Stream Restoration in Maryland

Keith Binsted

Partner - Lead Designer

01/23/2024

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- Keith Binsted – 8 years old
- Aspiring Hydrologist
- Favorite Food: Pizza Bagels

INTRODUCTION

- Keith Binsted – 30 years old
- Underwood & Associates – 100+ projects
    - Partner, Lead Designer: 2019 – present
    - Lead Designer: 2017 - present
    - Restoration Designer: 2015 - 2017
- Metropolitan Washington Council of Governments
    - Watershed Assessment Intern: 2014
- SUNY Environmental Science & Forestry – 2015
    - Bachelors of Environmental Science, Watershed Science focus
    - Minors in Urban Environmental Science, Water Resource Management

ith Underwood & Associates who will be handling the branch restoration, talks about the problem and solutions.

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capitalgazette.com

The Capital

Wednesday, October 25, 2023 A Capital-Gazette Newspaper® — Annapolis, MD $3.50

Pair of projects launched to cut headwater pollution

Years in the making, the plans aim to restore streams feeding the Severn River

By Dana Munro

Sediment plumes from Jabez Branch 3 and Severn Run have been polluting the Severn River.
DAVIS WALLACE

Two related projects, more than 10 years in the making, to restore part of a stream that is polluting the headwaters of the Severn River, began last week.

The first piece of the restoration, on state land, is being overseen by the Maryland Department of Natural Resources, the Resilience Authority of Annapolis and Anne Arundel County, and The Severn Riverkeeper. The second is being managed by the county's Bureau of Watershed Protection and Restoration and is on county property.

The project on the state-owned part of the stream, the Jabez Branch 3 of the Jabez Branch Waterway, is being paid for with $7.4 million in state money from the Chesapeake and Atlantic Coastal Bays Trust Fund.

The fund is financed mostly with dollars from rental car taxes, said Gabe Cohee, director of the Office of Resilience and Restoration in the Chesapeake and Coastal Service at the Department of Natural Resources. The county project will be funded by approximately $2 million of county money. The work will be the same, but will take place directly upstream of the state property.

The contractor for the projects, Underwood and Associates, will start working on the stream in December and the work is expected to take several months. Workers will essentially aim to restore this section of the stream to its original state, before the area was heavily developed and Interstate 97 was built. Runoff from an I-97 exit has caused severe erosion.

Pollution at the Severn River headwaters is caused by the Jabez Branch 3 stream, which feeds into the Jabez Branch Waterway, which in turn feeds into Severn Run and the Severn River.

The amount of runoff has increased with development in the Gambrills and Millersville area and has gouged a more than 10-foot-deep indentation in some parts of the tributary.

That deep channel funnels water carrying large quantities of sediment into the river. That sediment carries nitrogen and phosphorus, which lead to algae blooms and underwater bacteria that deplete the water's oxygen levels. The process has devastated the headwaters' yellow perch population, said Fred Kelly, executive director of The Severn Riverkeeper.

The contractor will strategically fill the eroded tributary with sand and gravel and create a channel within it that will gradually lead the water back up to the flood plain and

Turn to Stream, *Page 7*

INTRODUCTION

Underwood & Associates

- Established 1990
- Inventor & Patent holder of Regenerative Stream Channel (RSC)
- 1,000+ ecosystem restoration projects of varying size and complexity
  - Stream-Wetland Complex Restoration
  - Nature-based Stormwater Retrofits
  - Dynamic Living Shorelines

For more information, visit:

https://www.ecosystemrestoration.com/aboutus

SCAN ME

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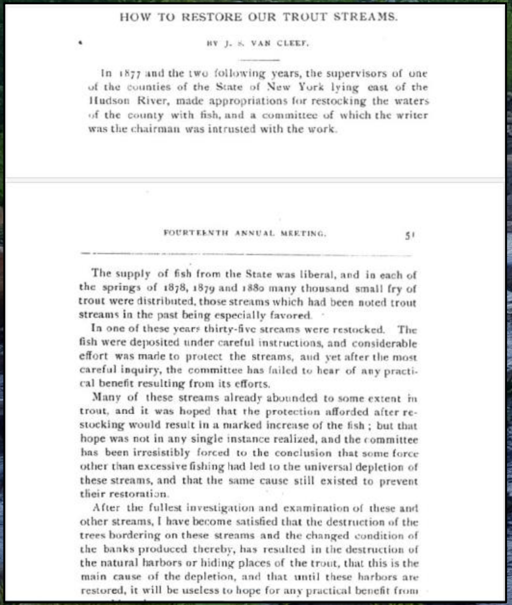
CREDITS & REFERENCES

1877	**J.S. Van Cleef**	How to Restore Our Trout Streams
1952	**US Forest Service**	Handbook on Improving Stream Habitat
1964	**Leopold, Wolman & Miller**	Fluvial Processes in Geomorphology
1972	**CWA**	
1998	**Rosgen**	A Geomorphological Approach to Restoration of Incised Rivers
2008	**Craig & Palmer**	Stream Restoration Strategies for Reducing River Nitrogen Loads
2008	**Walter & Merritts**	Natural Streams and the Legacy of Water-Powered Mills
2013	**Cluer & Thorne**	A Stream Evolution Model Integrating Habitat and Ecosystem Benefits
2015	**Smith & Wilcock**	Upland sediment supply and its relation to watershed sediment delivery in the contemporary mid-Atlantic Piedmont
2021	**Wohl, et.al**	Rediscovering, Reevaluating, and Restoring Lost River-Wetland Corridors



HOW TO RESTORE OUR TROUT STREAMS.

BY J. S. VAN CLEEF.

In 1877 and the two following years, the supervisors of one of the counties of the State of New York lying east of the Hudson River, made appropriations for restocking the waters of the county with fish, and a committee of which the writer was the chairman was intrusted with the work.

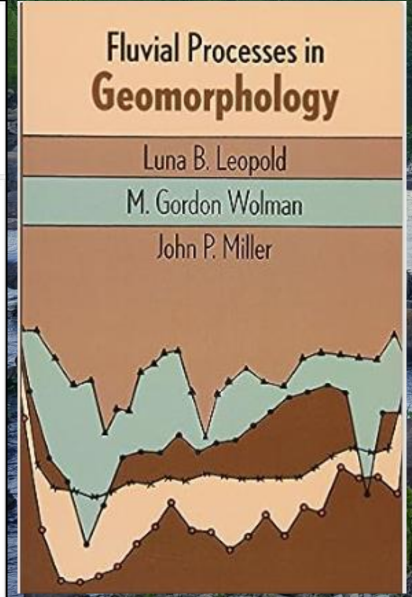
FOURTEENTH ANNUAL MEETING. 51

The supply of fish from the State was liberal, and in each of the springs of 1878, 1879 and 1880 many thousand small fry of trout were distributed, those streams which had been noted trout streams in the past being especially favored.

In one of these years thirty-five streams were restocked. The fish were deposited under careful instructions, and considerable effort was made to protect the streams, and yet after the most careful inquiry, the committee has failed to hear of any practical benefit resulting from its efforts.

Many of these streams already abounded to some extent in trout, and it was hoped that the protection afforded after restocking would result in a marked increase of the fish; but that hope was not in any single instance realized, and the committee has been irresistibly forced to the conclusion that some force other than excessive fishing had led to the universal depletion of these streams, and that the same cause still existed to prevent their restoration.

After the fullest investigation and examination of these and other streams, I have become satisfied that the destruction of the trees bordering on these streams and the changed condition of the banks produced thereby, has resulted in the destruction of the natural harbors or hiding places of the trout, that this is the main cause of the depletion, and that until these harbors are restored, it will be useless to hope for any practical benefit from

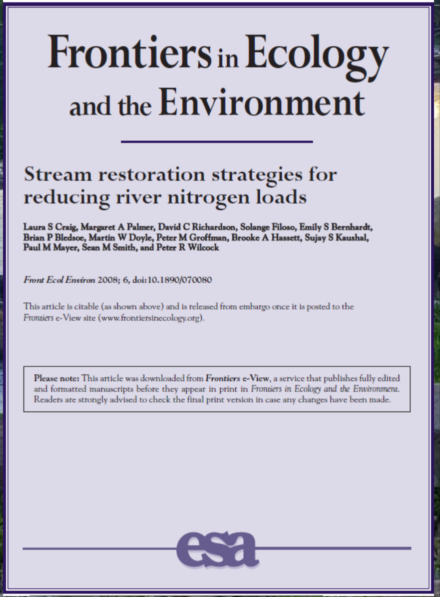


Fluvial Processes in Geomorphology

Luna B. Leopold

M. Gordon Wolman

John P. Miller



Frontiers in Ecology and the Environment

Stream restoration strategies for reducing river nitrogen loads

Laura S Craig, Margaret A Palmer, David C Richardson, Solange Filoso, Emily S Bernhardt, Brian P Bledsoe, Martin W Doyle, Peter M Groffman, Brooke A Hassett, Sujay S Kaushal, Paul M Mayer, Sean M Smith, and Peter R Wilcock

Front Ecol Environ 2008; 6, doi:10.1890/070080

This article is citable (as shown above) and is released from embargo once it is posted to the *Frontiers* e-View site (www.frontiersinecology.org).

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Natural Streams and the Legacy of Water-Powered Mills

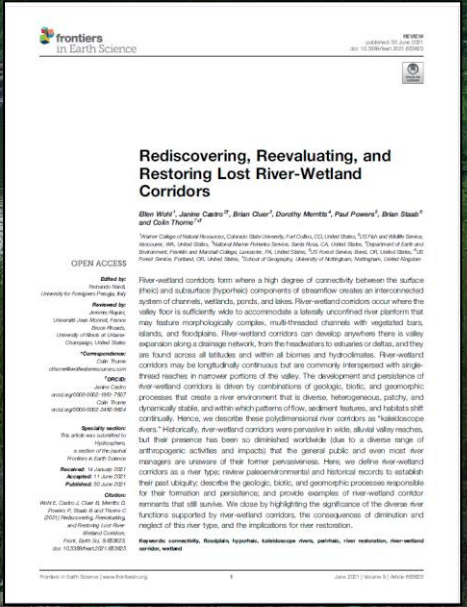
ROBERT C. WALTER AND DOROTHY J. MERRITTS Authors Info & Affiliations

SCIENCE • 18 Jan 2008 • Vol 319, Issue 5861 • pp. 299-304 • DOI: 10.1126/science.1151716

Abstract

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

toc/science/381/6659 hetypes for meandering streams.



frontiers in Earth Science

REVIEW

OPEN ACCESS

Rediscovering, Reevaluating, and Restoring Lost River-Wetland Corridors

Ellen Wohl[1], Janine Castro[2], Brian Cluer[3], Dorothy Merritts[4], Paul Powers[5], Brian Staab[6] and Colin Thorne[7]

CREDITS & REFERENCES

Slide adapted from:

Finding Common Ground to Promote Holistic Restoration Approaches in the Coastal Plain

Kevin Smith – National Stream Restoration Conference 2023

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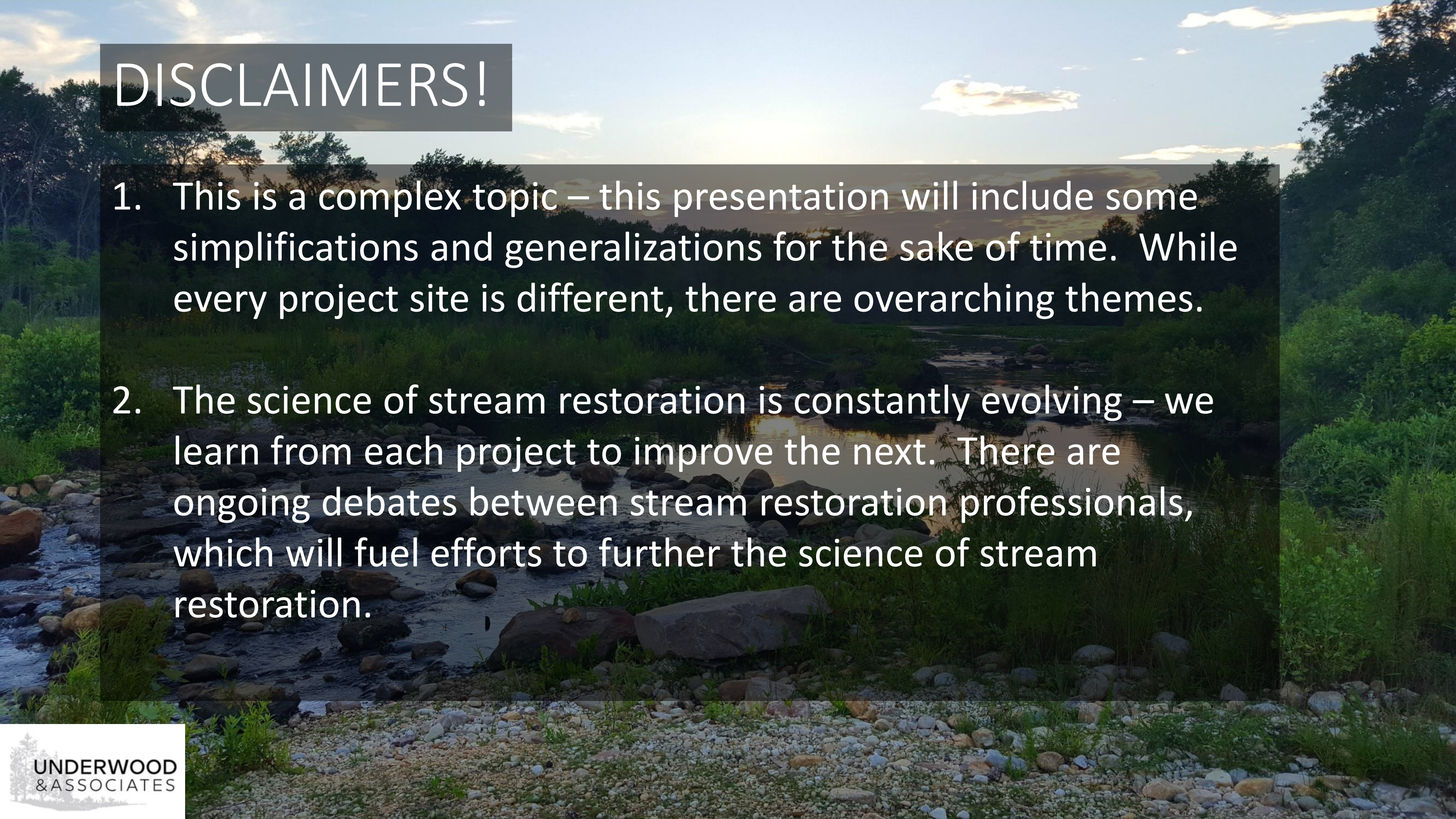
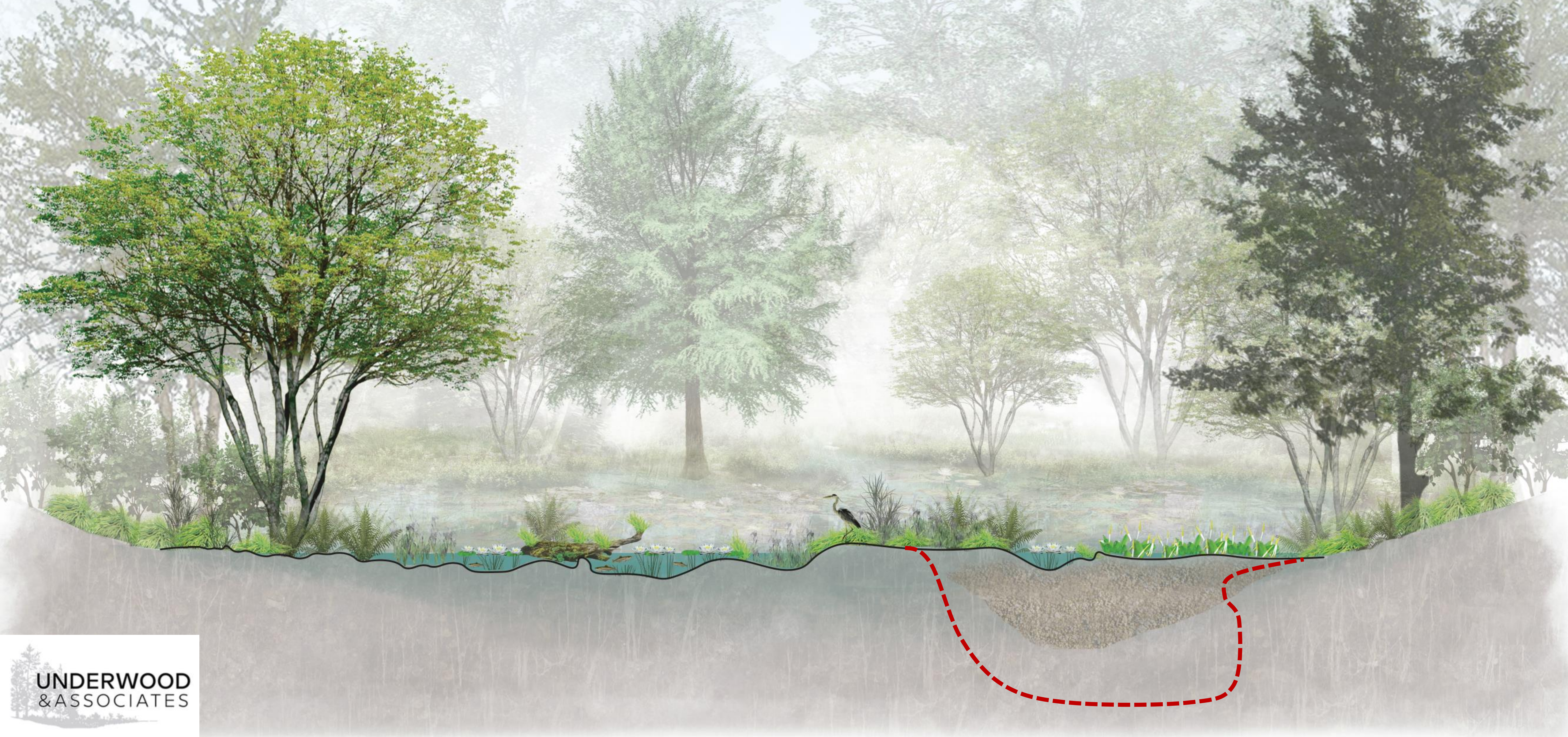


DISCLAIMERS!

1. This is a complex topic – this presentation will include some simplifications and generalizations for the sake of time. While every project site is different, there are overarching themes.

2. The science of stream restoration is constantly evolving – we learn from each project to improve the next. There are ongoing debates between stream restoration professionals, which will fuel efforts to further the science of stream restoration.

WHAT IS STREAM RESTORATION?



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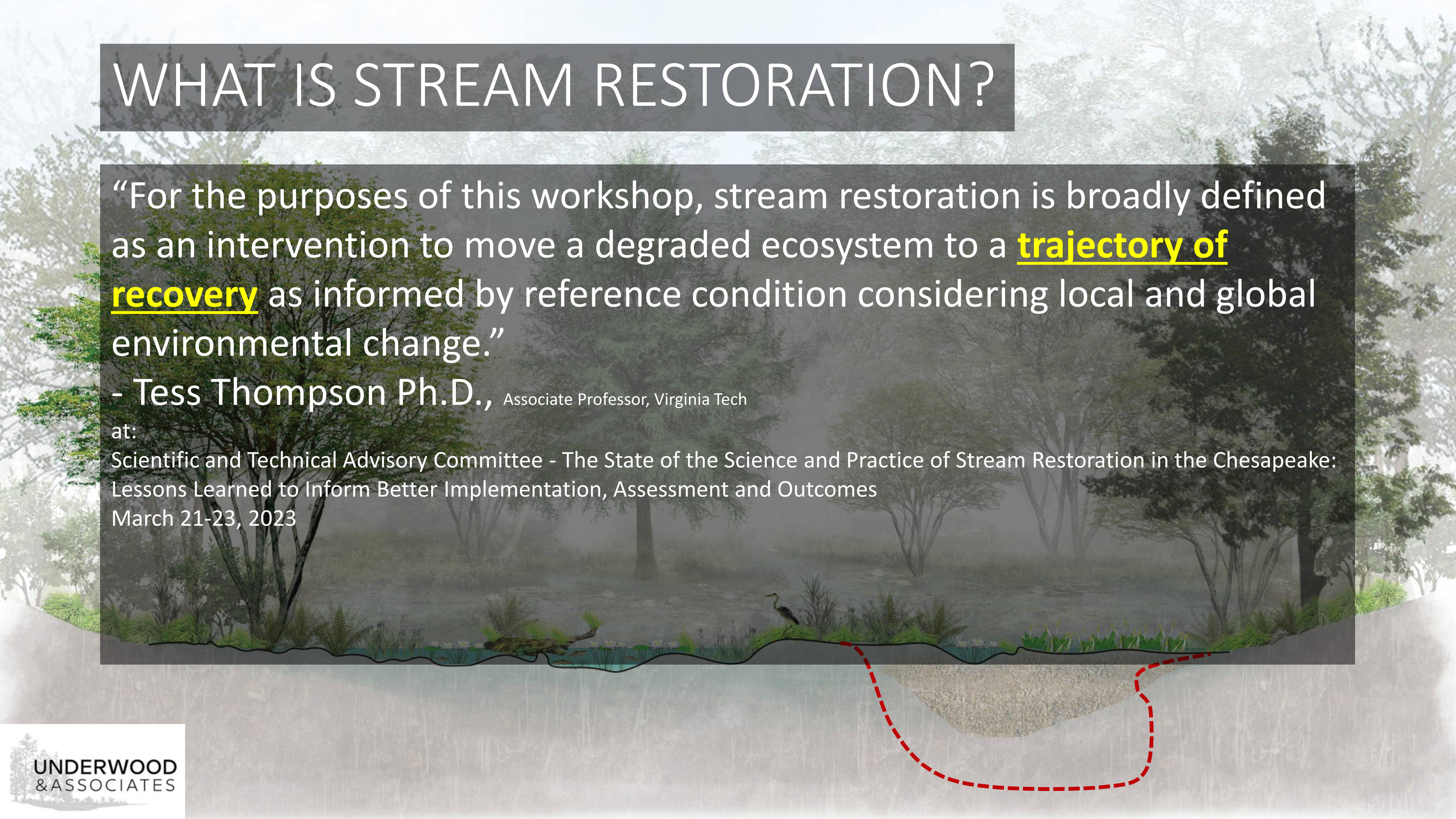
WHAT IS STREAM RESTORATION?



"For the purposes of this workshop, stream restoration is broadly defined as an intervention to move a degraded ecosystem to a **trajectory of recovery** as informed by reference condition considering local and global environmental change."

- Tess Thompson Ph.D., Associate Professor, Virginia Tech

at:
Scientific and Technical Advisory Committee - The State of the Science and Practice of Stream Restoration in the Chesapeake: Lessons Learned to Inform Better Implementation, Assessment and Outcomes
March 21-23, 2023

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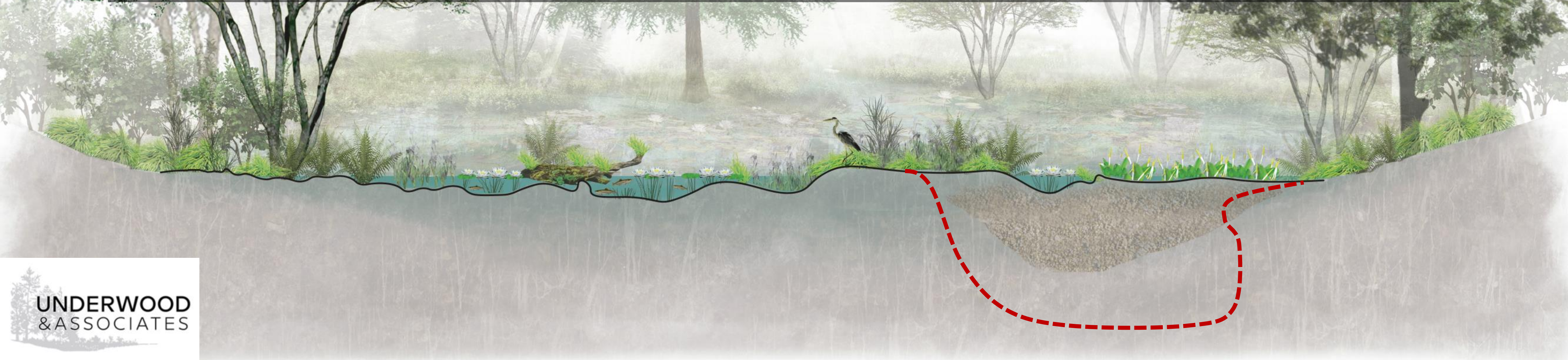
WHAT IS STREAM RESTORATION?

"The manipulation of the physical, chemical and biological characteristics of a site with the goal of returning **natural/historic functions** to a former or degraded aquatic resource."

from:
Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012.
A Function-Based Framework for Stream Assessment and Restoration Projects. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC
EPA 843-K-12-006.



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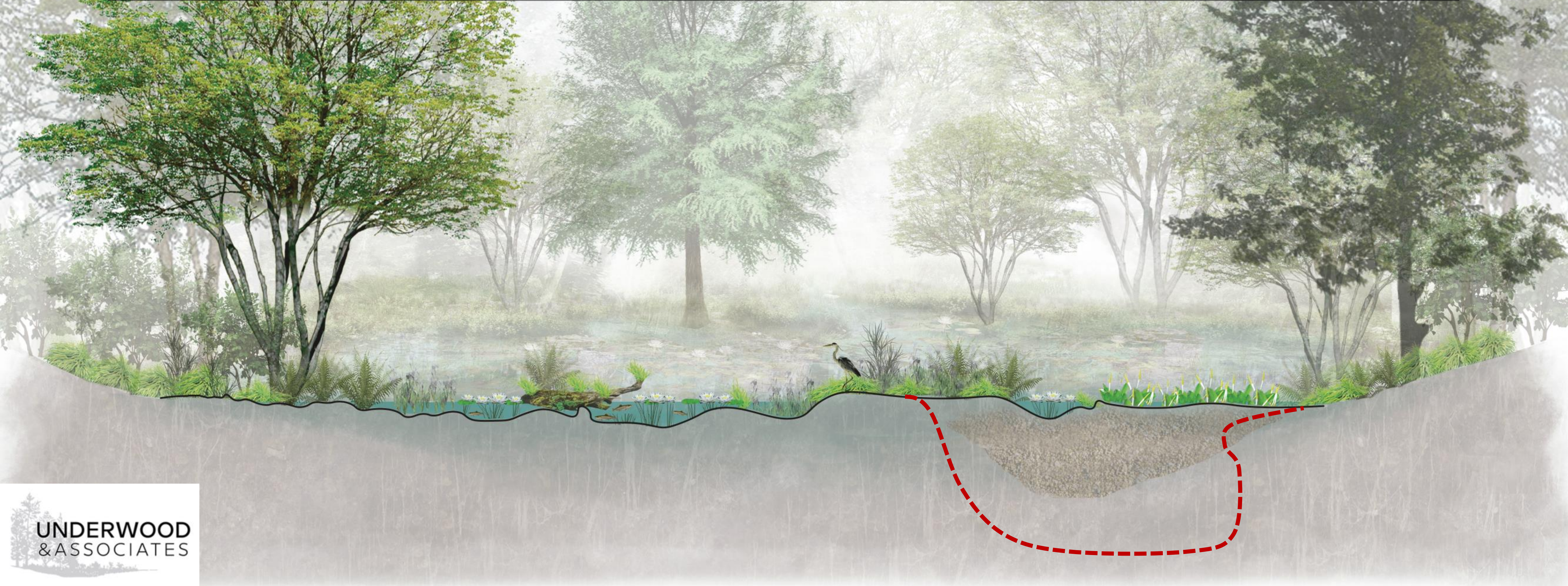
WHAT IS STREAM RESTORATION?

Reconnection of streambed and floodplain to **slow** water down, **spread** it out, and **soak** it in.



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WHAT IS NOT STREAM RESTORATION?

Concrete retaining walls

Block walls

Stone bank armoring

NEVER
Gabions, Dumped rip-rap, Sheet piling/planking, Geogrid/concrete/gabion mattresses, Non-biodegradable soil stabilization mats/systems

RESTRICTED
Imbricated rip rap, berm/pool cascades, boulder revetments

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WHY RESTORE STREAMS?

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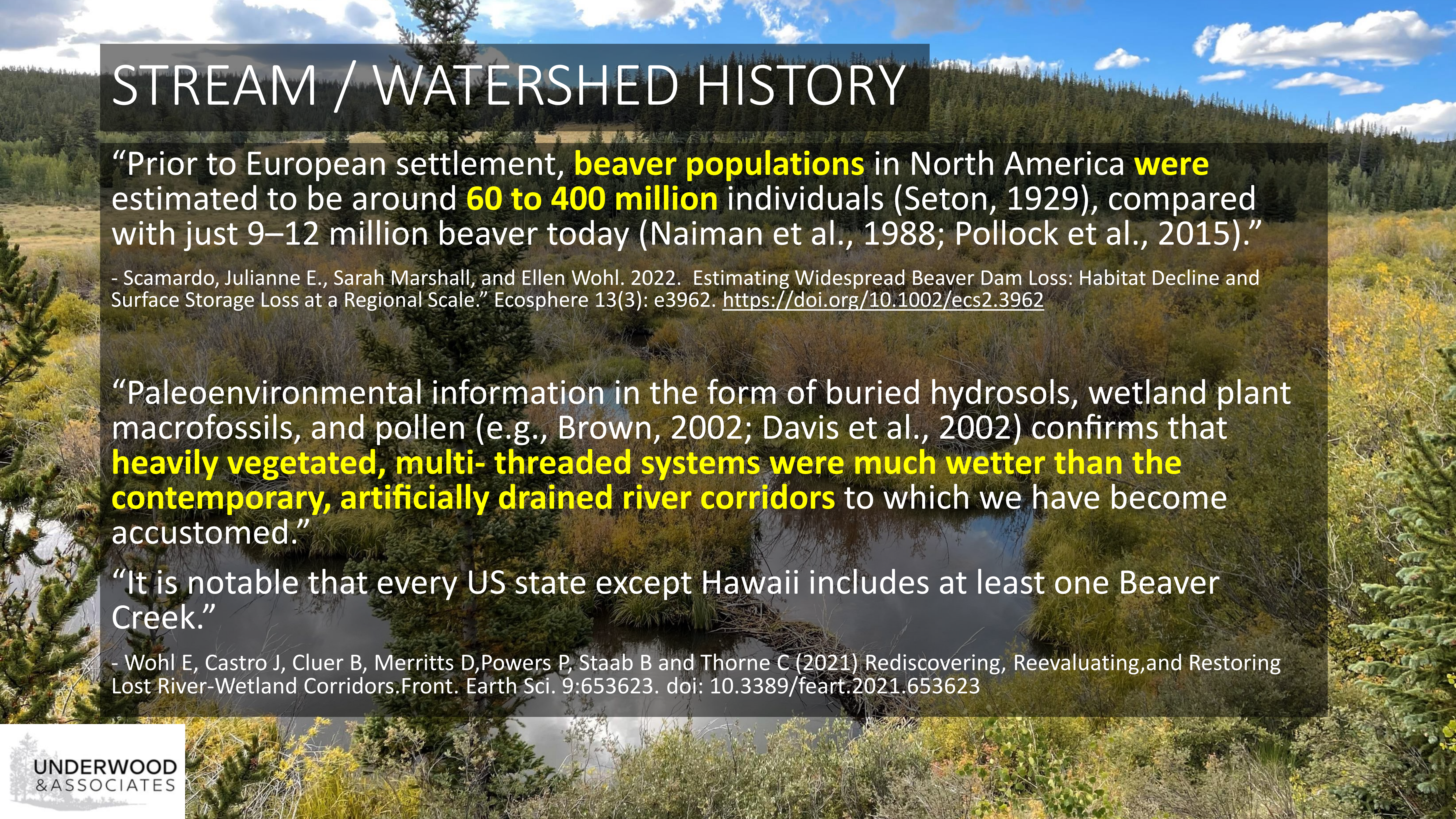
STREAM / WATERSHED HISTORY



“Prior to European settlement, **beaver populations** in North America **were** estimated to be around **60 to 400 million** individuals (Seton, 1929), compared with just 9–12 million beaver today (Naiman et al., 1988; Pollock et al., 2015).”

- Scamardo, Julianne E., Sarah Marshall, and Ellen Wohl. 2022. Estimating Widespread Beaver Dam Loss: Habitat Decline and Surface Storage Loss at a Regional Scale.” Ecosphere 13(3): e3962. https://doi.org/10.1002/ecs2.3962

“Paleoenvironmental information in the form of buried hydrosols, wetland plant macrofossils, and pollen (e.g., Brown, 2002; Davis et al., 2002) confirms that **heavily vegetated, multi- threaded systems were much wetter than the contemporary, artificially drained river corridors** to which we have become accustomed.”

“It is notable that every US state except Hawaii includes at least one Beaver Creek.”

- Wohl E, Castro J, Cluer B, Merritts D,Powers P, Staab B and Thorne C (2021) Rediscovering, Reevaluating,and Restoring Lost River-Wetland Corridors.Front. Earth Sci. 9:653623. doi: 10.3389/feart.2021.653623

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STREAM / WATERSHED HISTORY

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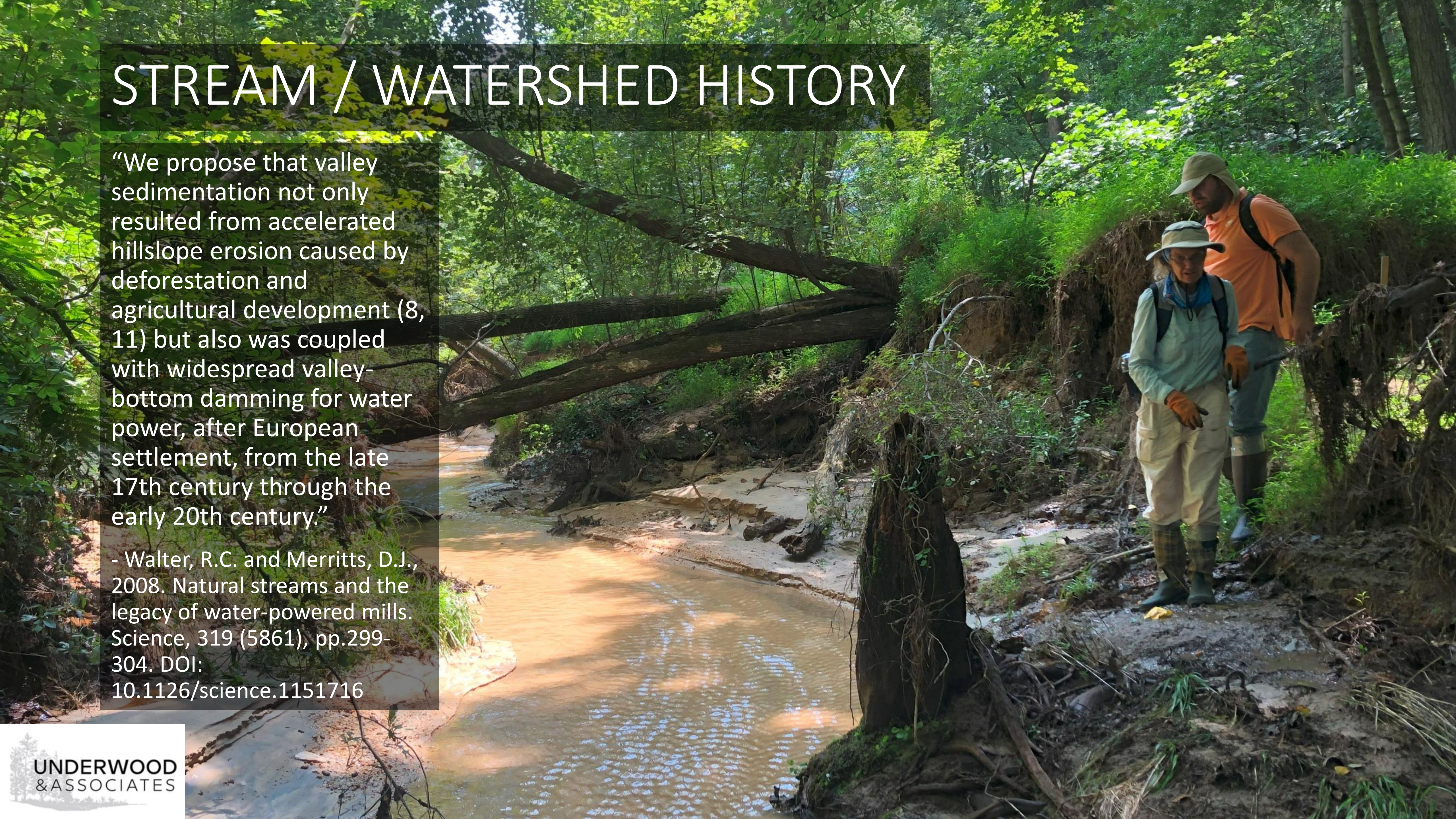
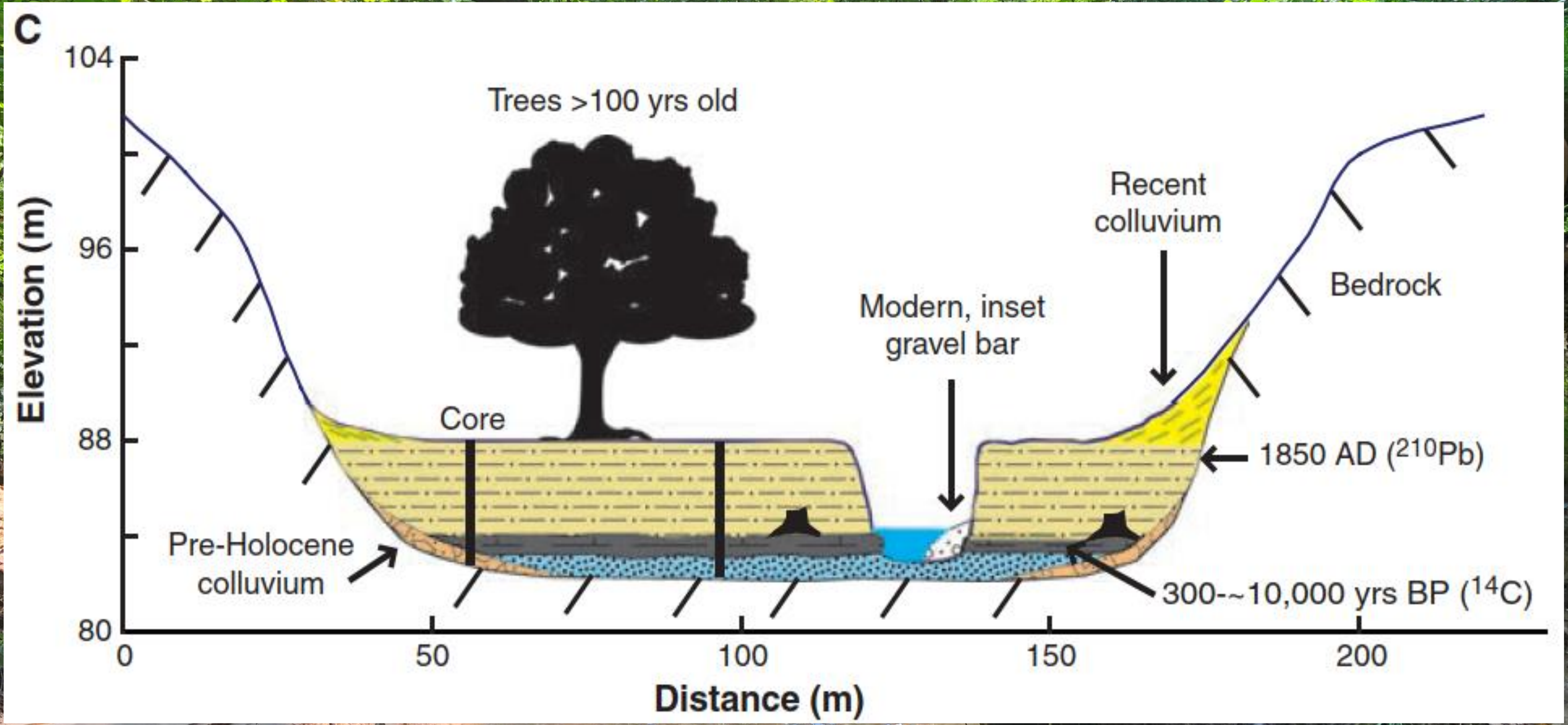
STREAM / WATERSHED HISTORY



> “We propose that valley sedimentation not only resulted from accelerated hillslope erosion caused by deforestation and agricultural development (8, 11) but also was coupled with widespread valley-bottom damming for water power, after European settlement, from the late 17th century through the early 20th century.”

- Walter, R.C. and Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. Science, 319 (5861), pp.299-304. DOI: 10.1126/science.1151716

STREAM / WATERSHED HISTORY



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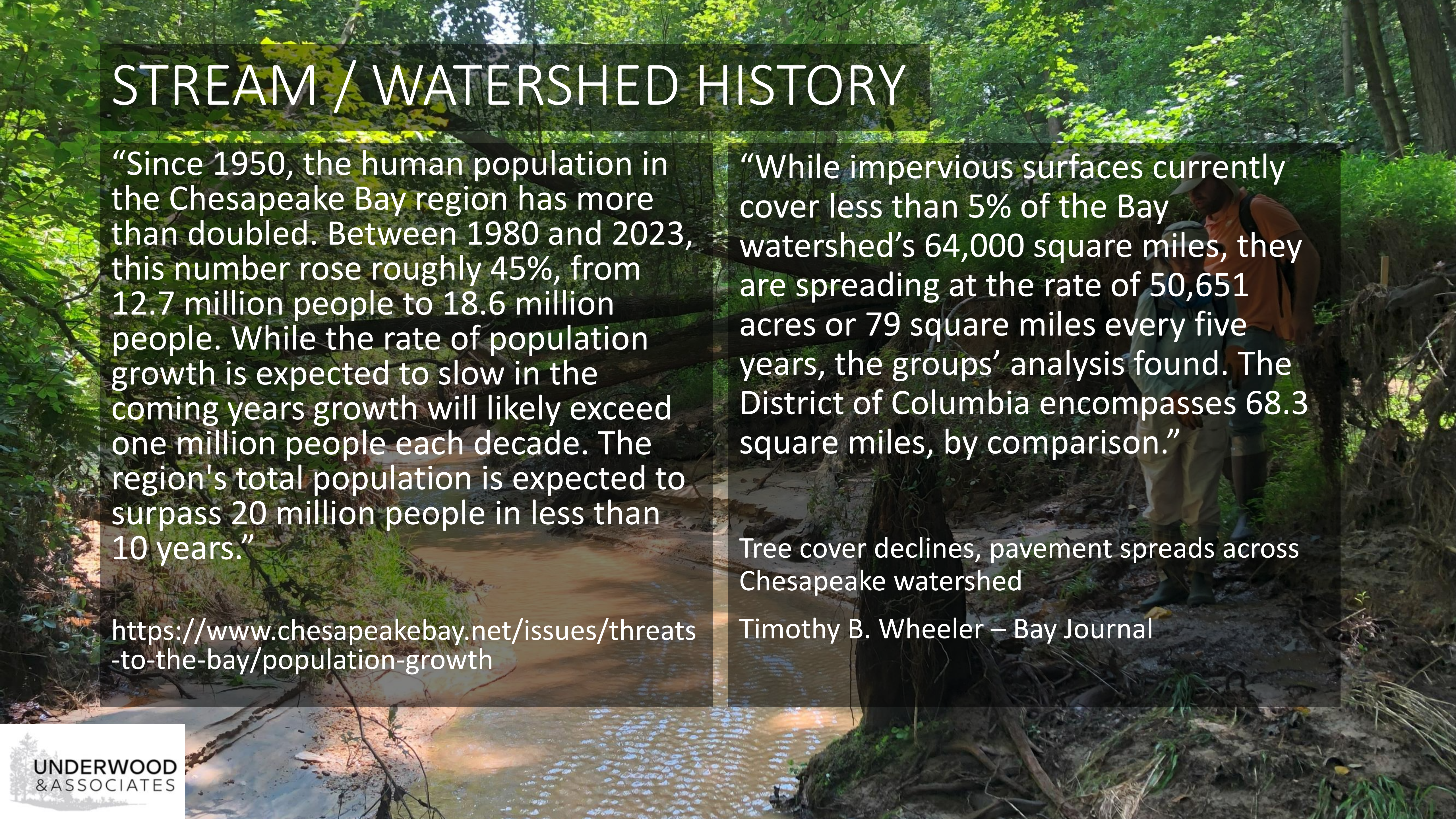


STREAM / WATERSHED HISTORY

“Since 1950, the human population in the Chesapeake Bay region has more than doubled. Between 1980 and 2023, this number rose roughly 45%, from 12.7 million people to 18.6 million people. While the rate of population growth is expected to slow in the coming years growth will likely exceed one million people each decade. The region's total population is expected to surpass 20 million people in less than 10 years.”

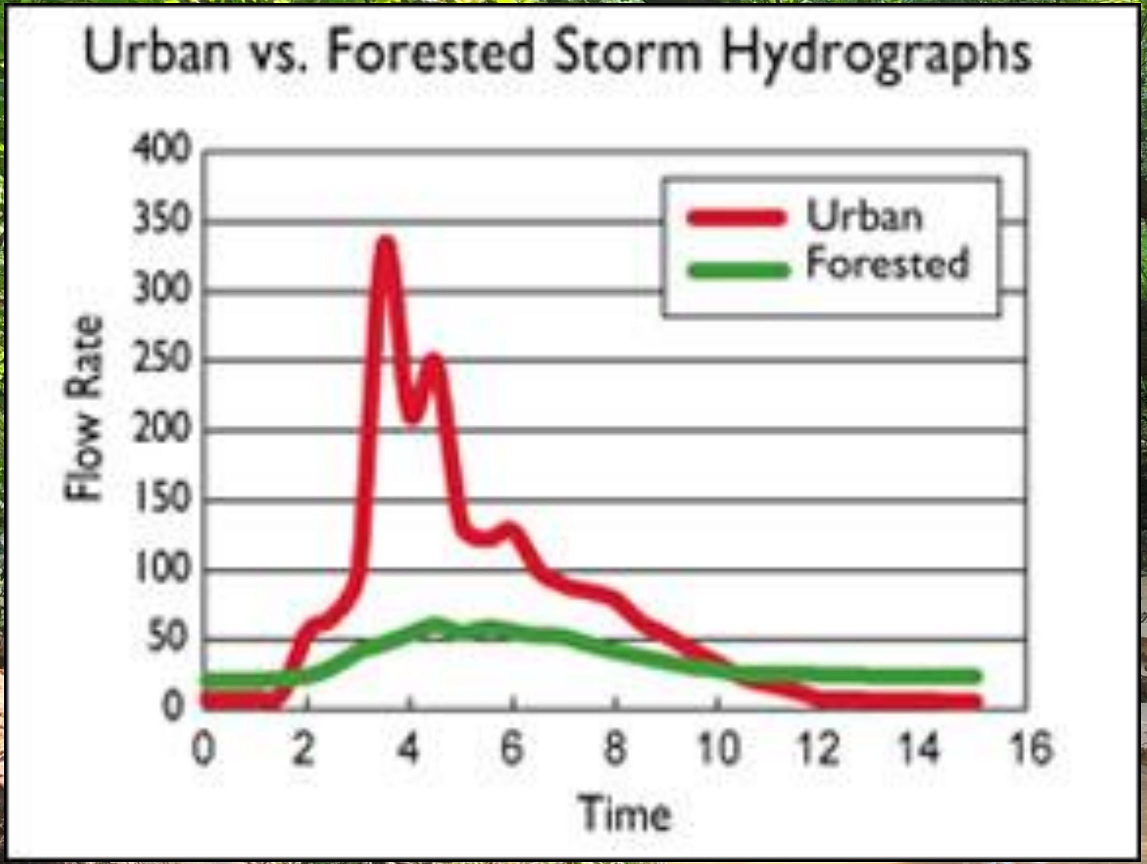
https://www.chesapeakebay.net/issues/threats-to-the-bay/population-growth

“While impervious surfaces currently cover less than 5% of the Bay watershed’s 64,000 square miles, they are spreading at the rate of 50,651 acres or 79 square miles every five years, the groups’ analysis found. The District of Columbia encompasses 68.3 square miles, by comparison.”

Tree cover declines, pavement spreads across Chesapeake watershed

Timothy B. Wheeler – Bay Journal

STREAM / WATERSHED HISTORY



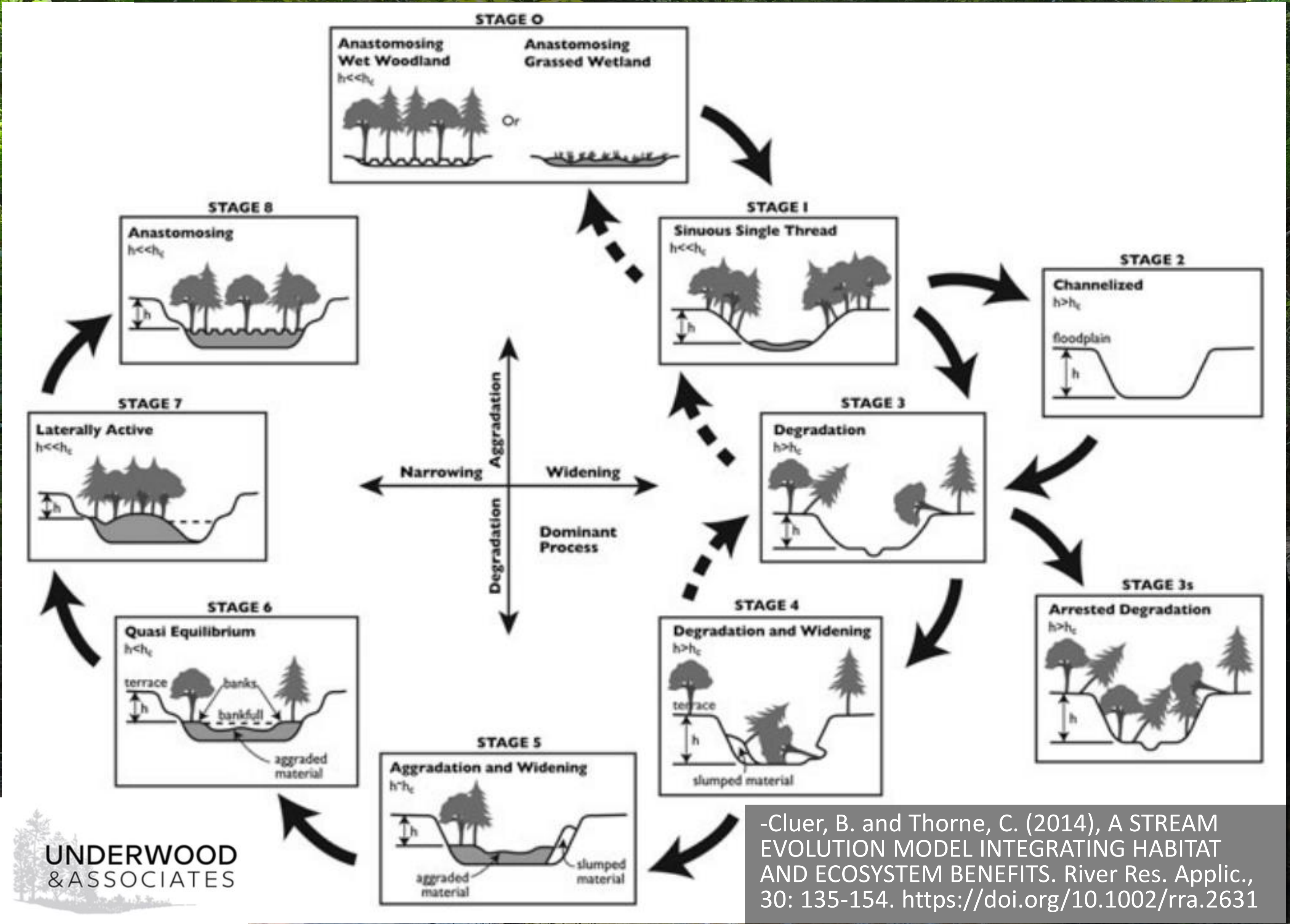
Storm hydrographs by Ken Belt

From: https://www.chesapeakequarterly.net/V07N2/side1/

“Changes to hydrographs are perhaps the most obvious and consistent changes to stream ecosystems influenced by urban land use, with urban streams tending to be more ‘‘flashy’’, i.e., **they have more frequent, larger flow events with faster ascending and descending limbs of the hydrograph**. The primary driver of these changes occurs from a combined effect of increased areas of impervious surfaces and more efficient transport of runoff from impervious surfaces by piped stormwater drainage systems (Dunne and Leopold 1978, Fig. 1).”

- Walsh, C. J., A. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. The urban stream syndrome: current knowledge and the search for a cure. P. Silver (ed.), Journal of the north american benthological society. North american benthological society, Lawrence, KS, 24(3):706-723, (2005).

STREAM / WATERSHED HISTORY



-Cluer, B. and Thorne, C. (2014), A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS. River Res. Applic., 30: 135-154. https://doi.org/10.1002/rra.2631

In summary

1. Slow & wide stream-wetland complexes were much more abundant
2. These streams-wetland complexes were buried by sediment-laden runoff
3. Increases in impervious surfaces and drainage result in increased peak flows.

   --------You are here--------
4. The stream channel reacts to the higher peak flow conditions, thus deepening and widening.

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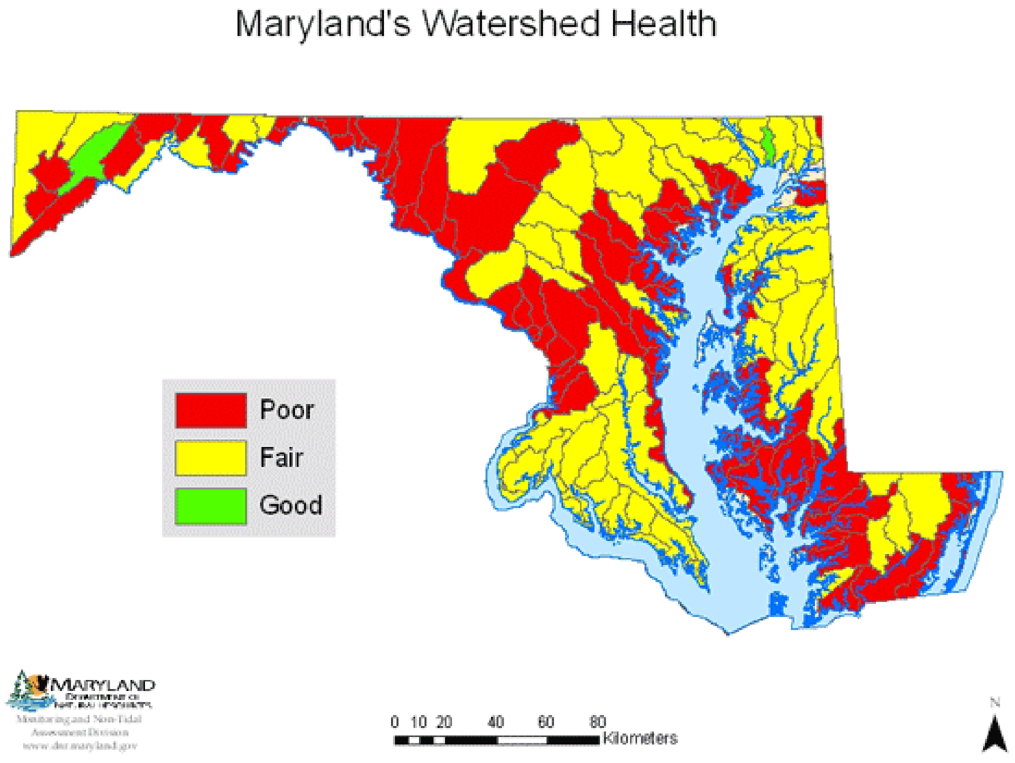
STREAM / WATERSHED HISTORY



Maryland Department of Natural Resources – Maryland Biological Stream Survey – Current Stream Health Overview

https://dnr.maryland.gov/streams/Pages/streamhealth/Current-Stream-Health-Overview.aspx

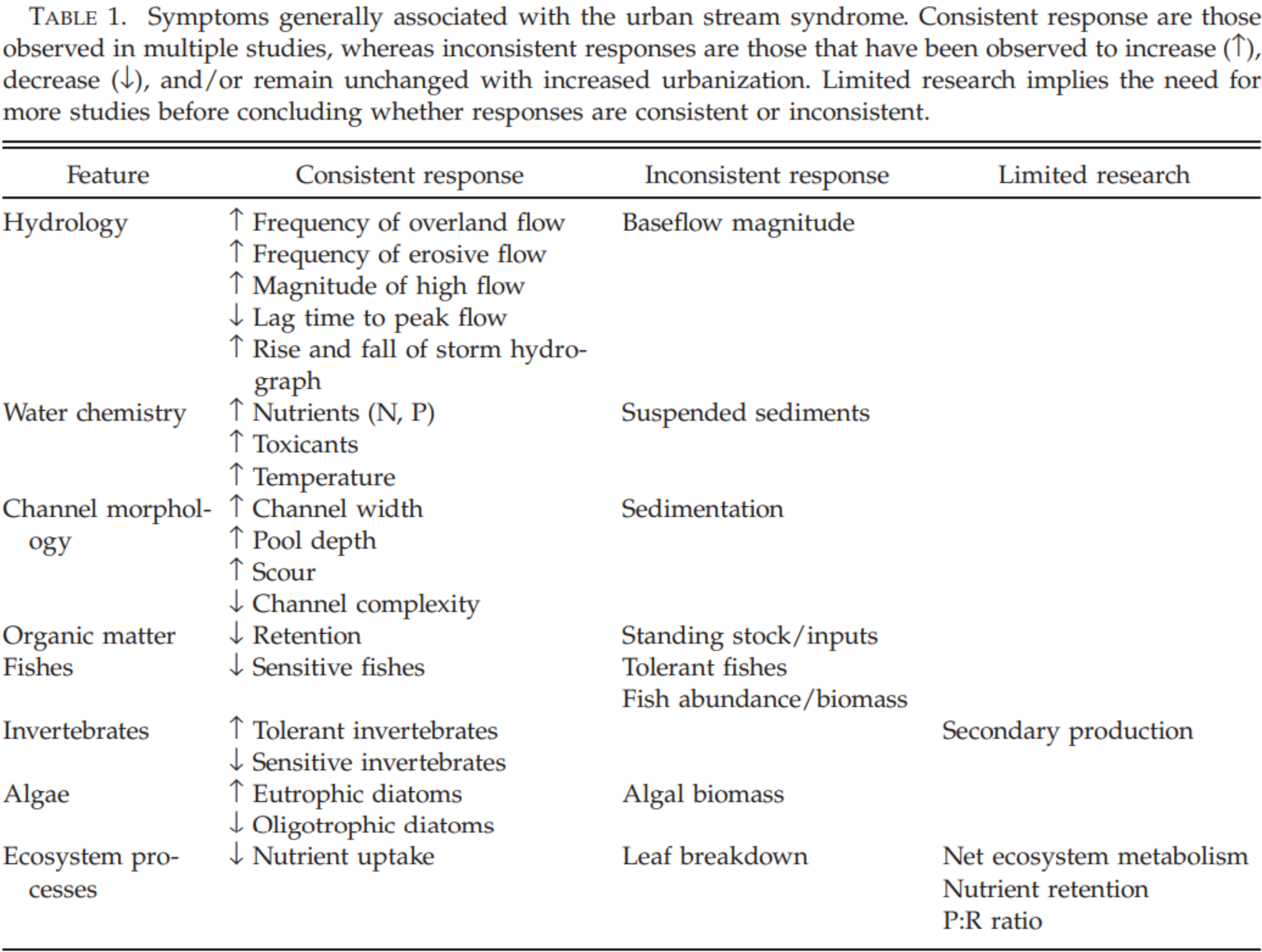


TABLE 1. Symptoms generally associated with the urban stream syndrome. Consistent response are those observed in multiple studies, whereas inconsistent responses are those that have been observed to increase (↑), decrease (↓), and/or remain unchanged with increased urbanization. Limited research implies the need for more studies before concluding whether responses are consistent or inconsistent.

Feature	Consistent response	Inconsistent response	Limited research
Hydrology	↑ Frequency of overland flow ↑ Frequency of erosive flow ↑ Magnitude of high flow ↓ Lag time to peak flow ↑ Rise and fall of storm hydrograph	Baseflow magnitude	
Water chemistry	↑ Nutrients (N, P) ↑ Toxicants ↑ Temperature	Suspended sediments	
Channel morphology	↑ Channel width ↑ Pool depth ↑ Scour ↓ Channel complexity	Sedimentation	
Organic matter	↓ Retention	Standing stock/inputs	
Fishes	↓ Sensitive fishes	Tolerant fishes Fish abundance/biomass	
Invertebrates	↑ Tolerant invertebrates ↓ Sensitive invertebrates		Secondary production
Algae	↑ Eutrophic diatoms ↓ Oligotrophic diatoms	Algal biomass	
Ecosystem processes	↓ Nutrient uptake	Leaf breakdown	Net ecosystem metabolism Nutrient retention P:R ratio

- Walsh, C. J., A. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. The urban stream syndrome: current knowledge and the search for a cure. P. Silver (ed.), Journal of the north american benthological society. North american benthological society, Lawrence, KS, 24(3):706-723, (2005).

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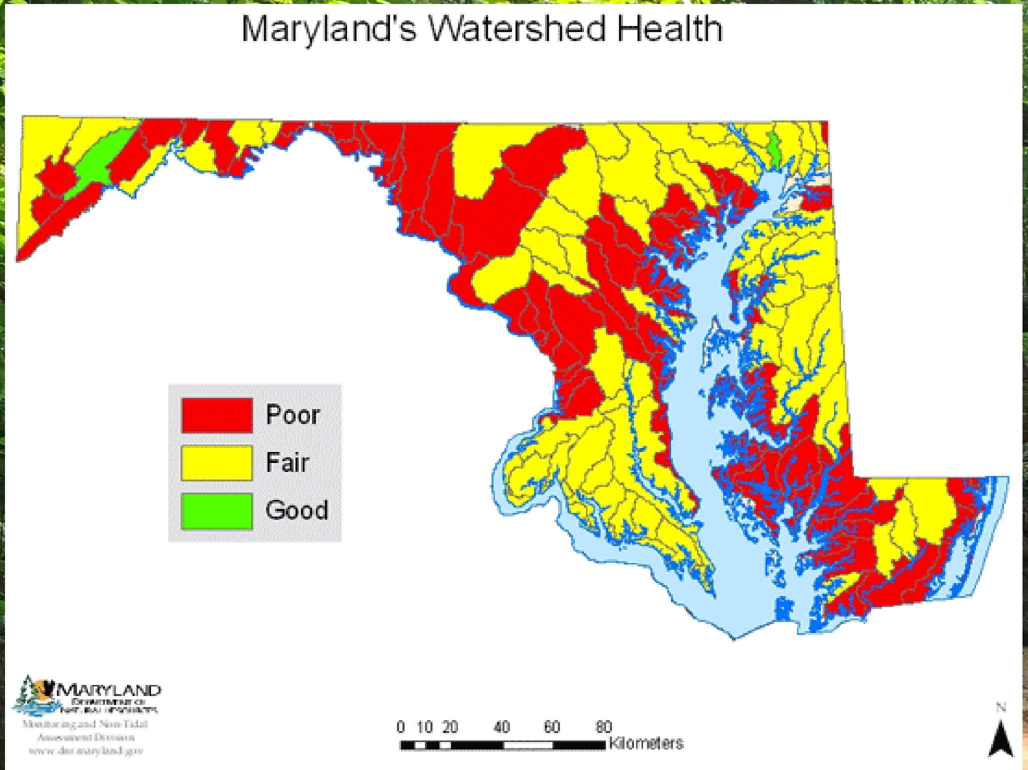
STREAM / WATERSHED HISTORY


Maryland's Watershed Health

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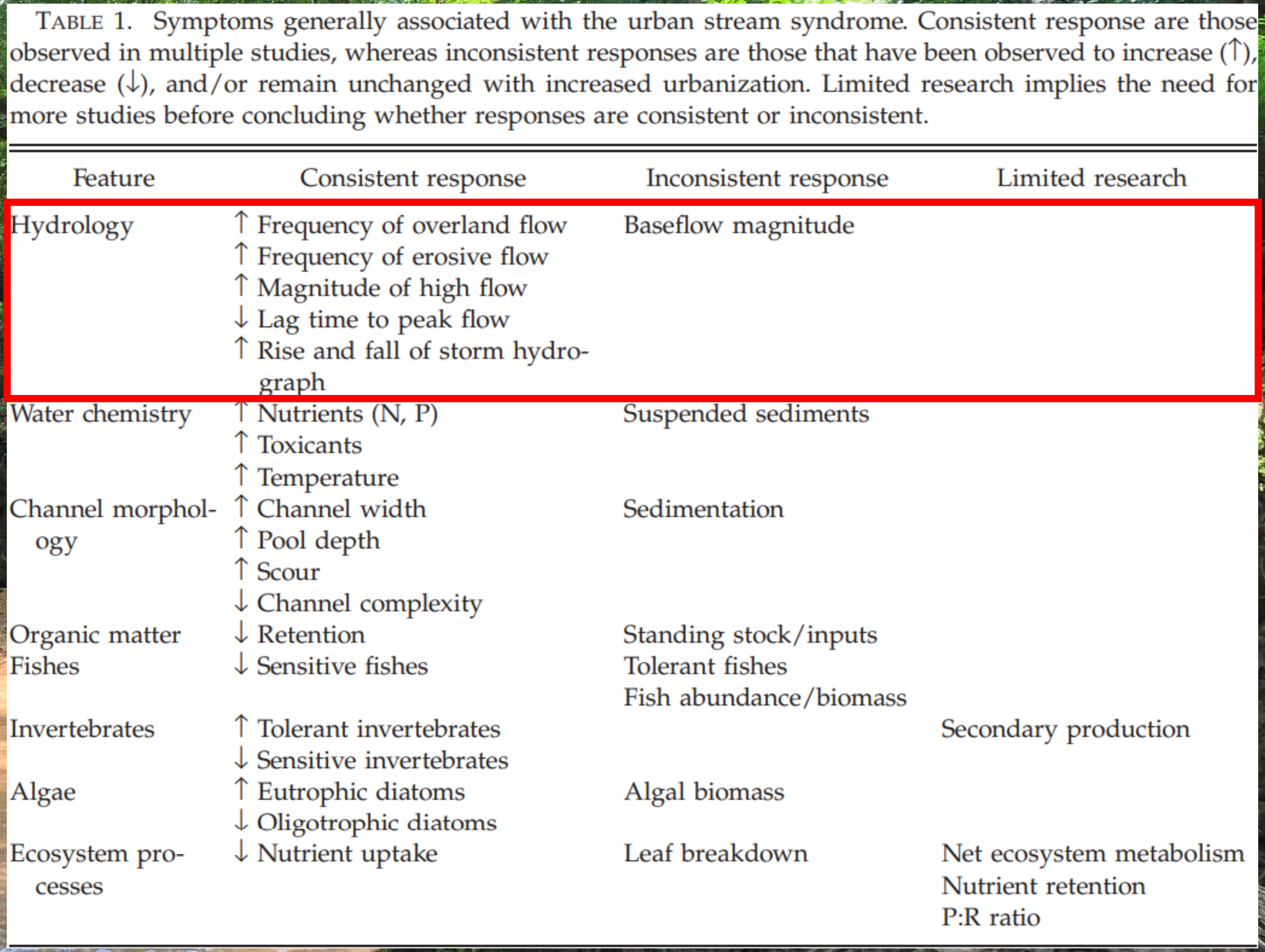
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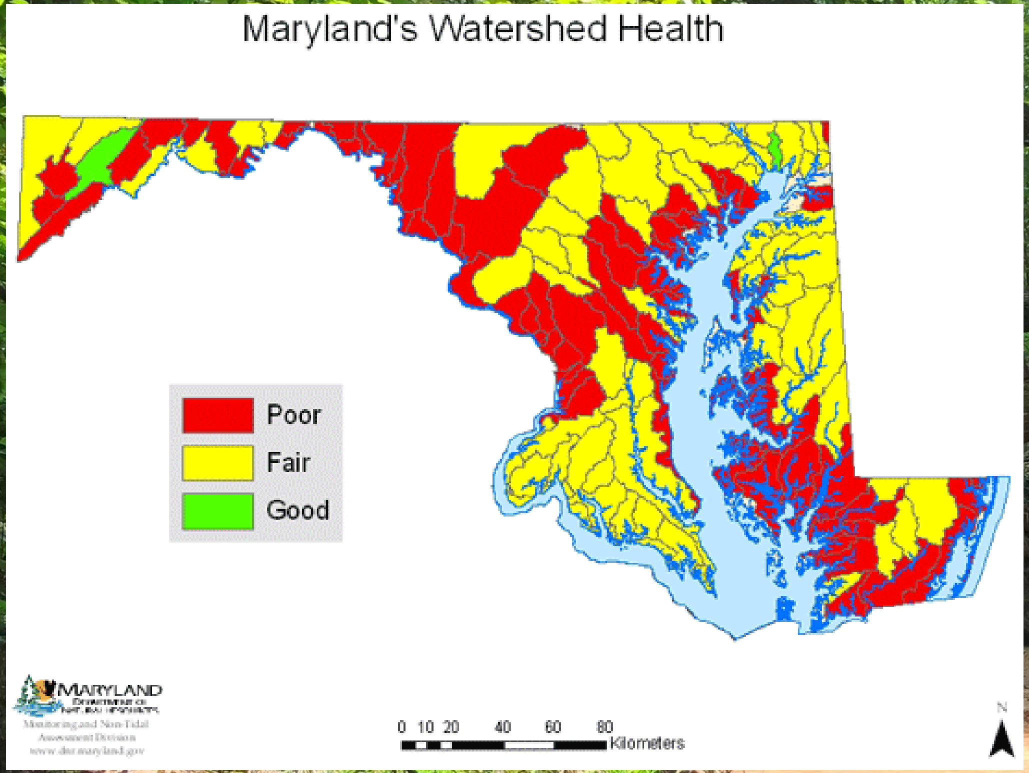

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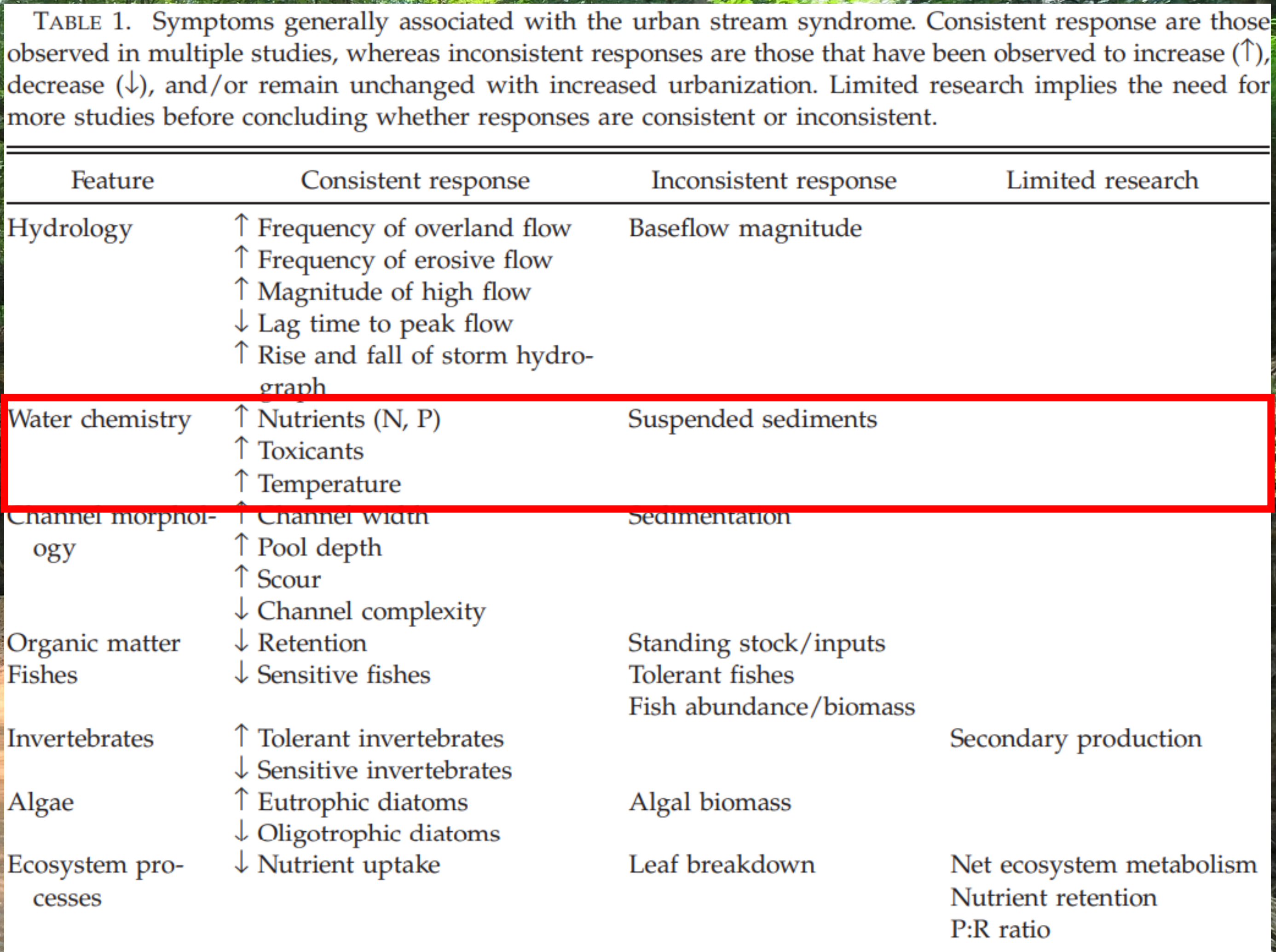

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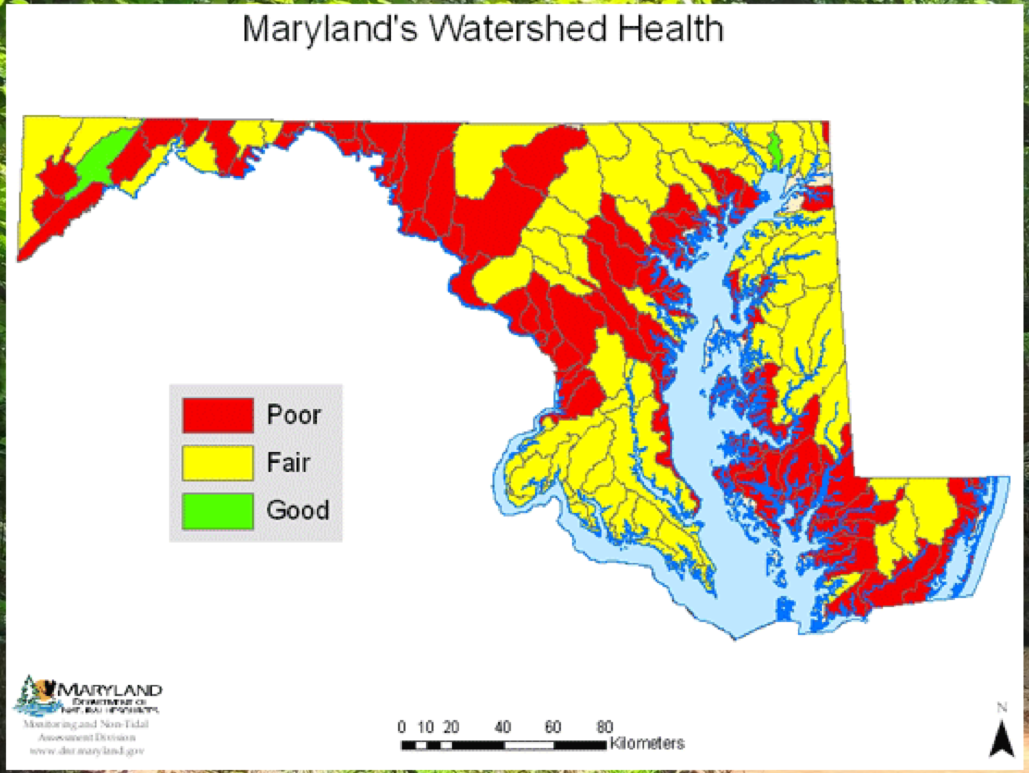

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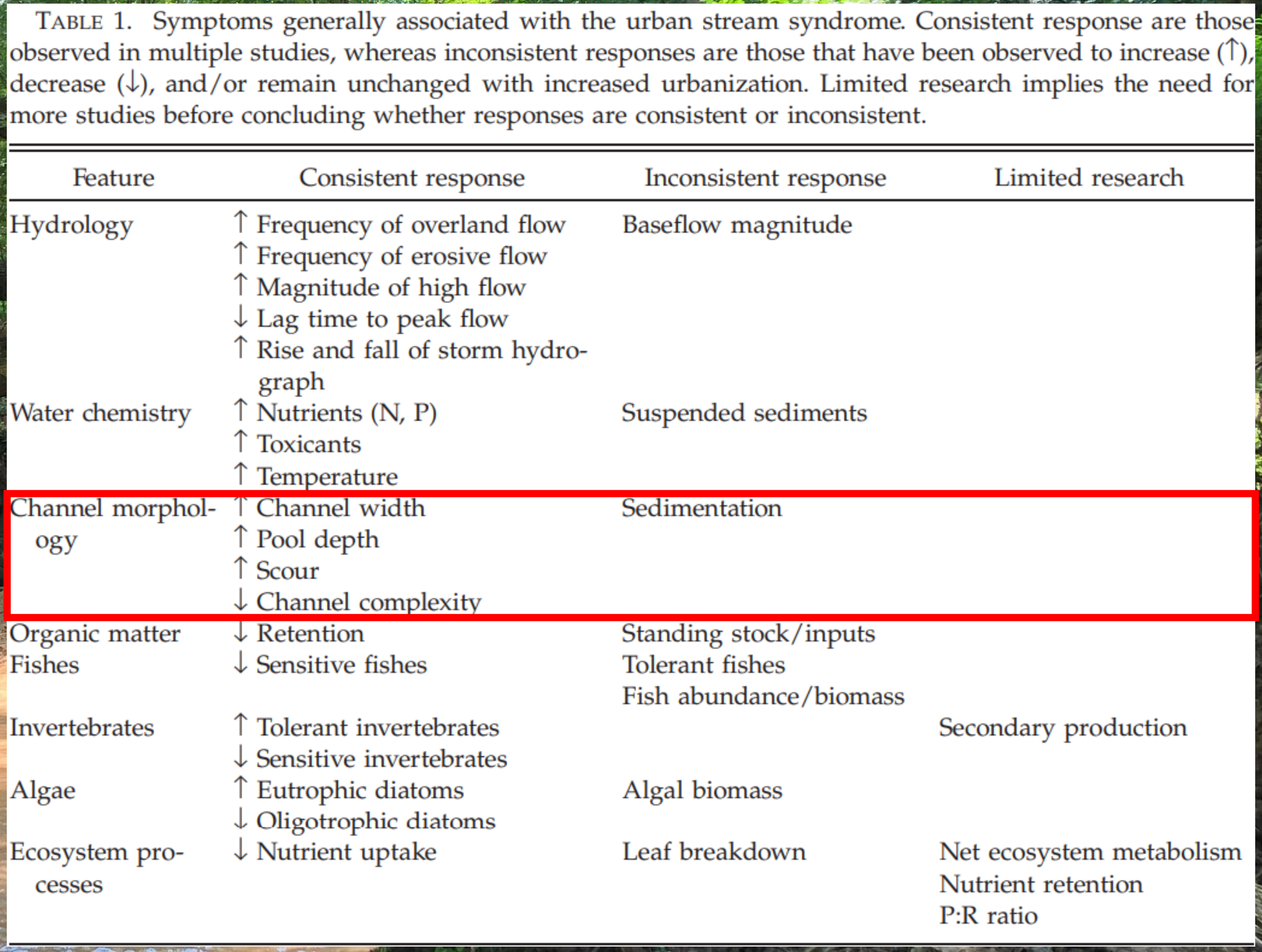

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Organic matter	↓ Retention	Standing stock/inputs	
Fishes	↓ Sensitive fishes	Tolerant fishes Fish abundance/biomass	
Invertebrates	↑ Tolerant invertebrates ↓ Sensitive invertebrates		Secondary production
Algae	↑ Eutrophic diatoms ↓ Oligotrophic diatoms	Algal biomass	
Ecosystem processes	↓ Nutrient uptake	Leaf breakdown	Net ecosystem metabolism Nutrient retention P:R ratio

- Walsh, C. J., A. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. The urban stream syndrome: current knowledge and the search for a cure. P. Silver (ed.), Journal of the north american benthological society. North american benthological society, Lawrence, KS, 24(3):706-723, (2005).

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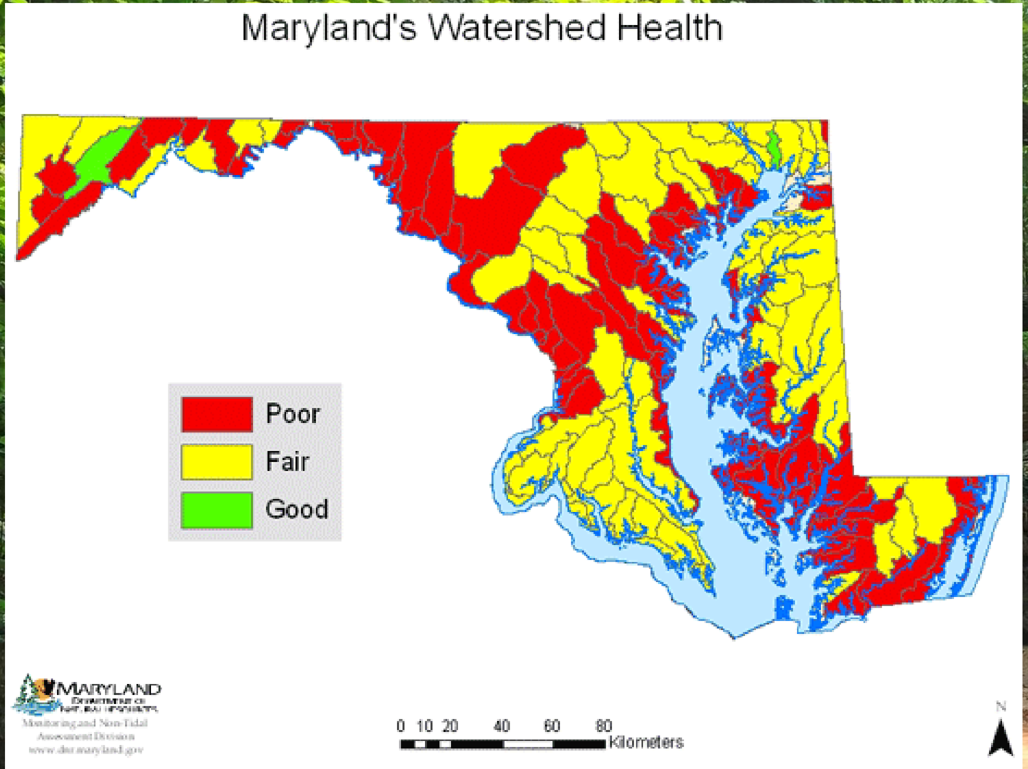
STREAM / WATERSHED HISTORY



Maryland Department of Natural Resources – Maryland Biological Stream Survey – Current Stream Health Overview

https://dnr.maryland.gov/streams/Pages/streamhealth/Current-Stream-Health-Overview.aspx

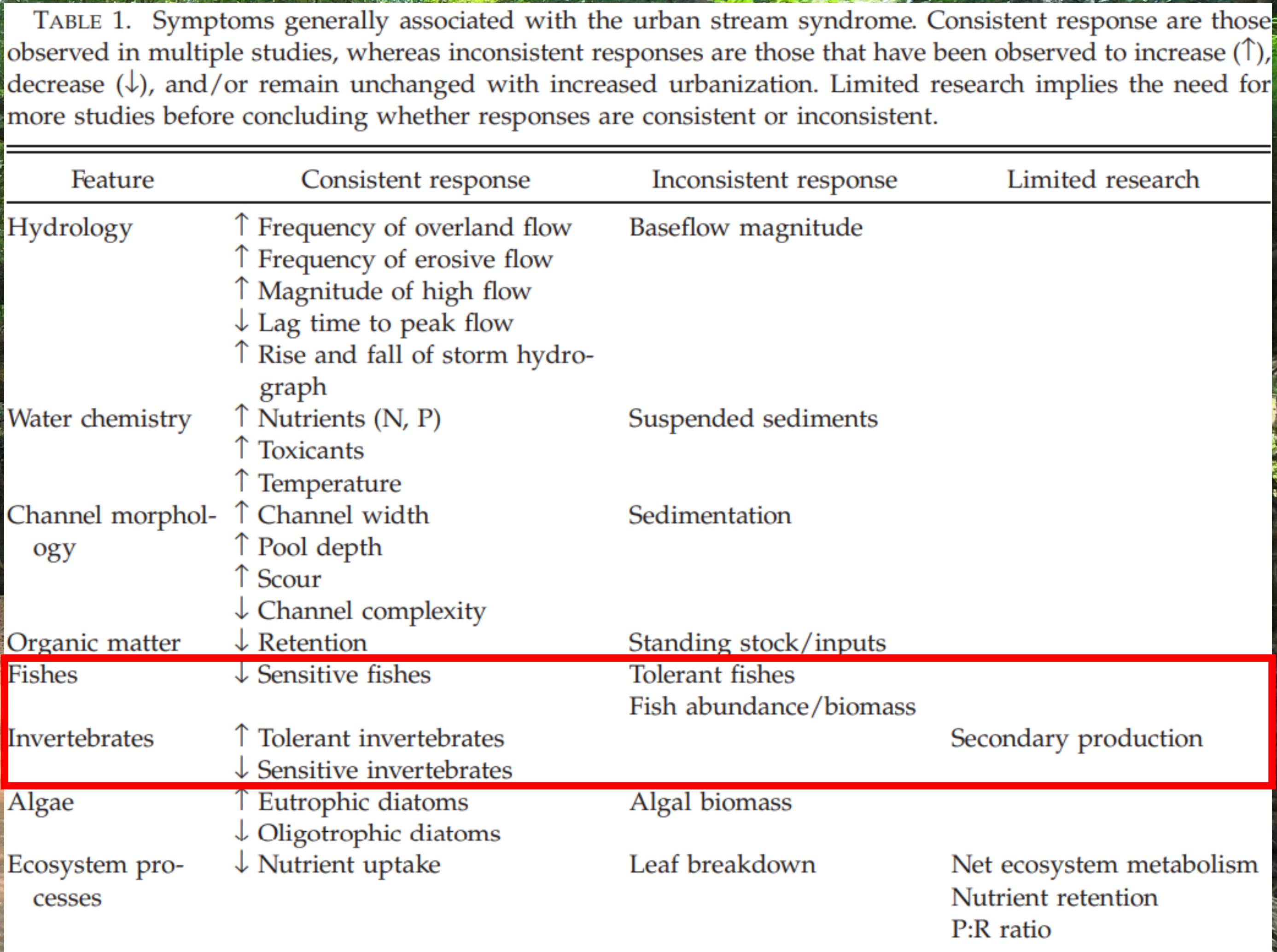


TABLE 1. Symptoms generally associated with the urban stream syndrome. Consistent response are those observed in multiple studies, whereas inconsistent responses are those that have been observed to increase (↑), decrease (↓), and/or remain unchanged with increased urbanization. Limited research implies the need for more studies before concluding whether responses are consistent or inconsistent.

Feature	Consistent response	Inconsistent response	Limited research
Hydrology	↑ Frequency of overland flow ↑ Frequency of erosive flow ↑ Magnitude of high flow ↓ Lag time to peak flow ↑ Rise and fall of storm hydrograph	Baseflow magnitude	
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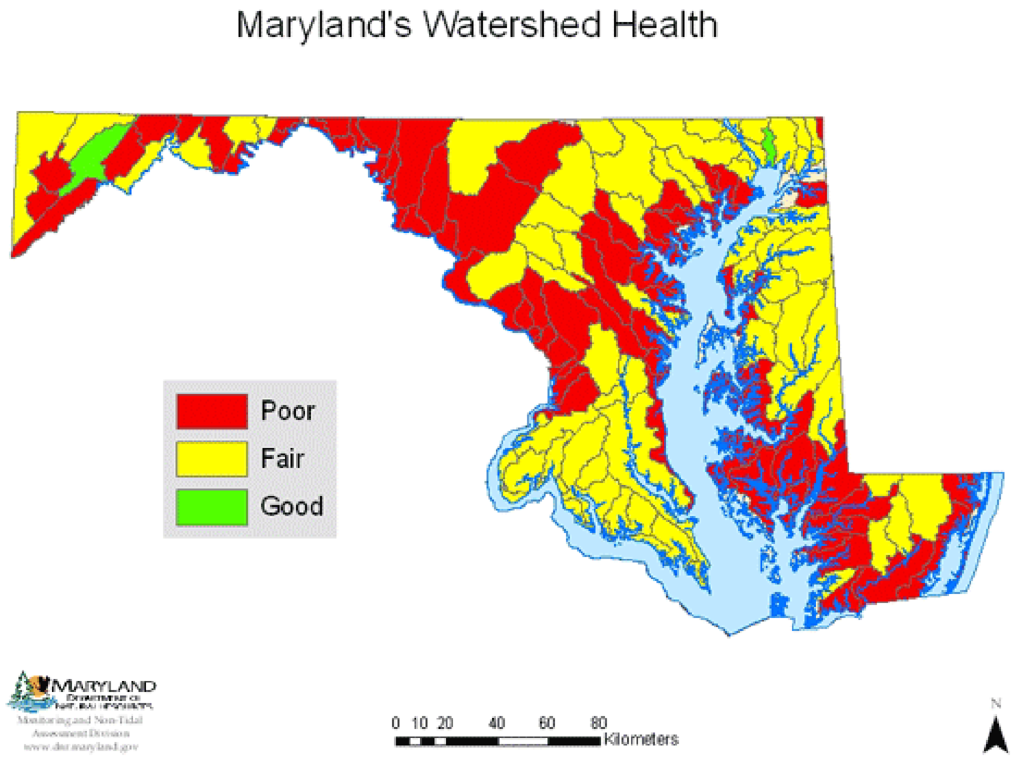
STREAM / WATERSHED HISTORY



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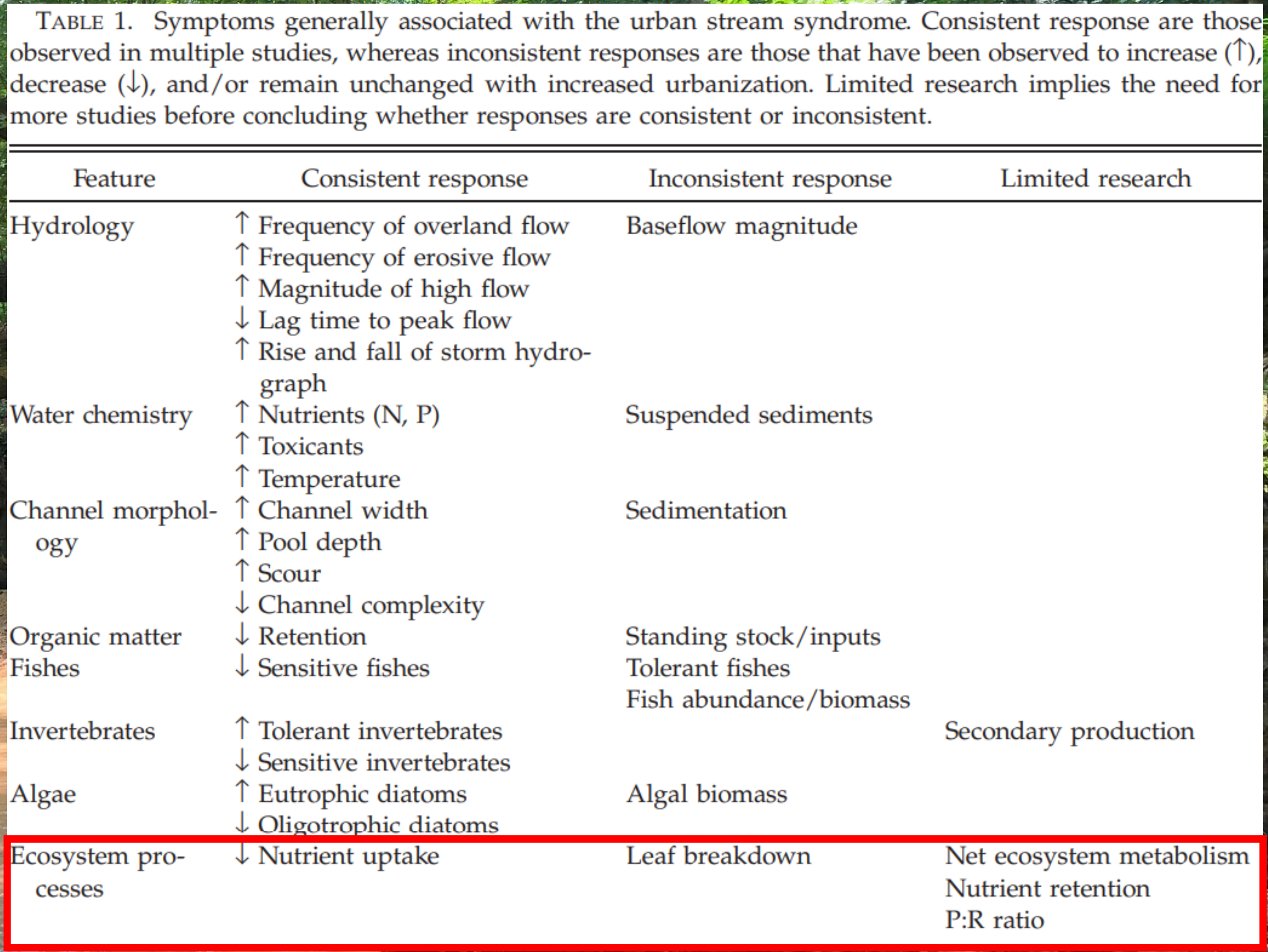

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REASONS FOR STREAM RESTORATION

- EROSION CONTROL (FOR TMDL / INFRASTRUCTURE PROTECTION)
- WETLAND CREATION / ENHANCEMENT / RESTORATION
- FLOOD CONTROL / PEAK FLOW REDUCTIONS
- IMPROVE FISHERIES (FISH PASSAGE, NURSERY HABITAT)
  WATER QUALITY IMPROVEMENT
- WILDLIFE HABITAT CREATION / BIODIVERSITY
- PUBLIC SAFETY
- RECREATION / IMPROVED ACCESS
- RARE, THREATEN, ENDANGERED (RTE) SPECIES RECOVERY
- CARBON SEQUESTRATION

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REASONS FOR STREAM RESTORATION

RIVER-WETLAND COORIDORS PROVIDE ALL OF THESE ECOSYSTEM FUNCTIONS

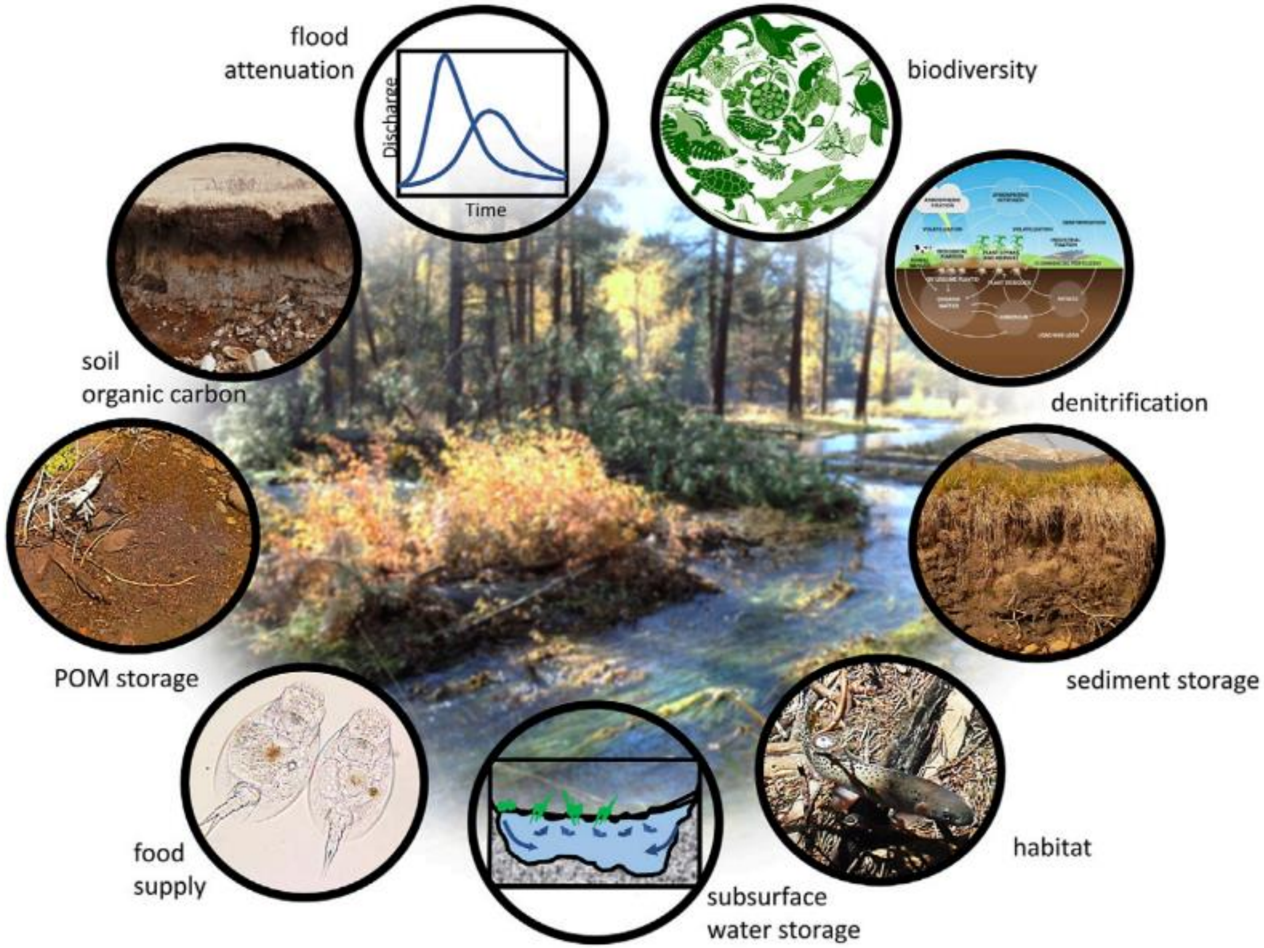

FIGURE 7 | Schematic illustration of river functions associated with river-wetland corridors ("biodiversity" image modified from Nelson et al. (2006); "denitrification" diagram from ibiologia.com; "food supply" image (rotifers) from Matthew A. Robinson, Wikimedia Commons).

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Wohl E, Castro J, Cluer B, Merritts D,Powers P, Staab B and Thorne C(2021) Rediscovering, Reevaluating,and Restoring Lost River-Wetland Corridors.Front. Earth Sci. 9:653623. doi: 10.3389/feart.2021.653623

HOW IS STREAM RESTORATION ACHIEVED?

EXISTING CONDITION

REFERENCE CONDITION

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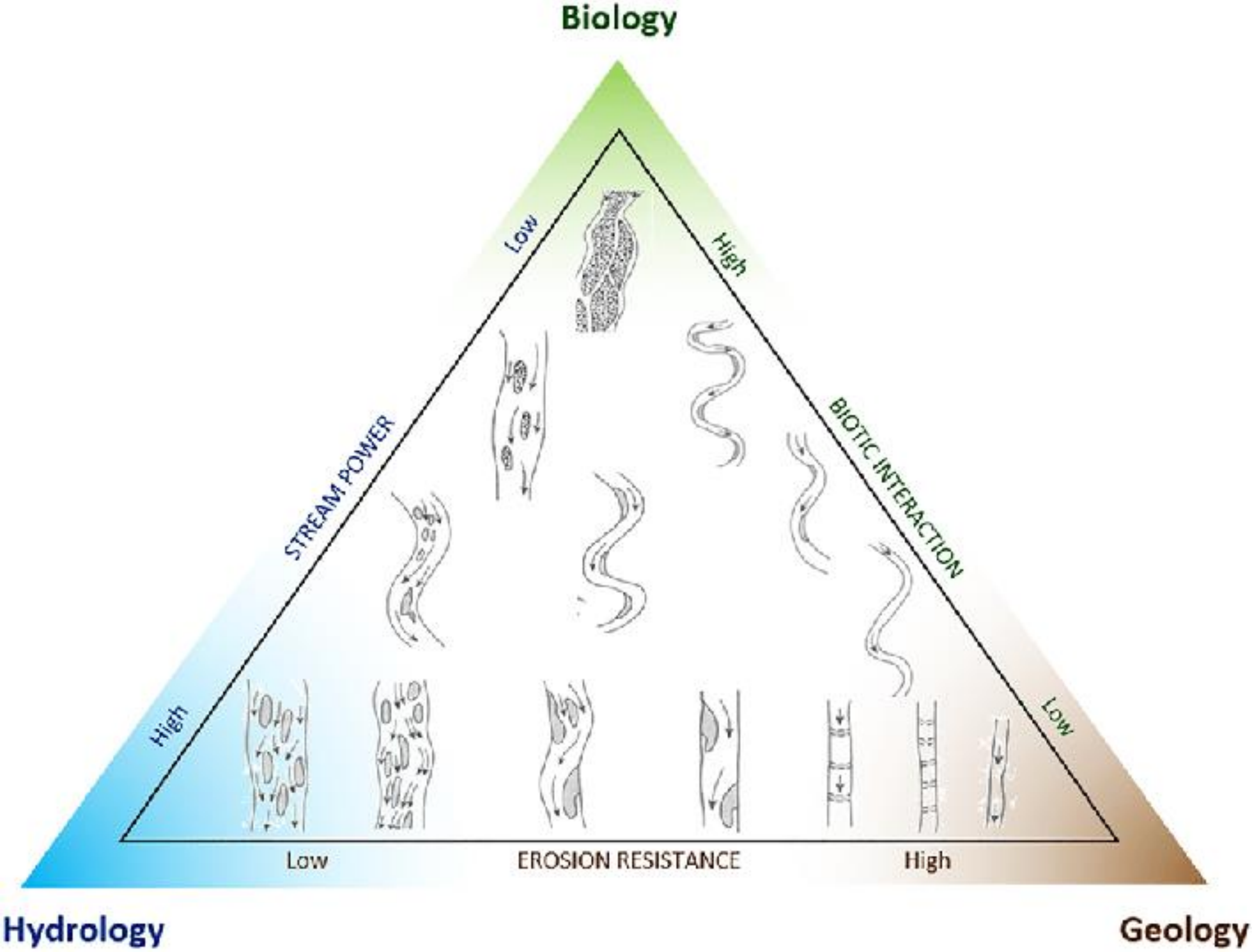
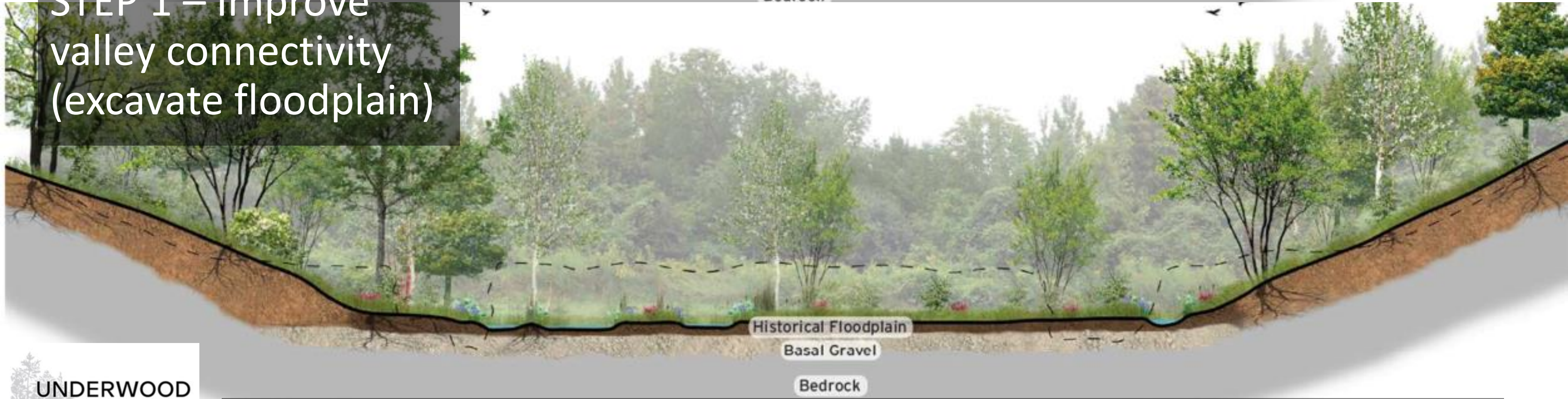
GENERAL REFERENCE CONDITIONS



JM, Thorne CR. The stream evolution triangle: Integrating geology, hydrology, and biology. River Res Applic. 2019; 35: 315–326. https://doi.org/10.1002/rra.3421

HOW IS STREAM RESTORATION ACHIEVED?

STEP 1 – Improve valley connectivity (excavate floodplain)



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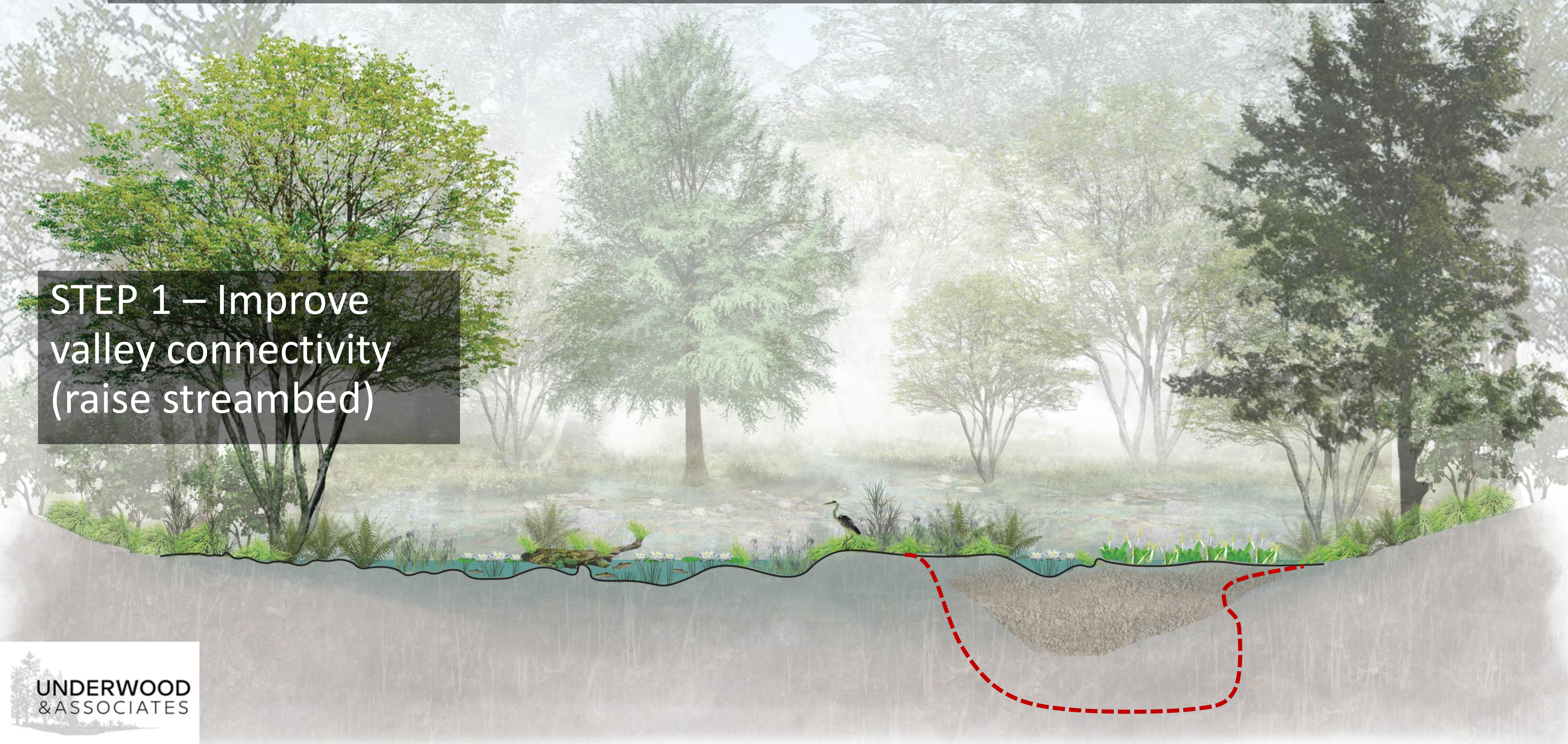
HOW IS STREAM RESTORATION ACHIEVED?



STEP 1 – Improve valley connectivity (raise streambed)

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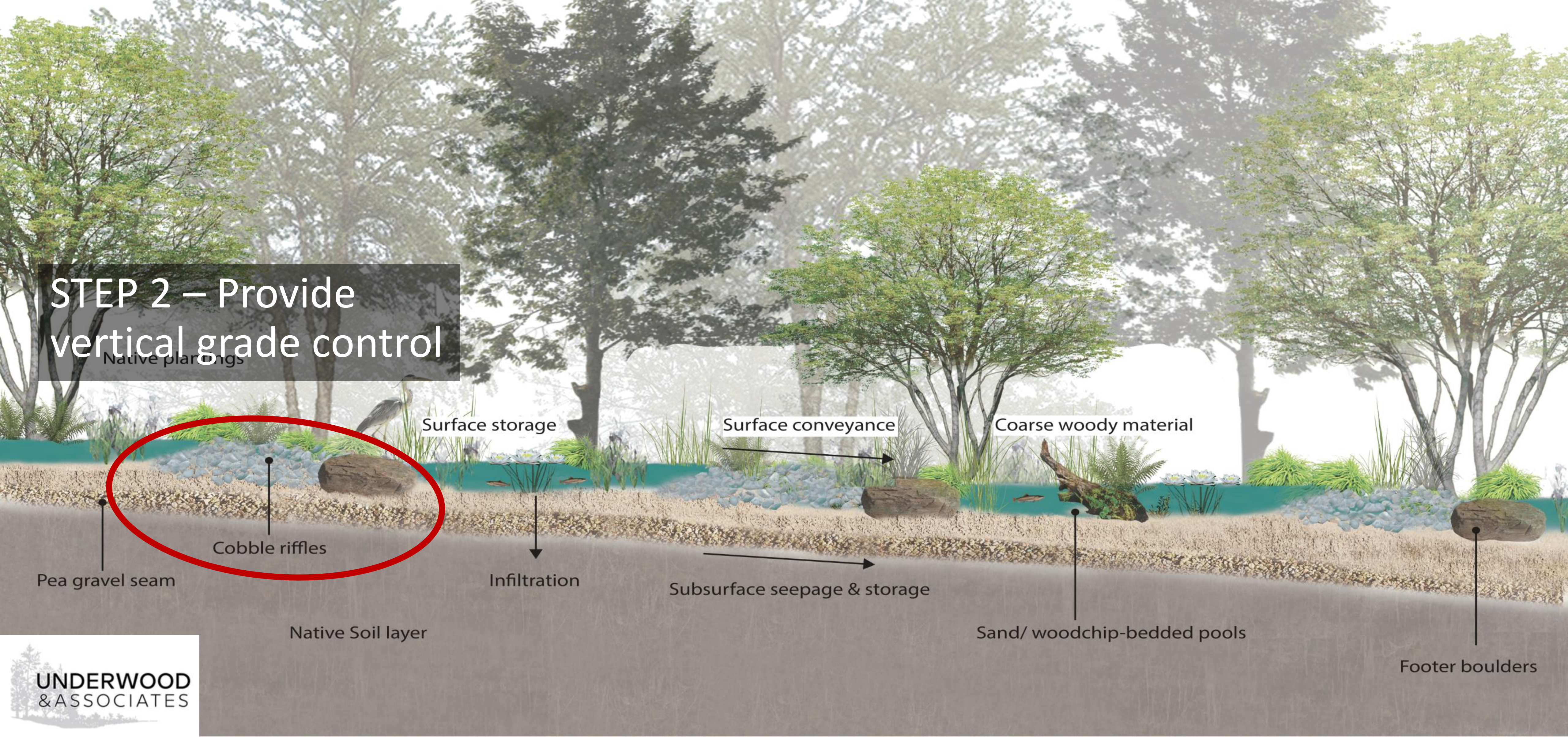
HOW IS STREAM RESTORATION ACHIEVED?

STEP 2 – Provide vertical grade control



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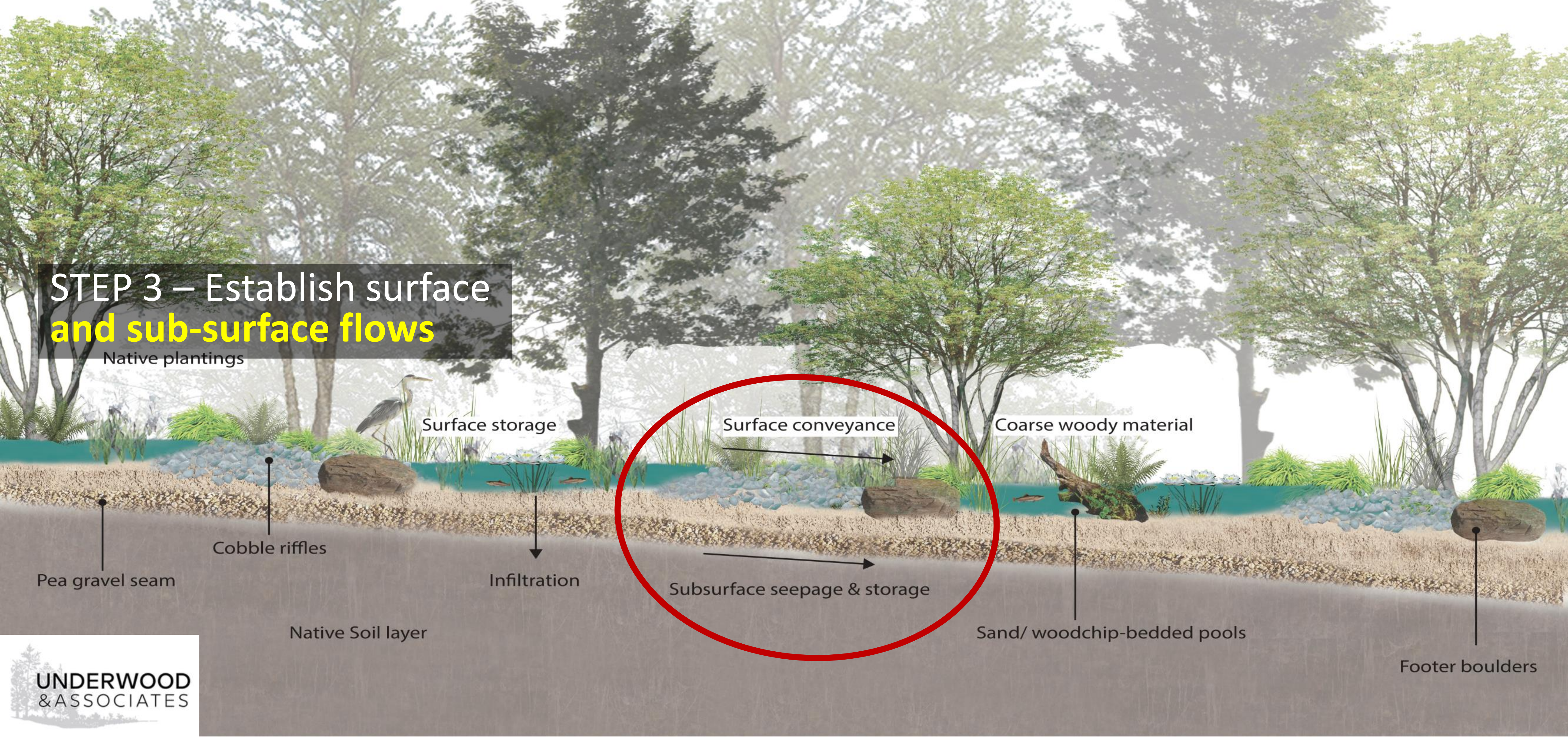
HOW IS STREAM RESTORATION ACHIEVED?

STEP 3 – Establish surface **and sub-surface flows**



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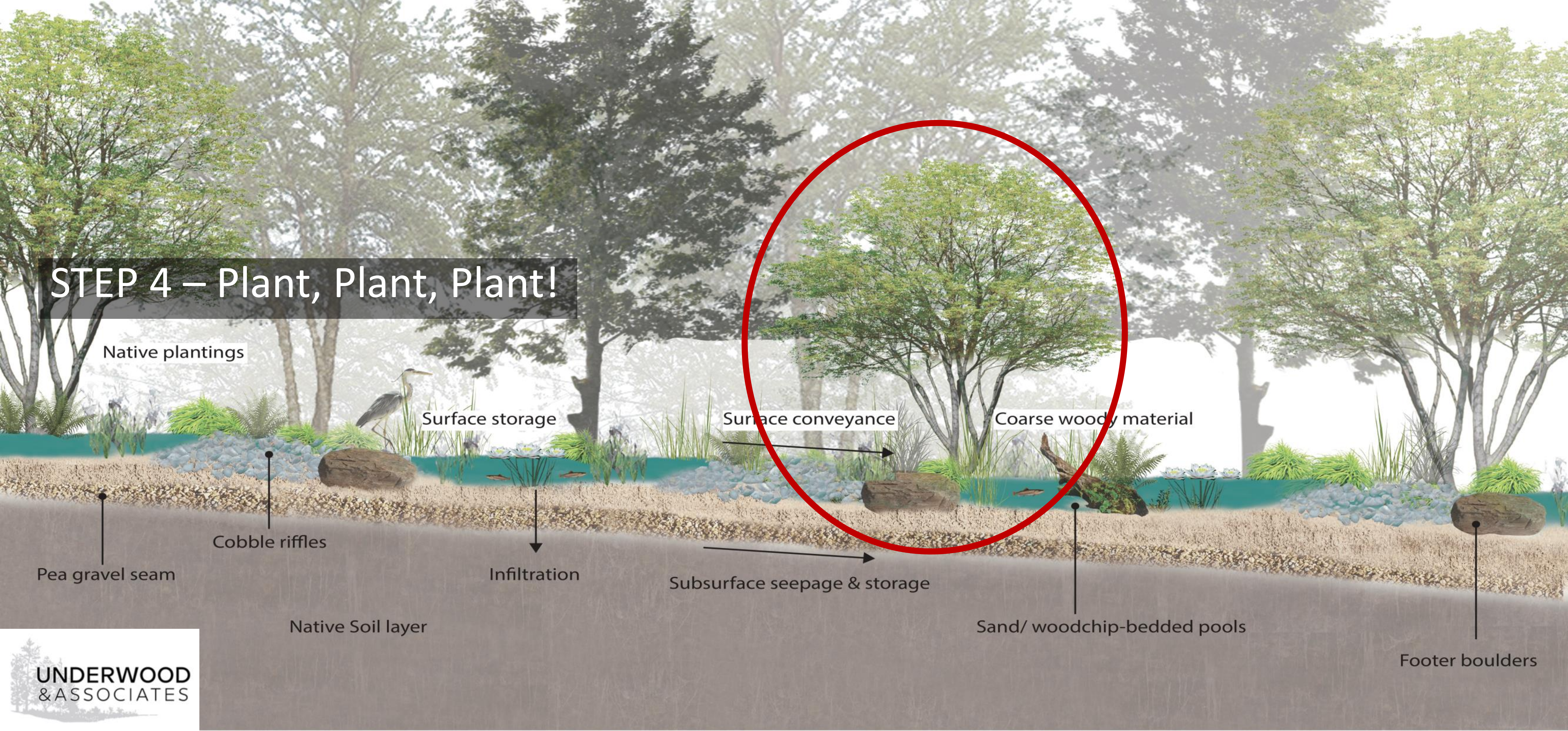
HOW IS STREAM RESTORATION ACHIEVED?

STEP 4 – Plant, Plant, Plant!



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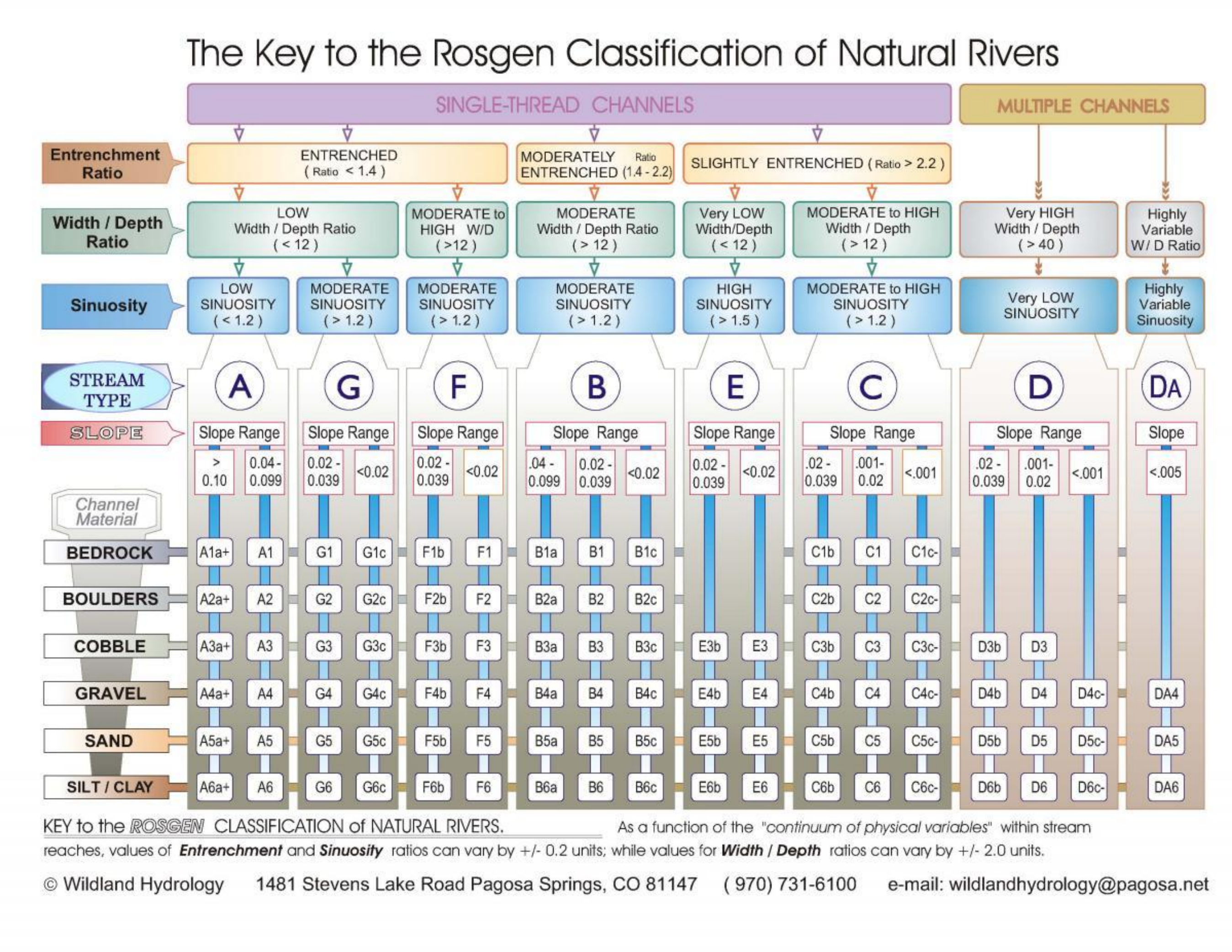
TYPES OF STREAM RESTORATION

- Natural Channel Design
  - Many Channel Types
- Regenerative Stream Channel
  - Baseflow Channel
- Legacy Sediment Removal
- Valley Restoration
- Beaver Dam Analogs
  - Beaver Reintroduction
- Stage 0 Restoration

NATURAL CHANNEL DESIGN



The Key to the Rosgen Classification of Natural Rivers

	SINGLE-THREAD CHANNELS														MULTIPLE CHANNELS			
Entrenchment Ratio	ENTRENCHED (Ratio < 1.4)						MODERATELY ENTRENCHED Ratio (1.4 - 2.2)			SLIGHTLY ENTRENCHED (Ratio > 2.2)								
Width / Depth Ratio	LOW Width / Depth Ratio (< 12)				MODERATE to HIGH W/D (>12)		MODERATE Width / Depth Ratio (> 12)			Very LOW Width/Depth (< 12)		MODERATE to HIGH Width / Depth (> 12)			Very HIGH Width / Depth (> 40)			Highly Variable W/ D Ratio
Sinuosity	LOW SINUOSITY (< 1.2)		MODERATE SINUOSITY (> 1.2)		MODERATE SINUOSITY (> 1.2)		MODERATE SINUOSITY (> 1.2)			HIGH SINUOSITY (> 1.5)		MODERATE to HIGH SINUOSITY (> 1.2)			Very LOW SINUOSITY			Highly Variable Sinuosity
STREAM TYPE	A		G		F		B			E		C			D			DA
SLOPE	Slope Range		Slope Range		Slope Range		Slope Range			Slope Range		Slope Range			Slope Range			Slope
	> 0.10	0.04 - 0.099	0.02 - 0.039	<0.02	0.02 - 0.039	<0.02	.04 - 0.099	0.02 - 0.039	<0.02	0.02 - 0.039	<0.02	.02 - 0.039	.001- 0.02	<.001	.02 - 0.039	.001- 0.02	<.001	<.005
Channel Material																		
BEDROCK	A1a+	A1	G1	G1c	F1b	F1	B1a	B1	B1c			C1b	C1	C1c-				
BOULDERS	A2a+	A2	G2	G2c	F2b	F2	B2a	B2	B2c			C2b	C2	C2c-				
COBBLE	A3a+	A3	G3	G3c	F3b	F3	B3a	B3	B3c	E3b	E3	C3b	C3	C3c-	D3b	D3		
GRAVEL	A4a+	A4	G4	G4c	F4b	F4	B4a	B4	B4c	E4b	E4	C4b	C4	C4c-	D4b	D4	D4c-	DA4
SAND	A5a+	A5	G5	G5c	F5b	F5	B5a	B5	B5c	E5b	E5	C5b	C5	C5c-	D5b	D5	D5c-	DA5
SILT / CLAY	A6a+	A6	G6	G6c	F6b	F6	B6a	B6	B6c	E6b	E6	C6b	C6	C6c-	D6b	D6	D6c-	DA6

KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

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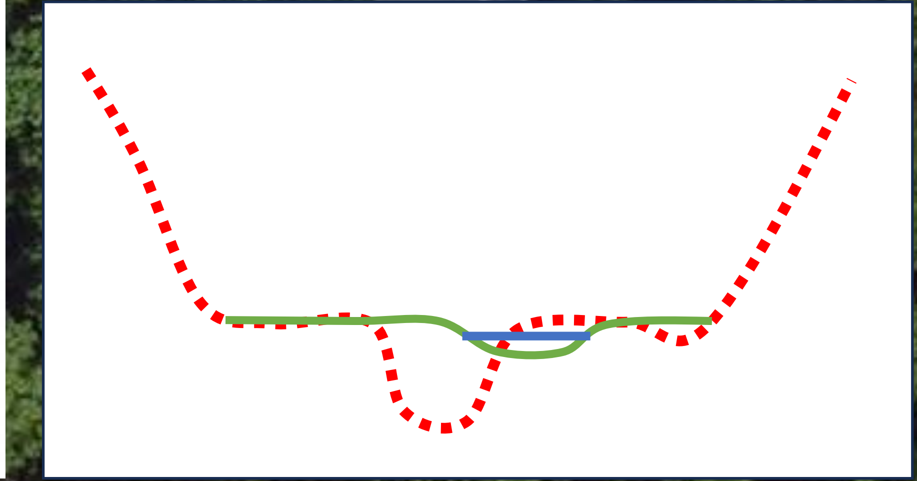

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NATURAL CHANNEL DESIGN

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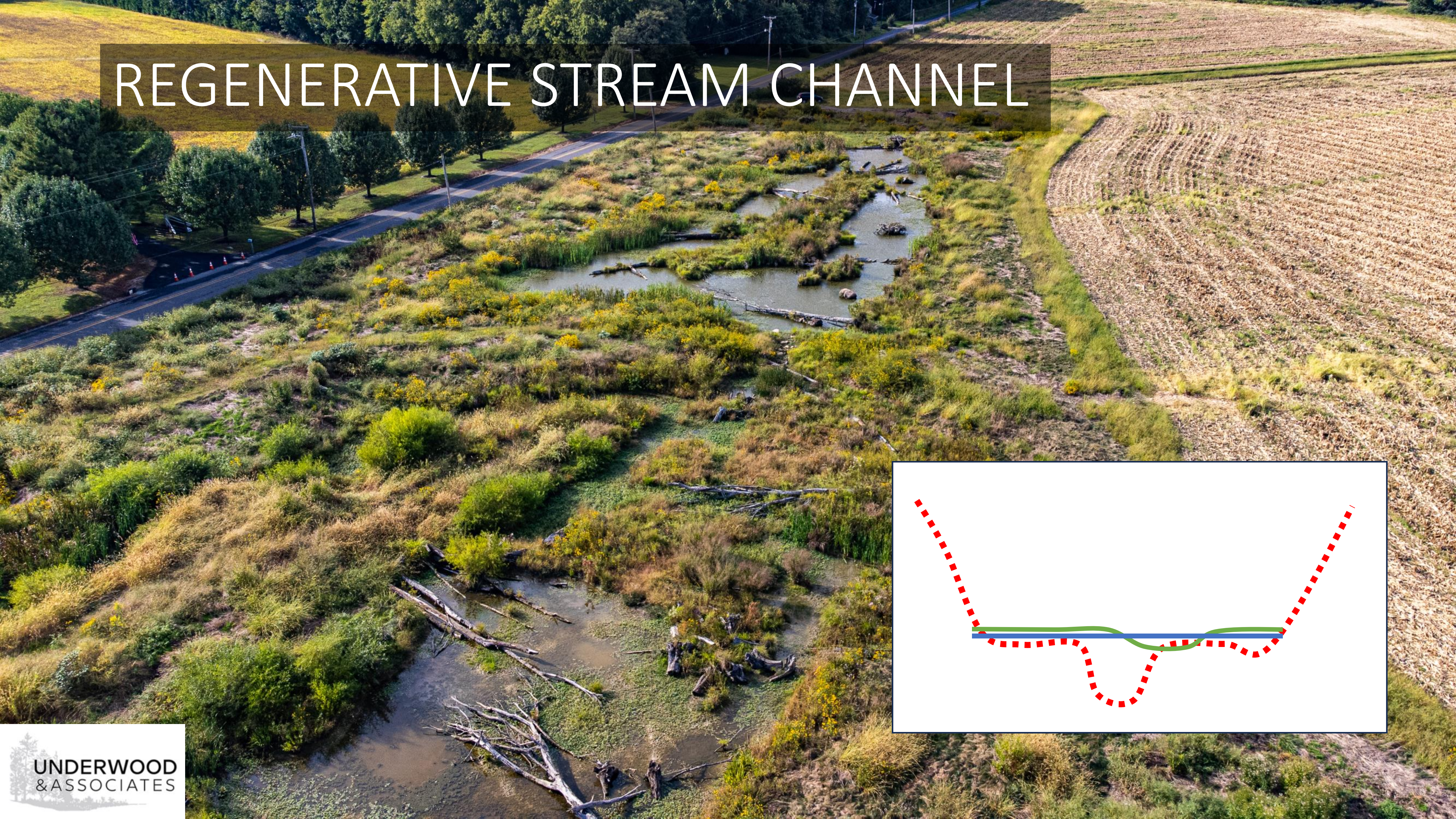
REGENERATIVE STREAM CHANNEL



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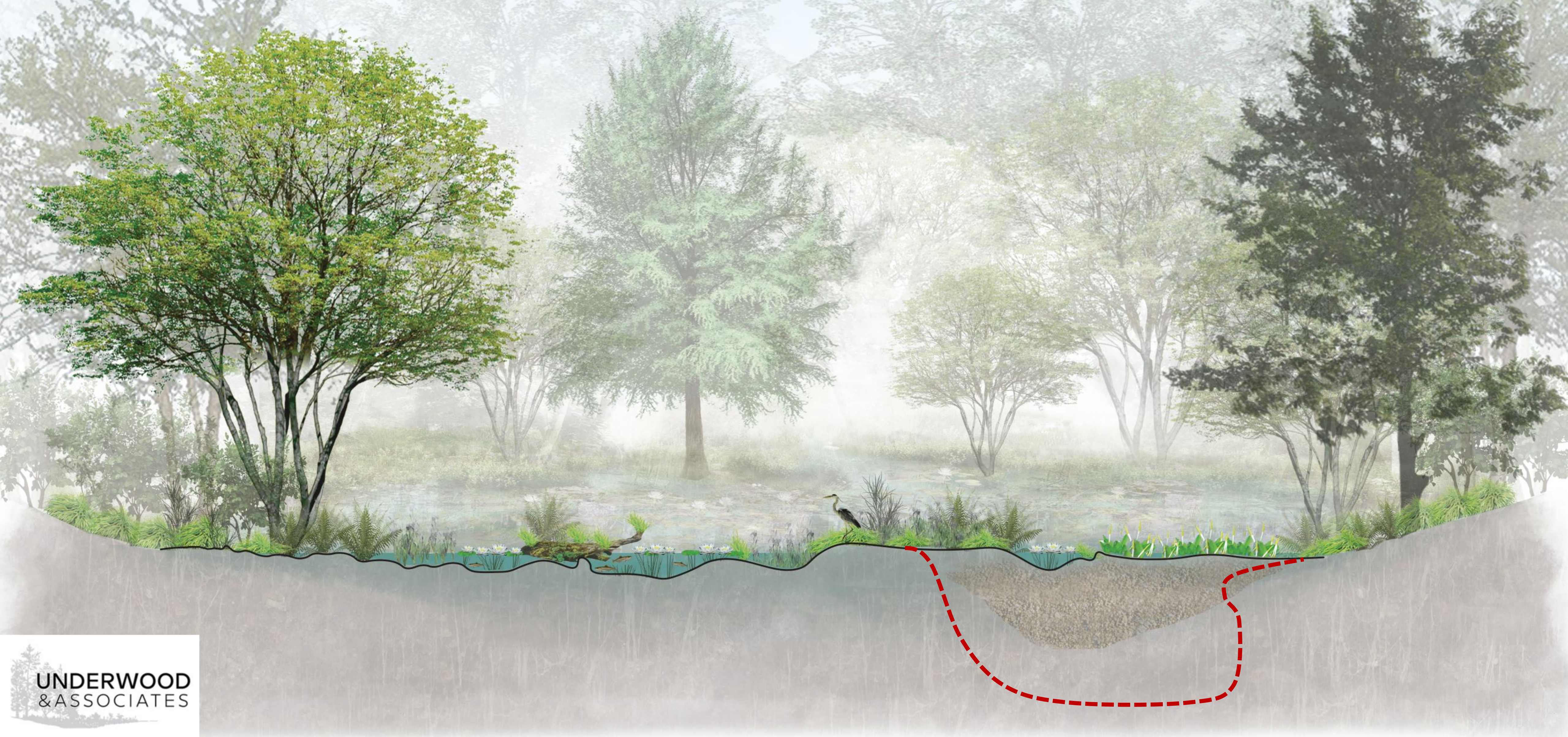
REGENERATIVE STREAM CHANNEL



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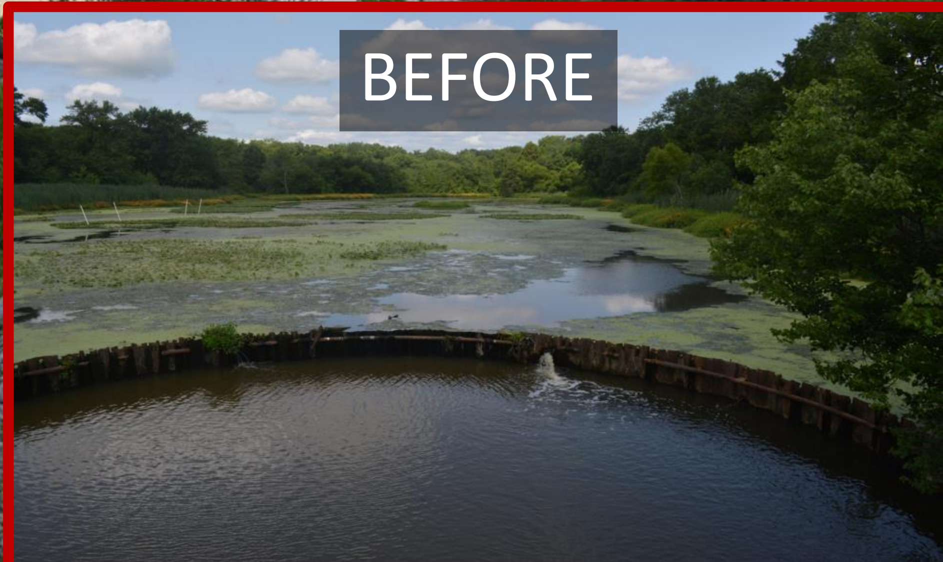
REGENERATIVE STREAM CHANNEL



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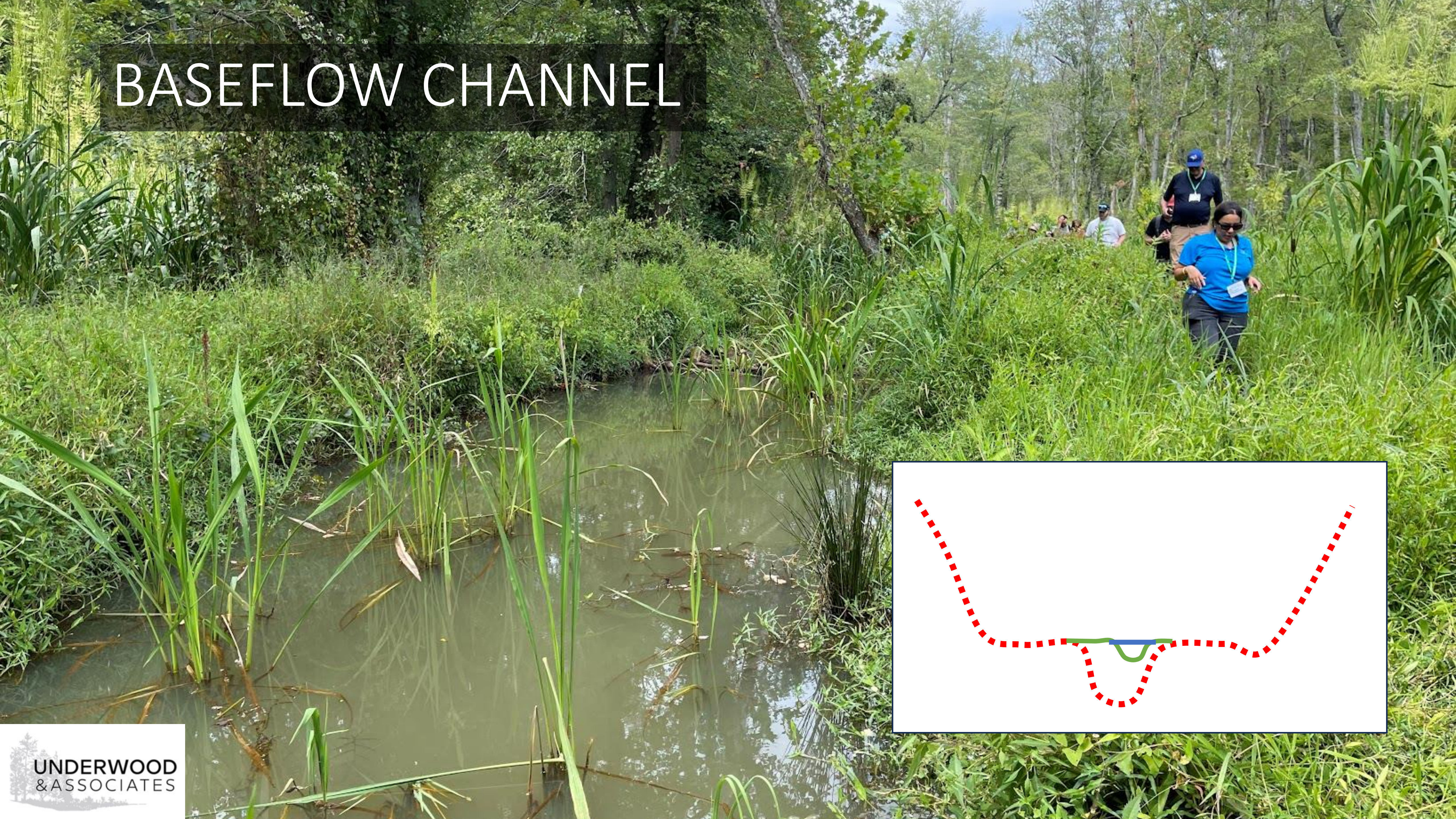
BASEFLOW CHANNEL



BASEFLOW CHANNEL

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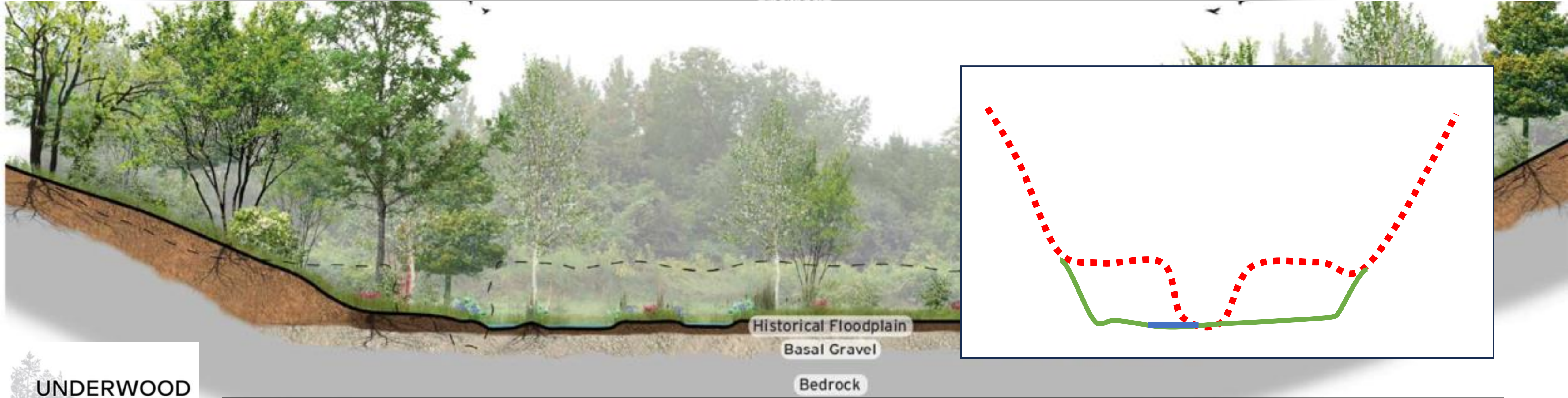
LEGACY SEDIMENT REMOVAL



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LEGACY SEDIMENT REMOVAL

http://www.bsr-project.org/photos.html

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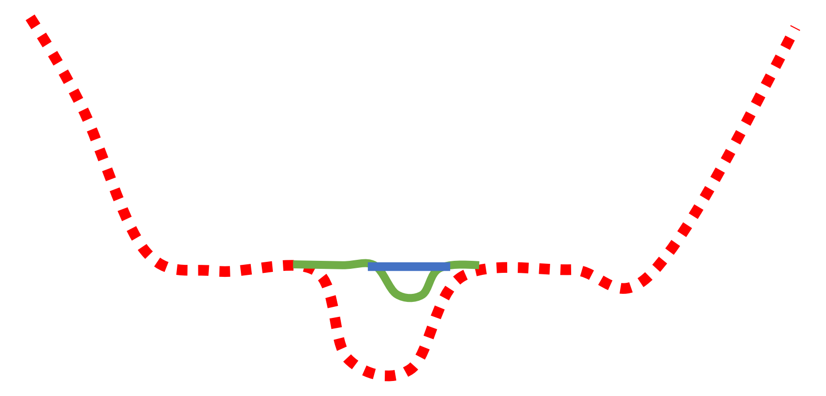
VALLEY RESTORATION

BEAVER DAM ANALOGS



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BEAVER DAM ANALOGS

BEAVER REINTRODUCTION

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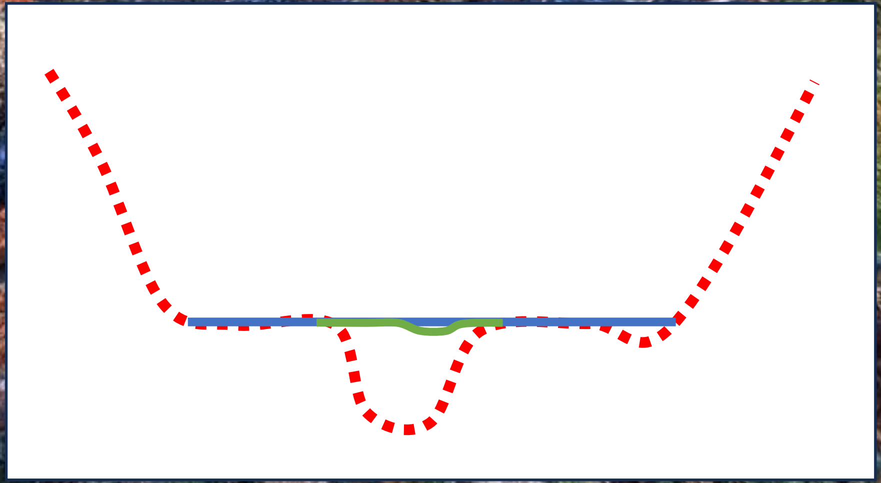
STAGE 0 RESTORATION



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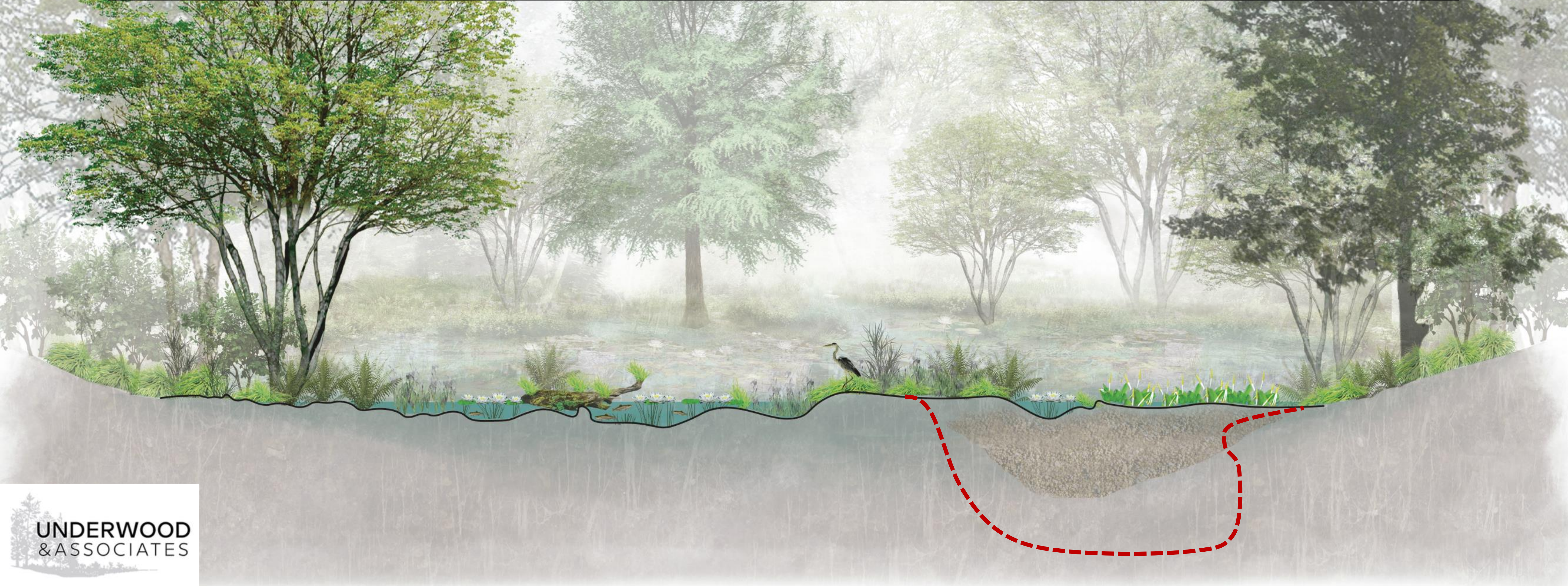
WHAT IS STREAM RESTORATION?

Reconnection of streambed and floodplain to **slow** water down, **spread** it out, and **soak** it in.



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HOW IS STREAM RESTORATION ACHIEVED?


EXISTING CONDITION


REFERENCE CONDITION

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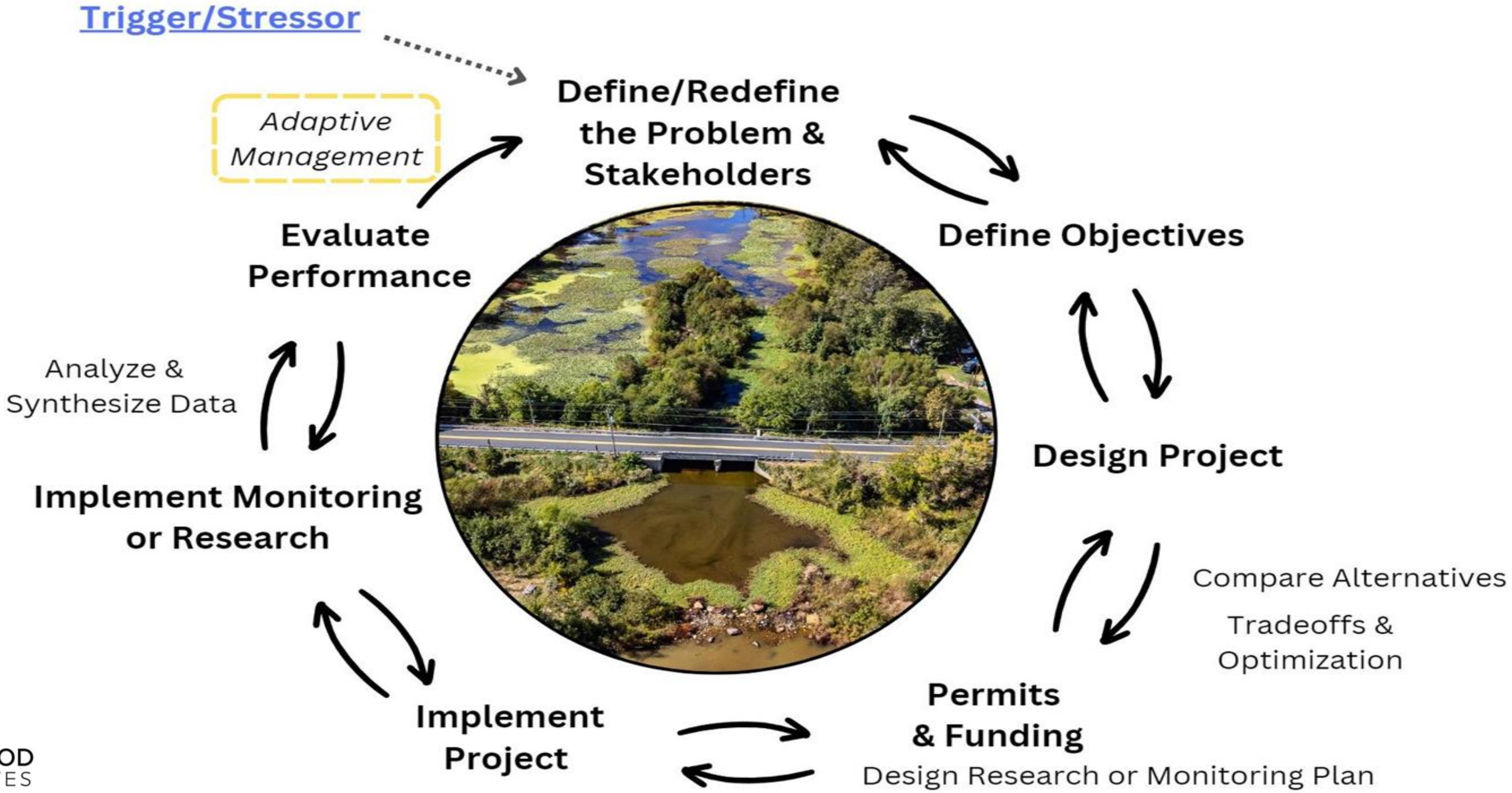
DESIGN CYCLE



Trigger/Stressor

Define/Redefine the Problem & Stakeholders

Define Objectives

Design Project

Compare Alternatives

Tradeoffs & Optimization

Permits & Funding

Design Research or Monitoring Plan

Implement Project

Implement Monitoring or Research

Analyze & Synthesize Data

Evaluate Performance

Adaptive Management

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CATTAIL CREEK – EXISTING CONDITIONS

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CATTAIL CREEK – EXISTING CONDITIONS

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CATTAIL CREEK – EXISTING CONDITIONS

CATTAIL CREEK – PROPOSED CONDITIONS

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HOW IS STREAM RESTORATION ACHIEVED?

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CATTAIL CREEK – AS-BUILT CONDITIONS

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CATTAIL CREEK – AS-BUILT CONDITIONS

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CATTAIL CREEK – AS-BUILT CONDITIONS

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CATTAIL CREEK – AS-BUILT CONDITIONS

CATTAIL CREEK – AS-BUILT CONDITIONS

CATTAIL CREEK – AS-BUILT CONDITIONS

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CATTAIL CREEK – AS-BUILT CONDITIONS

MONITORING & RESEARCH

PROJECT REMOVES:

45.8% PHOSPHORUS

49.7% NITROGEN

73.8% SEDIMENT

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The multiscale effects of stream restoration on water quality

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ARTICLE INFO

Keywords:
Stream restoration
Nutrient pollution
Stormwater
Best management practice
Total mean daily loads
Chesapeake Bay

ABSTRACT

Stream restoration is often considered as an effective watershed management tool to reduce riverine loads of nitrogen, phosphorus, and suspended sediments, and meet government-mandated water quality goals. However, despite the billions of dollars which have been spent on stream restoration, questions remain about its effectiveness for improving water quality, as many studies report either mixed success or lack the adequate methodological framework to detect water quality improvements. In this study, we measured fluxes of nutrients and sediment in an eroded stream before and after restoration by filling the eroded channel with a mixture of sand, gravel, and woodchips stabilized with rock weirs at intervals along the channel. Our monitoring design used a before-after-control-impact (BACI) approach at two spatial scales, one at the reach-scale, and one farther downstream to detect whether reach-scale changes in nutrient and sediment loads propagated downstream. At the reach scale, we found that the restoration enhanced stream function, removing 44.8% of the phosphate, 45.8% of the total phosphorus, 48.3% of the ammonium, 25.7% of the nitrate, 49.7% of the total nitrogen, and 73.8% of the suspended sediment. However, due to hydrological variance, monitoring stations farther downstream suggested no detectable changes at the larger spatial scale relative to a reference stream, which highlights the challenges of detecting watershed-scale responses to small-scale stream restoration projects. This study provides a methodological framework for evaluating the effect of stream restoration on water quality at multiple scales and shows that reach-scale improvements may not be detectable at watershed-scales.

1. Introduction

Streams are unique as they are both receptors of watershed discharge, and chemically and biologically reactive conveyances that transport and transform water, nutrients, and particulate matter from terrestrial environments to larger water bodies (Cole et al., 2007, Gibson et al., 2015, Gomi et al., 2002). In the urban-suburban environment, increased development of impervious surfaces has disrupted the natural ability of streams and their floodplains to process nutrients and sequester sediment due to increased peak flows, reduced base flows, and enhanced channel erosion, which together limit water transit time and decrease habitat for organisms responsible for the biological retention of nutrients (Galster et al., 2006, Shuster et al., 2005, Walsh et al., 2005a).

Historically, urban storm water has been managed primarily via rapid transmission of storm water to streams to prevent flooding (Dunne and Leopold, 1978). The increasing recognition that urbanization and historical storm water management systems continue to cause negative impacts on the ecological health of freshwaters has led to an increased push for retrofitting urban and suburban landscapes with green infrastructure, such as storm water detention ponds, to ameliorate the negative impacts of urbanization on receiving waters (Weber et al., 2006, Walsh et al., 2005b). Some studies have reported the relative success of green infrastructure in reducing nutrient and sediment discharges to streams at the watershed scale (Pennino et al., 2016, Dietz and Clausen, 2008).

Data from a recent study encompassing the period 1945–2012 indicated that although nitrogen loading within the Chesapeake Bay is beginning to decline, the reductions still lag behind many comparable estuaries undergoing intense management (Harding et al., 2016). As part of a push to improve water quality, the Chesapeake watershed Total Maximum Daily Load (TMDLs), adopted in 2010, have dictated pollutant reduction requirements of 25% for total nitrogen (TN), 24% for total phosphorus (TP), and 20% for total suspended sediment (TSS). The U.S. Environmental Protection Agency (EPA) has set a tight timeline requiring the implementation of all necessary pollution control measures to achieve these levels by 2025 (https://www.epa.gov/chesapeake-bay-tmdl).

Within the mid-Atlantic region of the U.S., and particularly the coastal plain of the Chesapeake Bay watershed, stream restoration has become an increasingly used tool to improve water quality and meet water quality goals such as TMDLs by enhancing the natural pollutant-

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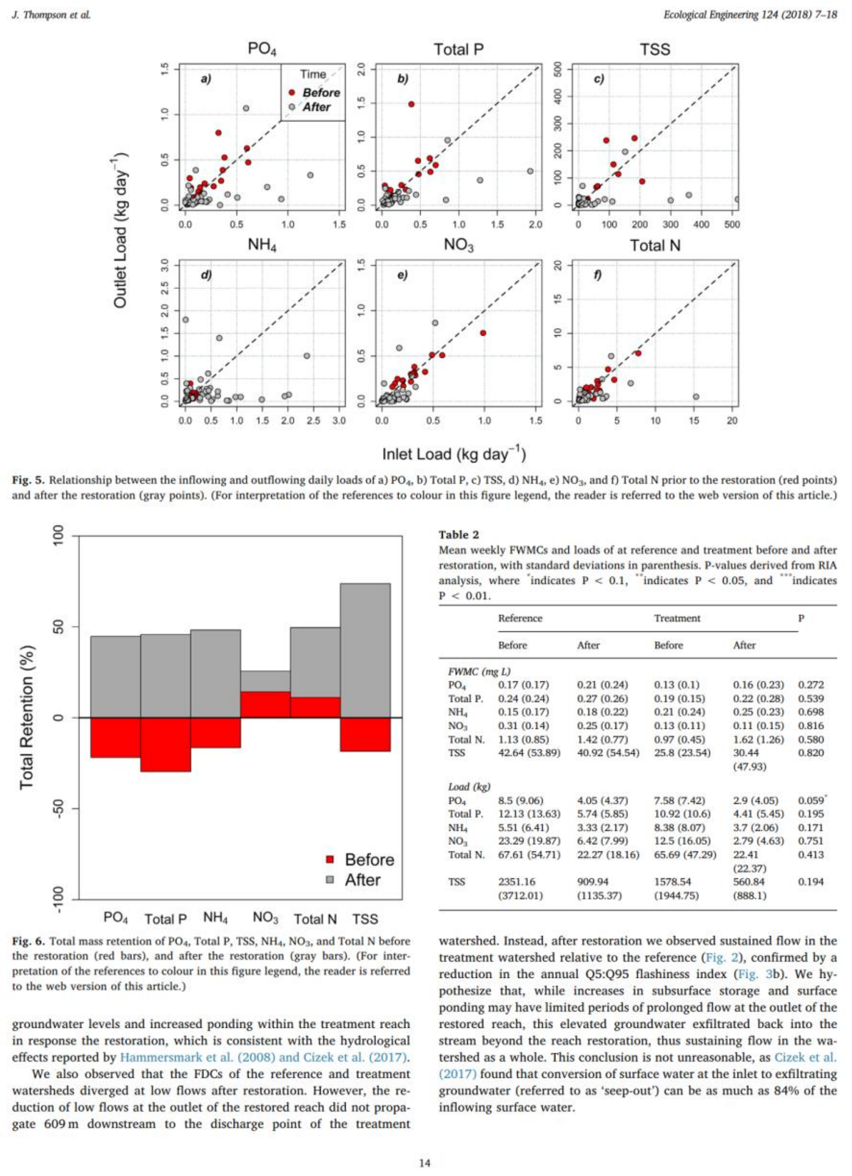

Fig. 5. Relationship between the inflowing and outflowing daily loads of a) PO$_4$, b) Total P, c) TSS, d) NH$_4$, e) NO$_3$, and f) Total N prior to the restoration (red points) and after the restoration (gray points). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 6. Total mass retention of PO$_4$, Total P, TSS, NH$_4$, NO$_3$, and Total N before the restoration (red bars), and after the restoration (gray bars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Mean weekly FWMCs and loads of at reference and treatment before and after restoration, with standard deviations in parenthesis. P-values derived from RIA analysis, where * indicates $P < 0.1$, ** indicates $P < 0.05$, and *** indicates $P < 0.01$.

	Reference		Treatment		P
	Before	After	Before	After	
FWMC (mg L)					
PO$_4$	0.17 (0.17)	0.21 (0.24)	0.13 (0.1)	0.16 (0.23)	0.272
Total P.	0.24 (0.24)	0.27 (0.26)	0.19 (0.15)	0.22 (0.28)	0.539
NH$_4$	0.15 (0.17)	0.18 (0.22)	0.21 (0.24)	0.25 (0.23)	0.698
NO$_3$	0.31 (0.14)	0.25 (0.17)	0.13 (0.11)	0.11 (0.15)	0.816
Total N.	1.13 (0.85)	1.42 (0.77)	0.97 (0.45)	1.62 (1.26)	0.580
TSS	42.64 (53.89)	40.92 (54.54)	25.8 (23.54)	30.44 (47.93)	0.820
Load (kg)					
PO$_4$	8.5 (9.06)	4.05 (4.37)	7.58 (7.42)	2.9 (4.05)	0.059*
Total P.	12.13 (13.63)	5.74 (5.85)	10.92 (10.6)	4.41 (5.45)	0.195
NH$_4$	5.51 (6.41)	3.33 (2.17)	8.38 (8.07)	3.7 (2.06)	0.171
NO$_3$	23.29 (19.87)	6.42 (7.99)	12.5 (16.05)	2.79 (4.63)	0.751
Total N.	67.61 (54.71)	22.27 (18.16)	65.69 (47.29)	22.41 (22.37)	0.413
TSS	2351.16 (3712.01)	909.94 (1135.37)	1578.54 (1944.75)	560.84 (888.1)	0.194

groundwater levels and increased ponding within the treatment reach in response the restoration, which is consistent with the hydrological effects reported by Hammersmark et al. (2008) and Cizek et al. (2017).

We also observed that the FDCs of the reference and treatment watersheds diverged at low flows after restoration. However, the reduction of low flows at the outlet of the restored reach did not propagate 609 m downstream to the discharge point of the treatment watershed. Instead, after restoration we observed sustained flow in the treatment watershed relative to the reference (Fig. 2), confirmed by a reduction in the annual Q5:Q95 flashiness index (Fig. 3b). We hypothesize that, while increases in subsurface storage and surface ponding may have limited periods of prolonged flow at the outlet of the restored reach, this elevated groundwater exfiltrated back into the stream beyond the reach restoration, thus sustaining flow in the watershed as a whole. This conclusion is not unreasonable, as Cizek et al. (2017) found that conversion of surface water at the inlet to exfiltrating groundwater (referred to as 'seep-out') can be as much as 84% of the inflowing surface water.

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MONITORING & RESEARCH

"Results of study provide evidence that RSCs decrease pollutant loads and **improve natural hydrological functions.**"

Increased baseflow by 6%, compared to a 6% loss of baseflow in the control

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Research papers

Changes in hydrology and pollutant loads from stream restoration in an urban headwater catchment

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Urban

ABSTRACT

Stream restoration structures can alter the hydrology and biogeochemical processes of urban headwater streams in important ways. As a stream restoration design, regenerative stormwater conveyance (RSC) structures are built to reconnect floodplains to stream channels, raise the groundwater table, and increase streamwater retention times. Altered hydrology and flow dynamics within restored stream reaches can affect solute concentrations and loads in baseflow and stormflow runoff. We monitored interannual changes in precipitation, groundwater and stream runoff before and after the implementation of a stream restoration using an RSC design in order to evaluate changes in hydrology and to estimate changes in solute loads of an urban headwater catchment in the Rock Creek watershed of Washington DC. A Before After Control Impact (BACI) experimental design was used. Compared to the control catchment, average recharge of the groundwater system of the RSC riparian area increased by 0.76 m in the post-restoration period and contributed to a 6 % increase in baseflow as a percentage of total runoff (compared to a decrease of 6 % in the control catchment). Area yields from the pre- to the post-restoration monitoring period decreased in both the RSC and control catchments, but significantly larger decreases in total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) occurred in the RSC catchment (i.e., −59 % vs −23 %, −54 % vs −28 %, and −76 % vs −40 %, respectively). Results of this study indicate that RSCs as stream restoration structures in degraded headwater catchments can result in important hydrological and biogeochemical changes that significantly reduce nutrient and sediment loads.

1. Introduction

The chemical composition of stream water in predominately urban and agricultural landscapes is an integration of naturally derived solutes and pollutants from various watershed land uses and disturbances (Allan, 2004, Williams et al., 2005). Key pollutants such as nitrogen (N), phosphorus (P) and sediments/solids in stream water generally increase with the extent of watershed development (Paul and Meyer 2001, Sweeney et al., 2004, Shuster et al., 2005, Grimm et al., 2005, Lowe and Likens 2005, Meyer et al., 2005, Williamson et al., 2008). Although the mechanisms responsible for this degradation vary according to the type of landscape and stressors (Walsh et al., 2005, Wenger et al., 2009, Walsh et al., 2012, Palmer et al., 2014), it is well known that increased stormwater runoff and resultant pollutant loads to streams associated with watershed development commonly deteriorate physical habitat conditions and ecological processes (Doyle et al., 2000, Poff and Zimmerman 2010, Vietz et al., 2012).

Although it has been shown that traditional stream restoration designs where in-stream structures are used to stabilize the existing channel have a limited capacity to reduce pollutant export (Bernhardt et al., 2005, Kenney et al., 2012), some novel designs may be more effective as a watershed management strategy to recover biophysical conditions and decrease pollutant loads (Craig et al., 2008). Designs increasingly used in urban watersheds of the mid-Atlantic (viz., Maryland) include regenerative stormwater conveyances (RSCs), valley restorations, and stream-wetland complexes (Filoso and Palmer 2011, Filoso et al., 2015, Williams et al., 2017). These designs are commonly used because they modify the hydrology and hydraulics of streams such that they may not only help prevent channel erosion (Smith et al., 2010), but also potentially enhance nutrient processing and retain suspended materials (i.e., sediment and solids) that would otherwise be transported to receiving waters that have become eutrophic with chronic turbidity problems resulting from these inputs (e.g., Chesapeake Bay; Williams et al., 2017).

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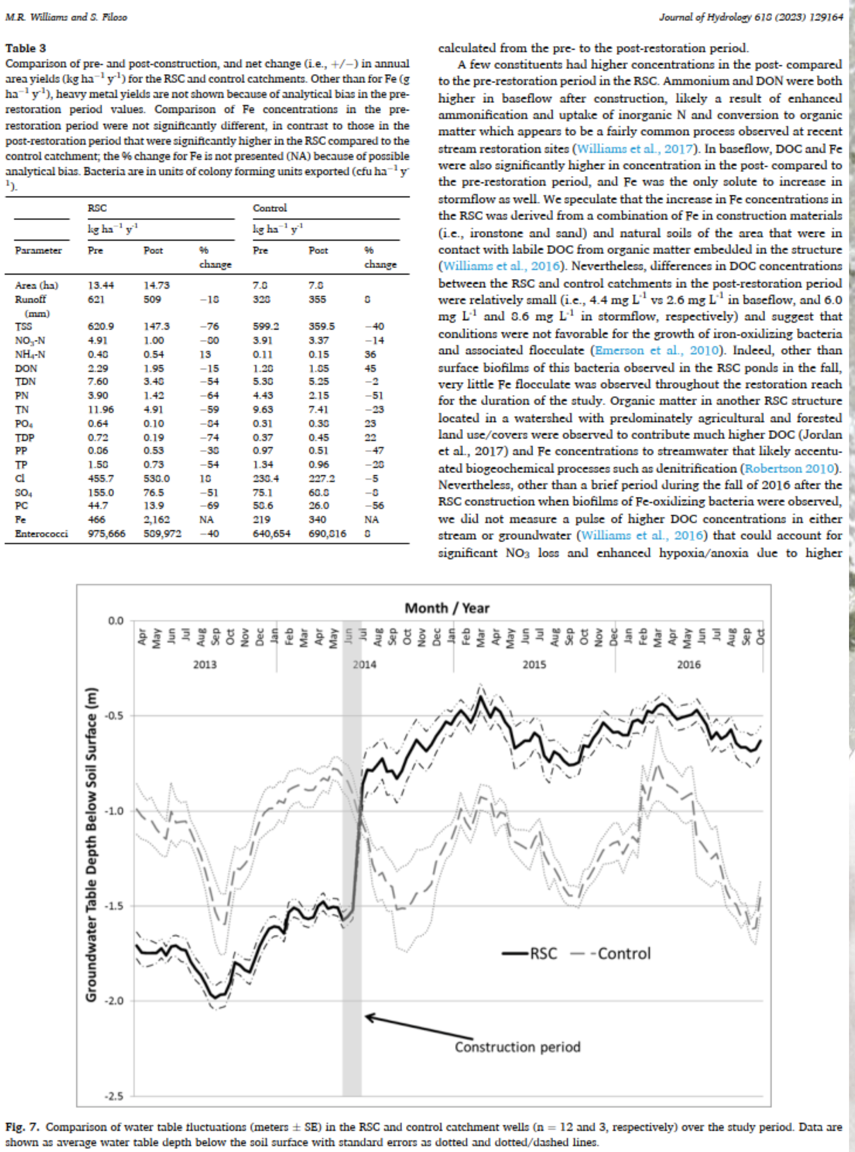

Table 3
Comparison of pre- and post-construction, and net change (i.e., +/−) in annual area yields (kg ha^{-1} y^{-1}) for the RSC and control catchments. Other than for Fe (g ha^{-1} y^{-1}), heavy metal yields are not shown because of analytical bias in the pre-restoration period values. Comparison of Fe concentrations in the pre-restoration period were not significantly different, in contrast to those in the post-restoration period that were significantly higher in the RSC compared to the control catchment; the % change for Fe is not presented (NA) because of possible analytical bias. Bacteria are in units of colony forming units exported (cfu ha^{-1} y^{-1}).

	RSC			Control		
	kg ha^{-1} y^{-1}			kg ha^{-1} y^{-1}		
Parameter	Pre	Post	% change	Pre	Post	% change
Area (ha)	13.44	14.73		7.8	7.8	
Runoff (mm)	621	509	−18	328	355	8
TSS	620.9	147.3	−76	599.2	359.5	−40
NO_3-N	4.91	1.00	−80	3.91	3.37	−14
NH_4-N	0.48	0.54	13	0.11	0.15	36
DON	2.29	1.95	−15	1.28	1.85	45
TDN	7.60	3.48	−54	5.38	5.25	−2
PN	3.90	1.42	−64	4.43	2.15	−51
TN	11.96	4.91	−59	9.63	7.41	−23
PO_4	0.64	0.10	−84	0.31	0.38	23
TDP	0.72	0.19	−74	0.37	0.45	22
PP	0.86	0.53	−38	0.97	0.51	−47
TP	1.58	0.73	−54	1.34	0.96	−28
Cl	455.7	538.0	18	238.4	227.2	−5
SO_4	155.0	76.5	−51	75.1	68.8	−8
PC	44.7	13.9	−69	58.6	26.0	−56
Fe	466	2,162	NA	219	340	NA
Enterococci	975,666	509,972	−40	640,654	690,816	8

calculated from the pre- to the post-restoration period.

A few constituents had higher concentrations in the post- compared to the pre-restoration period in the RSC. Ammonium and DON were both higher in baseflow after construction, likely a result of enhanced ammonification and uptake of inorganic N and conversion to organic matter which appears to be a fairly common process observed at recent stream restoration sites (Williams et al., 2017). In baseflow, DOC and Fe were also significantly higher in concentration in the post- compared to the pre-restoration period, and Fe was the only solute to increase in stormflow as well. We speculate that the increase in Fe concentrations in the RSC was derived from a combination of Fe in construction materials (i.e., ironstone and sand) and natural soils of the area that were in contact with labile DOC from organic matter embedded in the structure (Williams et al., 2016). Nevertheless, differences in DOC concentrations between the RSC and control catchments in the post-restoration period were relatively small (i.e., 4.4 mg L^{-1} vs 2.6 mg L^{-1} in baseflow, and 6.0 mg L^{-1} and 8.6 mg L^{-1} in stormflow, respectively) and suggest that conditions were not favorable for the growth of iron-oxidizing bacteria and associated flocculate (Emerson et al., 2010). Indeed, other than surface biofilms of this bacteria observed in the RSC ponds in the fall, very little Fe flocculate was observed throughout the restoration reach for the duration of the study. Organic matter in another RSC structure located in a watershed with predominately agricultural and forested land use/covers were observed to contribute much higher DOC (Jordan et al., 2017) and Fe concentrations to streamwater that likely accentuated biogeochemical processes such as denitrification (Robertson 2010). Nevertheless, other than a brief period during the fall of 2016 after the RSC construction when biofilms of Fe-oxidizing bacteria were observed, we did not measure a pulse of higher DOC concentrations in either stream or groundwater (Williams et al., 2016) that could account for significant NO_3 loss and enhanced hypoxia/anoxia due to higher

Fig. 7. Comparison of water table fluctuations (meters ± SE) in the RSC and control catchment wells (n = 12 and 3, respectively) over the study period. Data are shown as average water table depth below the soil surface with standard errors as dotted and dotted/dashed lines.

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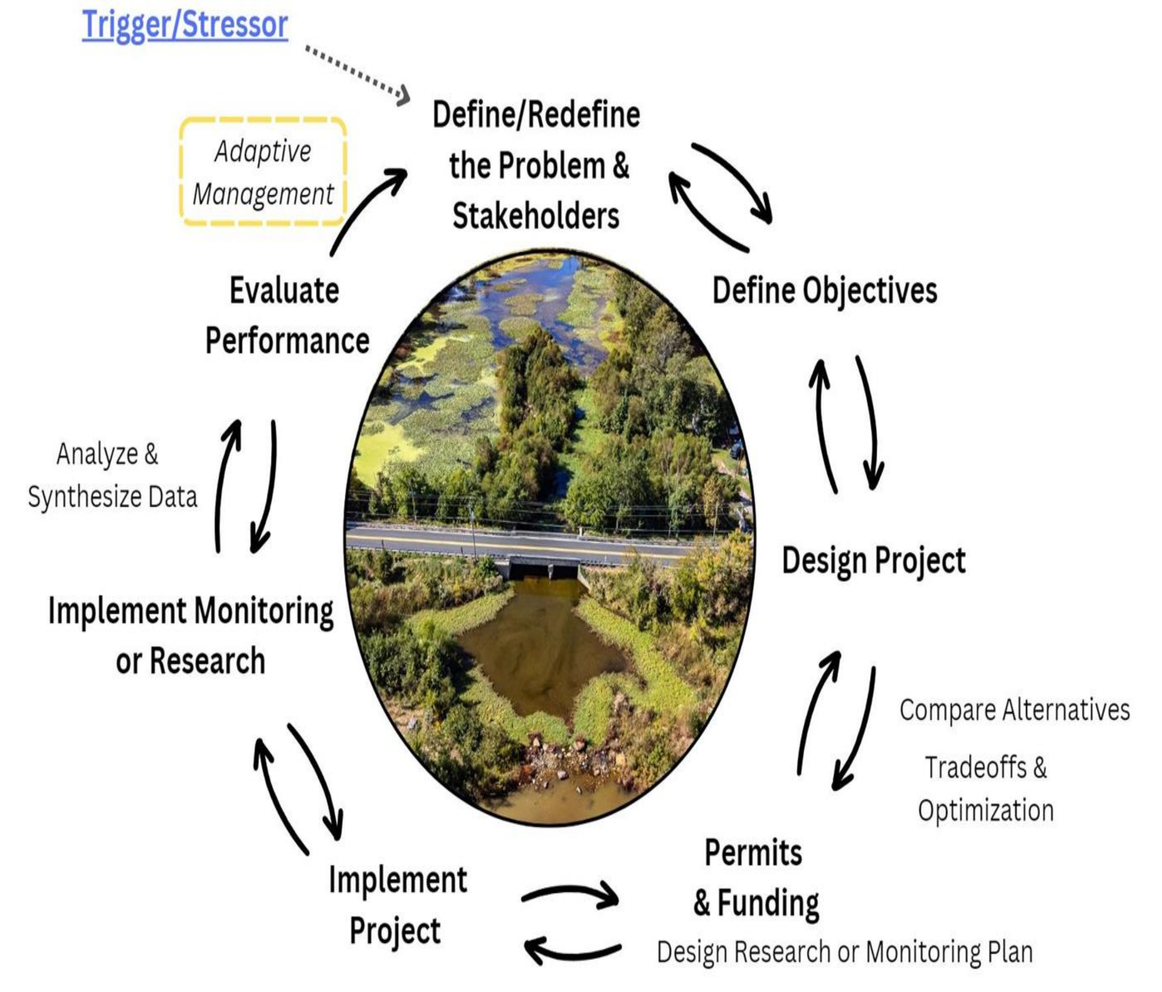
ADAPTIVE MANAGEMENT



Trigger/Stressor

Adaptive Management

Define/Redefine the Problem & Stakeholders

Define Objectives

Design Project

Compare Alternatives

Tradeoffs & Optimization

Permits & Funding

Design Research or Monitoring Plan

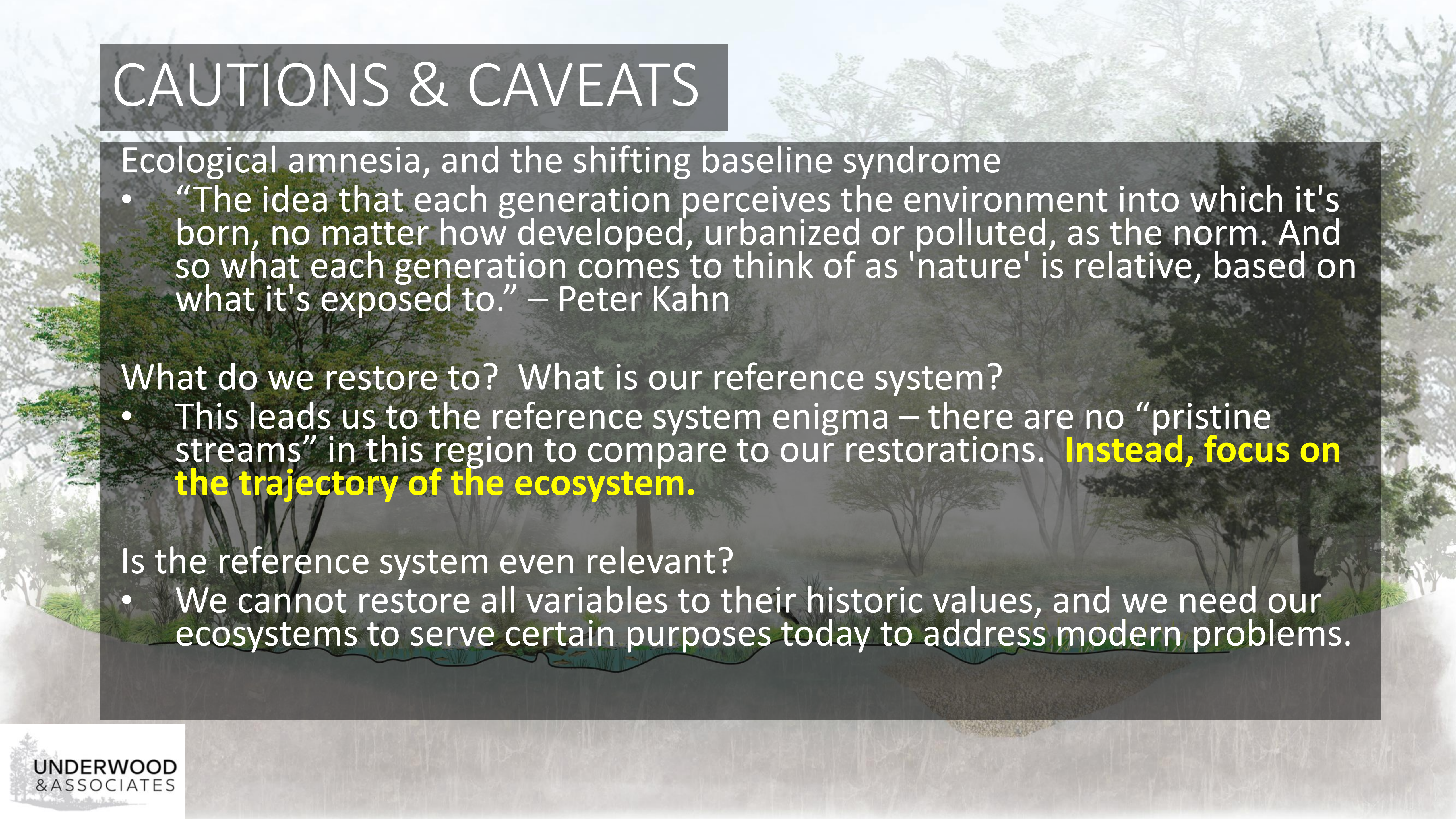
Implement Project

Implement Monitoring or Research

Analyze & Synthesize Data

Evaluate Performance

- We might not always get it right the first time due to the complexity of nature, or due to factors outside of our control
- Monitoring & research inform adaptive management and continue afterwards to inform future needs
- Common adaptive management:
  - Re-plantings
  - Invasive species removal
  - Repair grade controls



CAUTIONS & CAVEATS

Ecological amnesia, and the shifting baseline syndrome

- "The idea that each generation perceives the environment into which it's born, no matter how developed, urbanized or polluted, as the norm. And so what each generation comes to think of as 'nature' is relative, based on what it's exposed to." – Peter Kahn

What do we restore to? What is our reference system?

- This leads us to the reference system enigma – there are no "pristine streams" in this region to compare to our restorations. **Instead, focus on the trajectory of the ecosystem.**

Is the reference system even relevant?

- We cannot restore all variables to their historic values, and we need our ecosystems to serve certain purposes today to address modern problems.

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CAUTIONS & CAVEATS

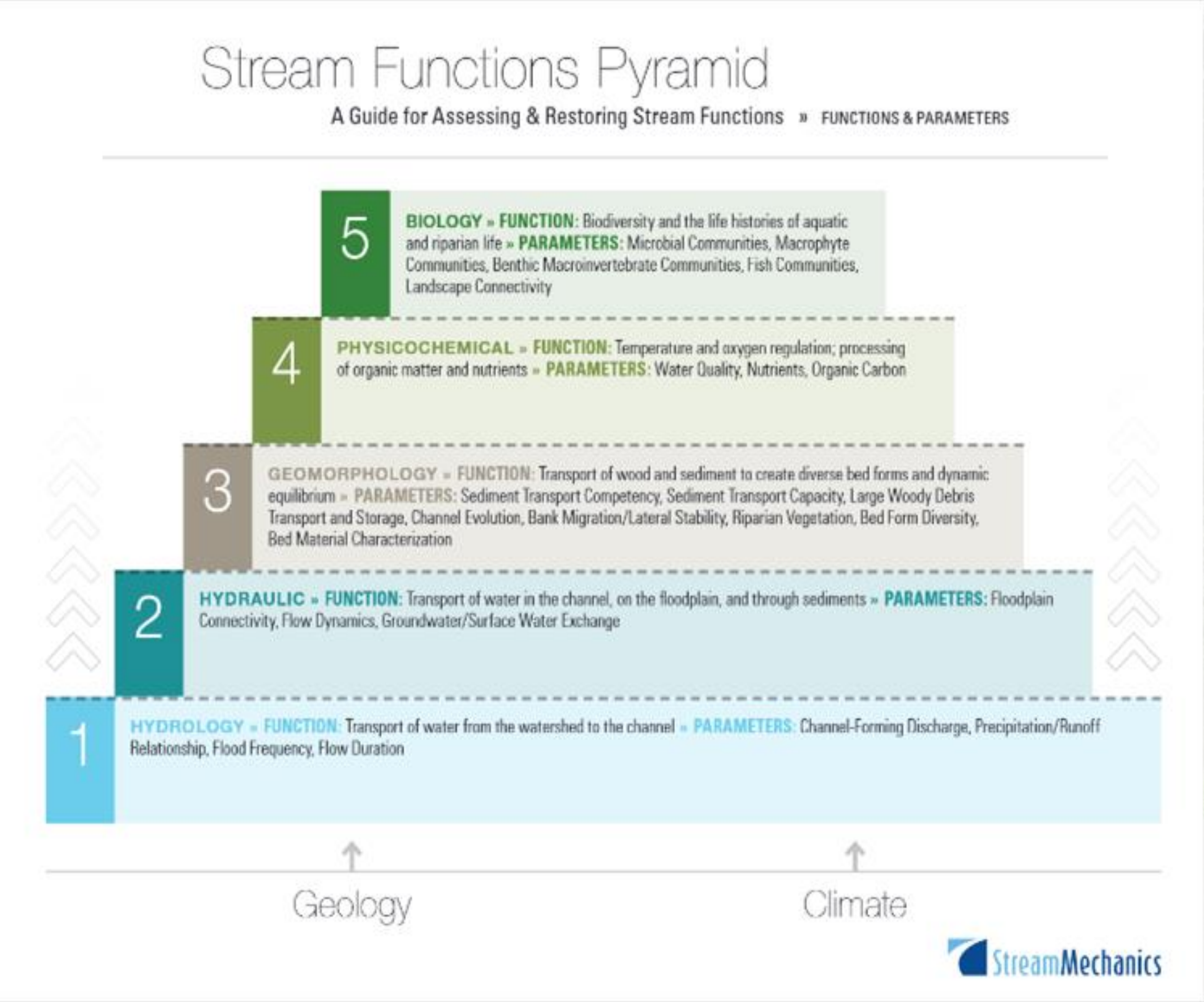
Due to changes in hydrology, what appears to be a stream now may not have been a stream yesterday.

When comparing restorations of new ephemeral streams back into wetland complexes, use the correct comparisons to measure success.

CAUTIONS & CAVEATS

In urban stream corridors, our goal should be to manipulate the stream valley to provide as much of the historic functions as possible in the modern context.

BUT - Restoration potential for urban stream valleys is limited by development that has encroached upon floodplains and the upstream contributing drainage area.



Stream Functions Pyramid

A Guide for Assessing & Restoring Stream Functions » FUNCTIONS & PARAMETERS

5 **BIOLOGY » FUNCTION:** Biodiversity and the life histories of aquatic and riparian life » **PARAMETERS:** Microbial Communities, Macrophyte Communities, Benthic Macroinvertebrate Communities, Fish Communities, Landscape Connectivity

4 **PHYSICOCHEMICAL » FUNCTION:** Temperature and oxygen regulation; processing of organic matter and nutrients » **PARAMETERS:** Water Quality, Nutrients, Organic Carbon

3 **GEOMORPHOLOGY » FUNCTION:** Transport of wood and sediment to create diverse bed forms and dynamic equilibrium » **PARAMETERS:** Sediment Transport Competency, Sediment Transport Capacity, Large Woody Debris Transport and Storage, Channel Evolution, Bank Migration/Lateral Stability, Riparian Vegetation, Bed Form Diversity, Bed Material Characterization

2 **HYDRAULIC » FUNCTION:** Transport of water in the channel, on the floodplain, and through sediments » **PARAMETERS:** Floodplain Connectivity, Flow Dynamics, Groundwater/Surface Water Exchange

1 **HYDROLOGY » FUNCTION:** Transport of water from the watershed to the channel » **PARAMETERS:** Channel-Forming Discharge, Precipitation/Runoff Relationship, Flood Frequency, Flow Duration

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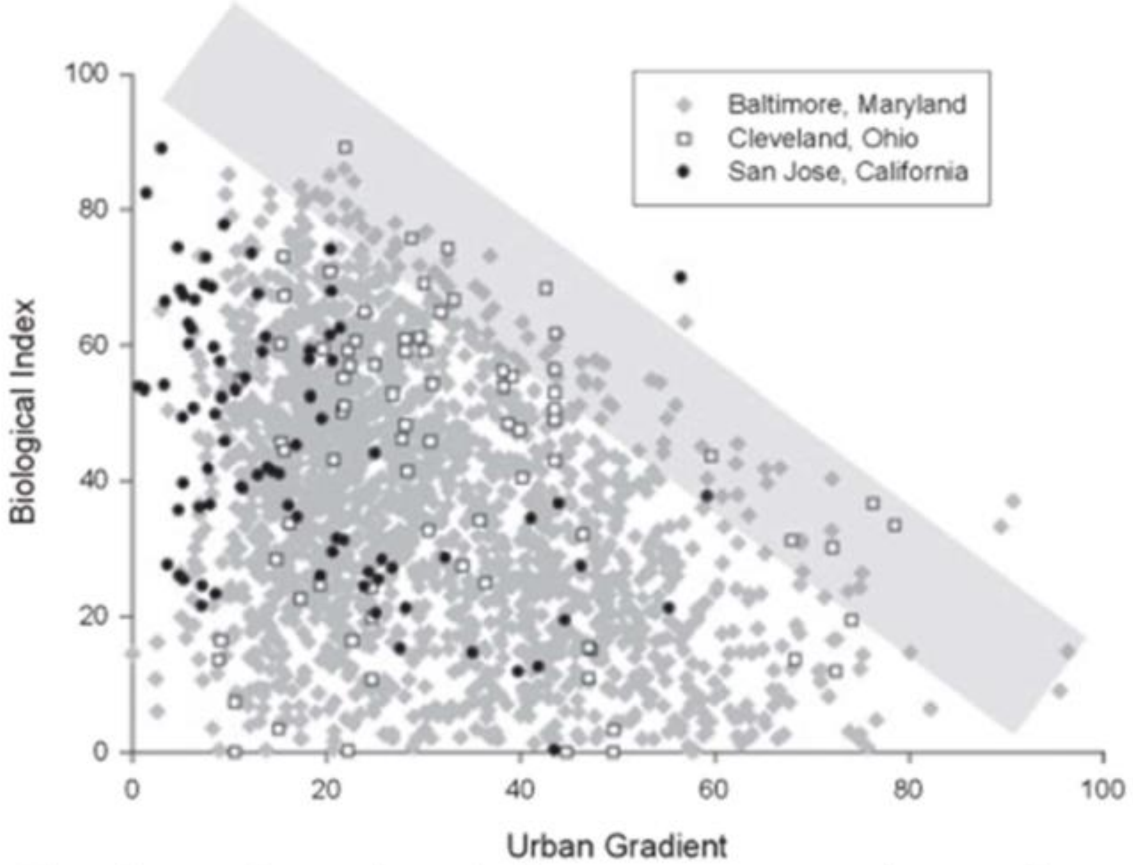
CAUTIONS & CAVEATS

Stream restoration is not a miracle cure. We must moderate our expectations for a site based on its restoration potential.

Within urbanized watersheds, restoration to 'pristine' biology may be out of our reach - but we can restore basic ecosystem functions.



Plot of macroinvertebrate index response to an urban gradient in 3 biomes across the US. From Paul et al. 2009.

Paul, M.J., D.W. Bressler, A.H. Purcell, M.T. Barbour, E.T. Rankin, and V.H. Resh. 2009. Assessment tools for urban catchments: defining observable biological potential. *Journal of the American Water Resources Association* 45(2): 320-330

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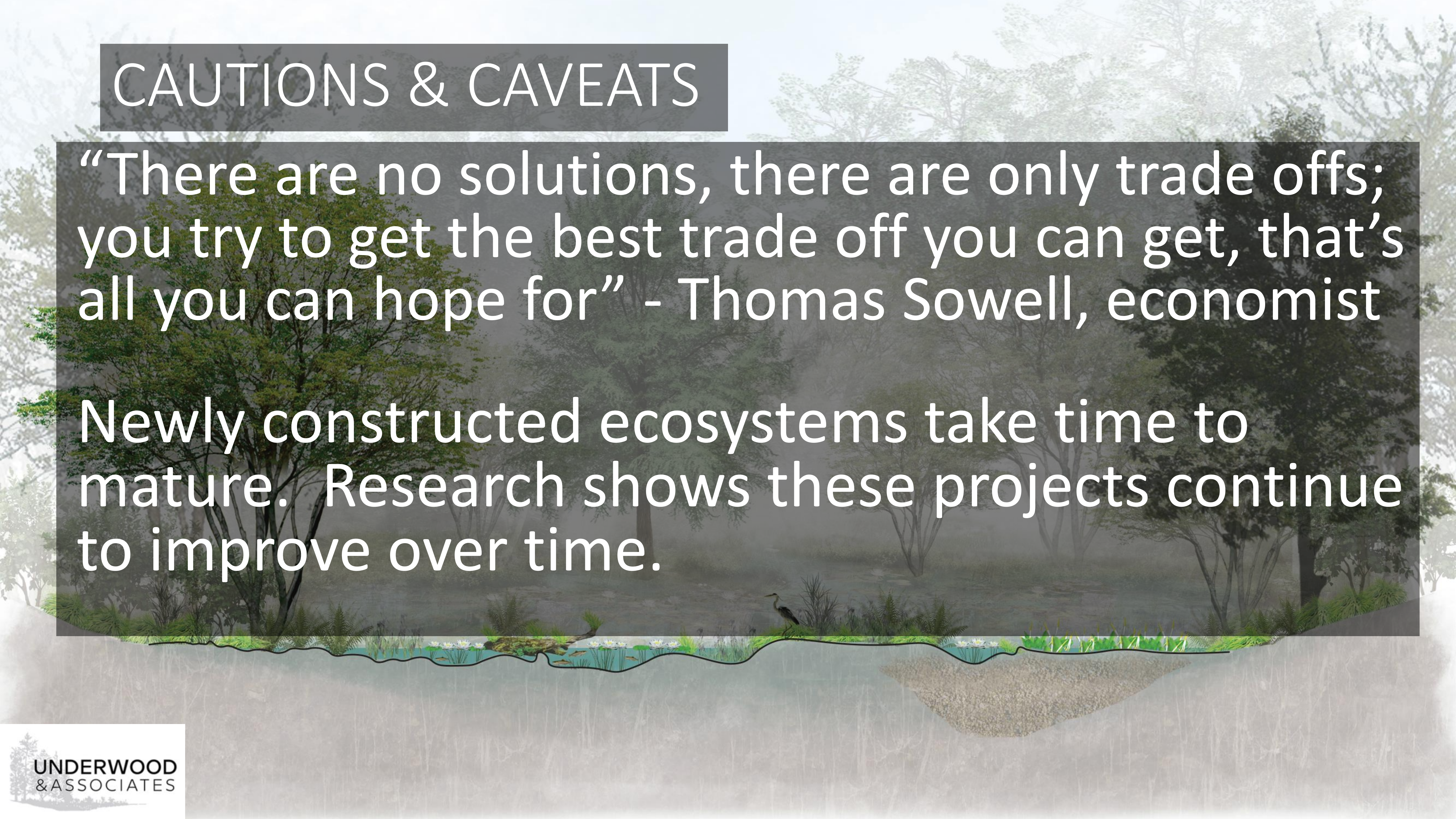

CAUTIONS & CAVEATS

"There are no solutions, there are only trade offs; you try to get the best trade off you can get, that's all you can hope for" - Thomas Sowell, economist

Newly constructed ecosystems take time to mature. Research shows these projects continue to improve over time.

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- FOR MORE INFORMATION VISIT ECOSYSTEMRESTORATION.COM
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- CONTACT ME AT KEITH.BINSTED@ECOSYSTEMRESTORATION.COM

SCAN ME

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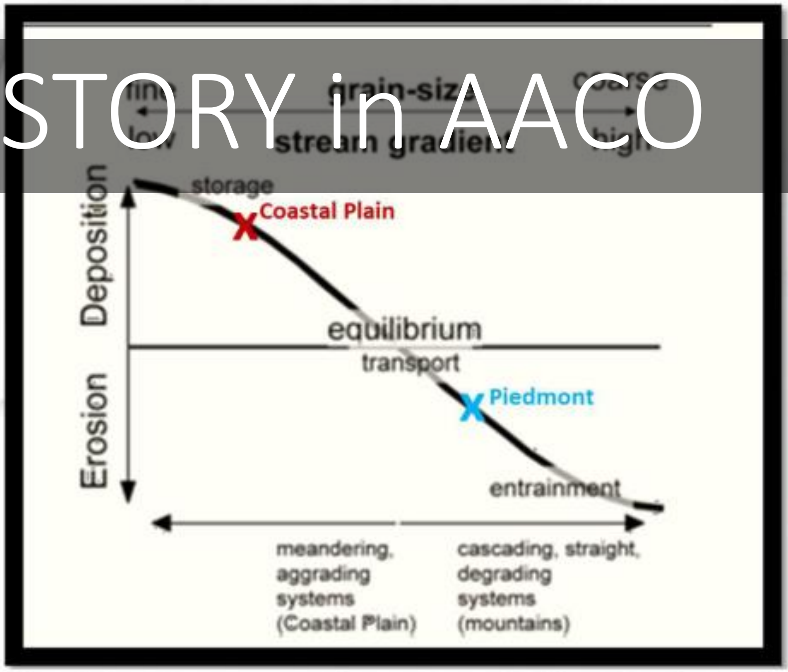
STREAM / WATERSHED HISTORY in AACO

Coastal Plain histories

Legacy sediment is standard for Coastal Plain

- Colonial deep water ports now miles from navigation
  - Siltation problem recognized in law by 1750s
- Over 800 land acres were added to Maryland alone between 1845 and 1938 (Gottschalk 1945)
- USGS-BWPR project in Anne Arundel County
  - Floodplains contain meters of legacy sediments
  - Stream beds on top of legacy sediments
  - Precolonial soils deep below ground, invisible
  - Very different floodplain environment, alder-fern wooded swamps, buried bogs. Large wood piles.

Preliminary Information-Subject to Revision. Not for Citation or Distribution.



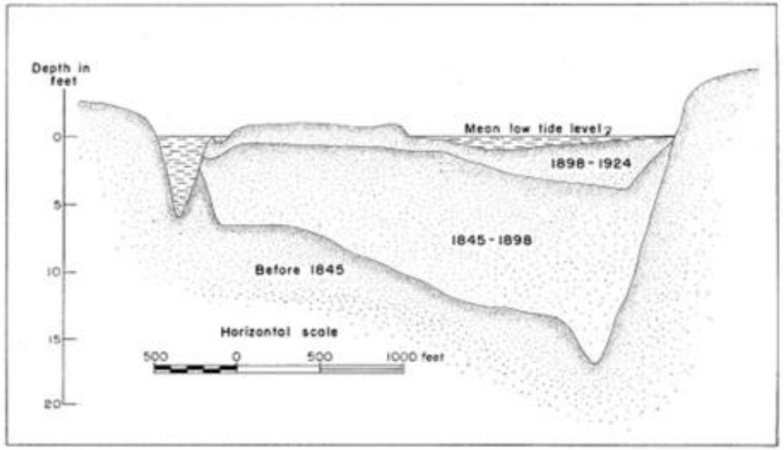


FIG. 5—Sedimentation of the Patapsco River arm of Baltimore harbor near the Hanover Street bridge.

(Gottschalk 1945)