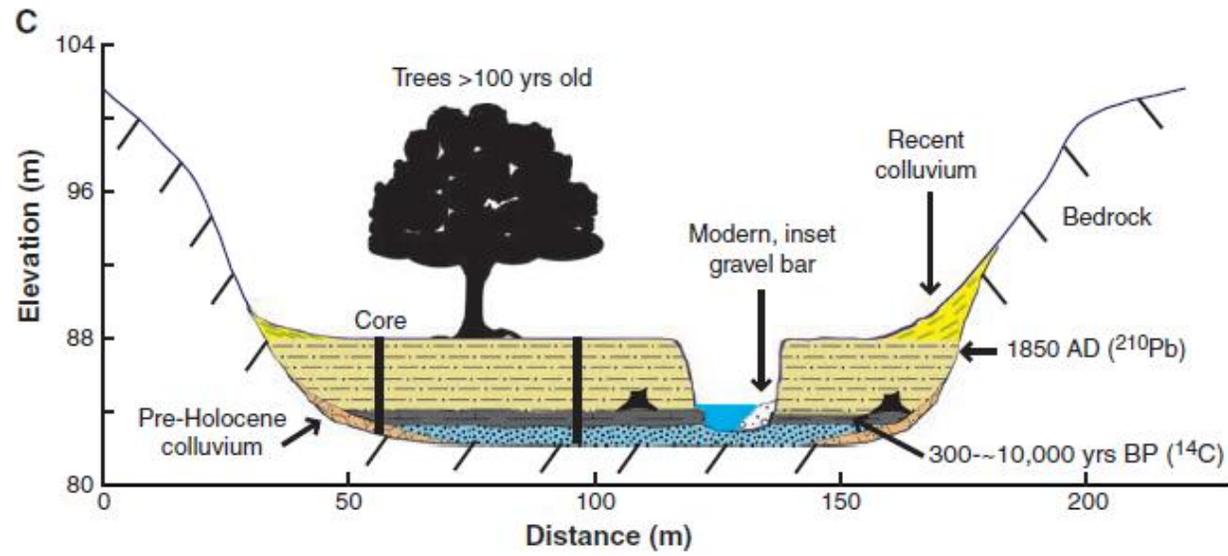
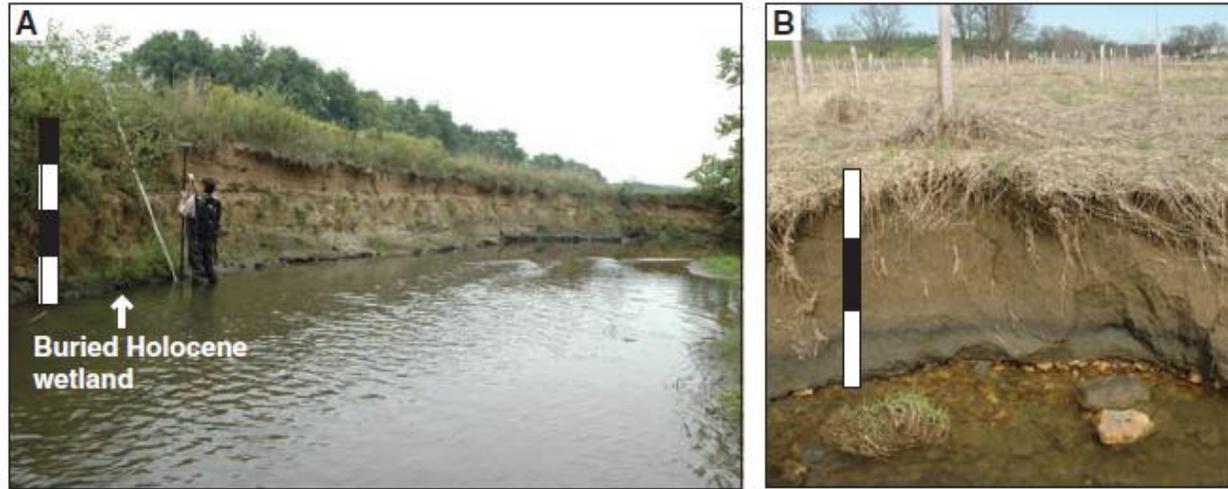
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Happ 1945



[Géodigital, CC BY-SA 4.0](#), via Wikimedia Common



How much?

| Place | Floodplain LS Depth (m) | Erosional Depth (in) | Author |
|--------------------------|-------------------------|------------------------|----------------------|
| Kentucky | 3 | - | Parola 2016 |
| Wisconsin | 1 | - | Happ 1944 |
| Piedmont, SC | 1 | 4 - 6 | Happ 1945 |
| Piedmont, MD | 1 - 2 | 6 | Costa 1975 |
| Wisconsin | 3.5 | - | Knox 1977 |
| Wisconsin, upper valleys | 0.5 | - | Knox 1987 |
| Wisconsin, lower valleys | 3 - 4 | - | Knox 1987 |
| Piedmont, GA | 1.6 | 5 | Jackson & Leigh 2005 |
| Wisconsin | - | 15 | Knox 2006 |
| Piedmont, PA | - | 2.8 - 7.9 (in storage) | Walter et al 2007 |
| Coastal Plain | 1.8 | - | Casarim 2010 |
| Raleigh, NC | - | 50-400x rate increase | Wegmann et al 2012 |
| Maine/VT | 1.5 - 2.5 | - | Johnson et al 2018 |

Conestoga Watershed: 475 mi² watershed storing 102x10⁶ tons (Walter et al 2007)

How to identify it?

- Anthropogenic
- Stratigraphic
- Chemical / Isotopic
- Vegetative

Identification - Anthropogenic



PA Tributary Strategy Steering Committee 2007



Mertz, Shadow Brook Mill Dam, Mill St

Law of superposition!



Tire in Otego Creek, Mertz 2024

Identification - Stratigraphic



Donovan et al 2016

Legacy Sediment

- Color and texture of upland soil
- Fine, prominently stratified, poorly formed
- Low in organic C

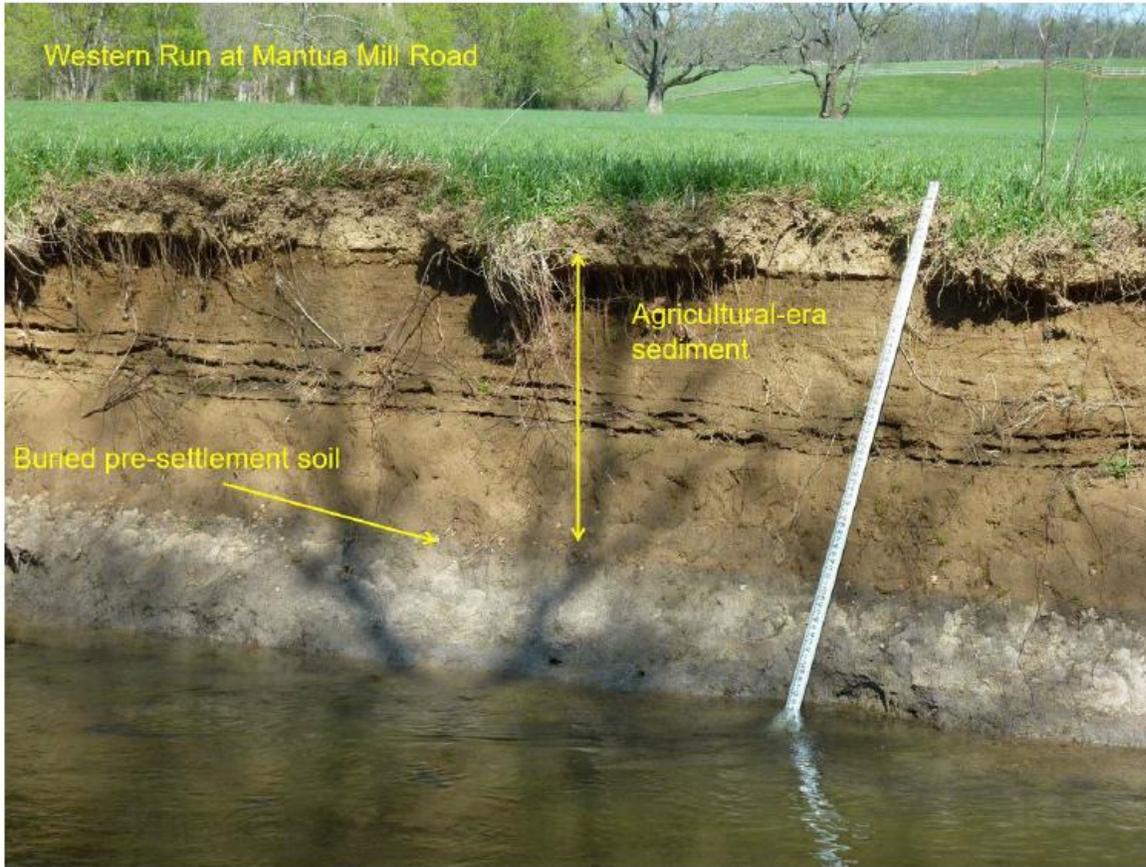
Holocene wetland

- Mineral and organic C rich
- Massive, well-formed fine soils
- High in organic C

Basal Gravel

- Variable: fluvial, colluvial, not present

Variations due to depositional environment and sediment supply



Miller et al 2019

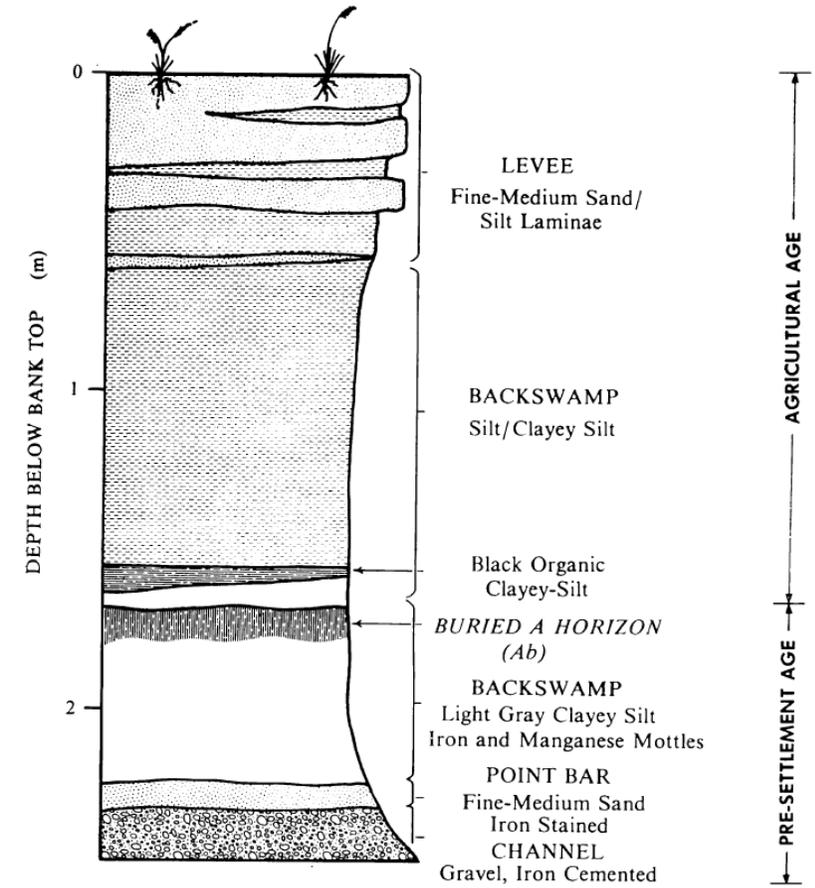
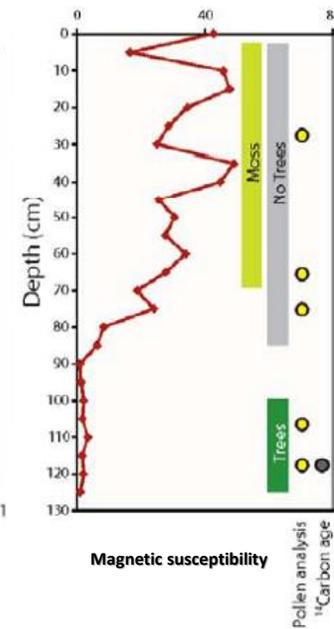
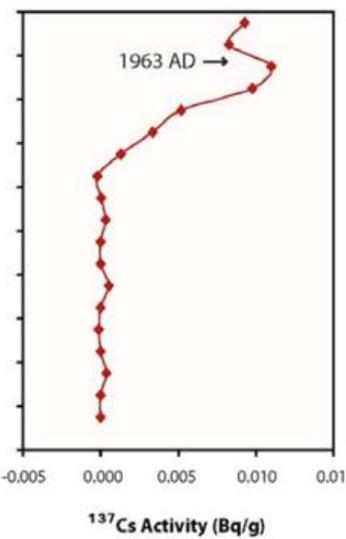
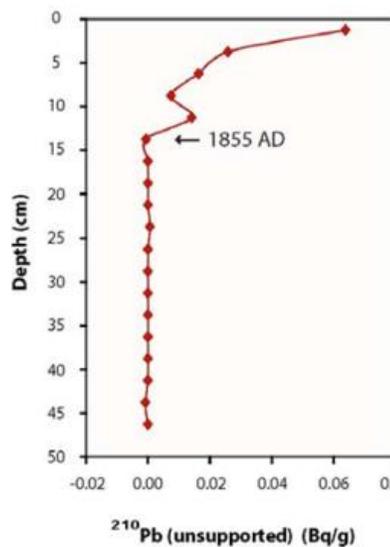
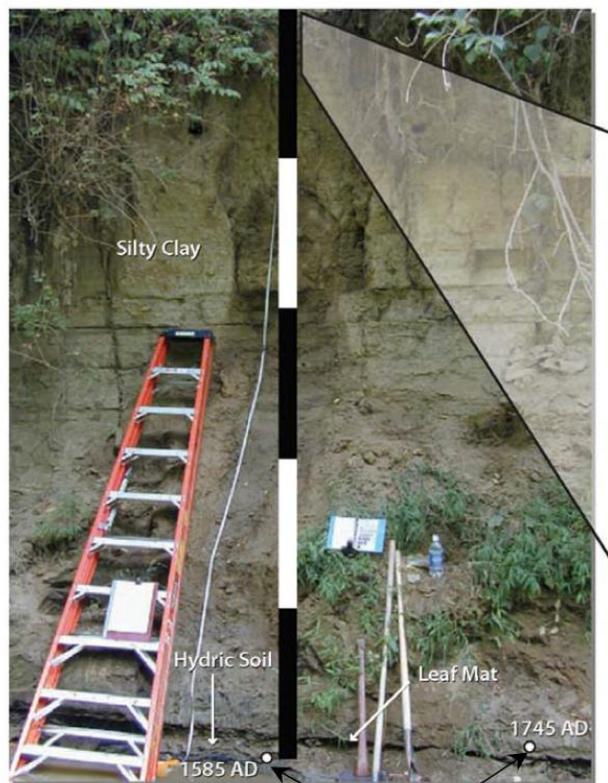


Fig. 3. Typical cutbank stratigraphy. Section measured at the Deer Creek site showing lithofacies and age distinctions. Brown, Agricultural age, levee, backswamp, and organic backswamp sediments overlie backswamp, point bar, and channel facies of Pre-settlement age. The buried A horizon (Ab) marks the Pre-settlement flood plain surface.

Jacobson & Coleman 1986

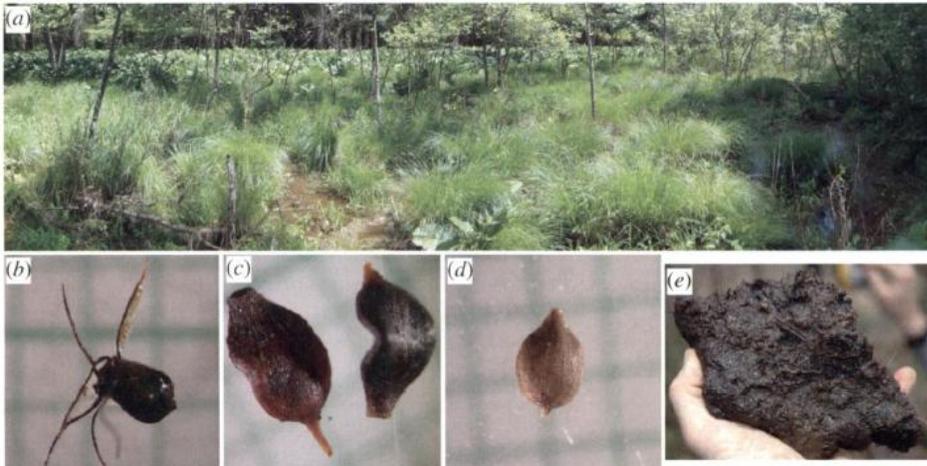
Identification – Chemical / Isotopic



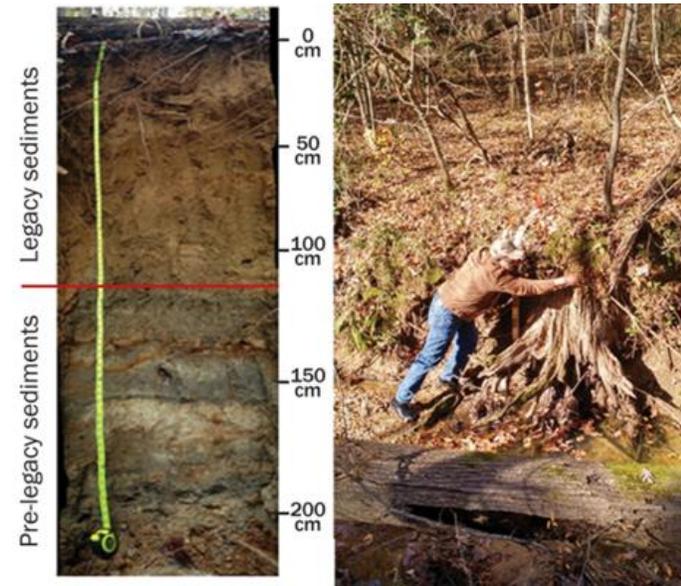
Radiocarbon Dates

Identification - Vegetative

- Buried wetland seed beds, pollen, leaf mats, stumps in growing position
- Decreased hydrophytic vegetation



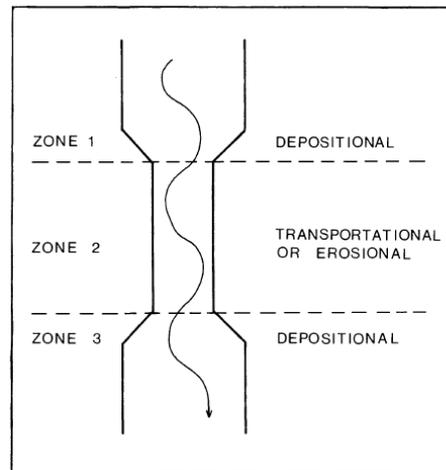
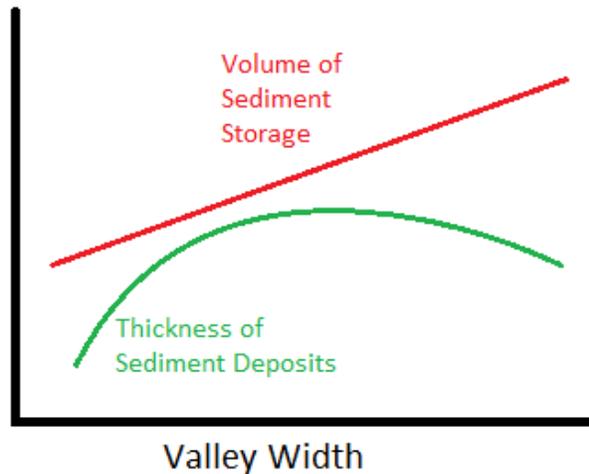
Merritts et al 2011



James et al 2020

Where did it go?

- Generally: Increased storage volume downstream
- Variations: valley width, stores, backwatering



Magilligan 1985



[420Traveler at English Wikipedia, CC BY-SA 4.0](#), via Wikimedia Commons

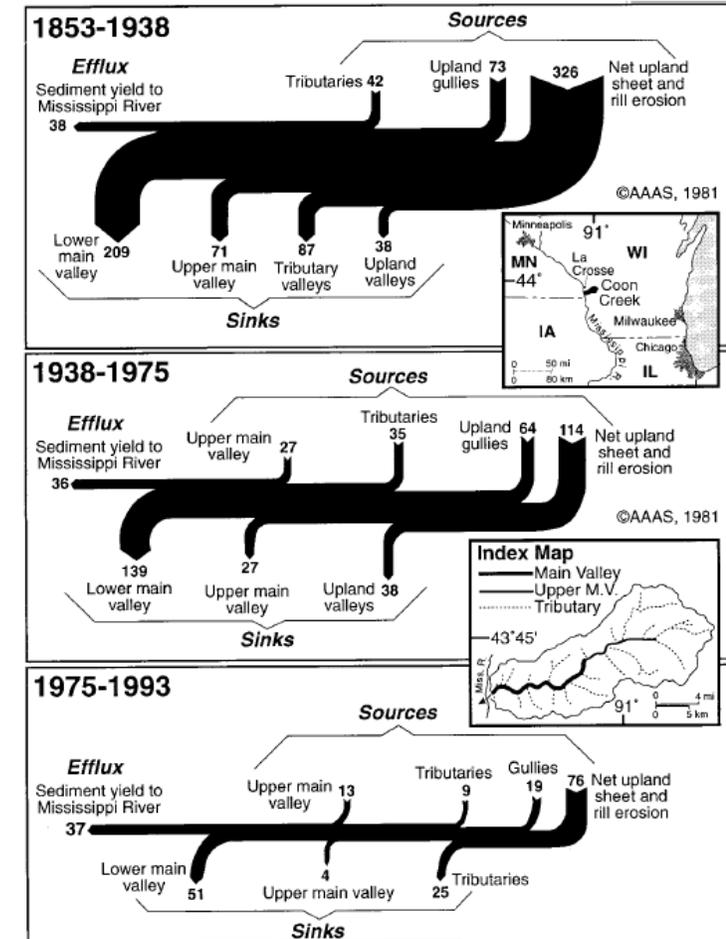
Where did it go?

| Study Location | Floodplain Storage (% total) | Colluvial Storage (% total) | Transported Out of Watershed (% total) | % LS removed from floodplains | Source |
|-------------------|------------------------------|-----------------------------|--|-------------------------------|-------------------|
| Piedmont, MD | 14% | 50% | 36% | - | Costa 1975 |
| Piedmont, MD | 50-60% | - | 50% | - | Happ 1945 |
| Wisconsin | - | - | 7-15% | - | Knox 2006 |
| Piedmont, PA | - | - | - | 10% | Gutshall 2011 |
| Piedmont, PA / MD | - | - | - | 11-23% | Miller et al 2019 |
| Minnesota | - | - | - | 13-36% | Beach 1994 |

UMV: < ½ traveled 4km from erosional source (Beach 1994)

Sources and Sinks

- Modern Era
 - Sources:
 - Tribs incising + widening into LS
 - Upland erosion
 - Sinks:
 - Higher order valley bottoms
- Sediment yield unchanged! (decoupled)



Trimble 1999

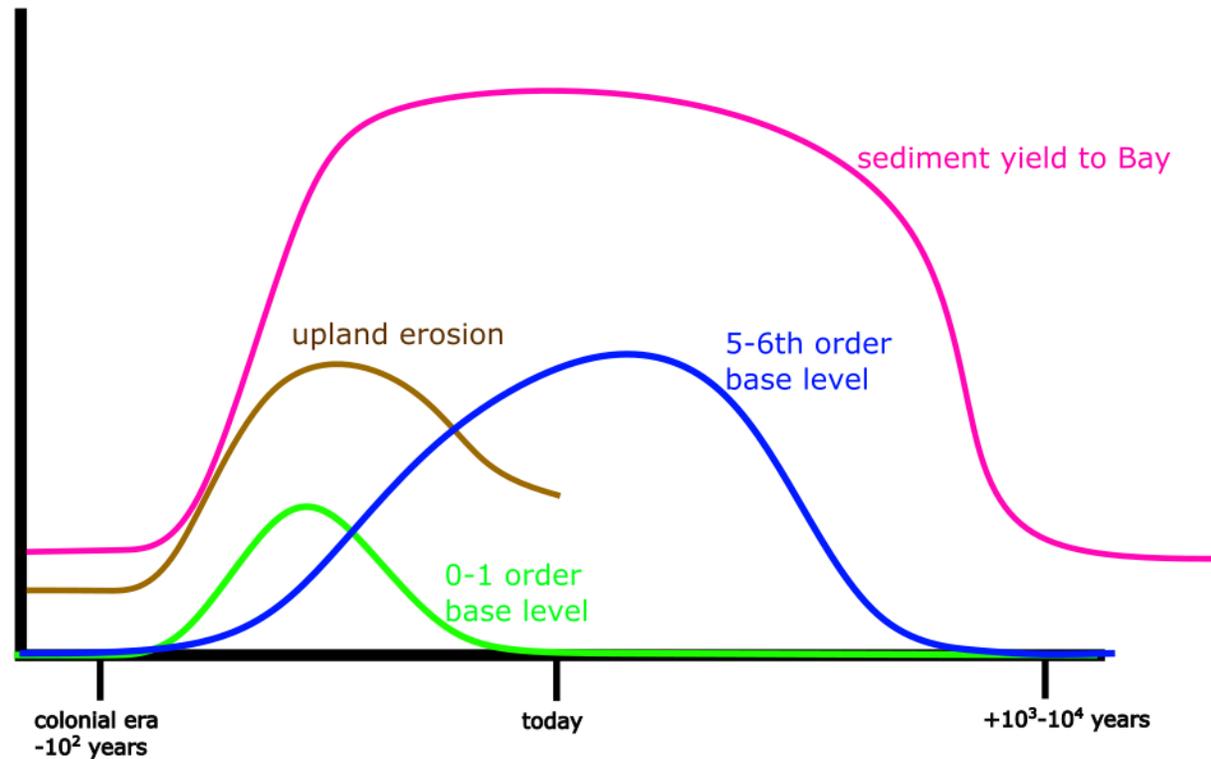
Sources: McKelvey 1939; Costa 1975; Jacobson & Coleman 1986; Trimble 1987; Knox 1987; Trimble 1999; Jackson & Leigh 2005; Knox 2006; Hupp et al 2013; Gellis & Brakebill 2013; Smith and Wilcock 2014; Donovan et al 2014; Miller et al 2019

Sediment lag example

- If upland erosion in Georgia Piedmont stopped today...
 - 6-10,000 years to remove legacy sediment in floodplain

Sediment lag

Down-watershed cascade of base-level rise (aggradation) and base-level fall (degradation)



Sources: McKelvey 1939; Costa 1975; Jacobson & Coleman 1986; Knox 1987; Trimble 1999; Jackson & Leigh 2005; Knox 2006; Hupp et al 2013

Upland improvements

- Since 1930
 - Lower order sediment yield down 66-75%
 - Middle order deposition down 80%
- Persistent problems:
 - Agricultural land
 - Streambank erosion
 - Persistent elevated peak flow
- High order yield remains unchanged

sediment lag



Tim McCabe / Photo courtesy of [USDA Natural Resources Conservation Service](#).



Photo by and (c)2006 Derek Ramsey (Ram-Man), [CC BY-SA 2.5](#), via Wikimedia Commons

What are its effects?

Base-level rise and fall...

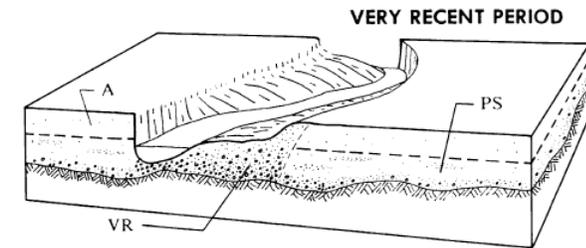
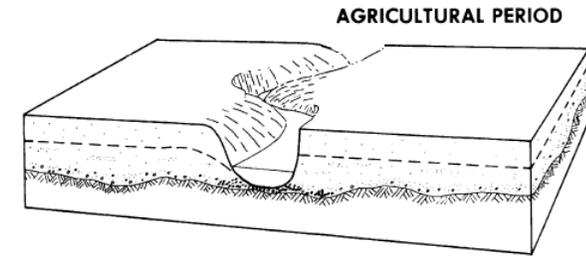
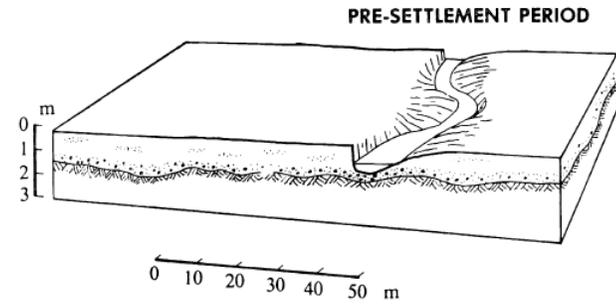


Streambank erosion

Nutrients and pollutants

Hydrologic and Hydraulic

Vegetation and Wetlands



Streambank erosion

| Study Location | Streambank erosion contribution to yield | Source |
|----------------|--|-------------------------|
| Piedmont, GA | 50-80% | Jackson & Leigh 2005 |
| Piedmont, PA | 30-80% | Walter & Merritts 2008 |
| Piedmont, PA | 50-100% | Massoudieh et al. 2012 |
| Piedmont, GA | 75-90% | Makundan et al 2010 |
| Piedmont, PA | 52% | Gellis & Brakebill 2013 |
| Piedmont, NC | >50% | Wegmann et al 2013 |
| Piedmont, MD | 70% (+-50%); 40% legacy sediments | Donovan et al 2014 |
| Piedmont | 50% | Jiang et al 2020 |
| Piedmont | 50-100% | Lutgen et al 2020 |

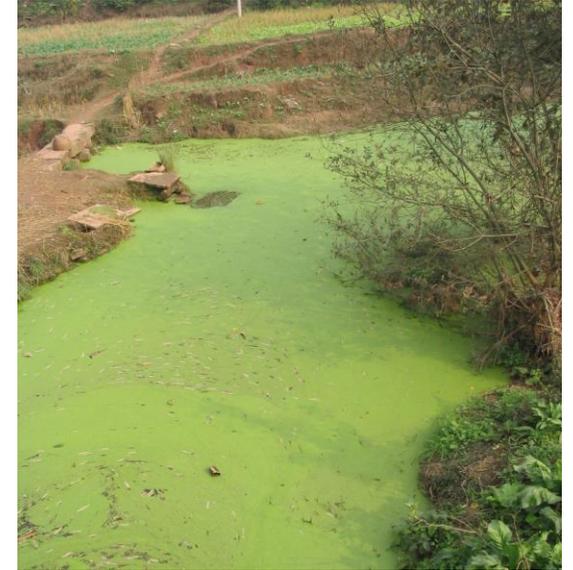


Land Studies, Inc

Low order streams: lower rate, higher total contribution

Nutrients and pollutants

- Lower nutrients, higher availability
- Other pollutants: heavy metals, pathogens, etc
 - “Legacy” exposure
- Example: Big Spring Run, PA
 - Nitrogen: 0.3 to 4.1 lbs/ft/yr
 - Phosphorus: 0.2 to 1.8 lbs/ft/yr



[Felix Andrews \(Floybix\)](#), [CC BY-SA 3.0](#), via [Wikimedia Commons](#)

Hydrologic and Hydraulic Effects

5x increase in peak flow

3-10x increase shear stress

7x decrease in channel capacity

Disconnected aquifer

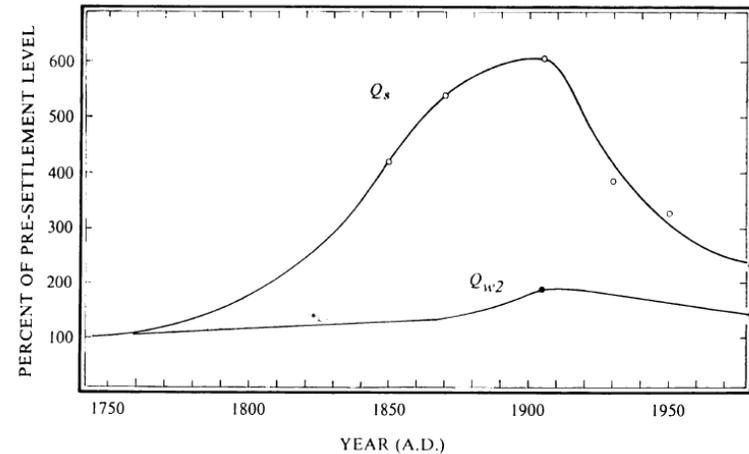
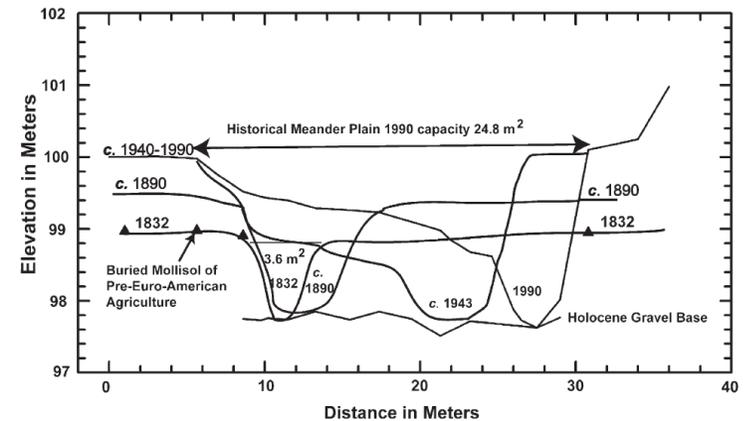


Fig. 6. Flood discharge and sediment supply. Estimated relative changes in sediment delivered to streams, Q_s , and discharge of 2 yr recurrence flows, Q_{w2} . See text for calculations.

Jacobson & Coleman 1986



Knox 2006

Sources: Knox 1977; Knox 1987; Jackson & Leigh 2005; Knox 2006; Walter & Merritts 2008; Gutshall 2011; Parola et al 2011; Livers & Snyder 2025

Vegetation and Wetlands

- Upland fill terraces with upland vegetation
- Loss of wetland habitat and ecosystem functions



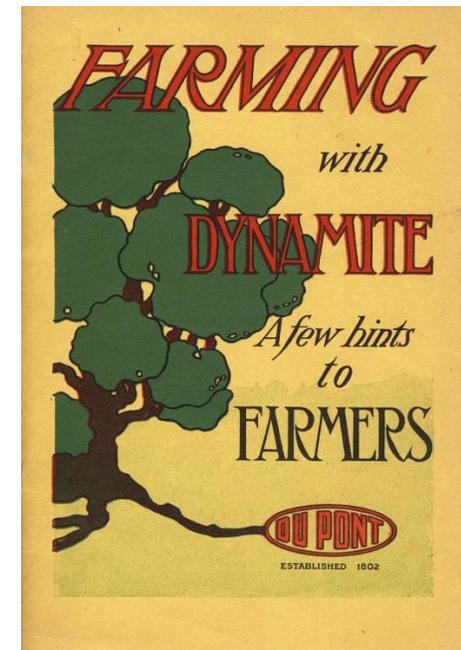
Fig. 5. Legacy sediment on Greenhorn Creek, California composed of hydraulic gold mining tailings. High terrace is ~30 m above present channel. At the time of maximum sediment production, braided channels were graded at the high terrace level. When mining ceased, the channel incised, although it has not yet returned to pre-mining levels (James, 1989). Photographed December, 2004 by author.

James 2013

Other alterations

- Burial, straightening, dredging, berming, moving to valley walls
 - Straightening increases sediment transport capacity up to 50x
- 70% of Kentucky streams channelized or moved

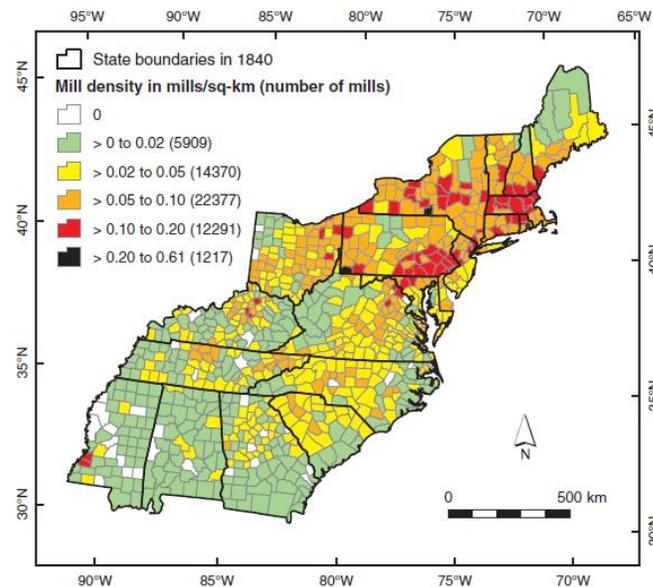
.... dams



Du Pont, via [Internet Archive](#)

Dams

- 1840: 65,000 in Eastern US
- Peak mill dam construction from 1780 – 1860

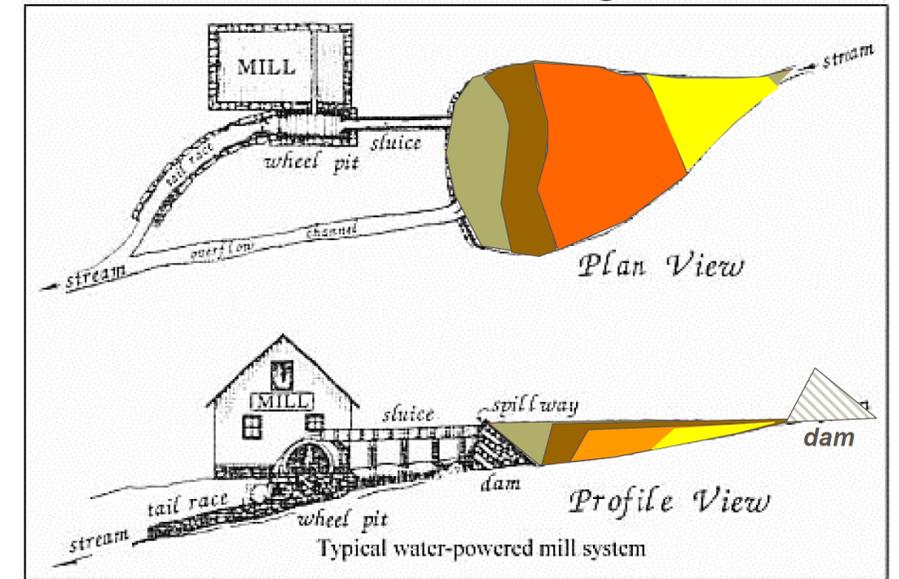
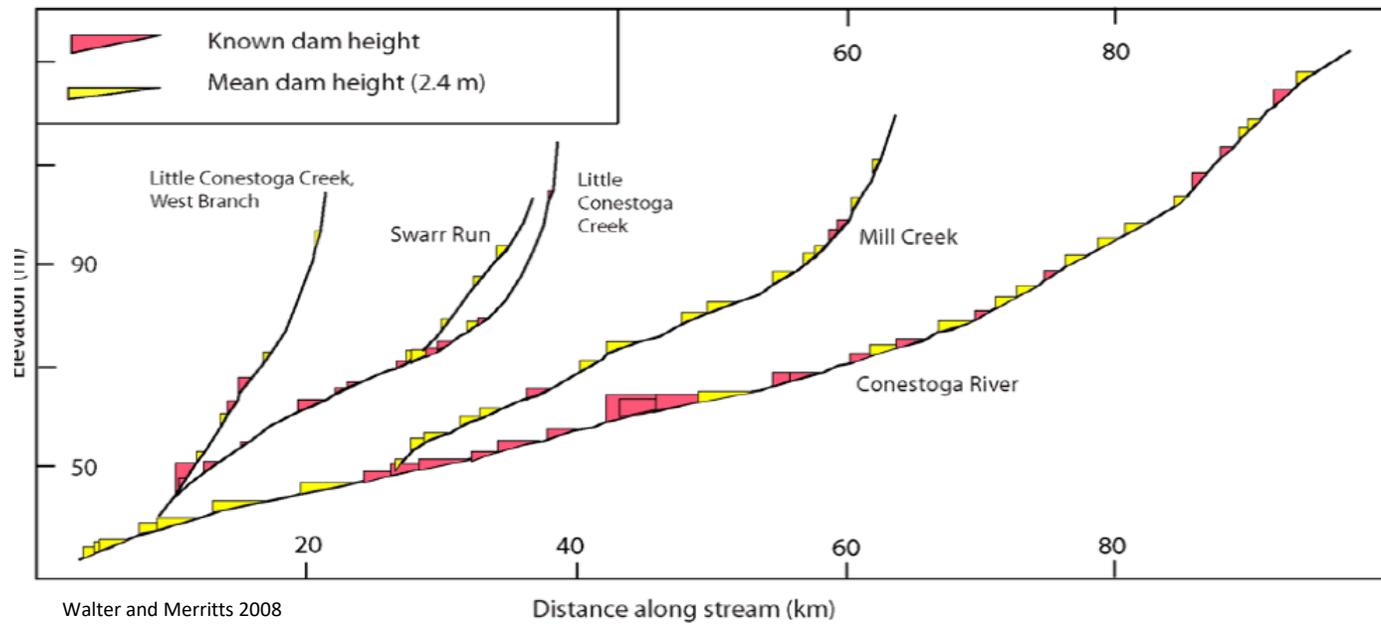


Walter & Merritts 2008



Mertz 2025, Morris Dam

Dams



Valley flat or fill terrace?

- Thinly laminated fines
- Stillwater conditions



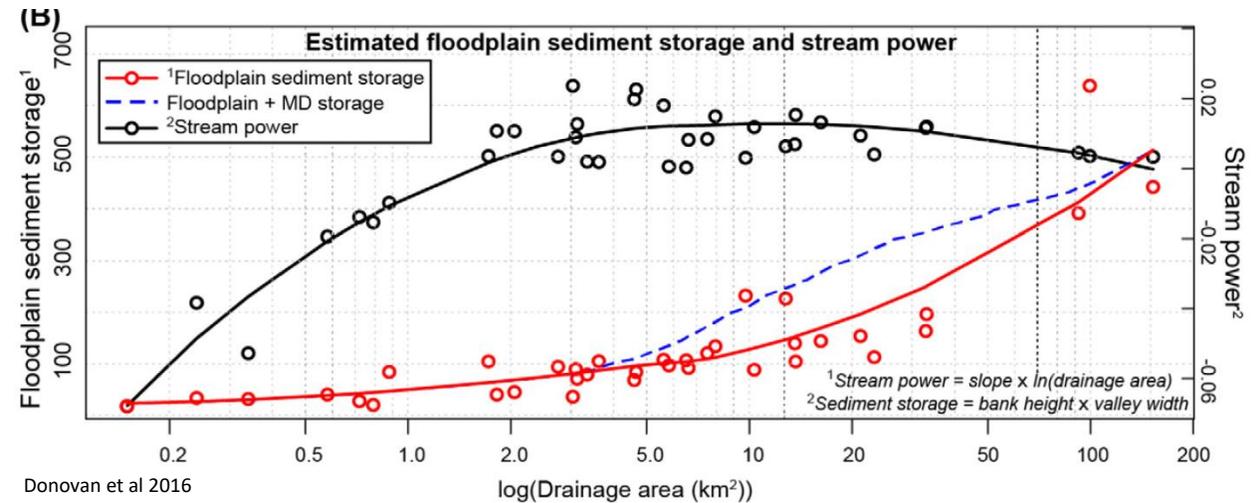
Fleming et al 2019

Influence of mildams

- Sufficient but not necessary
- Erosion hotspots
 - 15% more erosion than non-dammed reaches
- Increased floodplain deposition outside of slackwater

Effect of mill dams

- Dictated by:
 - spacing of dams
 - valley width, gradient
 - sediment delivery
 - trapping efficiency
 - dam lifespan

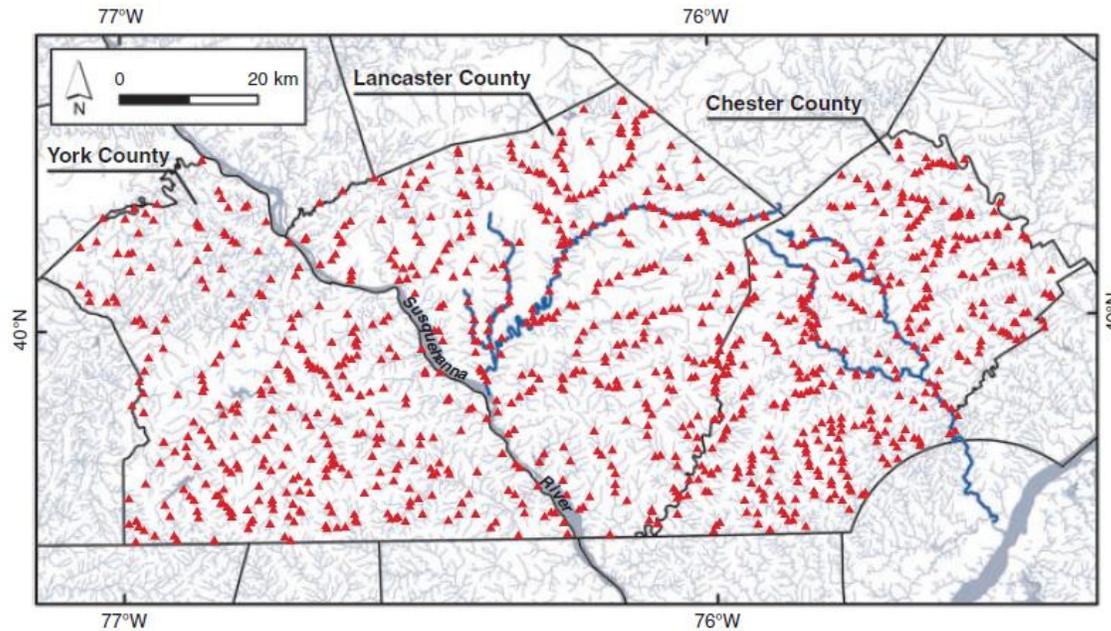


Relevance to Otsego County?

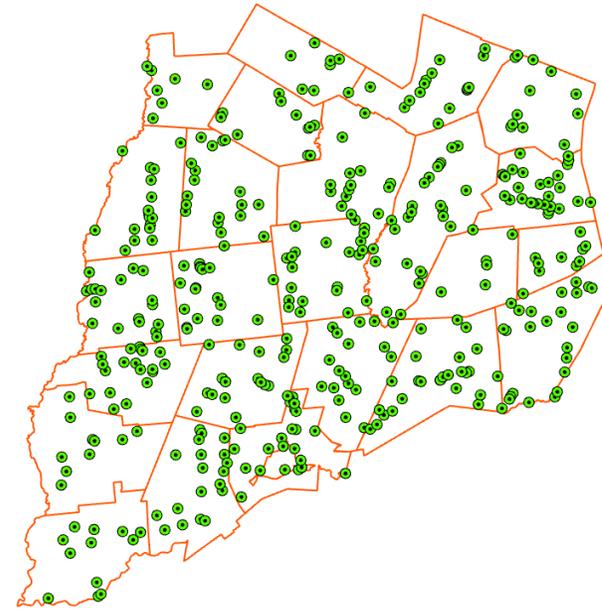
| | Otsego | South-Central PA |
|---------------------------|-------------------|------------------|
| Landform | Dissected Plateau | Piedmont |
| Glaciation | Glaciated | Peri-glaciated |
| Soils (k-factor average) | 0.25 | 0.33 |
| Average Slope (%) | 13.6% | 7.8% |
| Annual Rainfall (in) | 47.6 | 44.8 |
| 24-hour 1-year storm (in) | 2.0 | 2.5 |

Mill Dam Relevance

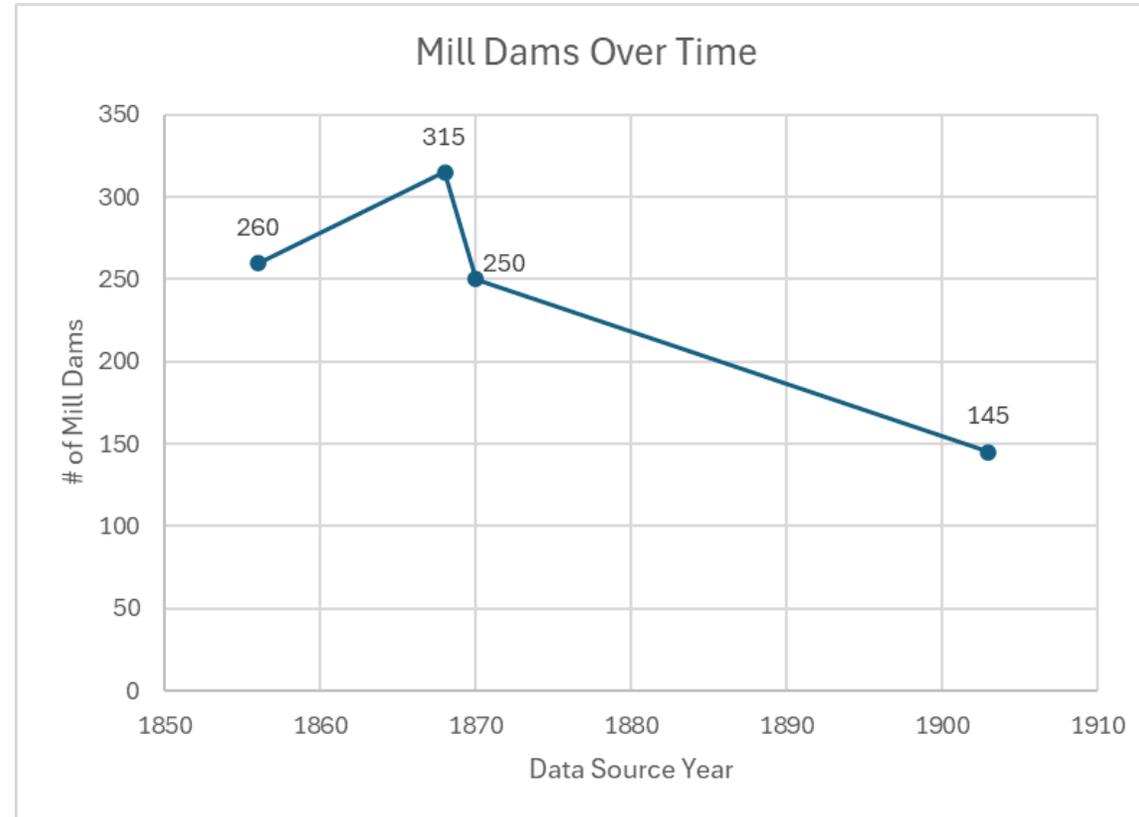
- Otsego, NY: 401 mill dams between 1868 – 1903
 - Higher concentration than PA Piedmont



Walter and Merritts 2008

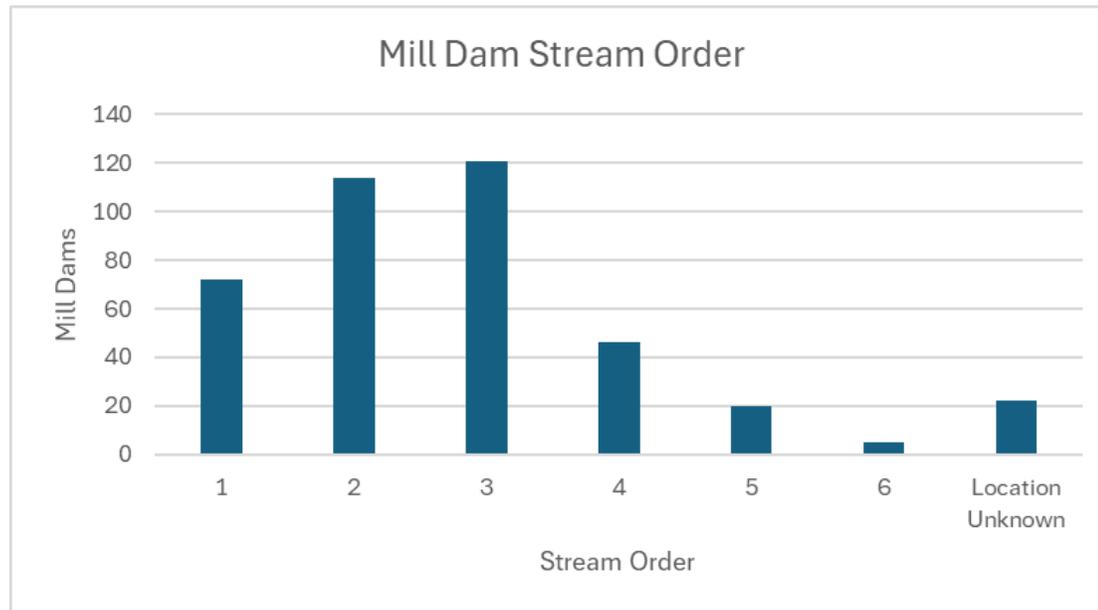


Otsego Mill Dam Data



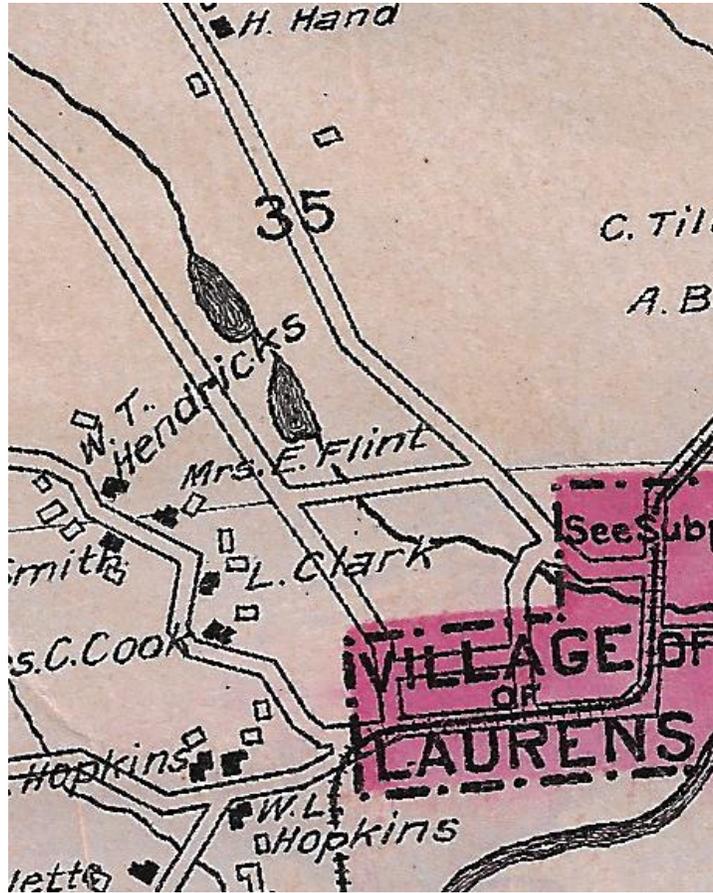
Otsego Mill Dam Data

- 4% on DEC dam safety list

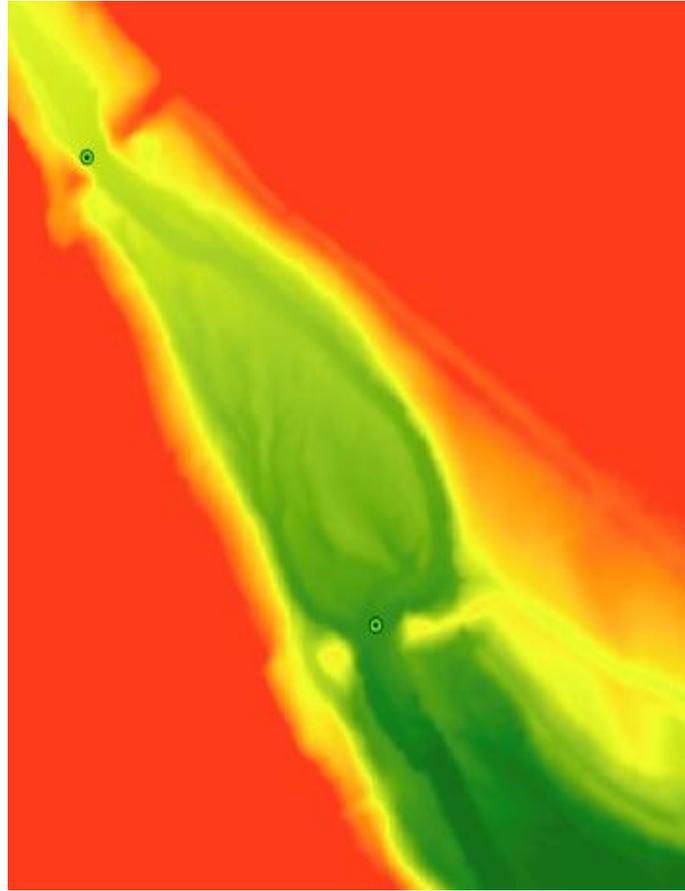


| Types of Water Powered Mills | |
|------------------------------|-----|
| Saw | 308 |
| Other | 80 |
| Grist | 58 |
| Cider | 17 |
| Factory | 14 |
| Cotton | 7 |
| Clover | 7 |
| Planing | 6 |

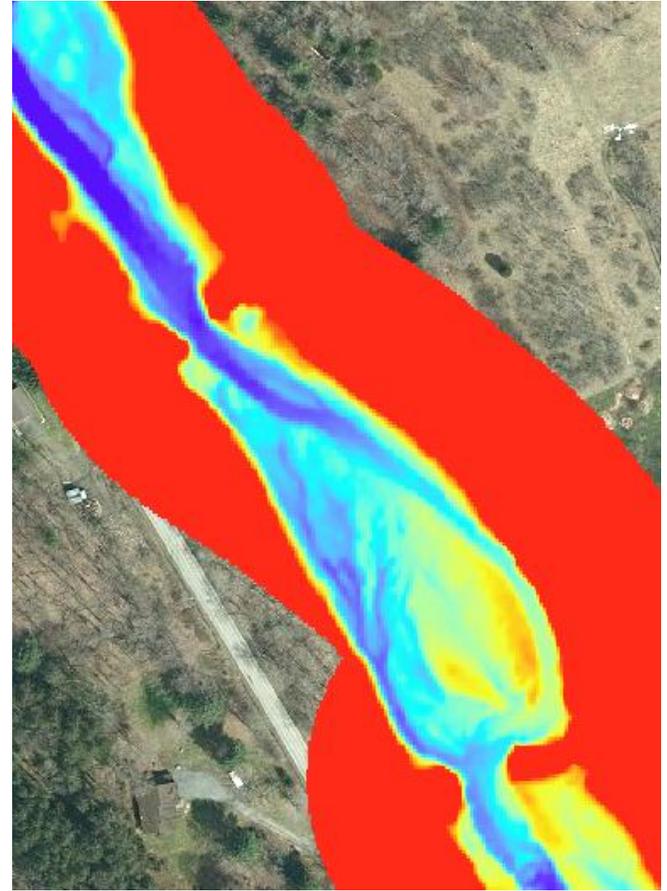
Laurens, NY



1868 Atlas of Otsego County



1m Digital Elevation Model

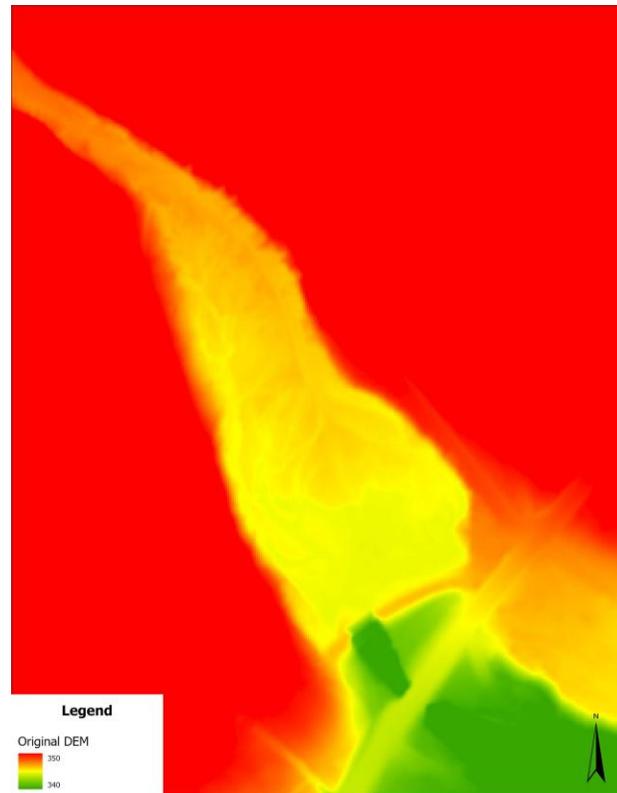


1m Relative Elevation Model

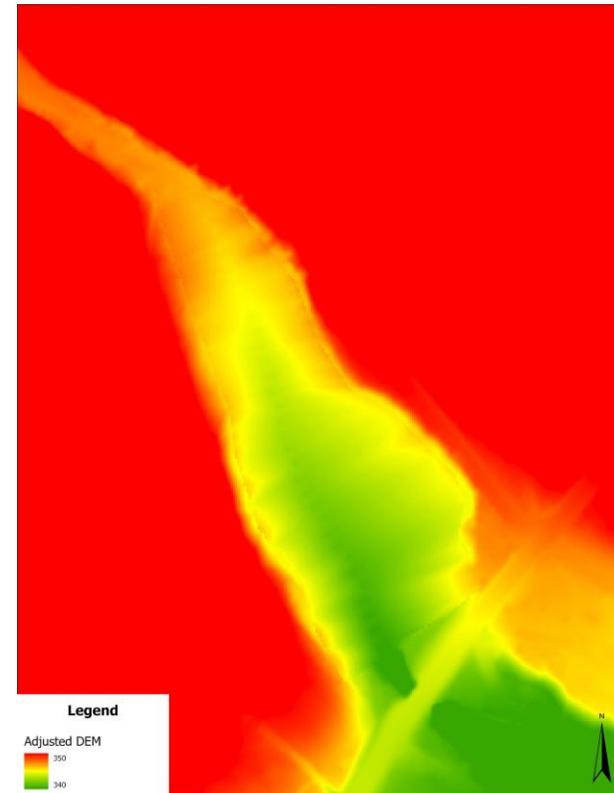
Morris Pond



Morris Pond



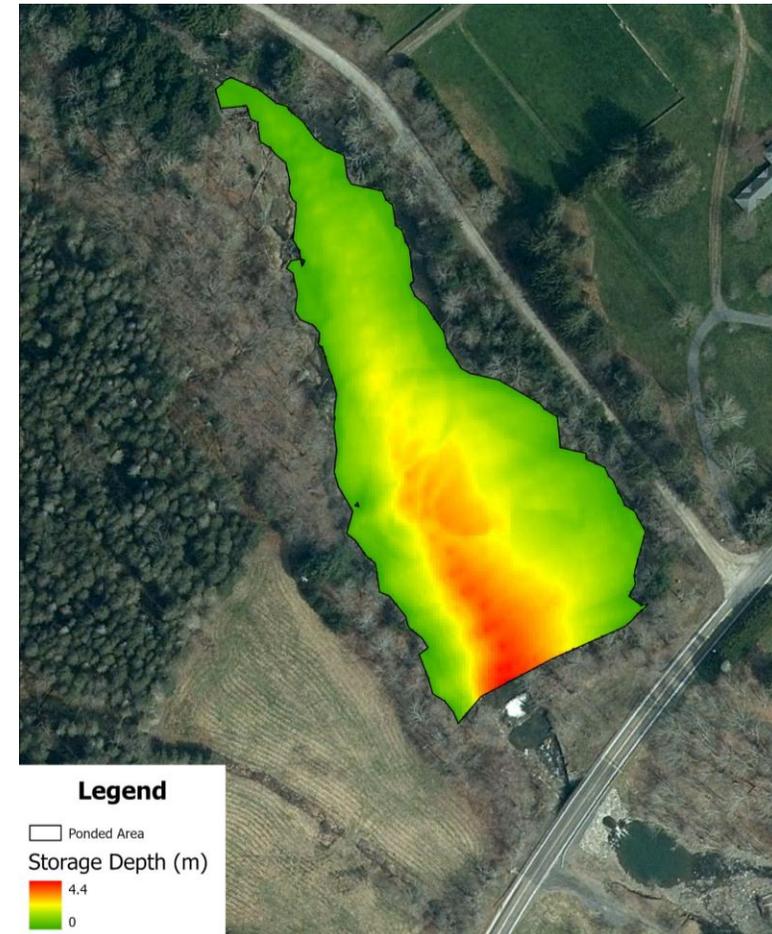
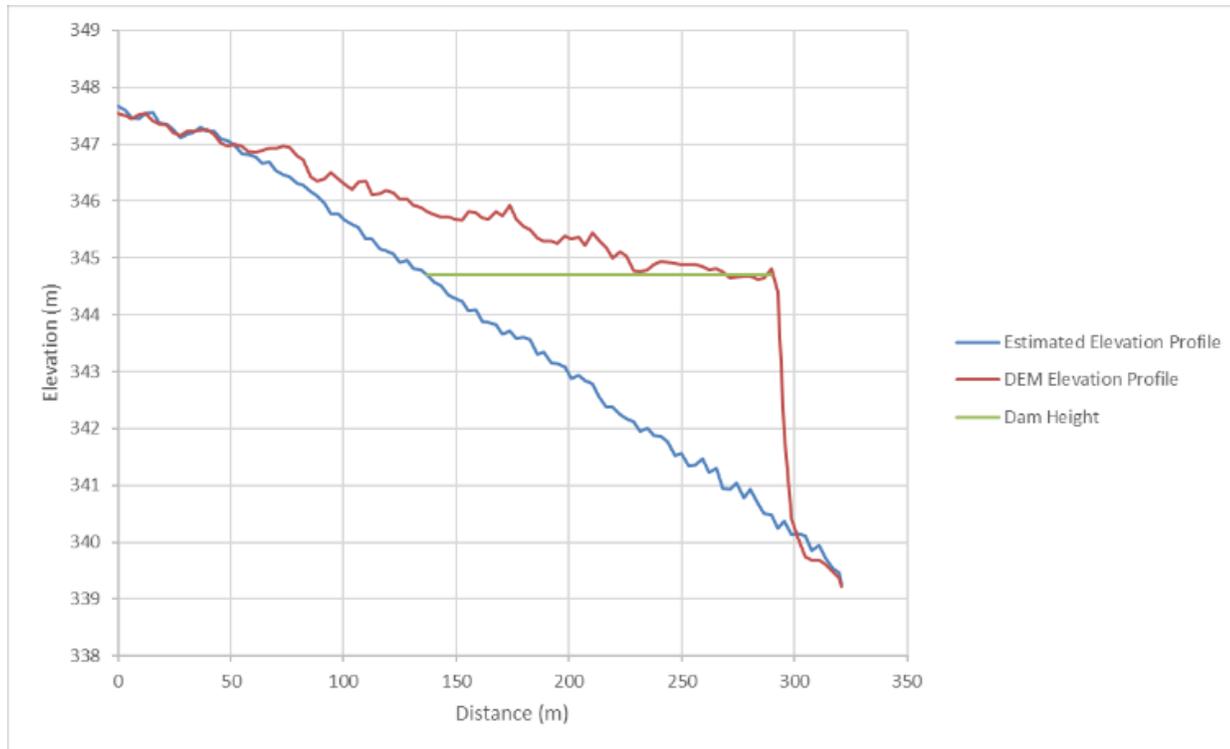
Morris Pond, 1m DEM



Morris Pond, 1m DEM
dam removed (estimate)

Morris Pond

15.86 acre-ft of stored sediment behind
15ft dam



Not just mill dams

- Watershed size, confluences, unconfined valleys all seem to increase sediment depths

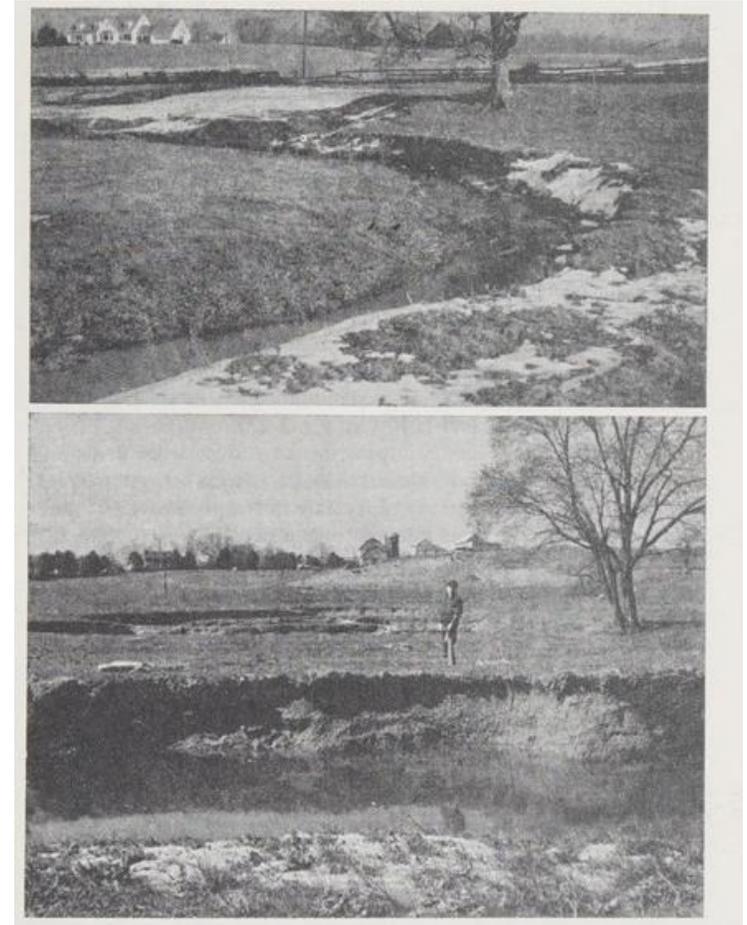


Otego Creek



There is no “undisturbed” reference reach

- Brandywine River, Seneca Creek, Watts Branch, Western Run
 - Dams and extensive LS
- Incised meandering streams
 - 1-2 year recurrence bankfull flow



Fluvial Processes in Geomorphology by Leopold, Wolman, and Miller via [Archive.org](https://www.archive.org)

What's beneath the sediment?

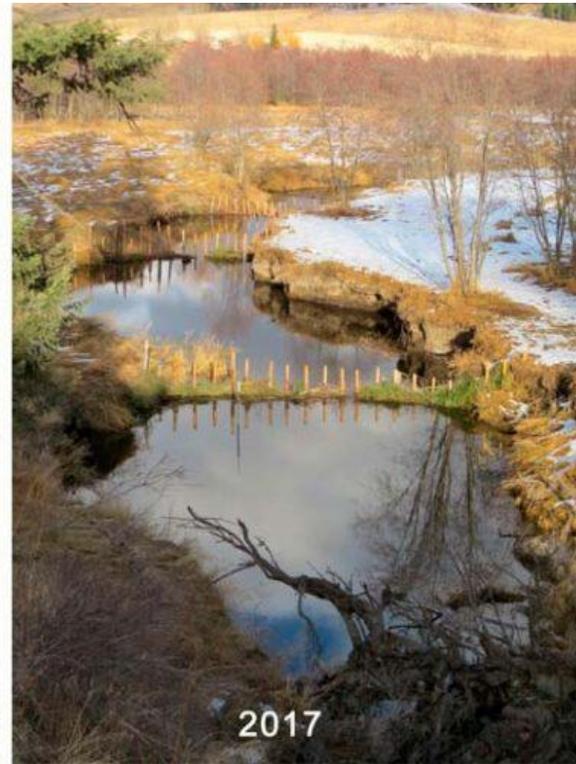
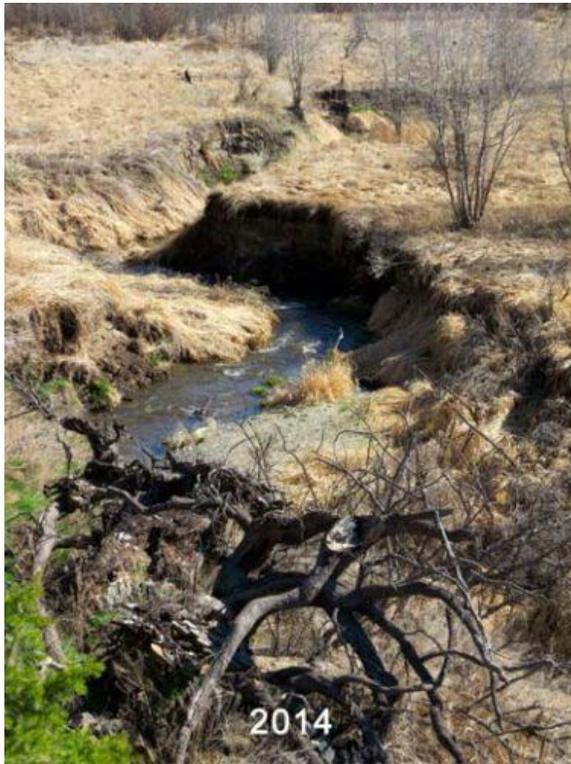
- Stream-wetland complexes
- Driven by beaver and LWD
- Anastomosing channels



Wegmann

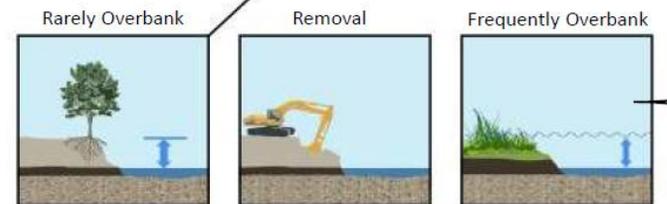
What does this mean for restoration?

Raise streambed



Wegmann

Lower floodplain



EPA-STAC Workshop 2023

Base-level rise

- Techniques
 - PALS, BDAs, Beaver reintroduction
- Benefits
 - Floodplain function
 - Accelerated recovery (10-100x)
- Pitfalls
 - Legacy sediment aquitard
 - Potentially unstable



Wegmann



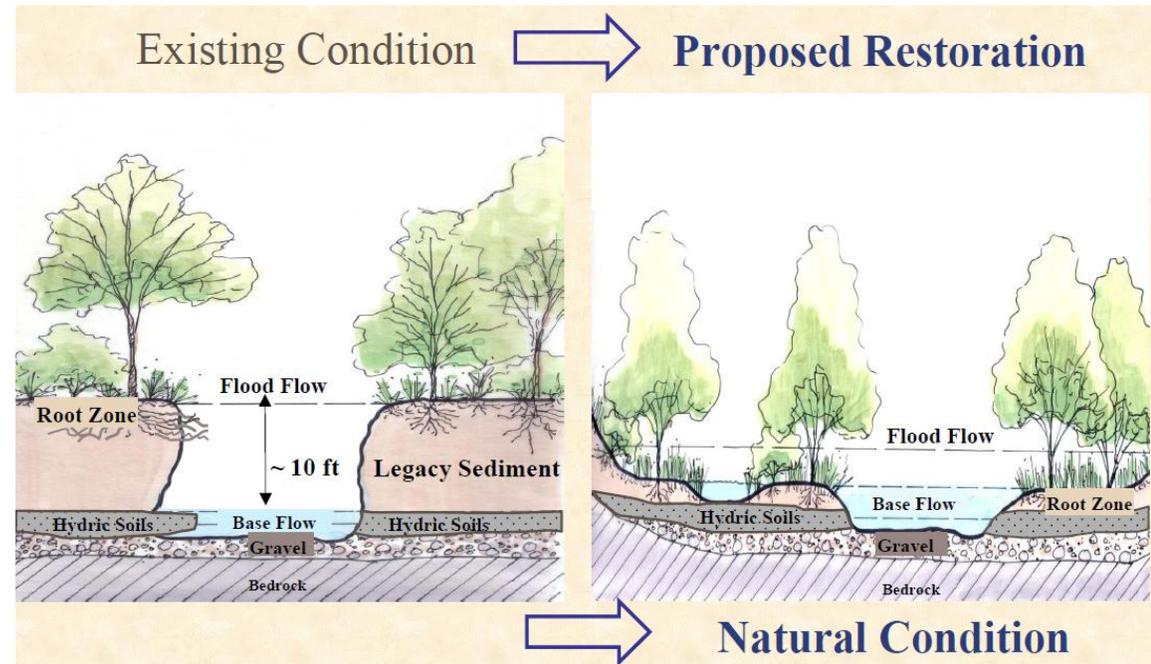
Wegmann

Sources: Shields et al; Pollock et al 2014; Brown et al 2018

Image Attribution: [Steve from Washington, DC, USA, CC BY-SA 2.0](#), via Wikimedia Commons

Legacy sediment removal (LSR) effects

- Floodplain access
 - Flood storage
 - Reduced shear stress
 - Groundwater recharge
- Unbury wetland
 - Hydrophytic vegetation
 - Denitrification
 - Hyporheic exchange
 - Sediment removal
- Anastomosing morphology
 - Habitat complexity



PA Tributary Strategy Steering Committee 2007

Restoration goals

Source



- Thermal pollution
- Nutrients and sediment
- Low base flow
- High peak flow



Sink



- Hyporheic exchange
- Denitrification and deposition
- Sustained base flow
- Floodplain storage

How do we design to these goals?

Stepwise 2-D analysis of shear stress

1. Define floodplain
 - a) shear stress < vegetation threshold
2. Define baseflow channel
 - a) bank height \leq soil capillary fringe
 - b) bed depth \approx aquifer elevation
 - c) shear stress < bed + bank thresholds
3. Add profile controls
 - a) buried in floodplain
 - b) sized to maximum shear stress calculated
4. Add pools, woody debris, backwater channels, etc



Project Example - Big Spring Run

- 1.68mi² watershed
- Mill dam site
- Bank erosion: 1.1 ft/yr, 0.2 tons/ft/yr
- Silty loam soils
- 50% ag
46% developed
4% forest

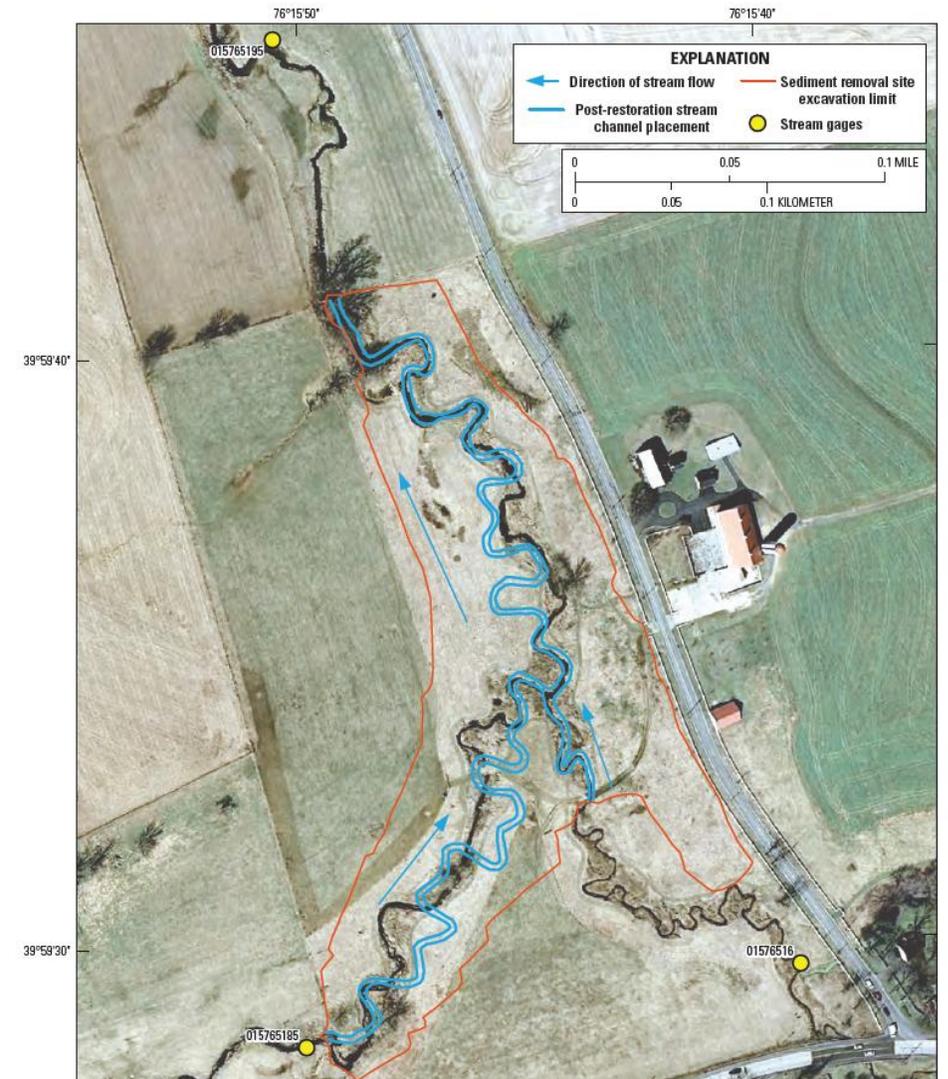


Land Studies, Inc

Big Spring Run - Project Actions

- 22,955 tons of sediment removed
- N removed: 63,670 pound
- P removed: 26,346 pounds
- Wetland restored: 4.7 acres
- Floodplain storage: 13.3 acre-ft

Sources: Langland et al 2020; Forshay et al 2022



Langland et al 2020

Big Spring Run – Project Results

| | Before | After | Change |
|---|--------|-------|--------|
| Suspended Sediment (mg/L) | 556 | 74 | -87% |
| Total Phosphorus (mg/L) | 0.19 | 0.04 | -79% |
| Groundwater ammonia ($\mu\text{g/L}$) | 71.45 | 7.1 | -90% |
| Groundwater nitrate | - | - | -18% |
| Net nitrification | - | - | -50% |

- C limited \rightarrow N limited
- Increased floodplain access + hydrophytic vegetation
- Increased carbon storage

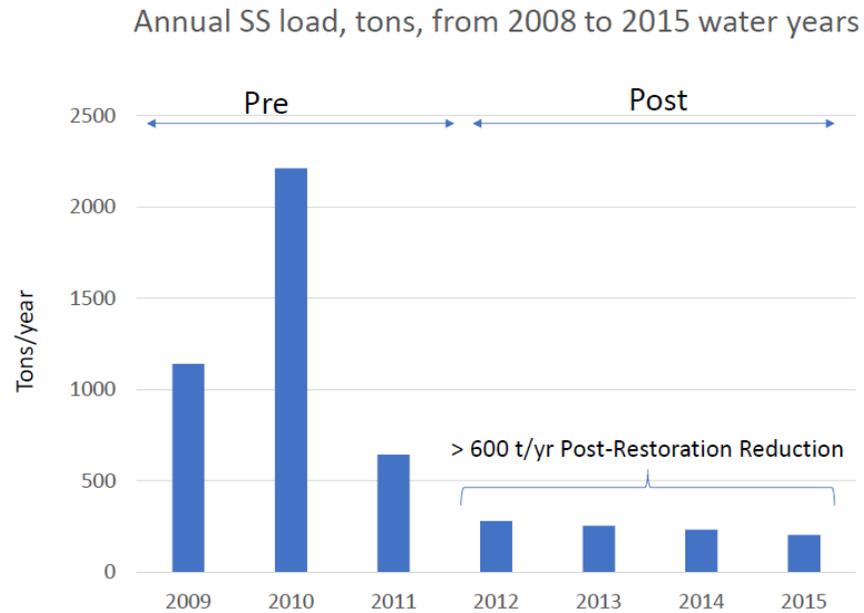


Walter et al 2007

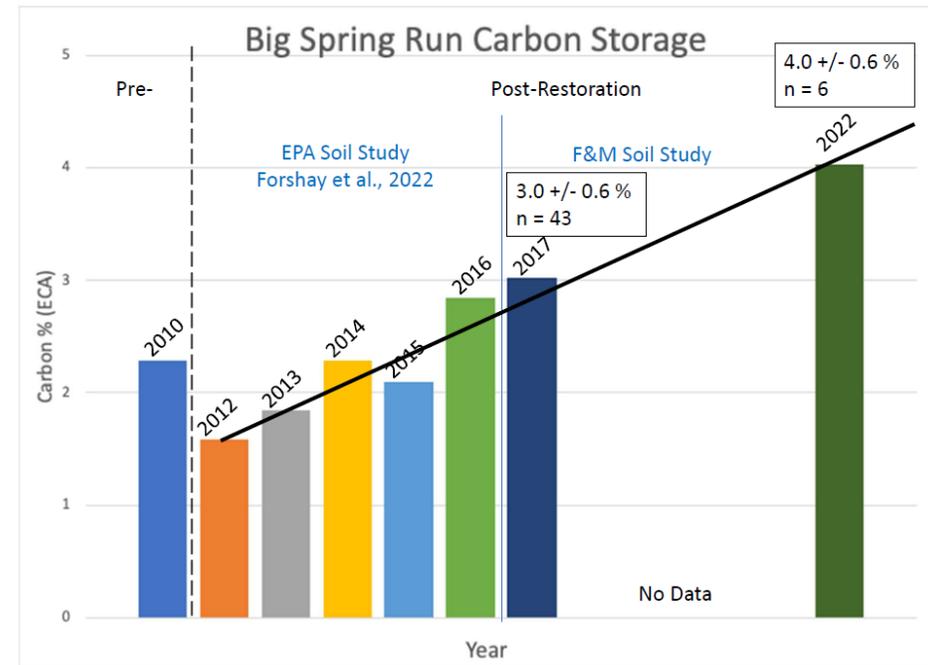


EPA-STAC Workshop 2023

Big Spring Run – Project Results



Langland 2020 USGS Report



EPA-STAC Workshop 2023

Other Projects



Figure 13. Saucon Creek at Saucon Valley Country Club – Before Restoration



EPA-STAC 2013



Figure 3. Approximately 1 meter of sandy fine sediment deposited over the valley bottom was excavated to expose pre-settlement gravel. Logs were placed over gravel and were at least partially buried to provide grade control across the valley bottom and to provide habitat wherever they were exposed by stream flow.



Figure 4. Slabcamp Creek restored valley bottom and channel reestablished on pre-settlement gravels. Photo taken approximately one year after construction.

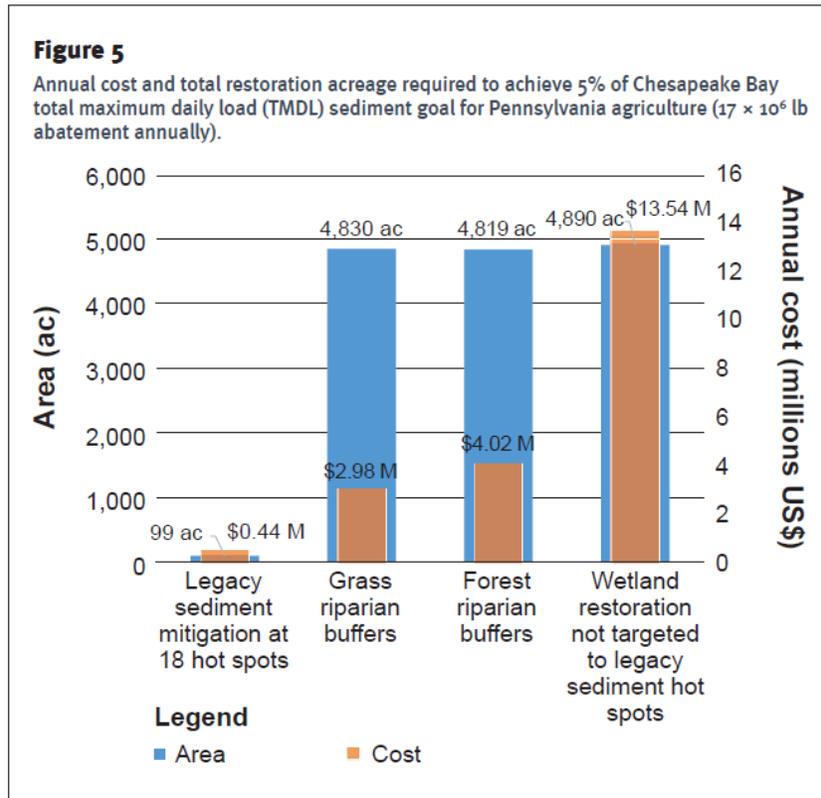
Parola et al 2011

Review of other project results

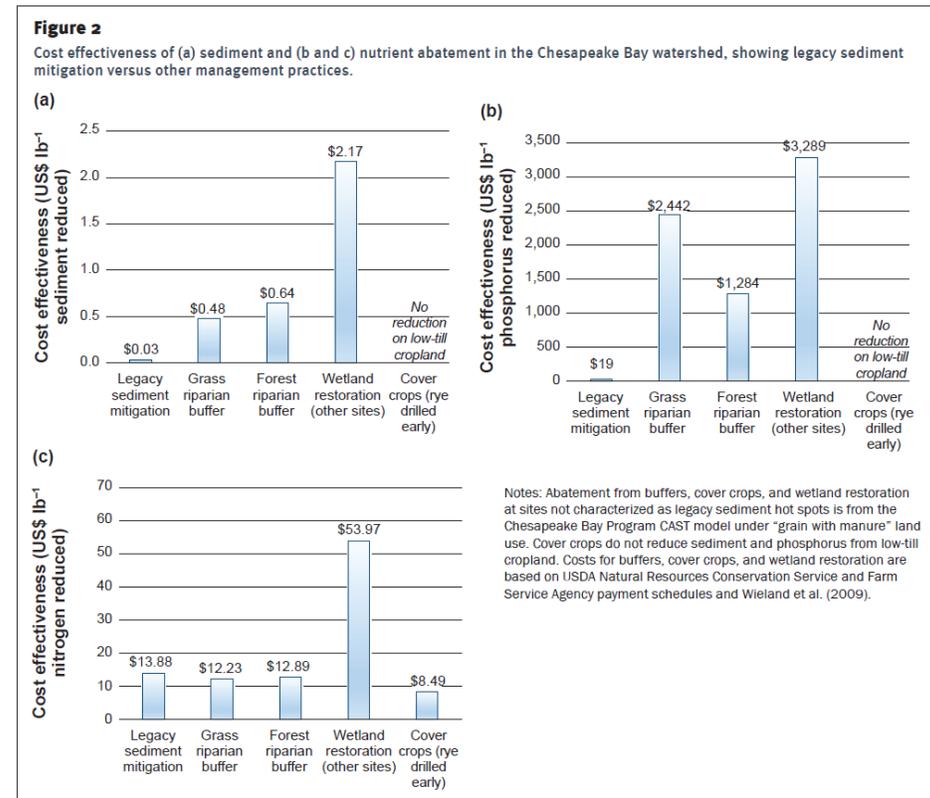
- Denitrification
 - 10x over 3 years
 - Carbon limited → Nitrogen limited
 - Groundwater nitrate decreased
 - Improved by water retention time
 - Sediment / Phosphorus
 - Sediment and total phosphorus reductions
 - Aquatic Organisms
 - 3-4x EPT index
 - 2x fish species diversity
 - Floodplain
 - Increased carbon
 - Increased floodplain access
 - Vegetation
 - Increased hydrophytic vegetation and herbaceous diversity
 - Project Scope
 - Larger projects more effective
 - Negative impacts
 - Decreased woody basal area
 - Construction turbidity
- *Nutrient responses can vary by site, especially surface water Nitrogen

Cost Effectiveness

- High upfront cost, “cheap” annualized cost



Fleming et al 2019



Fleming et al 2019

Chesapeake Bay Credits

- CAST LSR Credit Calculator:
<https://cast.chesapeakebay.net/streamcalculator>
- LSR Eligible for credit under Stream Restoration Protocols:
 1. Prevented sediment
 2. Nutrient processing during baseflow
 3. Floodplain reconnection value

Project Funding

- Nutrient trading for NPDES compliance
- MS4 / TMDL compliance
 - <https://www.conservationfinancenetwork.org/2022/01/24/removing-sediment-to-restore-wetlands-clears-revenue-paths>
- Sell excavated topsoil

Project Pitfalls

- Uncontrolled sediment supply
- Regulatory compliance - improving
- Upfront cost - cheaper annualized
- Removed sediment disposal - nearby farm fields
- Existing wetlands
- Applicability to other physiographic regions?

Next Steps

1. Identify mill dam locations ✓
2. Map erosion and legacy sediment hot spots ✓
3. Create field identification sheet for legacy sediment ✓
4. Identify ideal test sites ✓
5. Sediment sampling for nutrients, pollutants, and geochronology
6. Sediment budgeting
7. Pre-restoration monitoring of project site
8. Site wetland surveys, vegetation surveys
9. Implement LSR and floodplain restoration project
10. Post-restoration monitoring

Monitoring

- Only 6% of stream restoration projects in Chesapeake Bay Watershed have monitoring
- Crucial to understanding LSR effects

Conclusions

- LSR is a powerful tool
- Only one of many
 - upland BMPs still just as if not more important than LSR
- Unlikely to restore “pristine” past
 - but we can restore some function

Recommended Sources

- Stream-wetland complexes
 - A stream evolution model integrating habitat and ecosystem benefits; Cluer and Throne 2014
 - Shifting stream planform state decreases stream productivity yet increases riparian animal production; Venarsky et al 2018
- Beaver effects
 - Beaver-dams as geologic agents; Ruedemann & Schoonmaker 1938
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 - Legacy Sediment: A conceptual model and perspective on the role of dams; Livers & Snyder 2025
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 - Legacies lost and found: Improving stream restoration practices: BSR Restoration monitoring experiment; EPA-STAC Workshop 2023
 - Functional lift of a headwater stream-wetland complex restoration revealed by a decade of environmental and ecological monitoring; Robinson et al 2023
- Beaver, BDA, & LWD based restoration
 - Using beaver dams to restore incised stream ecosystems; Pollock et al 2014
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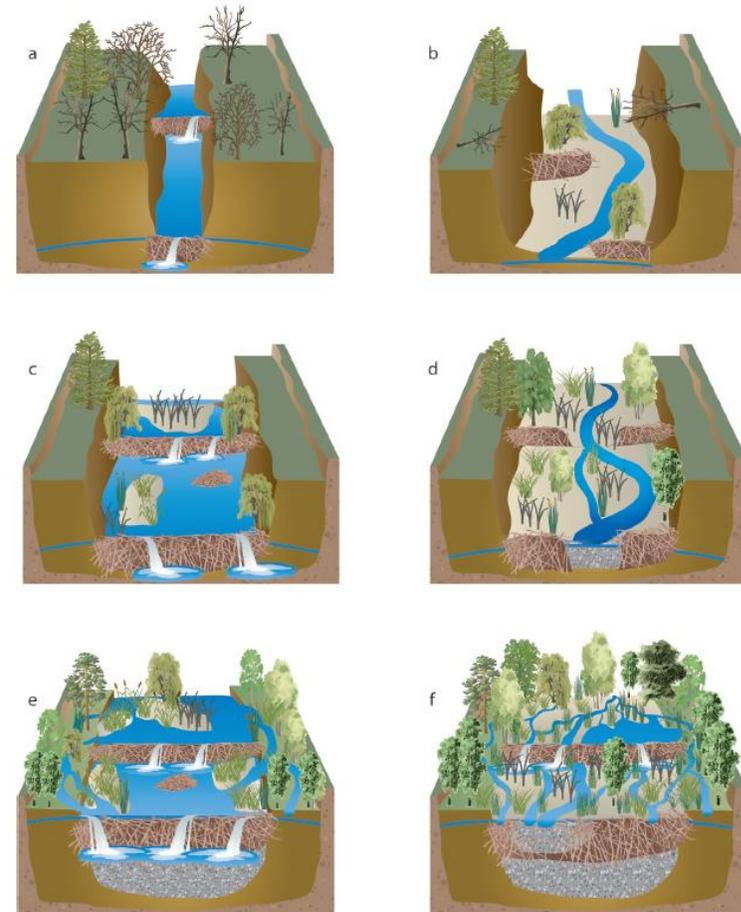
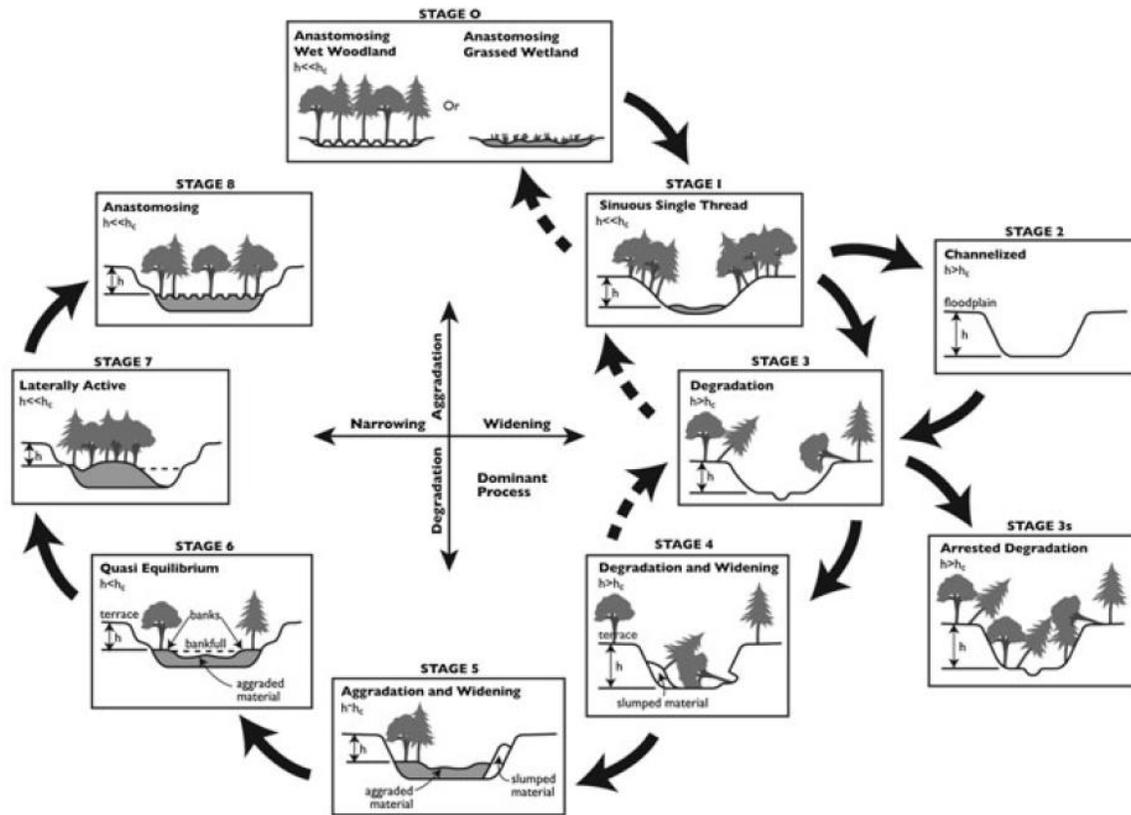
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mertzr@otsegoilandwater.com - contact me for help finding papers and my complete notes on all sources

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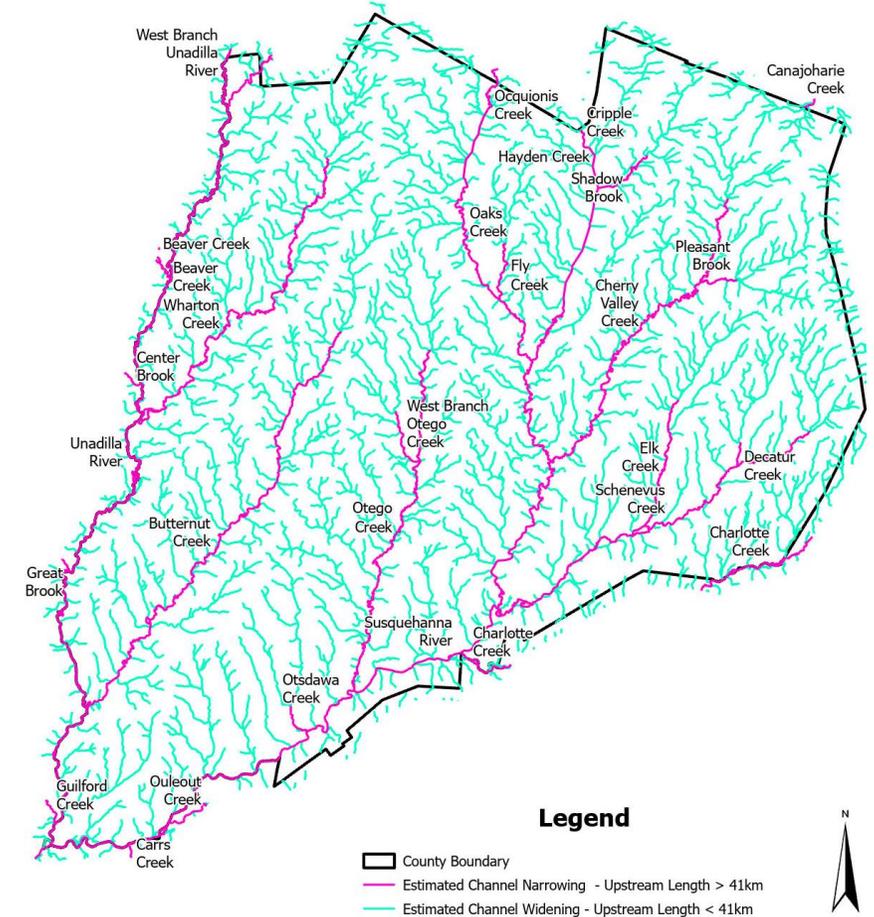
If there's time...

Updated Stream Evolution Model (SEM)

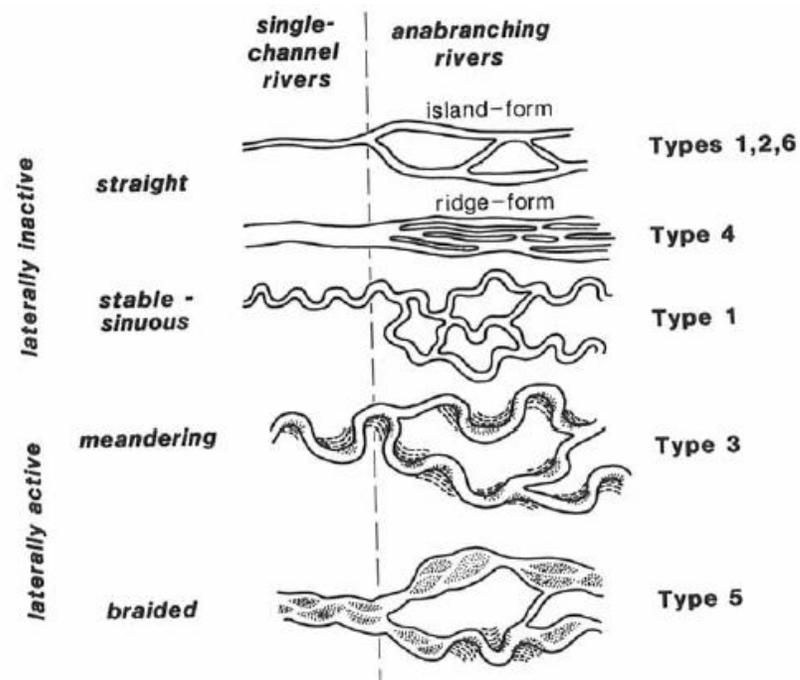


LS Effects on Channel Dimension

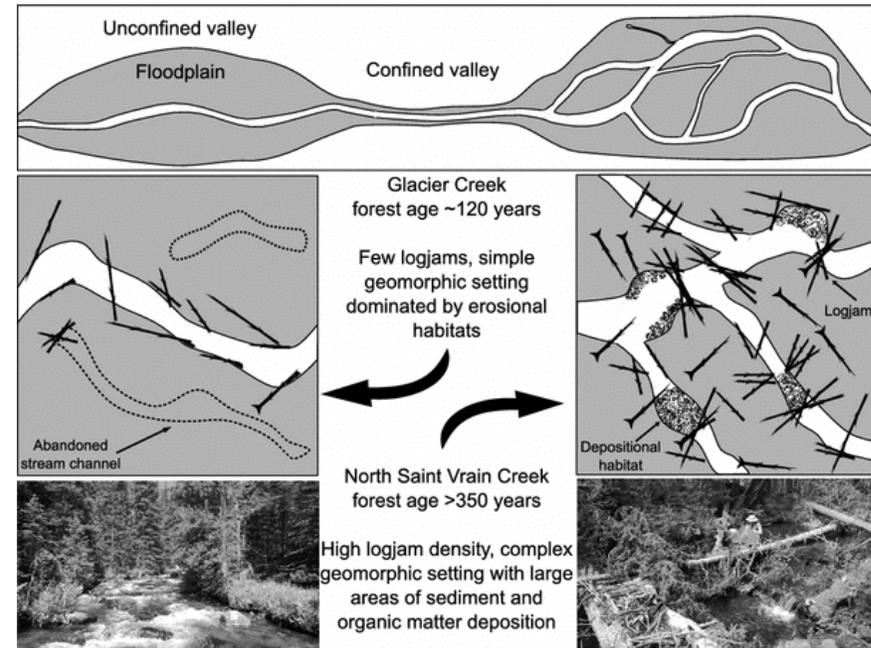
- Low order streams → wider and shallower
 - bedload dominated
- High order streams → narrower and deeper
 - suspended sediment dominated



Anastomosing Streams



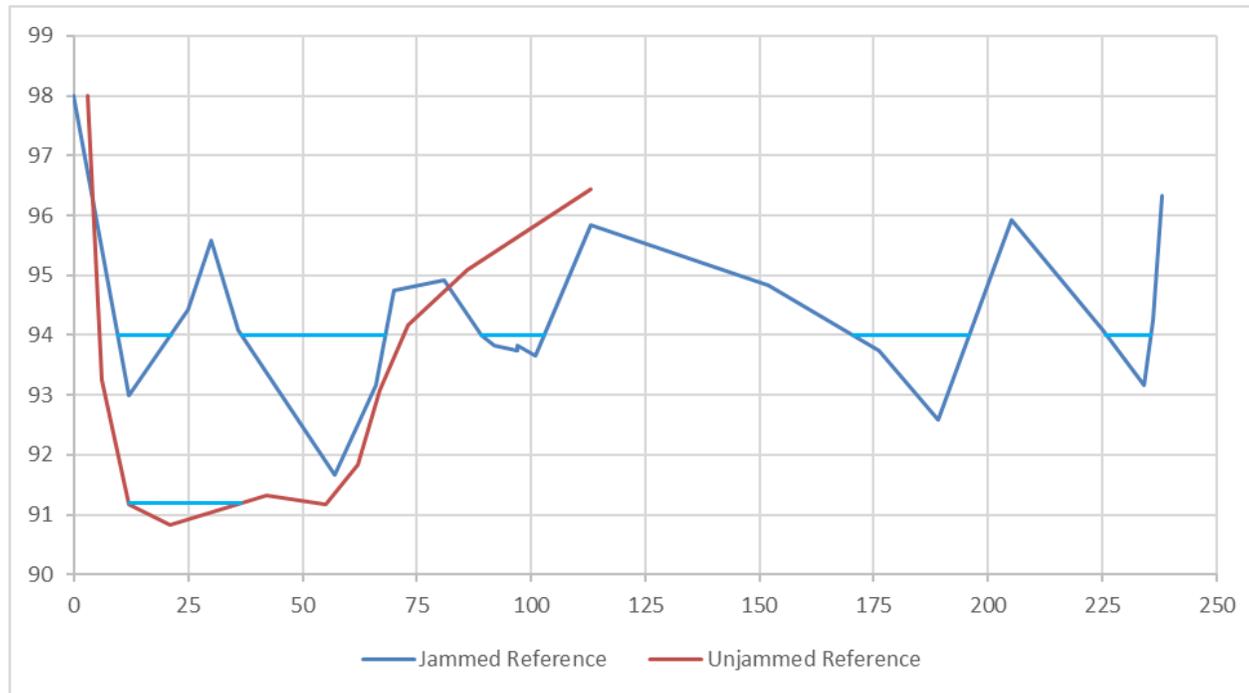
Nanson et al 1996



Venarsky et al 2018

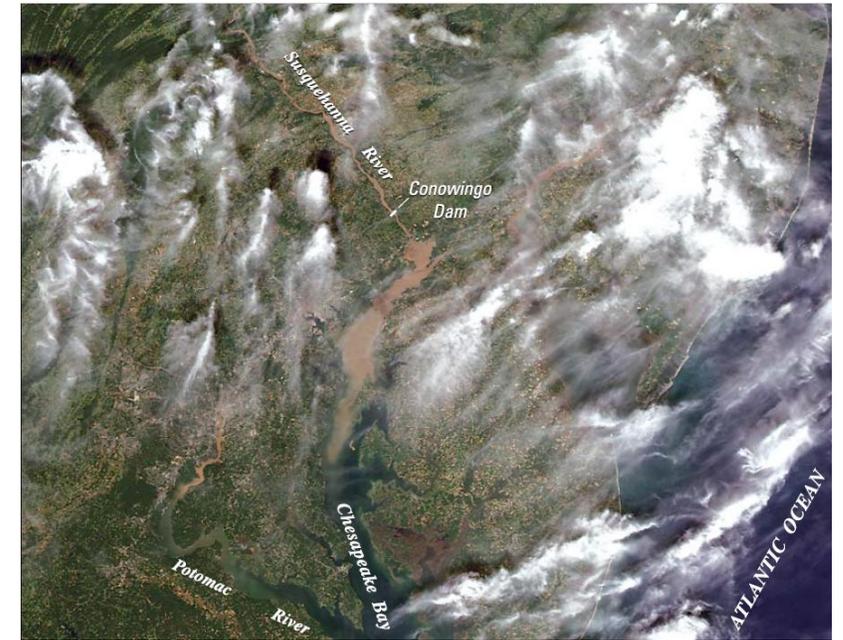
Anastomosing Remnants

- 80+ year-old log-jam on Schenevus Creek

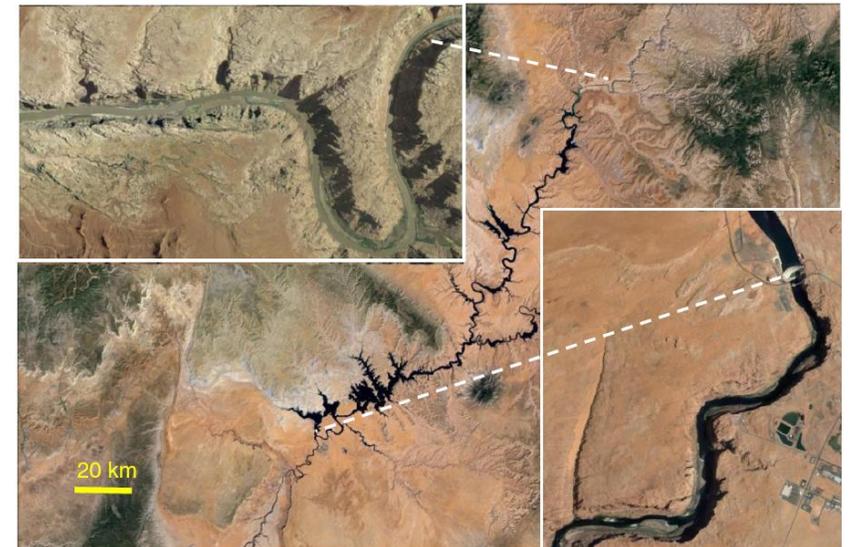


Trapping Efficiency

- Never 100%
- Low-head dams on low order streams have TE of 40-80%
- Multifactorial

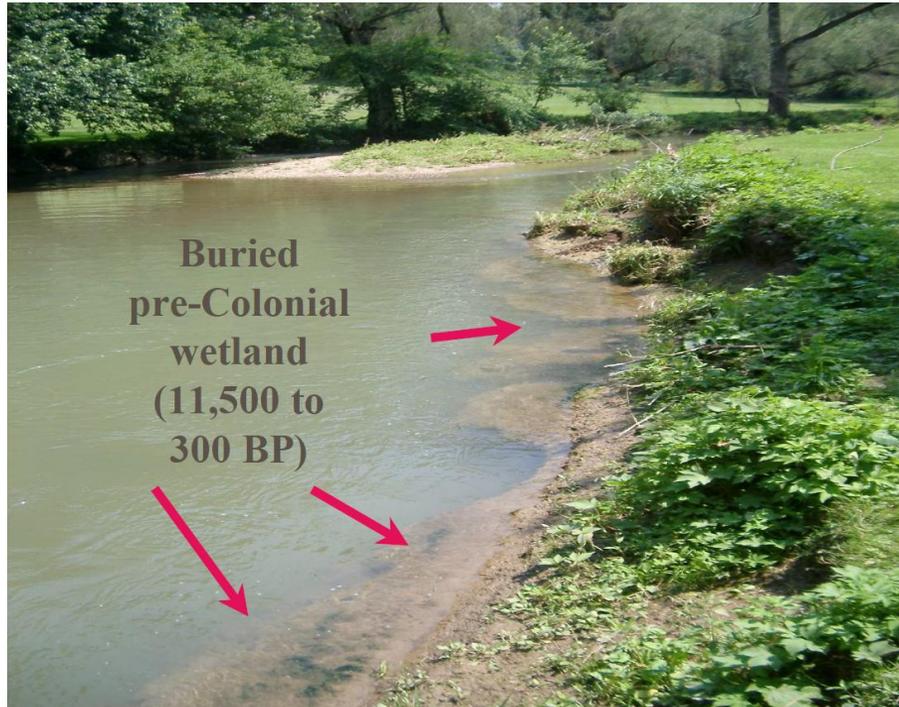


Gellis et al 2005



Gellis et al 2005

Bed mobilization



PA Tributary Strategy Steering Committee 2007



Mertz - Shadow Brook, 2025