HISTORIC WATERSHED ALTERATIONS

REGIONAL PATTERNS

PA Water Resources Restoration Conference

March 3-4, 2026

Benjamin Hayes

Bucknell University

ALTERATIONS TO PA STREAMS AND RIVERS

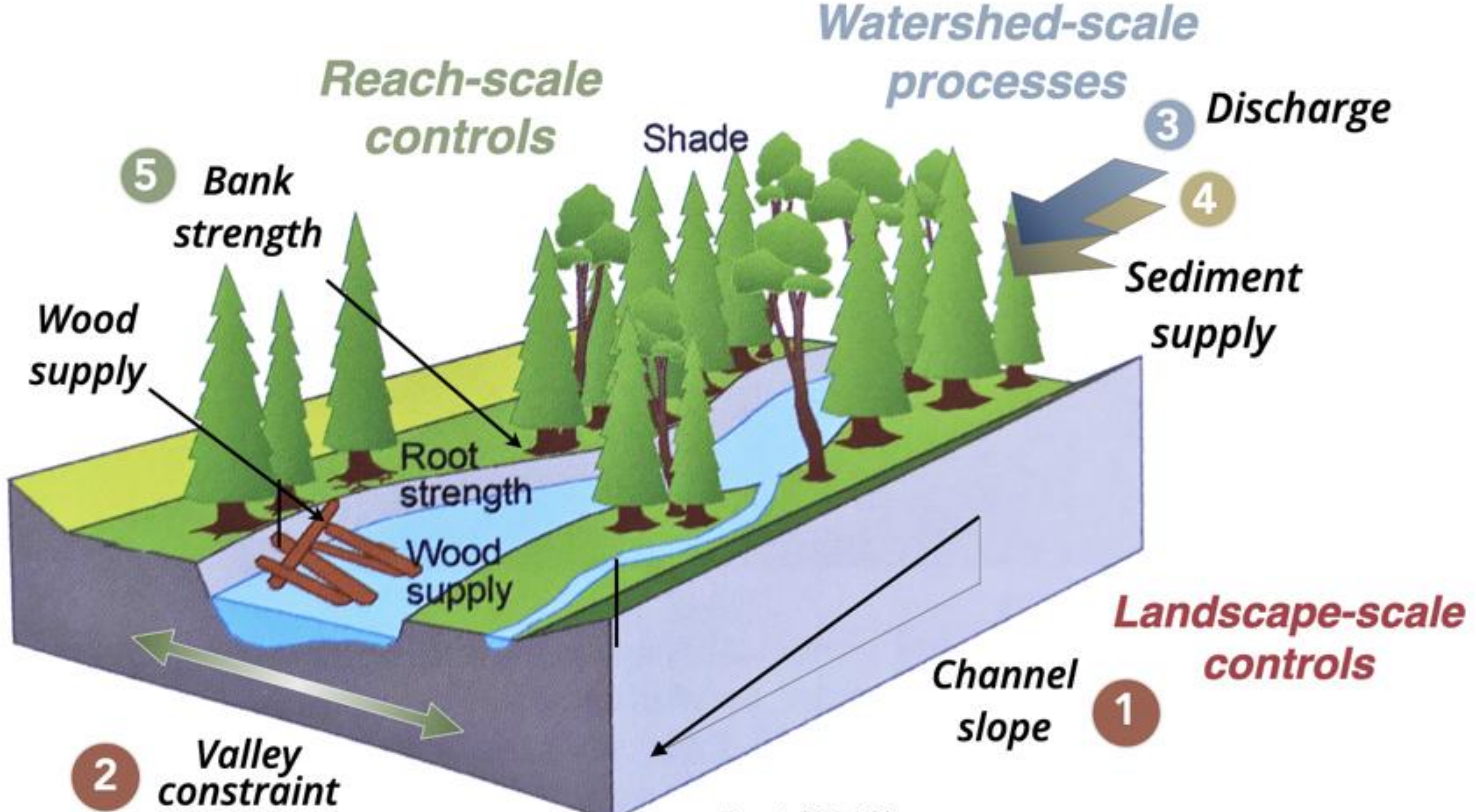
1. **Oil, coal and natural gas.** Dewatering of entire watersheds for underground workings, strip mines and associated impacts on water quality and quantity
2. **Mining** and **dredging.** In-channel gravel bars and commercial sand and gravel pits.
3. **Hydropower**. Historic water-powered mills and modern power plants (conventional hydroelectric, nuclear, and natural gas).
4. **Logging.** Historic clearcutting and hillslope erosion; alteration of channels for log drives.
5. **Flood control**. Dams and levees; dredging and channelization.
6. **Agriculture**. Channelization and installation of drain tiles; water resources extraction for livestock; nutrient management plans; fertilizer and associated water quality concerns.
7. **Urbanization**. Soil compaction/impervious areas; stormwater runoff/water quality problems.
8. **Industry**. Manufacturing plants and new technology centers
9. **Transportation**. Historic canals and railroads, highways, bridges, winter maintenance.

FOOD FOR THOUGHT .....

1. Both social and fluvial-ecological systems are far from being in **equilibrium**.
2. They are characterized by **thresholds**, **multiple states**, and **surprising phenomena**.
3. Because of the connection between ecological and societal systems, cross-scale **interactions happen**. These interactions must be recognized and anticipated.
4. We should be aware of **slowly evolving conditions**.
5. **Short-term measures can not resolve persistent, chronic problems,** nor can they deal with **continuous change**.

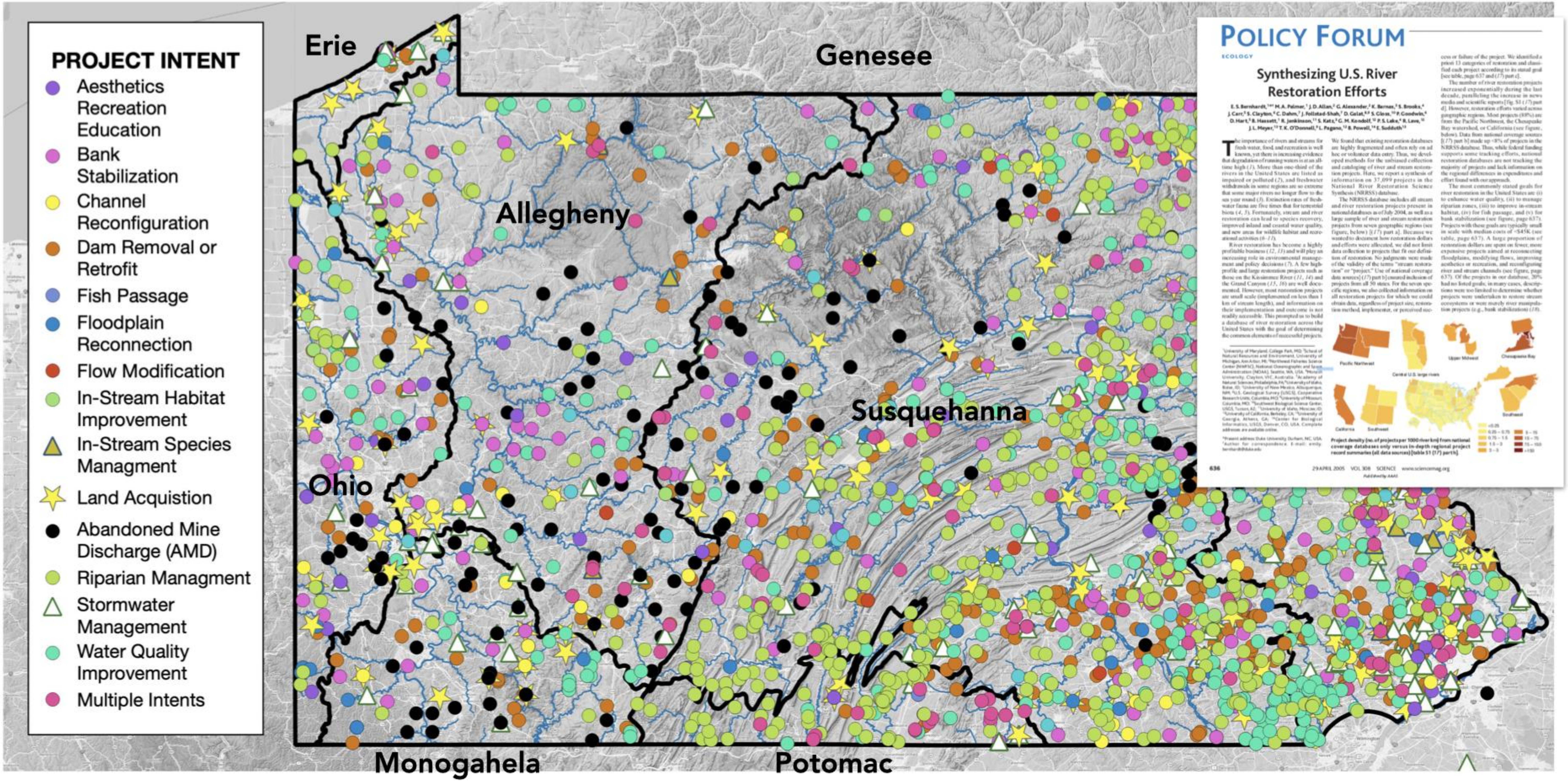
KEY CONCEPTS

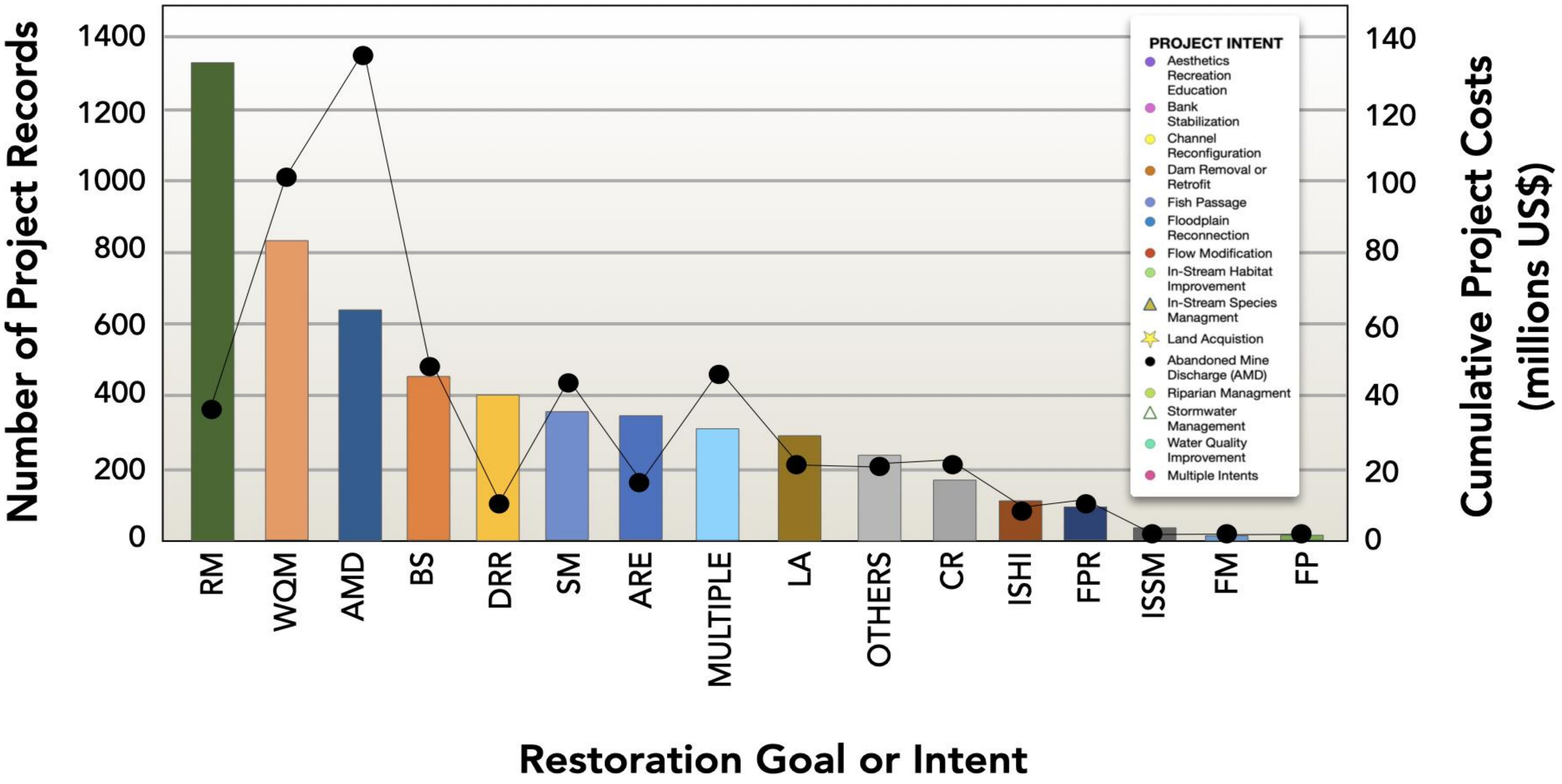
- Behavior - how and why systems respond to perturbations
- Process linkages and inherited disfunction (cascading effects)
- Episodic memory - its affect on possible outcomes in the future



Roni (2018)

Bernhardt et.al. (2025), *Science*, **209**, p. 636-637.





Number of Project Records
1400
1200
1000
800
600
400
200
0
Cumulative Project Costs (millions US$)
140
120
100
80
60
40
20
0
PROJECT INTENT
Aesthetics Recreation Education
Bank Stabilization
Channel Reconfiguration
Dam Removal or Retrofit
Fish Passage
Floodplain Reconnection
Flow Modification
In-Stream Habitat Improvement
In-Stream Species Managment
Land Acquistion
Abandoned Mine Discharge (AMD)
Riparian Managment
Stormwater Management
Water Quality Improvement
Multiple Intents
RM
WQM
AMD
BS
DRR
SM
ARE
MULTIPLE
LA
OTHERS
CR
ISHI
FPR
ISSM
FM
FP
Restoration Goal or Intent

PROJECT DESIGN

- 36% of the projects **hired a consultant to take the lead** or **provide input toward the restoration design**.

- Most commonly, designers were **government agency staff** (45%), particularly from state agencies.

- Interviewees reported that **past experience was the most common source of knowledge** influencing design (84%).

- Only 13% relied primarily on preexisting frameworks like manuals, agency guidelines, or other literature.

- Only 3% used analytical (numerical/stochastic) models for process-based design alternatives.

PROJECT IMPLEMENTATION

- Vast majority (80%) of the project managers and implementers **made some effort to minimize the impact of construction efforts by changing the timing of the project to accommodate:**
  - *reproductive cycles of key species*
  - *relocating native plants or animals,*
  - *minimizing turbidity impacts,*
  - *other related impacts*

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    - *minimizing turbidity impacts,*
    - *other related impacts*

- Many of the interviewees drew attention to the **importance of stakeholders** to the restoration process - 61% of the interviewed projects occurred on private property.
    - *86% received in-kind contributions or services from citizens and/or landowners.*

PROJECT EVALUATION

- **Less than half** of the interviewed projects **had explicit, measurable project objectives** stated in proposals or **evaluation standards**.
  - ***52% "completely successful"***
  - ***36% "partially' successful"***

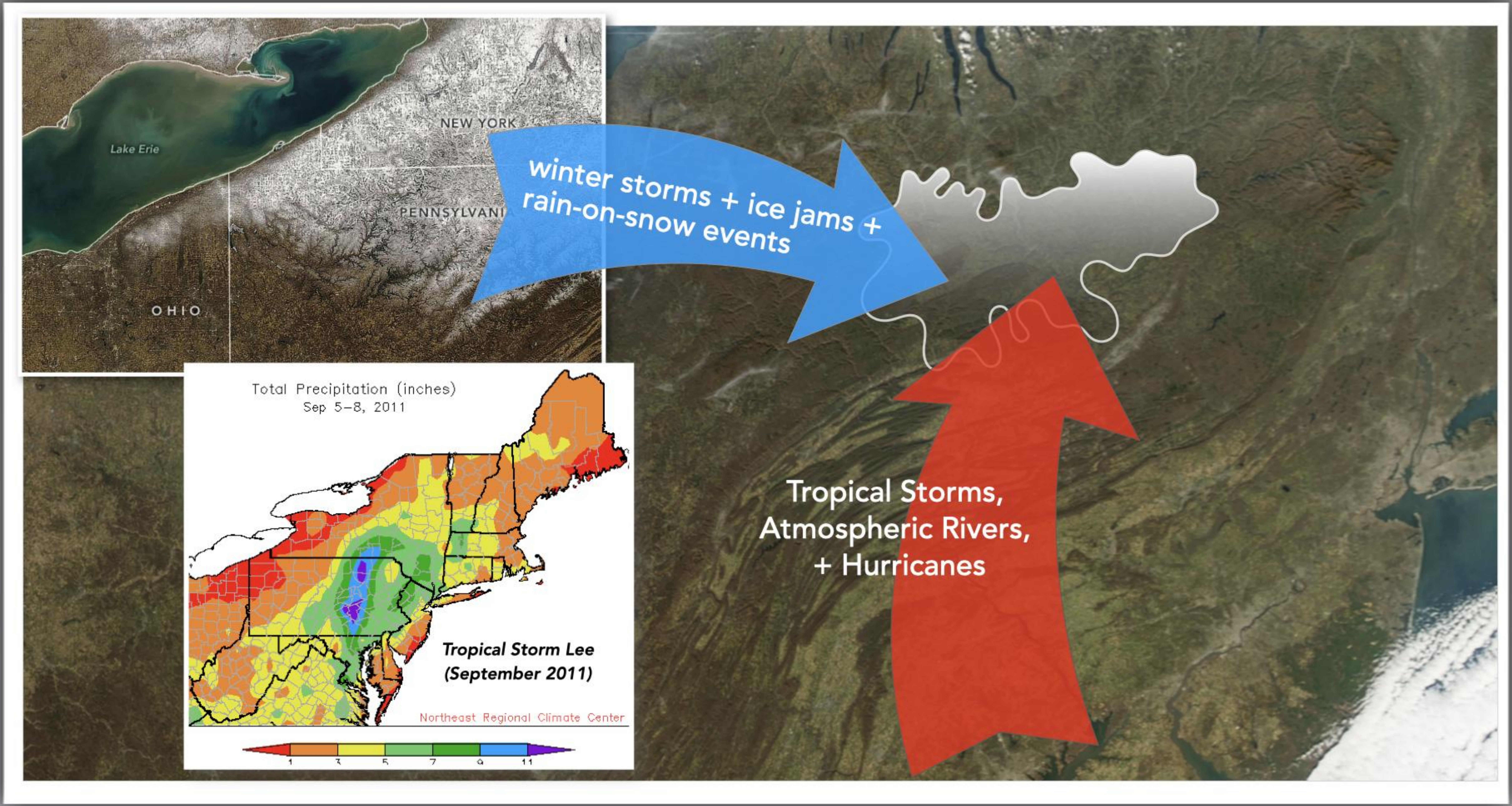
- Few projects cited improvements in-stream **hydrology** (7%).

- Cited grounds for "success" included ecosystem responses:
  - *positive effects on **fish and wildlife** (67%)*
  - ***stream morphology** (19%)*

What are the signs telling us?
Where should we be heading?

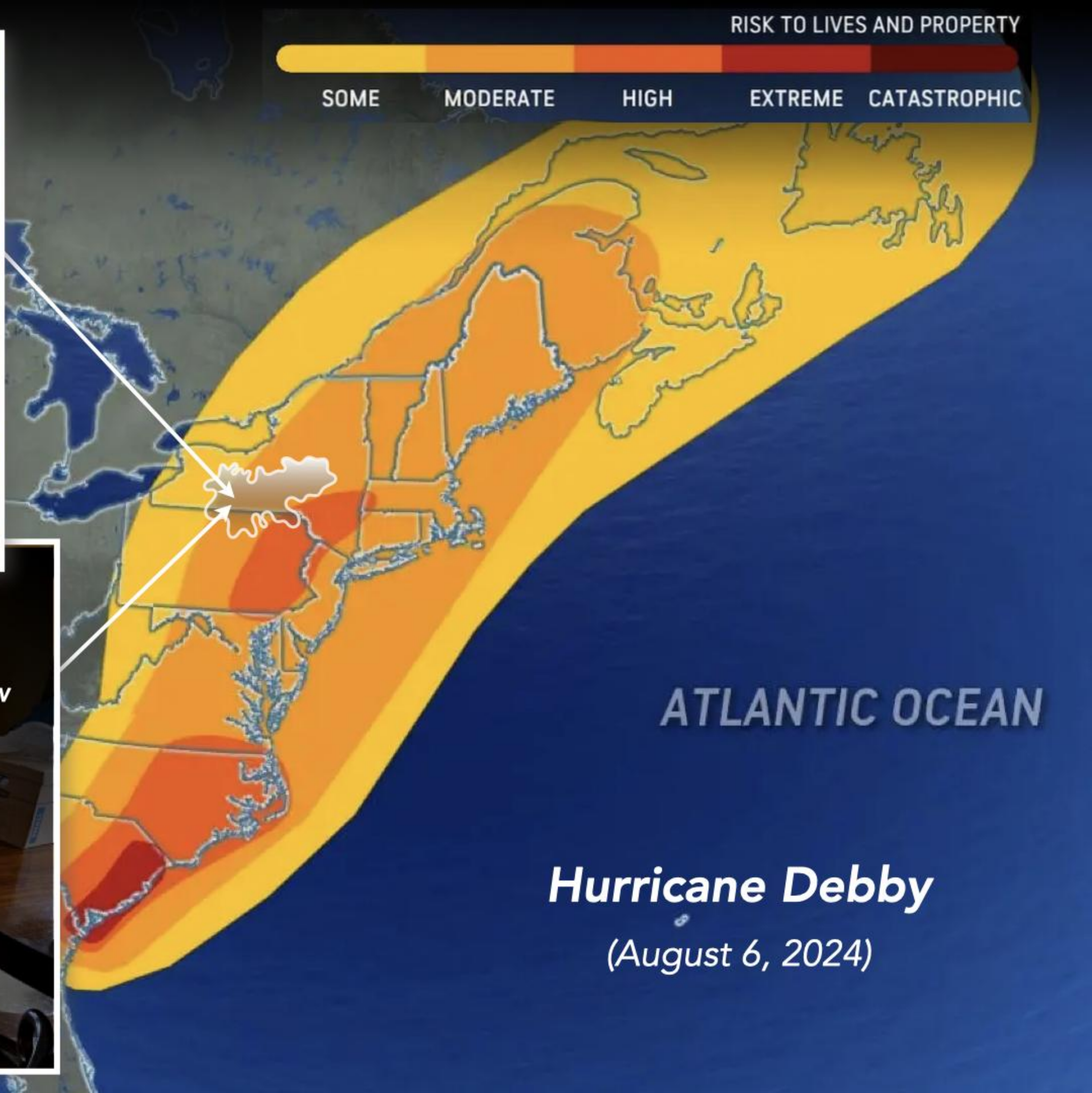
- Restore degraded fluvial networks in ways that allow them to respond to pertubations (e.g., floods) through **natural** physical and biological adjustments
- Continue to function in response to 1st order system drivers, such as climate change

Key Concept


Lake Erie
NEW YORK
PENNSYLVANIA
OHIO
winter storms + ice jams + rain-on-snow events
Total Precipitation (inches)
Sep 5-8, 2011
Tropical Storm Lee (September 2011)
Northeast Regional Climate Center
1
3
5
7
9
11
Tropical Storms, Atmospheric Rivers, + Hurricanes

Debris in the wake of Debby in Canisteo, N.Y.

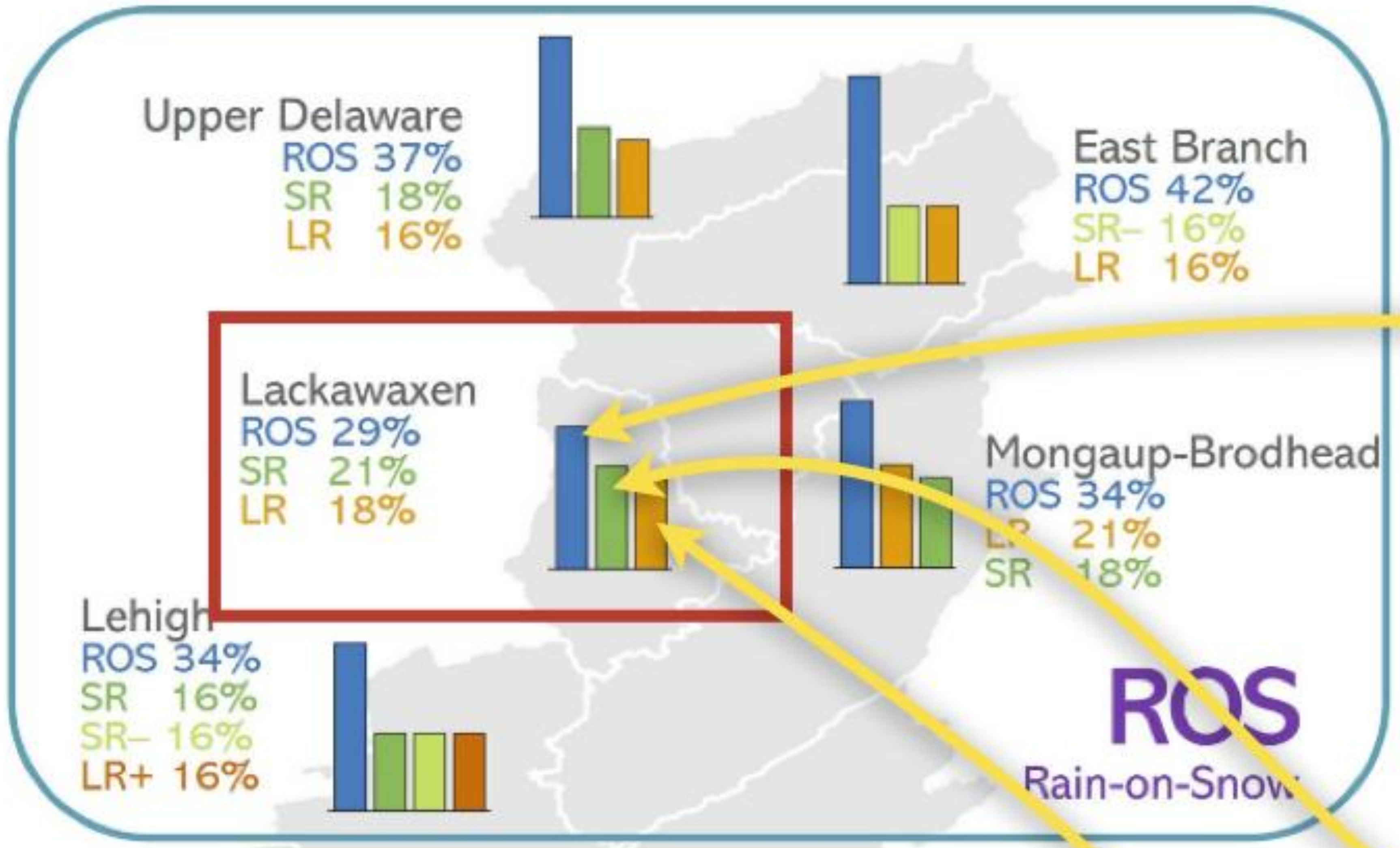
Ann Farkas walks through her damaged home in Canisteo, New York, after Tropical Storm Debby swept through the area.



Hurricane Debby

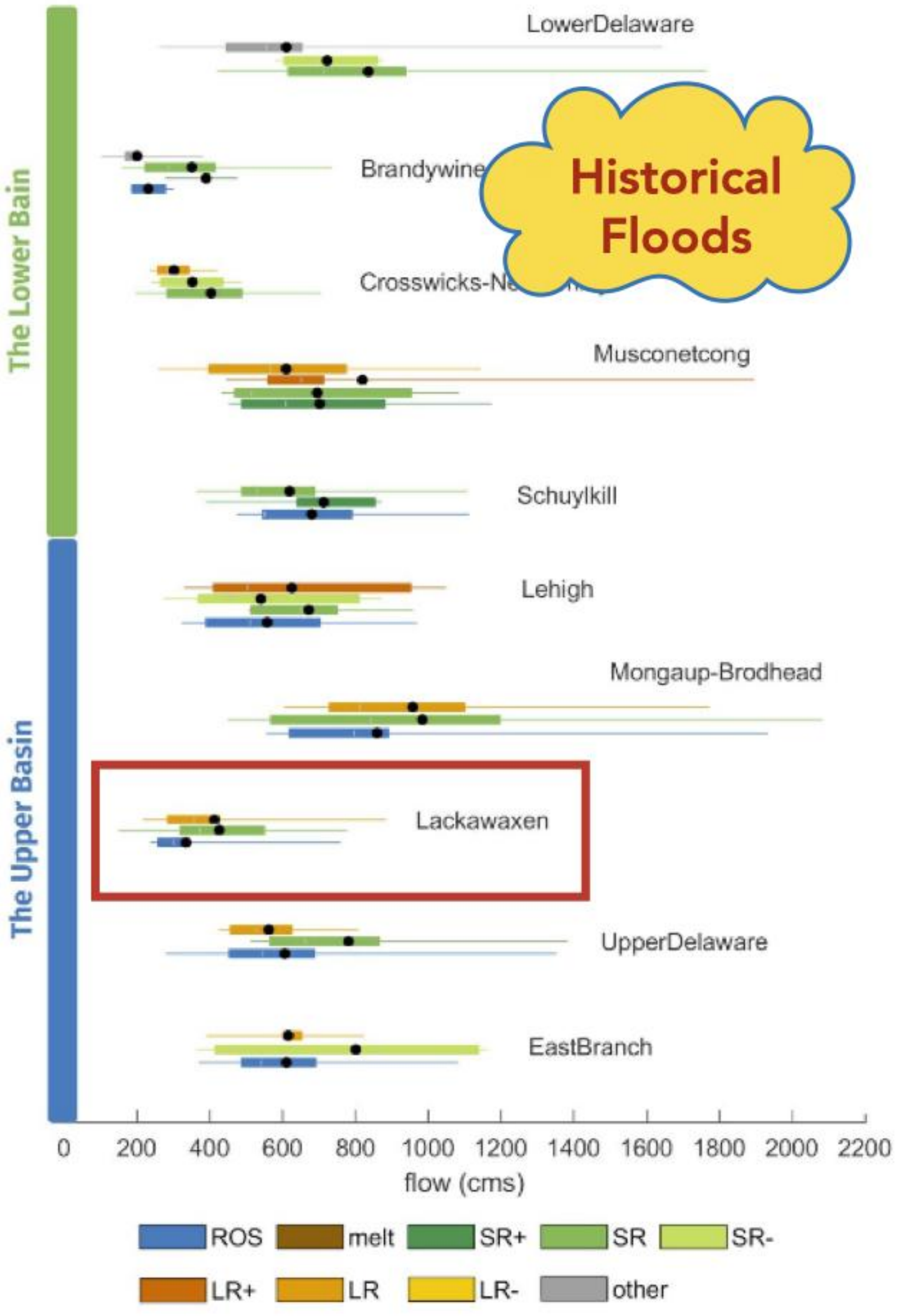
(August 6, 2024)

SHIFTING FLOOD PATTERNS



- **Snowmelt** (**Melt**)
- **Rain-on-snow** (**ROS**)
- **Short-duration, high-intensity rain** with different soil antecedent moisture conditions (AMC):
  - dry (SR–),
  - normal (SR),
  - wet (SR+)
- **Long-duration, lower-intensity rain** classified by AMC:
  - dry (LR–),
  - normal (LR)
  - wet (LR+).

From: Sun, N., et al. (2024). Amplified extreme floods and shifting flood mechanisms in the Delaware River Basin in future climates. ***Earth's Future****, v. 12.*



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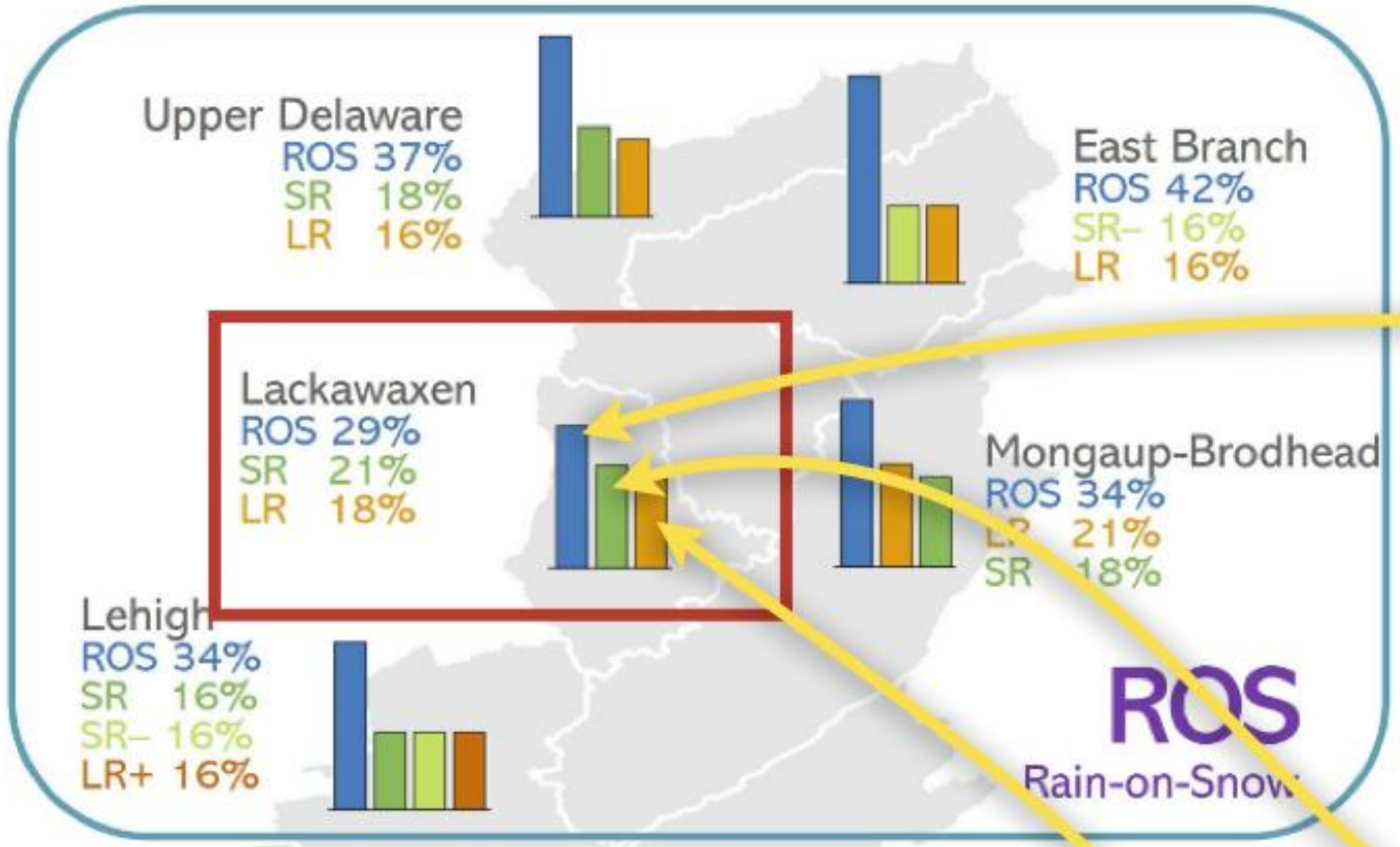

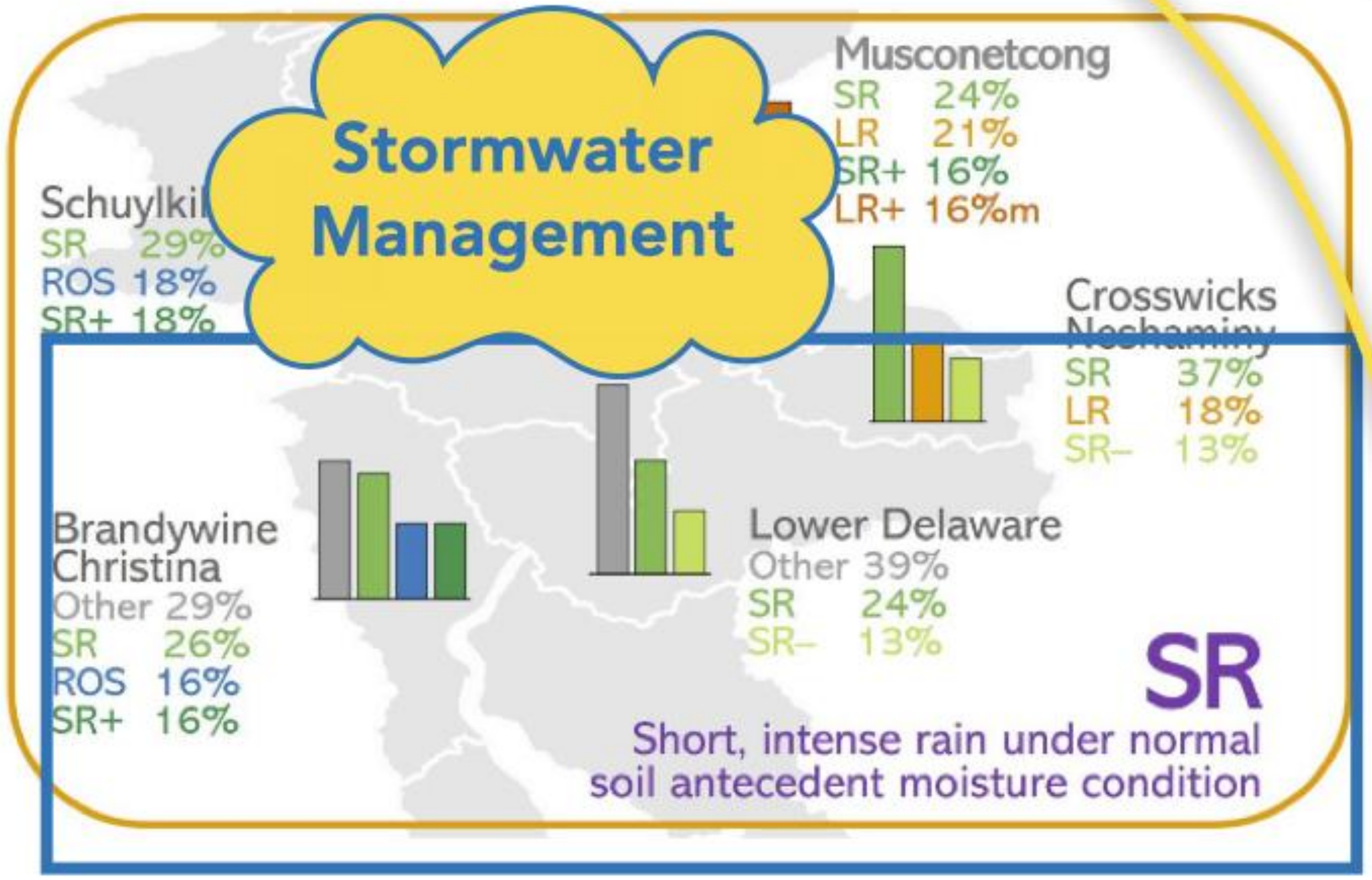

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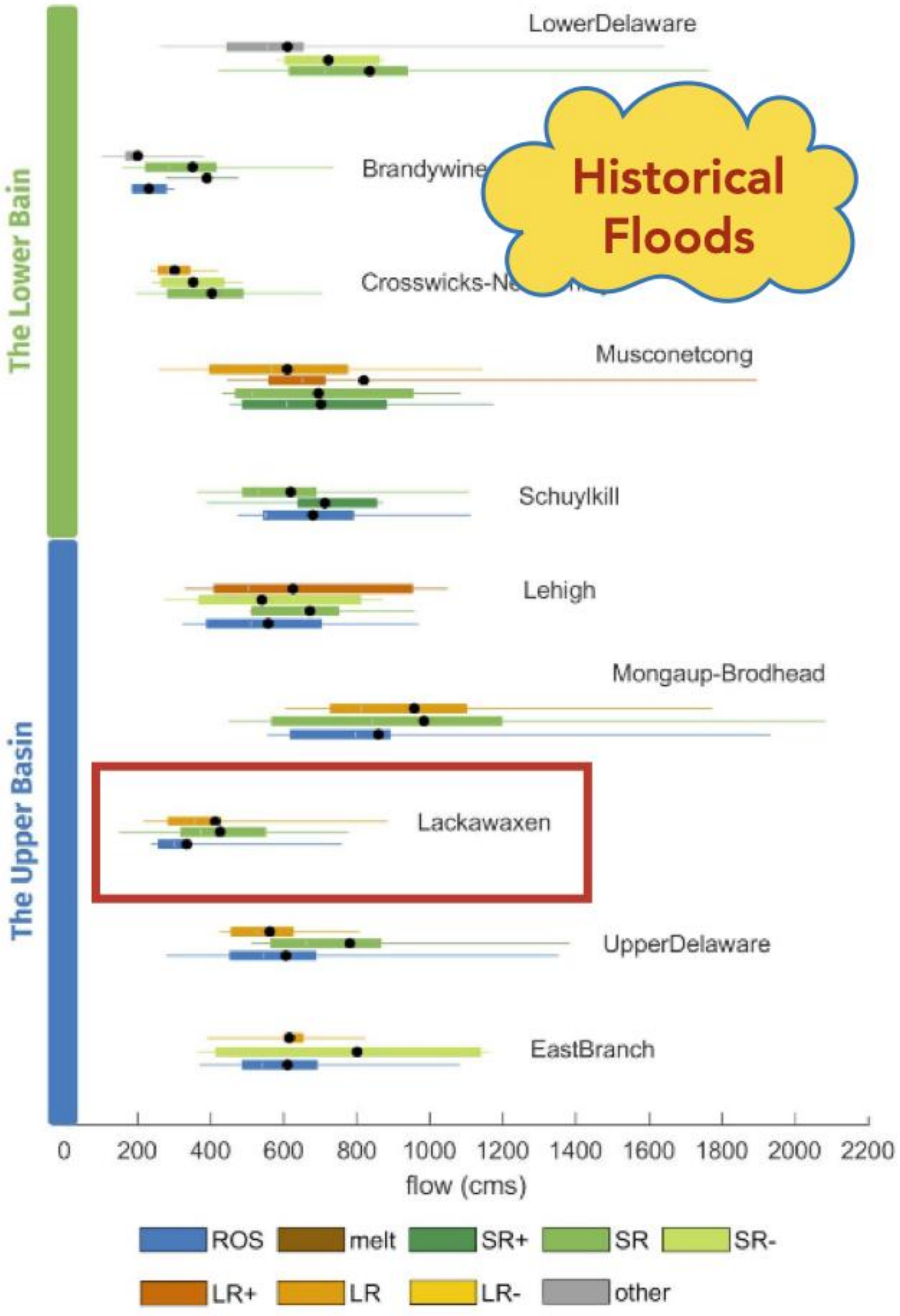
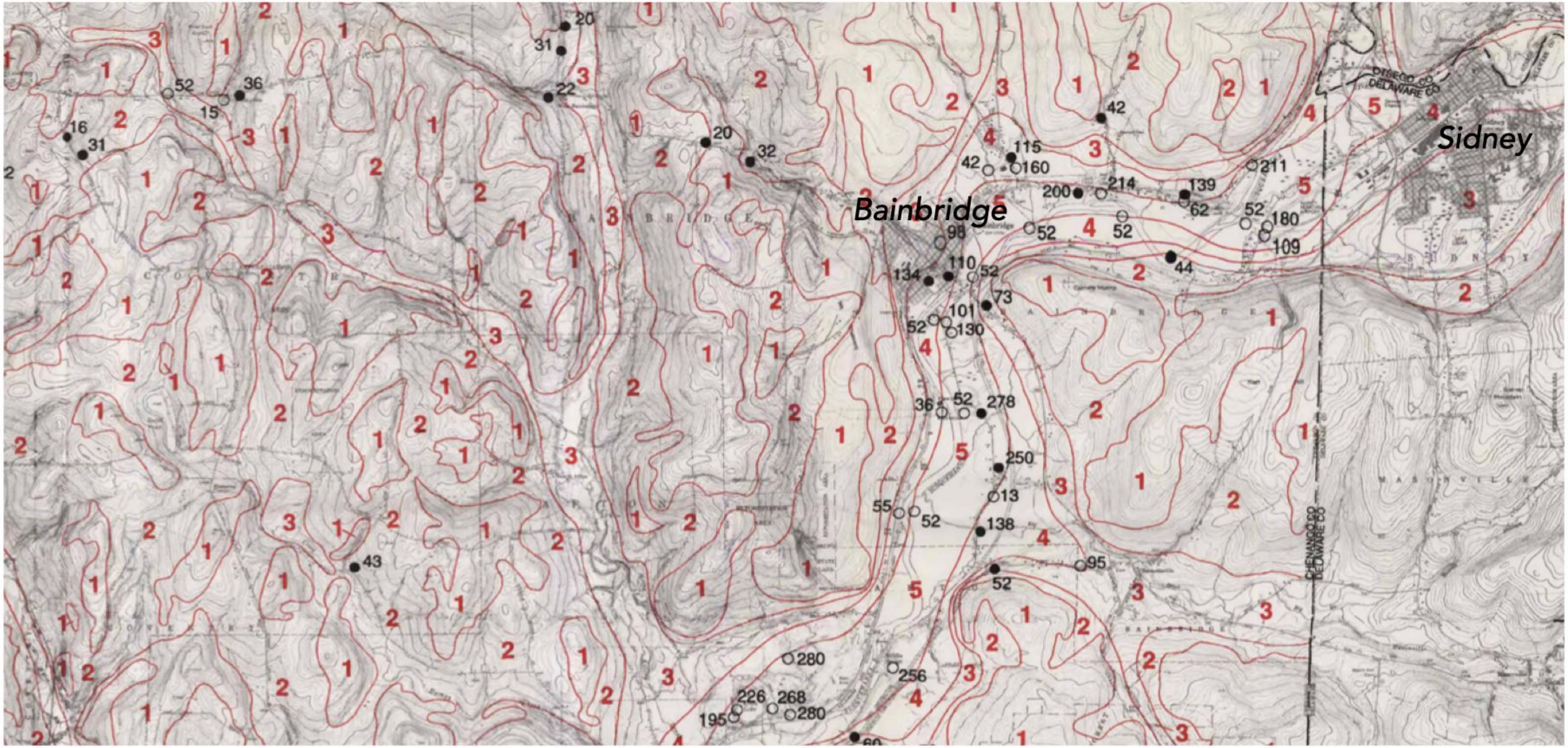


High Plateau Section
(Warren, Clarion, Forest, McKeen, Elk, Cameron counties)
Flat-lying sedimentary rocks, with lower relief, broad hillslopes and narrow valley floors
YOU ARE HERE
Glaciated Plateaus
(Bradford, Tioga, Sullivan and Lycoming counties)
Gravel-bed rivers, complex assemblage of alluvium, till, valley-train outwash, and underlying ice-contact deposits
Deep Valley Section
(Clinton, Potter, Tioga, Lycoming, and Sullivan counties)
Gravel-bed streams flowing through narrow canyons carved in flat-lying sedimentary rocks, with steep hillslopes, high relief, and narrow valley floors
Ridge & Valley Province
(Centre, Union,Northumberland, Snyder, Columbia, Montour, Luzerne, Mifflin, & Juniata counties)
Broad limestone valleys, shale hillslopes and meandering streams with suspended sediment loads
Piedmont Province
(Franklin, Perry, Cumberland, York, Lancaster, York, Berks, Chester, Leighigh, and Bucks counties)
Rolling hills and valleys, low relief, meandering streams with suspended sediment loads

FINGERPRINT OF PLEISTOCENE GLACIATION

McPherson (1993). Hydrogeology of unconsolidated deposits in Chenango County, New York, ***USGS Water Resources Investigations Report 91-4138.*** https://10.3133/wri914138



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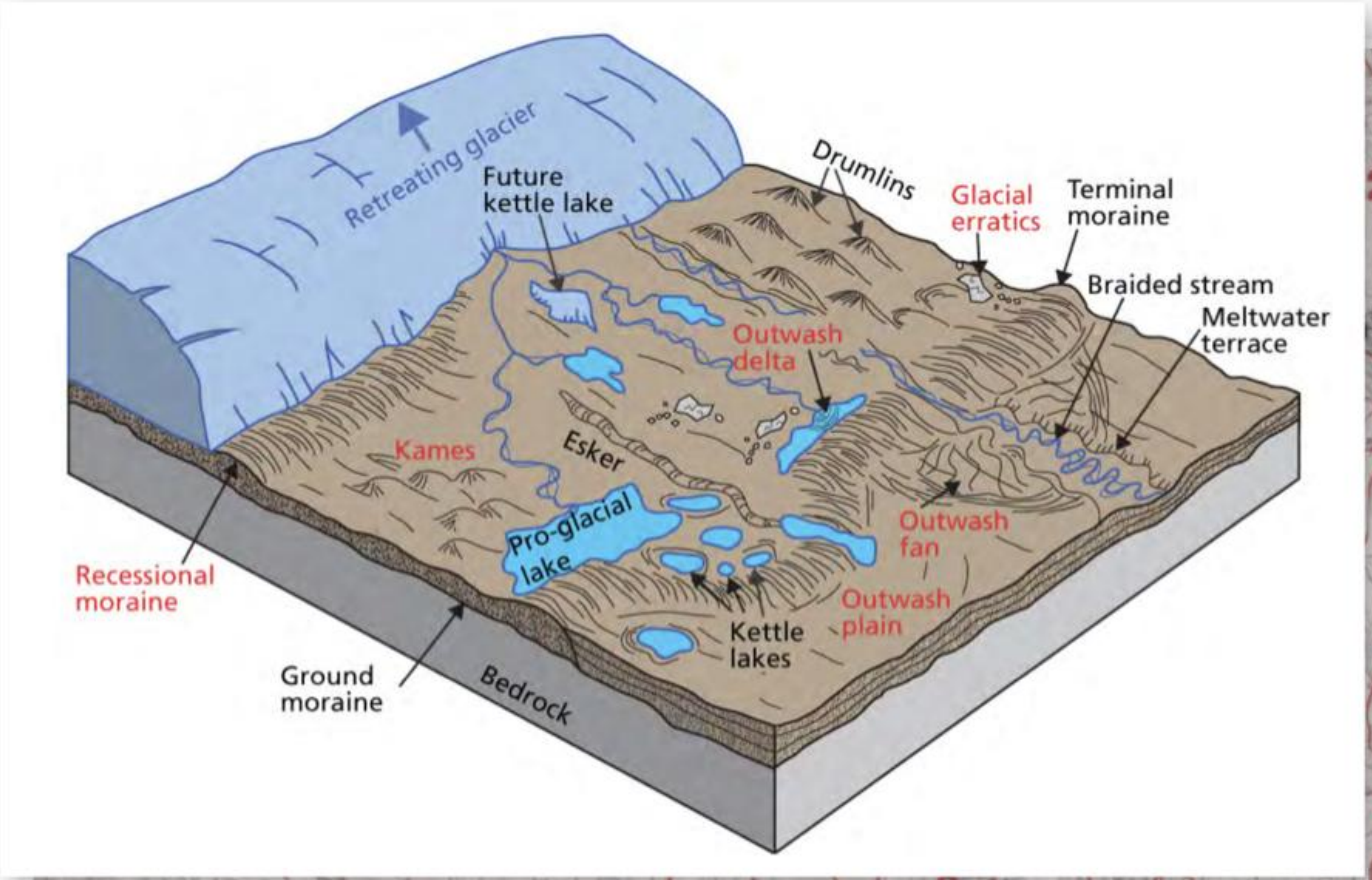

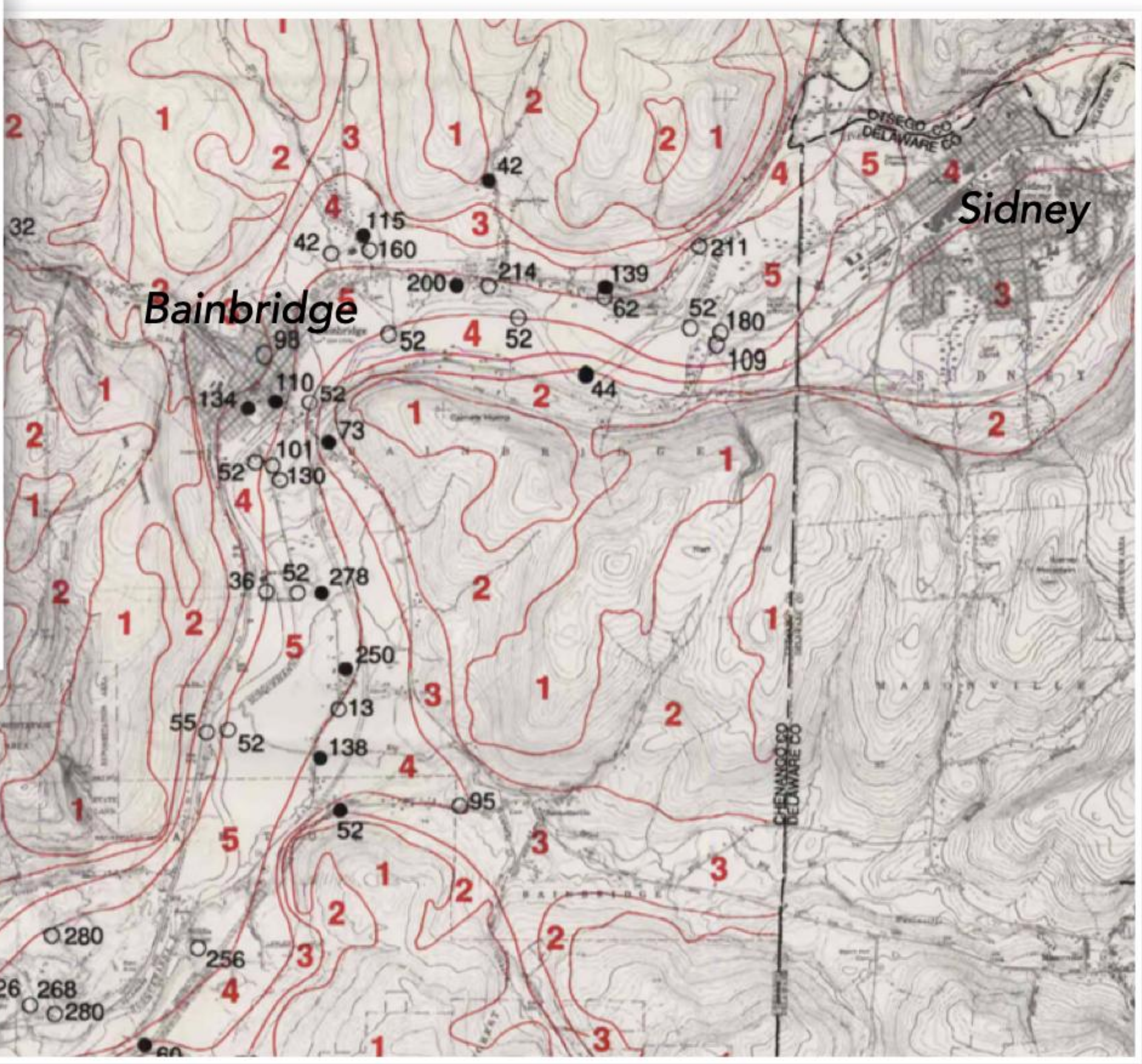

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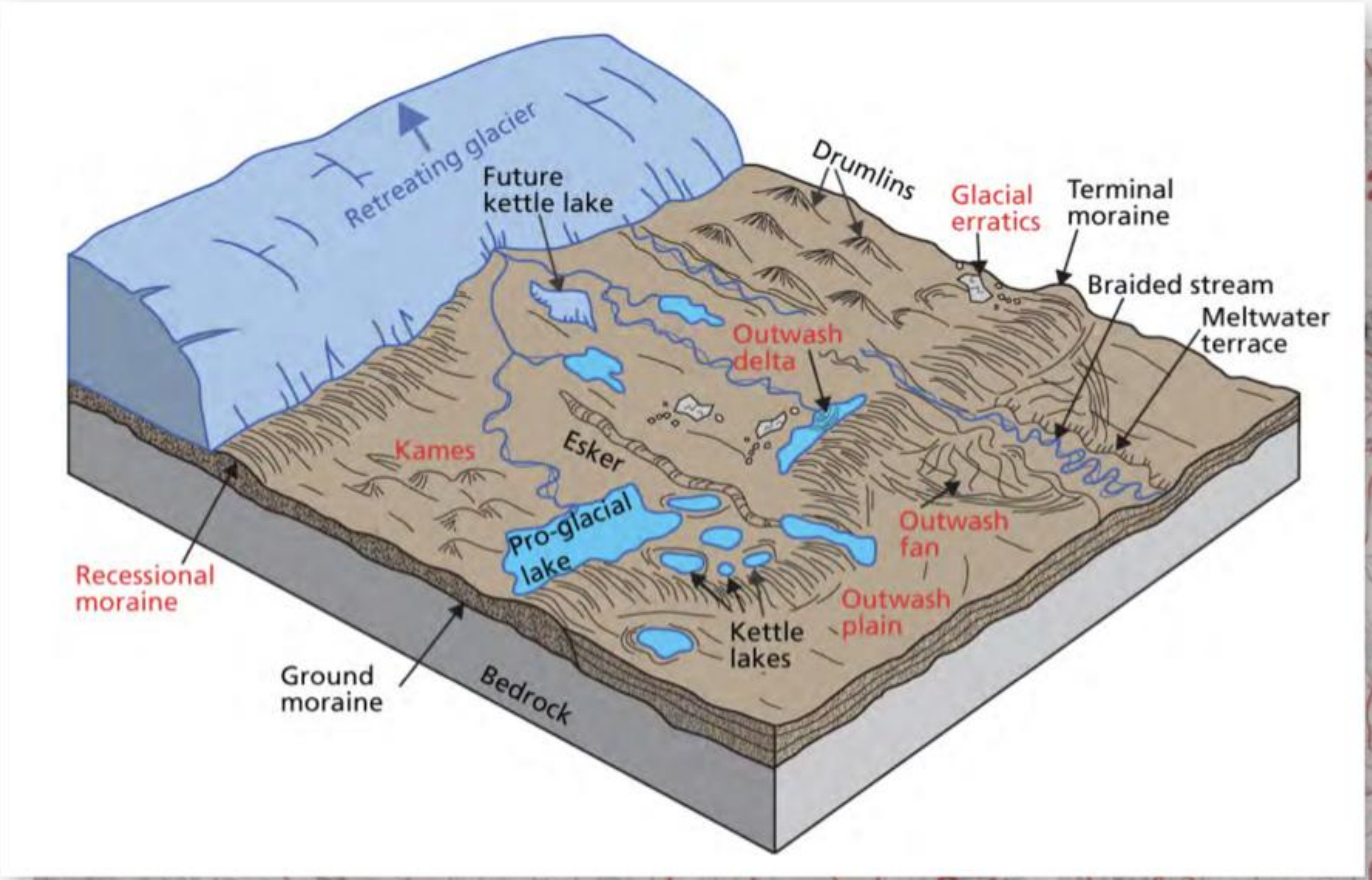
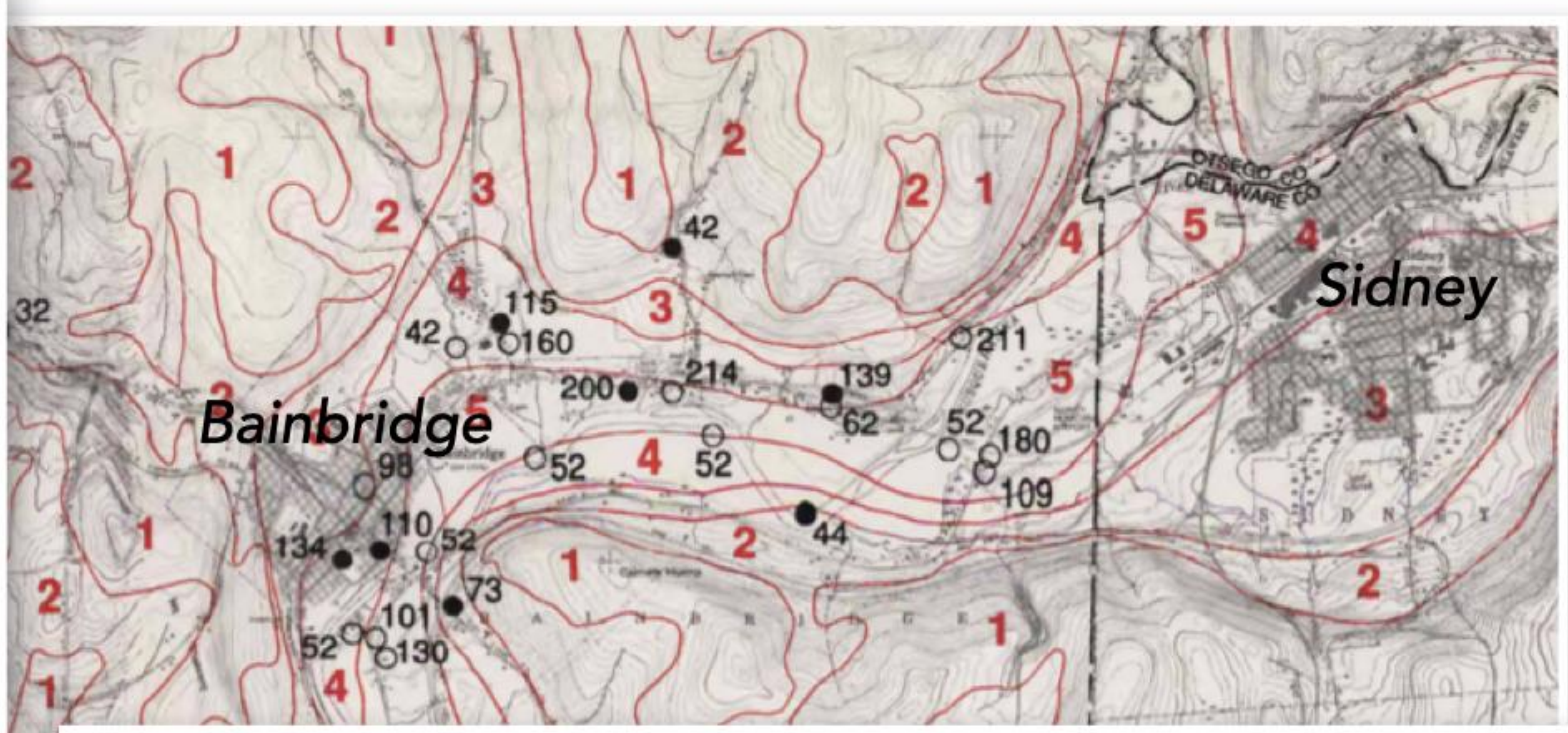
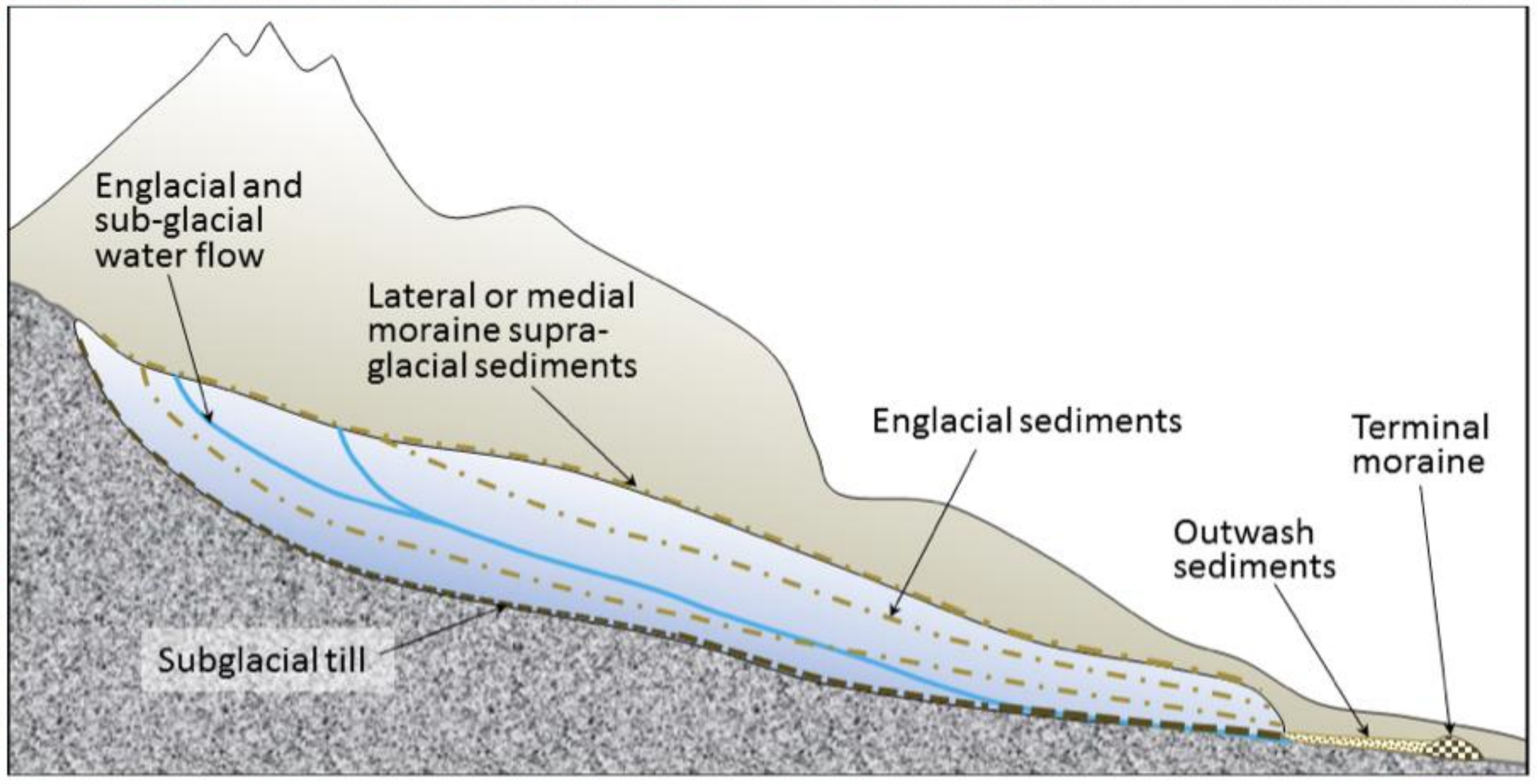
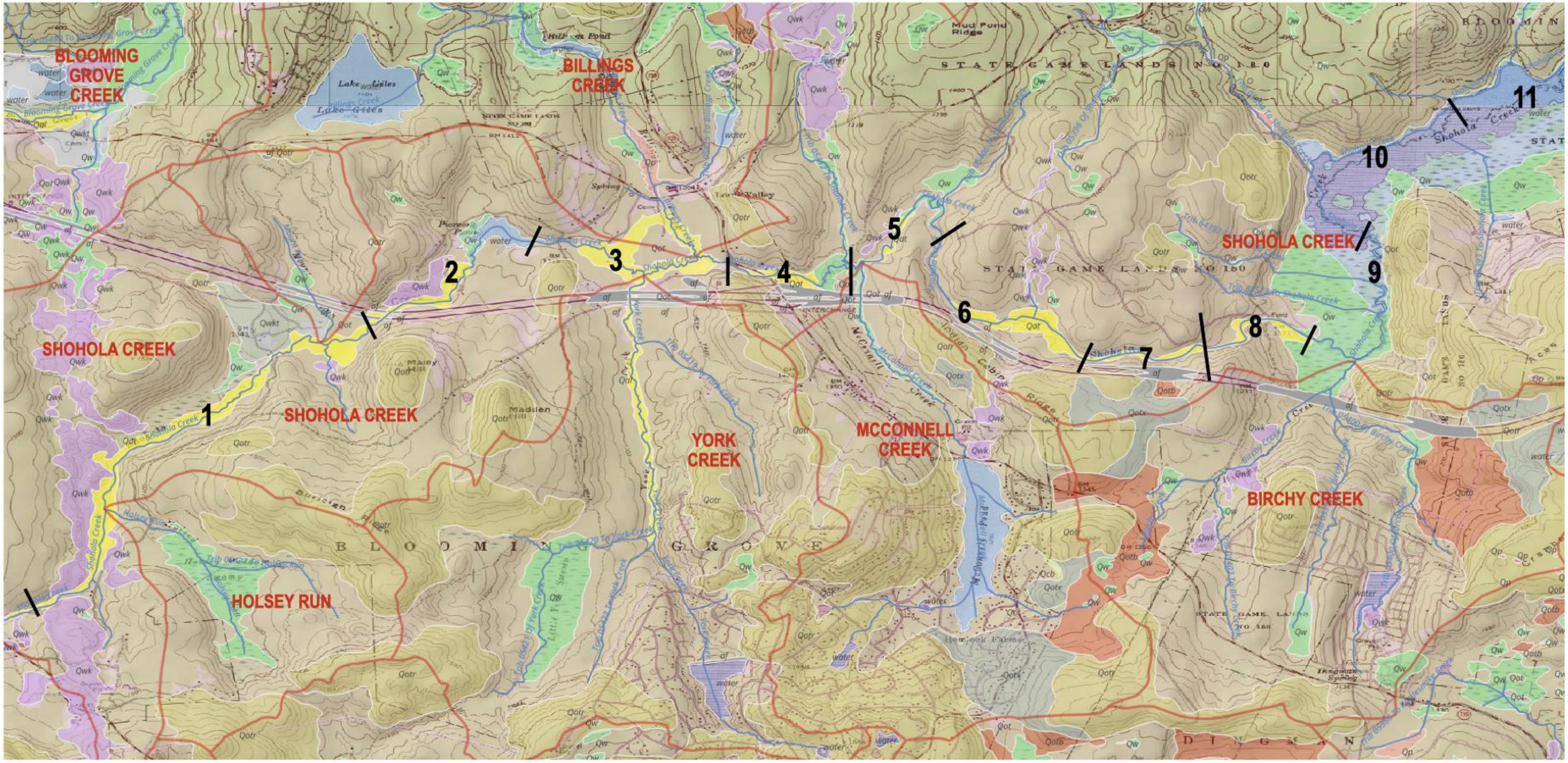


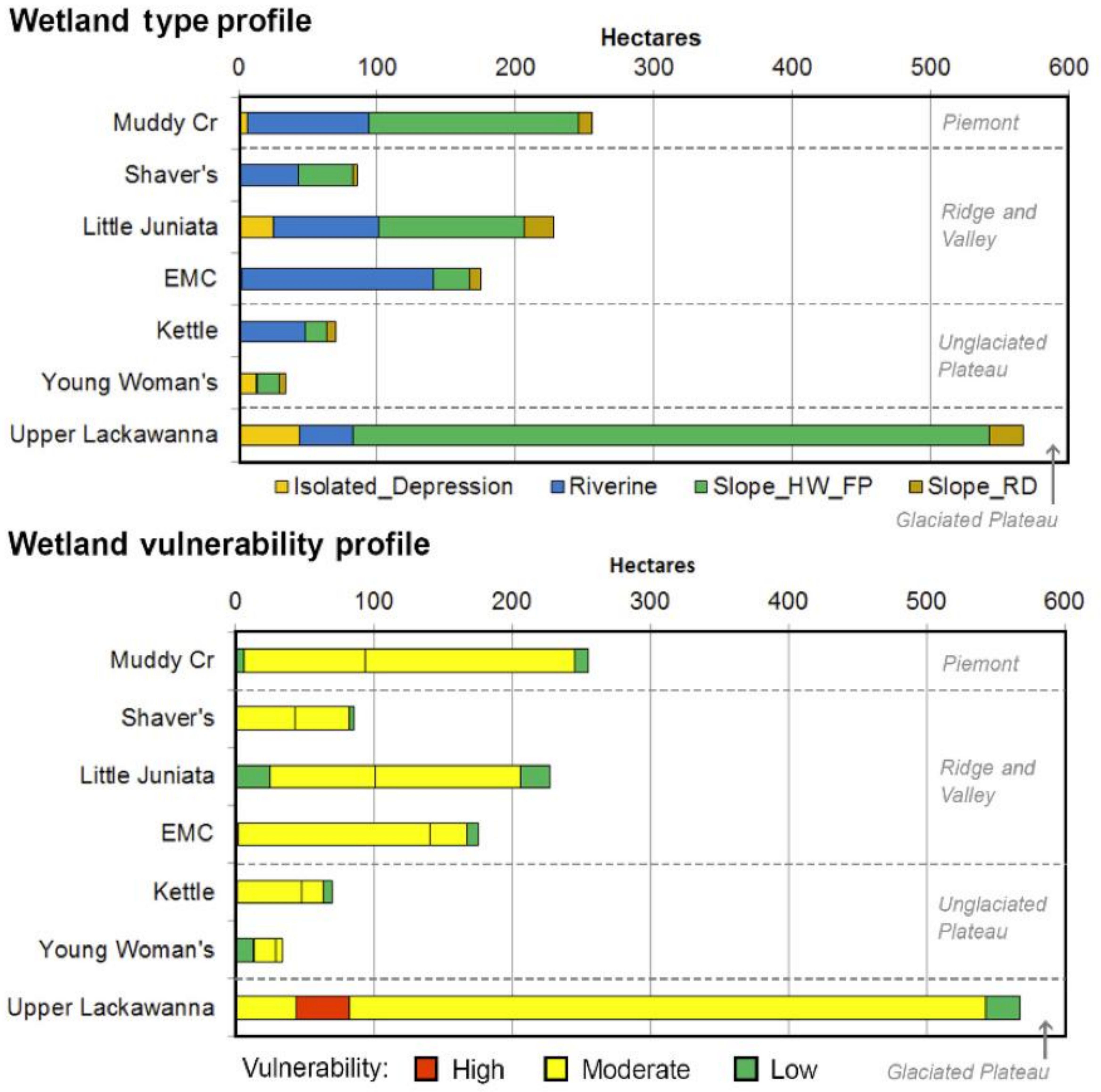


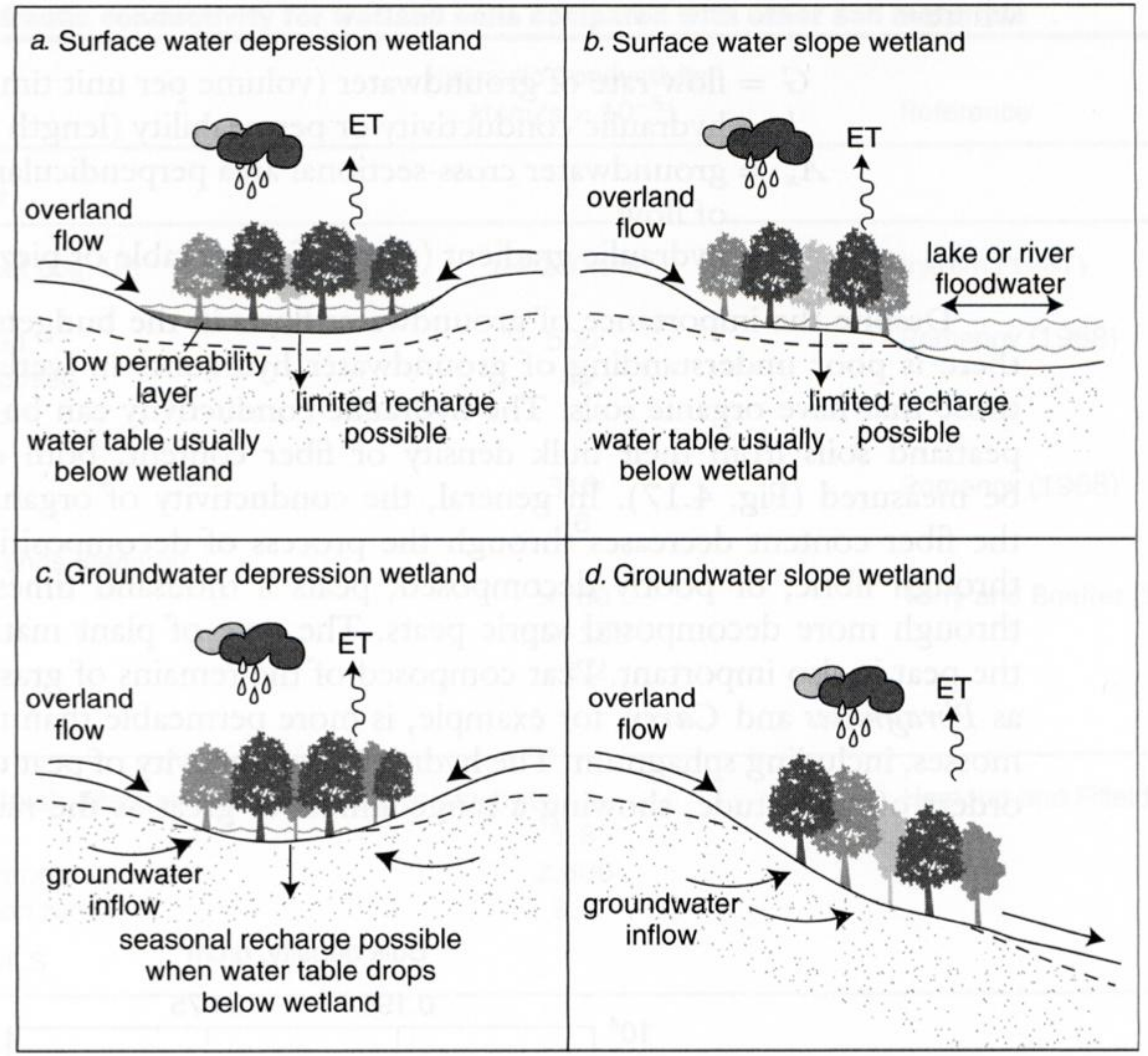


HOW WATER FLOWS THROUGH THE LANDSCAPE TODAY



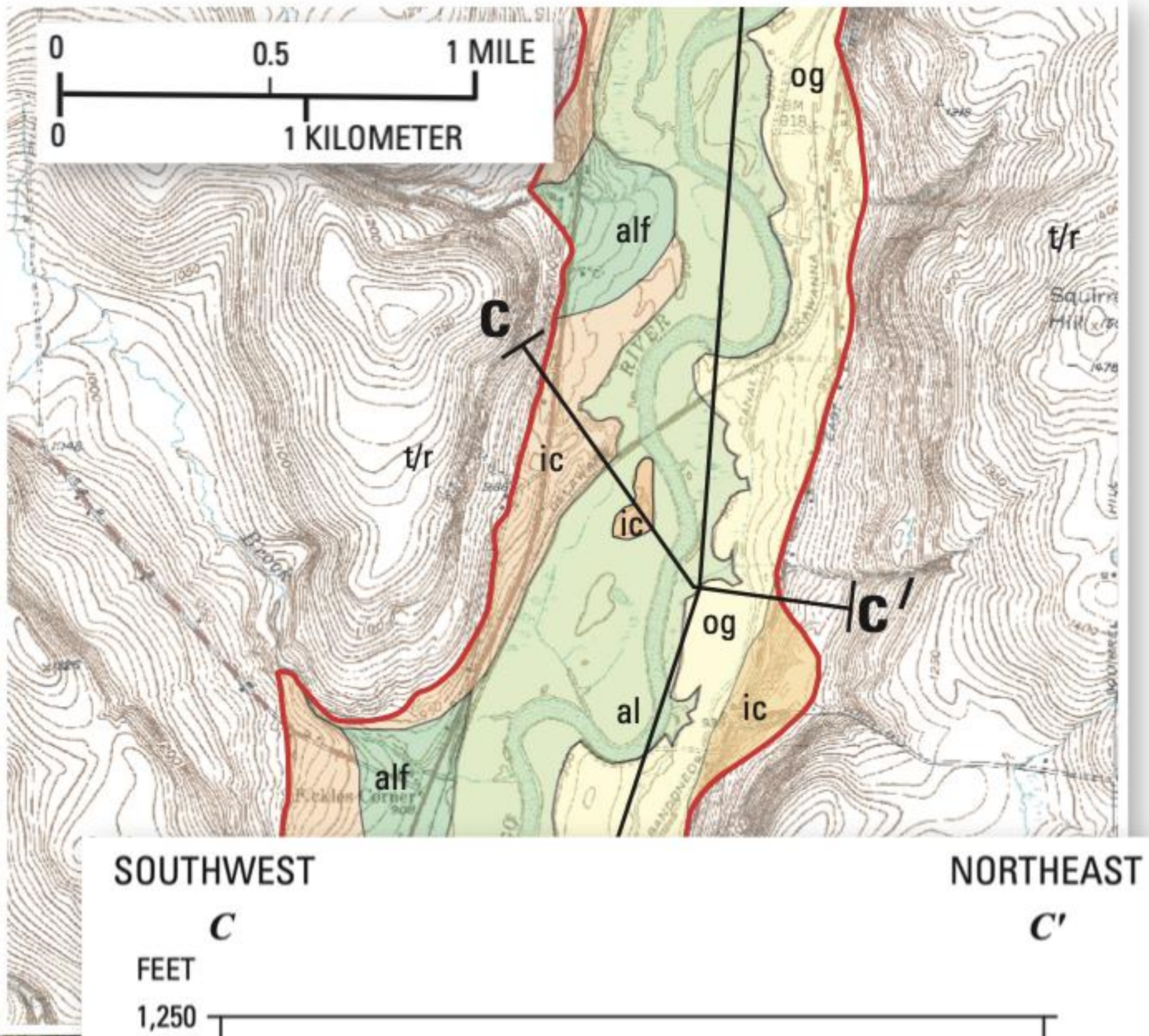
WETLAND VULNERABILITY

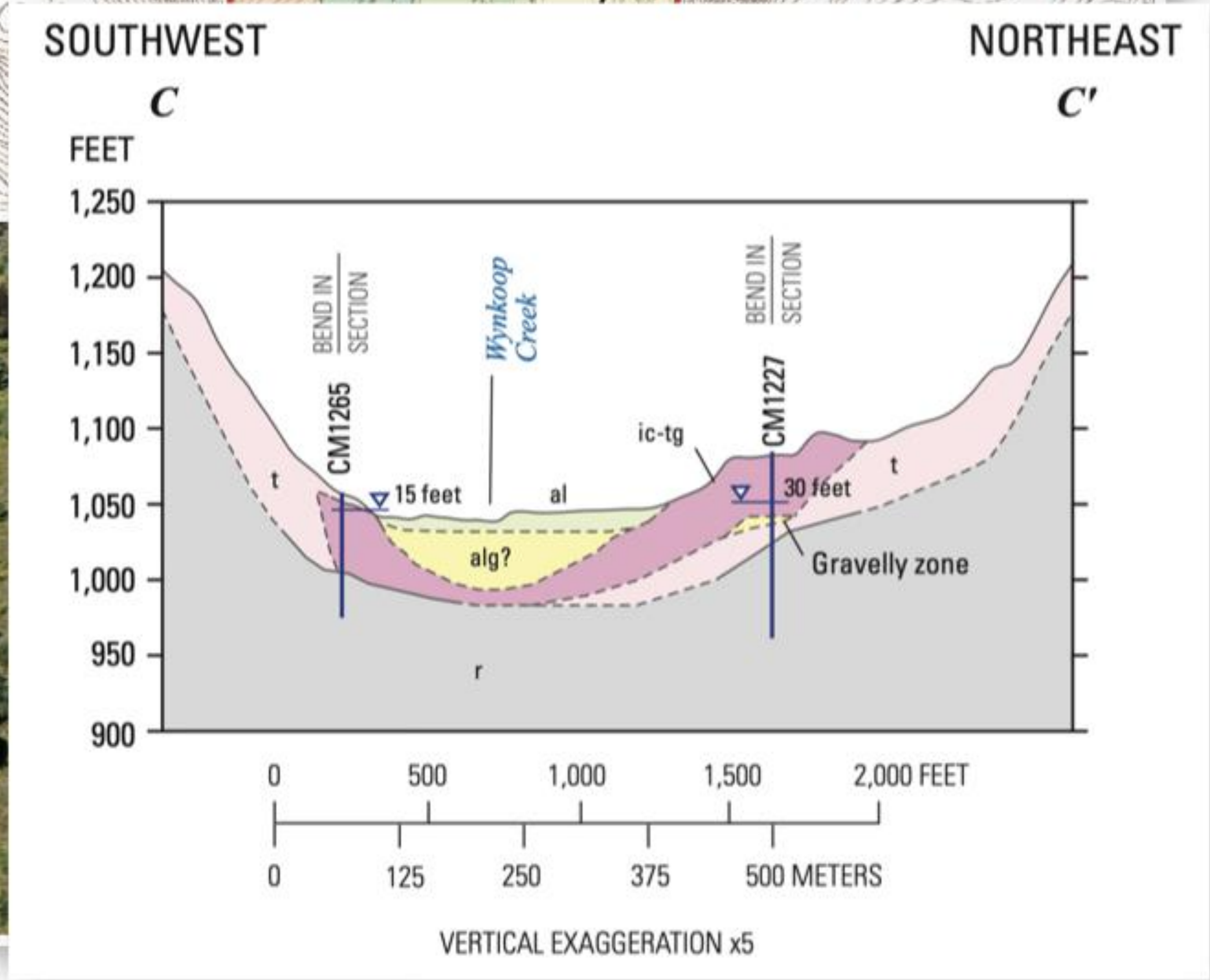




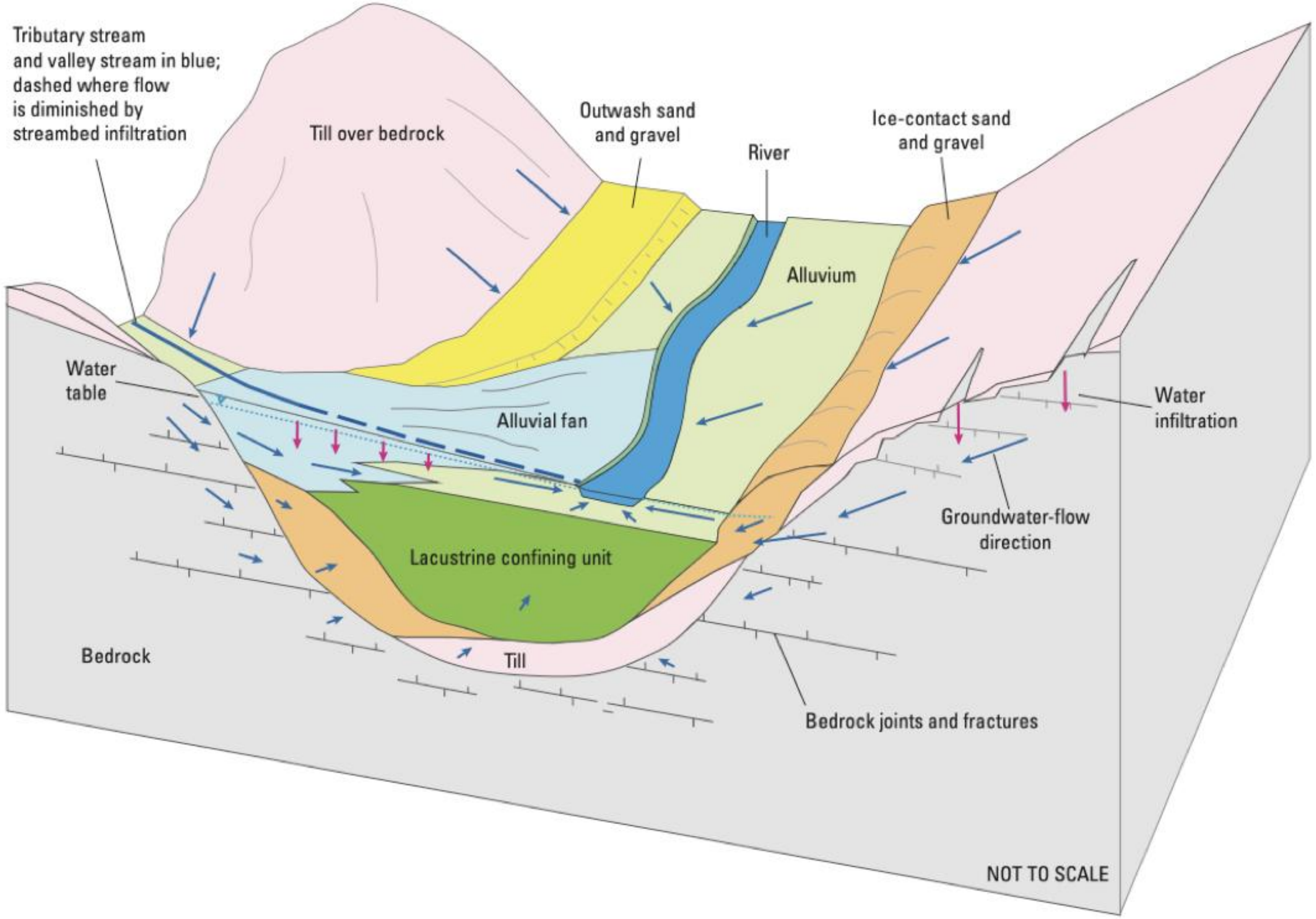
QUATERNARY VALLEY FILL DEPOSITS

Wyncoop Creek (Chemung Watershed) downstream of Hicks



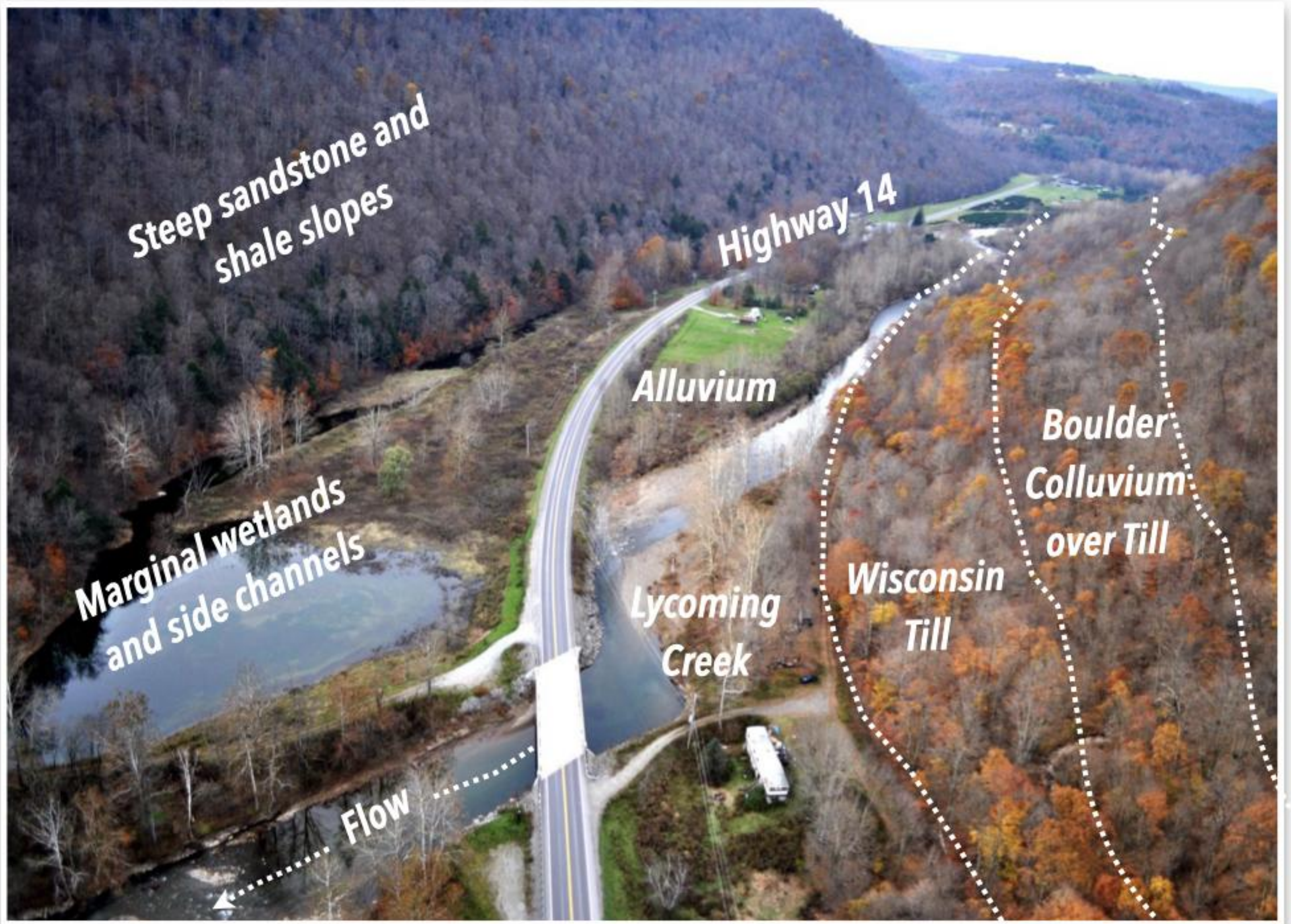


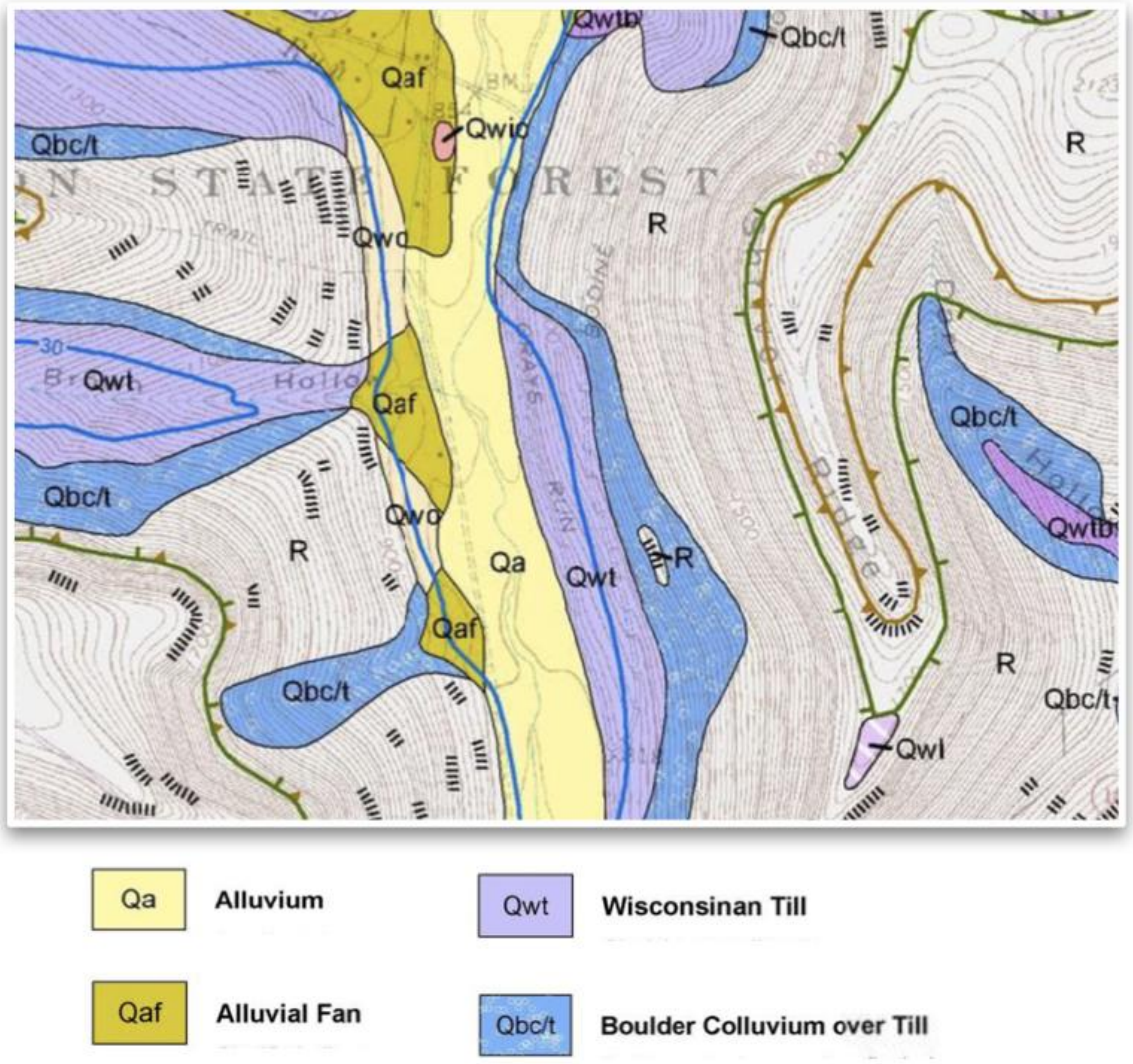
GEOLOGIC SETTING



Glacial Outwash

Glacial lacustrine (lake) deposits





Valley architecture and sediment source areas

(1) **alluvium** in valley bottom (2) **till** on valley margins, (3) **alluvial fans**, and (4) **colluvium**

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Rolling hills and valleys, low relief, meandering streams with suspended sediment loads

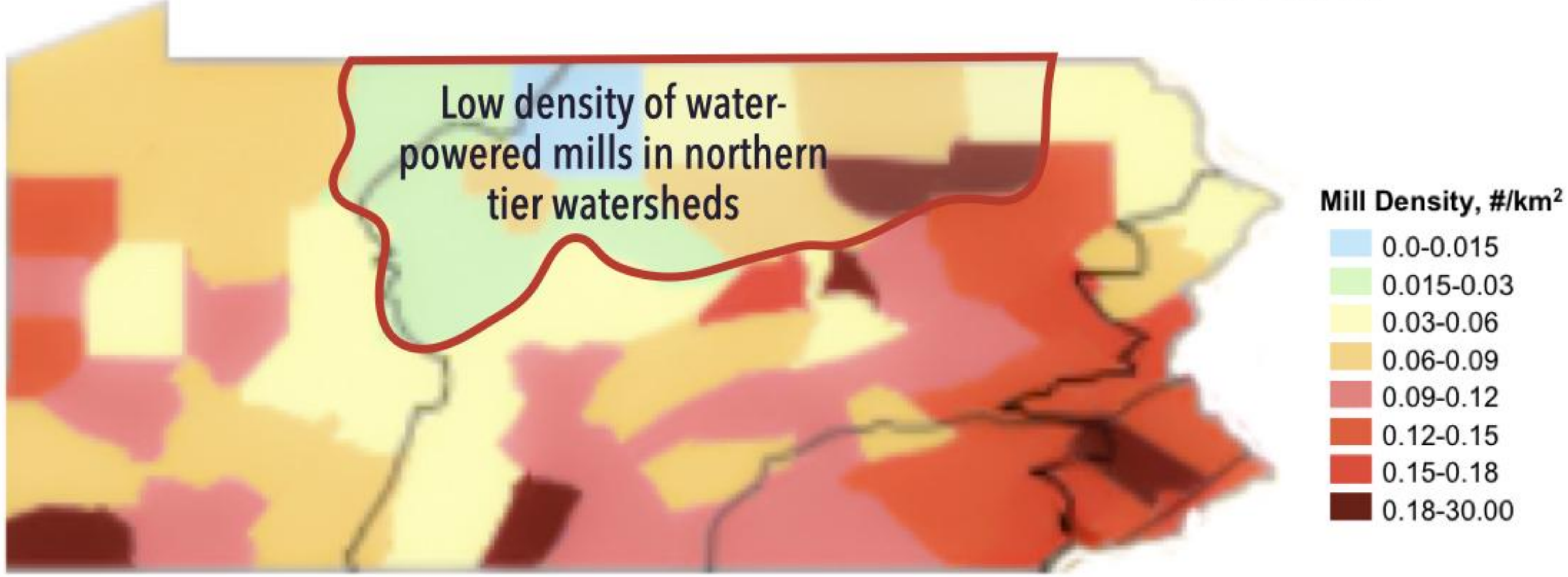
Episodic Memory #4:

- ***Extensive low-head dam construction***
- ***Streams no longer lotic but lentic ecosystems***
- ***Longitudinal connectivity severely fragmented***

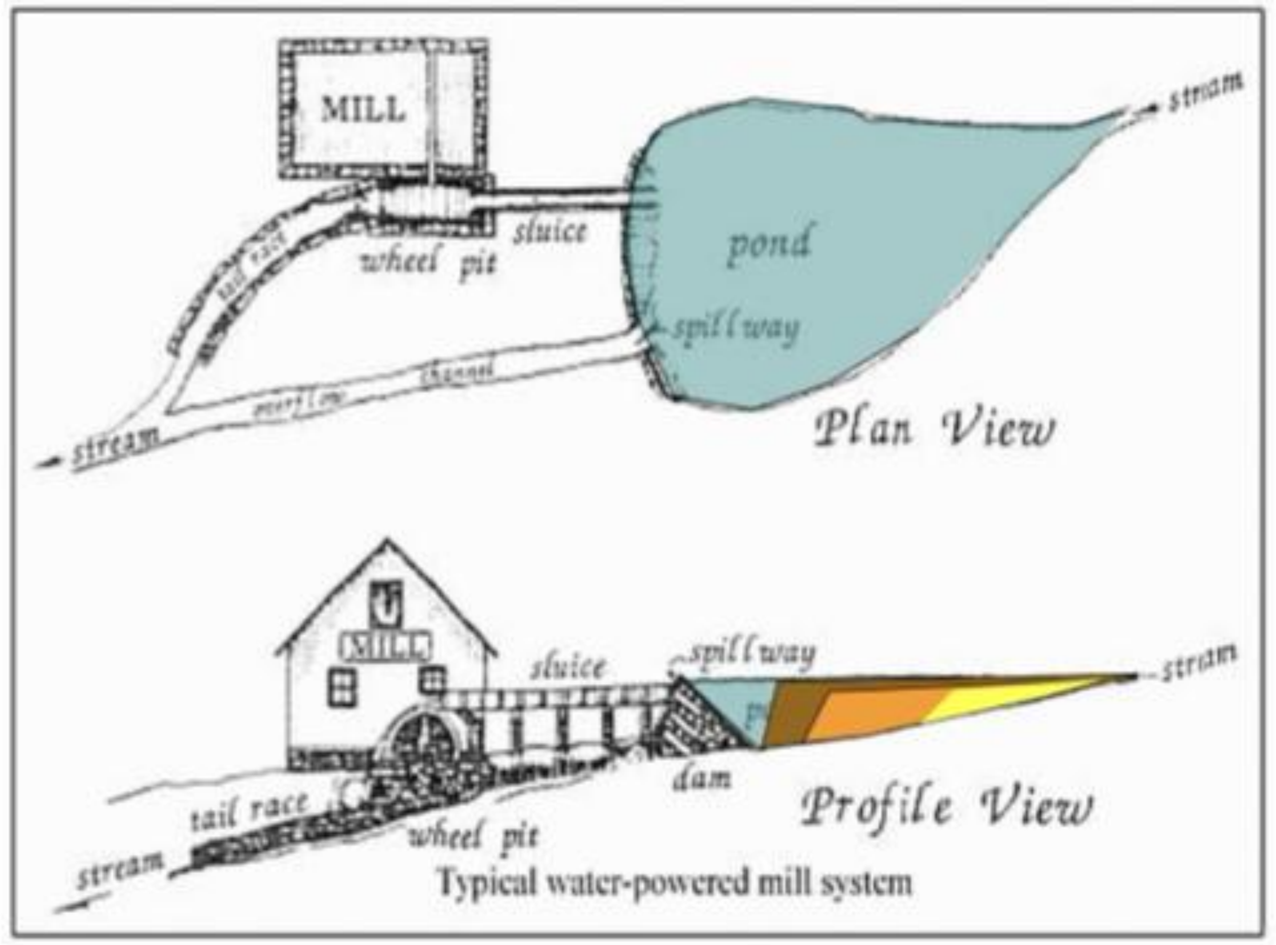
Water-powered mills

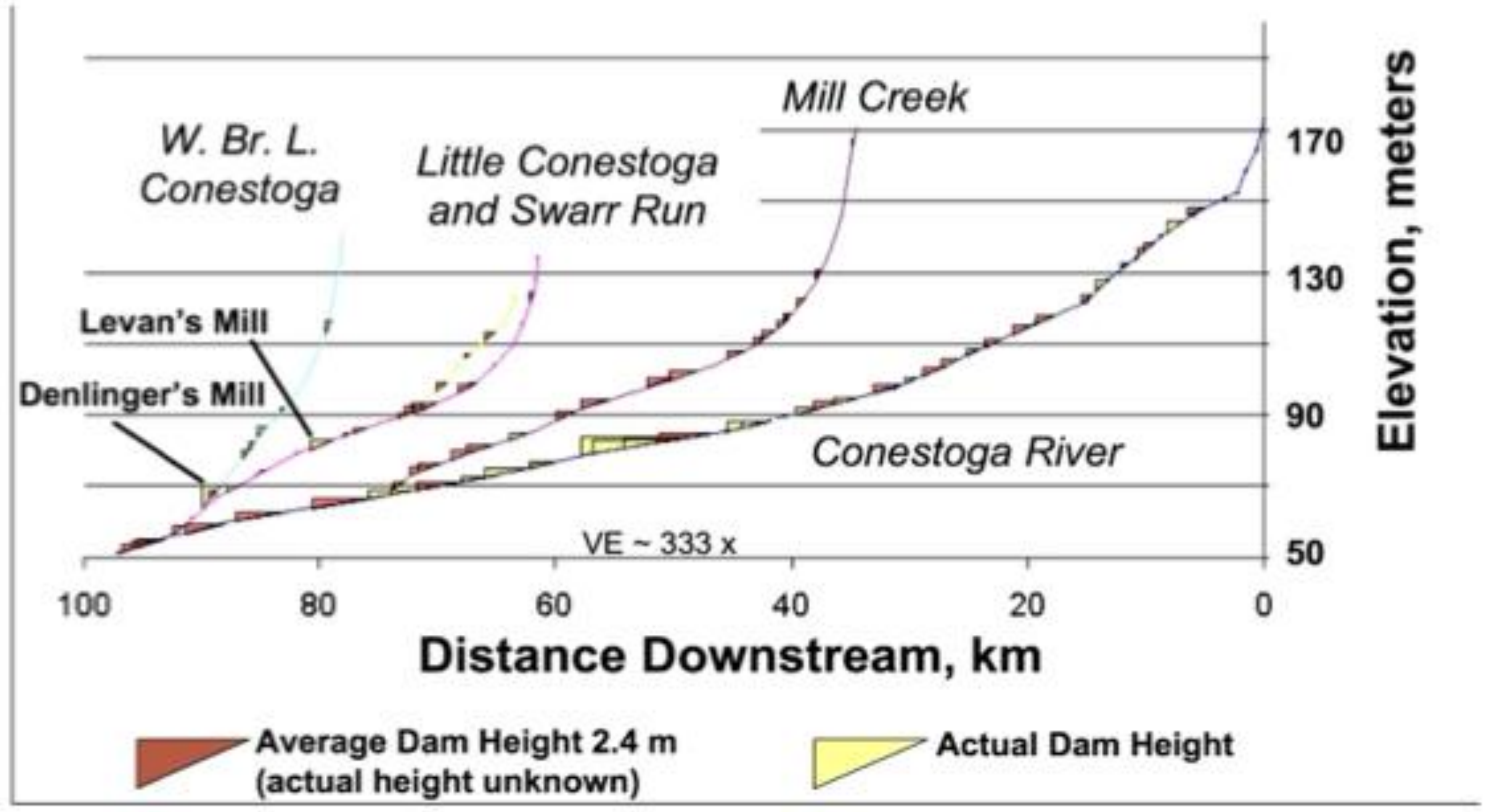
~60,000 mills

(1840 census)



Walter and Merritts (2008)





Episode 4: Construction of water-powered mills

Change in baselevel; conversion of streams from lotic to lentic systems; legacy sediment deposition

A. **Colonial/Early Era (1660s–1750s)**: Small-scale mills used for lumber and basic grain processing.

B. **Agricultural Expansion (1760s–1830s)**: Major construction period to support growing iron work and agricultural communities.

C. **Industrialization (1840s–1870s):** Transition period where many water-powered mills were upgraded with efficient turbines.

D. **Decline (Late 19th–Early 20th Century):** Mills began to be replaced by steam power in the late 1800s due to unreliable water flow.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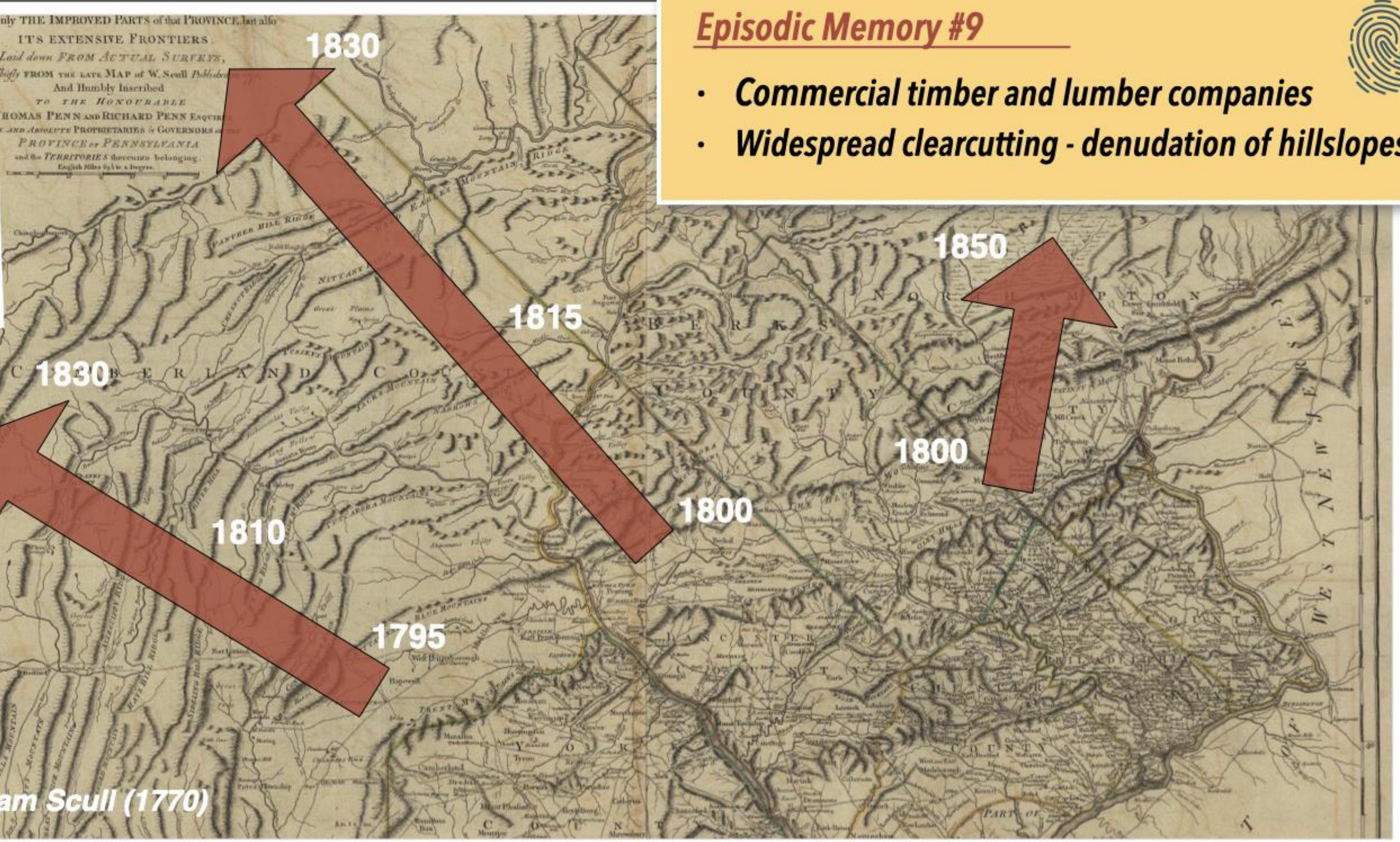


Episodic Memory #9

- ***Commercial timber and lumber companies***
- ***Widespread clearcutting - denudation of hillslopes***

Episode 6: 19th century timber harvesting

Log drives, splash dams, rafts, and arks prior to 1880 | narrow-gauge railroads until 1915.

Use of Pennsylvania streams for 19th century timber harvests

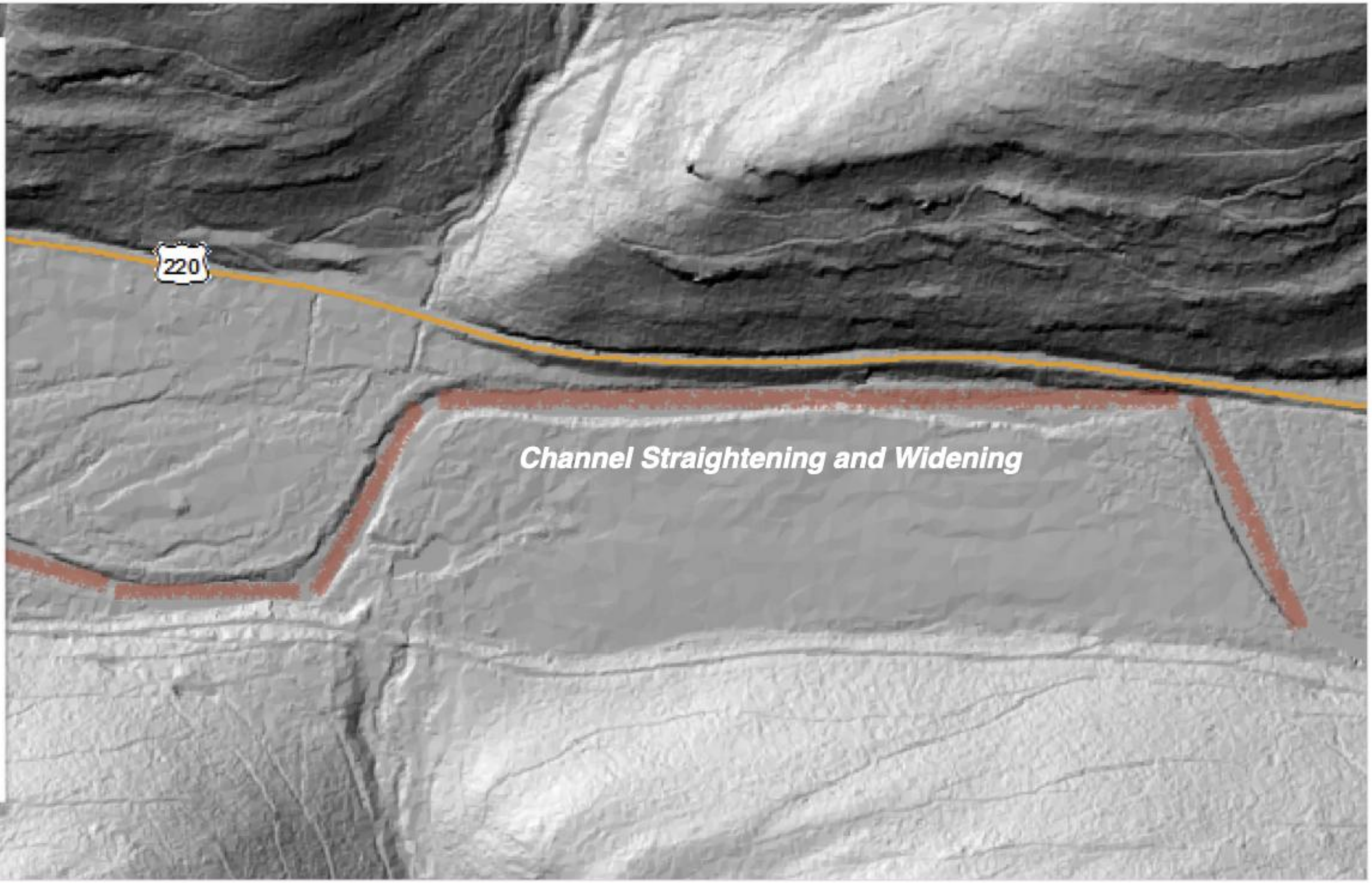
Log drives most efficient way to transport timber downstream to mills or rafting facilities on the rivers

Channel modification and "stream improvements" for log drives

Channel straightening & widening; berming; removal of channel obstructions

CUSH CREEK IMPROVEMENT COMPANY

*"... improvements consist of **dams** erected on streams, the building of **cribs**, **piers**, etc. and the <u>cleaning out of streams</u> 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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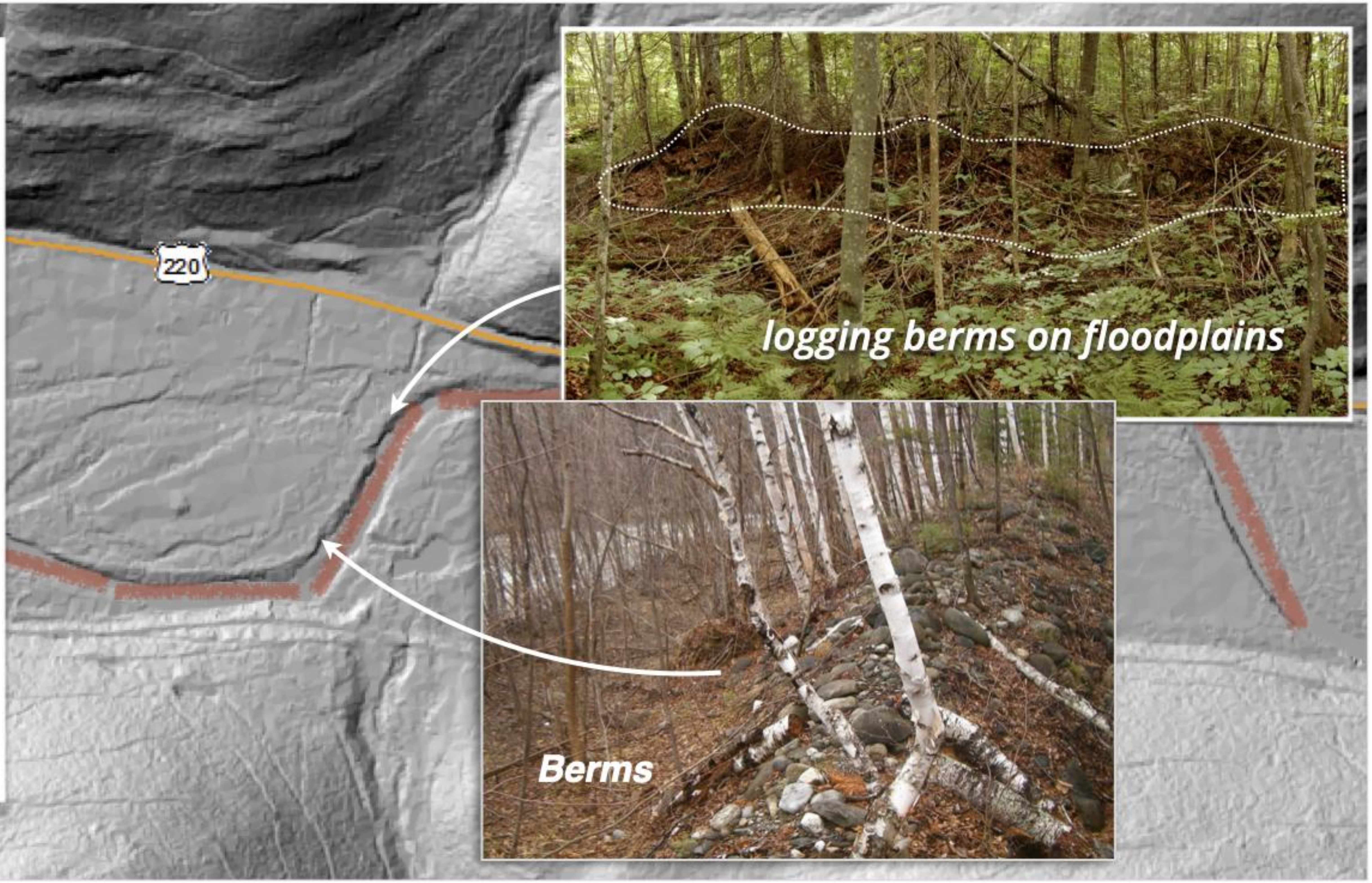

Channel modification and "stream improvements" for log drives

Channel straightening & widening; berming; removal of channel obstructions

Episodic Memory #7:

- ***Splash dams, log booms***
- ***Widespread denudation of hillsides***
- ***Erosion and sedimentation***

Splash dams used extend the log drive "season"

Could produce a wave of water 2 to 4 feet high for as much as two hours

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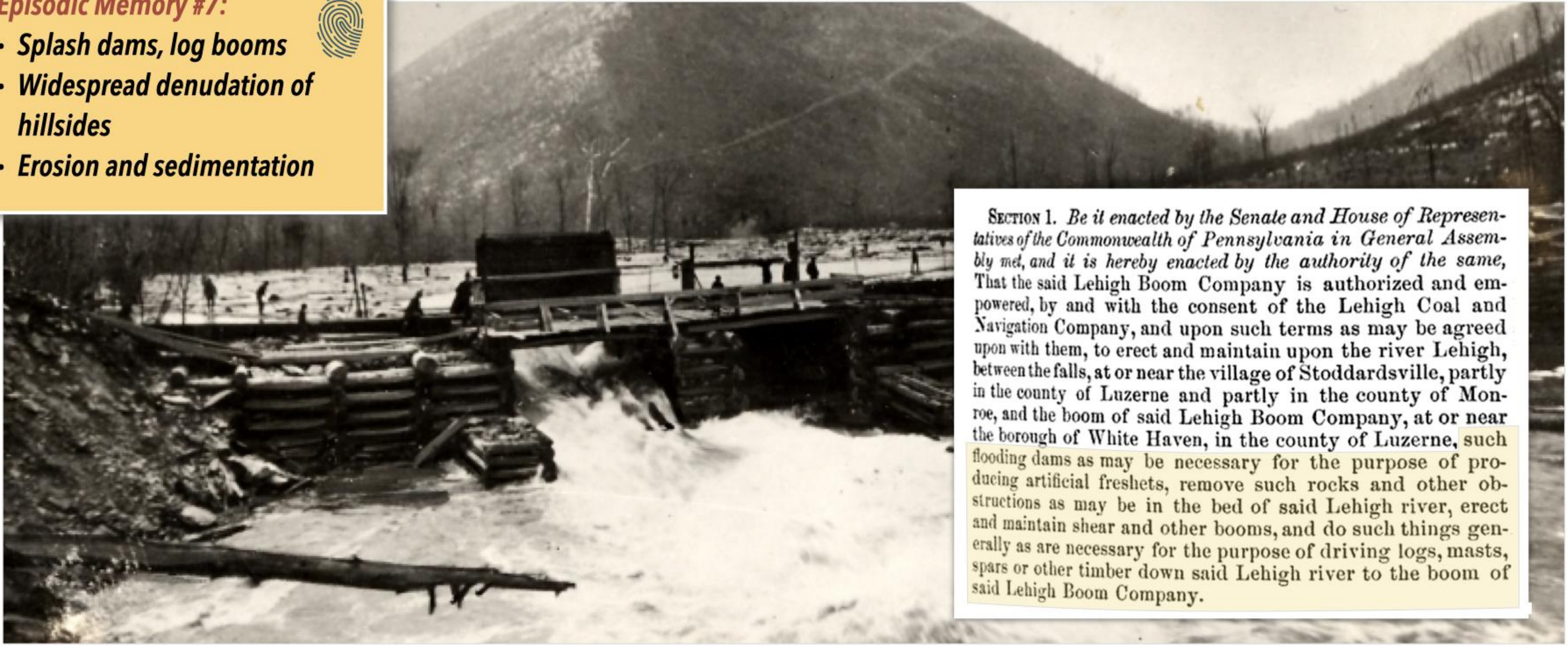


SECTION 1. *Be it enacted by the Senate and House of Representatives of the Commonwealth of Pennsylvania in General Assembly met, and it is hereby enacted by the authority of the same,* That the said Lehigh Boom Company is authorized and empowered, by and with the consent of the Lehigh Coal and Navigation Company, and upon such terms as may be agreed upon with them, to erect and maintain upon the river Lehigh, between the falls, at or near the village of Stoddardsville, partly in the county of Luzerne and partly in the county of Monroe, and the boom of said Lehigh Boom Company, at or near the borough of White Haven, in the county of Luzerne, such flooding dams as may be necessary for the purpose of producing artificial freshets, remove such rocks and other obstructions as may be in the bed of said Lehigh river, erect and maintain shear and other booms, and do such things generally as are necessary for the purpose of driving logs, masts, spars or other timber down said Lehigh river to the boom of said Lehigh Boom Company.

Splash dams used extend the log drive "season"

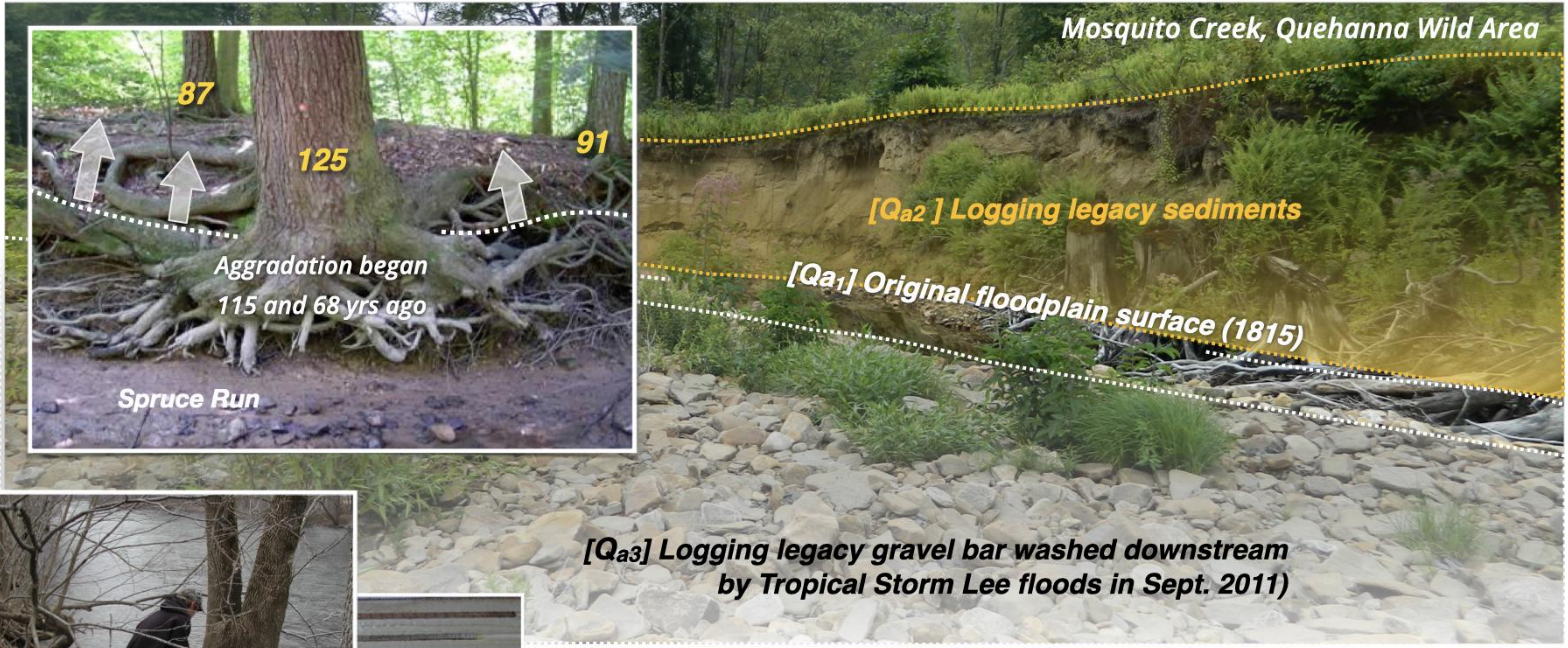
Could produce a wave of water 2 to 4 feet high for as much as two hours

Complete denudation of northern-tier watersheds

"Pennsylvania desert"

Complete denudation of northern-tier watersheds

"Pennsylvania desert"

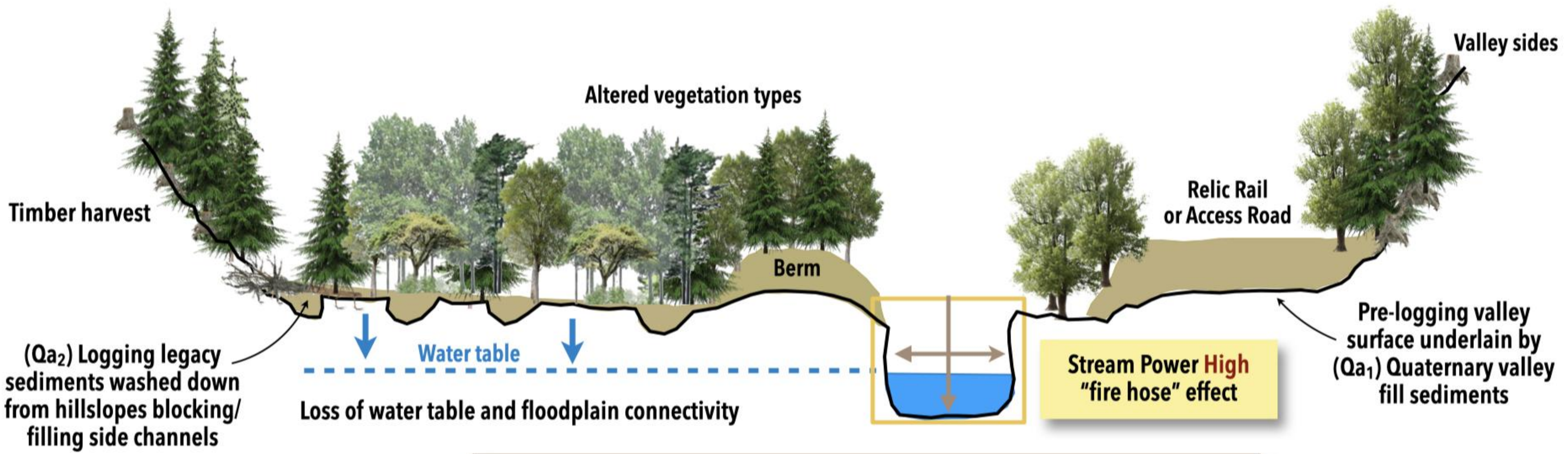


Logging legacy sediments

Sediment storage and metastable condition

Present-day Condition

Oversimplified and Disconnected Fluvial System - Low Resiliency and Redundancy



Channel INCISION and WIDENING
HIGH stream power (from deposition to transport)
MINIMAL to NO large wood debris and habitat complexity
ARMORED bed substrate - POOR spawning conditions

Disequilibrium and Complex Response

Channel shift, simultaneous cutting and filling of channels, aggradation at bridges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Episodic Memory #10 (Agriculture)

- *Intensive tillage and crop production*
- *Ditching and installation of drainage pipes*
- *Loss of riparian wetlands and trees*

Croplands	USA	PA
No till (%)	37	70
Reduced till (%)	35	15-10
Intensive till (%)	28	5-15
Cover crop (%)	40	43

Post-World War II agriculture

Increase in acreage under crops

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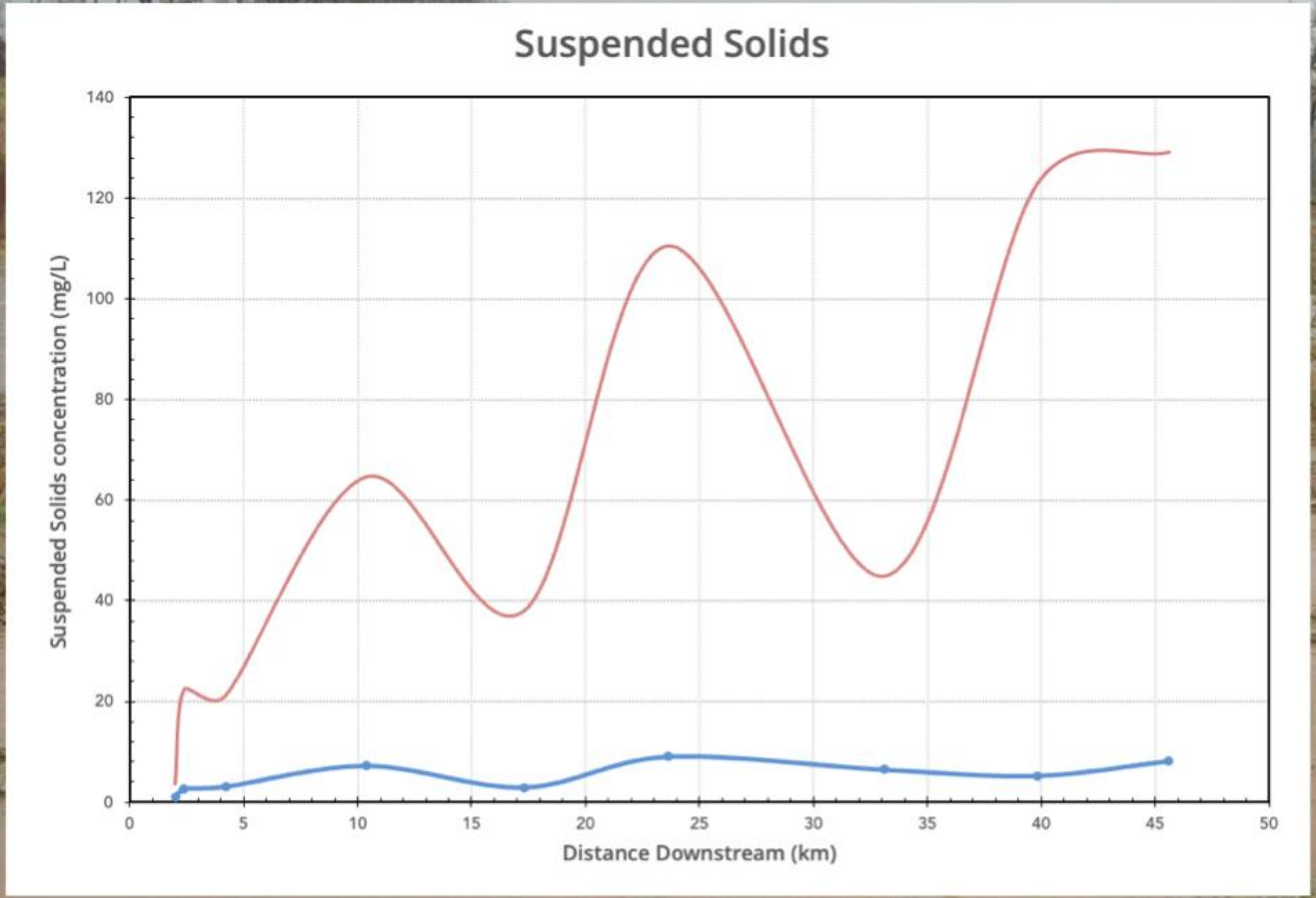
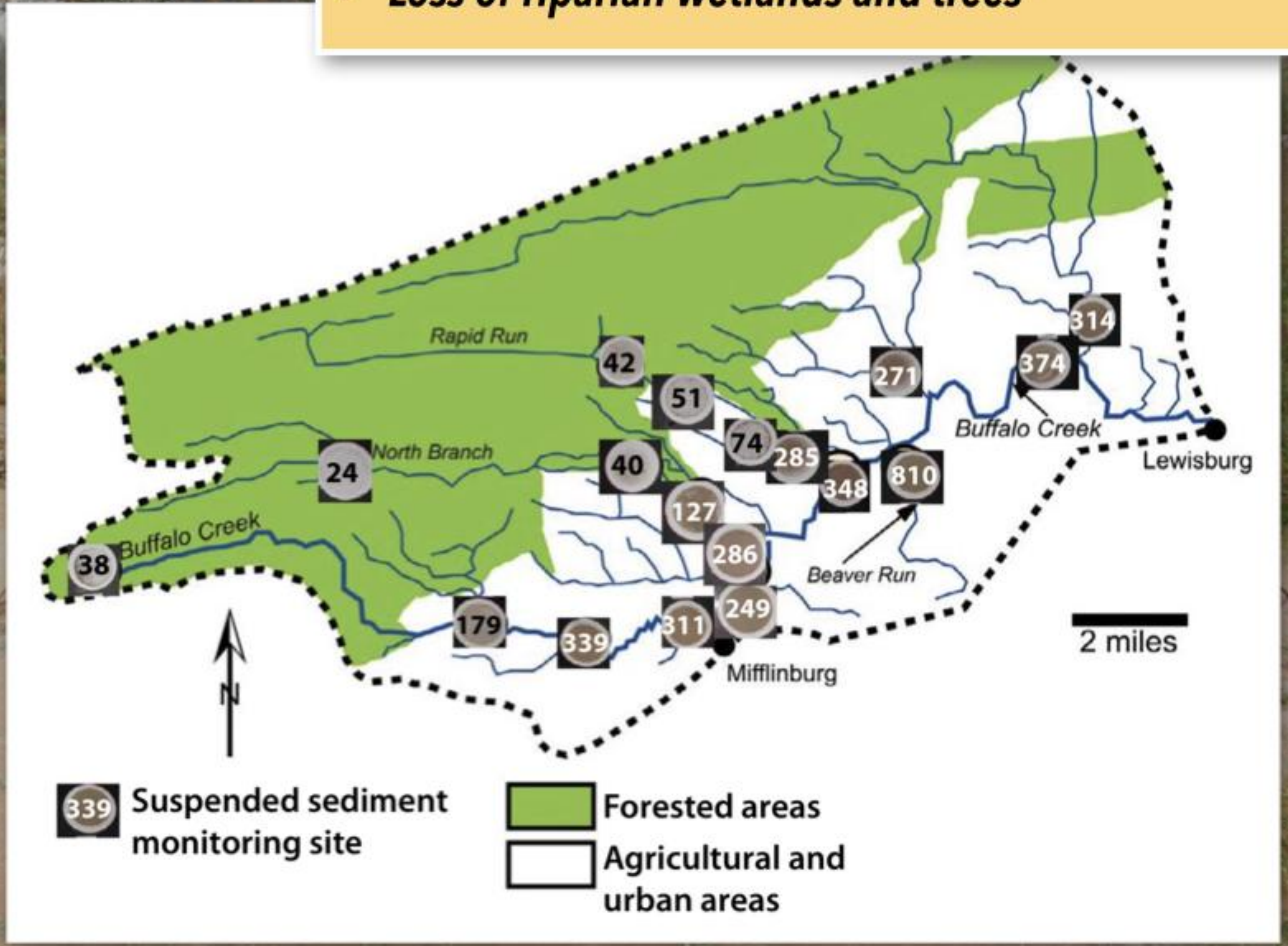
- ***Ditching and installation of drainage pipes***
- ***Loss of riparian wetlands and trees***





The water quality standard for total suspended solids (TSS) varies depending on the intended use of the water. For drinking water, standards are typically very low, often below 1 mg/L after treatment, while for municipal sewer discharges, limits are generally less strict, around 350 mg/L. For surface water, limits can be as low as 30 mg/L.

Post-World War II agriculture

Increase in acreage under crops

Post-World War II agriculture

Specialization; increase in acreage under crops; channelization and drainage

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Specialization; increase in acreage under crops; channelization and drainage

Episodic Memory #10 (Agriculture)

- ***Intensive tillage and crop production***
- ***Ditching and installation of drainage pipes***
- ***Loss of riparian wetlands and trees***

Post-World War II agriculture

Specialization; increase in acreage under crops; channelization and drainage

53%

Groundwater wells

Rural groundwater wells ranging in depth from 45 ft to 400 ft; averaging 137 ft.

49%

Farms have ponds

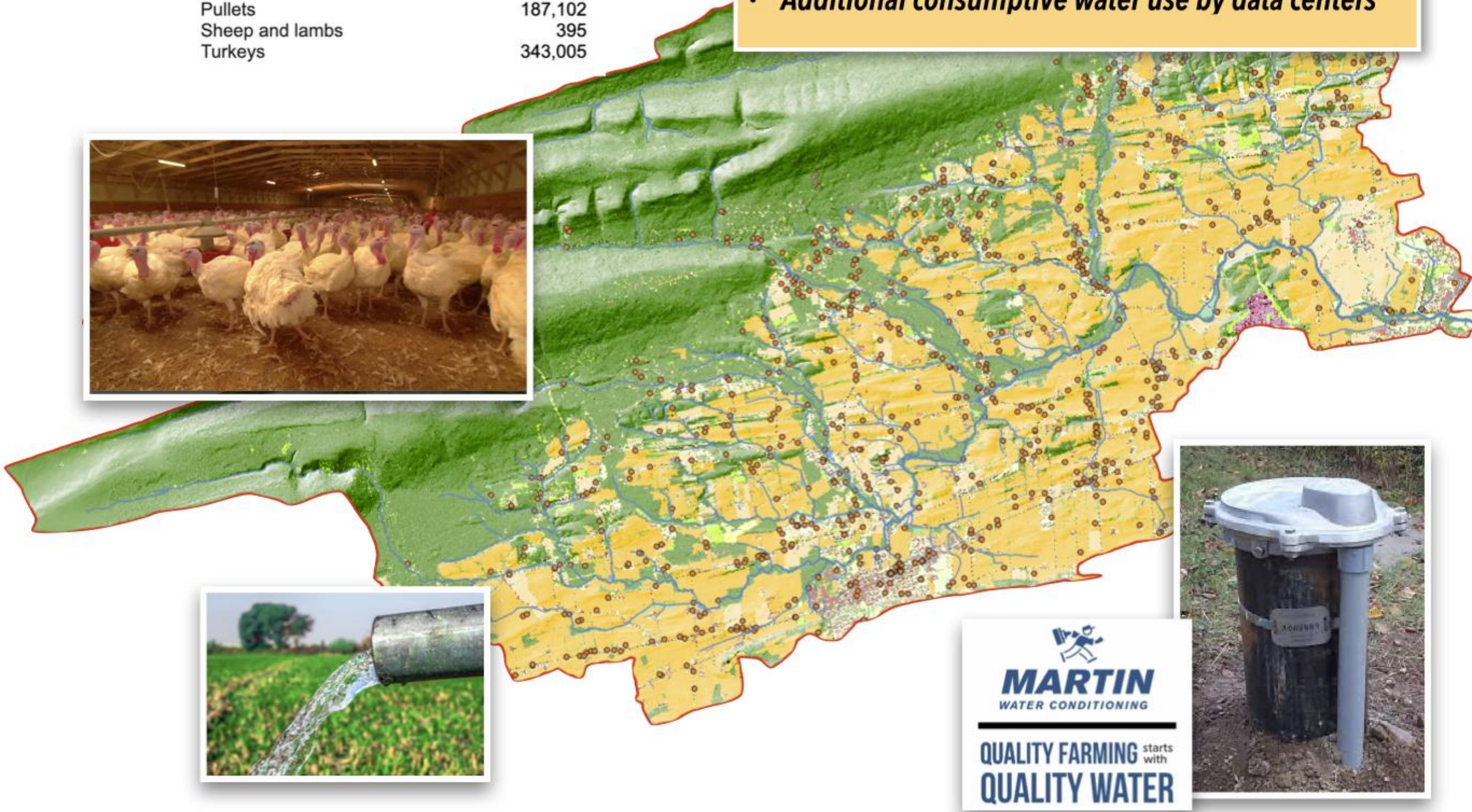
Poultry need to drink water and the need is estimated to be 3,500 gallons of water per barn, per day.

Livestock Inventory (Dec 31, 2022)

Broilers and other meat-type chickens	2,237,341
Cattle and calves	19,457
Goats	196
Hogs and pigs	70,632
Horses and ponies	791
Layers	601,161
Pullets	187,102
Sheep and lambs	395
Turkeys	343,005

Episodic Memory #11

- *Large-scale swine and poultry facilities*
- *Excess animal waste disposal*
- *Lack of up-to-date water resource management plans for planners and county commissioners*
- *Additional consumptive water use by data centers*

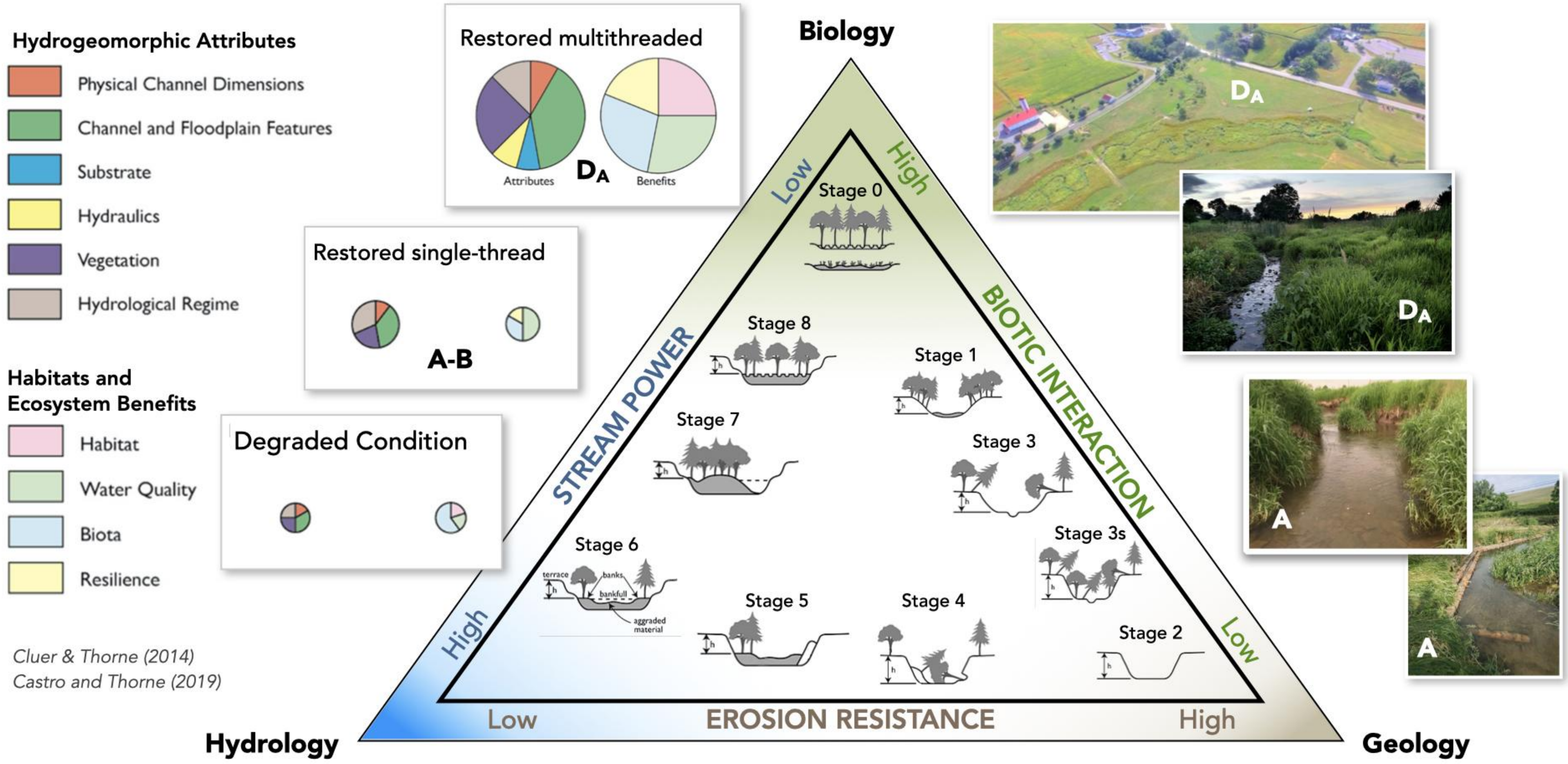


Estimated Daily Groundwater Withdrawals (MGD)

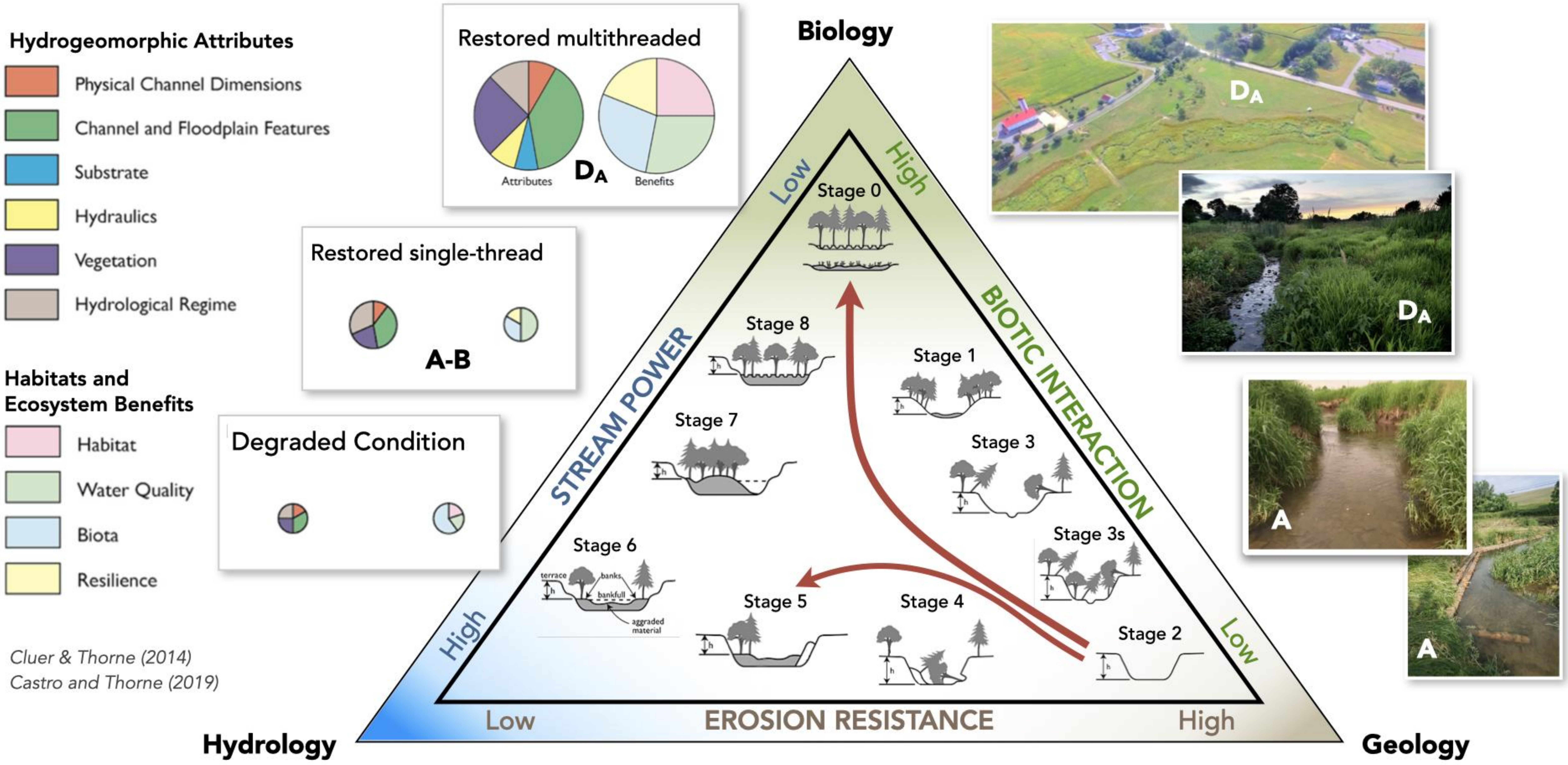
	Useage	Return
Rural home	0.54	-
Livestock	1.9	-
Irrigation + operations	0.9	0.2
Total	**1.8**	**0.2**

MARTIN
WATER CONDITIONING
QUALITY FARMING starts with QUALITY WATER

FUNCTIONAL STREAM RESTORATION APPROACHES



FUNCTIONAL STREAM RESTORATION APPROACHES



Cluer & Thorne (2014)
Castro and Thorne (2019)

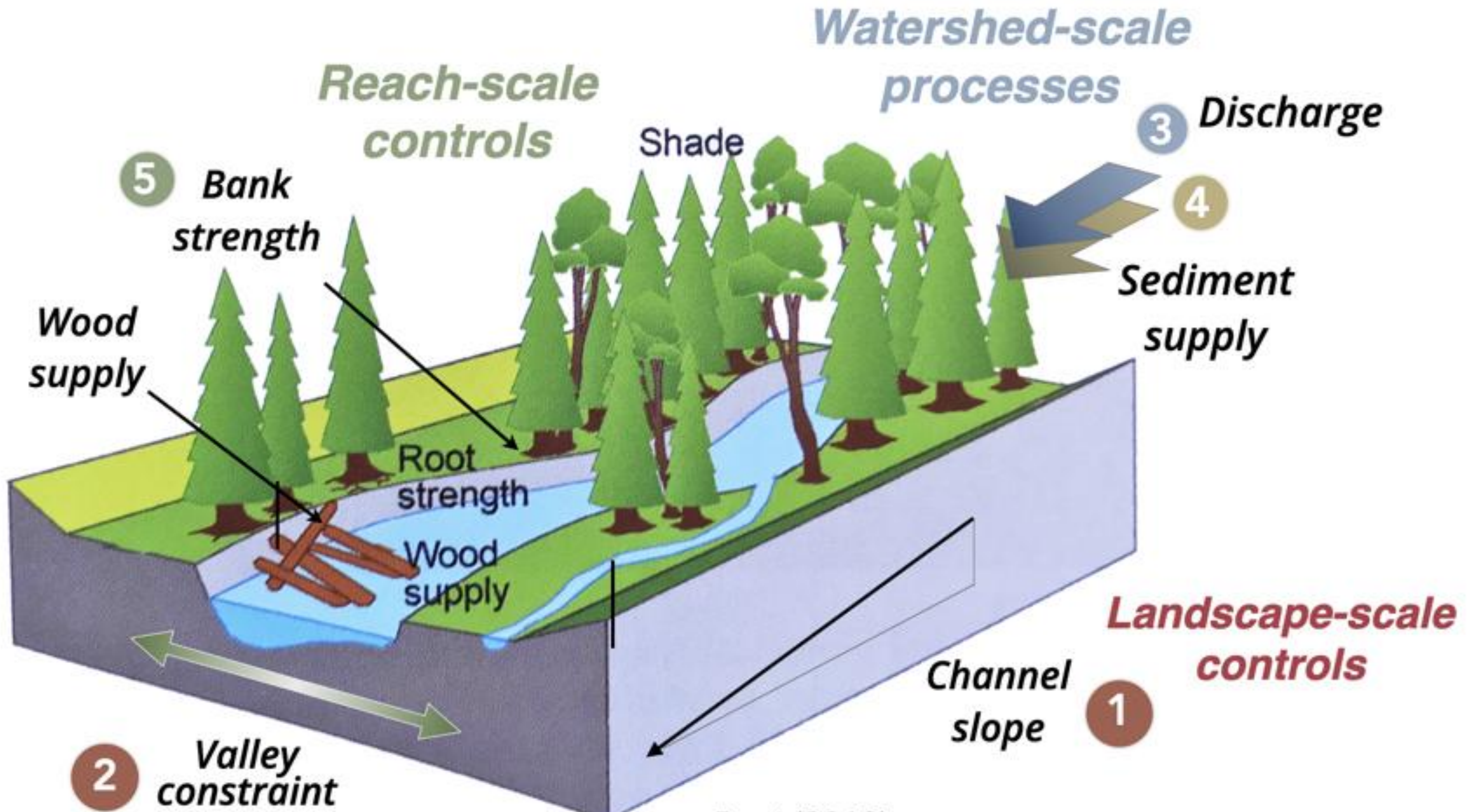
RESOURCE RESTORATION "MIND MAP"

FOOD FOR THOUGHT .....

1. Both social and fluvial-ecological systems are far from being in **equilibrium**.
2. They are characterized by **thresholds**, **multiple states**, and **surprising phenomena**.
3. Because of the connection between ecological and societal systems, cross-scale **interactions happen**. These interactions must be recognized and anticipated.
4. We should be aware of **slowly evolving conditions**.
5. **Short-term measures can not resolve persistent, chronic problems,** nor can they deal with **continuous change**.

KEY CONCEPTS

- Behavior - how and why systems respond to perturbations
- Process linkages and inherited disfunction (cascading effects)
- Episodic memory - its affect on possible outcomes in the future



Roni (2018)