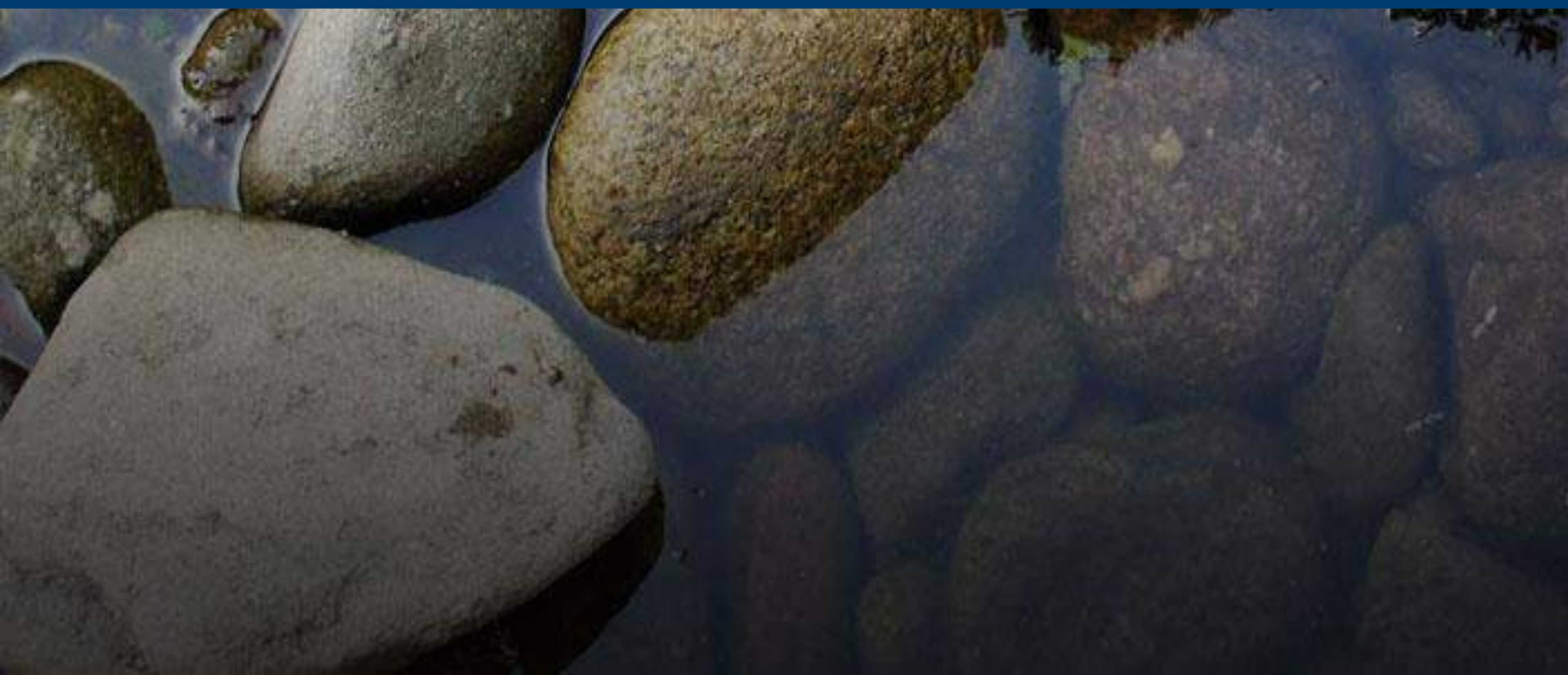
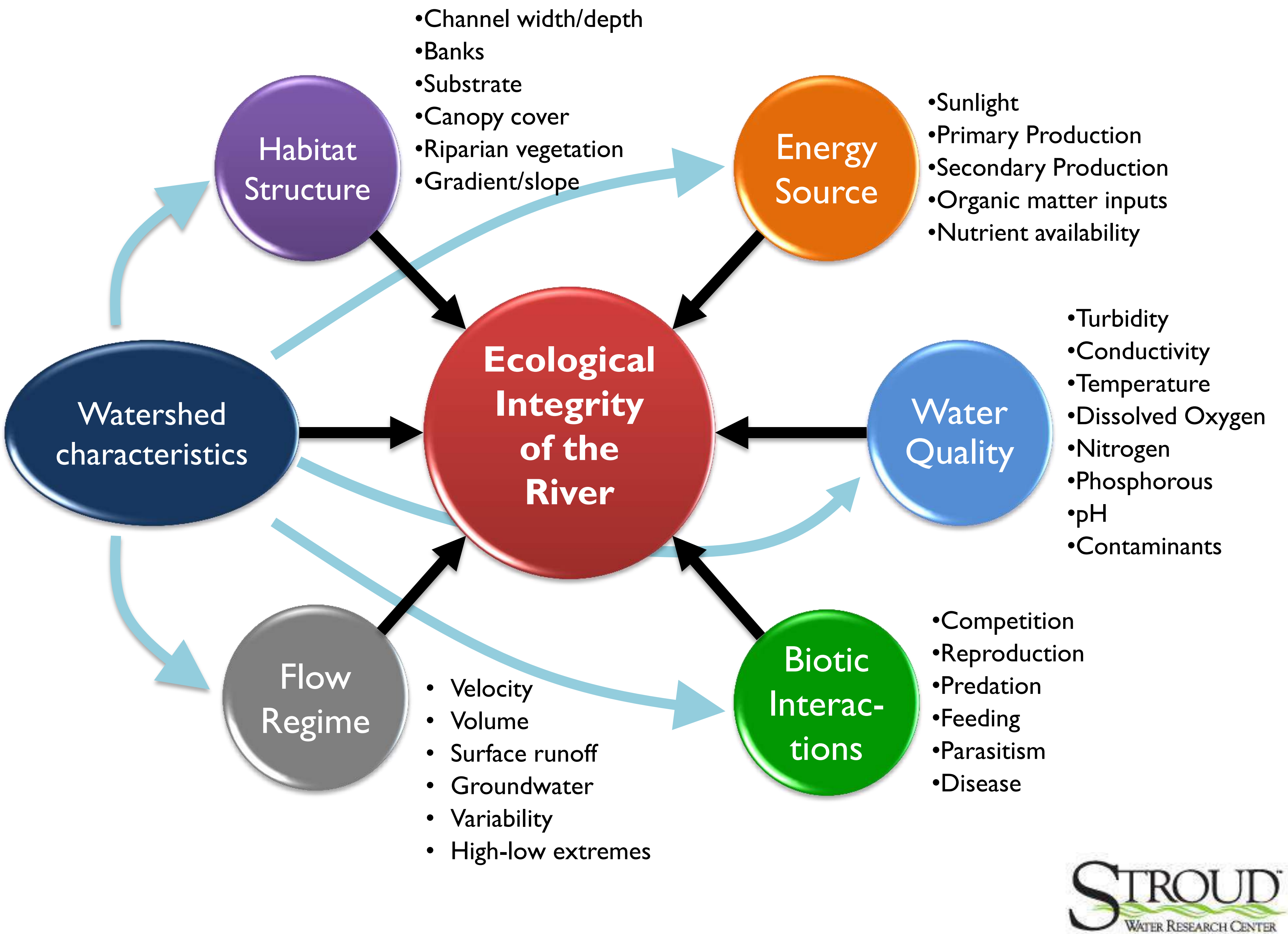
STROUD™
WATER RESEARCH CENTER

ADVANCING KNOWLEDGE AND STEWARDSHIP OF FRESH WATER SYSTEMS THROUGH RESEARCH, EDUCATION, AND RESTORATION

Watershed Hydrology and Geomorphology

Dr. Melinda Daniels, PhD
Fluvial Geomorphologist




•Channel width/depth
•Banks
•Substrate
•Canopy cover
•Riparian vegetation
•Gradient/slope
Habitat Structure
Energy Source
•Sunlight
•Primary Production
•Secondary Production
•Organic matter inputs
•Nutrient availability
•Turbidity
•Conductivity
•Temperature
•Dissolved Oxygen
•Nitrogen
•Phosphorous
•pH
•Contaminants
Watershed characteristics
Ecological Integrity of the River
Water Quality
Flow Regime
Biotic Interac-tions
•Competition
•Reproduction
•Predation
•Feeding
•Parasitism
•Disease
• Velocity
• Volume
• Surface runoff
• Groundwater
• Variability
• High-low extremes
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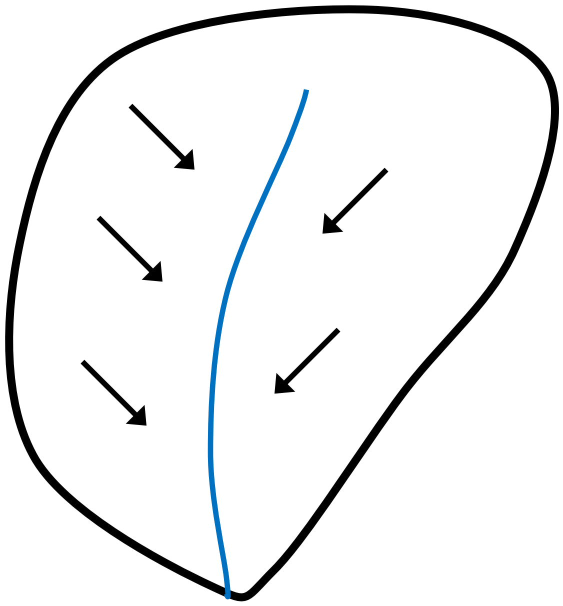
Definitions

- Hydrology - science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment
- Fluvial – processes associated with rivers and streams
- Geomorphology - the study of the physical features of the surface of the earth and their relation to its geological structures
- Fluvial Geomorphology

The Watershed

- Water-receiving area that drains into a stream
- All of the precipitation that falls into a watershed flows into that watershed's stream



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Watershed Boundaries

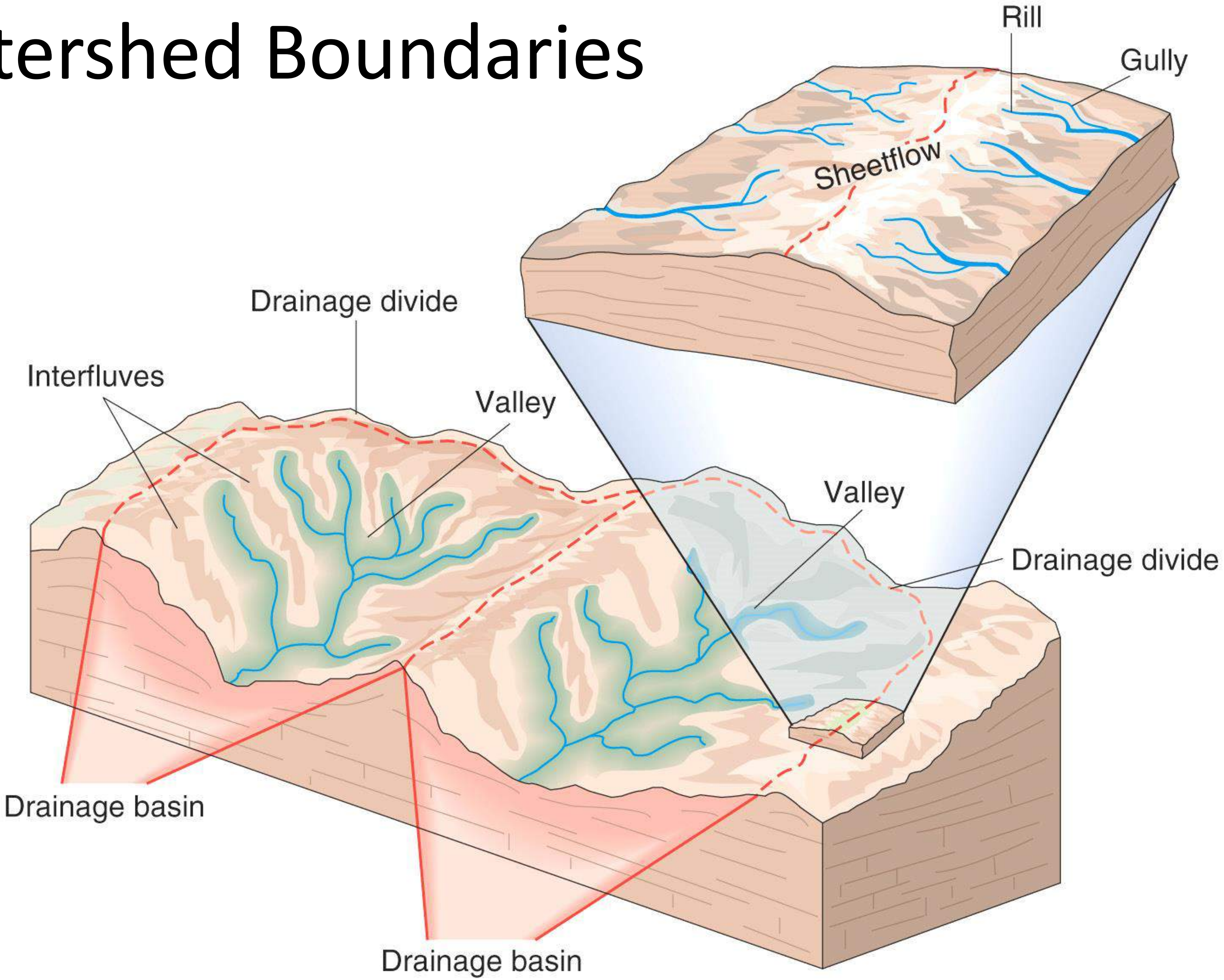
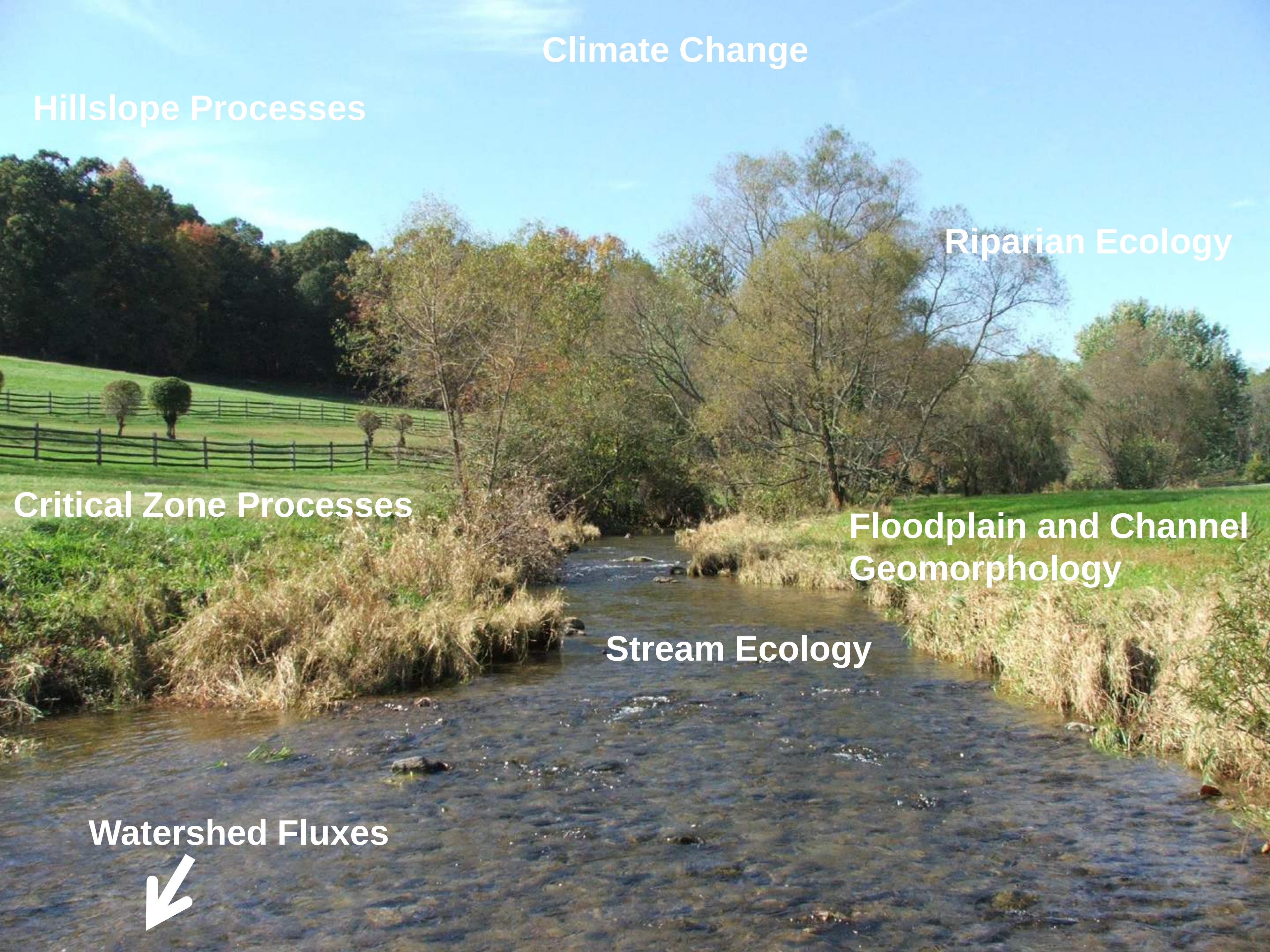
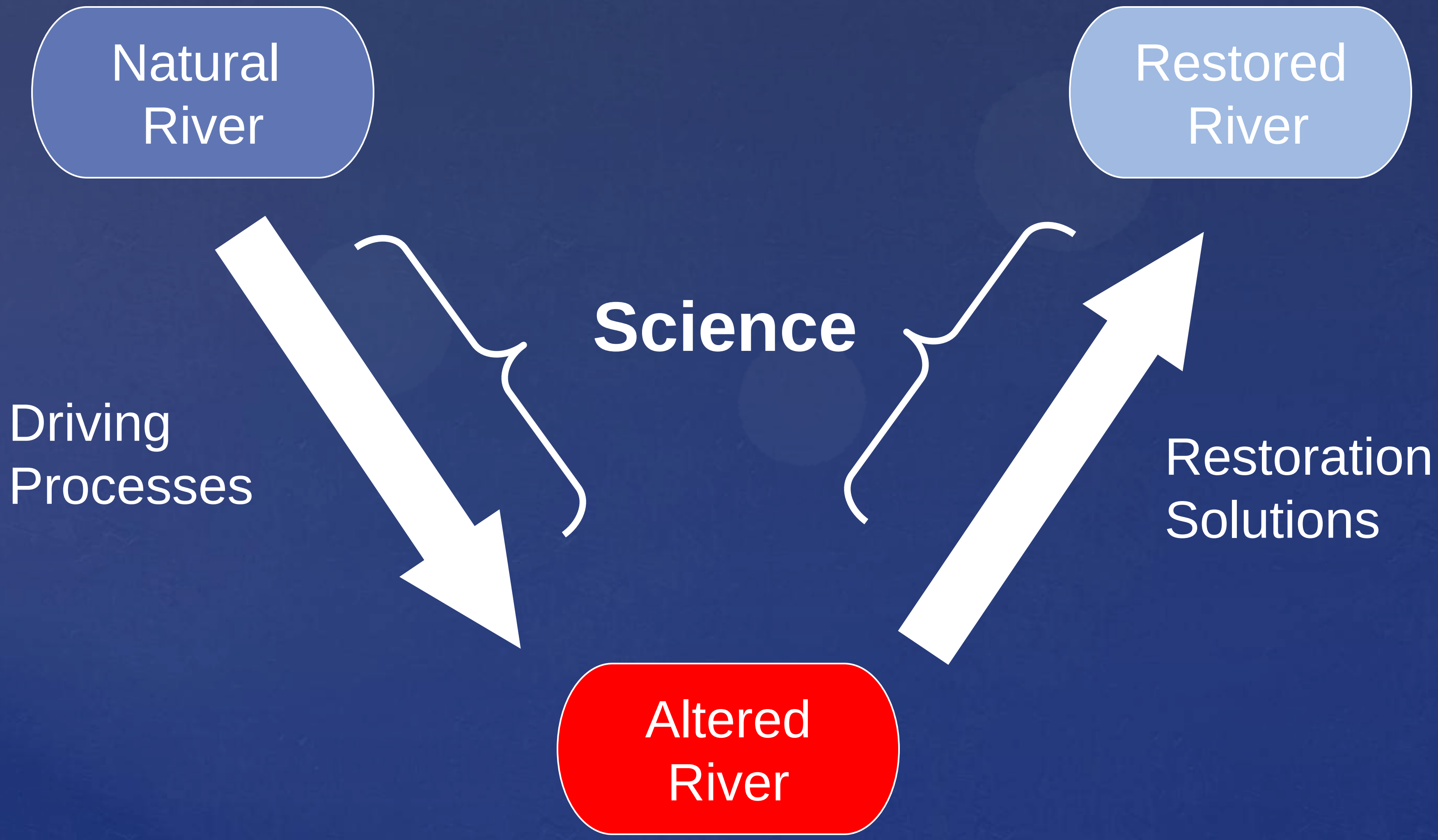


Figure 14.4


Climate Change
Hillslope Processes
Riparian Ecology
Critical Zone Processes
Floodplain and Channel Geomorphology
Stream Ecology
Watershed Fluxes

How do we achieve restoration?

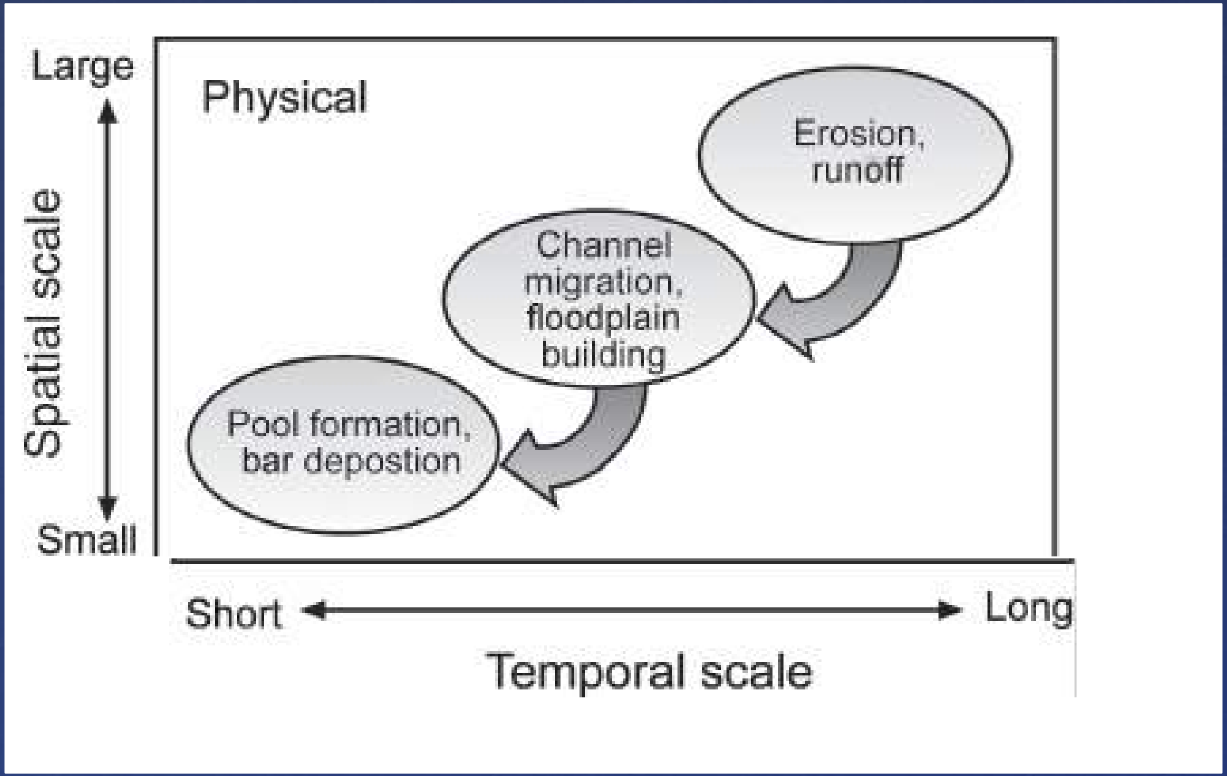


Important to evaluate landscape to local scales

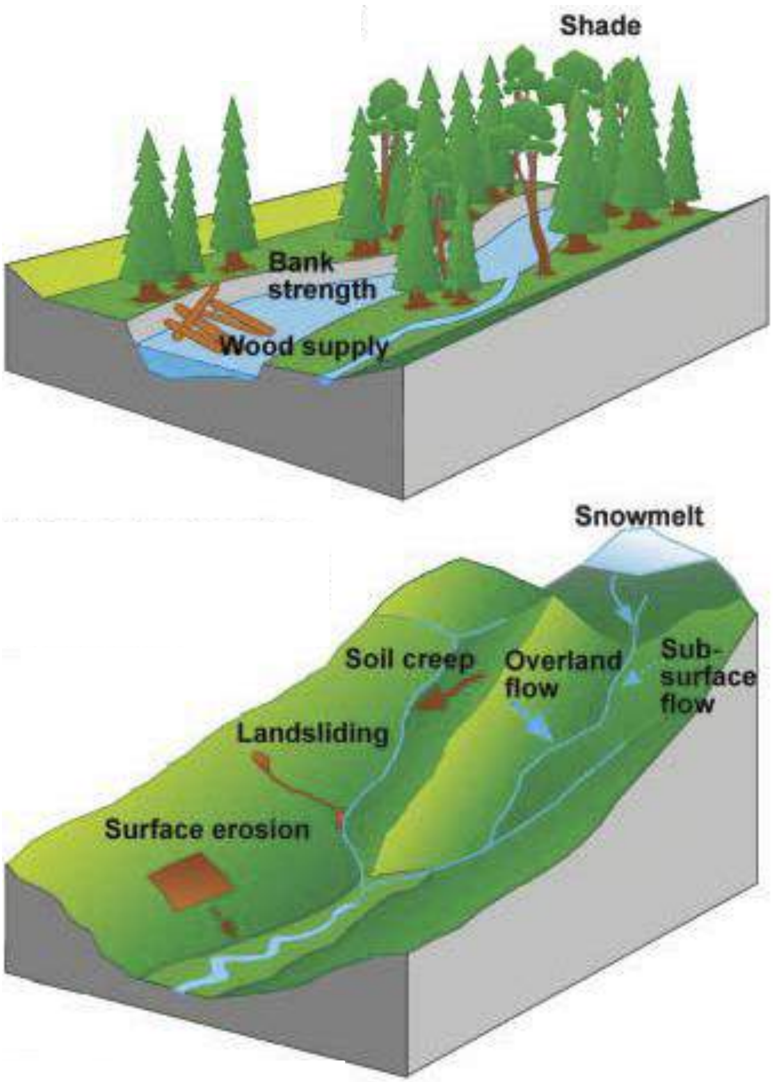
Natural River

Driving Disturbance Agents

Altered River



Beechie et al. 2010

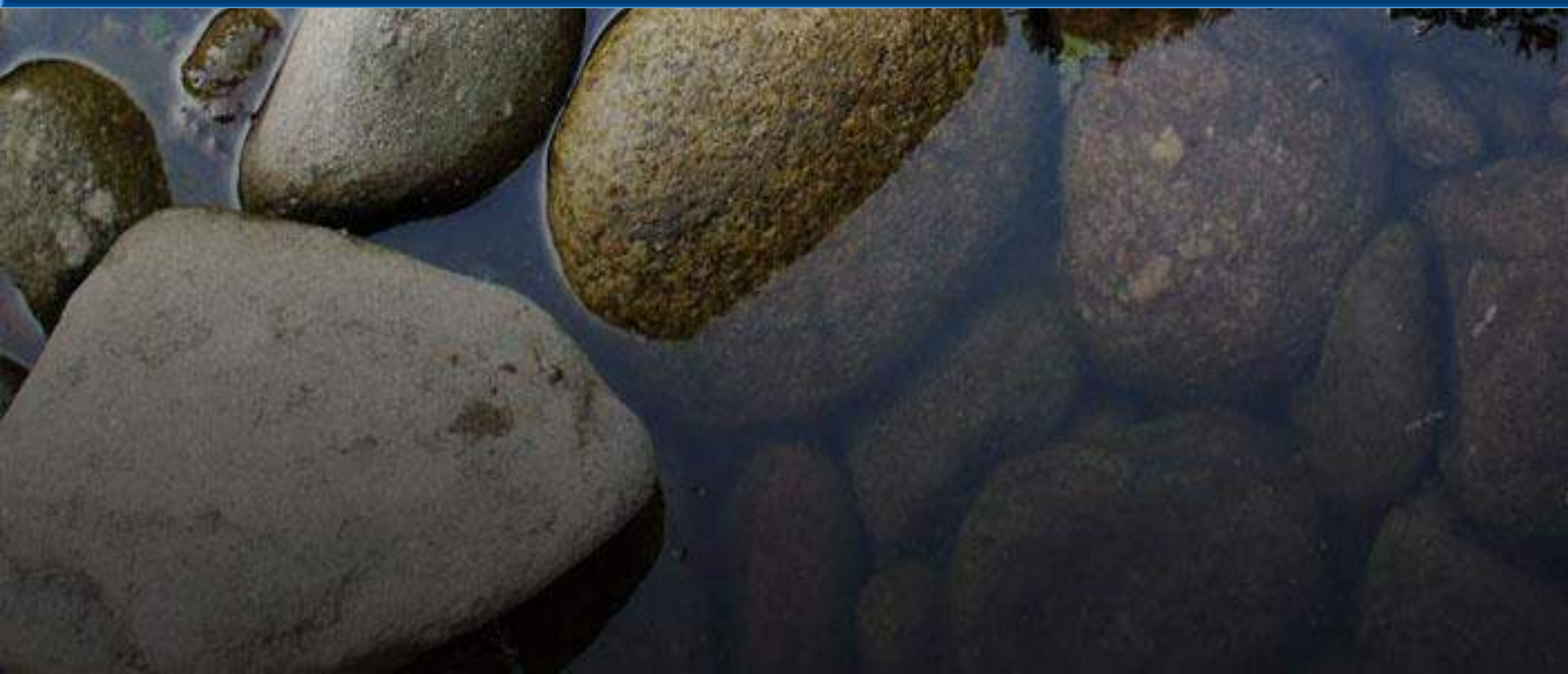


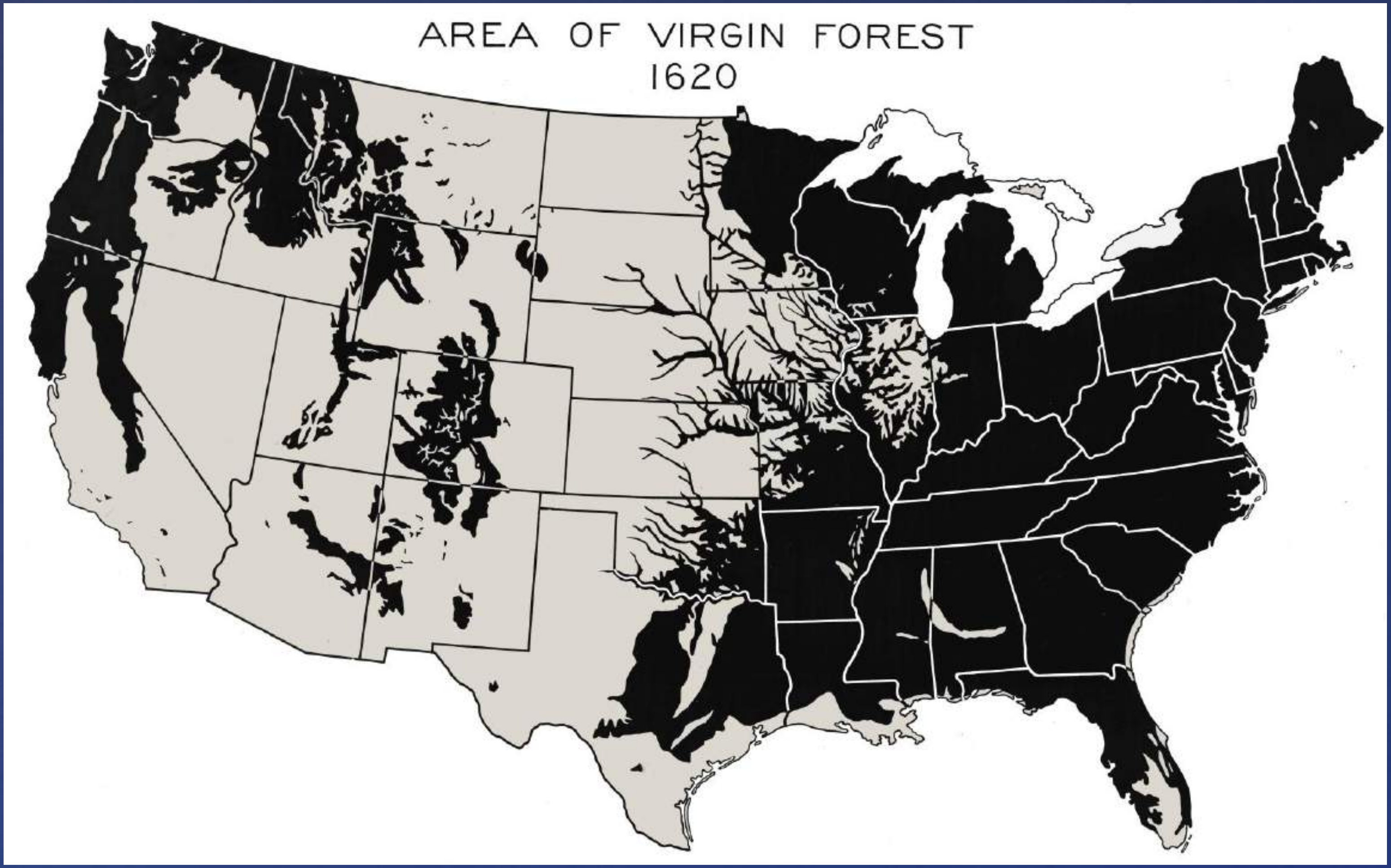
Beechie et al. 2010

Reach Scale

Landscape Scale

The Natural Stream Reference Condition



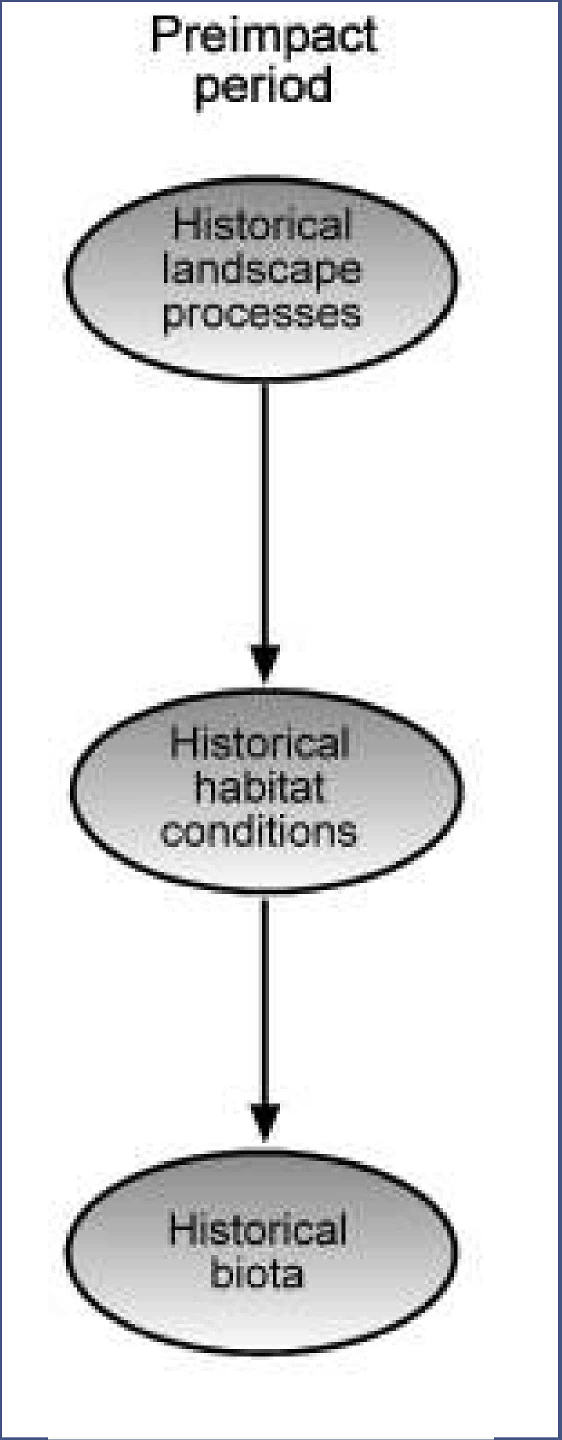

AREA OF VIRGIN FOREST
1620

McClain Printing Company

thenaturalistscorner.com

wvhighlands.org

McClain Printing Company



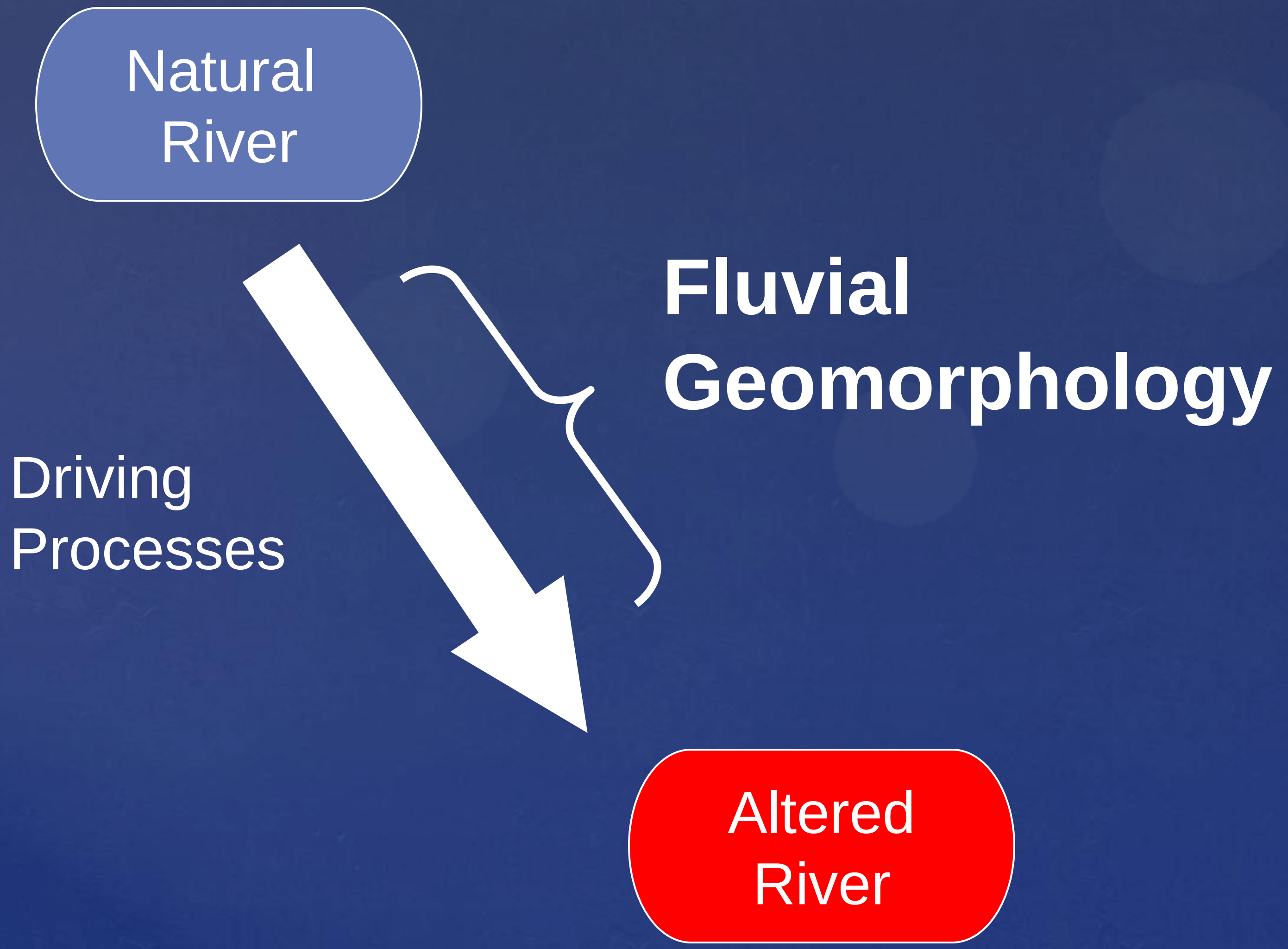
Natural River

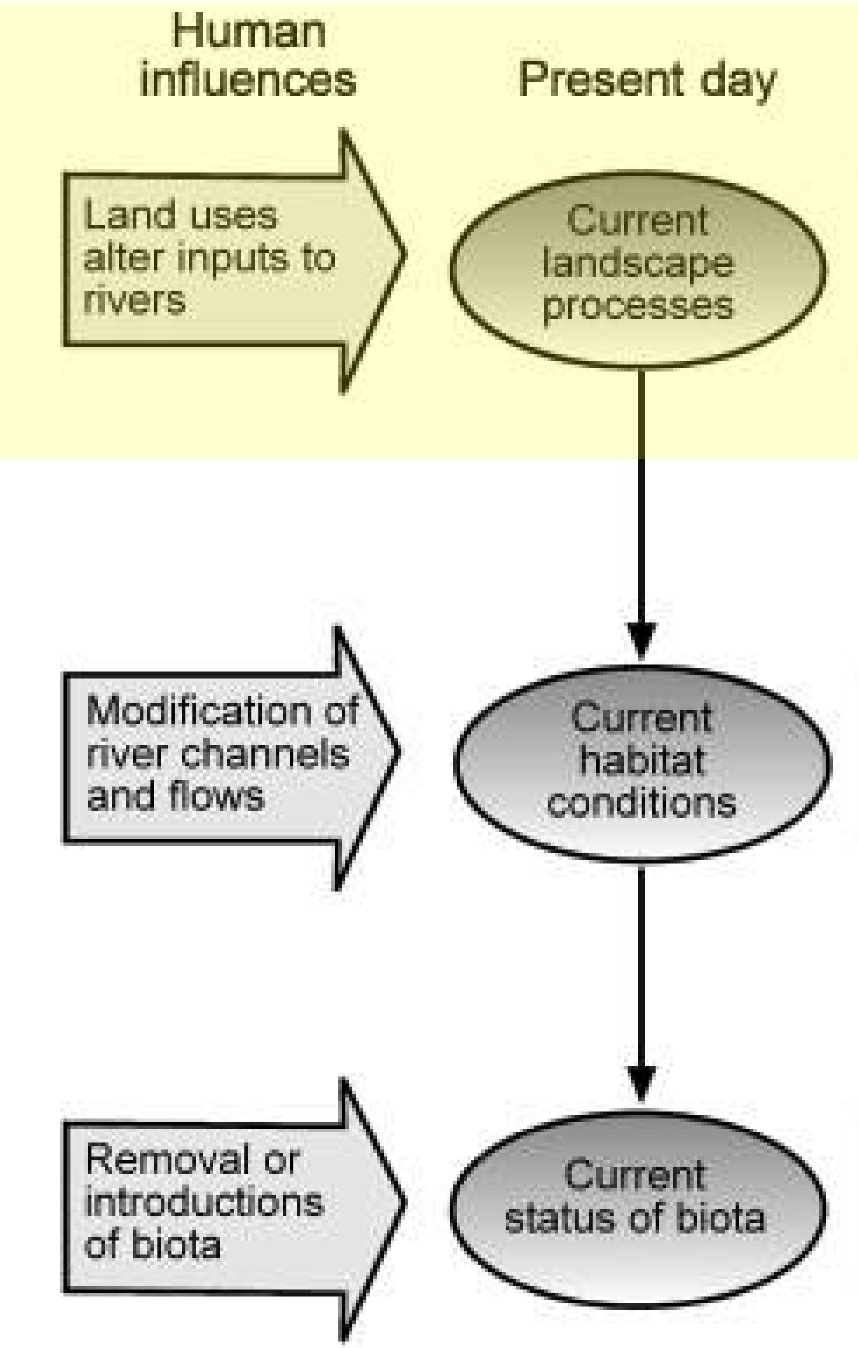
Forested Landscape
High Wood Loads
Beaver

Deep Pools, Abundant Gravels, Complex Channels
Shade and Cover, Cold Water
Moderated Flow Regime

Abundant Trout
Sea Runs of Shad
Freshwater Mussels

What's wrong with our rivers?



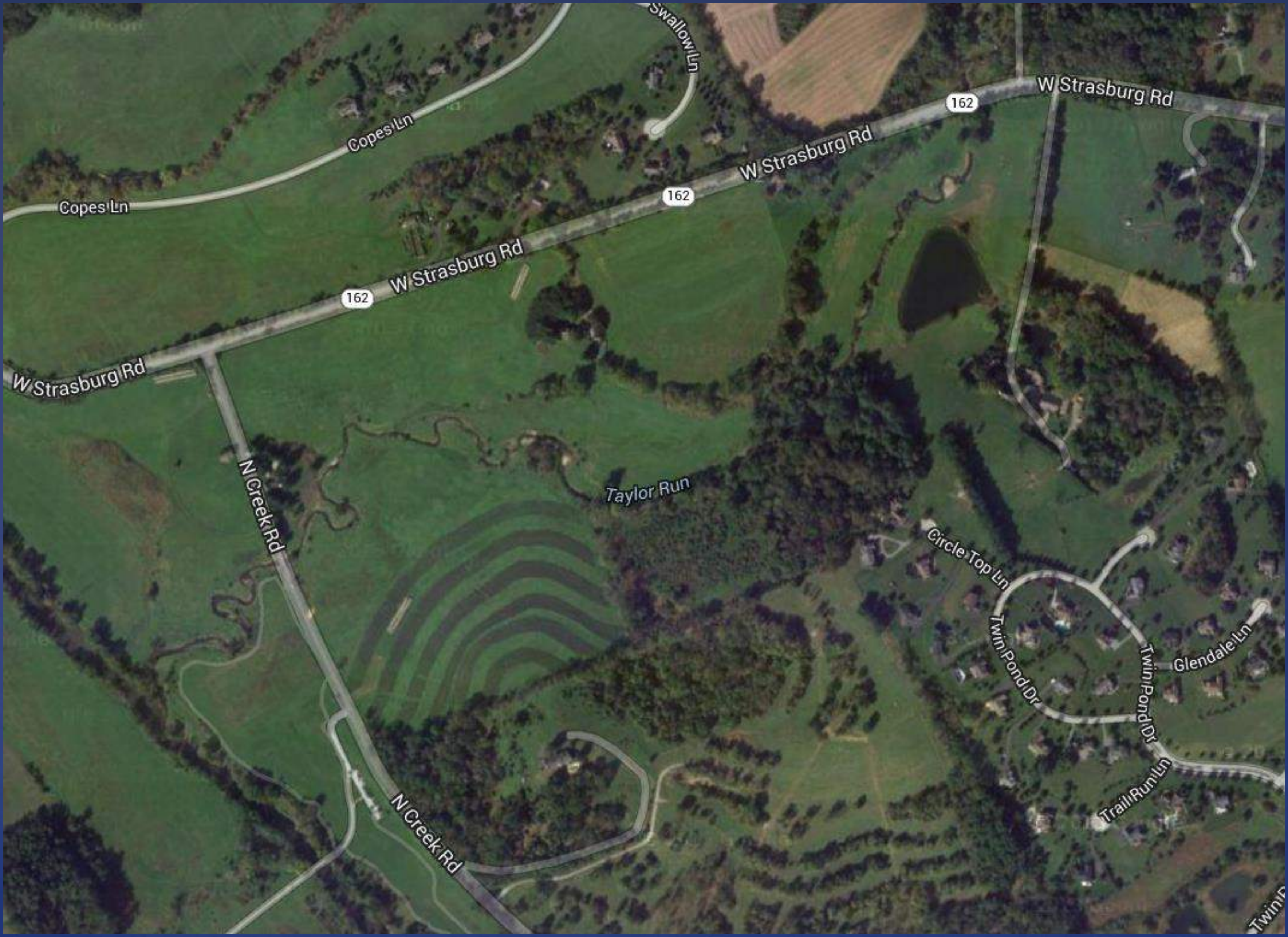


Altered River

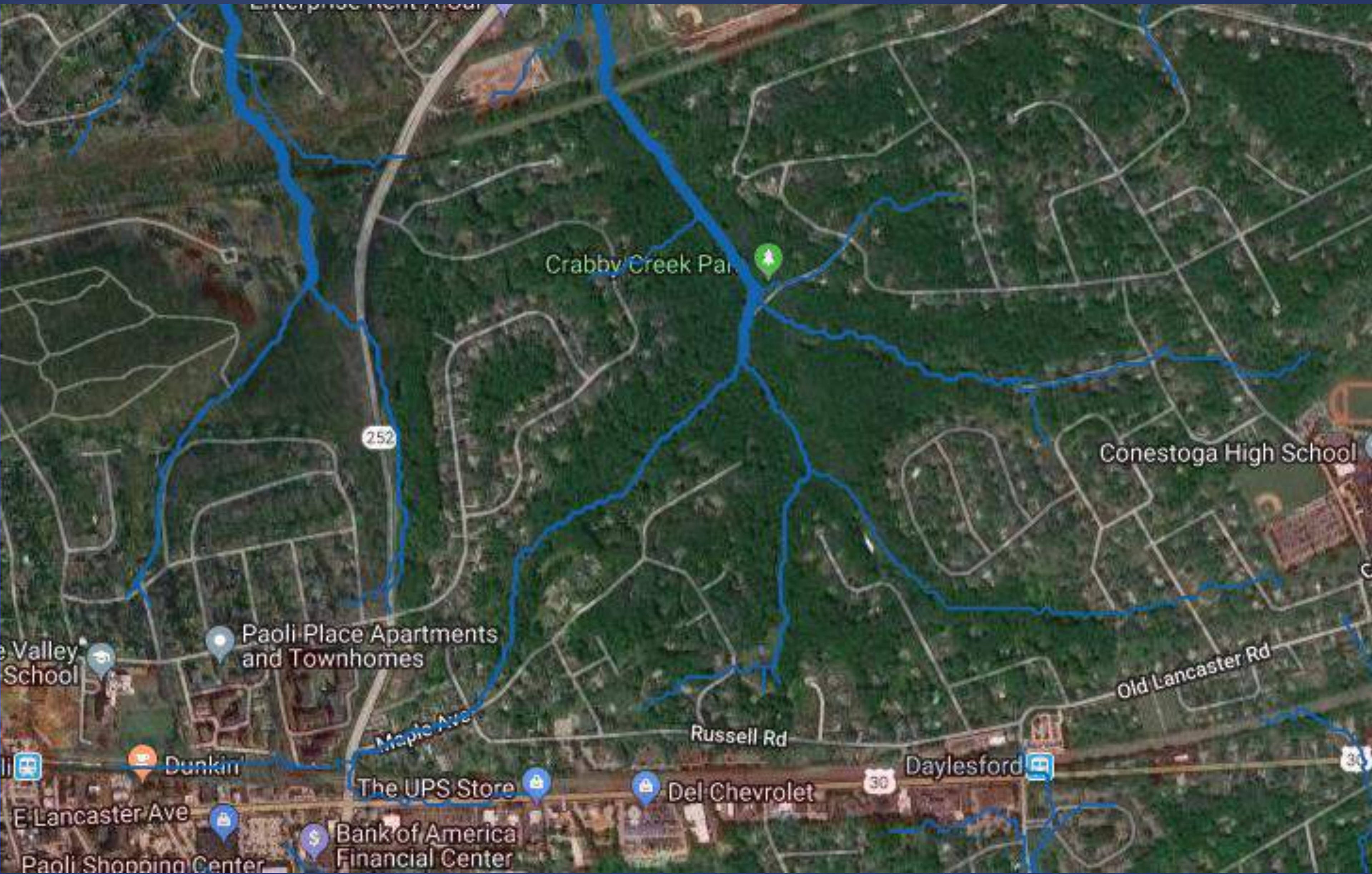
Ag/Urban/Forest Remnants

Low Wood Loads

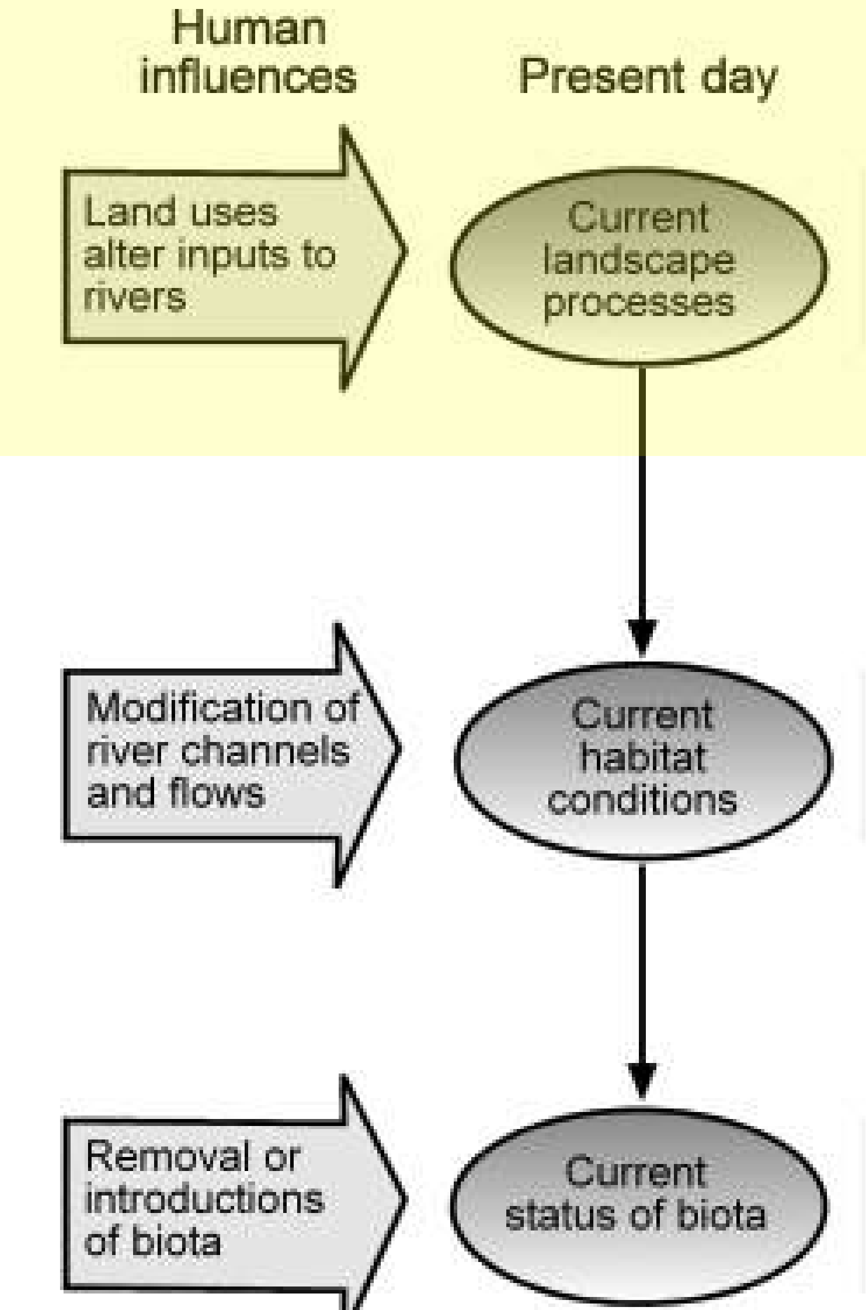
Absence of Beaver Dams


Swallow Ln
W Strasburg Rd
162
Copes Ln
W Strasburg Rd
162
Copes Ln
W Strasburg Rd
162
W Strasburg Rd
N Creek Rd
Taylor Run
Circle Top Ln
Twin Pond Dr
Twin Pond Dr
Glendale Ln
Trail Run Ln
N Creek Rd


W Strasburg Rd
Taylor Run
Imagery ©2013 DigitalGlobe, U.S. Geological Survey, USDA Farm Service Agency, Map data ©2013 Google



Crabby Creek Park
Conestoga High School
252
Paoli Place Apartments
and Townhomes
Valley
School
Old Lancaster Rd
Maple Ave
Russell Rd
Dunkin'
The UPS Store
Del Chevrolet
30
Daylesford
E Lancaster Ave
Bank of America
Financial Center
Paoli Shopping Center



Altered River

Shallow Pools

Limited Gravels

Simple Channels

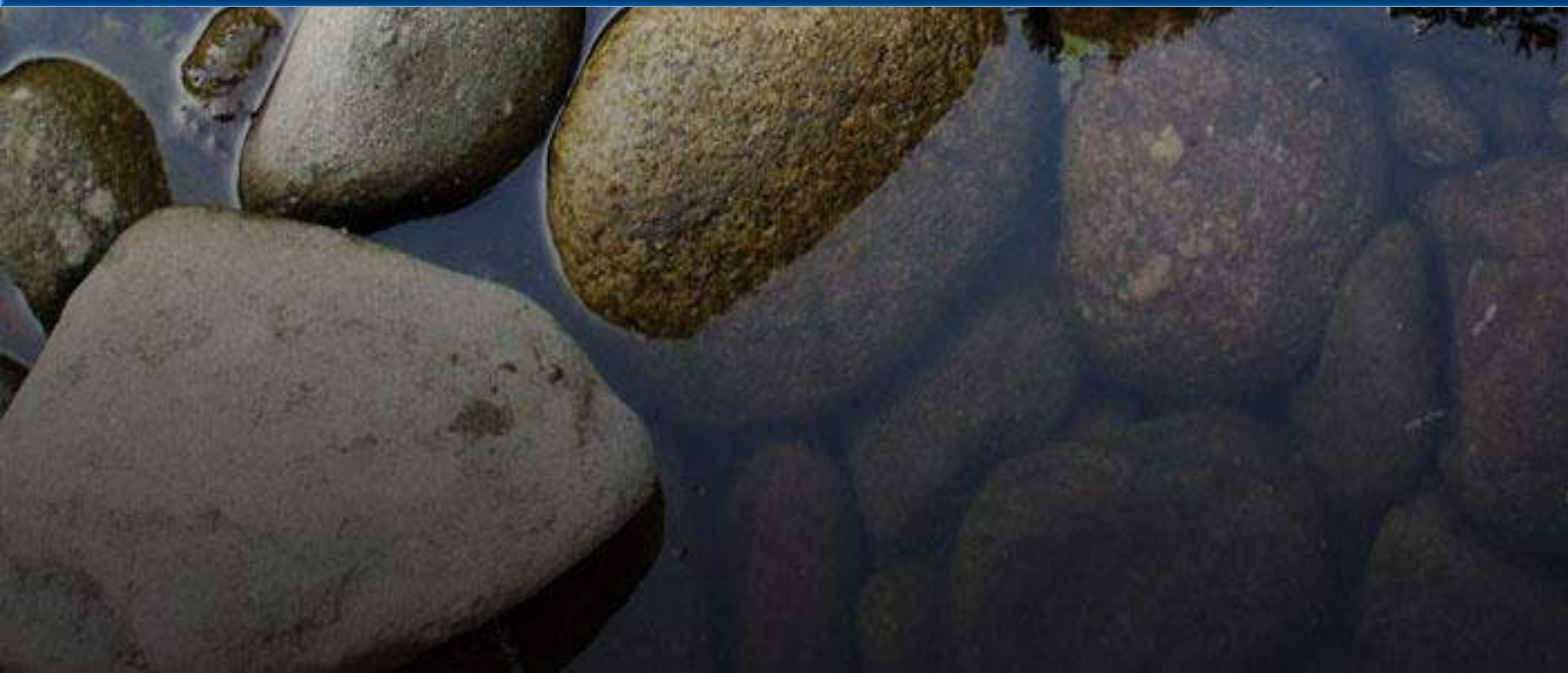
Lack of Shade and Cover

Warmer water

Flashier Flow Regime

Fragmentation

Watershed Hydrology



Hydrology

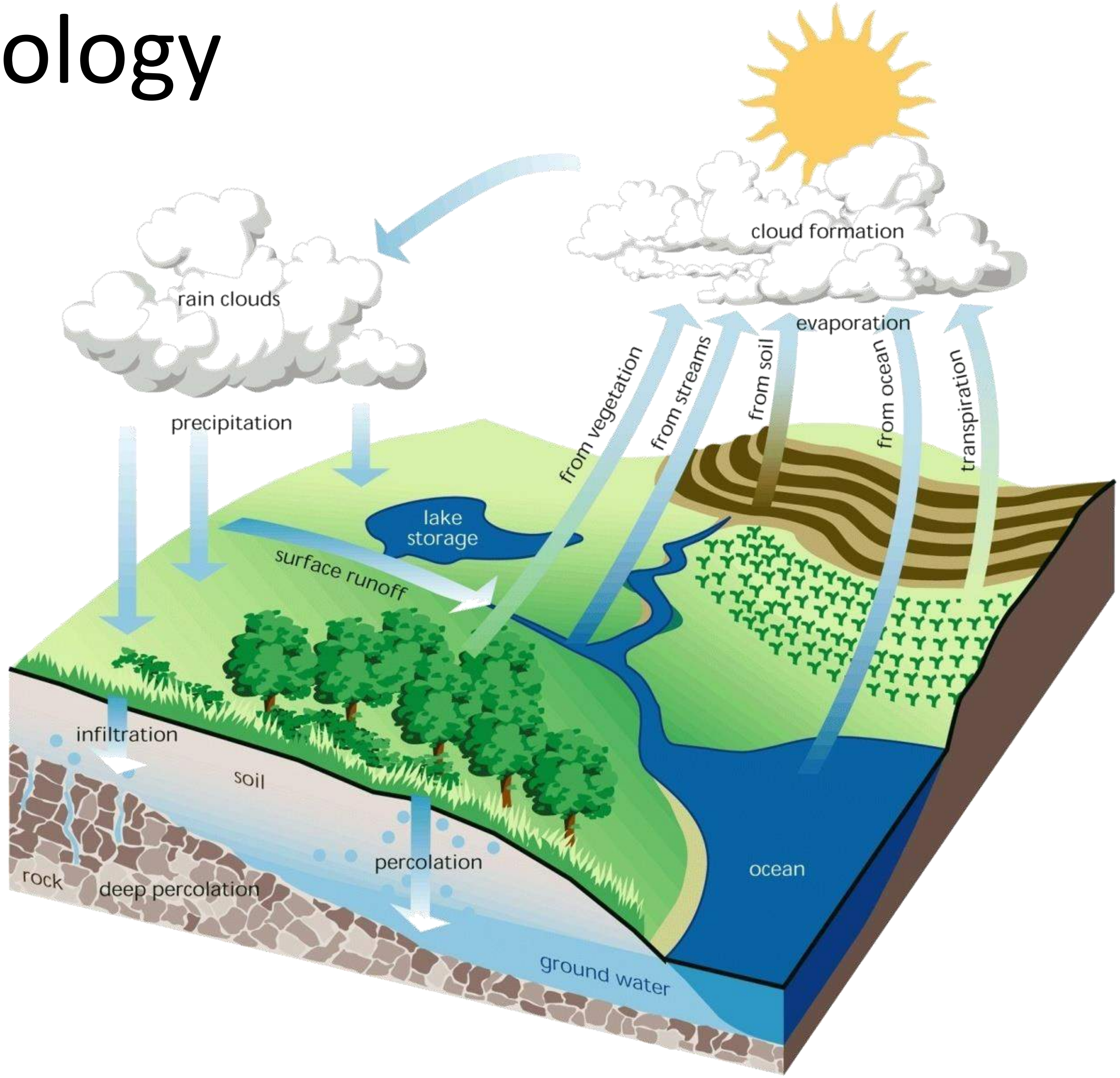
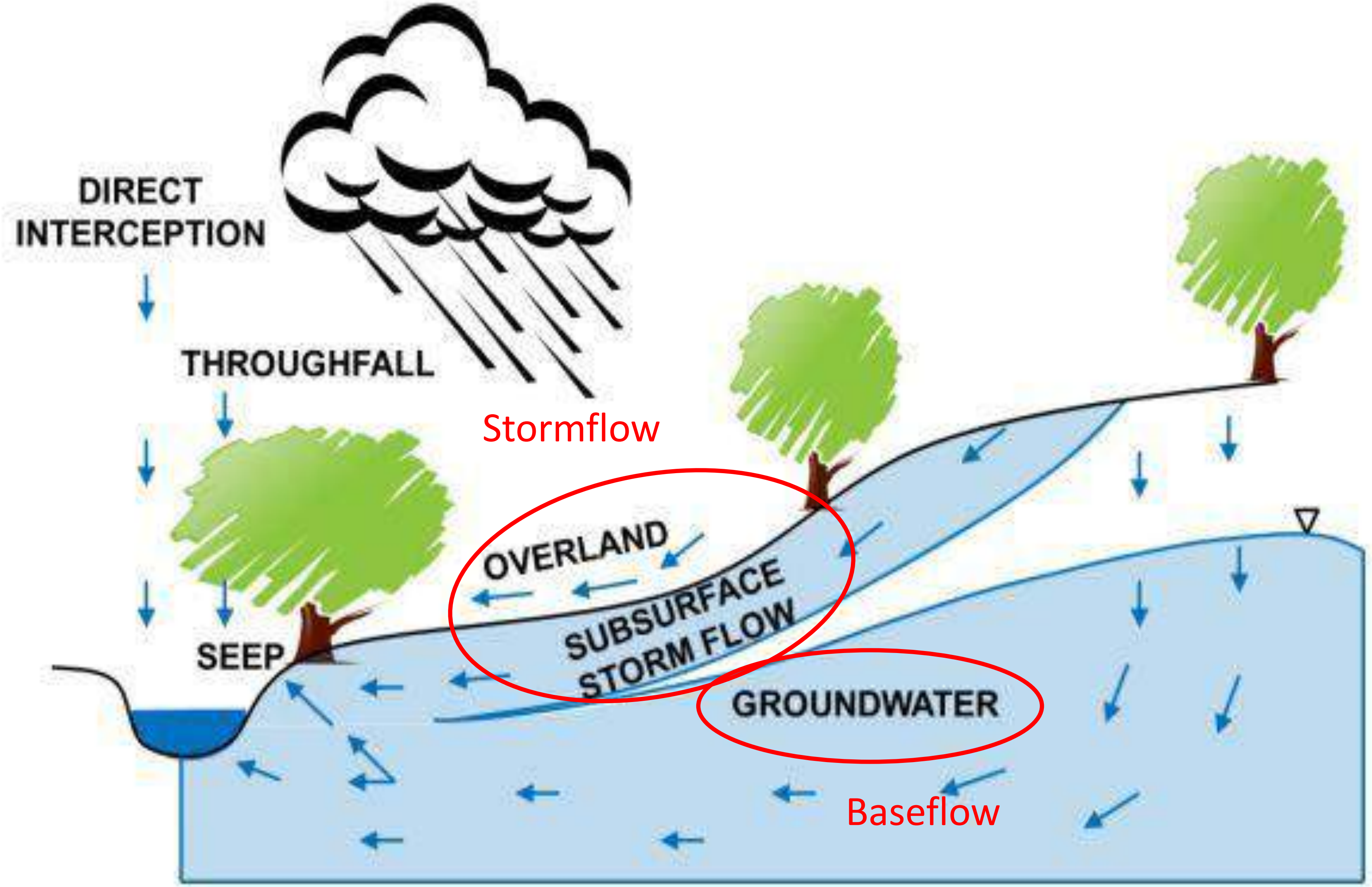


Fig. 2.2 -- The hydrologic cycle. The transfer of water from precipitation to surface water and ground water, to storage and runoff, and eventually back to the atmosphere is an ongoing cycle.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).



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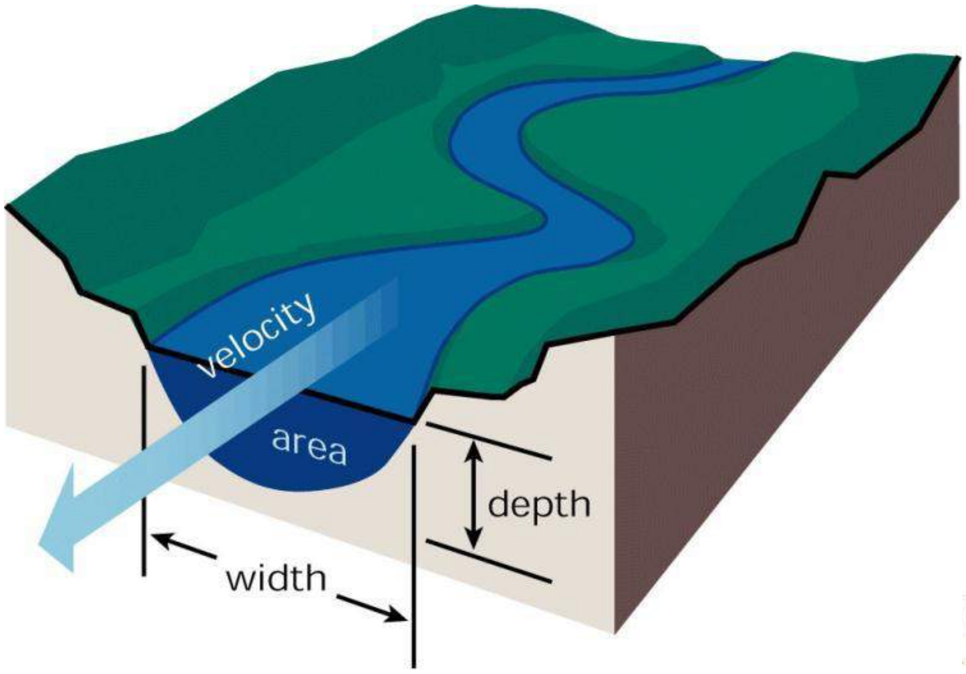
Discharge

- volume of water passing point in channel per unit time
- $Q = A * v$
  - Q = discharge, m^3/s
  - A = x-sectional area (m^2) = Depth * Width
  - v = velocity (m/s)



Hydrograph

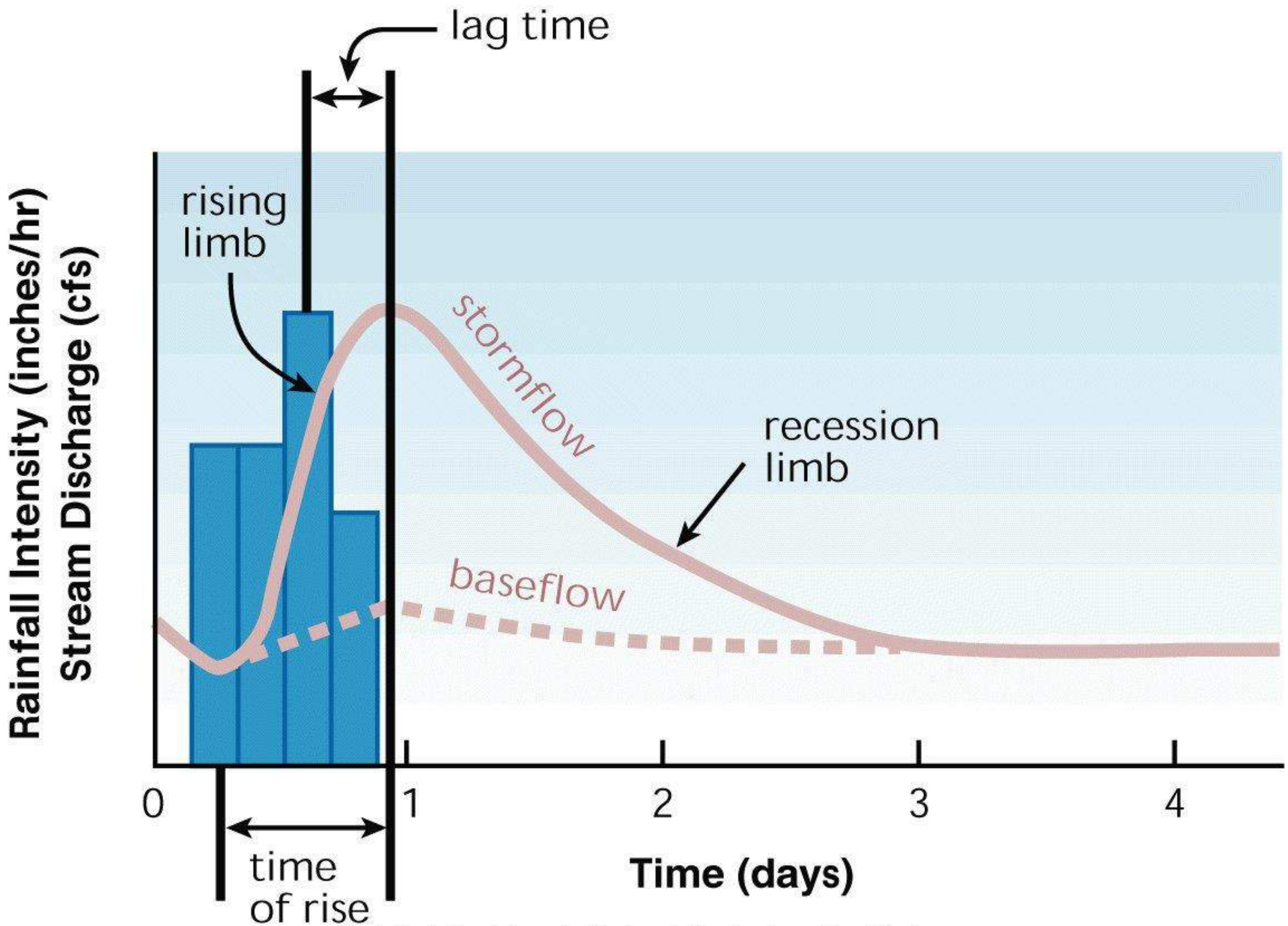


Fig. 1.14 A storm hydrograph. A hydrograph shows how long a stream takes to

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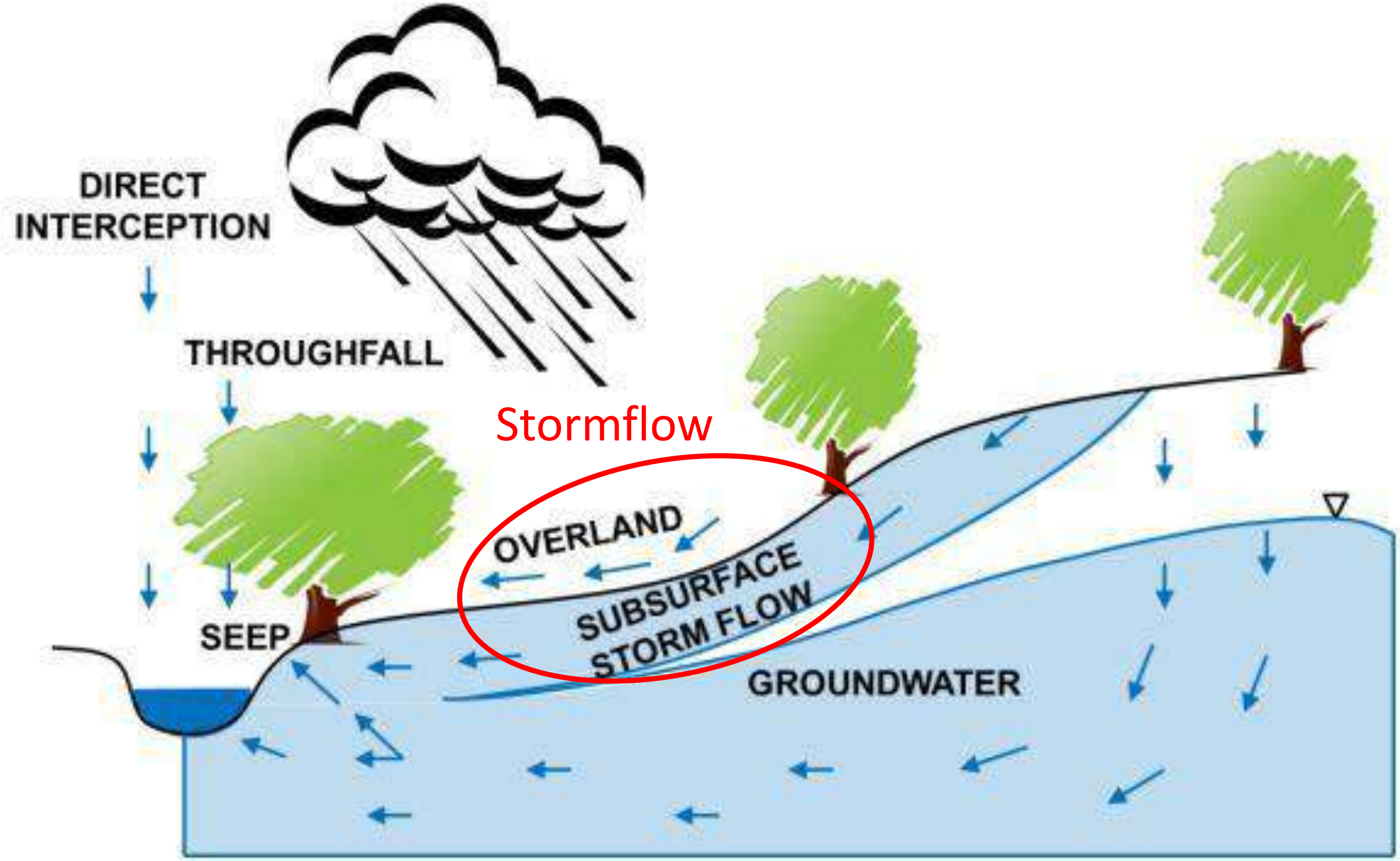
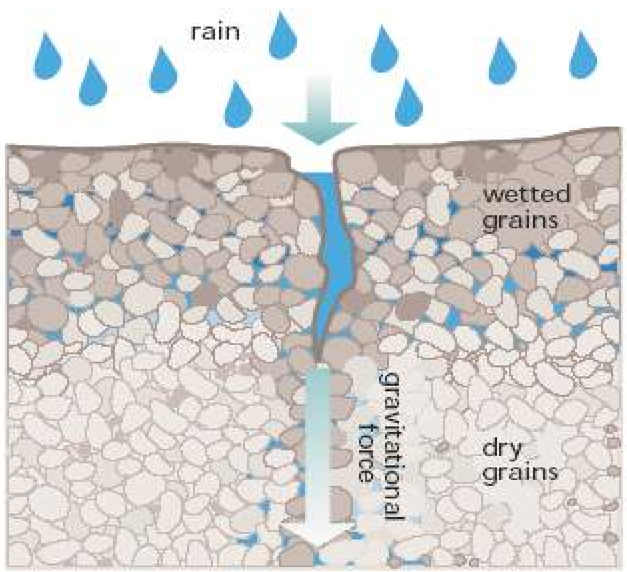
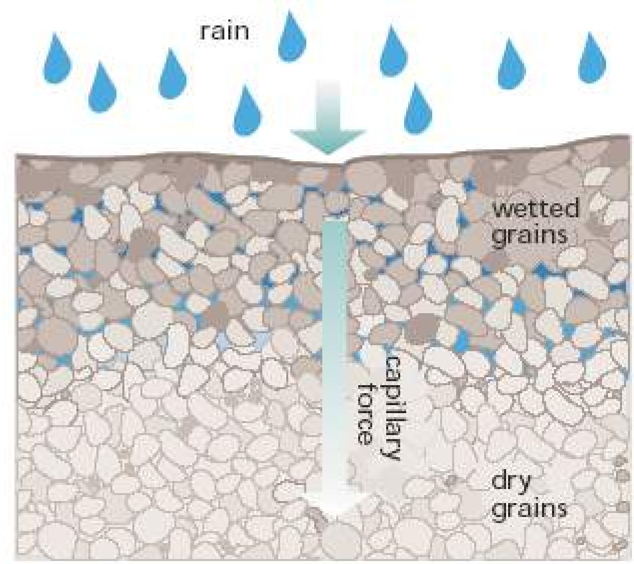
Stormflow



DIRECT INTERCEPTION
THROUGHFALL
Stormflow
OVERLAND
SUBSURFACE STORM FLOW
SEEP
GROUNDWATER

- Infiltration
  - Movement of water into soil pores
- Infiltration rate
  - Amount soaking in over time
- Infiltration capacity
  - Maximum rate water infiltrates a soil





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Infiltration and Runoff

- No Runoff if Rainfall Rate < Infiltration Rate
- If Rainfall Rate > Infiltration Rate
  - Water stands in small depressions
  - Travels down slope as Surface Runoff

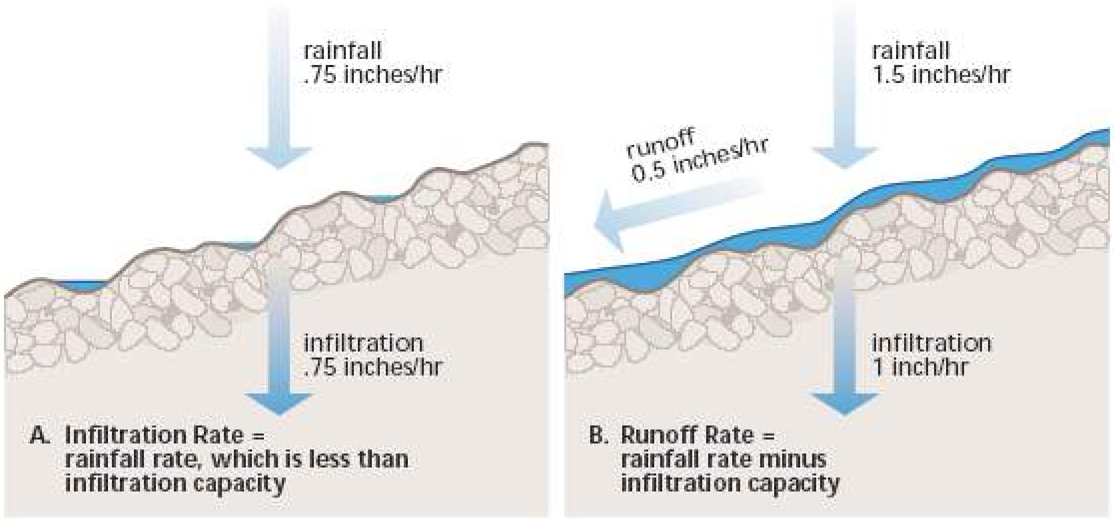

Figure 2.6: Infiltration and runoff. Surface runoff occurs when rainfall intensity exceeds infiltration capacity.

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Infiltration Rate of a Soil

- Determined by
  - Ease of entry through soil surface
  - Storage capacity of soil
  - Transmission rate through soil

Primary Factors Influencing Runoff

- **Land use/land cover**
- Hydrologic soil groups
- Precipitation intensity
- Topography
- Antecedent watershed conditions
  - Saturated soils
  - Frozen soils/snowcover

Table 1 HSG based on USDA soil classification

HSG	Soil Texture
A	Sand, loamy sand or sandy loam
B	Silt or loam
C	Sandy clay loam
D	Clay loam, silt clay loam, sandy clay, silty clay, or clay

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Runoff Curve Numbers – developed urban lands

Cover description		Curve numbers for hydrologic soil group			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	Poor condition (grass cover <50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good condition (grass cover >75%)	39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and roads	Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right of way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Western desert urban areas	Natural desert landscaping (pervious area only)	63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	96	96	96	96
Urban districts	Commercial and business (85% imp.)	89	92	94	95
	Industrial (72% imp.)	81	88	91	93
Residential districts by average lot size	$^1/_8$ acre or less (town houses) (65% imp.)	77	85	90	92
	$^1/_4$ acre (38% imp.)	61	75	83	87
	$^1/_3$ acre (30% imp.)	57	72	81	86
	$^1/_2$ acre (25% imp.)	54	70	80	85
	1 acre (20% imp.)	51	68	79	84
	2 acres (12% imp.)	46	65	77	82

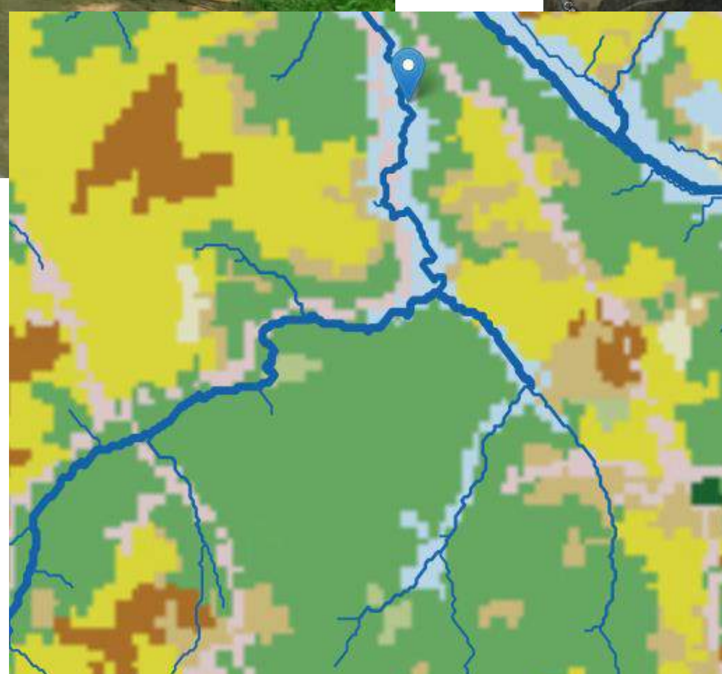
Runoff Curve Numbers for agricultural lands

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment	Hydrologic condition	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + R	Poor	65	73	79	81
		Good	61	70	77	80

Runoff Curve Numbers for agricultural lands

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[c]	48	65	73
Woods—grass combination (orchard or tree farm).	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

Natural, less developed, more forested, riparian buffers



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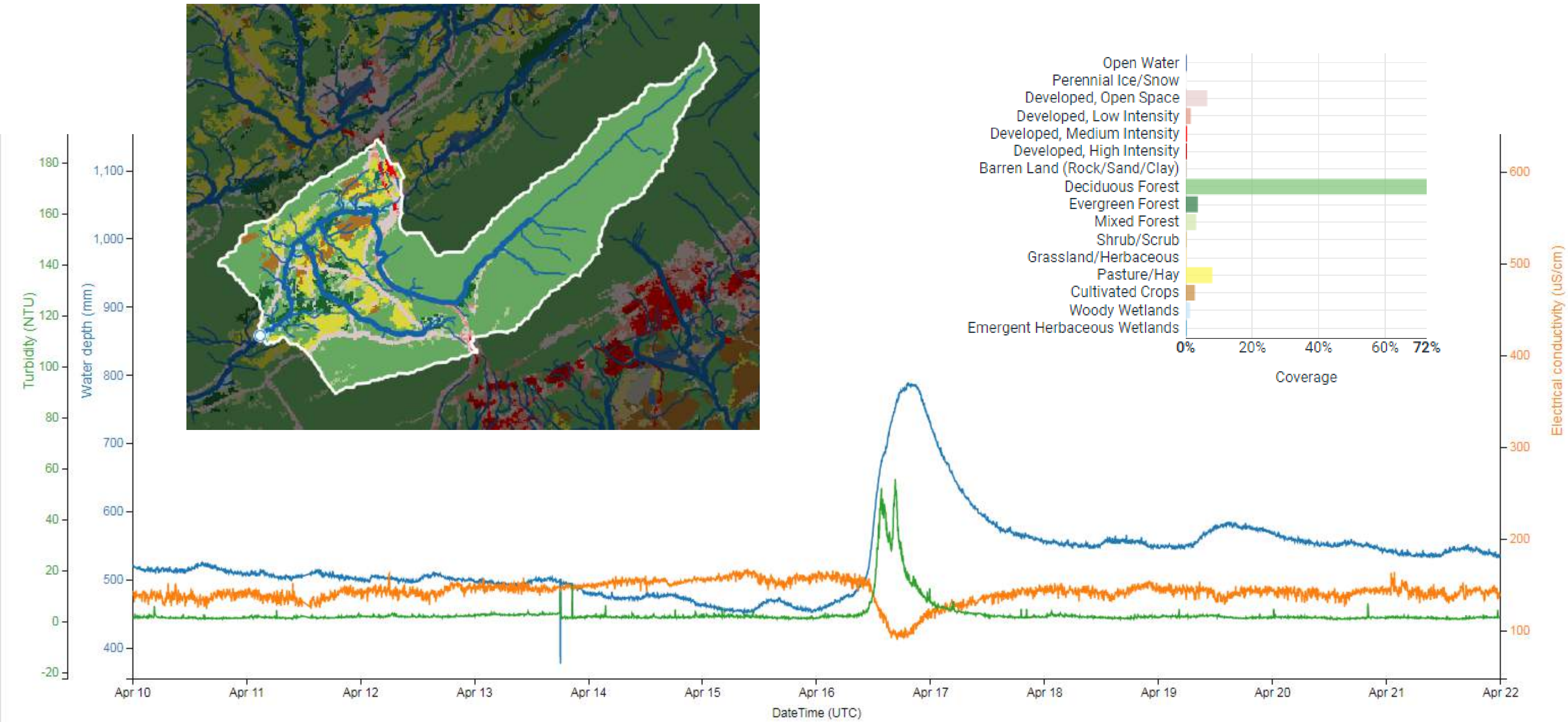
Natural, less developed, more forested, riparian buffers



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Near Surface Water Movement

- Forests moderate runoff
- Interception
  - Leaf shape & texture
  - Time of year
  - Vertical and horizontal density
  - Vegetation age

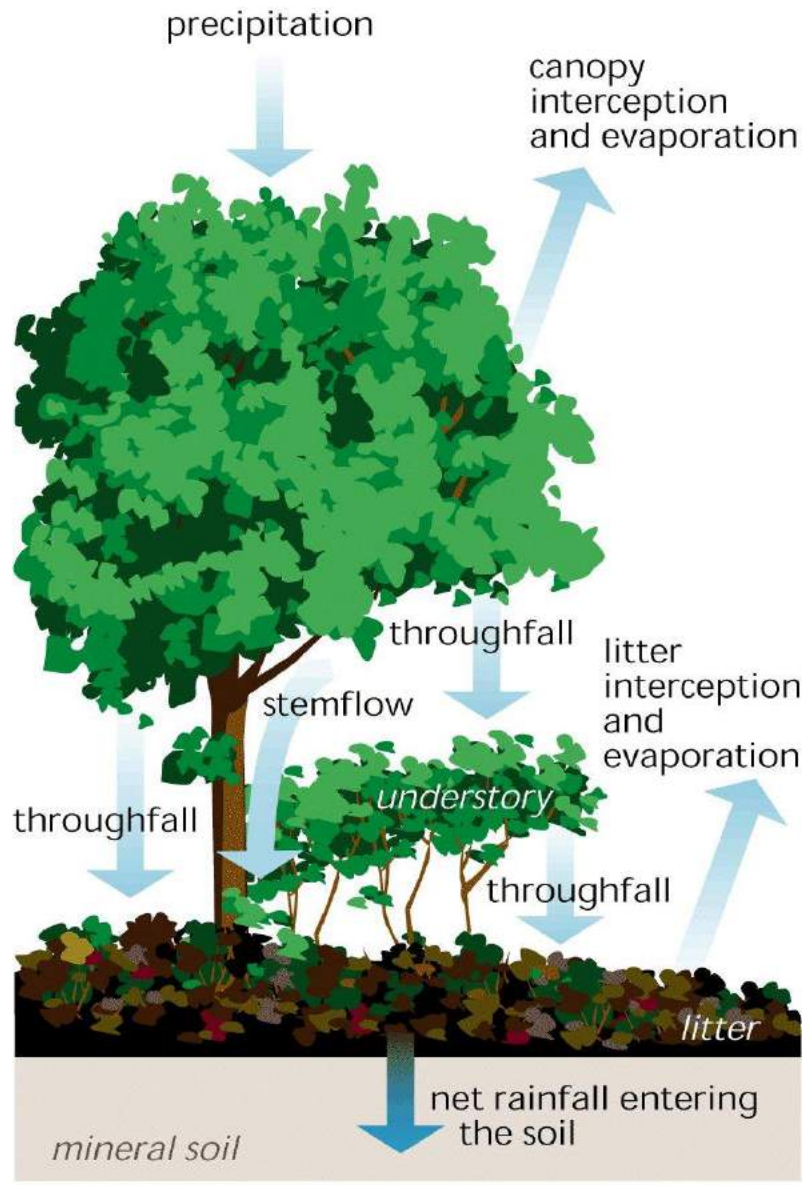
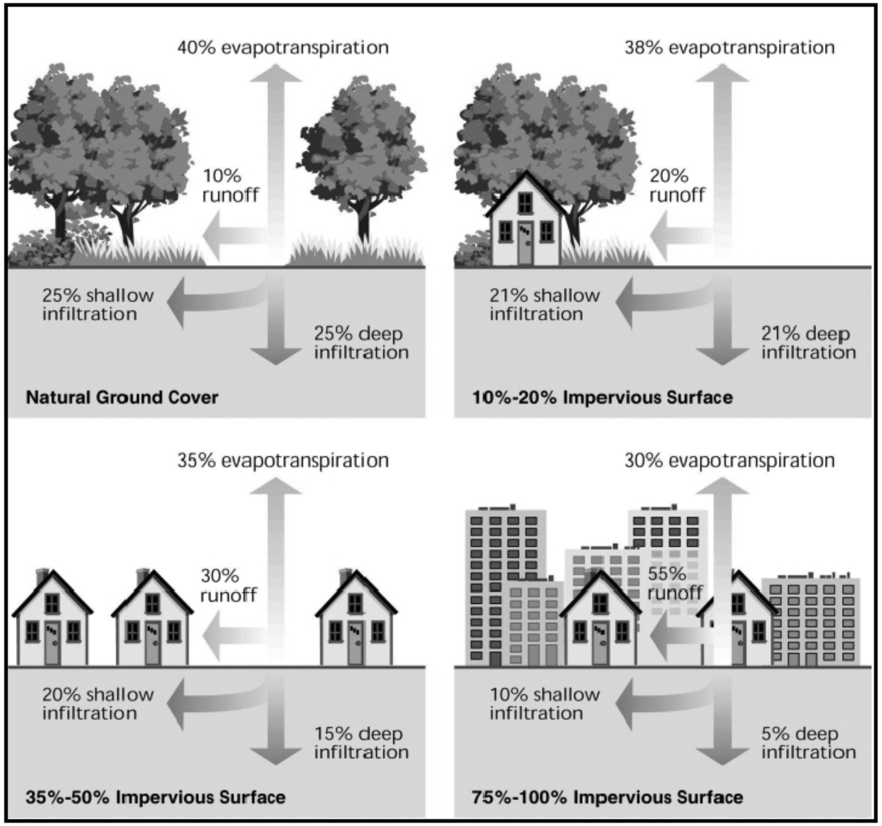
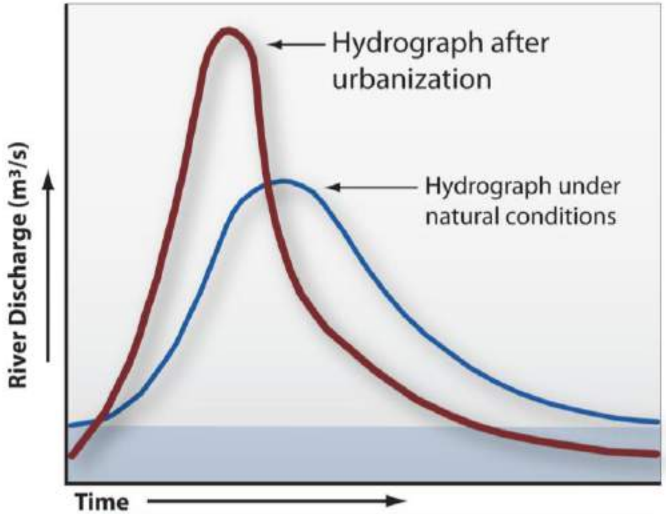


Fig. 2.3 -- Typical pathways for forest rainfall. A portion of precipitation never reaches the ground because it is intercepted by vegetation and other surfaces.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).

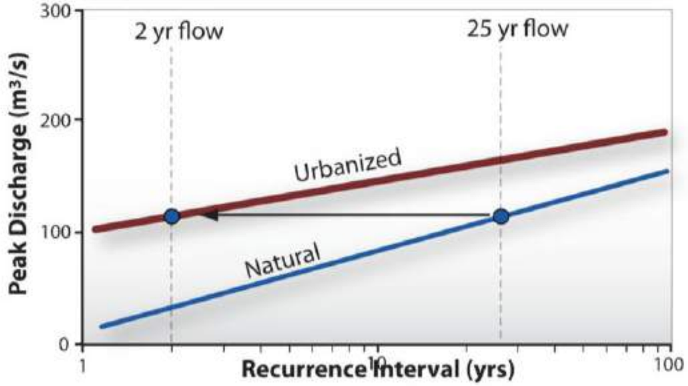
Watershed Land Use Change



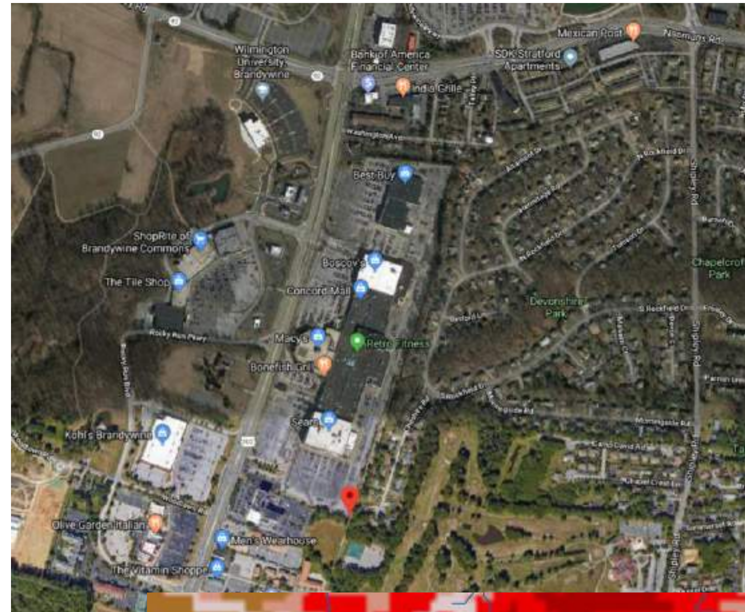


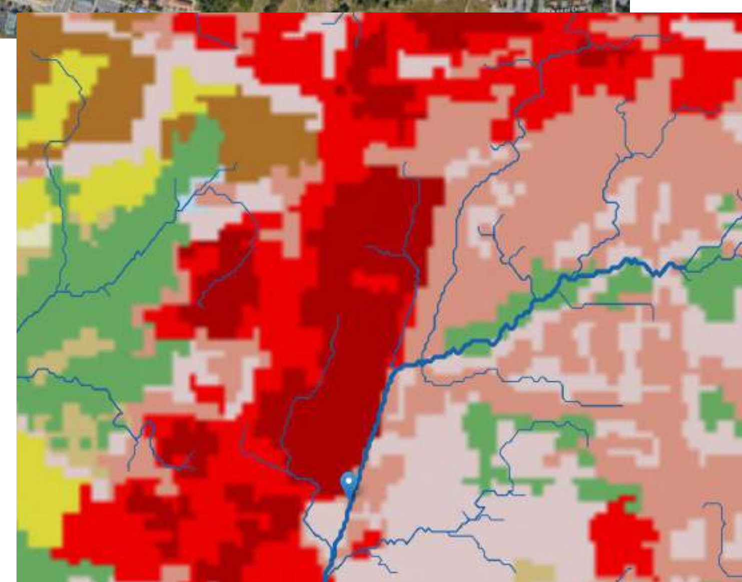
Before development, rainfall followed a more convoluted path through the landscape - held in detention storage by pit and mound topography, infiltrating into organic-rich forest soil and moving slowly to the channel. The infiltrating water fed baseflow during times when it was not raining. Flood peaks were lower and came later.

After urbanization, rainfall moves rapidly to the channel with little chance to infiltrate during storms, thus baseflow is reduced. Flowing directly off impervious surfaces such as parking lots, runoff enters streams quickly raising their level. Flood peaks now come sooner and are higher, increasing flood hazards and the tempo of geomorphic change. For example, the natural 25 yr flow becomes the much more frequent 2 year flow.

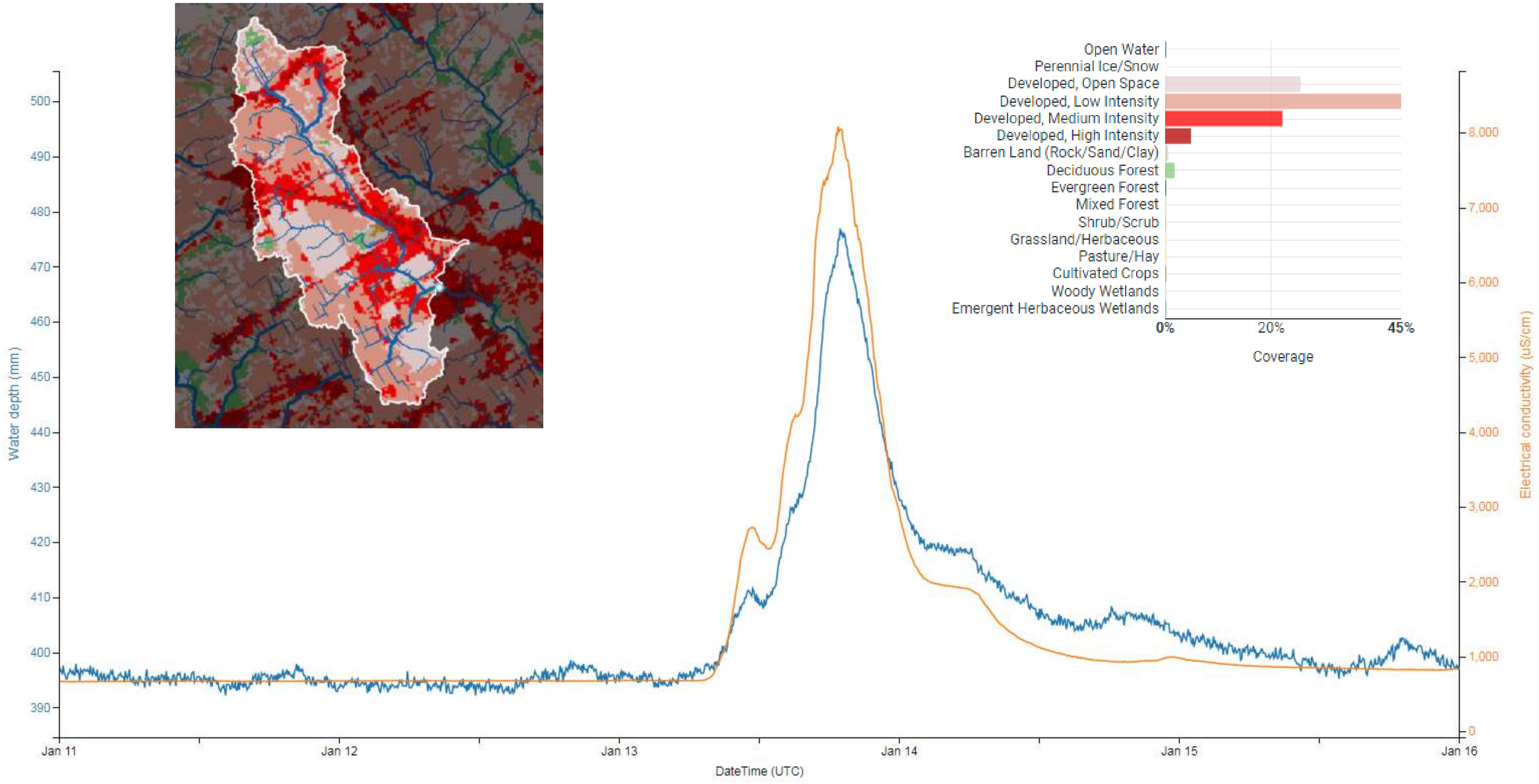


Urban, developed, less vegetation, impervious surfaces





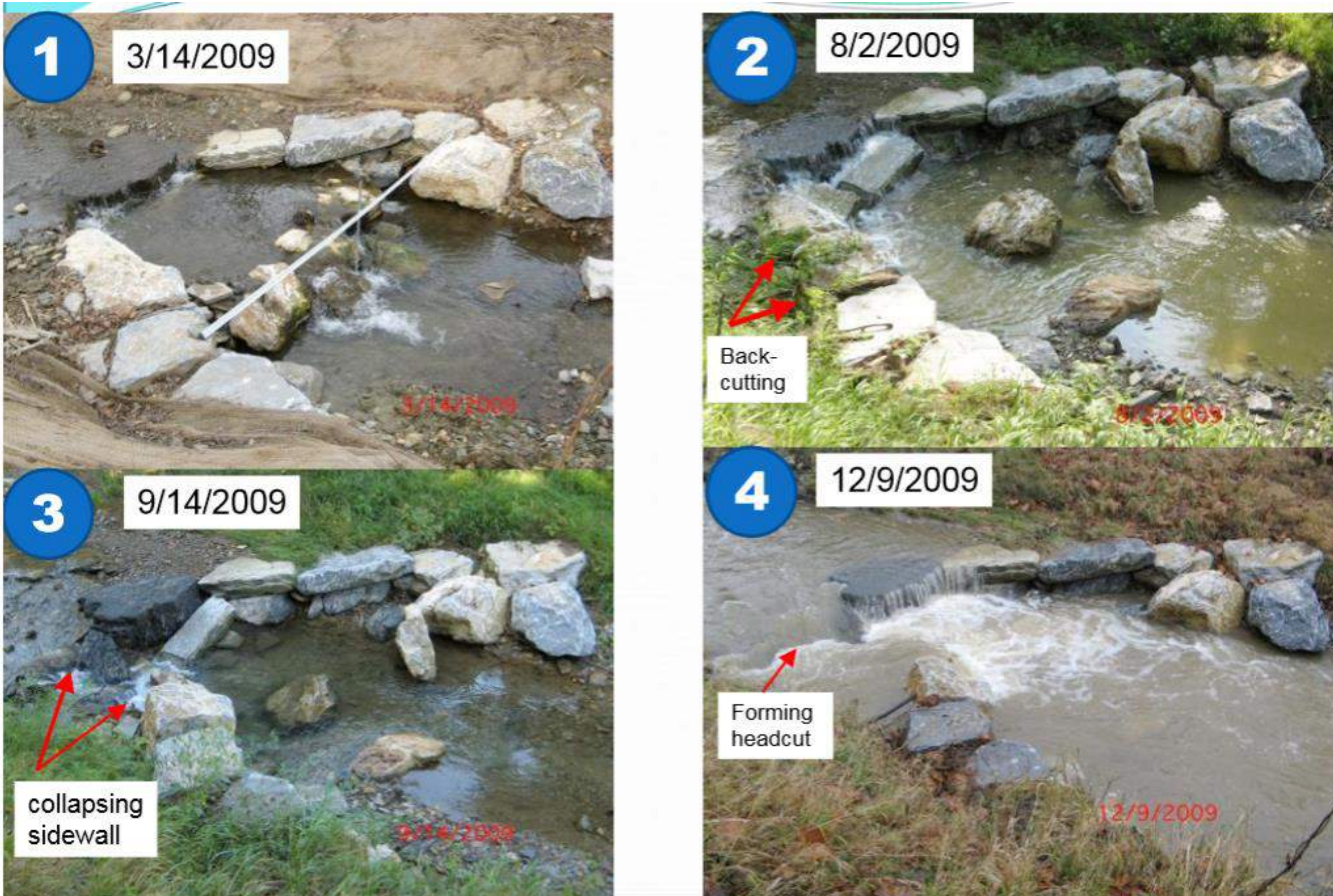
Urban, developed, less vegetation, impervious surfaces



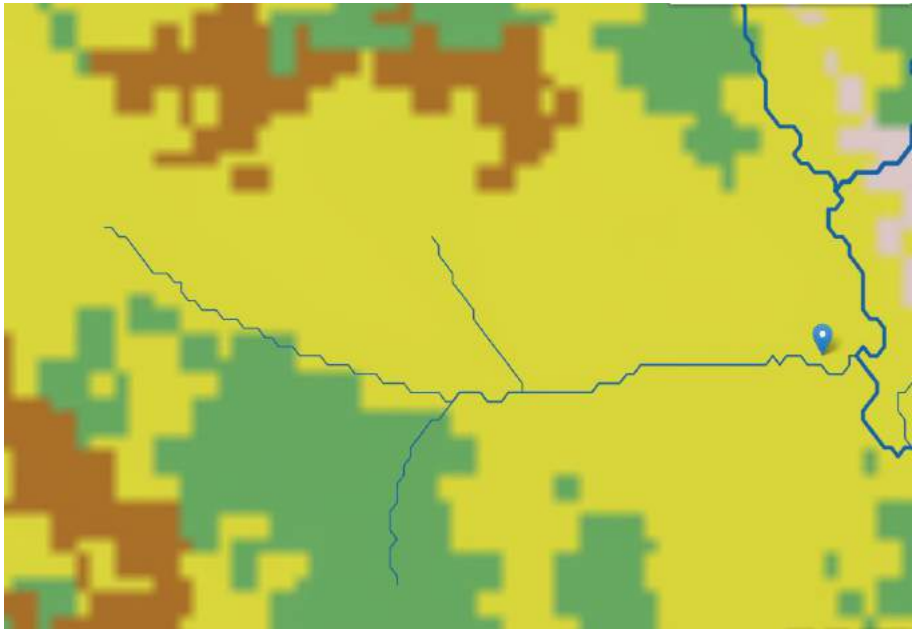
Urban Watershed Restoration

- Stormwater management BEFORE stream restoration

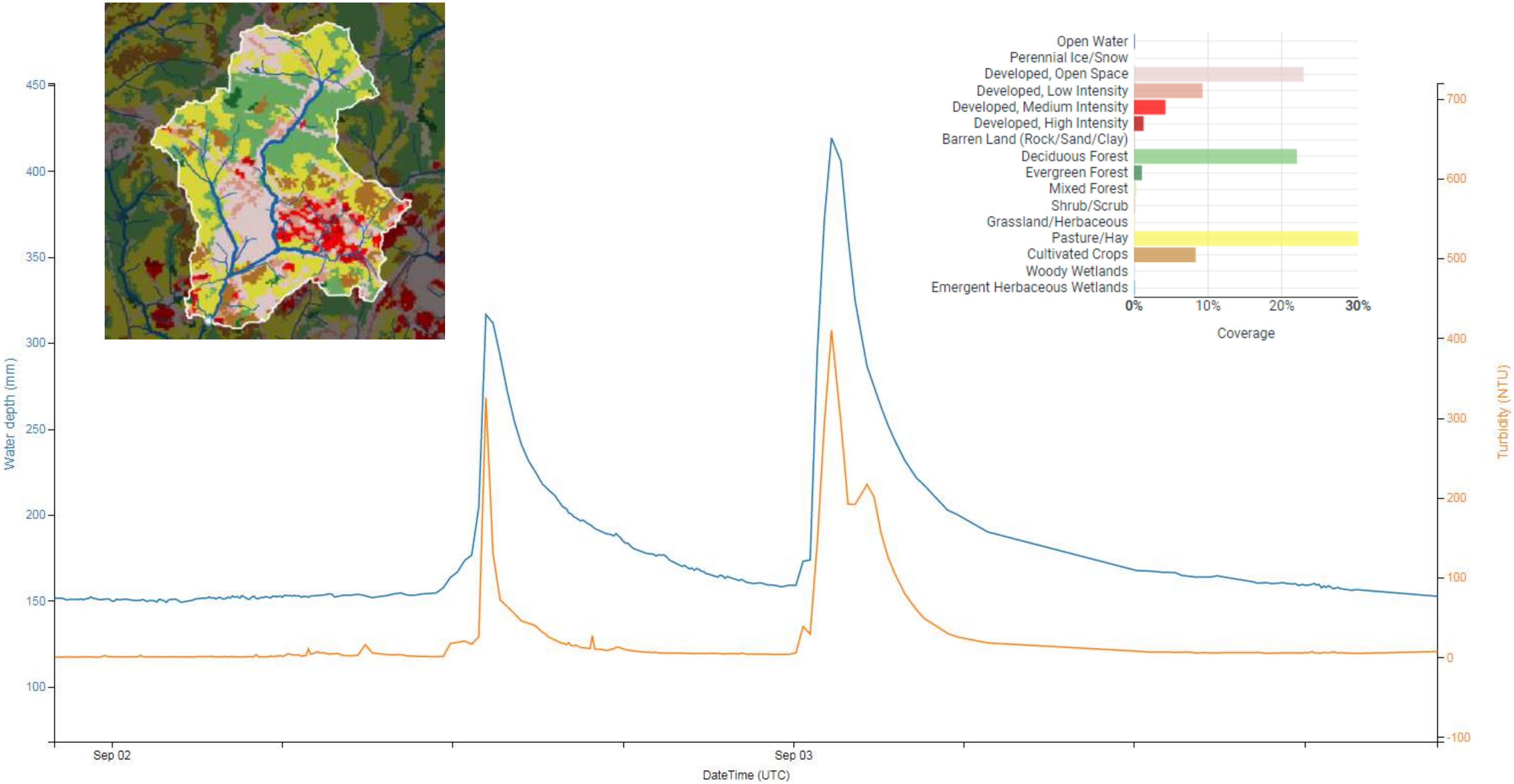
Uncontrolled urban stormwater will destroy any in-channel restoration investment



Agriculture, less developed, animals/crops, nutrients, and sediment



Agriculture, less developed, animals/crops, nutrients, and sediment



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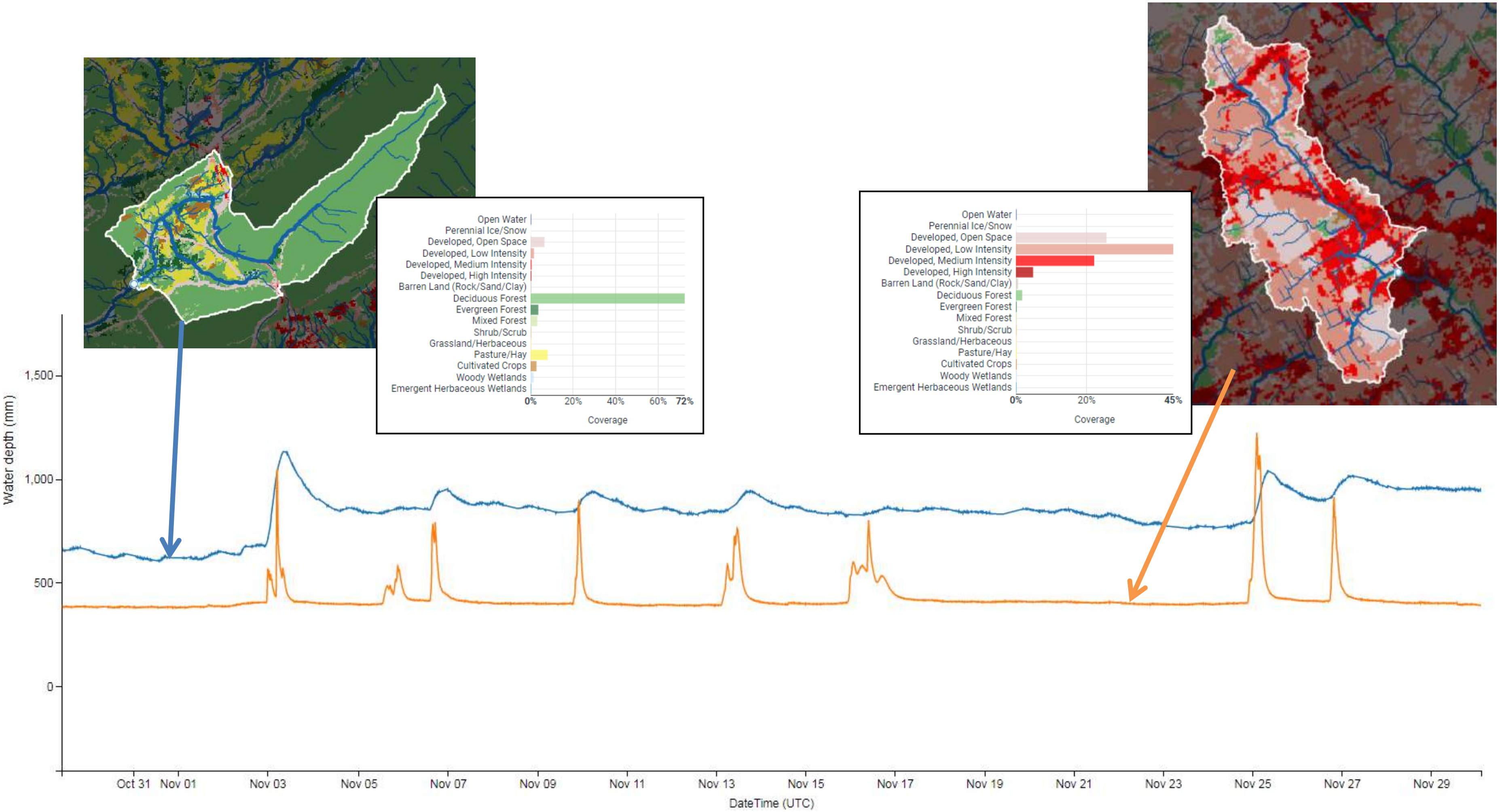
Natural versus Urban – Flow



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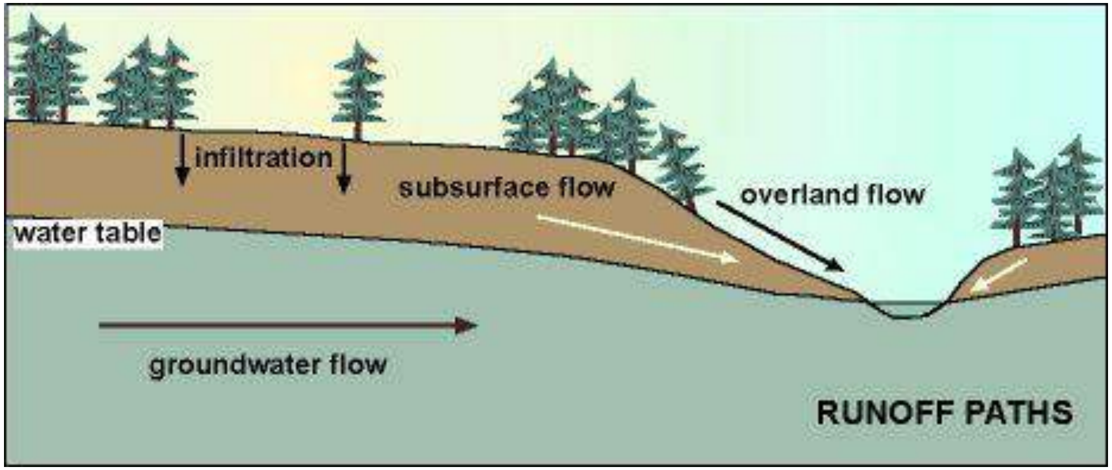
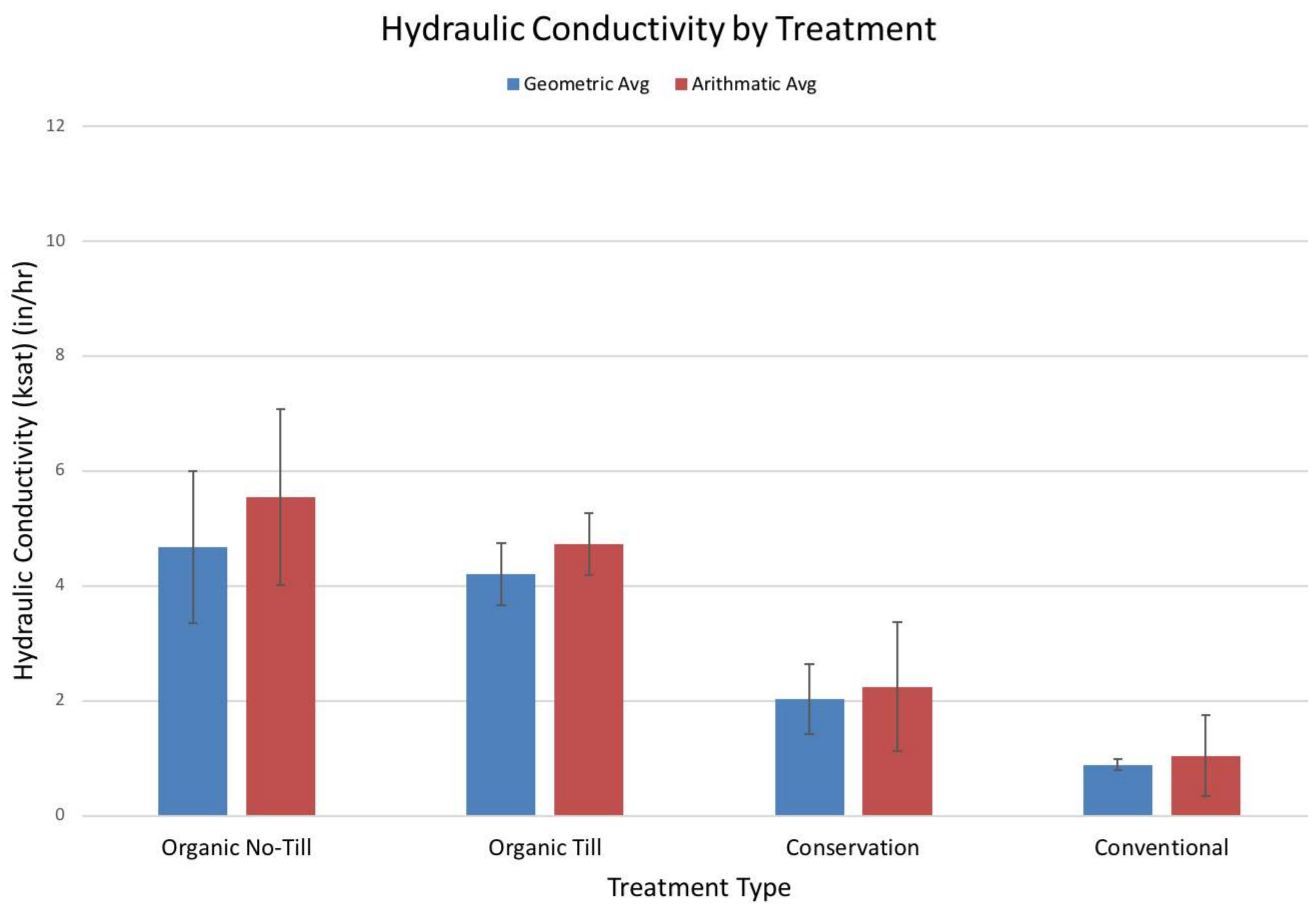
Hydrologic Watershed Restoration for Flood Control



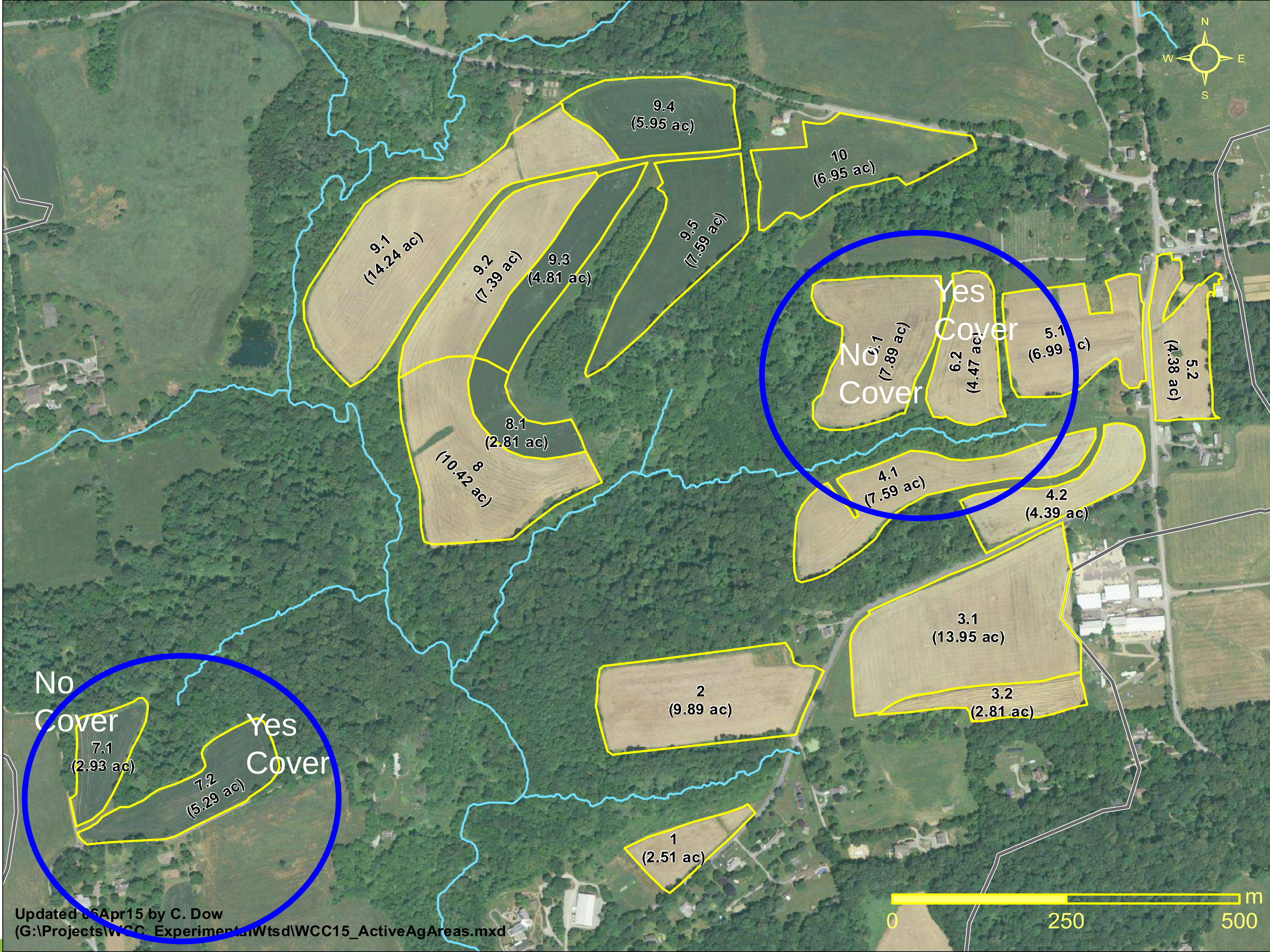
- *Increase infiltration*
- *Increase concentration time*
- *Increase baseflow (cools in summer, warms in winter)*

Case Study: How Farming Practices Can Alter Watershed Hydrology

USDA Conservation Innovation Grant: Evaluating How Conventional, Conservation, and Organic Farming Management Practices Enhance Soil Health and Improve Water Quality



Hydraulic Conductivity by Treatment
Geometric Avg
Arithmatic Avg
Hydraulic Conductivity (ksat) (in/hr)
12
10
8
6
4
2
0
Organic No-Till
Organic Till
Conservation
Conventional
Treatment Type



N
W
E
S
9.4
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10
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9.1
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9.2
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9.3
(4.81 ac)
9.5
(7.59 ac)
8.1
(2.81 ac)
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(10.42 ac)
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Cover
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Cover
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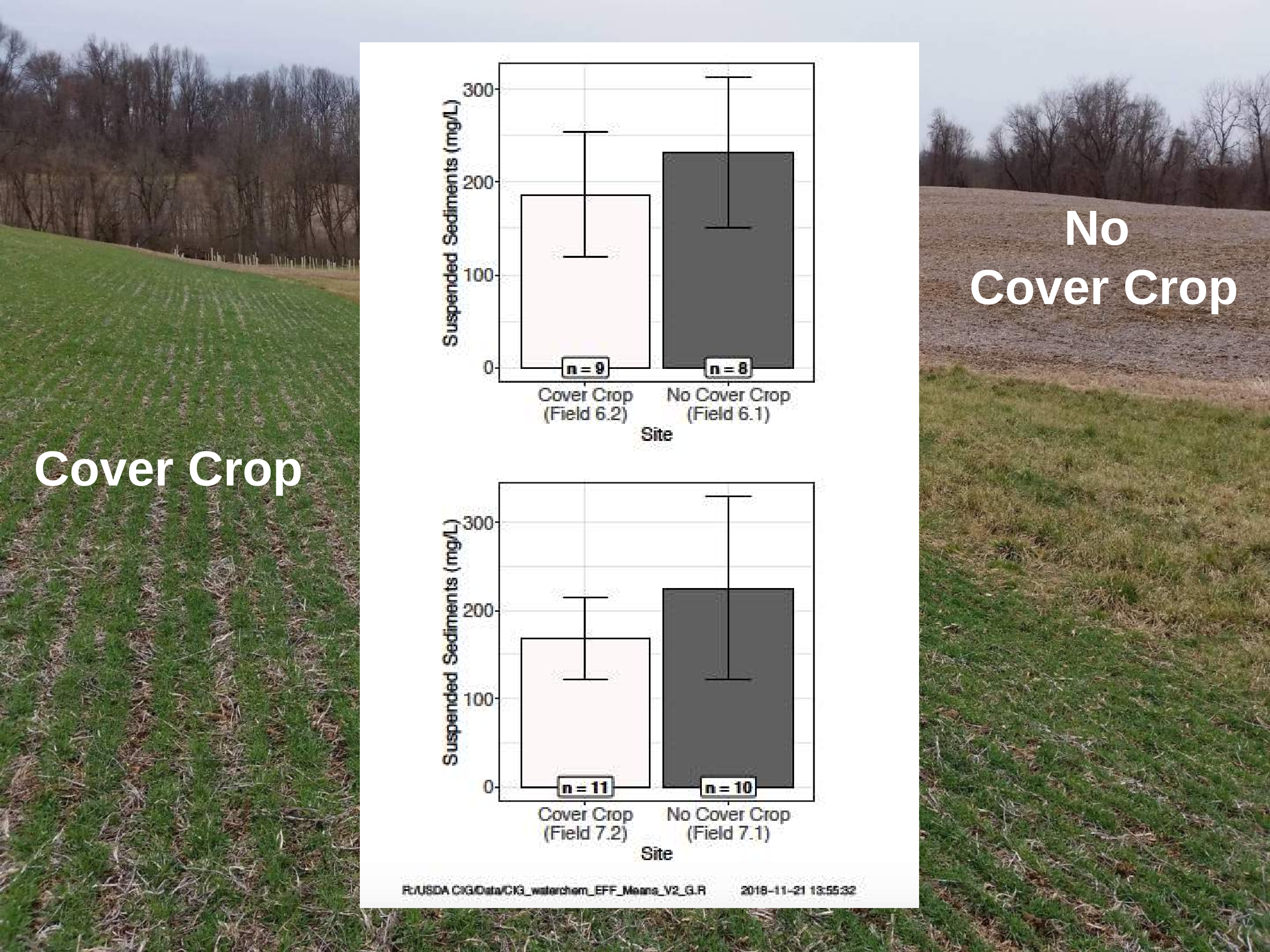
(7.89 ac)
6.2
(4.47 ac)
5.1
(6.99 ac)
5.2
(4.38 ac)
4.1
(7.59 ac)
4.2
(4.39 ac)
3.1
(13.95 ac)
3.2
(2.81 ac)
2
(9.89 ac)
1
(2.51 ac)
No
Cover
7.1
(2.93 ac)
Yes
Cover
7.2
(5.29 ac)
m
0
250
500
Updated 06Apr15 by C. Dow
(G:\Projects\WCC_ExperimentalWtsd\WCC15_ActiveAgAreas.mxd


EFF7.1
EFF7.2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Cover Crop
Cover Crop
Suspended Sediments (mg/L)
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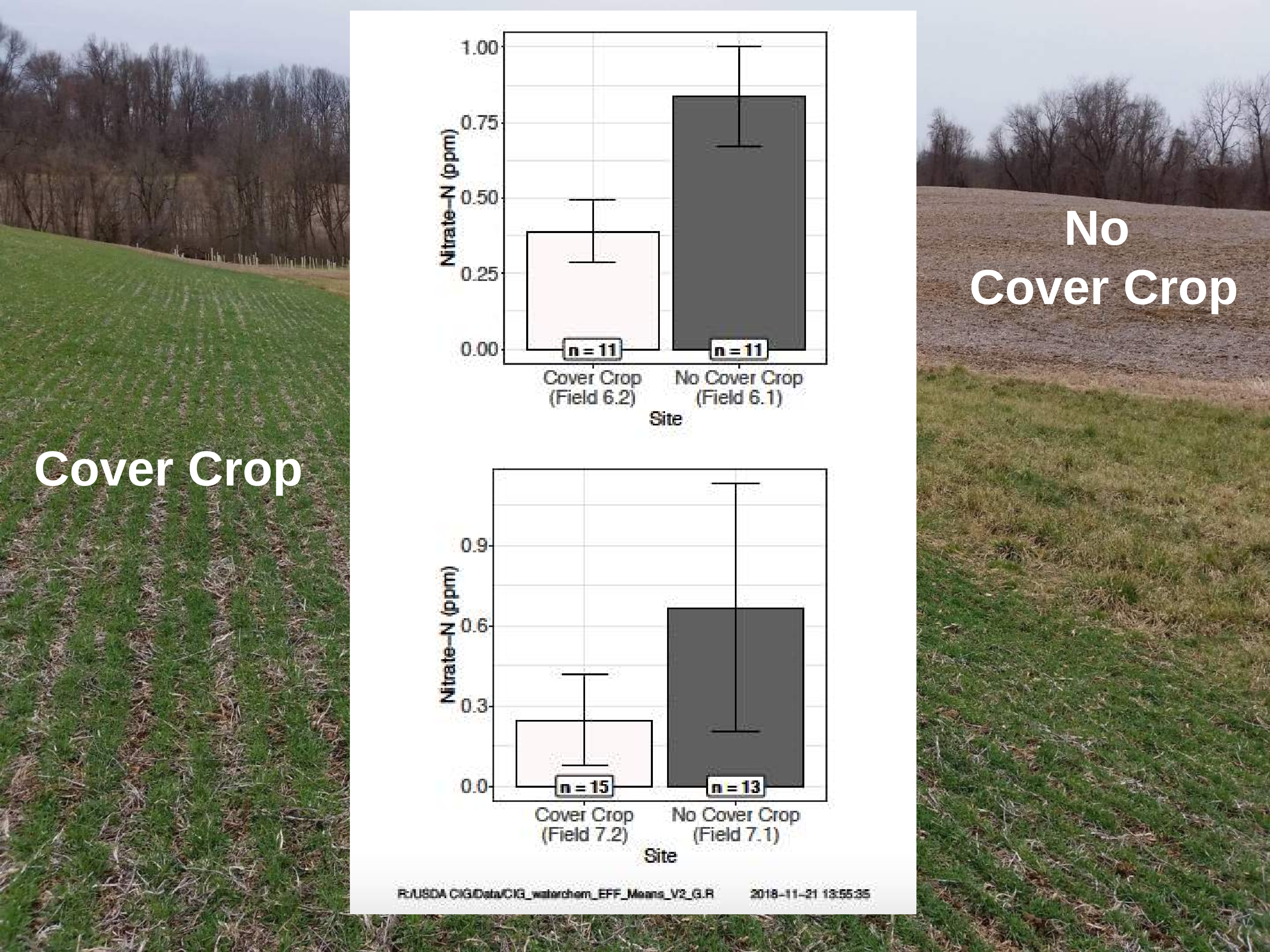
200
100
0
n = 9
n = 8
Cover Crop
(Field 6.2)
No Cover Crop
(Field 6.1)
Site
Suspended Sediments (mg/L)
300
200
100
0
n = 11
n = 10
Cover Crop
(Field 7.2)
No Cover Crop
(Field 7.1)
Site
R:/USDA CIG/Data/CIG_waterchem_EFF_Means_V2_G.R
2018-11-21 13:55:32


Cover Crop
No
Cover Crop
Nitrate–N (ppm)
1.00
0.75
0.50
0.25
0.00
n = 11
n = 11
Cover Crop
(Field 6.2)
No Cover Crop
(Field 6.1)
Site
Nitrate–N (ppm)
0.9
0.6
0.3
0.0
n = 15
n = 13
Cover Crop
(Field 7.2)
No Cover Crop
(Field 7.1)
Site
R:/USDA CIG/Data/CIG_waterchem_EFF_Means_V2_G.R
2018–11–21 13:55:35

Case Study: Hydrologic Restoration of Agricultural Watershed

Hurricane Sandy Coastal Resiliency Competitive Grant Program

The Hurricane Sandy Coastal Resiliency Competitive Grant Program supports projects that reduce communities' vulnerability to the growing risks from coastal storms, sea level rise, flooding,

PROGRAM INFORMATION

New Grantee Information

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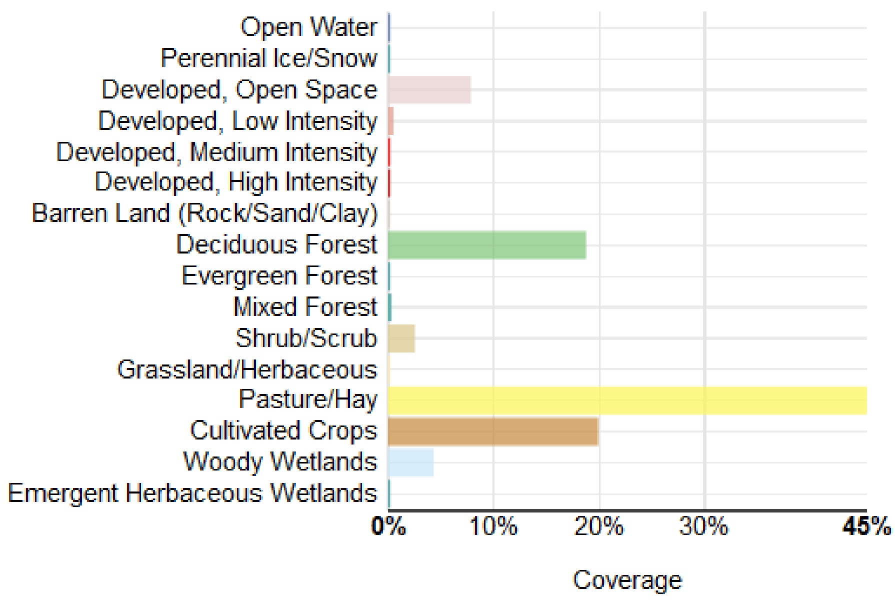
White Clay Creek Watershed
Chester County, PA

Total Area 8 km^2

Land cover distribution from National Land Cover Database (NLCD 2011)



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“Level-lip spreader” located behind Stroud Water Research Center before construction


Level-lip spreader during construction


Level-lip spreader during construction


Level lip spreader after construction

“Level-lip spreaders” are shallow conservation swales built along the contour of the slope that collect surface runoff during rainstorms. With most storms the water that is collected will infiltrate into the ground, sediments settle out, and the water flows as groundwater to the stream. In big storms the water will flow over the level-lip evenly into the streamside forest before reaching the stream. Level-lip spreaders help reduce flooding and prevent nutrients and sediments from reaching the stream. These swales are being designed by Chester County Conservation District in partnership with the Stroud Center.


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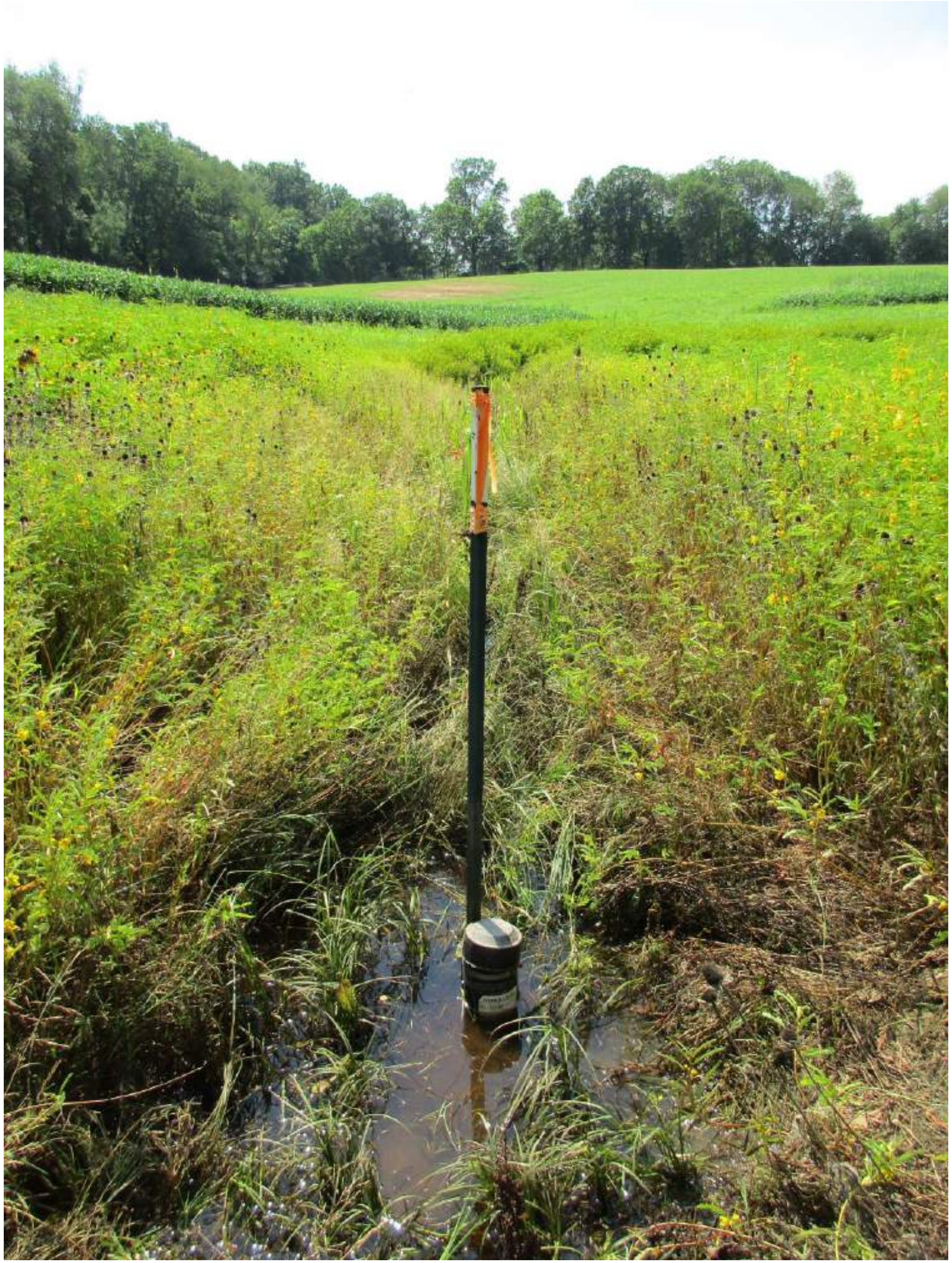
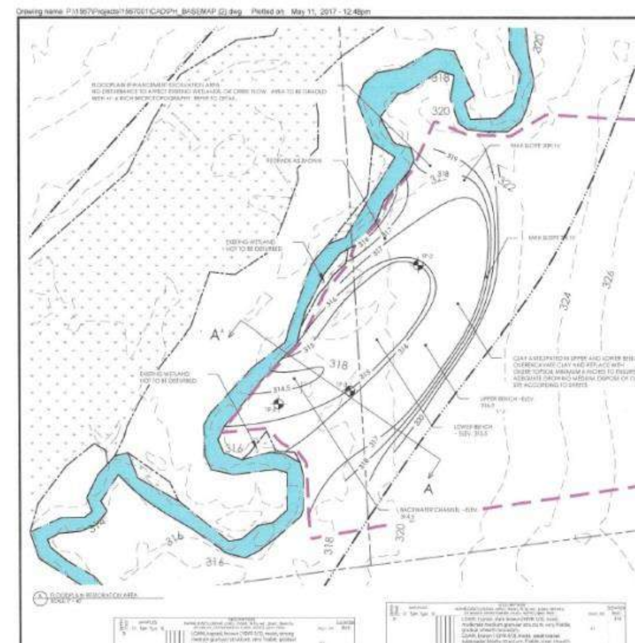


Level Lip Spreaders and Wetland storage > 10,000 m^3
(~25% of a 2 inch, 24 hour storm event)

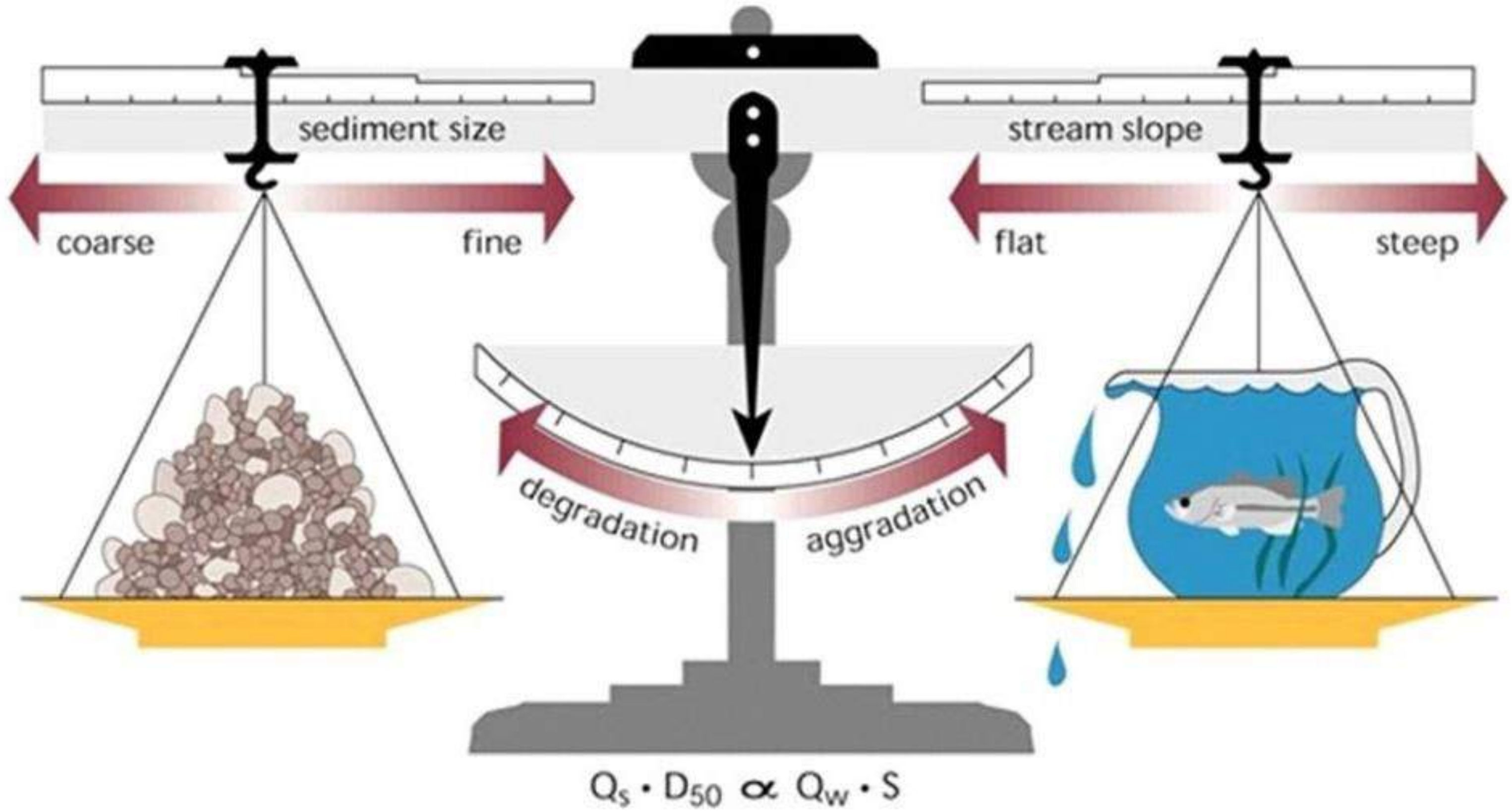


Princeton Hydro

Questions

Stream Geomorphology

The Master Variables: Water and Sediment



G.K. Gilbert, Mackin and others….

“Graded” river is just able to transport load supplied to it

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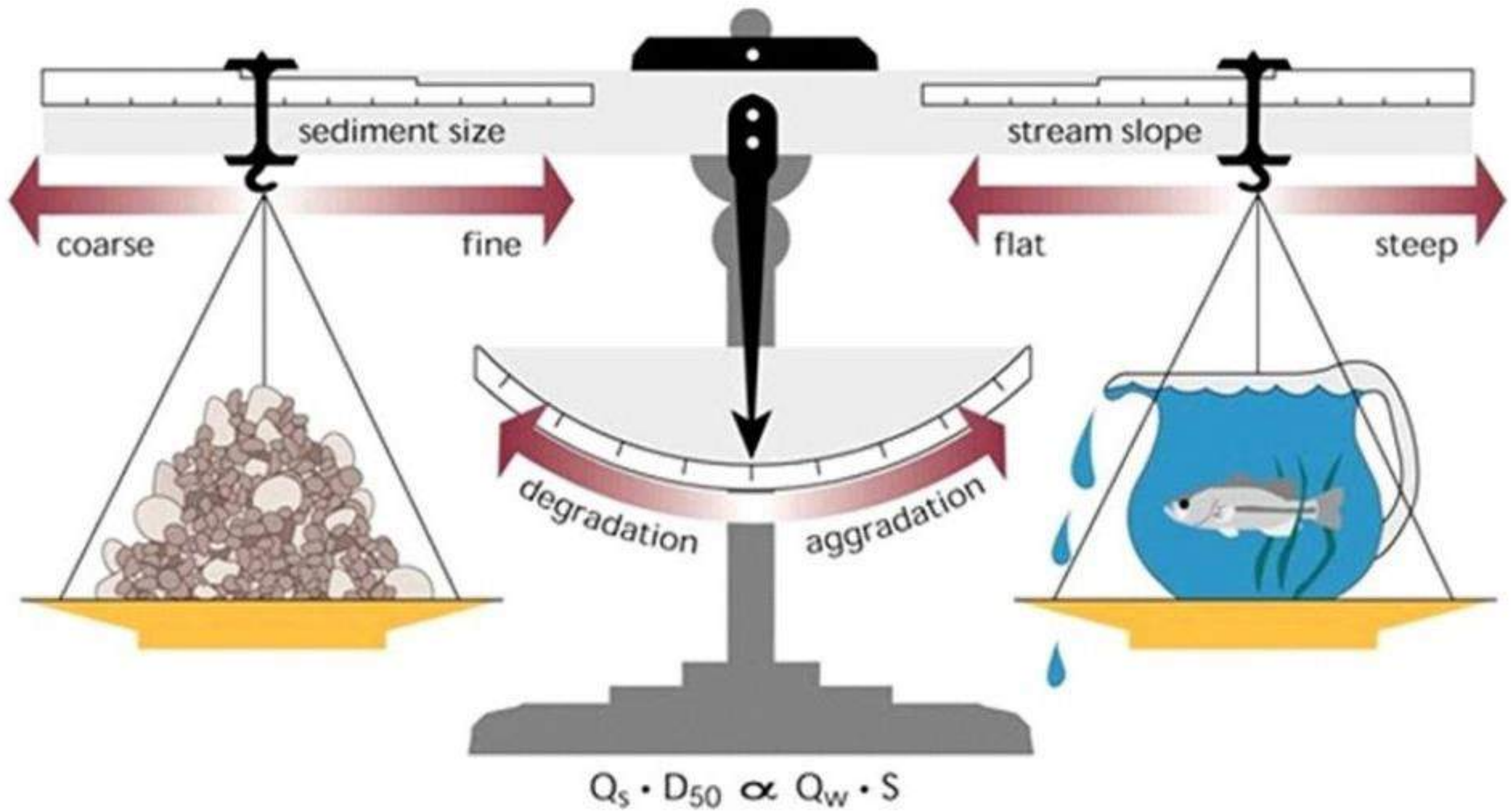
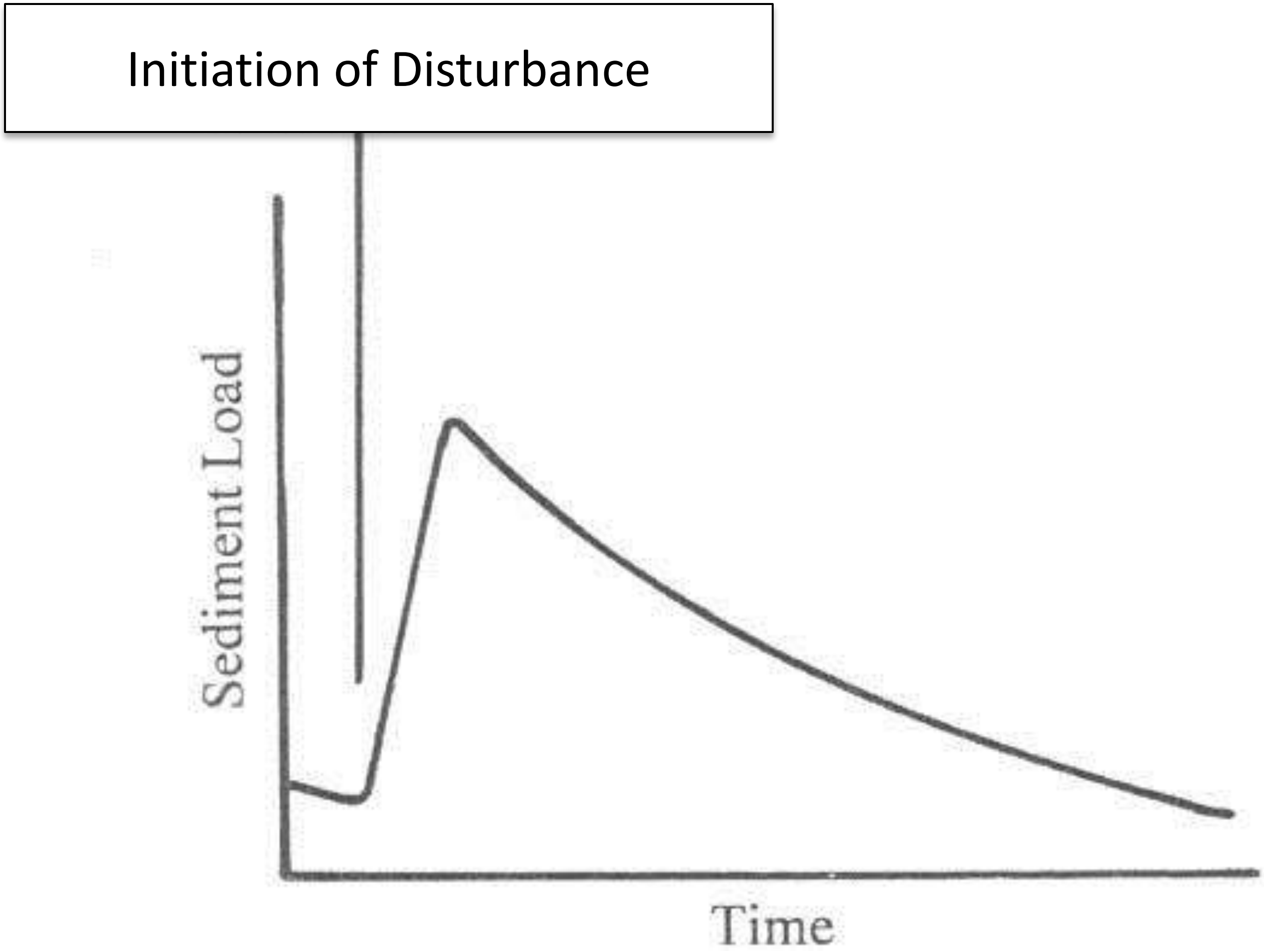
Leopold and Bull (1979)….

Slope, width, depth, velocity, roughness, pattern and channel morphology mutually adjusted to provide the power and efficiency necessary to transport the load supplied from the drainage basin without aggradation or degradation of the channel

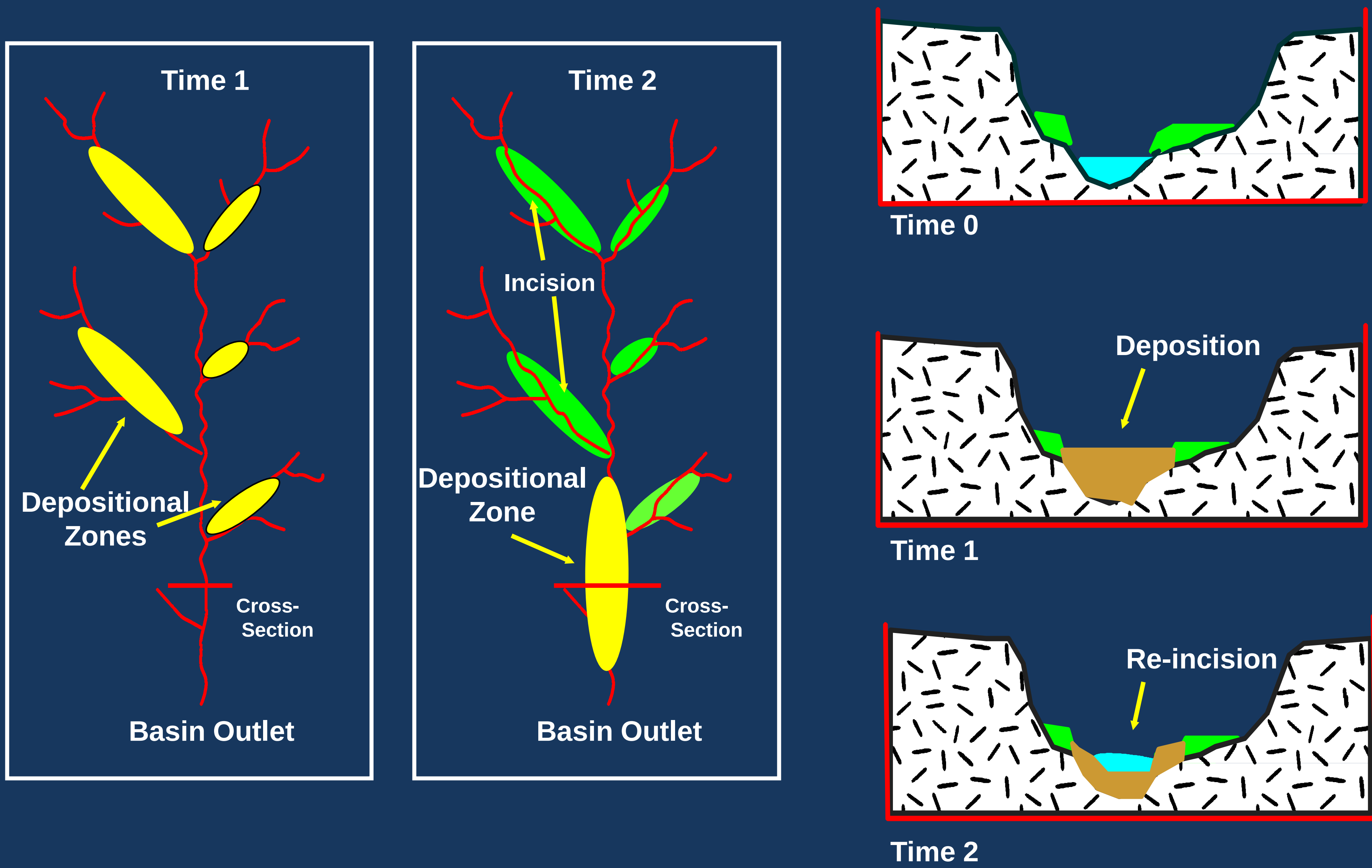


Curve approaching equilibrium

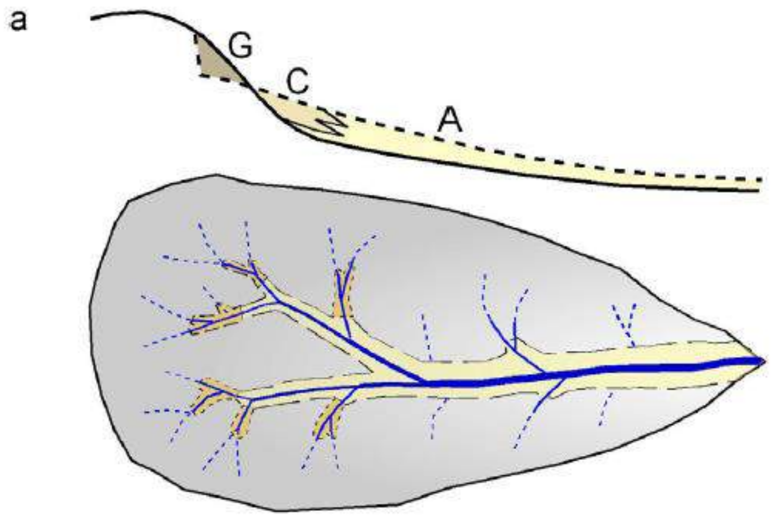


From Miller, 1997

Complex Response



(Adapted from Schumm, 1973, 1977)



James, L.A. 2013.

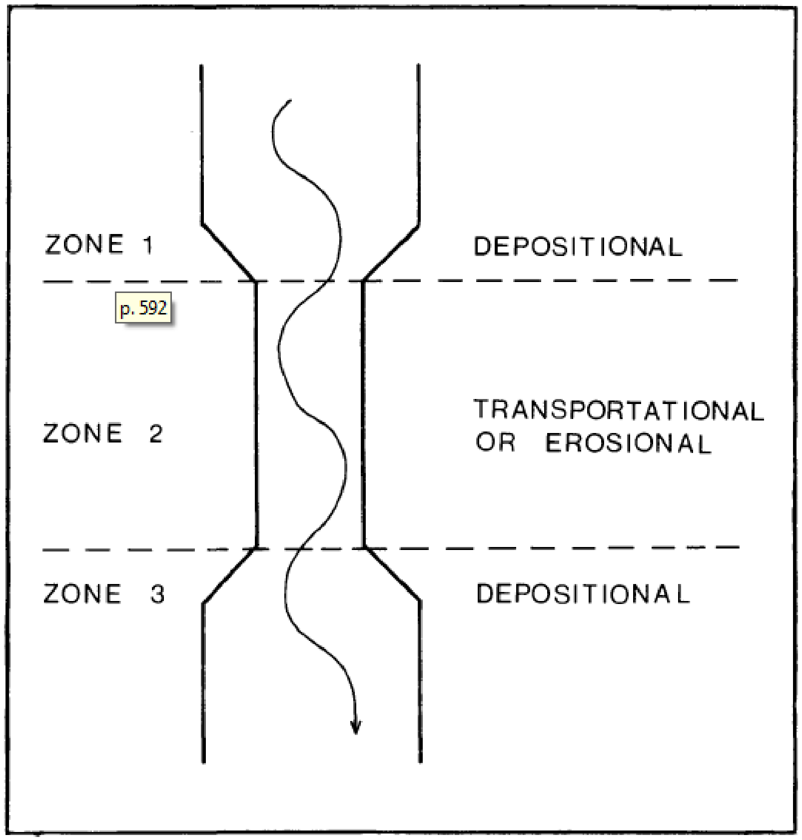
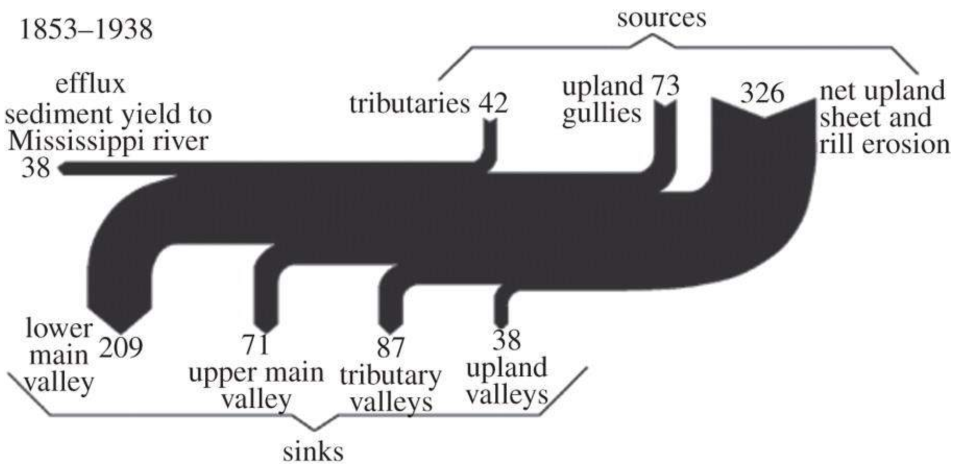


Figure 9. Theoretical floodplain sedimentation model.

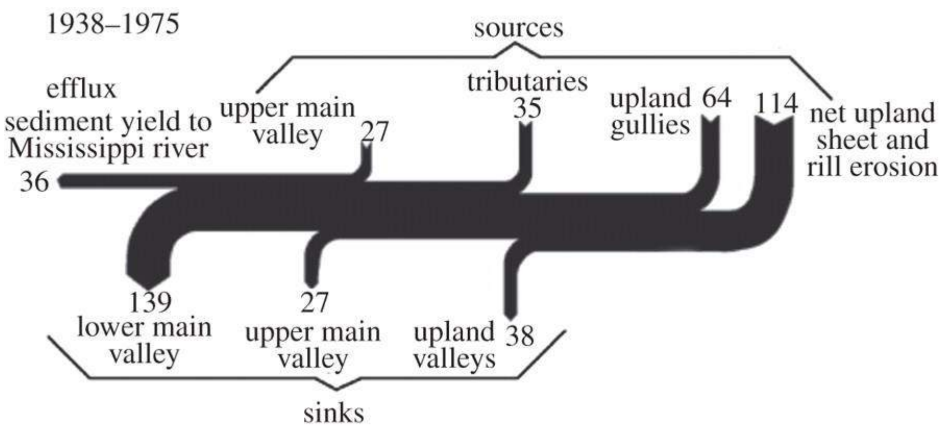
Magilligan, 1985

log Ca = -0.35 + (0.993) log Wf + (0.052) log Ad

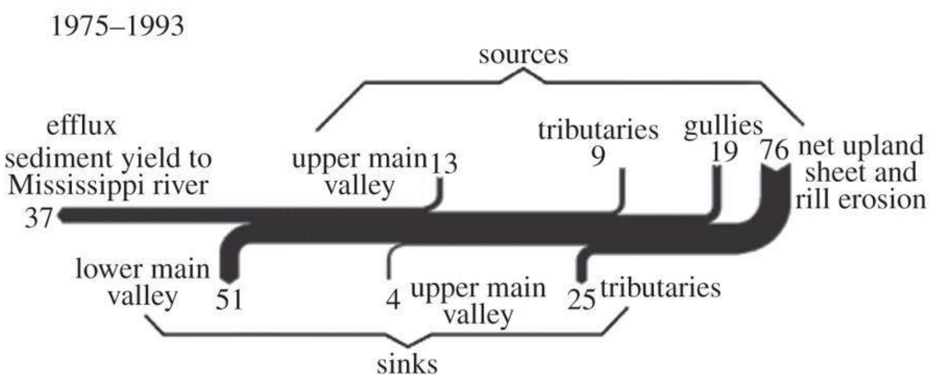
Ca = cross-sectional area of post-settlement alluvium
Wf = **floodplain width**
Ad = **drainage area**



Settlement, land clearing, poor farming practices



Soil Conservation Service, improved farming practices



Improved farming practices

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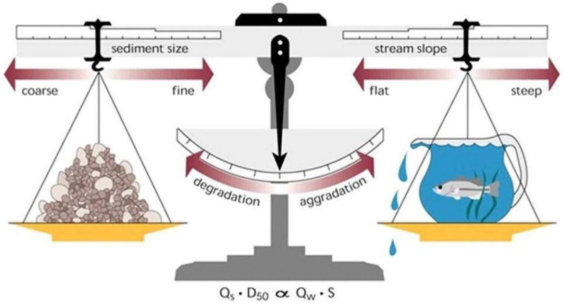
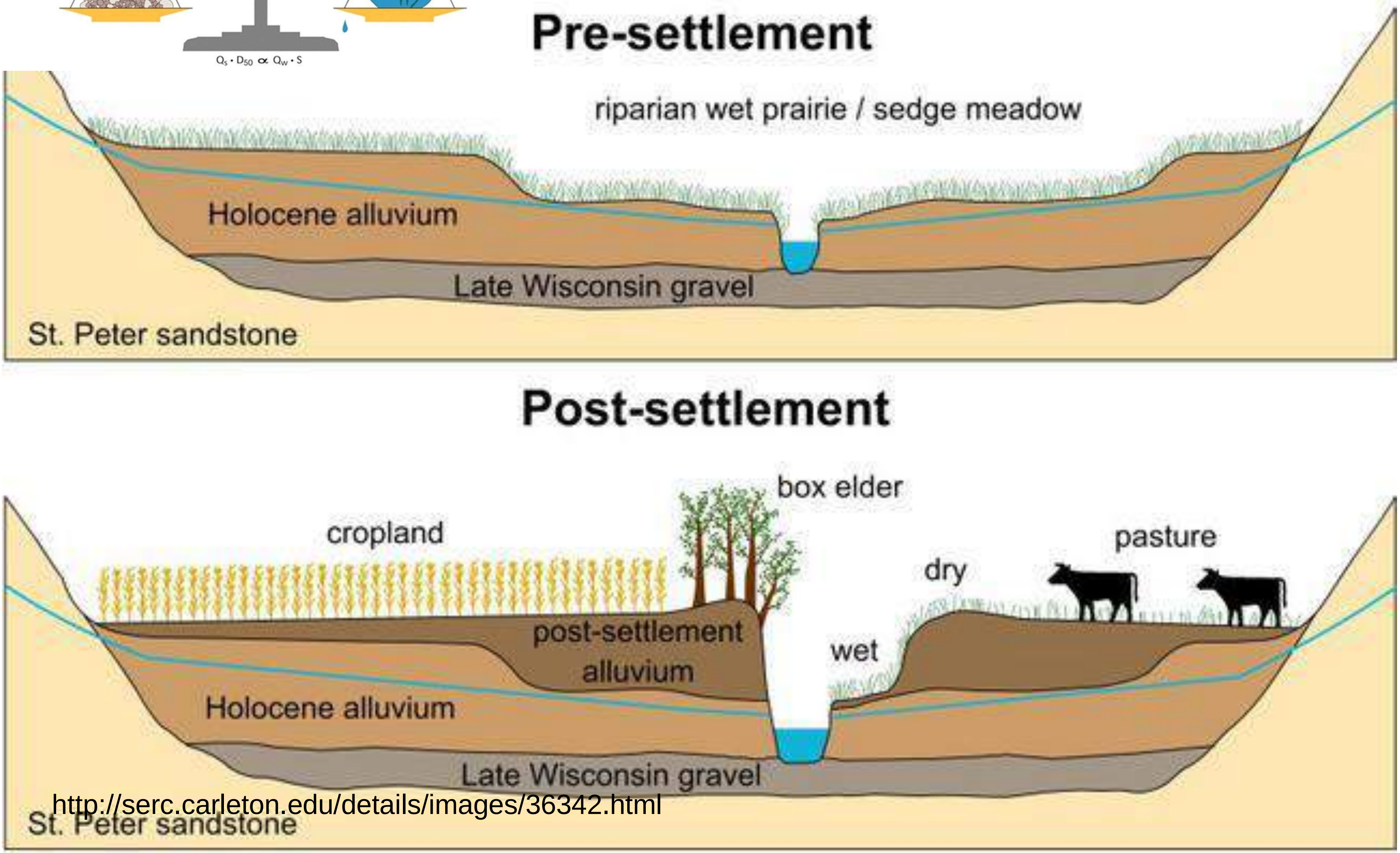
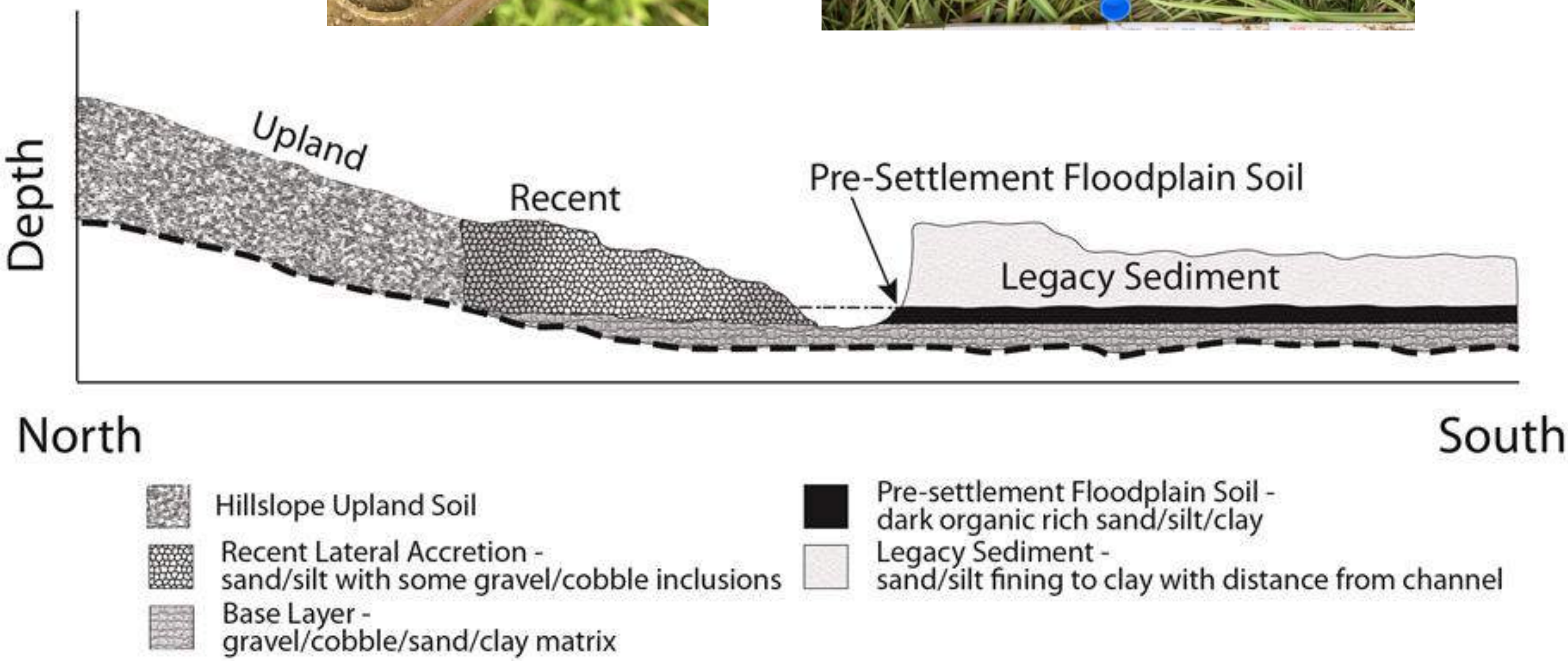


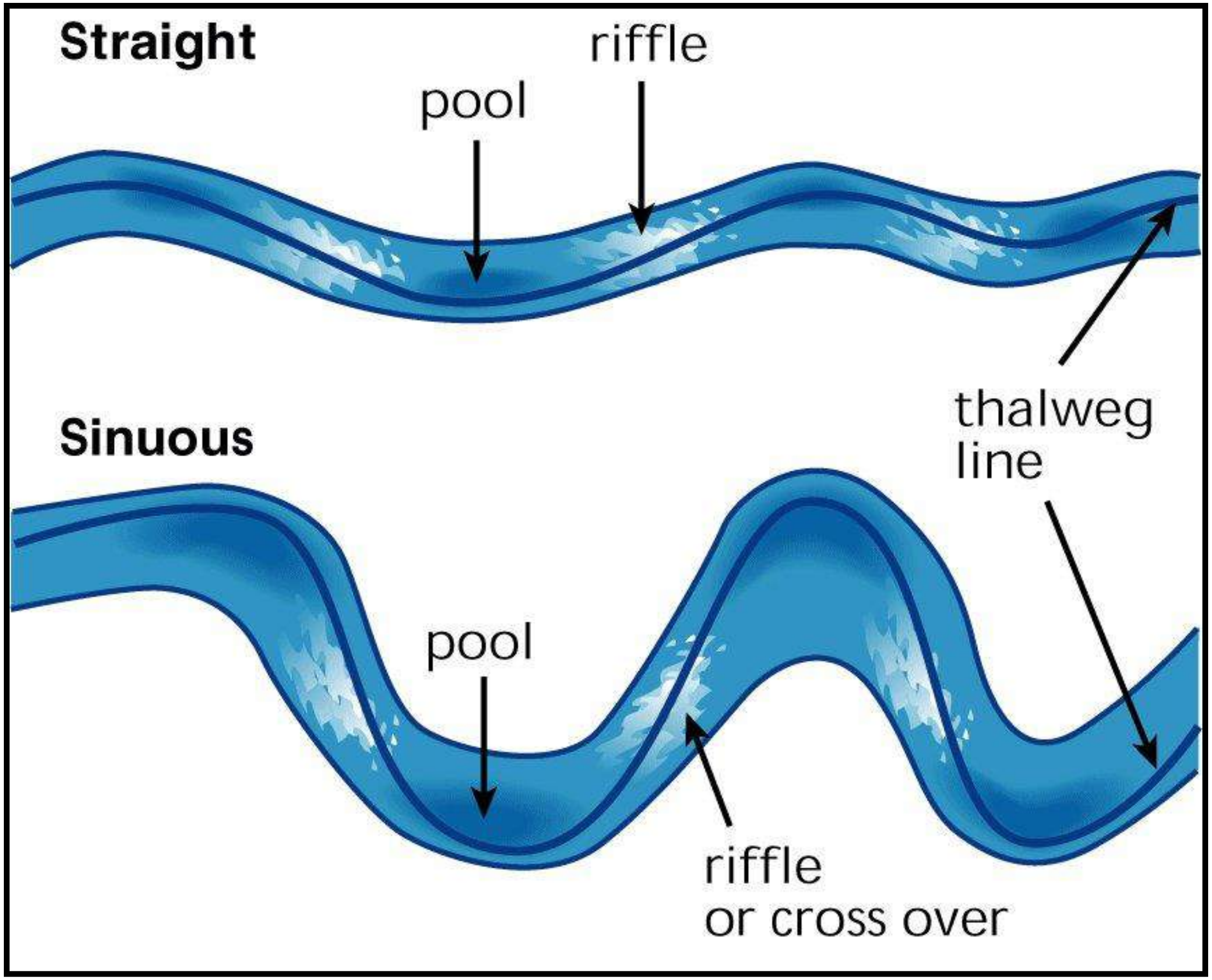


http://serc.carleton.edu/details/images/36342.html


Leg Sed 18
SITE 9
PCL 26-28"
Sample 3


Depth
Upland
Recent
Pre-Settlement Floodplain Soil
Legacy Sediment
North
South
Hillslope Upland Soil
Recent Lateral Accretion - sand/silt with some gravel/cobble inclusions
Base Layer - gravel/cobble/sand/clay matrix
Pre-settlement Floodplain Soil - dark organic rich sand/silt/clay
Legacy Sediment - sand/silt fining to clay with distance from channel

Habitat Units



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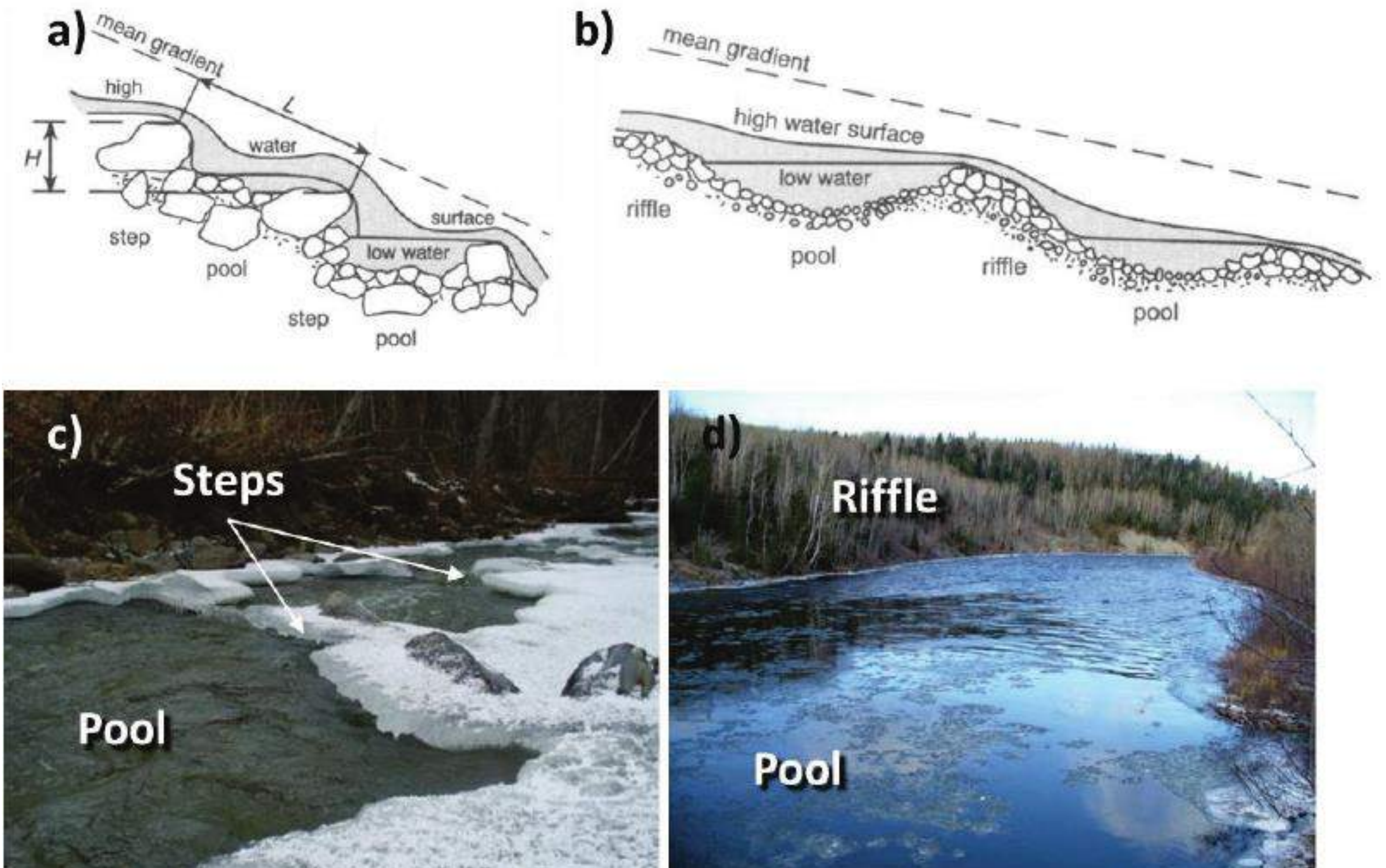
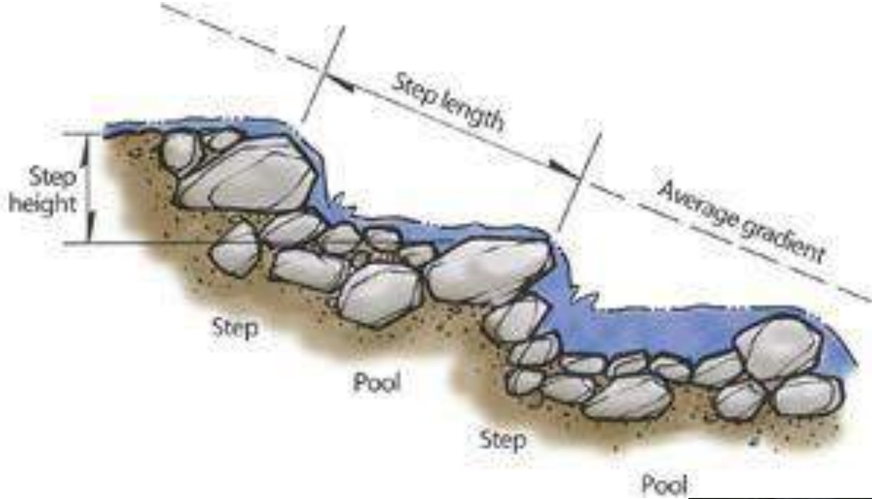
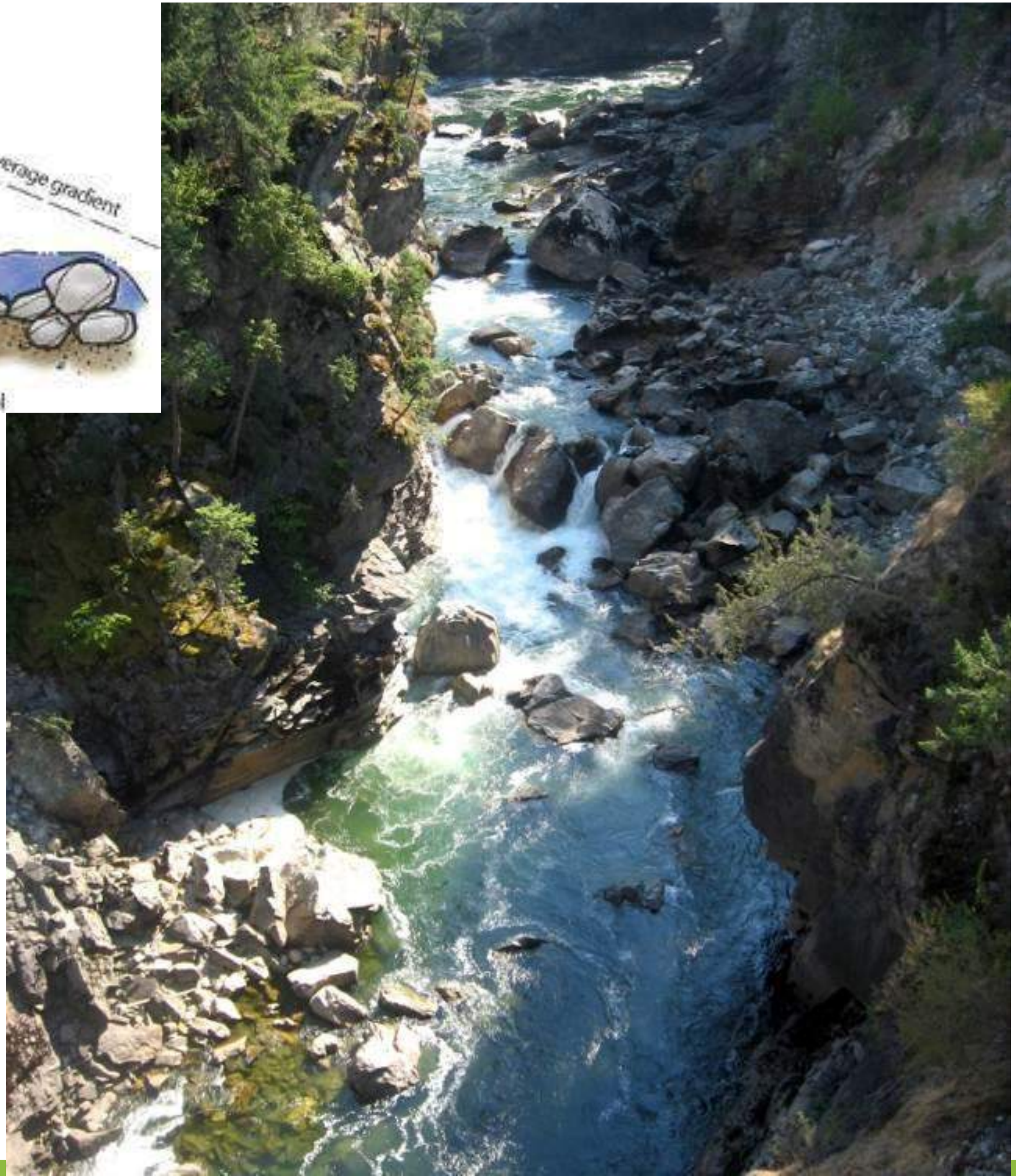

a)
mean gradient
high
L
H
water
surface
step
pool
low water
step
pool
b)
mean gradient
high water surface
low water
riffle
pool
riffle
pool
c)
Steps
Pool
d)
Riffle
Pool



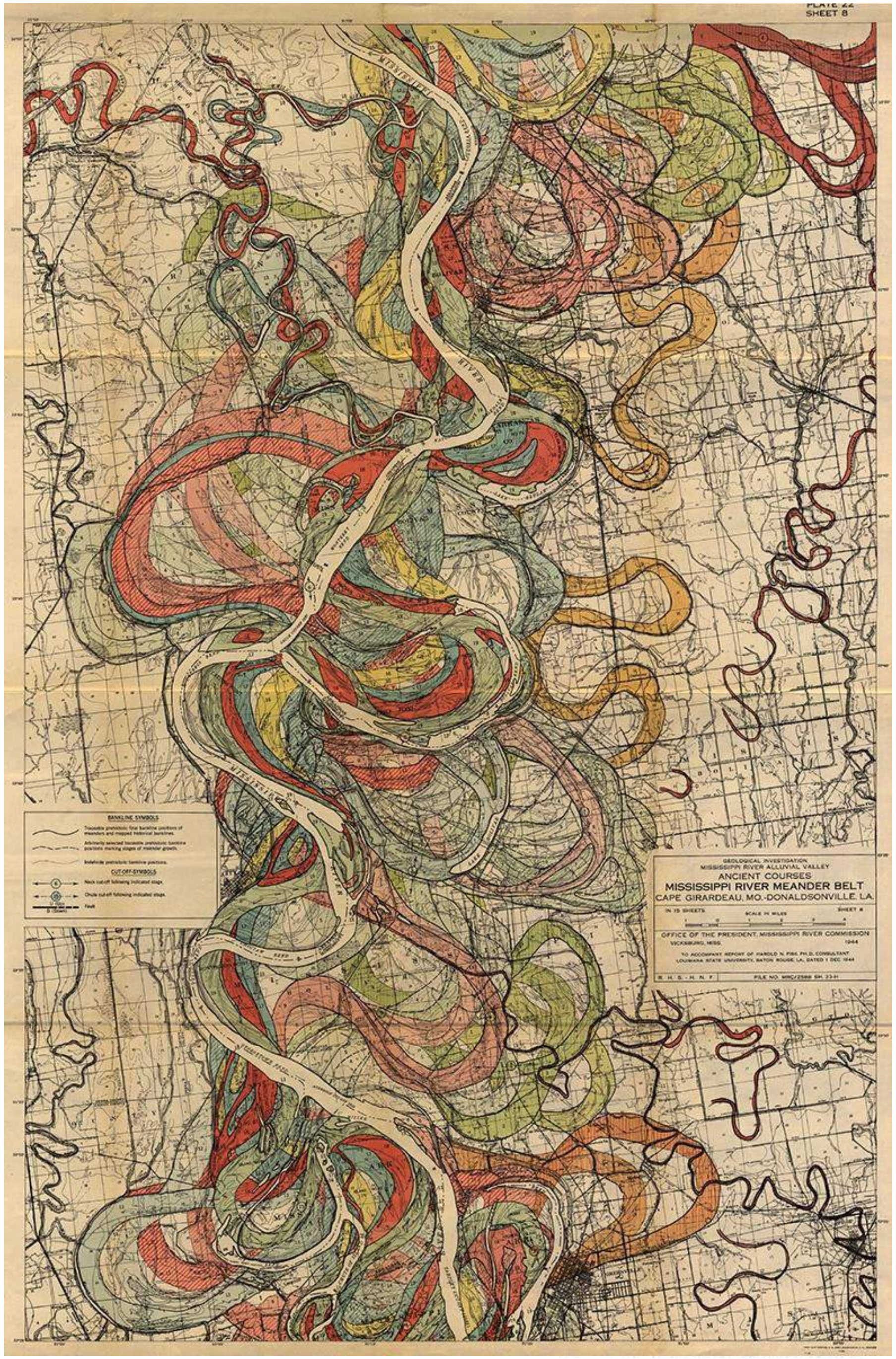
Step Pool Reach

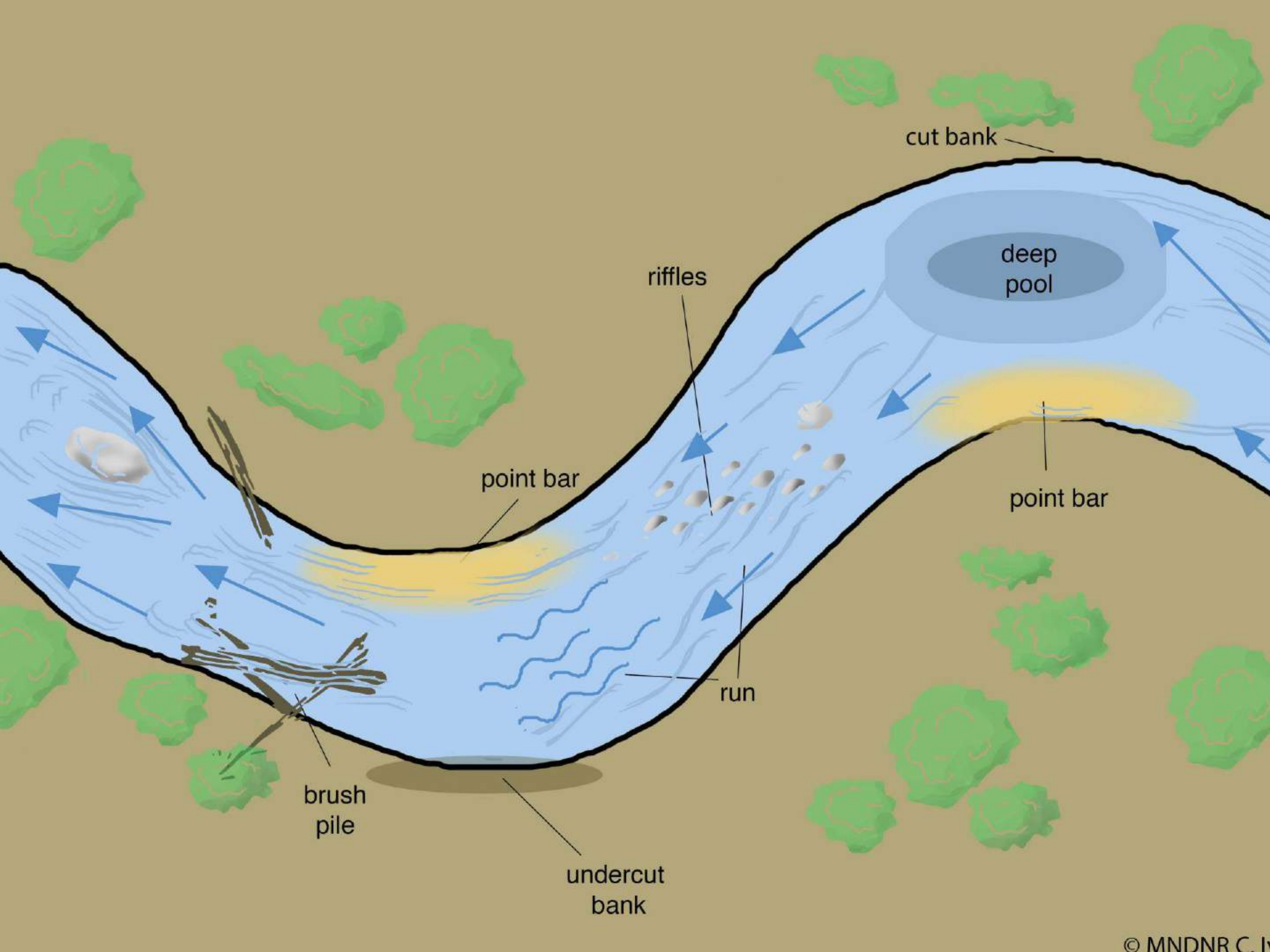


The time factor...

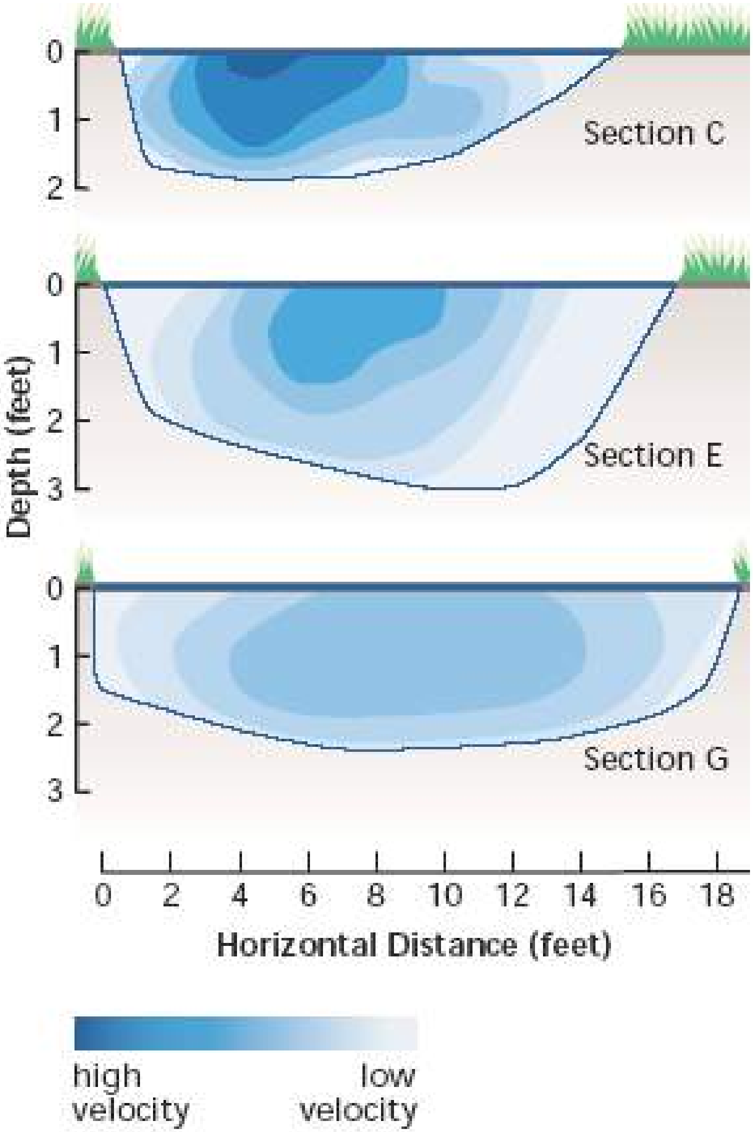
Bank Erosion

- Normal, natural, important and expected process!

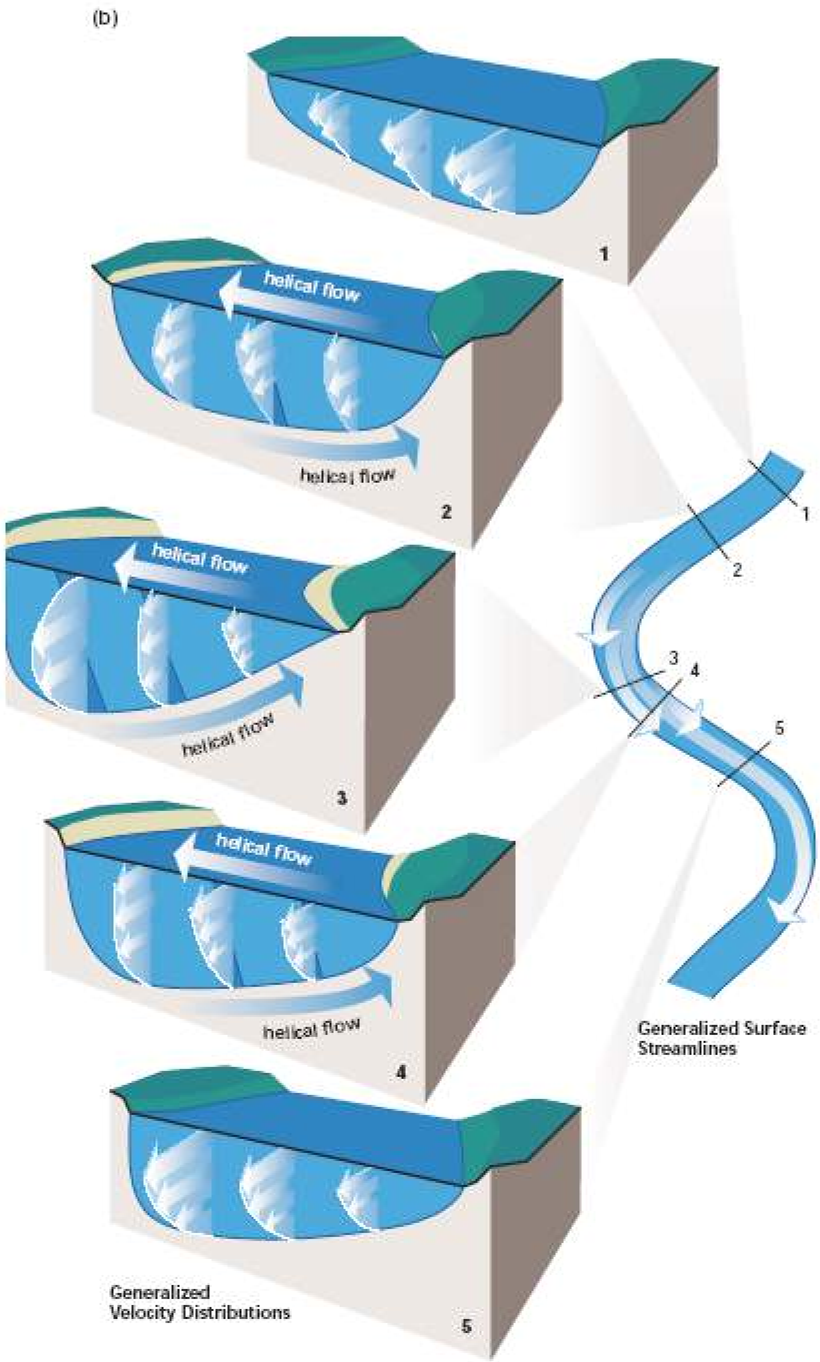



cut bank
deep
pool
riffles
point bar
point bar
run
brush
pile
undercut
bank

Channel V



0
1
2
Section C
0
1
2
3
Section E
0
1
2
3
Section G
Depth (feet)
0 2 4 6 8 10 12 14 16 18
Horizontal Distance (feet)
high velocity
low velocity



(b)
1
helical flow
helical flow
2
helical flow
helical flow
3
helical flow
helical flow
4
5
Generalized Velocity Distributions
Generalized Surface Streamlines
1
2
3
4
5

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Grass does little to protect banks – root depths too shallow

Vegetation bank stabilization

Restoration Should Focus On Process Instead Of Form

Why focus on process?

- Organisms are adapted to local/regional habitat conditions
- Habitats are by nature <u>dynamic in both space and time</u> and are controlled by physical stream processes

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River Ecosystem Engineers

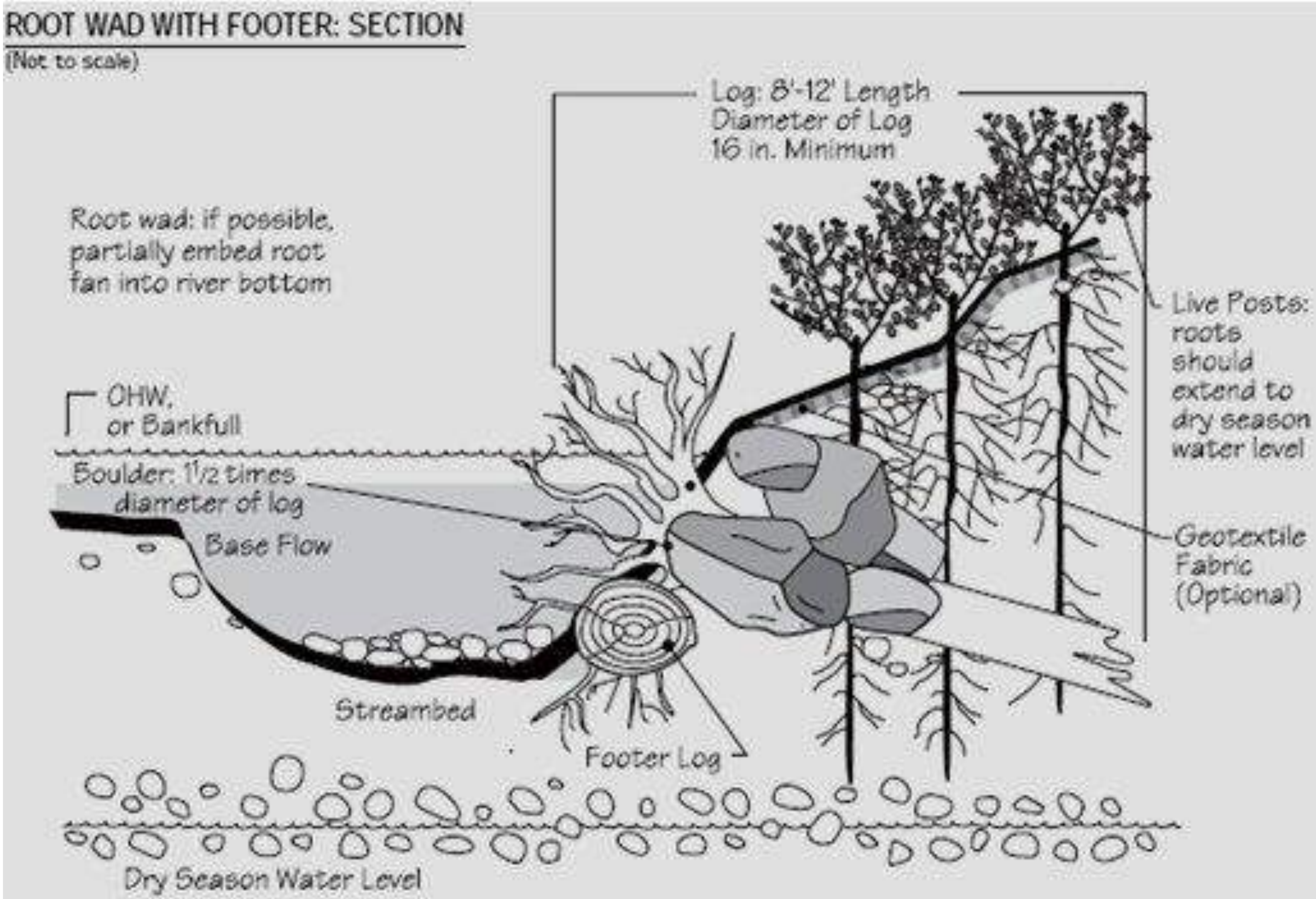

Gravel Bar
Deep
Pool


©mongabay.com


Restored River

Restored River

Deeper Pools
More Gravels
Increased Complexity, Shade and Cover
Cooler Water
Moderated Flow Regime
Re-Connected Habitats


ROOT WAD WITH FOOTER: SECTION
(Not to scale)
Log: 8'-12' Length
Diameter of Log
16 in. Minimum
Root wad: if possible, partially embed root fan into river bottom
OHW, or Bankfull
Boulder: 1½ times diameter of log
Base Flow
Live Posts: roots should extend to dry season water level
Geotextile Fabric (Optional)
Streambed
Footer Log
Dry Season Water Level

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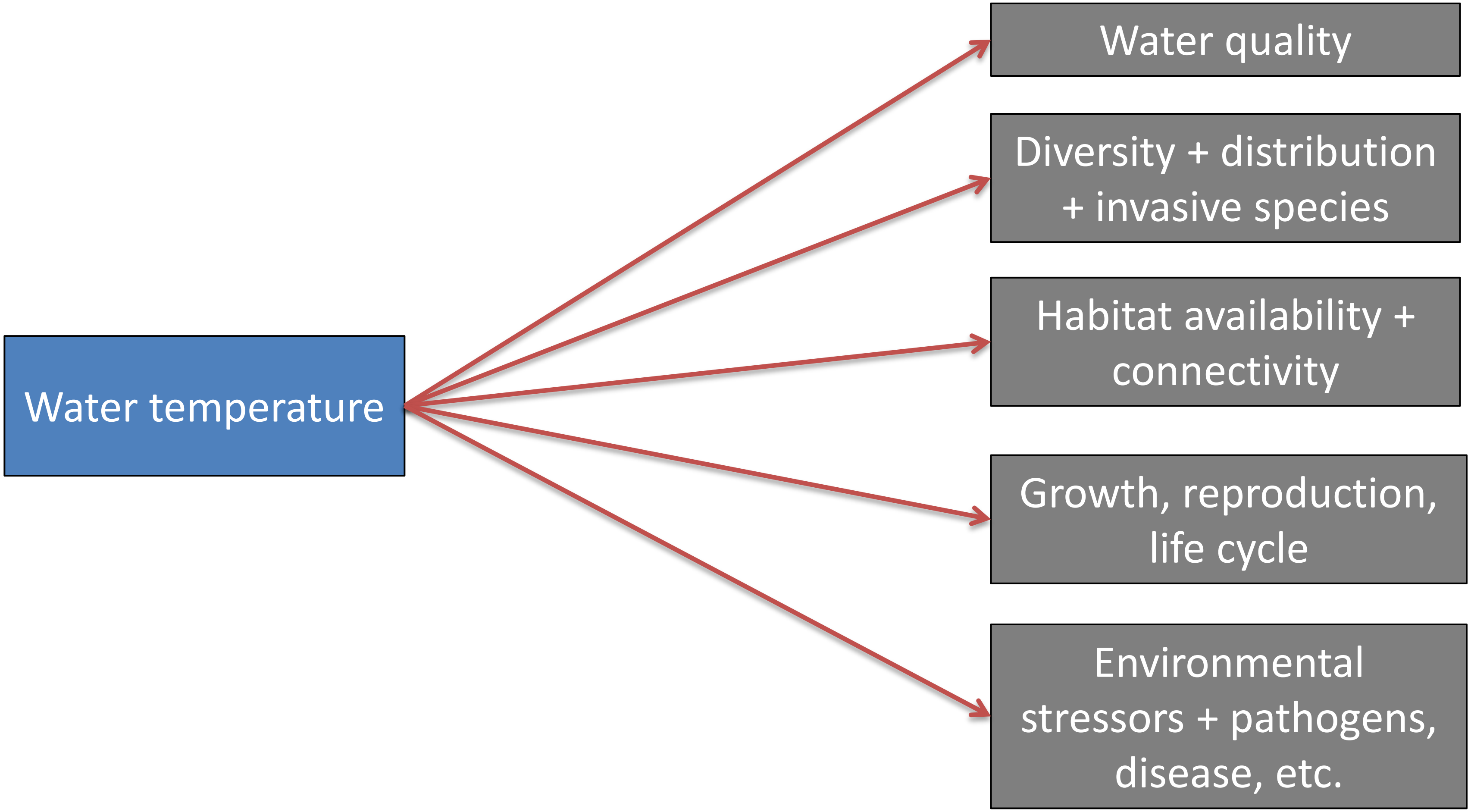
www.ifwf.org

Water Temperature

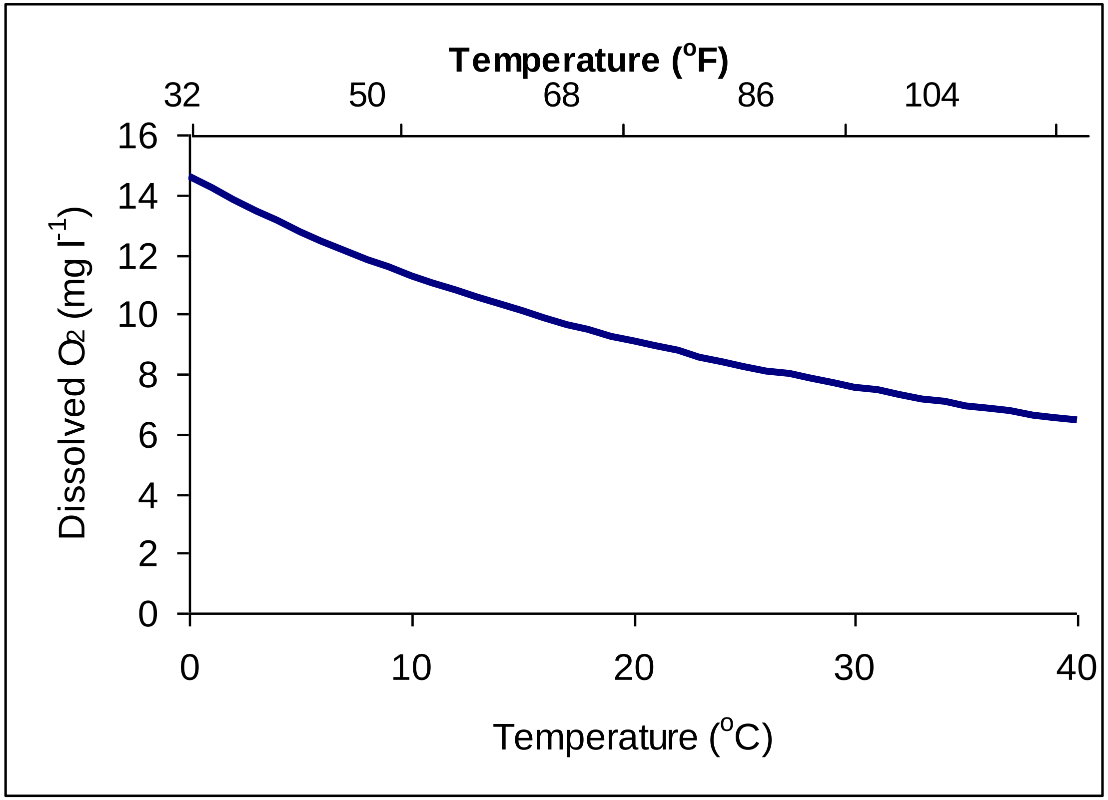


And more…

Water temperature

Water temperature → Water quality

Influence on O_2 Concentration



O_2 concentration influences:

- chemical reactions, phosphate release

Drivers of the temperature regime:

- Exposure
  - Lack of riparian shading
- Turbidity
  - Suspended solids which absorb and scatter light
- Reach volume to surface area
  - Shallow water is usually more dynamic and exposed to air temps
- Groundwater inputs
  - Cooler in summer, warmer in winter
  - Can acts as a thermal refuge
- Water depth

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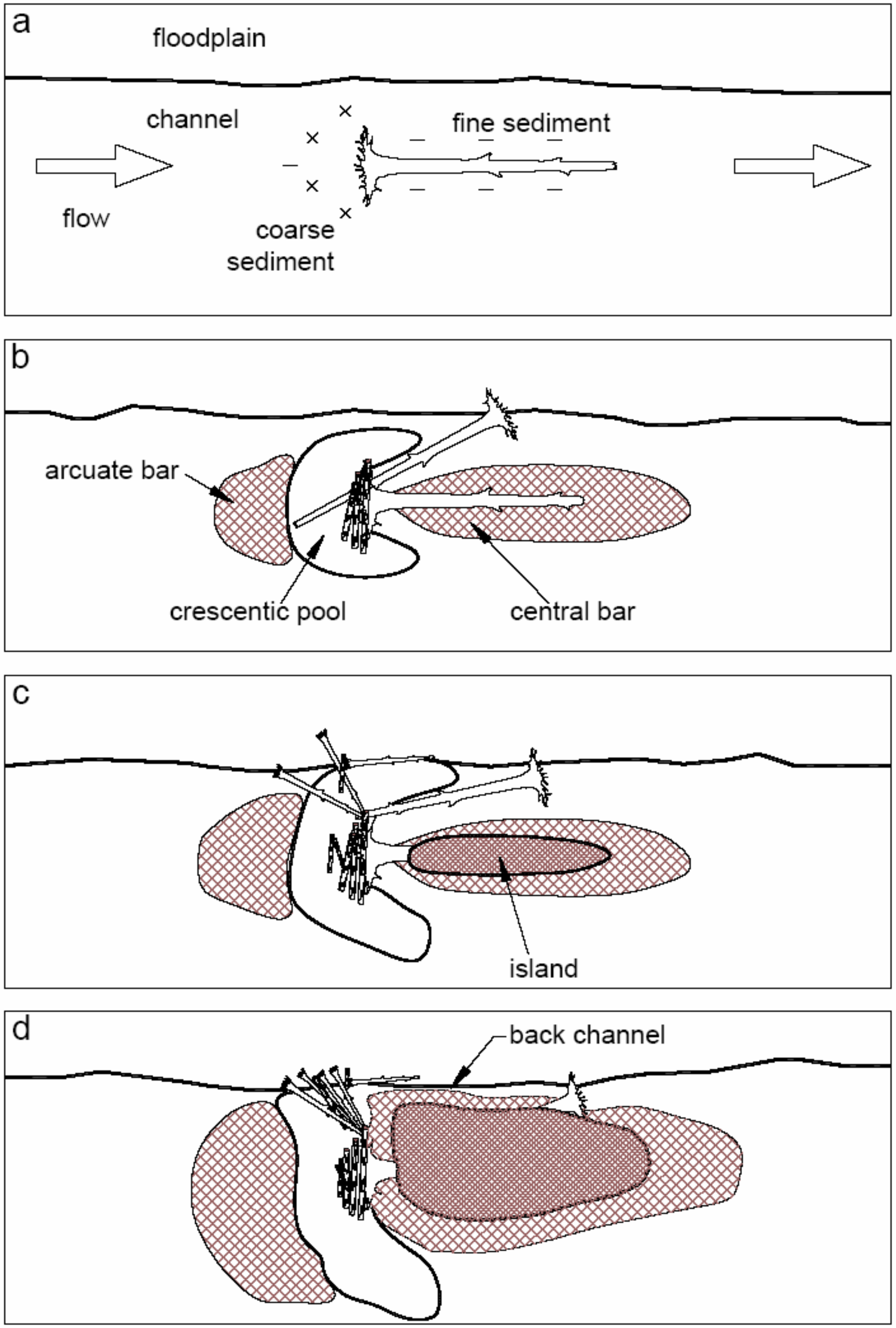
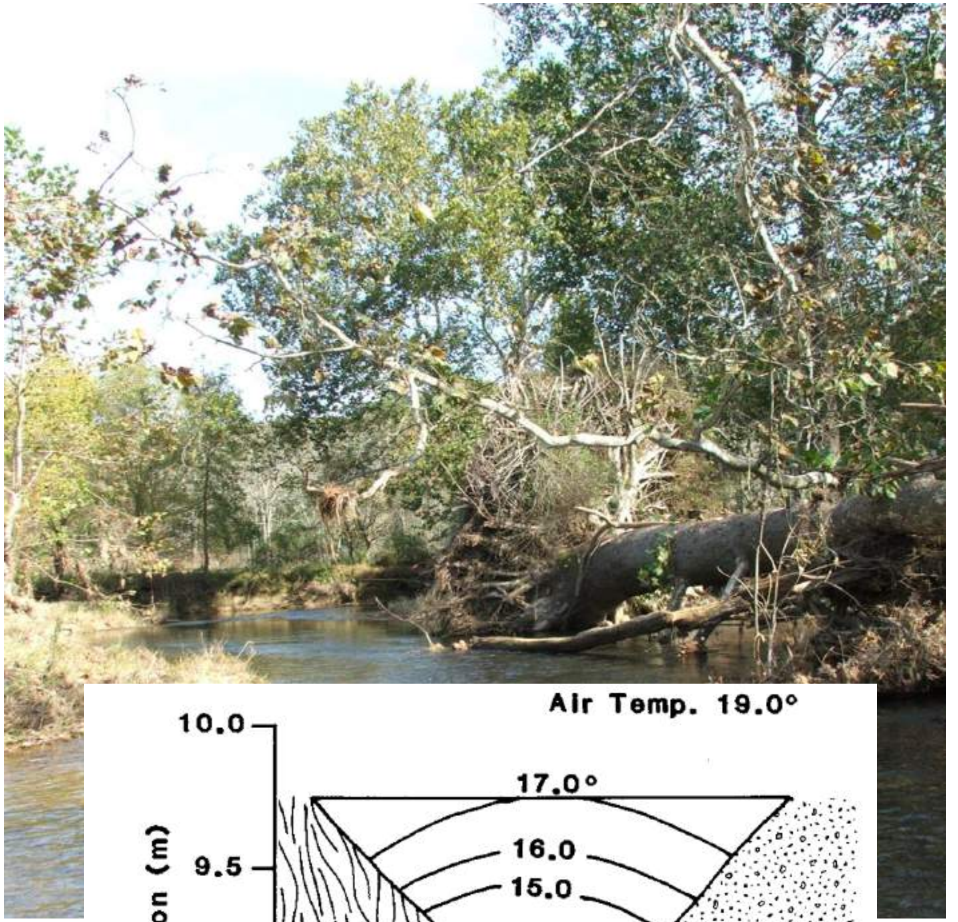
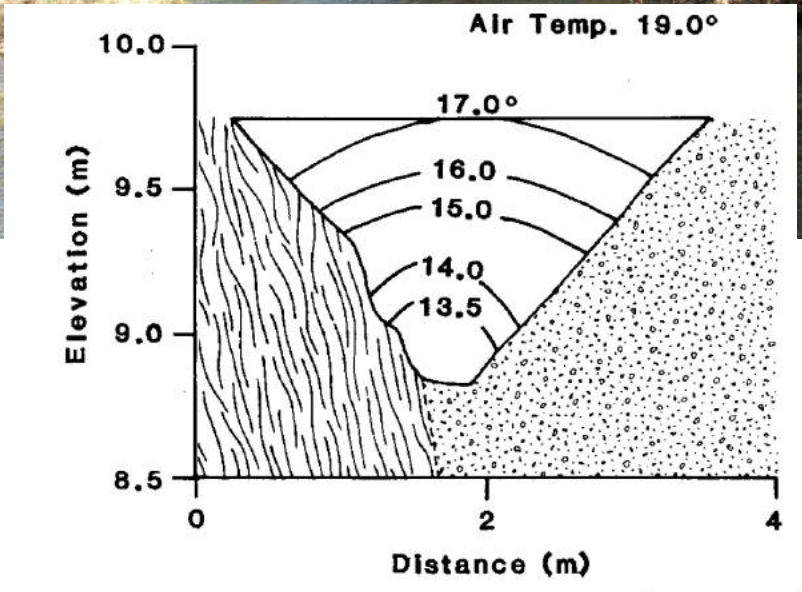
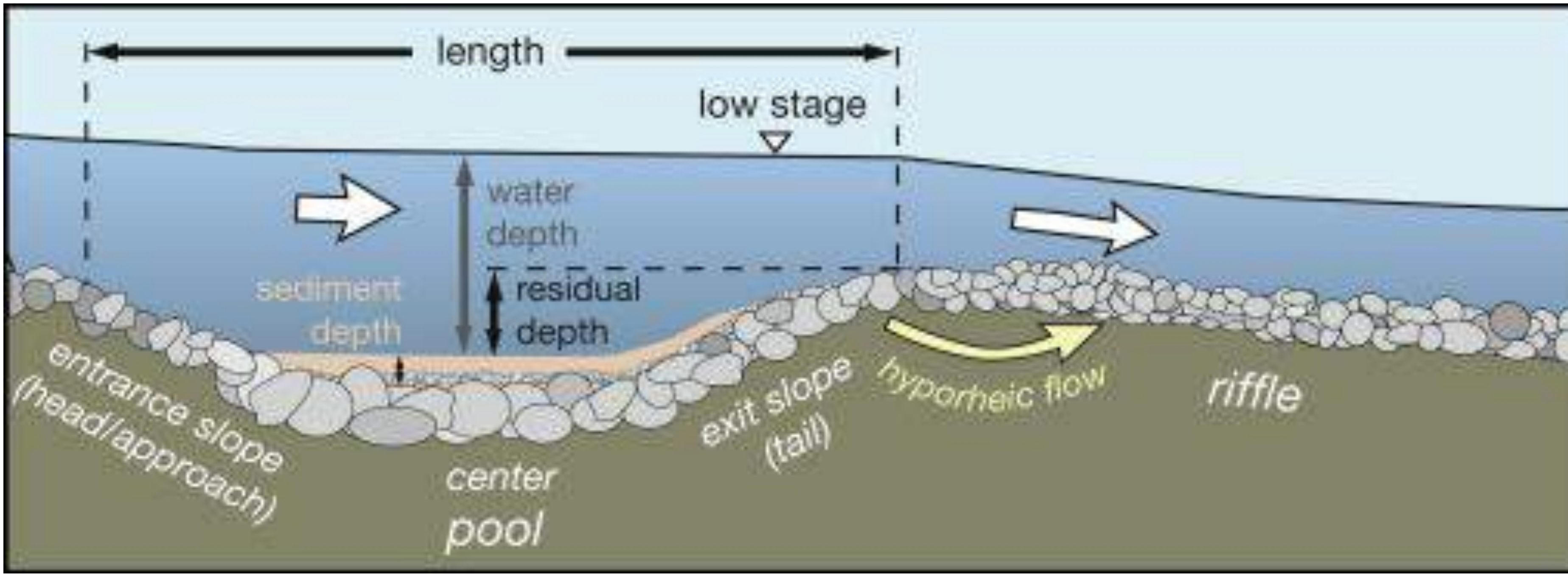


Saldi-Caromile et al., 2004



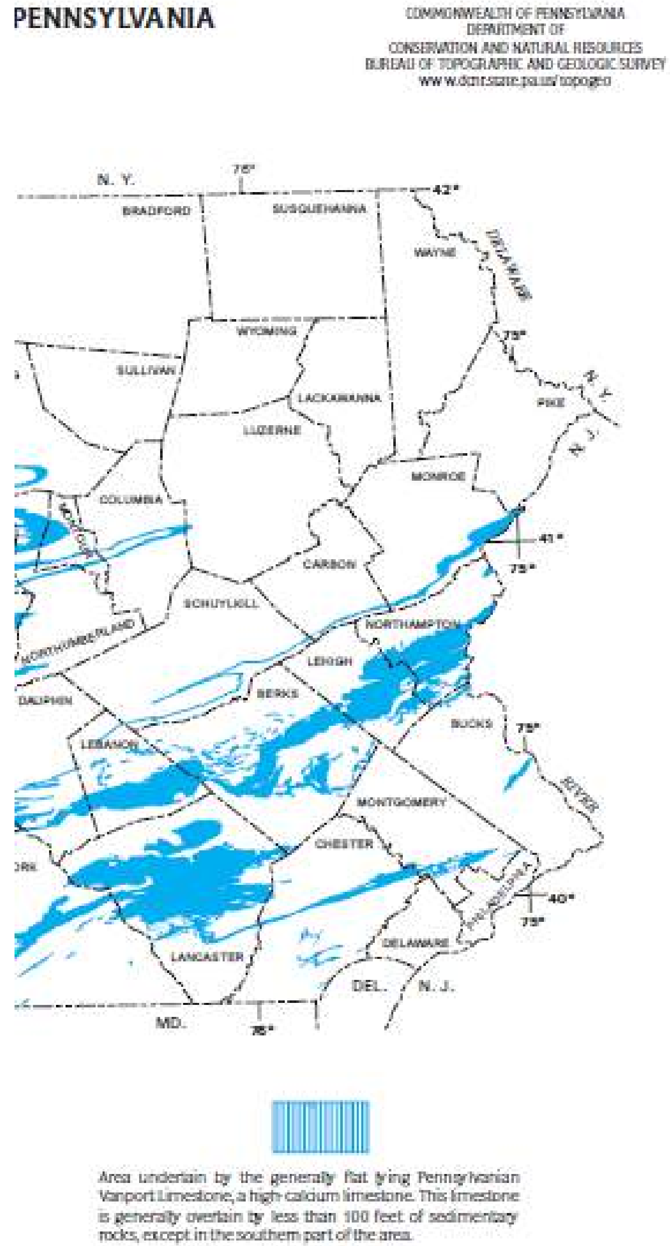


Nielson et al., 1994


length
low stage
water
depth
sediment
depth
residual
depth
entrance slope
(head/approach)
center
pool
exit slope
(tail)
hyporheic flow
riffle

Alkalinity

- capacity of water to resist changes in pH
- important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater
- derived from watershed geology and land use



Case Study: How Riparian Forest Restoration Transforms a Stream

Long-Term Research in Environmental Biology (LTREB): Trajectory for the Recovery of Stream Ecosystem Structure and Function during Reforestation

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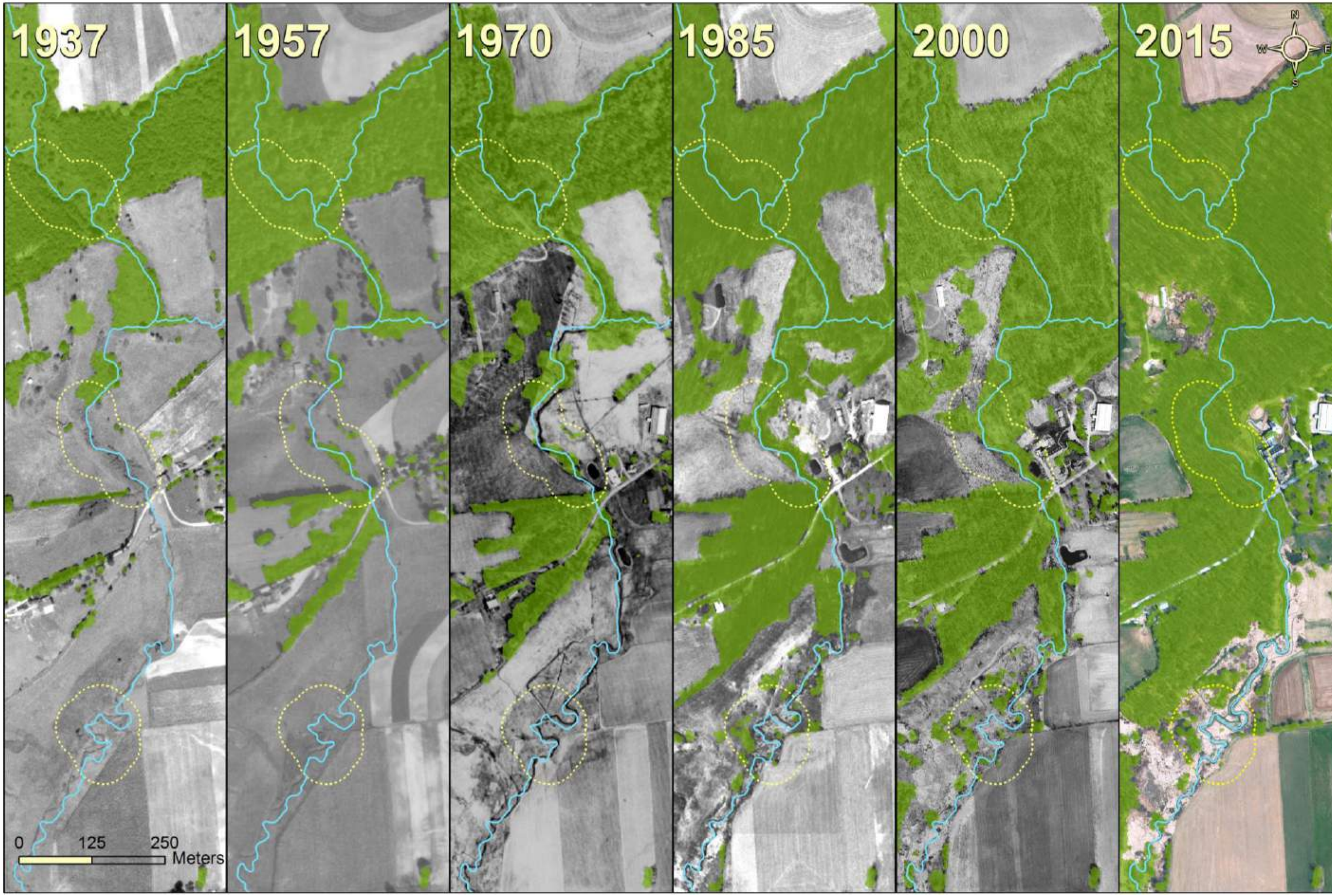
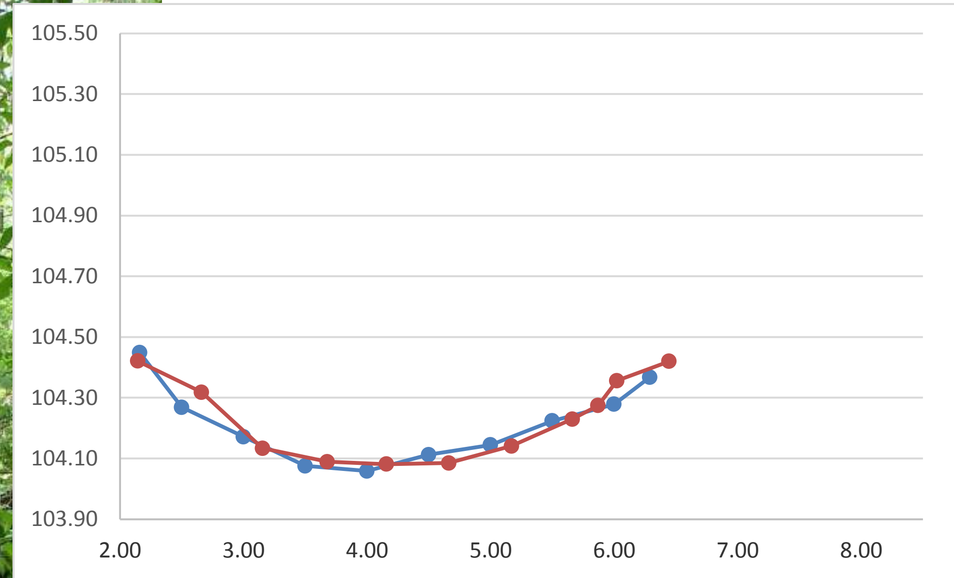
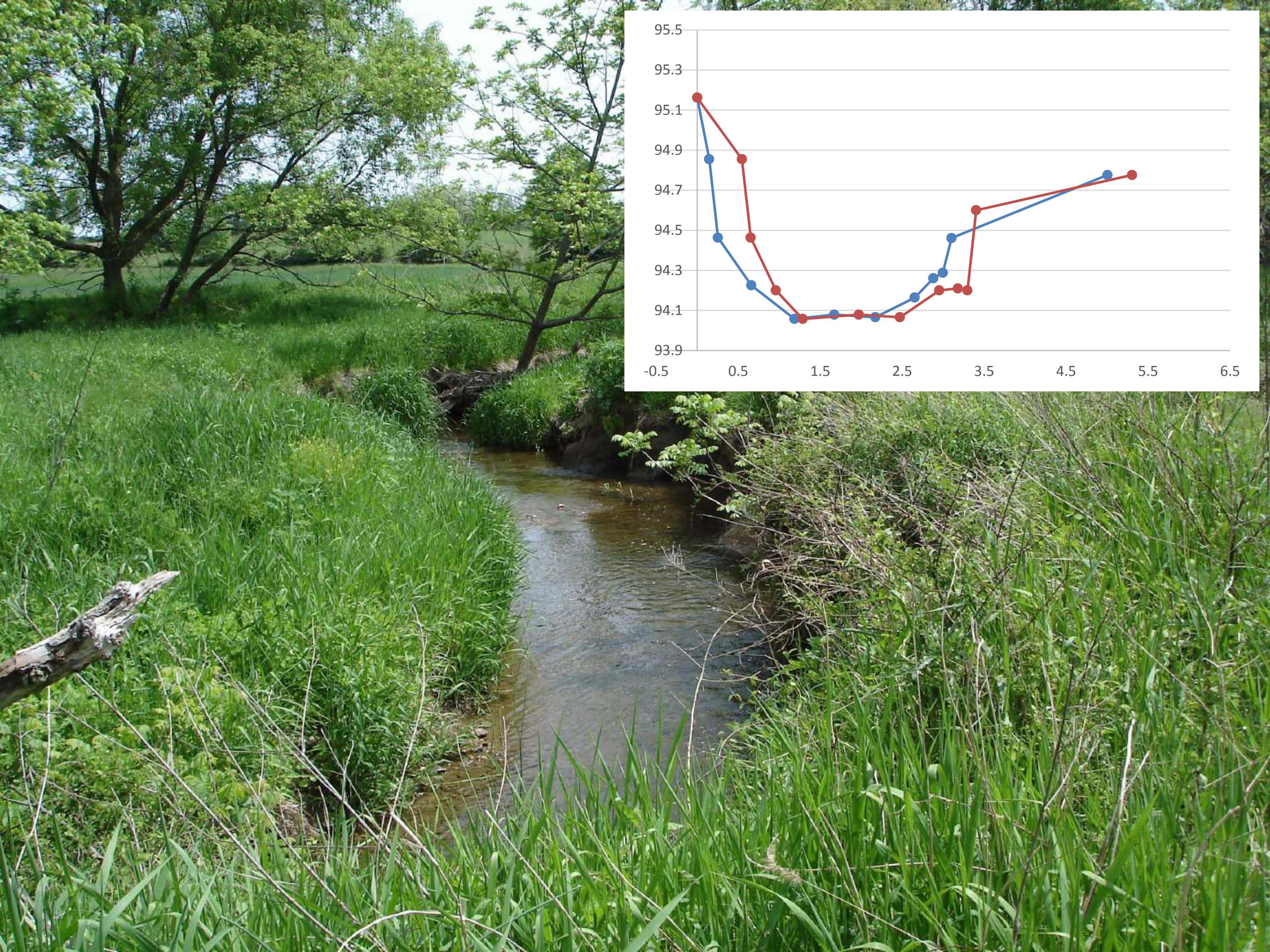

1937
1957
1970
1985
2000
2015
N
W
E
S
0
125
250
Meters

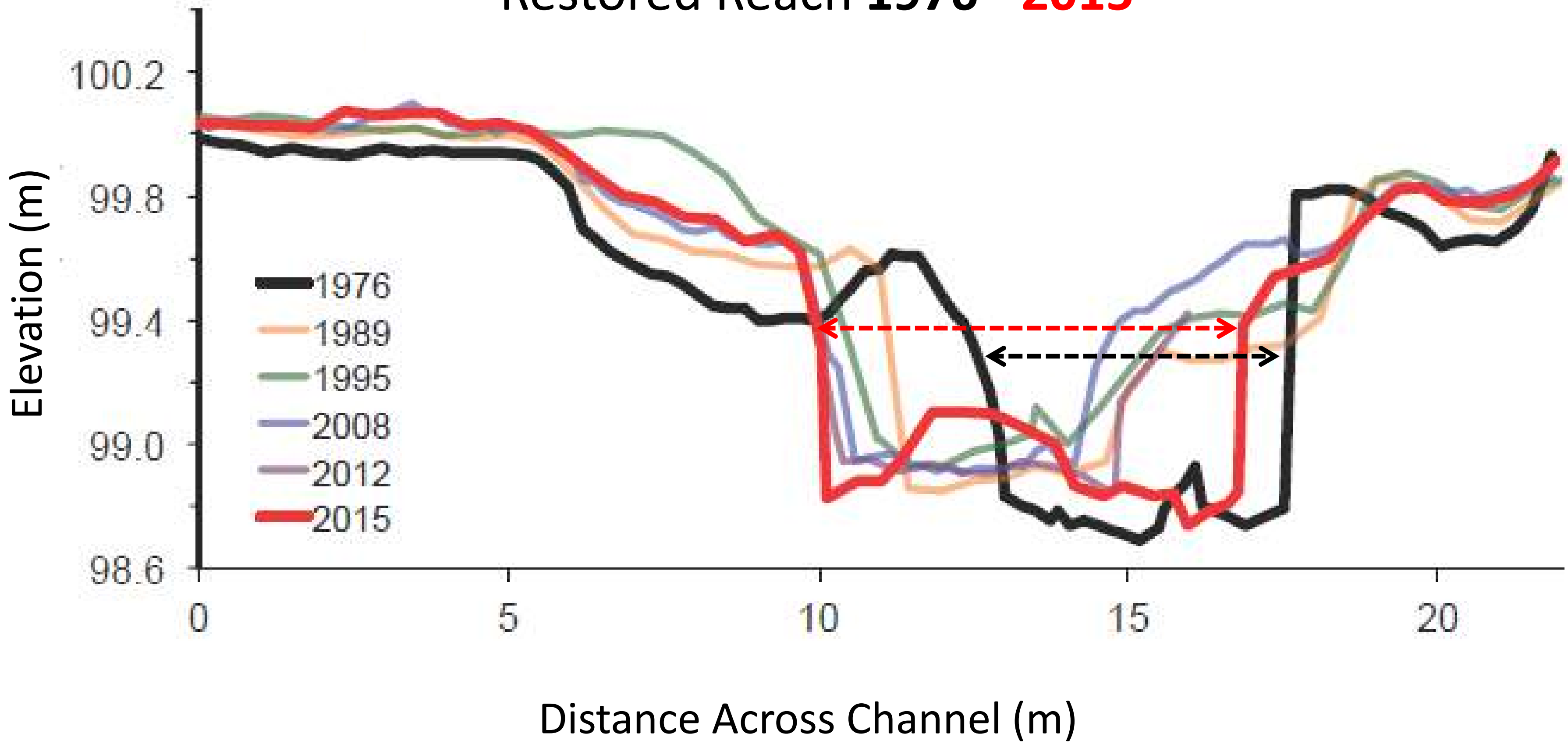

105.50
105.30
105.10
104.90
104.70
104.50
104.30
104.10
103.90
2.00
3.00
4.00
5.00
6.00
7.00
8.00


95.5
95.3
95.1
94.9
94.7
94.5
94.3
94.1
93.9
-0.5
0.5
1.5
2.5
3.5
4.5
5.5
6.5

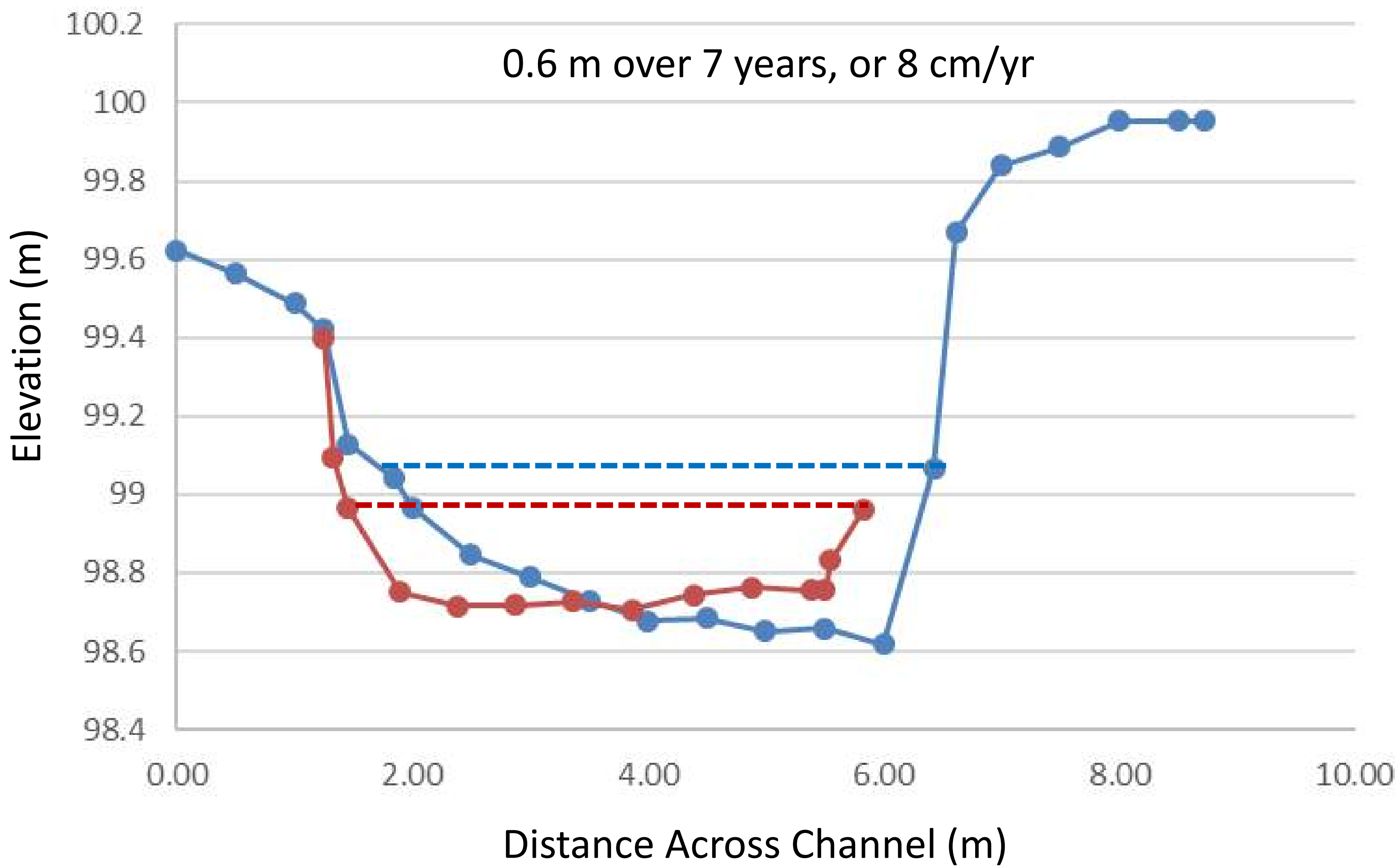

2003

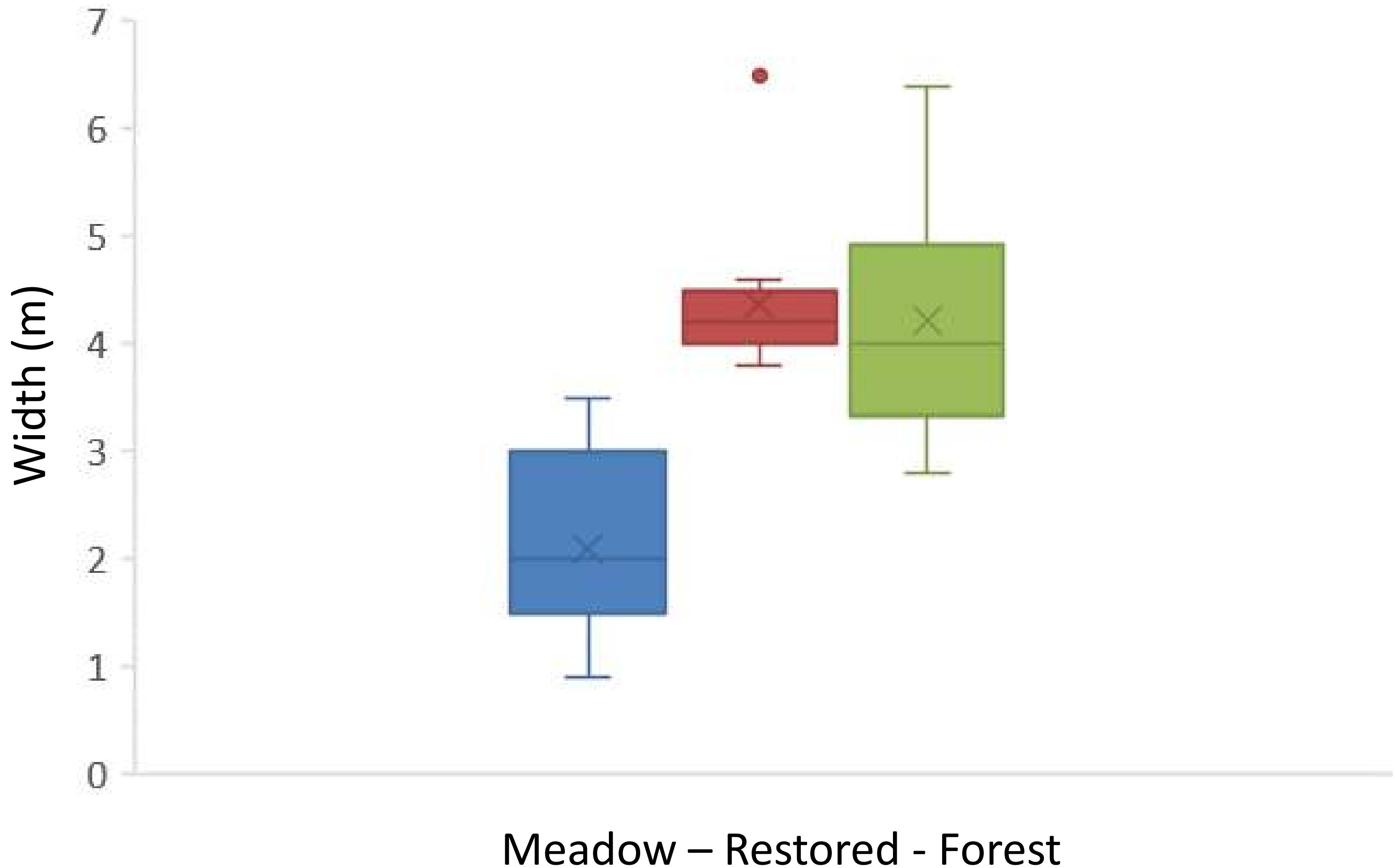
3m over 39 years, or 8cm/yr

Restored Reach **1976 - 2015**

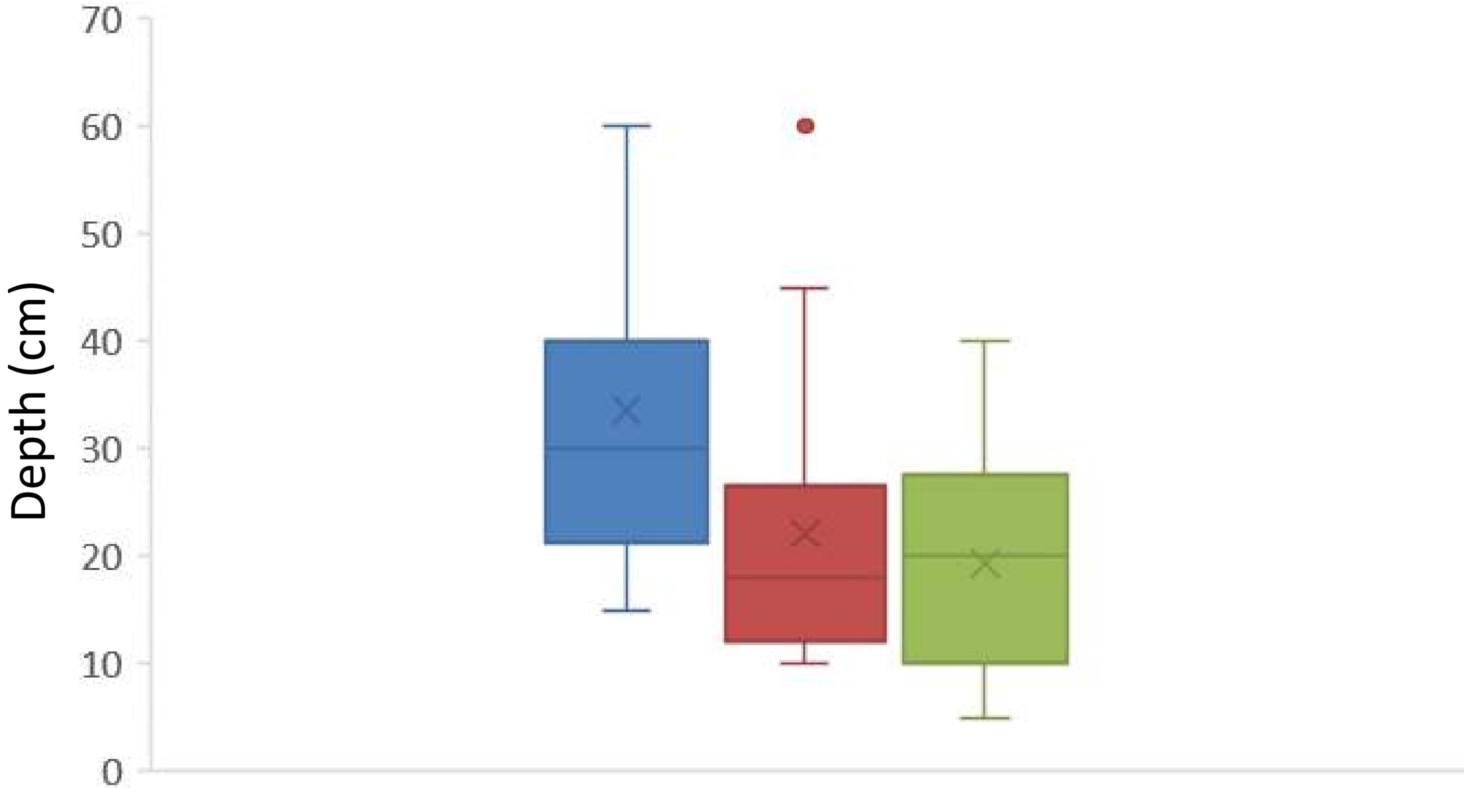


Restored Reach 2012 - 2019

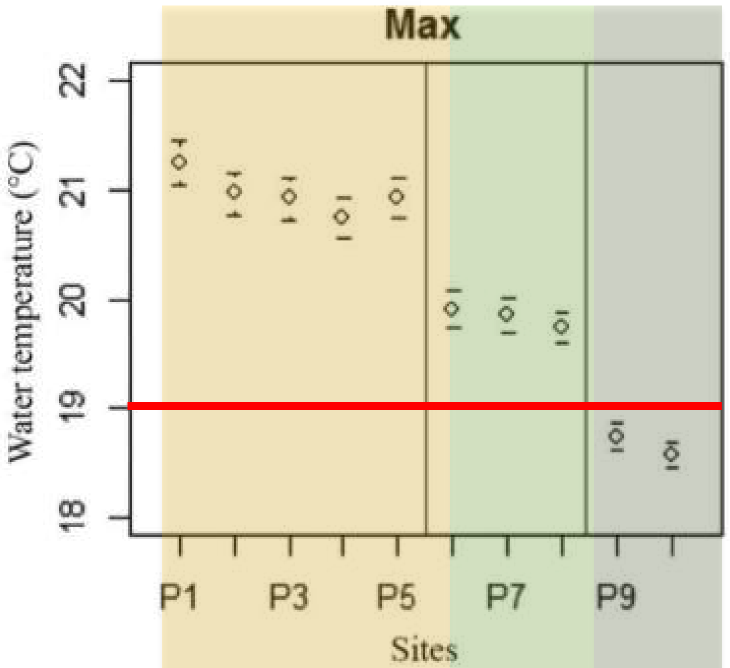


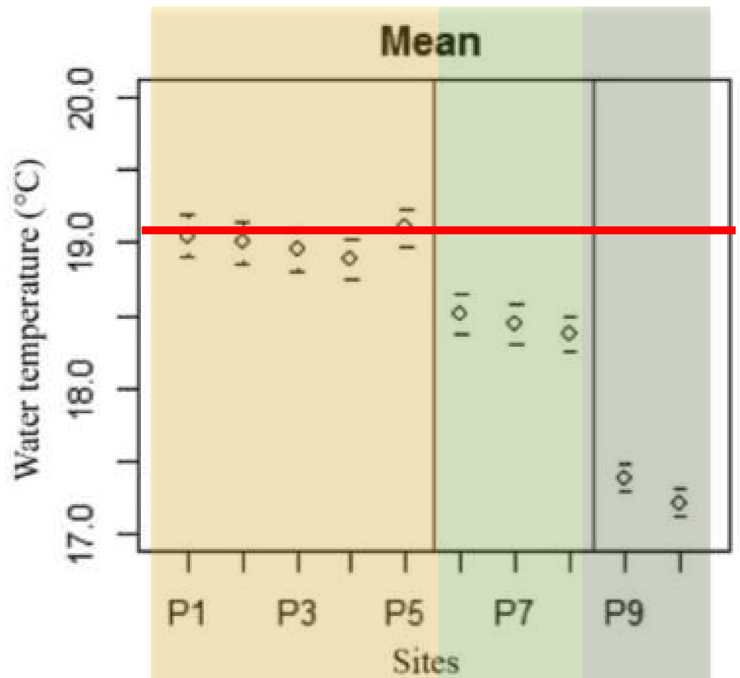


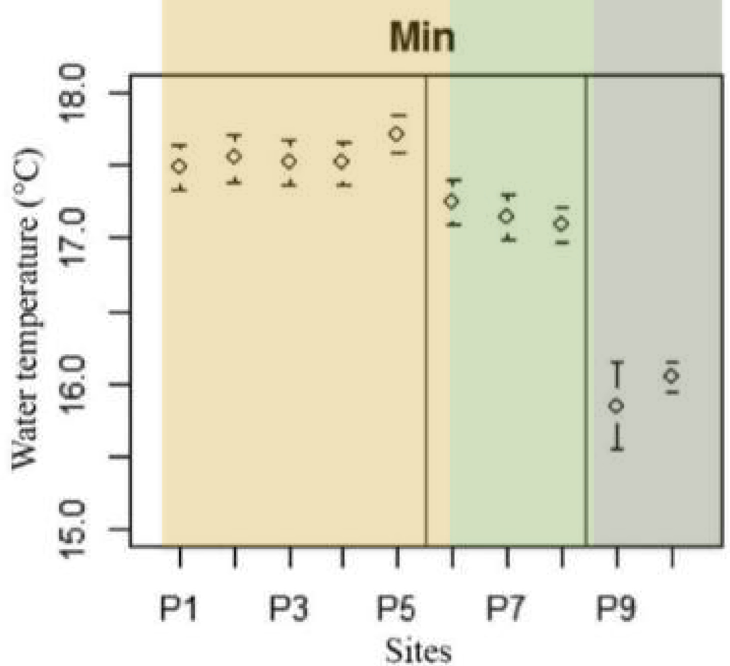
Width (m)
0
1
2
3
4
5
6
7
Meadow – Restored - Forest

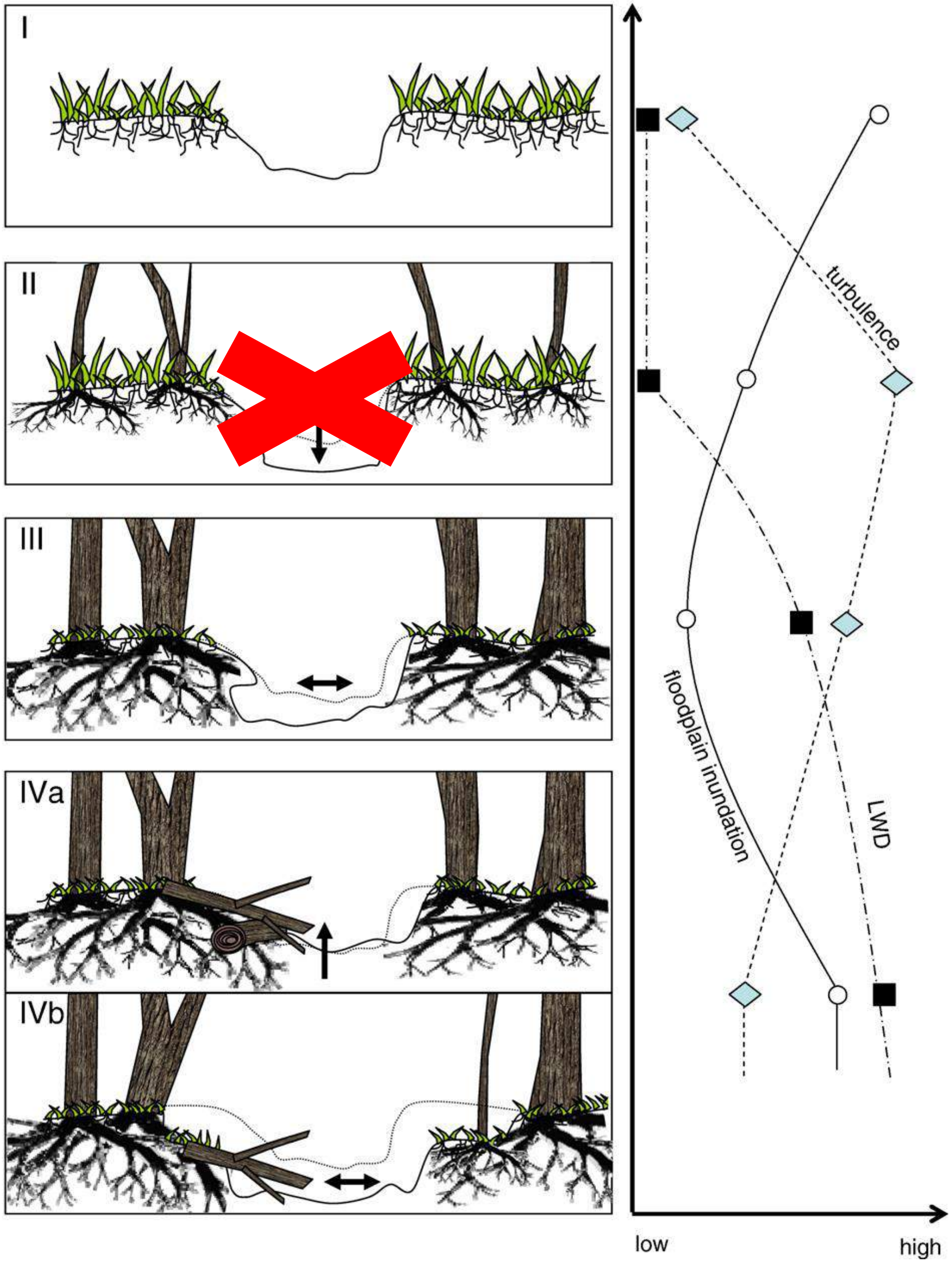


Meadow – Restored - Forest


Max
Water temperature (°C)
18
19
20
21
22
P1
P3
P5
P7
P9
Sites


Mean
Water temperature (°C)
17.0
18.0
19.0
20.0
P1
P3
P5
P7
P9
Sites


Min
Water temperature (°C)
15.0
16.0
17.0
18.0
P1
P3
P5
P7
P9
Sites



Shading

Inc on

Widening

Infilling/Aggradation

QUESTIONS