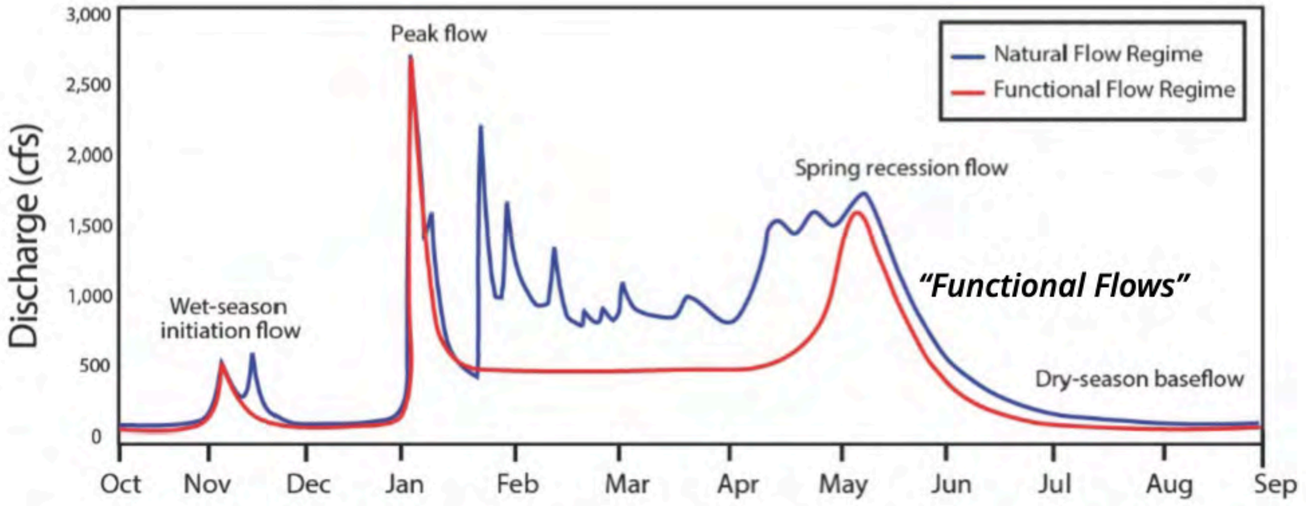
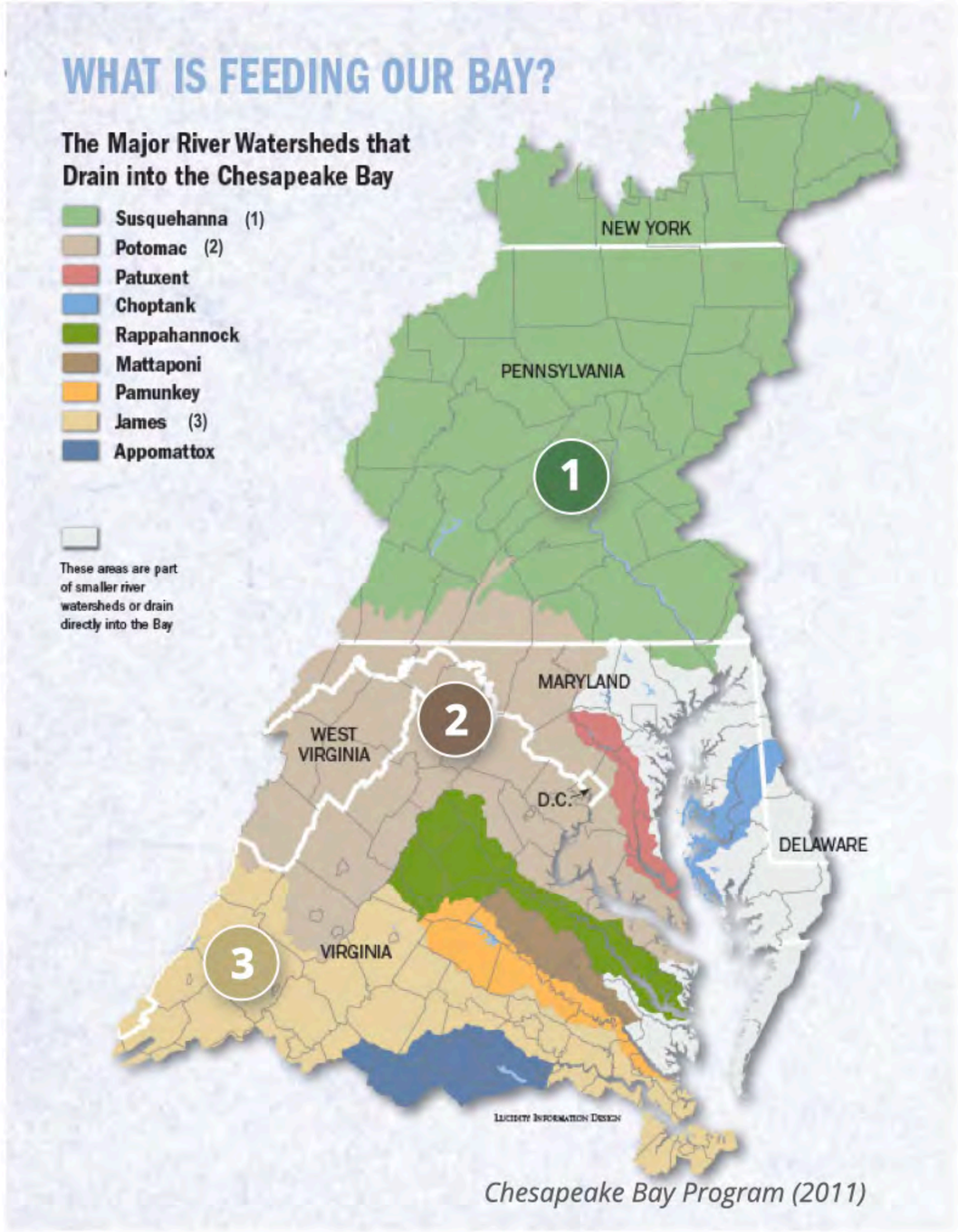
Environmental Flows

- **Careful evaluation and integration of competing uses** is required to allocate a portion of water to meet society's need for water supply, crop production, energy generation, recreation, and flood management.

- Environmental flow management means making decisions that (1) **minimize** ecological impacts of new water developments, (2) **direct** water development to least-sensitive water bodies, and (3) **prioritize** flow restoration efforts.

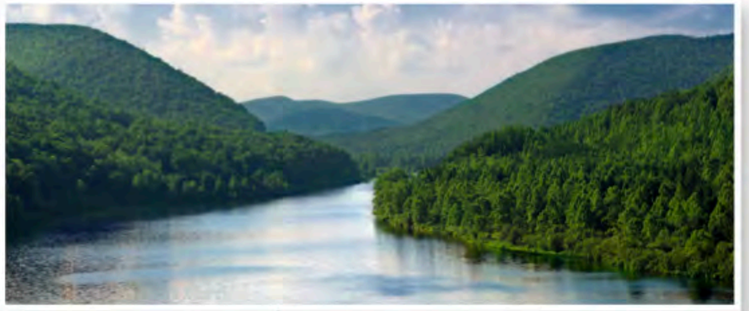


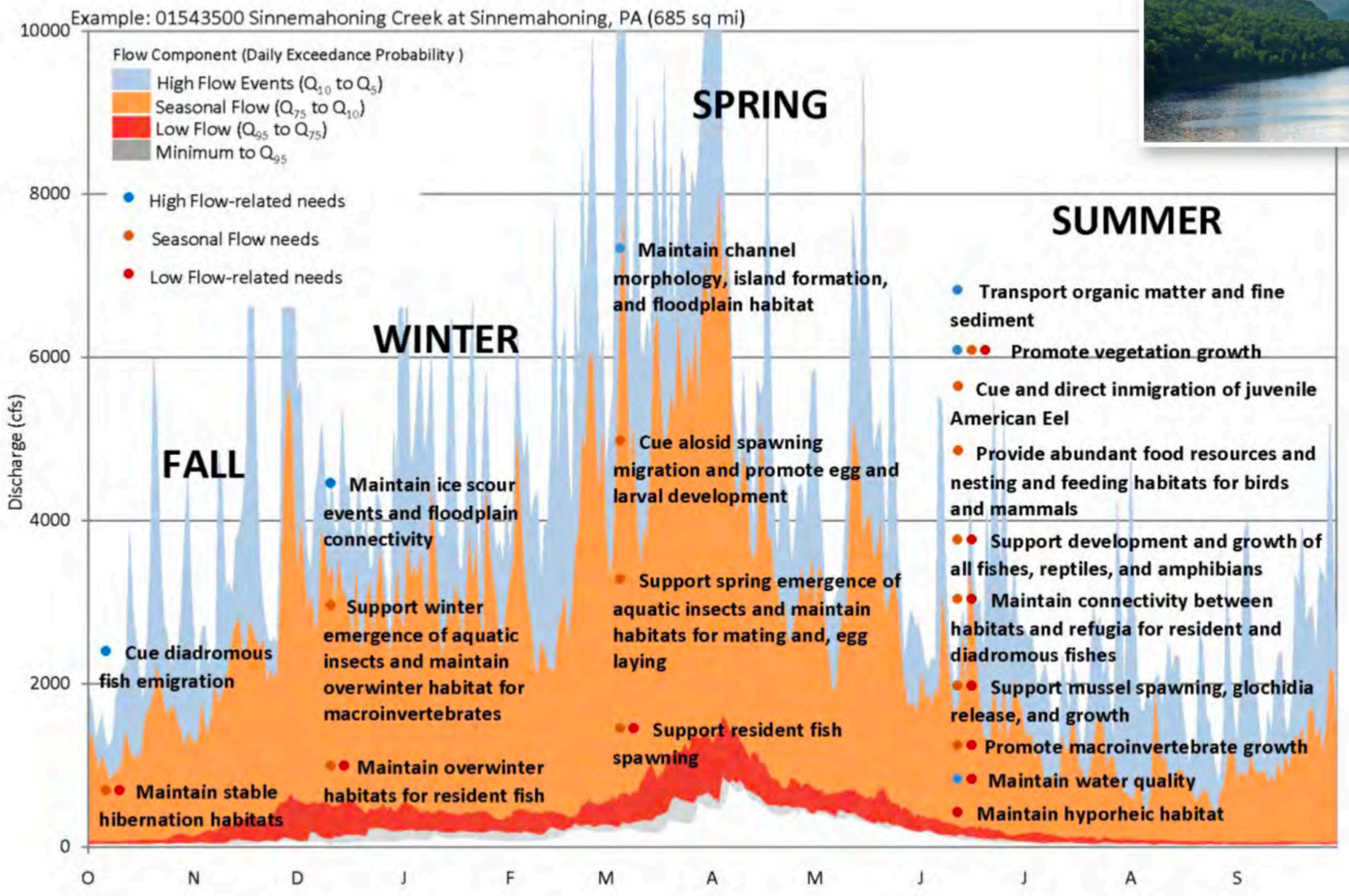
Yellen et. al. (2015)



Chesapeake Bay Program (2011)

From: DePhilip, M. and Moberg, T., The Nature Conservancy, 2010)





Ecological Limits Of Hydrologic Alteration (ELOHA)

SCIENTIFIC PROCESS

Step 1. Hydrologic Foundation

Baseline Hydrographs

Hydrologic Model and Stream Gauges

Developed Hydrographs

Step 2. Stream Classification

Stream Hydrologic Classification

Geomorphic Stratification

Step 3. Flow Alteration

Degree of Hydrologic Alteration

Hydrologic Alteration by River Type

Monitoring

Step 4. Flow-Ecology Relationships

Flow - Ecology Hypotheses

Ecological Data and Indices

Flow Alteration-Ecological Response Relationships by River Type

SOCIAL PROCESS

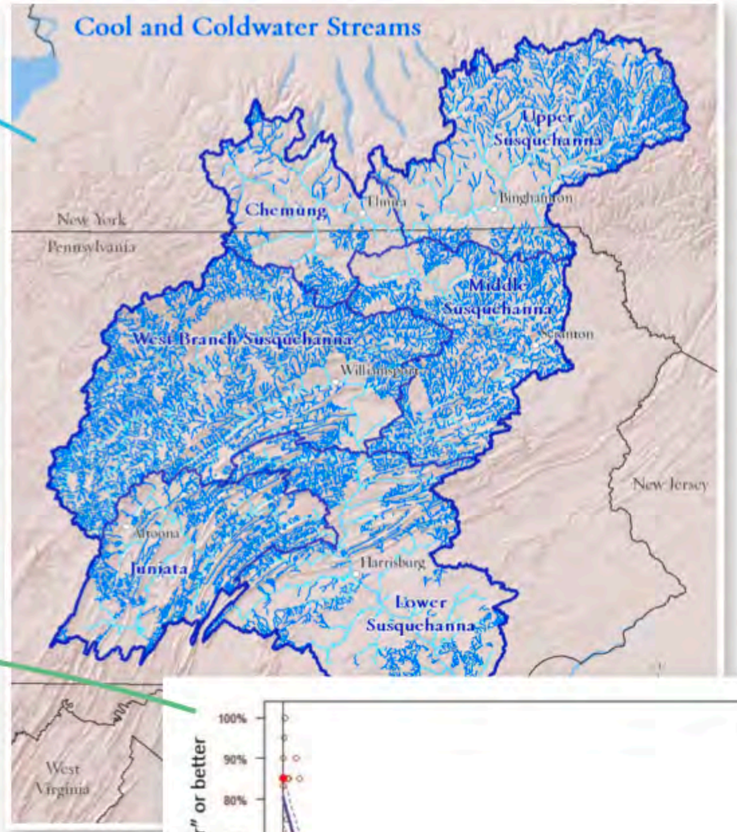
Implementation

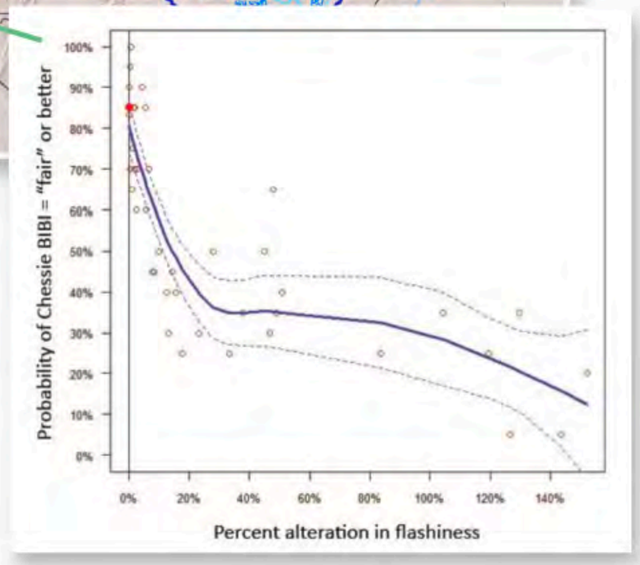
Environmental Flow Standards

Acceptable Ecological Conditions

Societal Values and Management Needs

Adaptive Adjustments





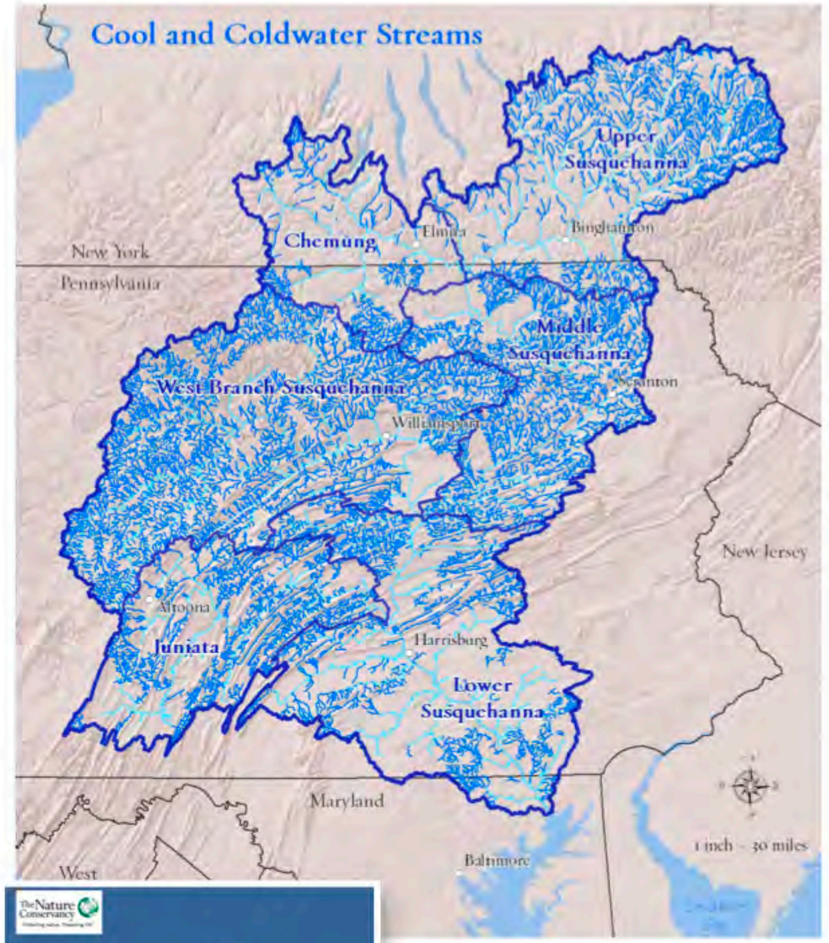
From: Poff et. al. (2010)

River type classification

Group segments into ecologically similar natural streams

Table 2.1 Source classes and designations combined into basinwide stream classification.

Headwater and Small Stream type	Source Classification and Class or Designation
Cool and coldwater streams	Pennsylvania - all streams designated as cold water fisheries (CWF) (25 Pa Code § 93) New York – all streams with designated use T (trout) or TS (trout-spawning) (NYCRR Part 701) Maryland – any streams with designated use III (Nontidal Cold Water) or III-P: (Nontidal Cold Water and Public Water Supply) (COMAR 26.08.02)
Warmwater streams	Pennsylvania – all streams designated as warm water fisheries (WWF) New York – all streams (Class A, B, C, D) and not designated as T or TS Maryland – all warmwater streams in Olivero and Anderson (2008) and not designated III or III-P
High baseflow streams	All “Class 2” streams in USGS HIP classification for Pennsylvania (described in Apse et al. 2008)

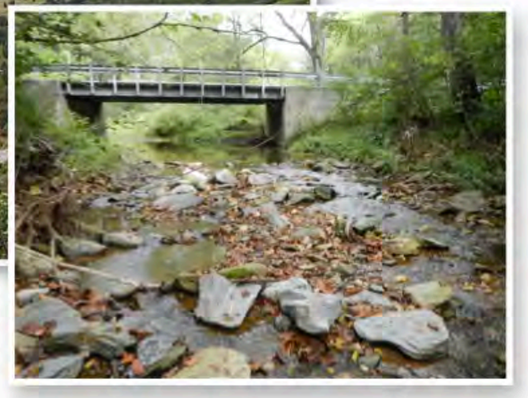


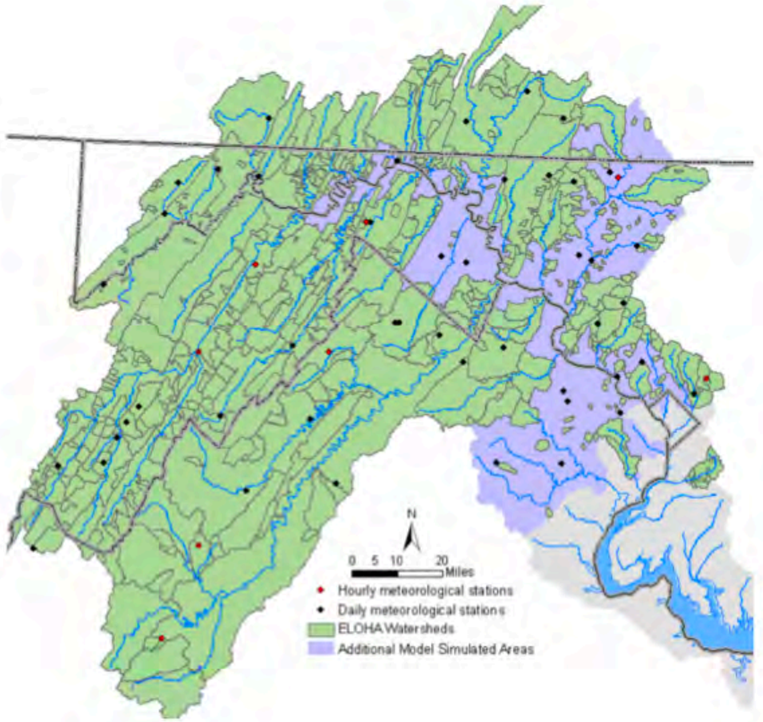
Ecological Flow Recommendations (EFRs) study led by The Nature Conservancy (TNC), Susquehanna RIver Basin Commission (SRBC) and US Army Corps of Engineers.

(DePhilip, M. and Moberg, T., The Nature Conservancy, 2010)

Potomac River Environmental Flow Assessment (2011)

- Stream macroinvertebrates respond strongly to alteration in the duration and frequency of both high and low flow events, rise rate, flashiness, and magnitude of high flow events.
- Flow alteration-ecological relationships were developed for combinations of **six flow metrics** and **seven macroinvertebrate metrics**.
- Findings indicate that of the seven macroinvertebrate metrics, percent scrapers, percent clingers, and the Chessie BIBI were most responsive to flow alteration.
- **Degraded habitat** and **water quality conditions** modify and, if strong enough, conceal the flow alteration-ecological relationships.
- Water quality and habitat improvements can potentially ameliorate the impacts of increased flow alteration.

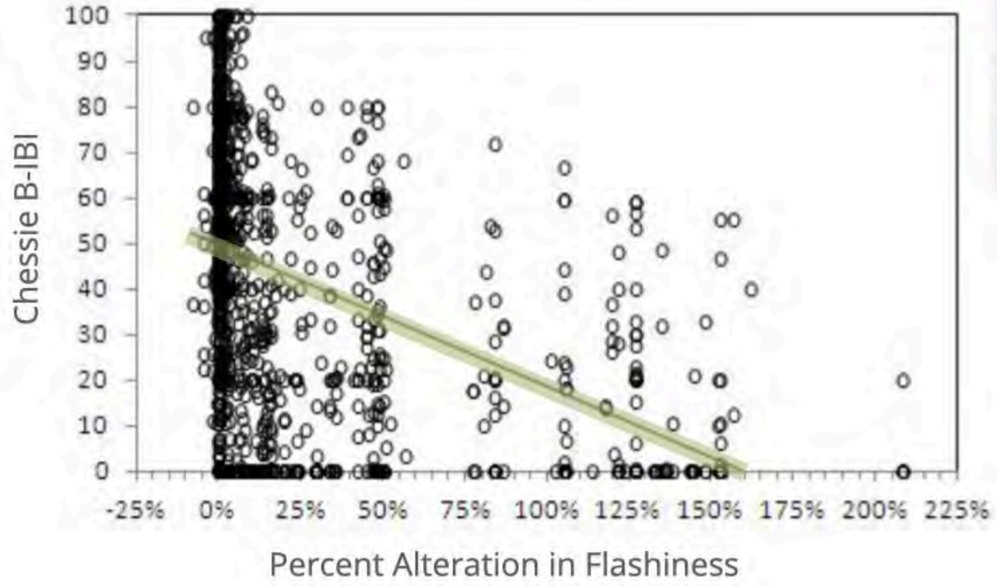


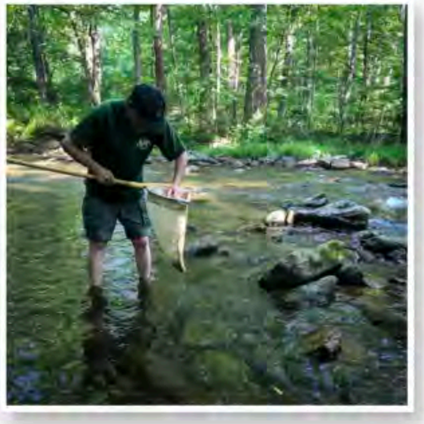


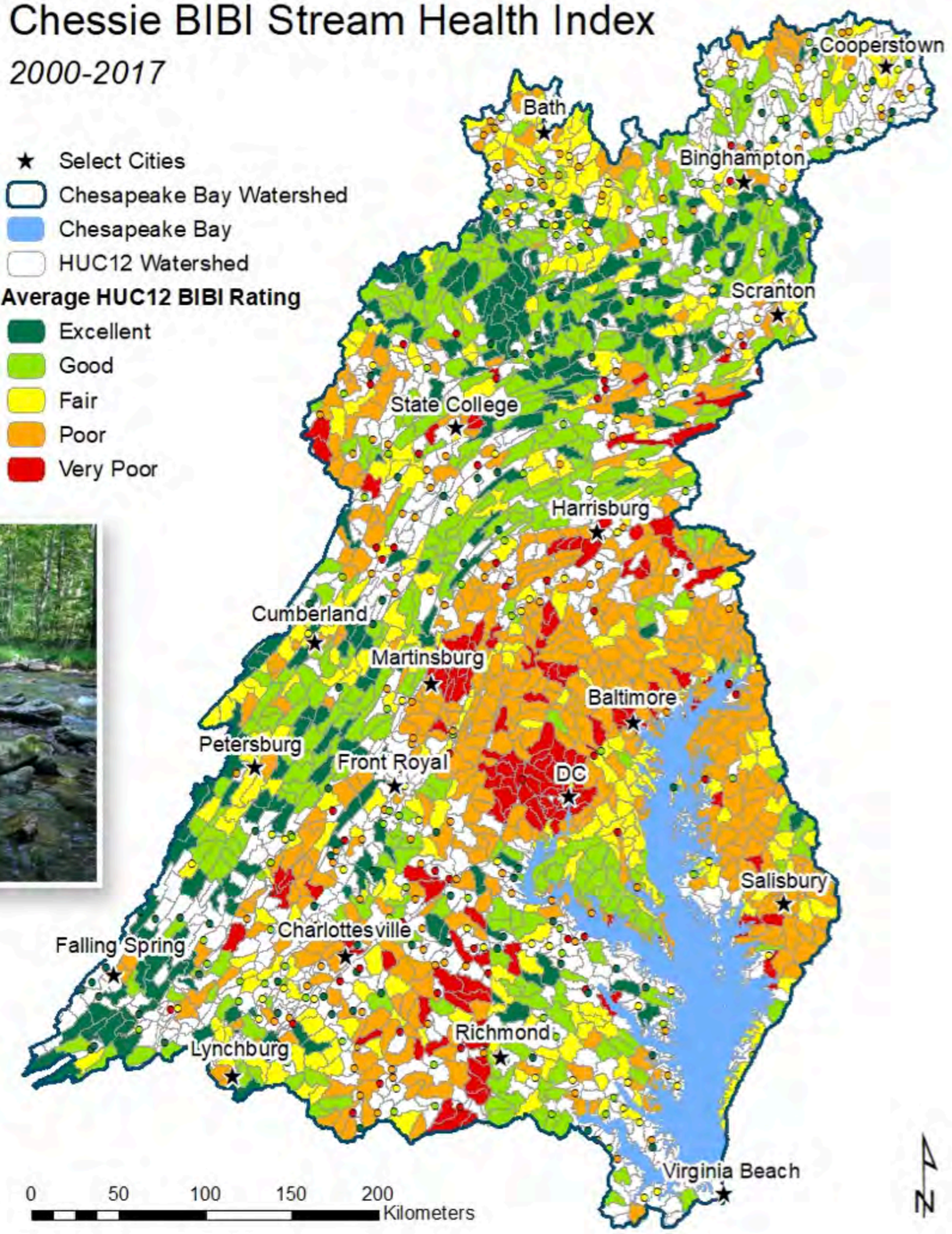
From: Cummins et. al., 2011

Chessie "B-IBI"

- The Chesapeake Basin-wide Index of Benthic Integrity (B-IBI) for stream macroinvertebrates
- A multi-metric index of biological health for freshwater streams and small, wadeable rivers in the Chesapeake Bay watershed.
- Composed of family-level macroinvertebrate metrics (indicators)
- Discriminates strongly between high quality and degraded stream conditions in each of the 12 bioregions in the watershed.







Making Flow-Ecology Relationships Operational

Translating traditional ecological condition goals into environmental flow criteria

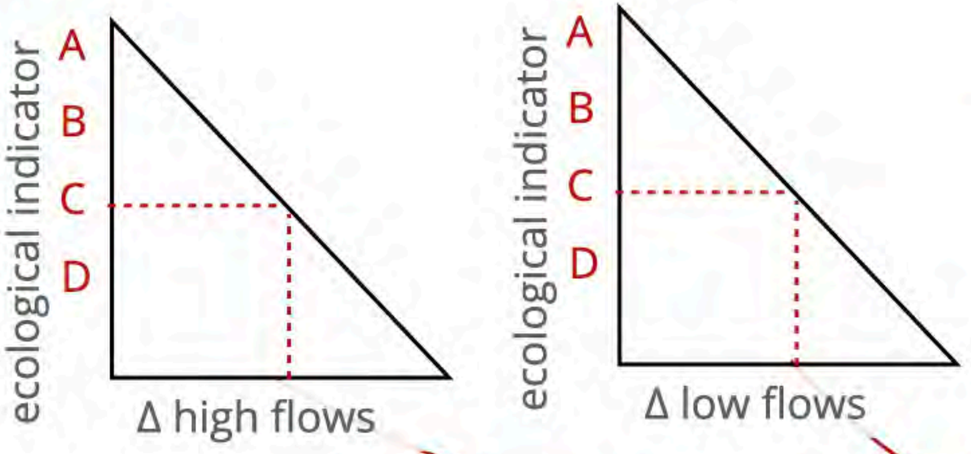
Expressed as degree of allowable flow alteration from baseline for two flow components (high and low flows)

Description of Ecological Condition Goals

	A	B	C	D
Physical				
Chemical				
Connectivity				
Biological				
Ecosystem Services				

Narrative Descriptions

Flow-Ecology Response Functions



Environmental Flow Matrix

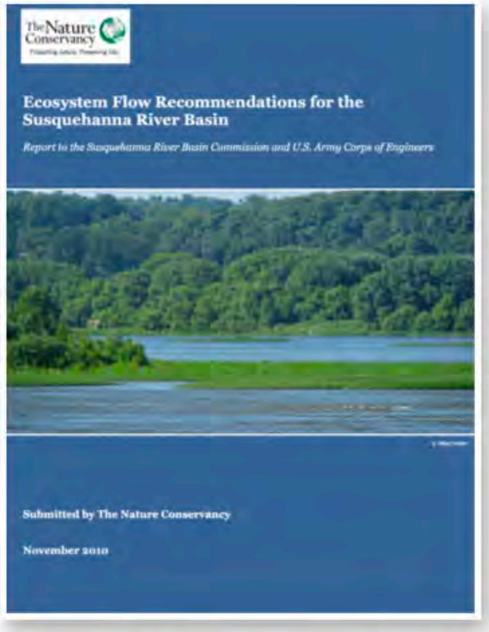
Condition Class	High Flows	Low Flows
A	±10	±10
B	±30	±30
C	±50	±50
D	±70	±70

(examples)

Spring ecosystem flow needs

March-May

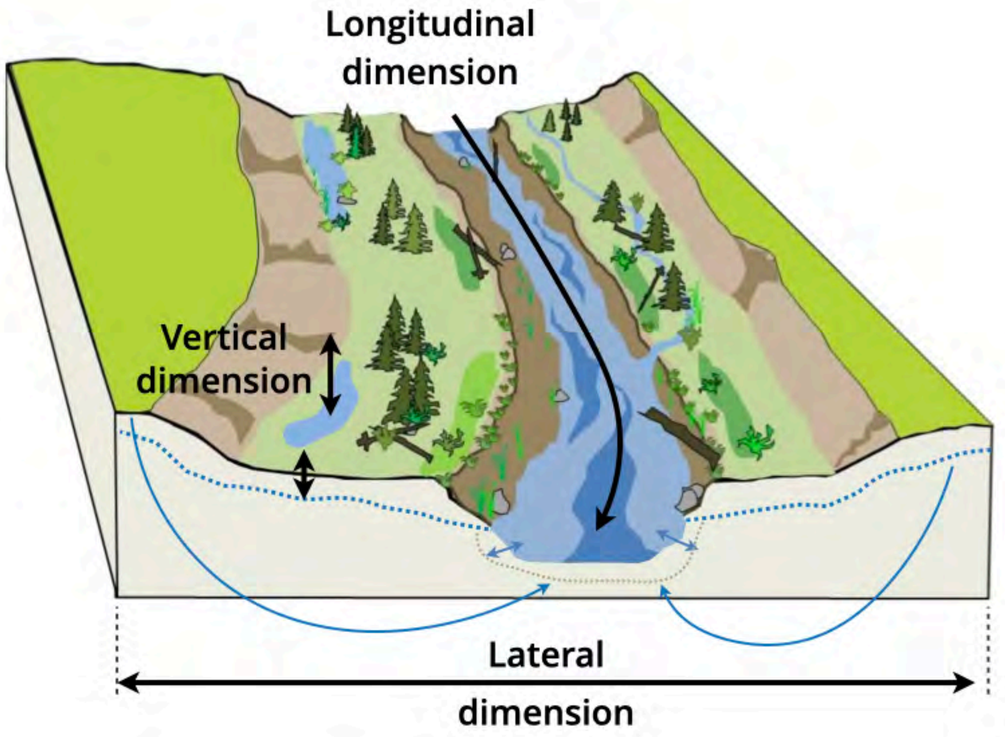
Flow Need	Flow Component			Habitat Type
	High Flows	Seasonal Flows	Low Flows	
Maintain channel morphology, island formation, and floodplain habitat	●			**All habitat types**
Promote vegetation growth	●	●	●	All habitat types
Cue alosid spawning migration and promote egg and larval development		●		**Mainstem and major tributaries**
Support spring emergence of aquatic insects and maintain habitats for mating and, egg laying		●		**All habitat types**
Support resident fish spawning		●	●	**All habitat types**
Maintain fall salmonid spawning habitat and promote egg, larval, and juvenile development (brook and brown trout)		●	●	Cool and coldwater streams; high baseflow streams
Maintain stable hibernation habitat for reptiles, amphibians, and small mammals		●	●	All habitat types
Cue and direct upstream migration of juvenile American eel		●		Mainstem and major tributaries
Promote/support development and growth of all fishes, reptiles, and amphibians		●	●	All habitat types



(DePhilip, M. and Moberg, T., The Nature Conservancy, 2010)

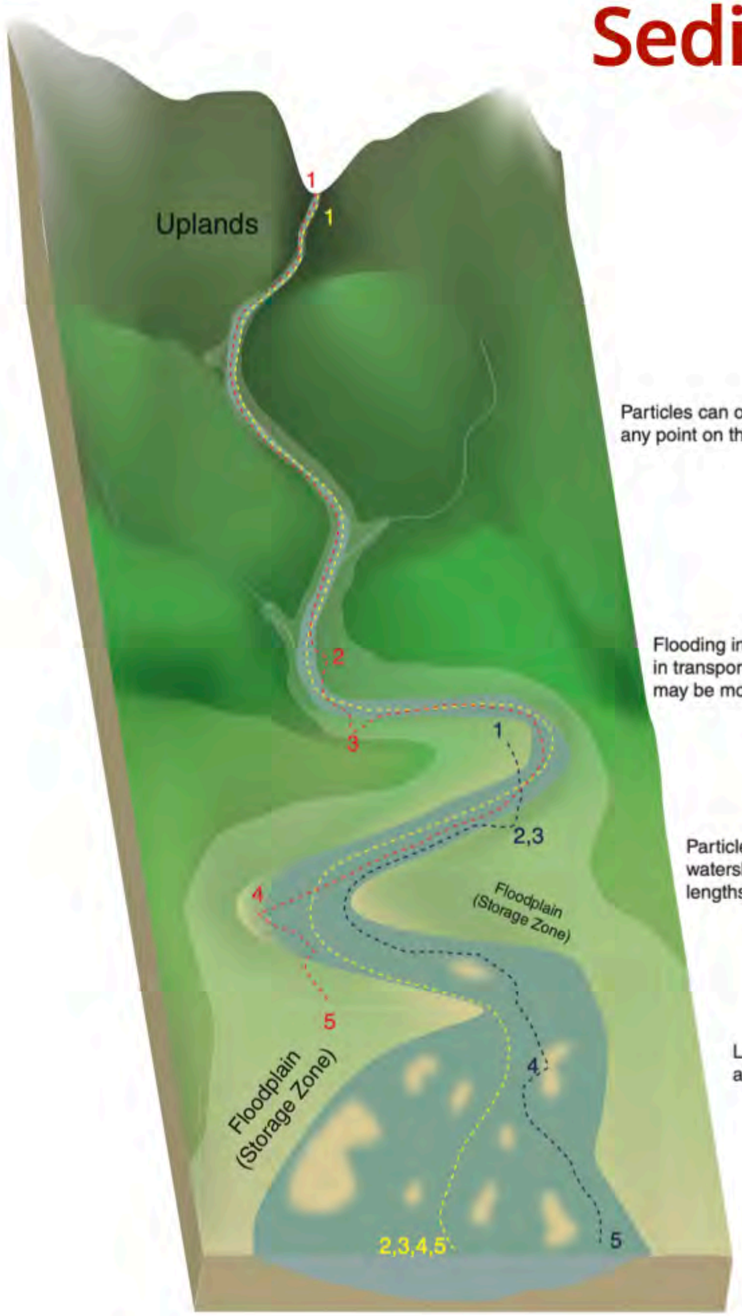
Summer ecosystem flow needs

June - August



Flow Need	Flow Component			Habitat Type
	High Flows	Seasonal Flows	Low Flows	
Transport organic matter and fine sediment	●			All habitat types
Maintain channel morphology, island formation, and floodplain habitat	●			All habitat types
Promote vegetation growth	●	●	●	**All habitat types**
Cue and direct upstream migration of juvenile American eel		●		**Mainstem and major tributaries**
Maintain connectivity between habitats and refugia for resident and diadromous fishes		●		**All habitat types**
Provide abundant food sources and maintain feeding and nesting habitat for birds and mammals		●		**All habitat types**
Cue alosid spawning migration and promote egg and larval development		●		Mainstem and major tributaries
Support spring emergence of aquatic insects and maintain habitats for mating, and egg laying		●		All habitat types
Promote/support development and growth of all fishes, reptiles, and amphibians		●	●	**All habitat types**
Support mussel spawning, glochidia release, and growth		●	●	**All habitat types**
Promote macroinvertebrate growth and insect emergence		●	●	**All habitat types**
Maintain fall salmonid spawning habitat and promote egg, larval, and juvenile development (brook and brown trout)		●	●	Cool and coldwater streams; high baseflow streams
Support resident fish spawning		●	●	All habitat types
Maintain water quality	●		●	**All habitat types**
Maintain hyporheic habitat			●	**All habitat types**

Sediment sources, sinks and fluxes

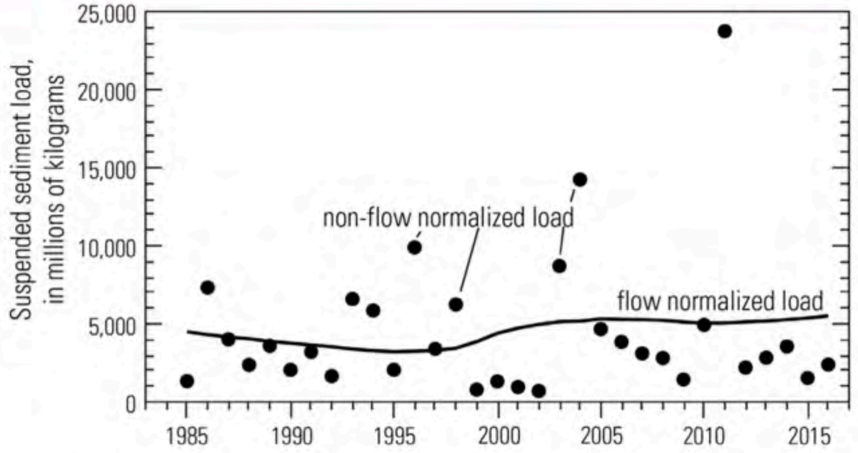


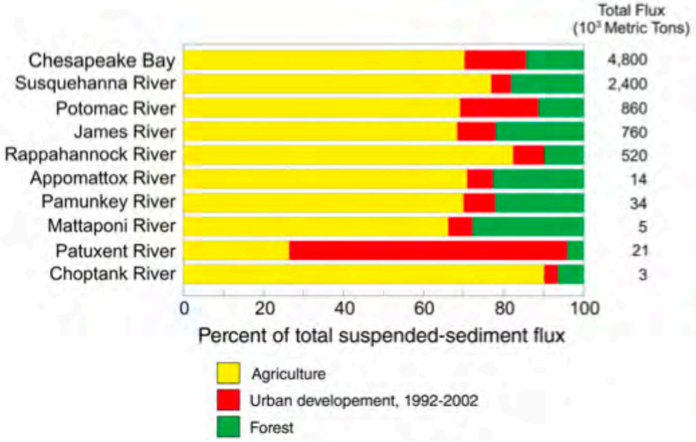
Particles can originate from any point on the landsape

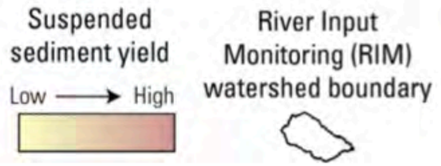
Flooding increases the amount of sediment in transport, though individual particles may be mobilized at any given time

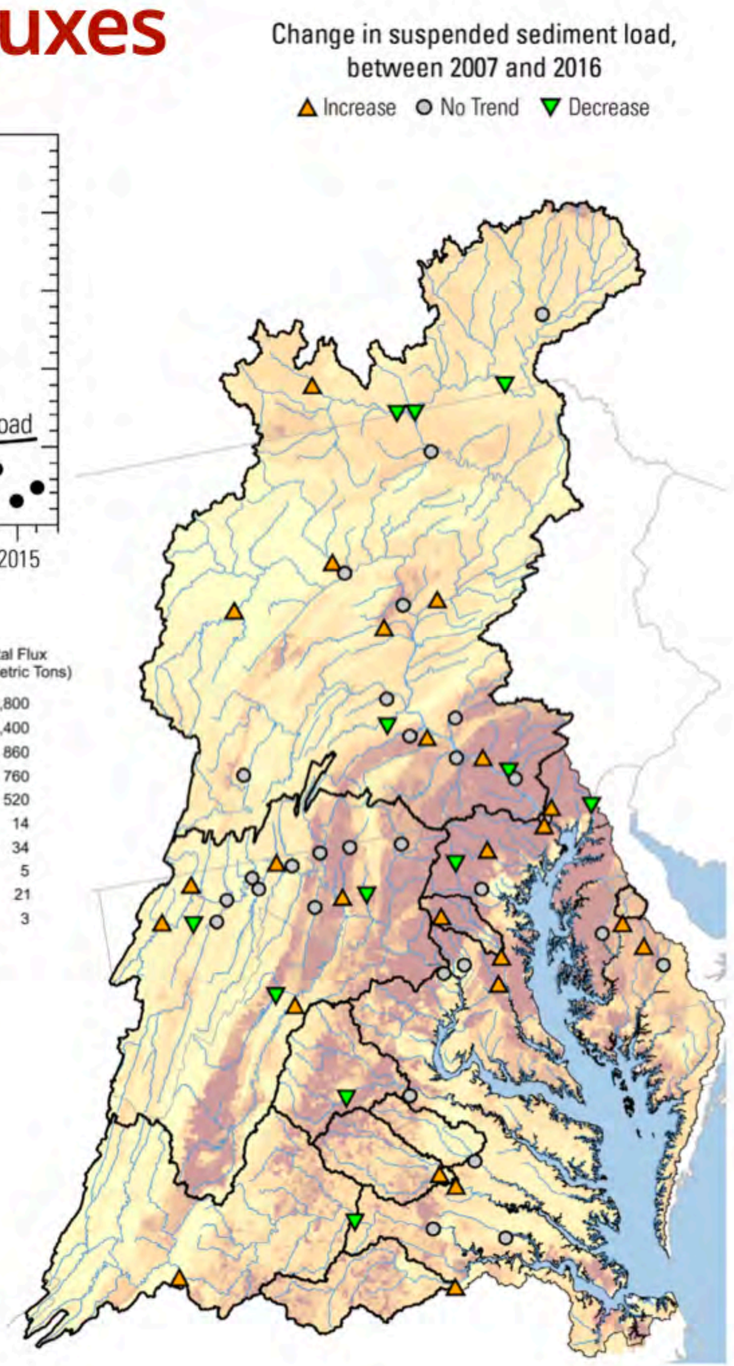
Particles travel at different rates through the watershed and can be stored for various lengths of time

Long term storage locations can be anywhere in the system

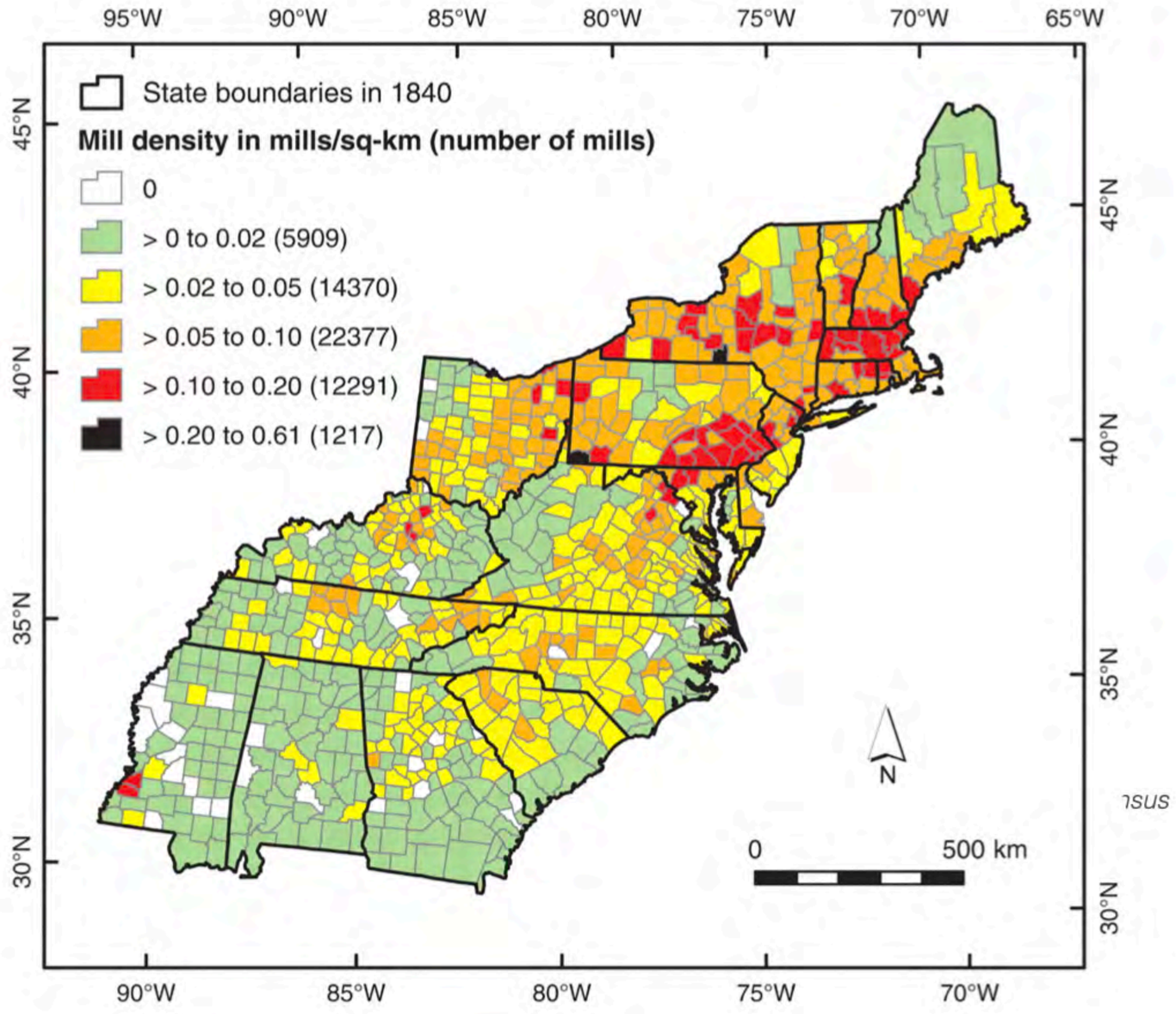




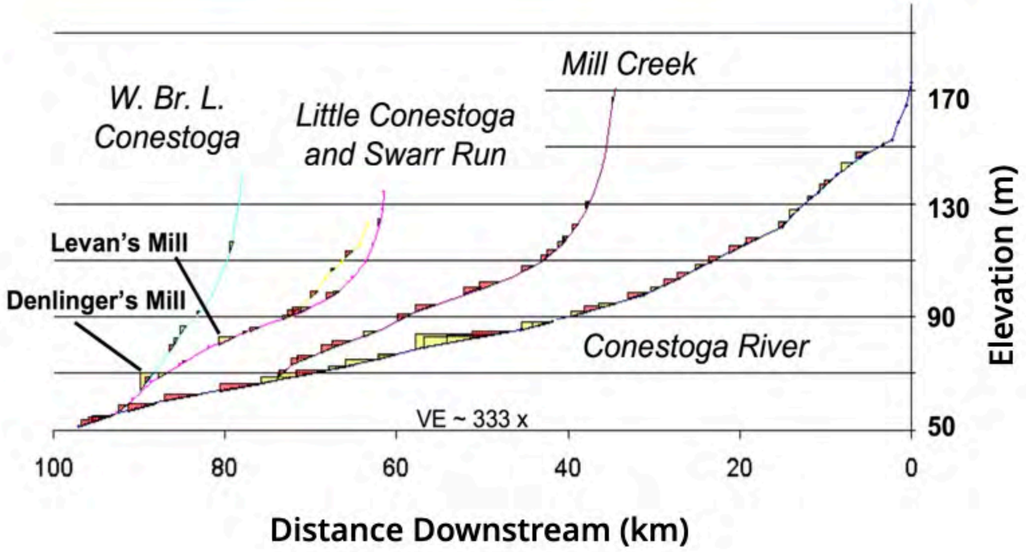




From: Noe et. al., 2019



Walter and Merritts (2008)



RAMP D RD

MILE RUN RD

2. Abandoned side channels and disconnected floodplain

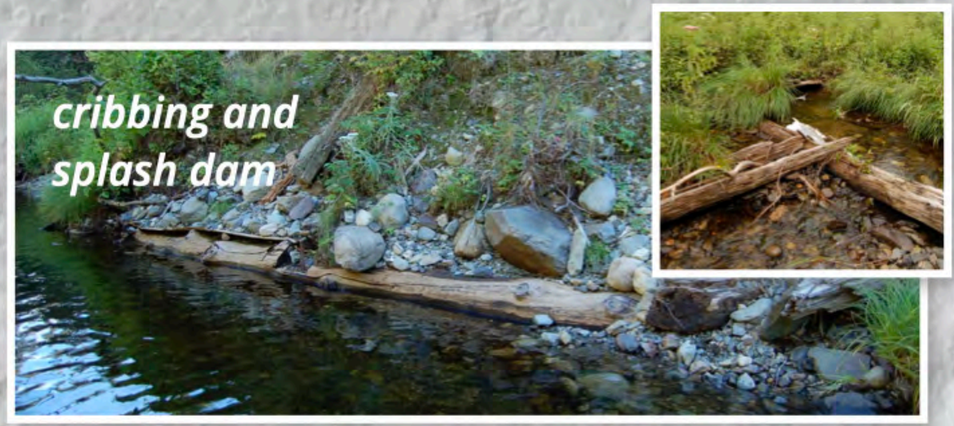
1. Channel dredging, straightening and widening

3. Logging railroads, sluices, splash dams, and other legacy infrastructure

White Deer Creek, Union County, PA

CUSH CREEK IMPROVEMENT COMPANY

*"... improvements consist of **dams** erected on streams, the building of **cribs**, **piers**, etc. and the cleaning out of streams between the points heretofore designated, the **removal of rocks**, **bars**, **logs**, and **driftwood** and **trees**, the **widening** and **deepening** the channel and the general improvements for the purposes of floating lumber thereon."*



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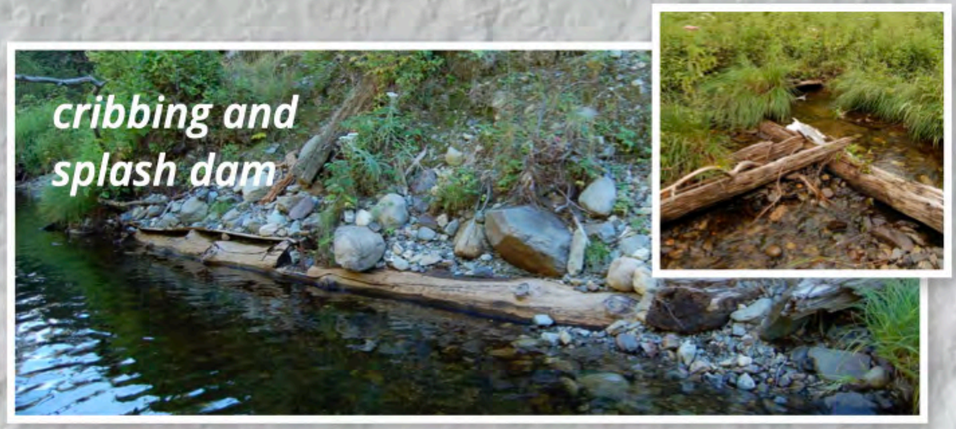
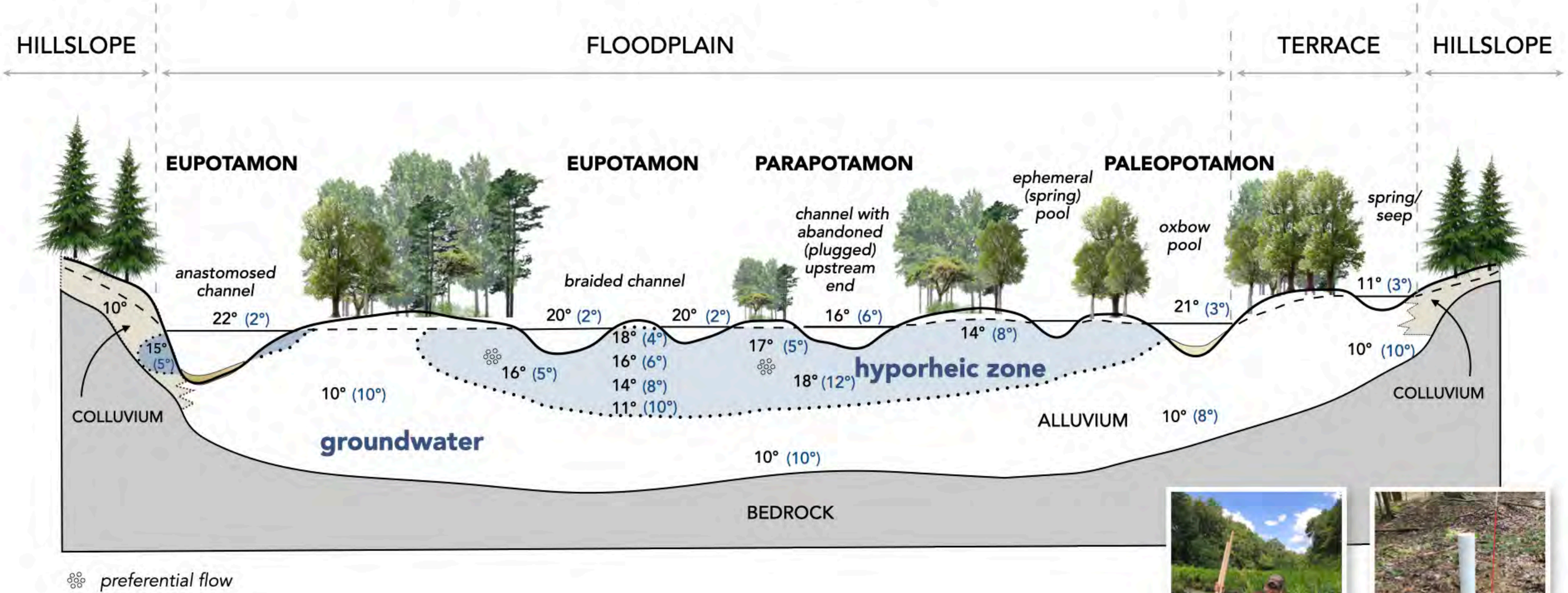
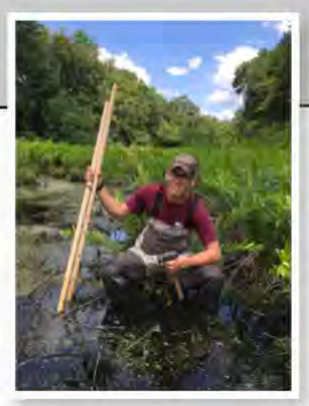
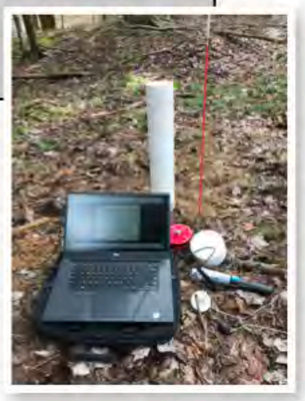


RIVER CORRIDOR TEMPERATURE DIVERSITY



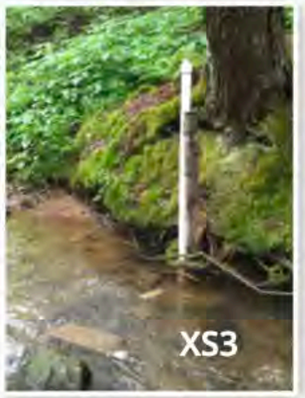


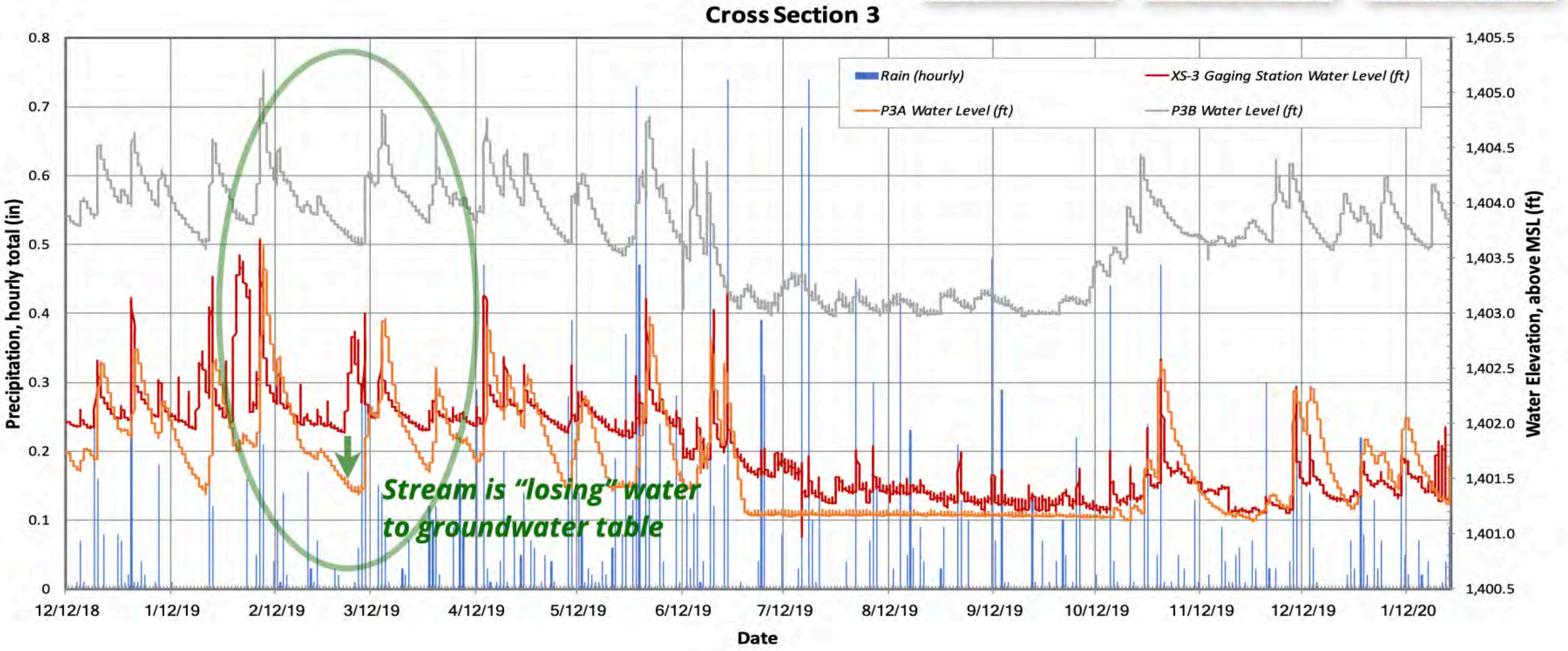


Based on author's field data and concepts by Amoros et al. (1987), Copp (1989) and Ward & Stanford (1995), and Brunke and Gonser (1997)

GROUNDWATER CONDITIONS

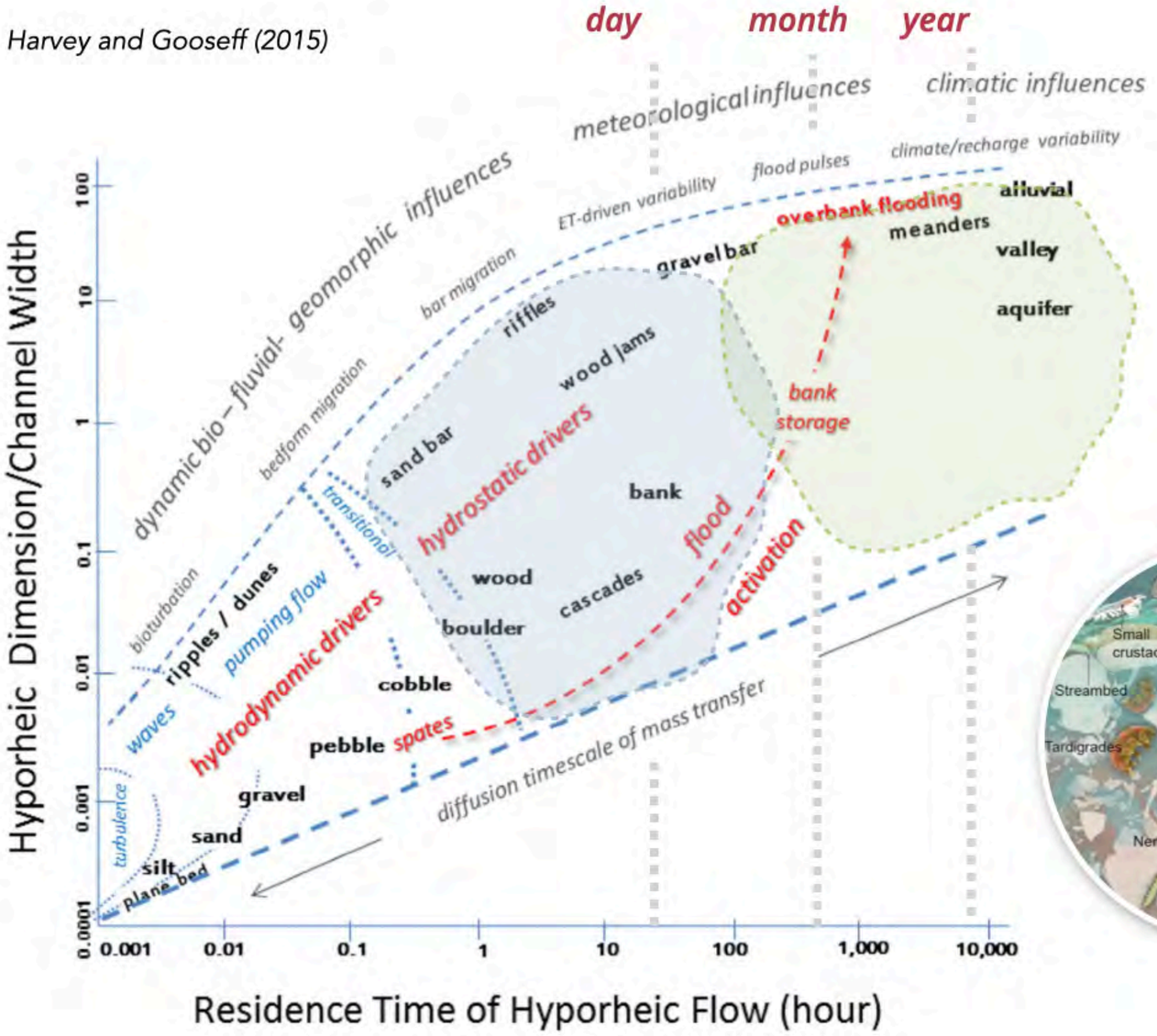
Groundwater recharge, hyporheic exchange, and evapotranspiration losses

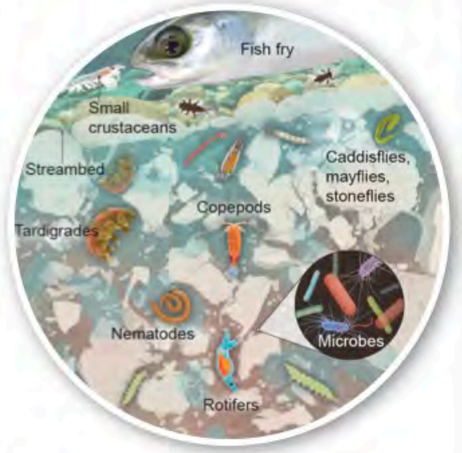




HYPORHEIC DIMENSIONS AND RESIDENCE TIME

Harvey and Gooseff (2015)





SCIENTIFIC AMERICAN®

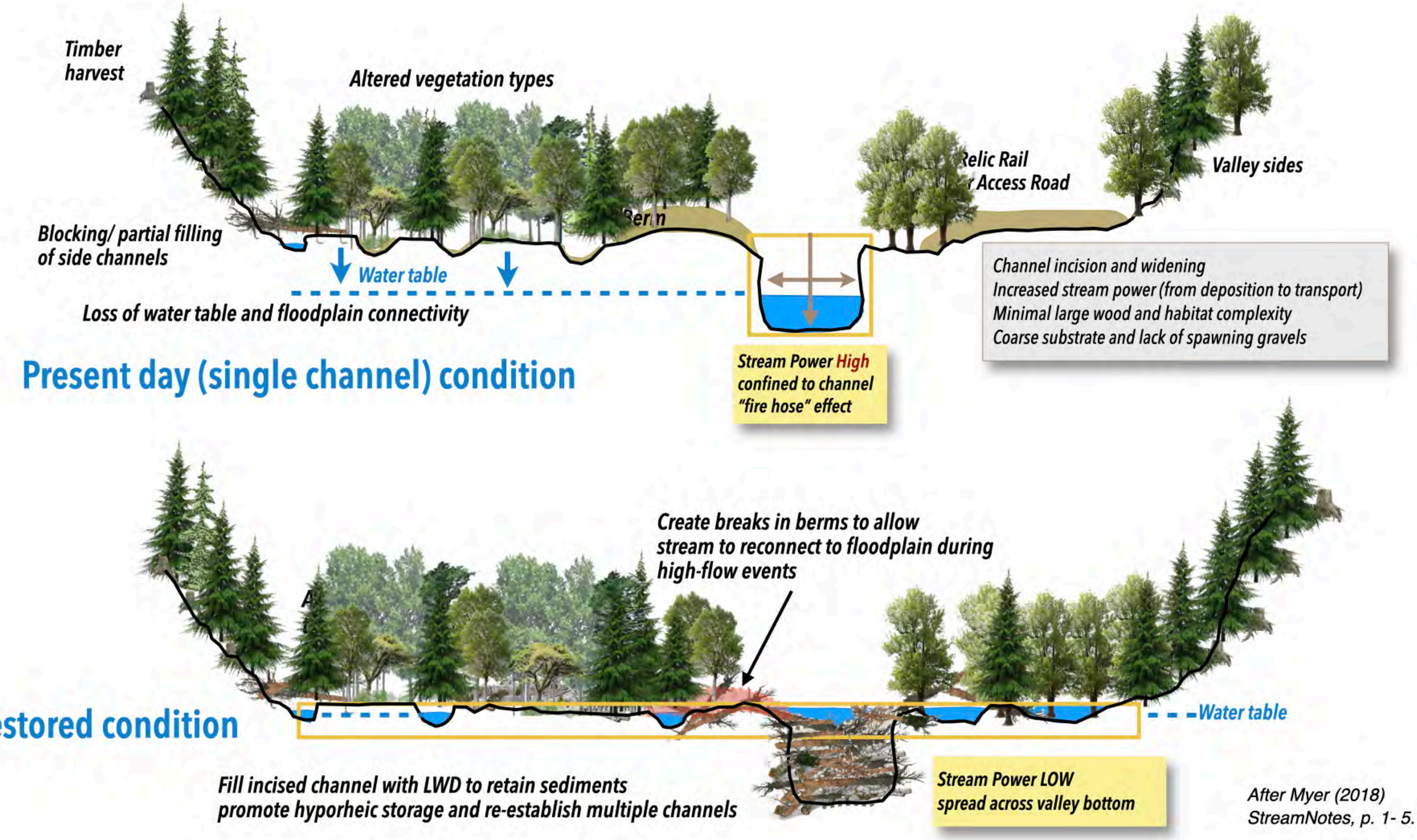
April 1, 2022

Stream team led by biologist Katherine Lynch (foreground) revived Thornton Creek by rebuilding its gut—a thick layer of wet earth, rich in microbes, hidden underneath the streambed. Credit: Jelle Wagenaar

To Revive a River, Restore Its Liver

Radical reconstruction in Seattle is bringing nearly dead urban streams back to productive life

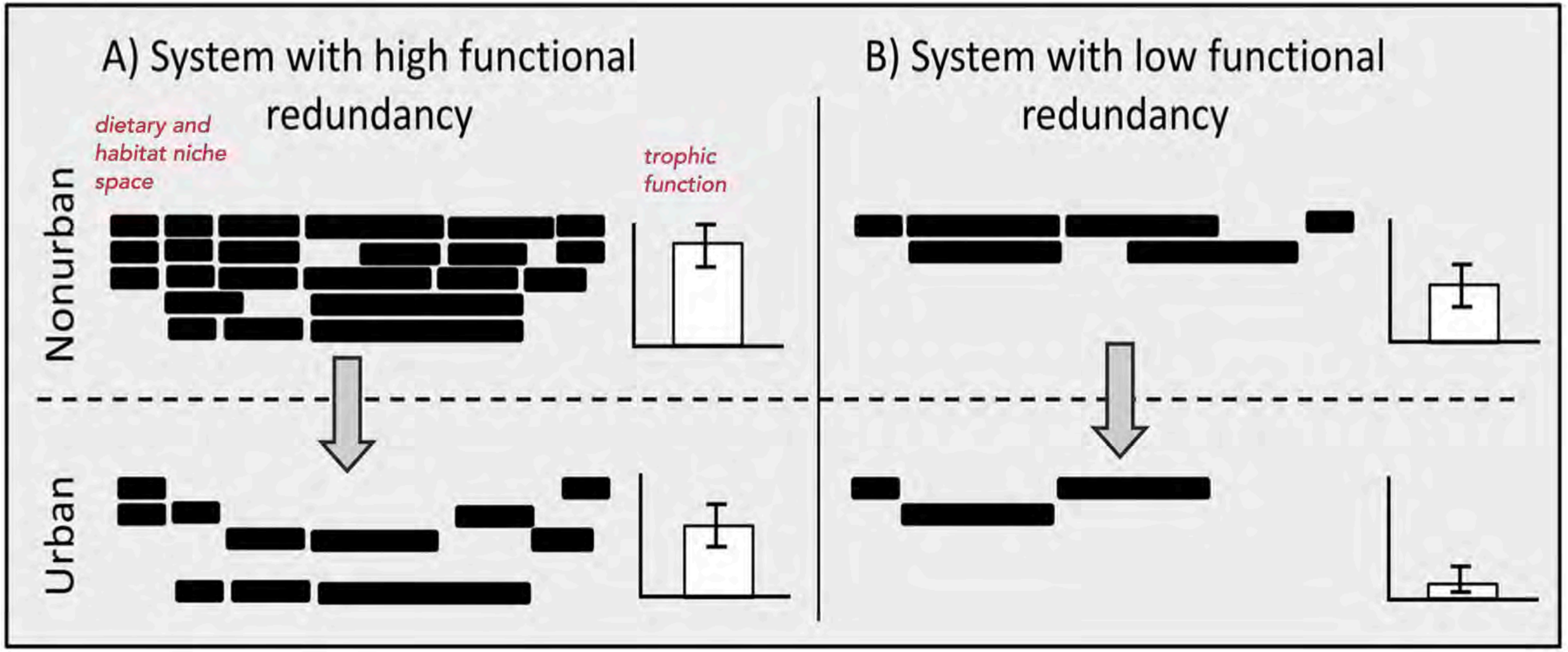
By Erica Gries



After Myer (2018)
StreamNotes, p. 1- 5.

RESTORING REDUNDANCY

Niche space, species diversity, and the insurance hypothesis

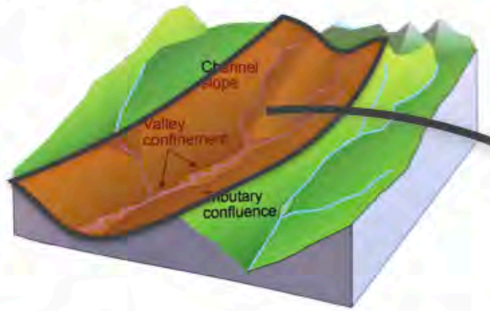


From: Utz, et. al. (2016)

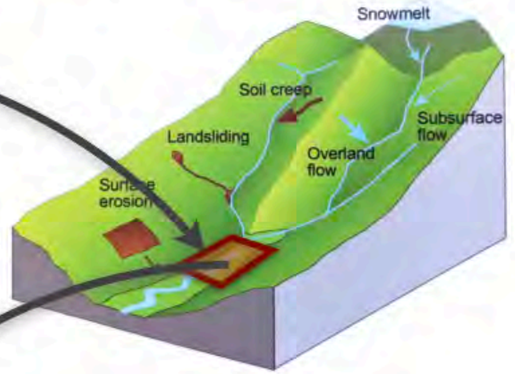
SCALE-DEPENDENCY OF CAUSALITY

Monitoring, assessment, explanation, valuation, and management

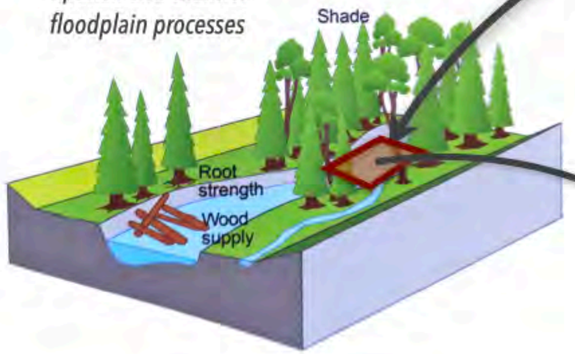
1 Landscape scale:
climatic and geologic processes



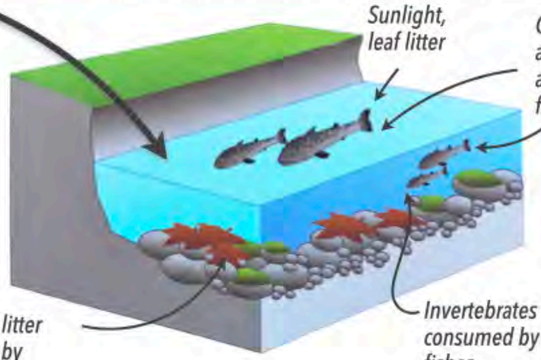
2 Watershed scale:
erosion and runoff processes



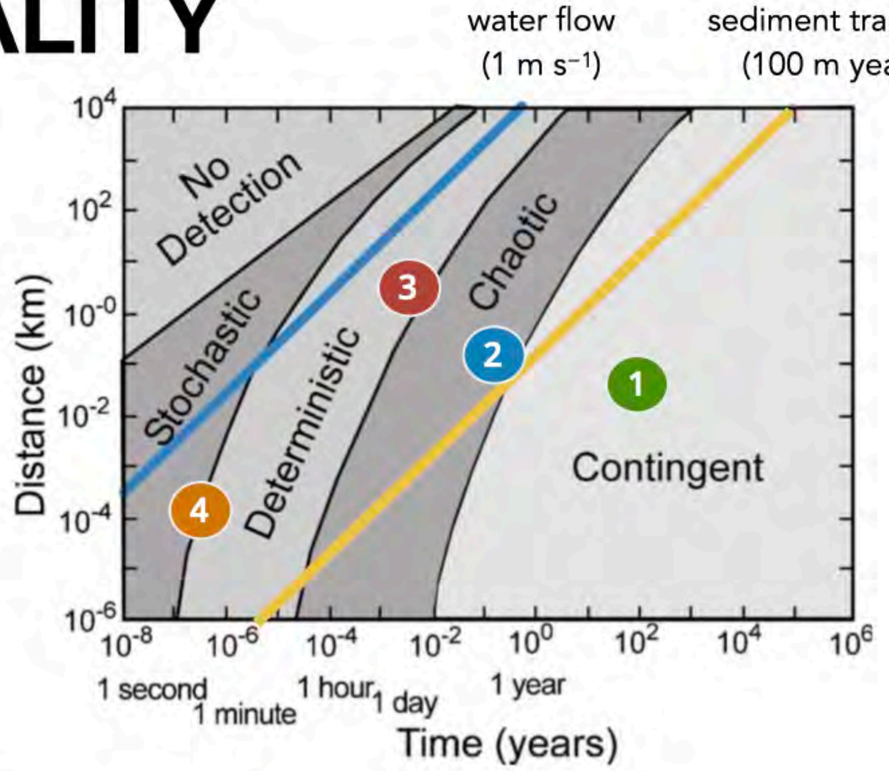
3 Reach scale:
riparian and channel-floodplain processes

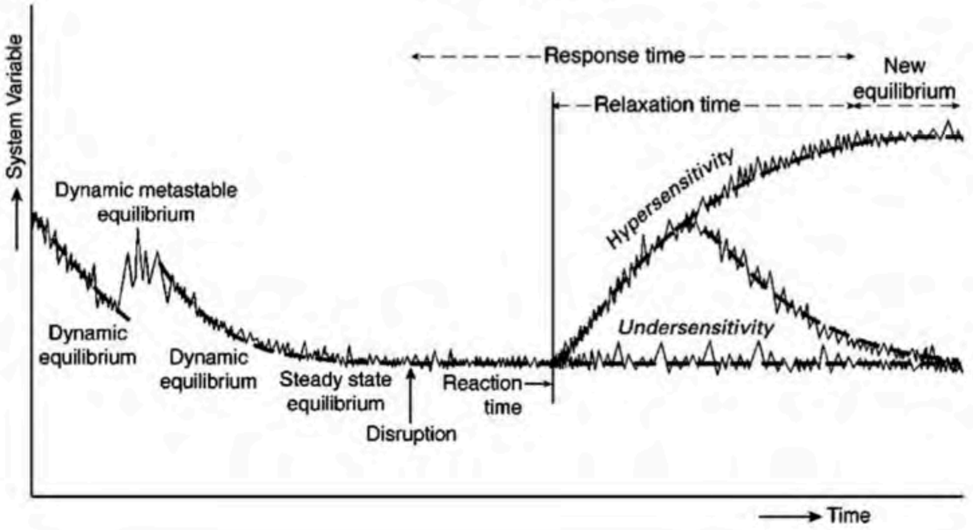


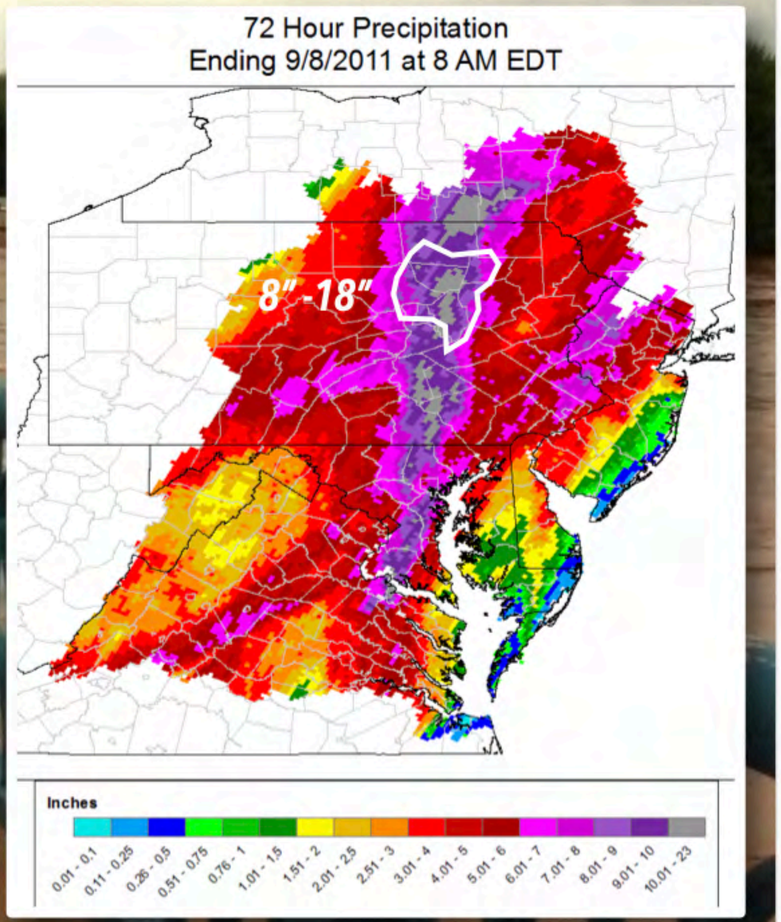
4 Channel unit scale:
Instream processes and biological interactions



Left: Roni and Beechie (2006);
Right: James and Marcus (2006); Church (1996)



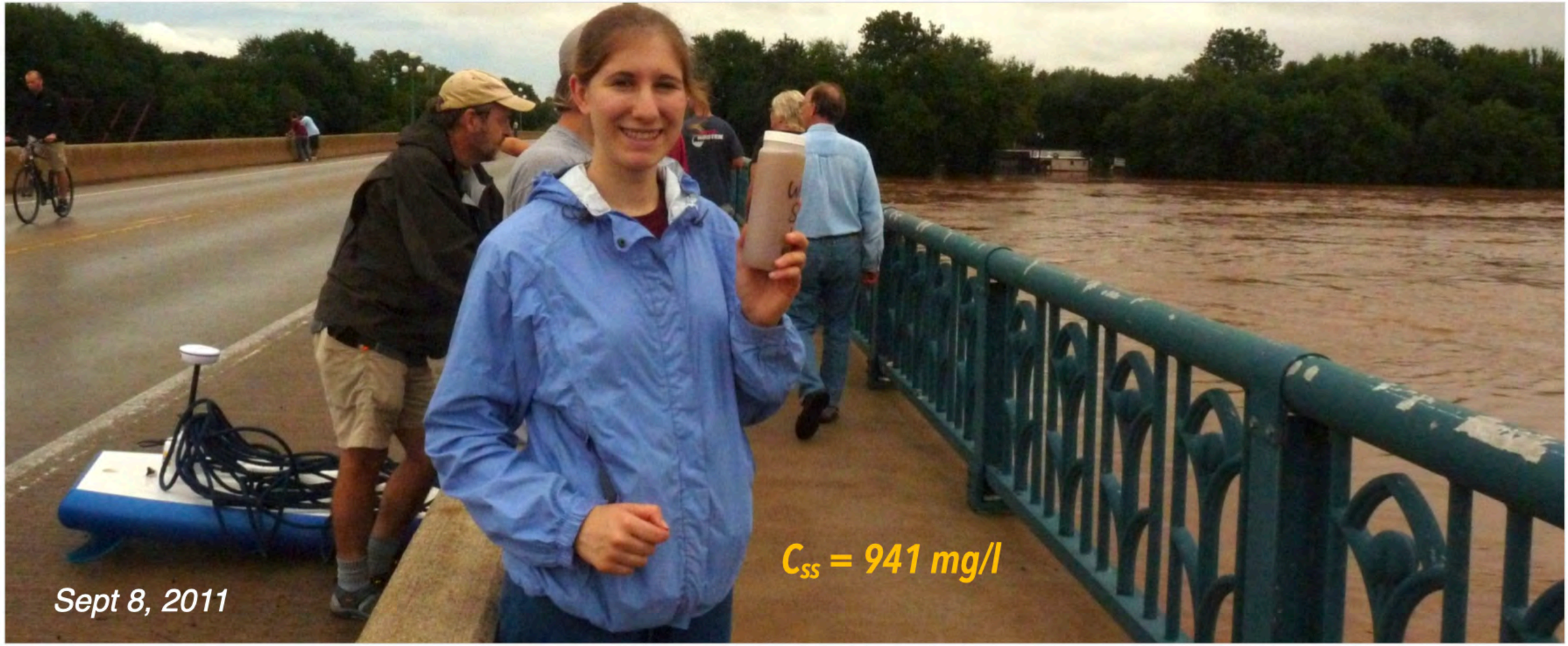




Record suspended sediment yields in plateau province

Q_{water} = 168,000 cfs Q_{SS} = 427,000 tons/day Q_{BL}= 10,050,750 tons/day

670,000 dump trucks



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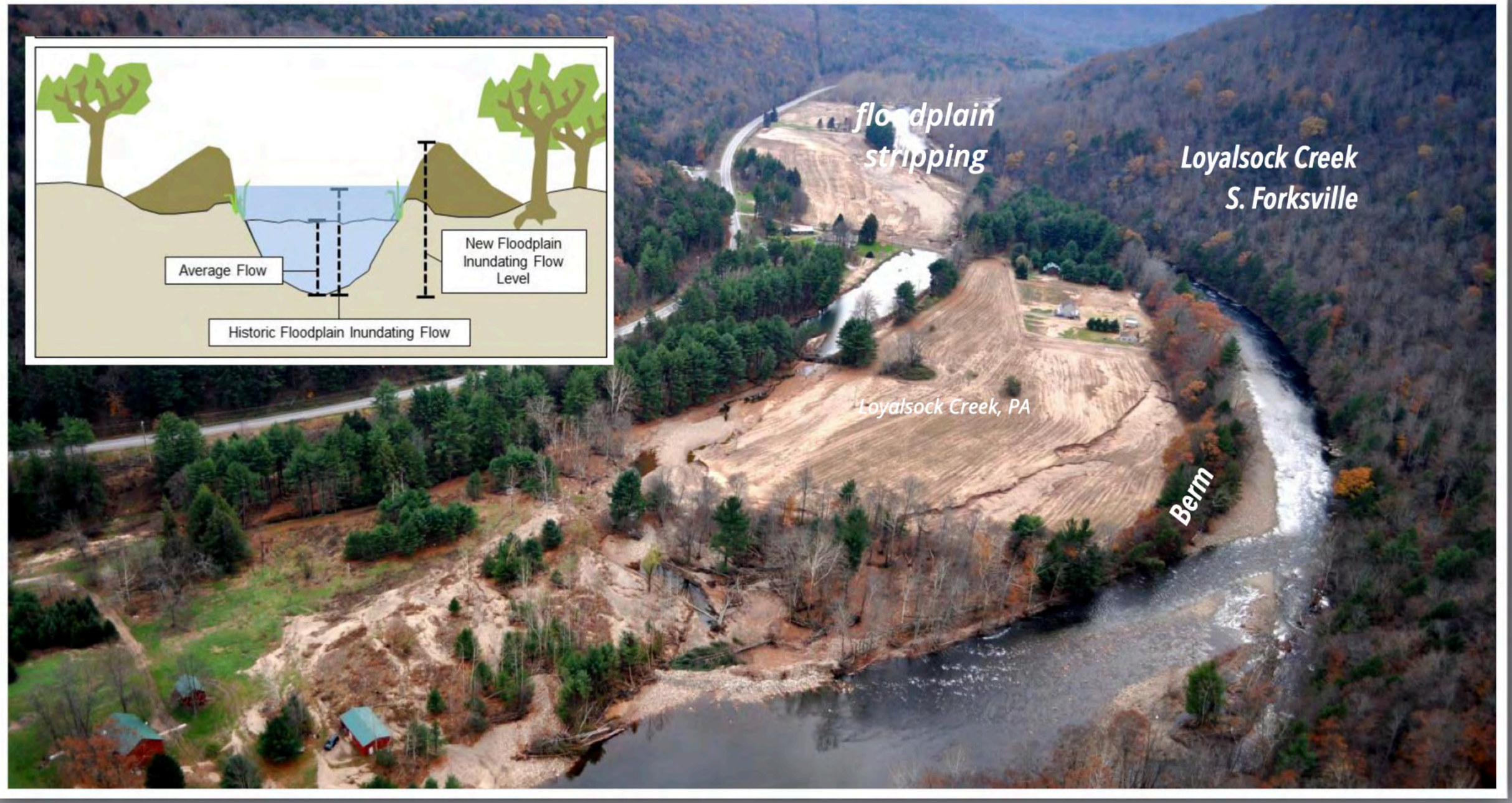
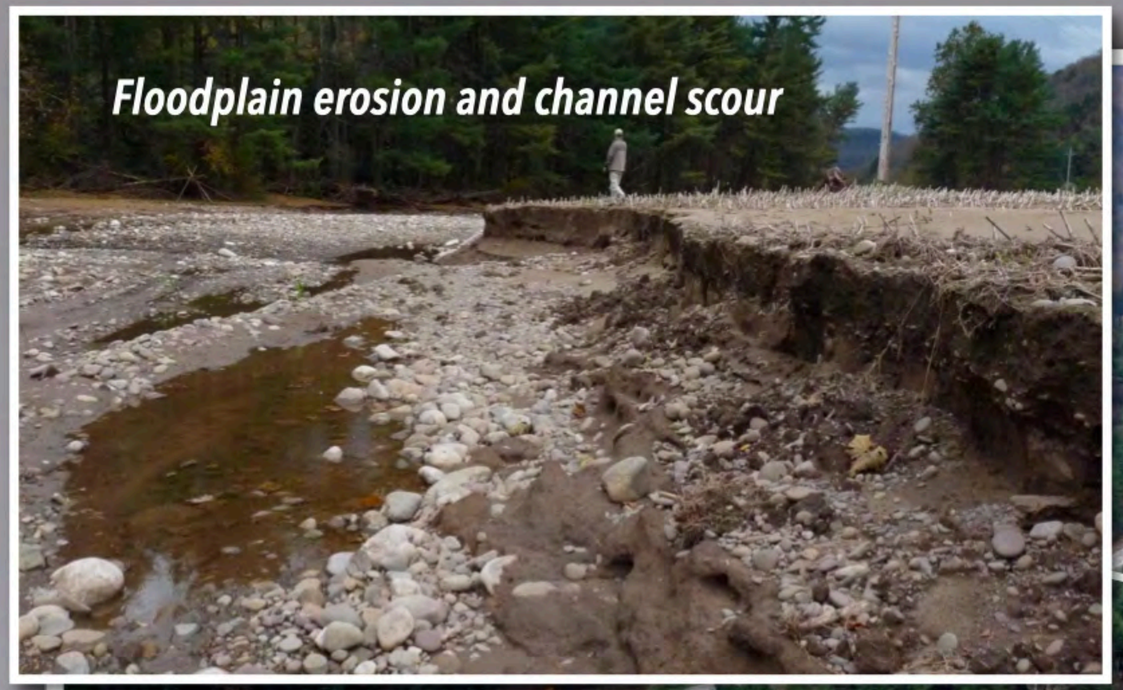

floodplain stripping
Loyalsock Creek
S. Forksville
Loyalsock Creek, PA
Berm
Average Flow
New Floodplain Inundating Flow Level
Historic Floodplain Inundating Flow



floodplain stripping

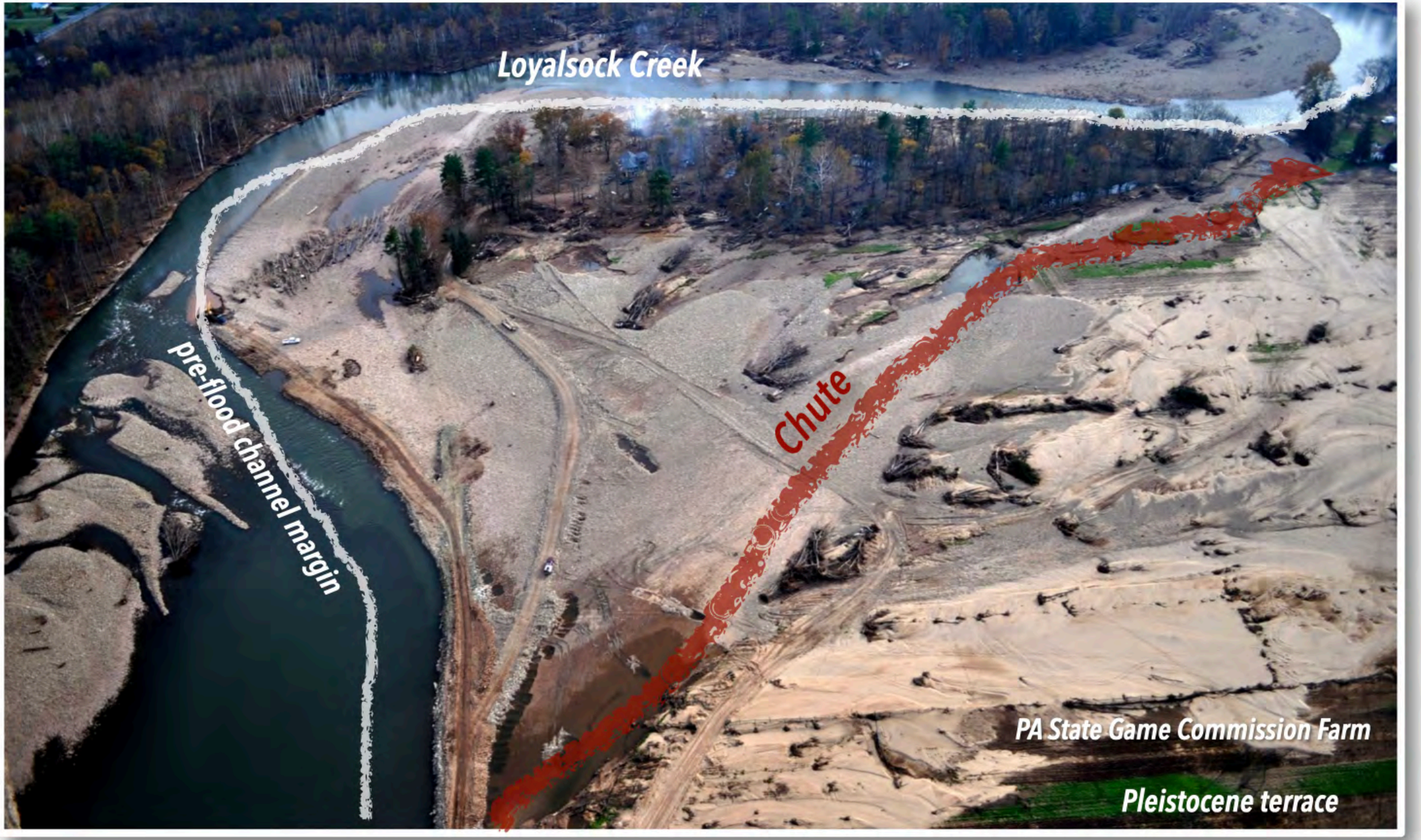
Loyalsock Creek
S. Forksville

Loyalsock Creek, PA

Berm

Berm breach

Floodplain Resetting Floods



Floodplain Resetting Floods

Total stream power, Ω

(W m^{-2})

$$\Omega = \gamma Q S$$

Unit stream power, ω

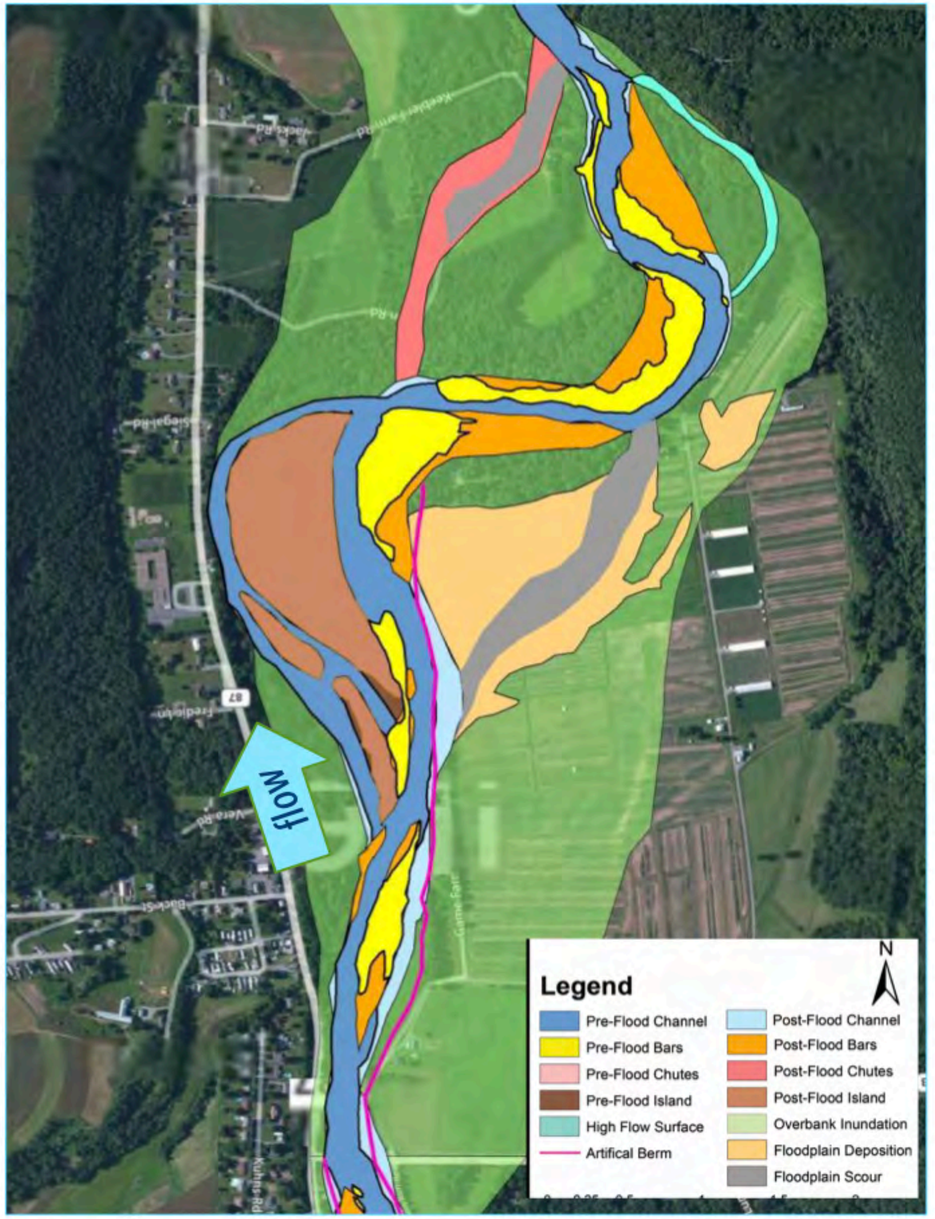
(W m^{-2} m^{-1})

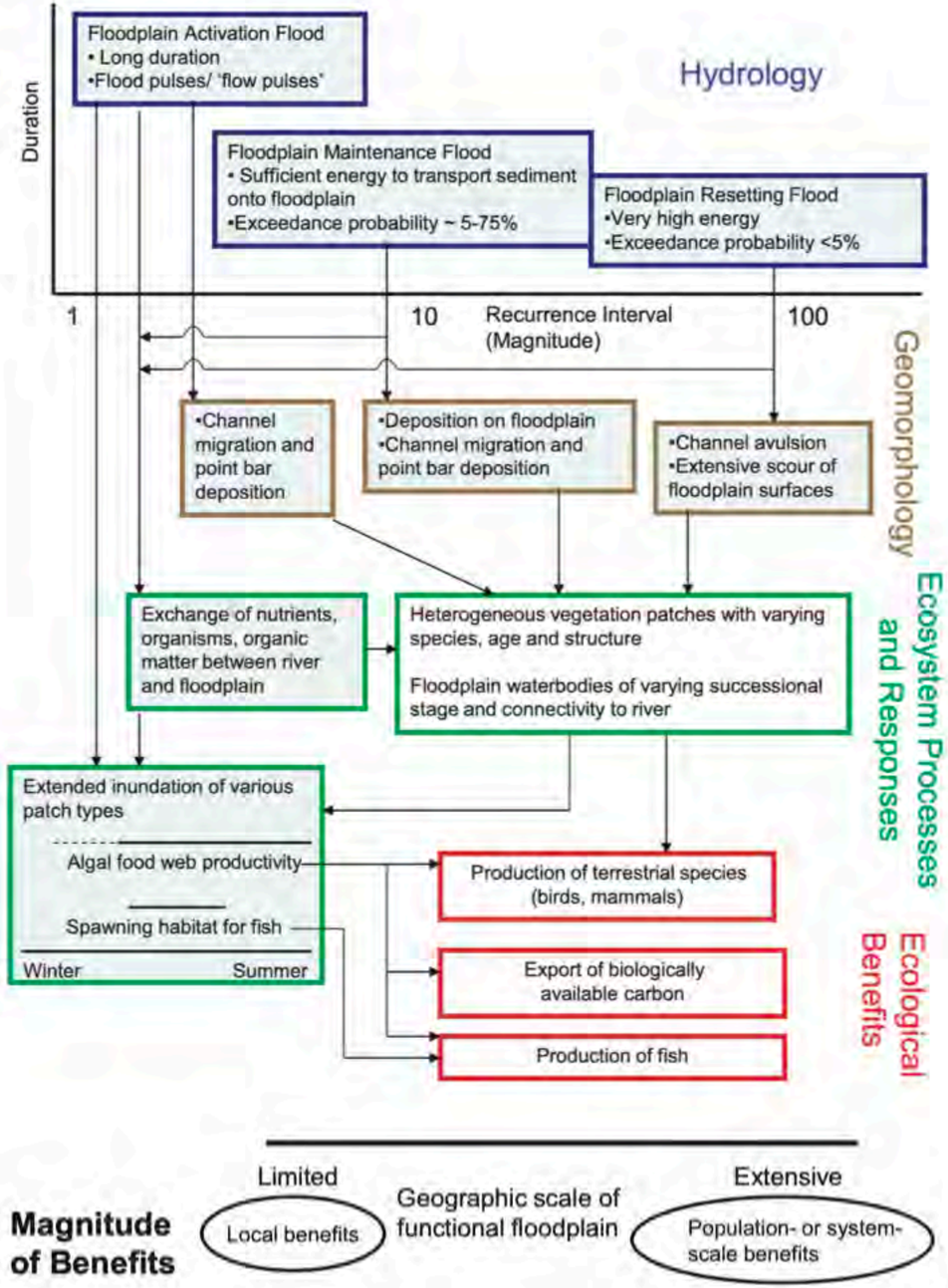
$$\omega = \frac{\Omega}{w}$$

Unit stream power (ω): = 2776.2 W m^{-2} / 25.1m W m^{-2} = = 707.1 W m^{-2}

*The threshold level of **channel instability** is around 35 W m^{-2}, while 300 W m^{-2} is a threshold for **floodplain stripping**.*

River Corridor Map





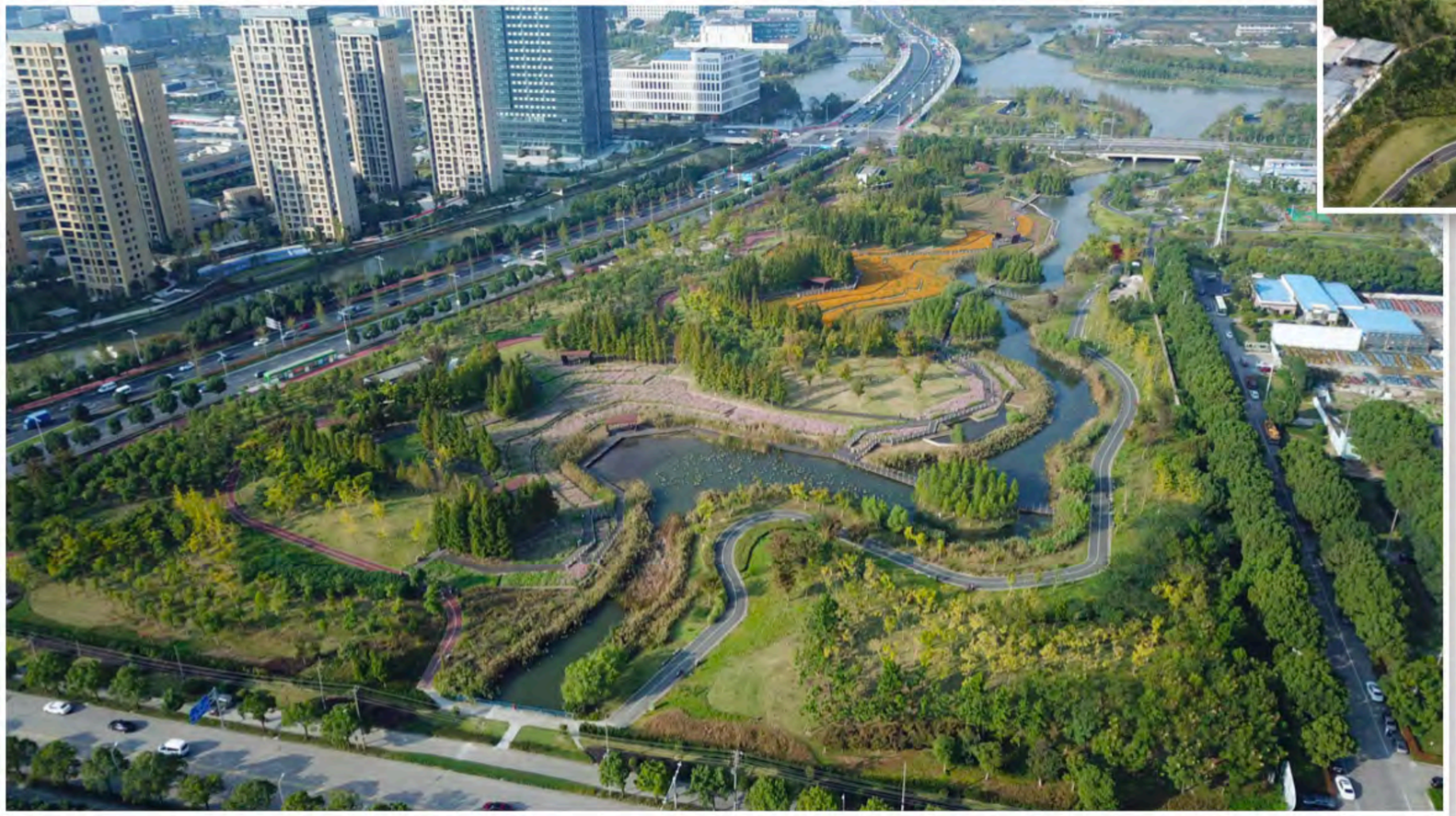
Opperman et. al., 2010

Action	Justification	Details
Conservation easement	Undeveloped floodplain lands can be placed into conservation easement to protect their natural functions and limit their financial burden on landowners.	• Work with local land owners and land management agencies to put lands into conservation easement. • An array of federal programs exist to support the natural use of floodplain lands such as; the Conservation Stewardship Program, Land and Water Conservation Fund, and the Flood Mitigation Assistance Program.
Land acquisition	Maintaining or recovering floodplain natural and beneficial functions may require acquiring and compensating for those lands. State, county and municipal planning offices, land and resource agencies, or flood control districts, may offer various ways to secure flood prone lands for restoration.	• Floodplain lands can be acquired through the buyout of repetitive loss properties. • Shorelines and floodplains are often under jurisdiction of the state or local governments that can manage them for restoration.
Federal land transfer	Flood control infrastructure is sometimes federally owned, and there may be opportunity to have lands turned over to local authorities.	• When working on federal flood control infrastructure, those lands may be turned over to local control following setback or removal.

American Rivers (2016)

River Corridor Management

Metropolitan Areas

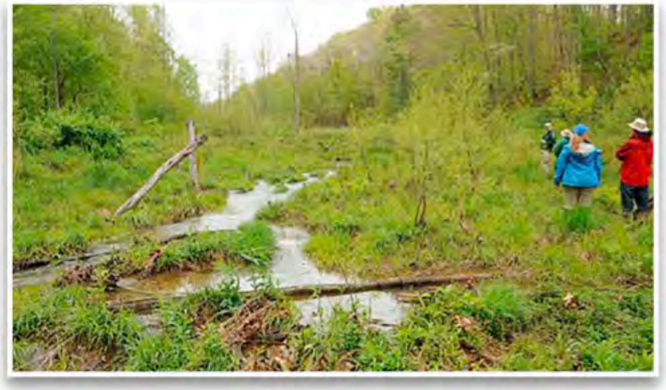


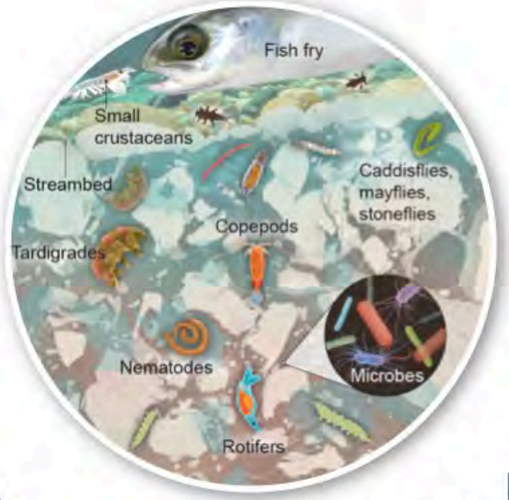
1. Site location and Challenges
2. Objectives and Design Strategies
   A. Preservation, reuse and regeneration: factory buildings, trees and water systems
   B. Terrain design based on hydro-ecological processes: terraces, curved banks and isles
   C. Diverse Vegetation: Wetlands, Crops, and Woods
   D. Immersive experiential facilities: boardwalk and pavilions
3. Provides holistic ecosystem services

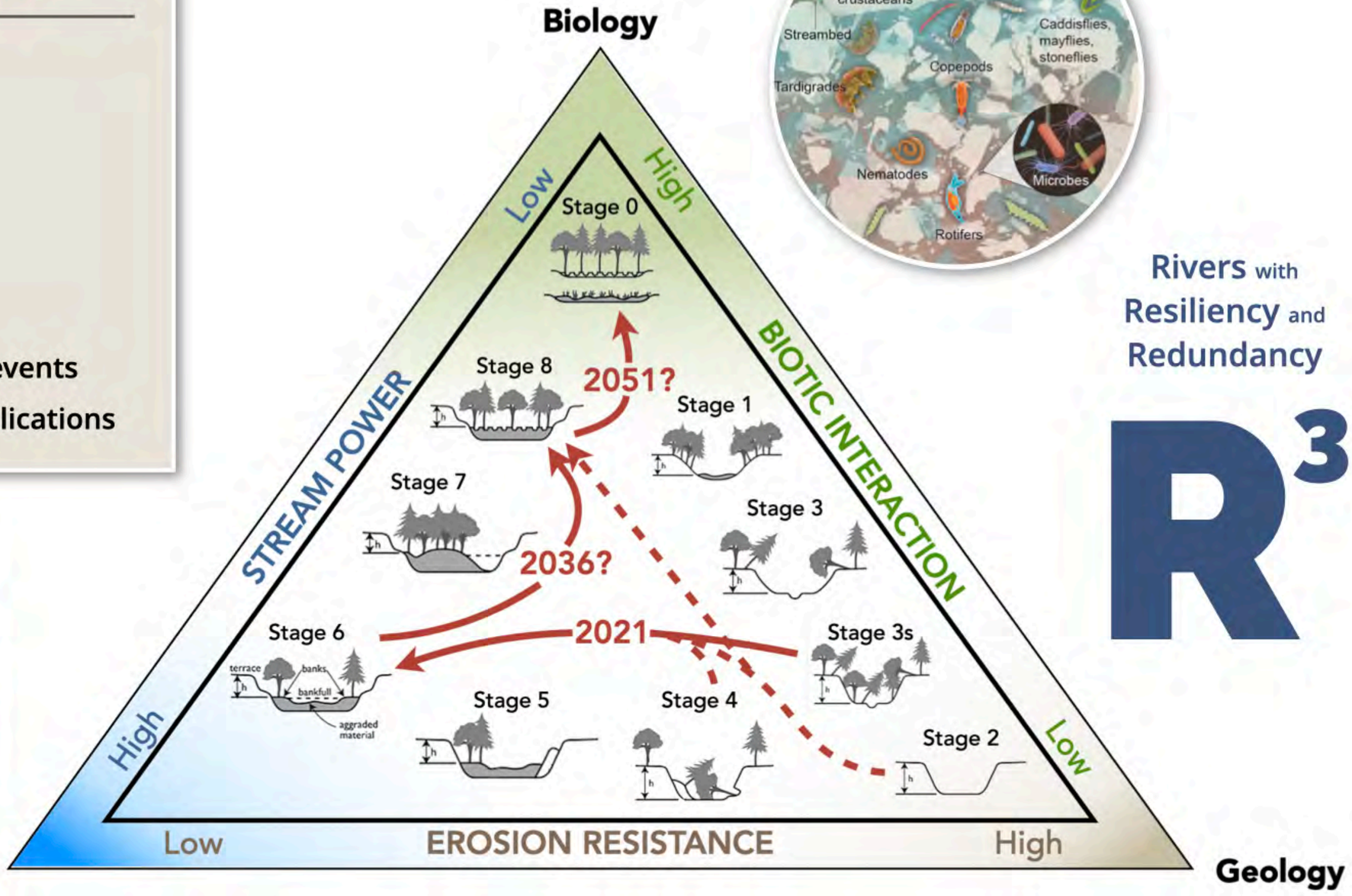
Ningbo Eastern New Town Ecological Corridor, Zhejiang, China (Turenscape)

Challenges and Questions

1. Monitoring and evaluation
2. Permitting
3. Mitigation
4. Stream quantification tools
5. Restoration techniques
6. Infrastructure conflicts
7. Non-stationarity and extreme events
8. Water law interpretation & implications



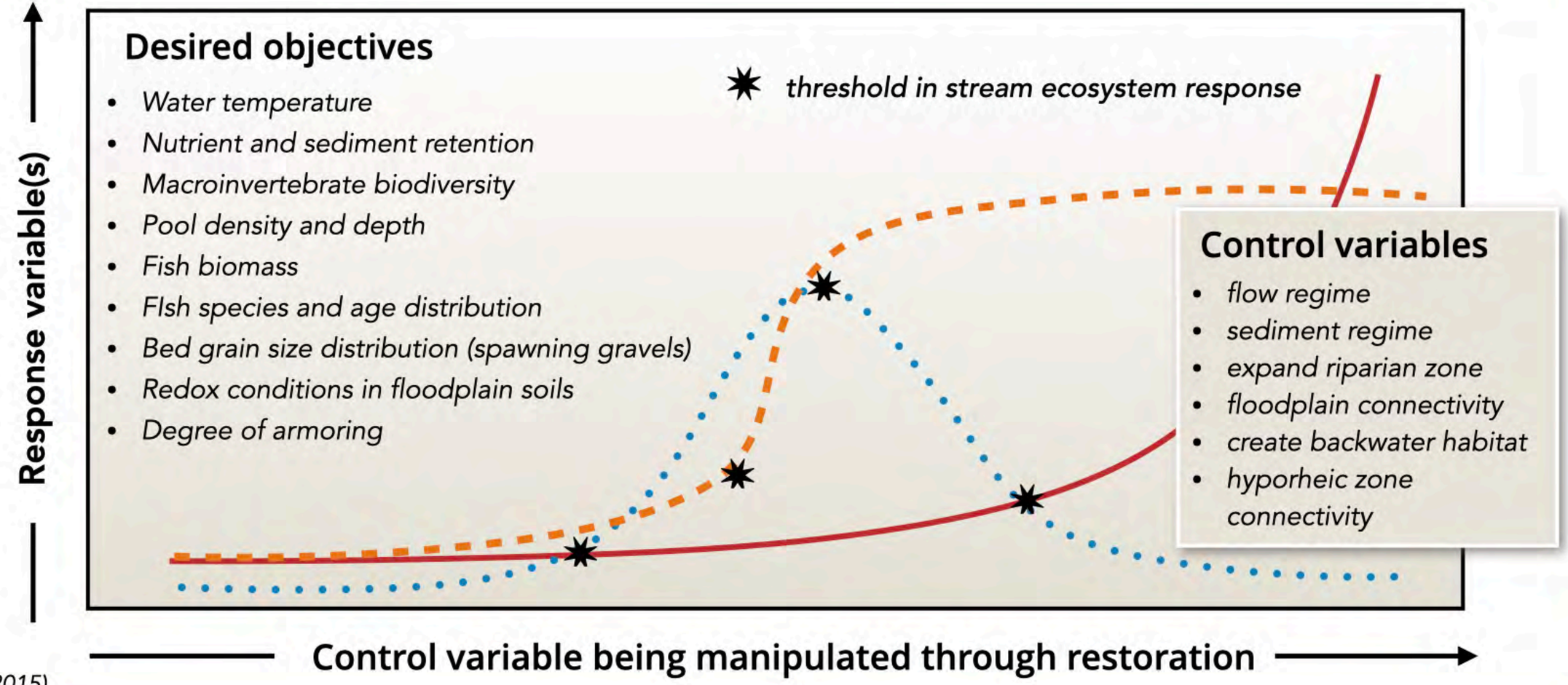




Rivers with Resiliency and Redundancy

R^3

Thorne et. al., 2021



Wohl et. al. (2015)

Ecosystem process-response and intrinsic thresholds

Response curve depends on pairings of control/response variables and different river ecosystems