The Importance of Boundary Conditions in Channel Stability and Ecology (why vegetation matters)

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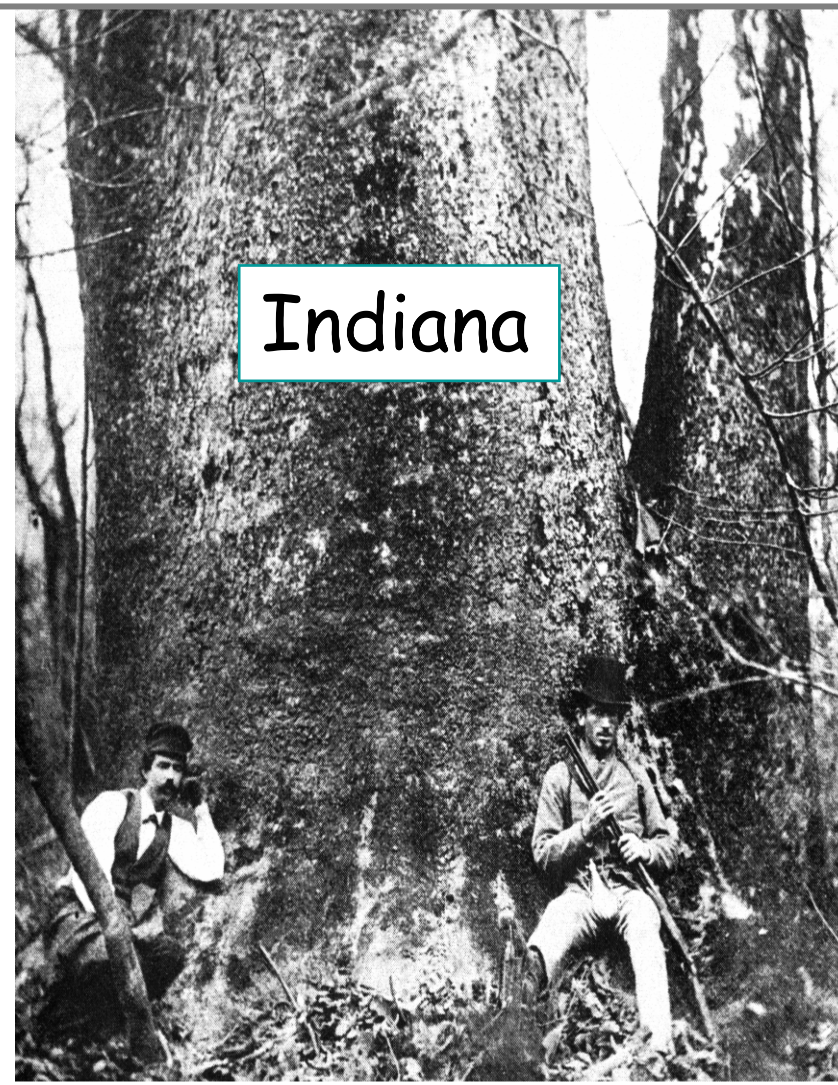
Trees have been around for about 350 million years during which time they have had a significant impact on landscape evolution and sedimentary geology.

Historic changes have occurred in forest distribution but in the characteristics of individual trees.

Humans have reduced forest cover from about 35% to about 12%. Similar to the exploitation of other biologic resources (e.g., fisheries), many forests are characterized by younger, smaller trees.

Most Current riparian forests bear little if any resemblance to their historic conditions:

Can you identify the trees below and where they were found?



Riviere des Moustiques Mapou Tree, Haiti

States of Local Streams

Root cohesion and roughness in Manoa Stream

Manoa Stream, O’ahu 5-19-08

Loss of vegetation and sediment input, right bank of Manoa Stream

Manoa Stream, O’ahu 5-19-08

Waimalu Stream, O’ahu 5-19-08

Waimalu Stream, O’ahu 5-19-08

Waimalu Stream, O’ahu 5-19-08

Halawa Stream, O’ahu 5-19-08

Some basic fluid mechanics

Velocity and Roughness

$\tau_b = ku^2$	*Chezy (1769) assumption - bed shear stress proportional to the square of velocity (k is a proportionality constant)*
$u^2 = \rho g/k\ (RS)$	*substitute for* τ_b *and* R
$C = (\rho g/k)^{0.5}$	*Chezy Friction Coefficient*
$u = C(RS)^{0.5}$	*Chezy Equation*
$C = R^{1/6}/n$	*empirical relation (Manning 1889)*
$u = k_1 R^{2/3}\ S^{1/2}/n$	*Manning's Equation*

Manning's ***n*** reflects the net effects of all variables contributing to flow resistance.

Shear Stress Partitioning

The force available to transport sediment is that component not dissipated by roughness.

τ_g *grain roughness*

τ_f *bedform roughness*

$\tau_{s(i)}$ *other sources (wood, bends, constriction, vegetation, etc.)*

$$\boldsymbol{\tau' = \tau_b - (\tau_g + \tau_f + \tau_{s(1)} + \tau_{s(2)} + \ldots)}$$

where τ' is the force available to do work (sediment transport, bank erosion, etc.). Losses can be up to **<u>90%</u>** in rough channels.

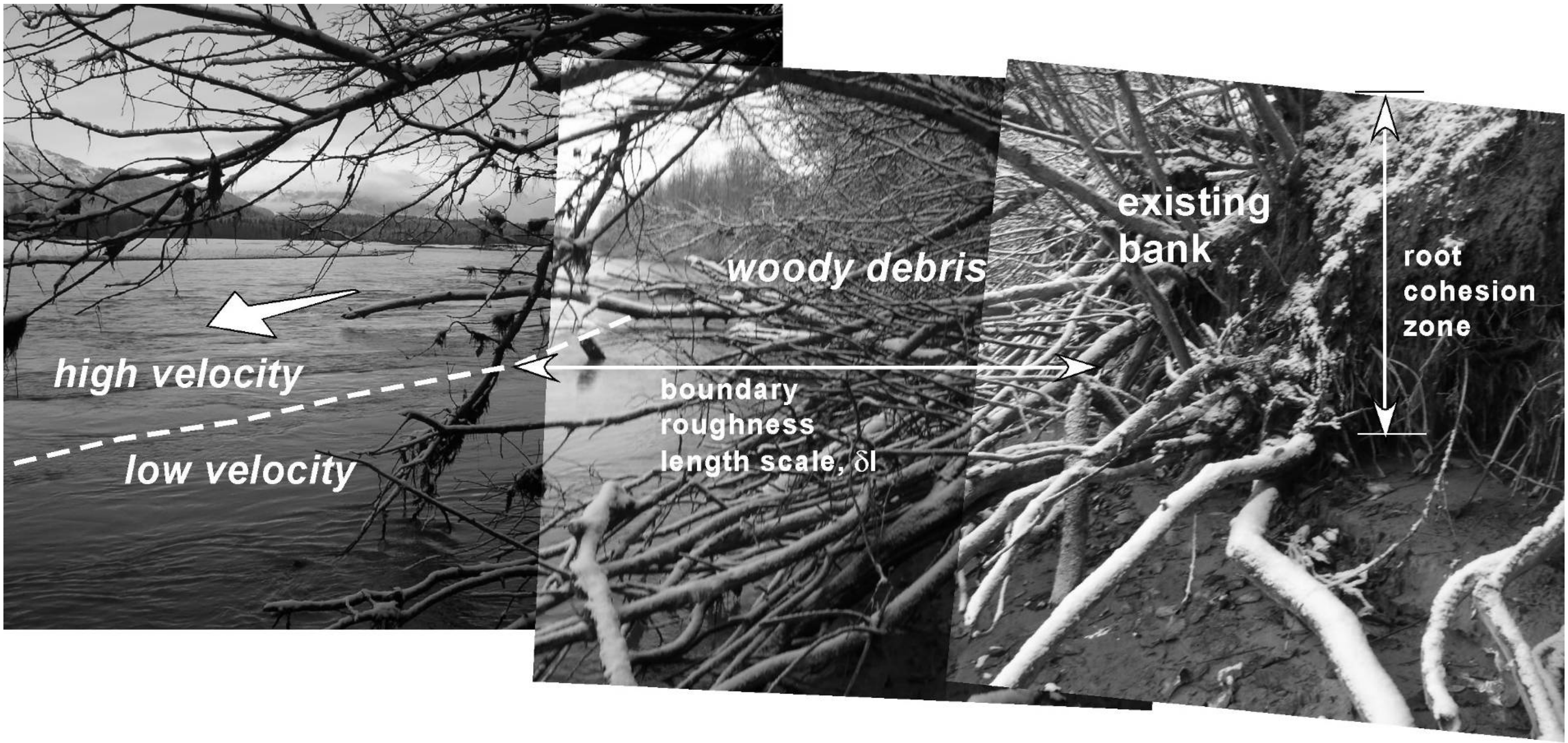
LWD covering less than 2% of the streambed can provide 50% of the total roughness or flow resistance. This results in a finer streambed substrate.

Buffington and Montgomery 1999, WRR 36, 3507-3521
Manga and Kirchner, 2000, WRR 36, 2373-2379.

Rough shoreline:

High velocity flowline is offset by boundary roughness provided by woody vegetation, reducing shear stress along the channel shoreline.

Natural Bank Roughening



Chilkat River, Klukwan, Alaska

Root Cohesion

Trees:
-add cohesion to bank materials
-lower pore pressures by ET
-increase roughness
-add surcharge
-armor unconsolidated banks

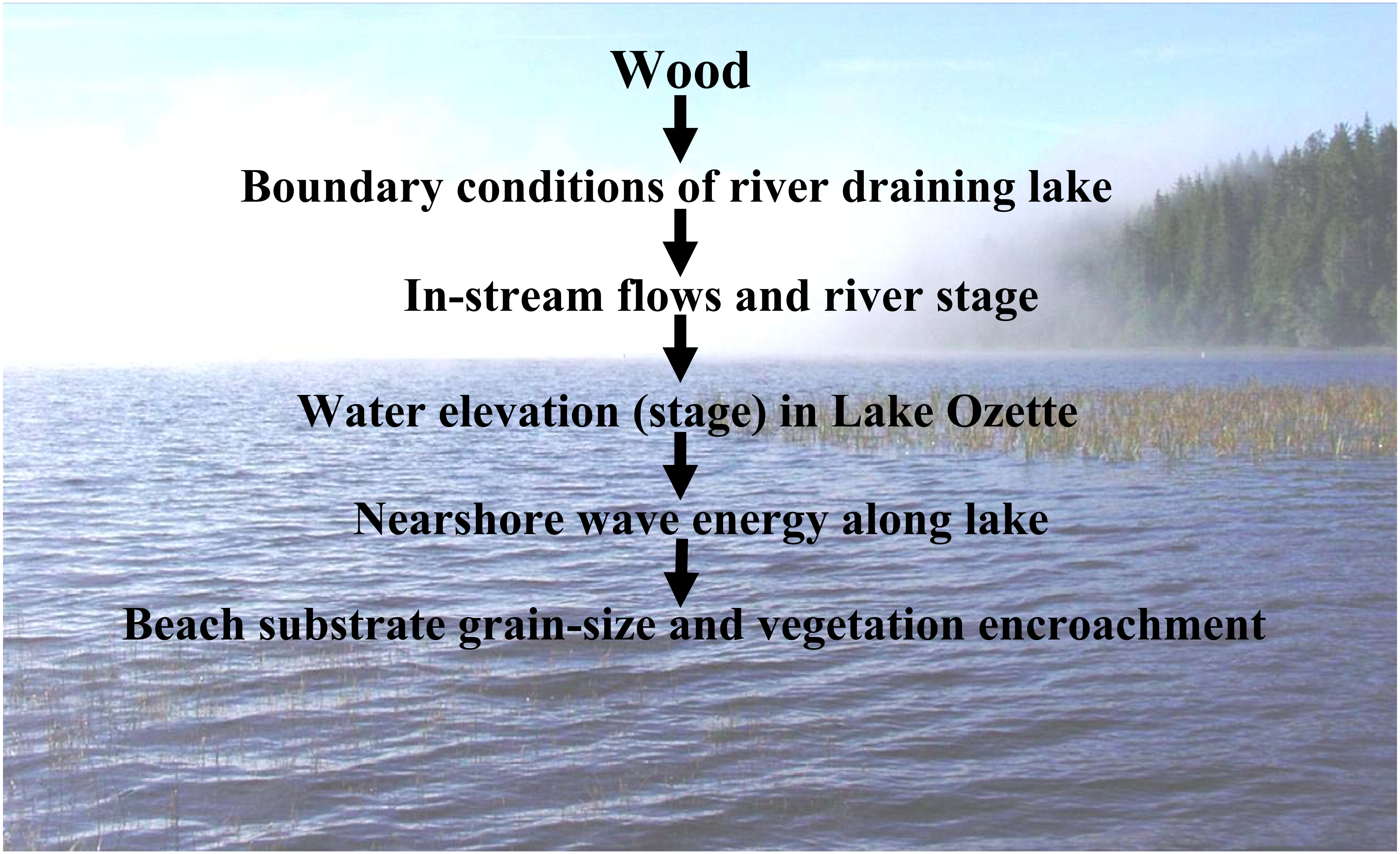
Coal Creek, WA 08-02

Manoa Stream, O’ahu 5-19-08

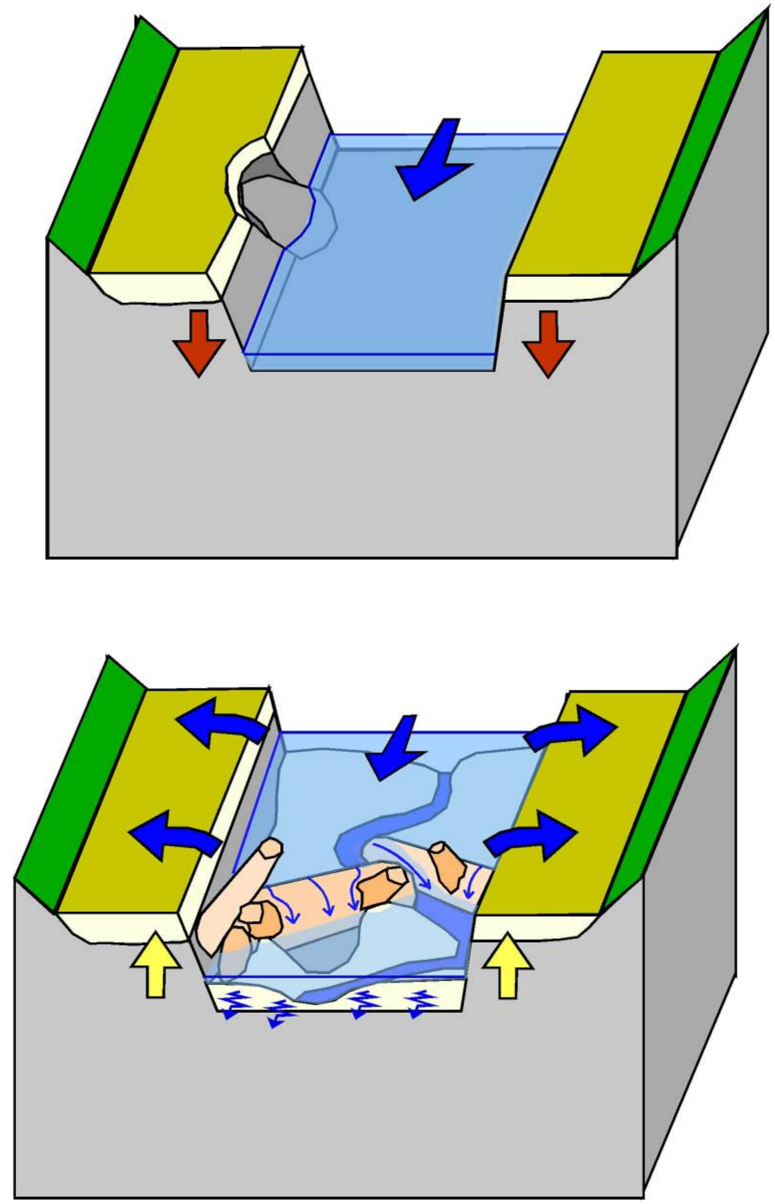
Influence of roughness on river stage

Brummer, Abbe and others 2006

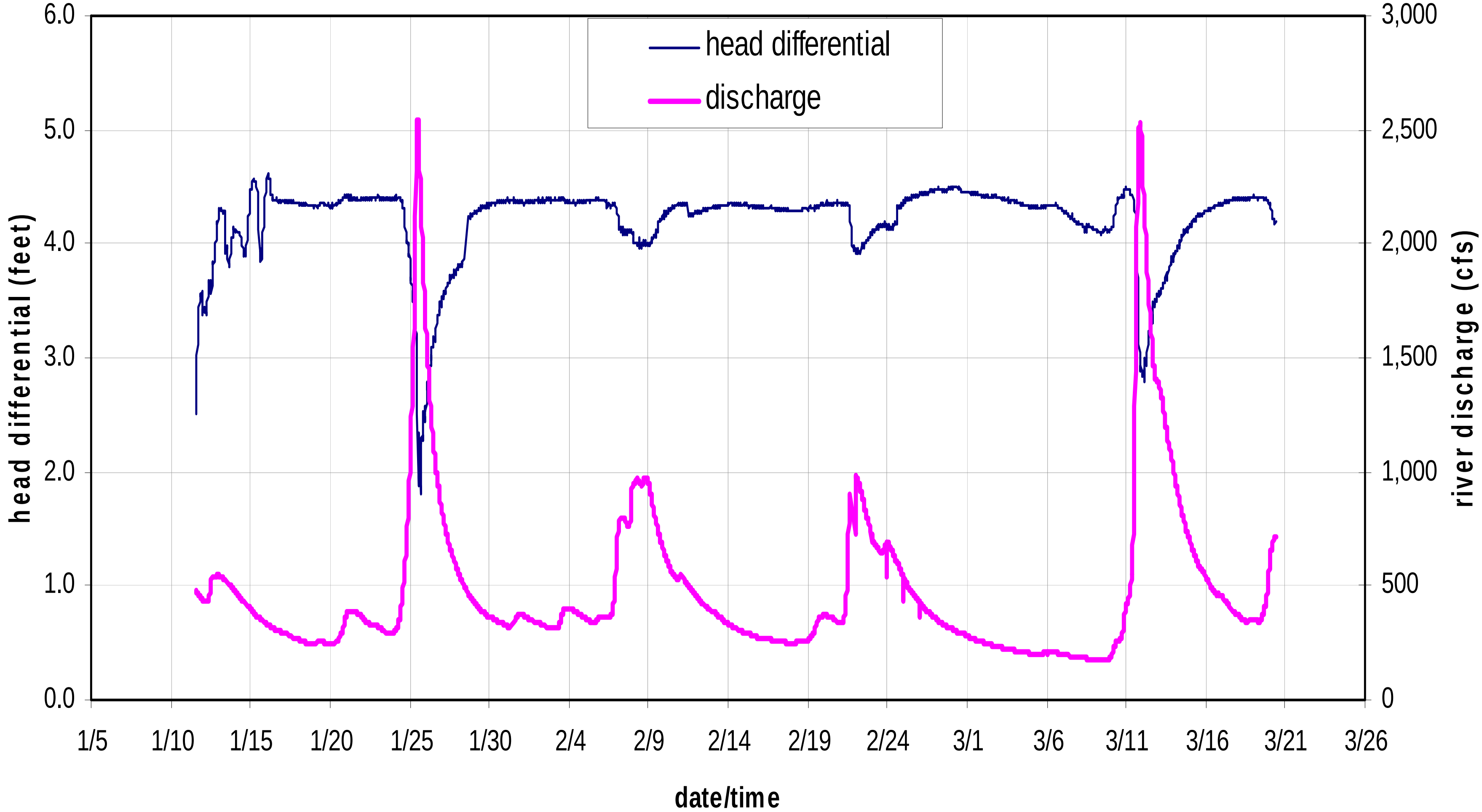
Hypothesis for collapse of beach spawning habitat



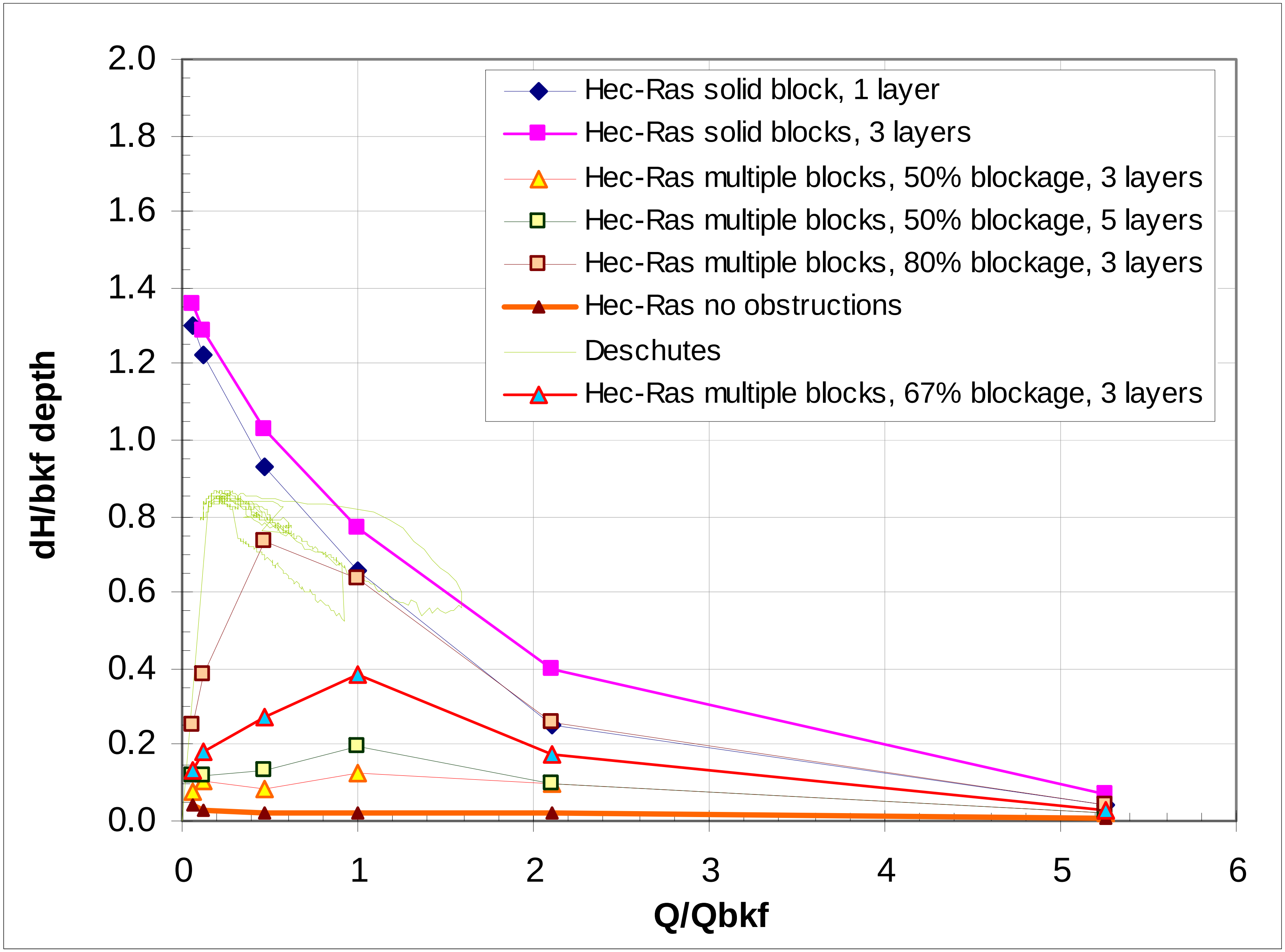
Increasing channel & bank roughness reduces flood wave celerity & increases diffusion. Reduced conveyance thereby increasing water elevations, but in downstream reaches this is moderated by reduced discharges.



Head differential due to wood accumulation in Deschutes River, WA



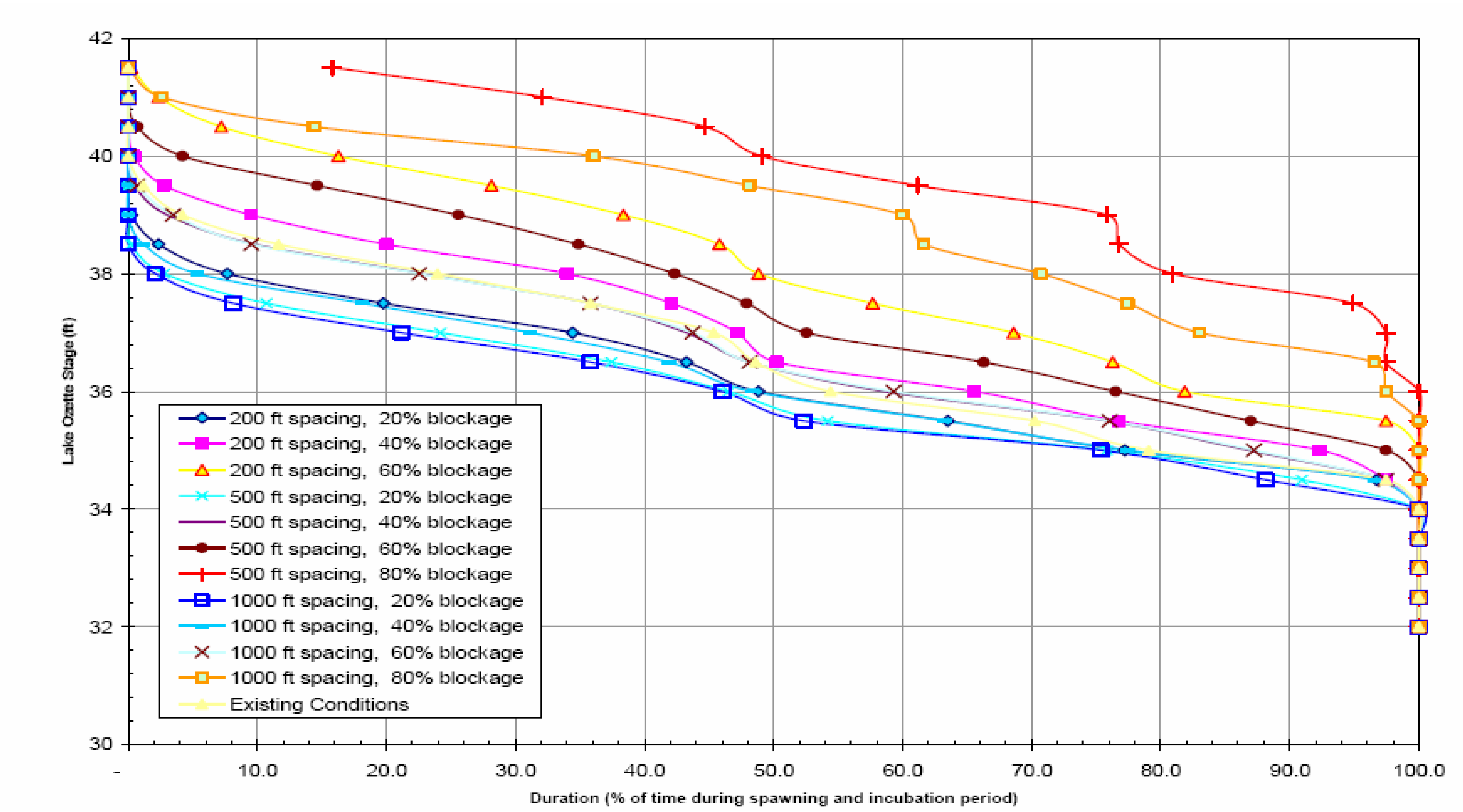
ΔH = *f*(Q)



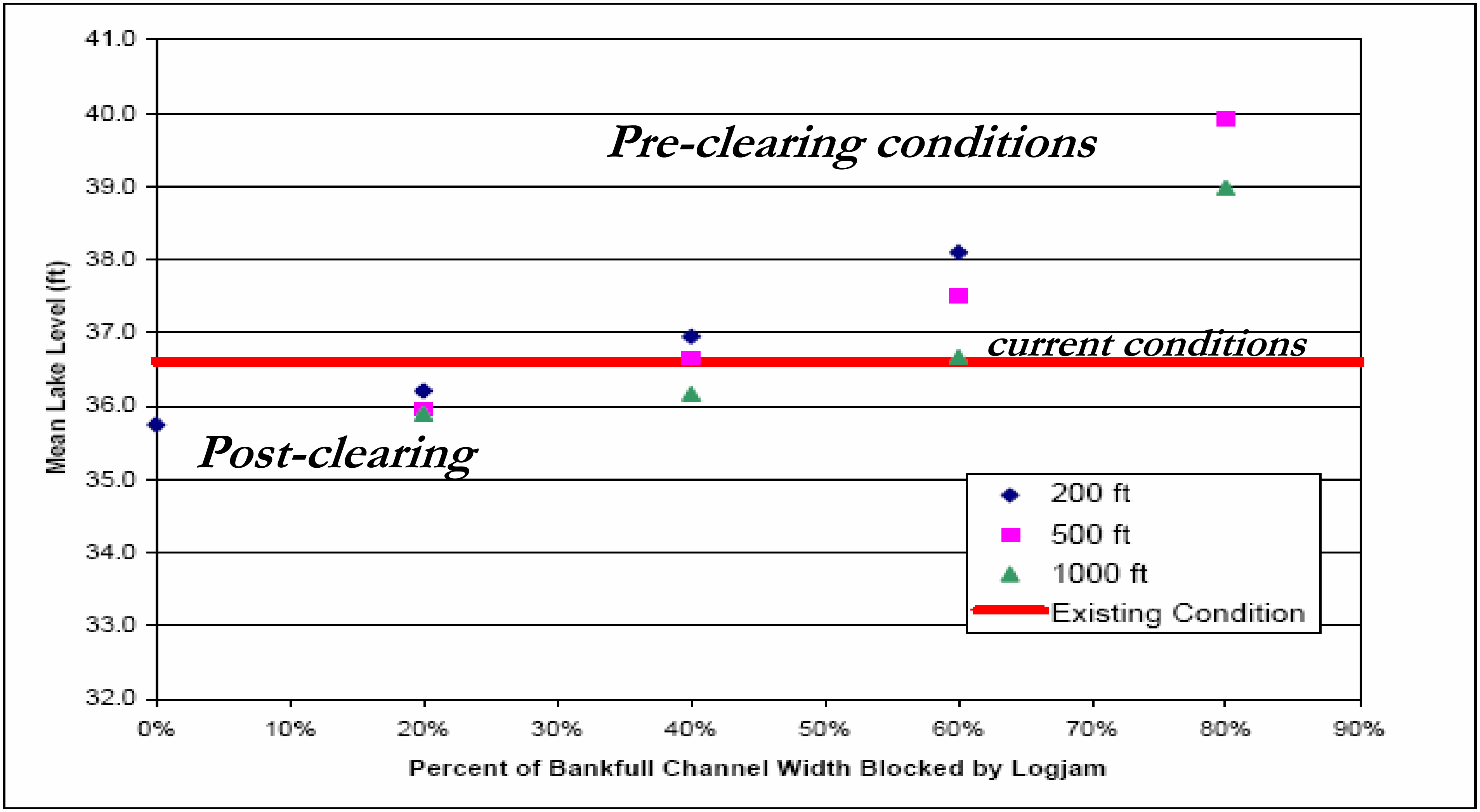
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
dH/bkf depth
0
1
2
3
4
5
6
Q/Qbkf
Hec-Ras solid block, 1 layer
Hec-Ras solid blocks, 3 layers
Hec-Ras multiple blocks, 50% blockage, 3 layers
Hec-Ras multiple blocks, 50% blockage, 5 layers
Hec-Ras multiple blocks, 80% blockage, 3 layers
Hec-Ras no obstructions
Deschutes
Hec-Ras multiple blocks, 67% blockage, 3 layers

Model Results

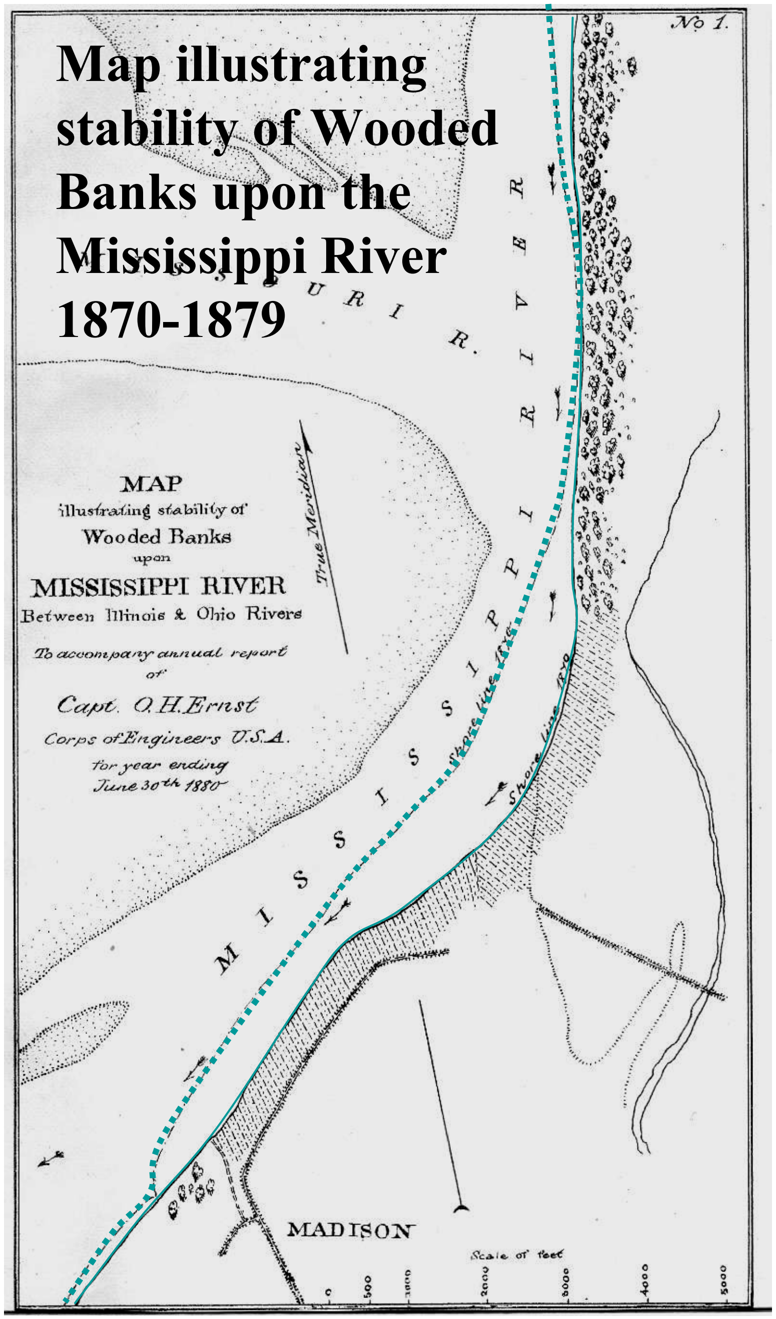
Flow Duration

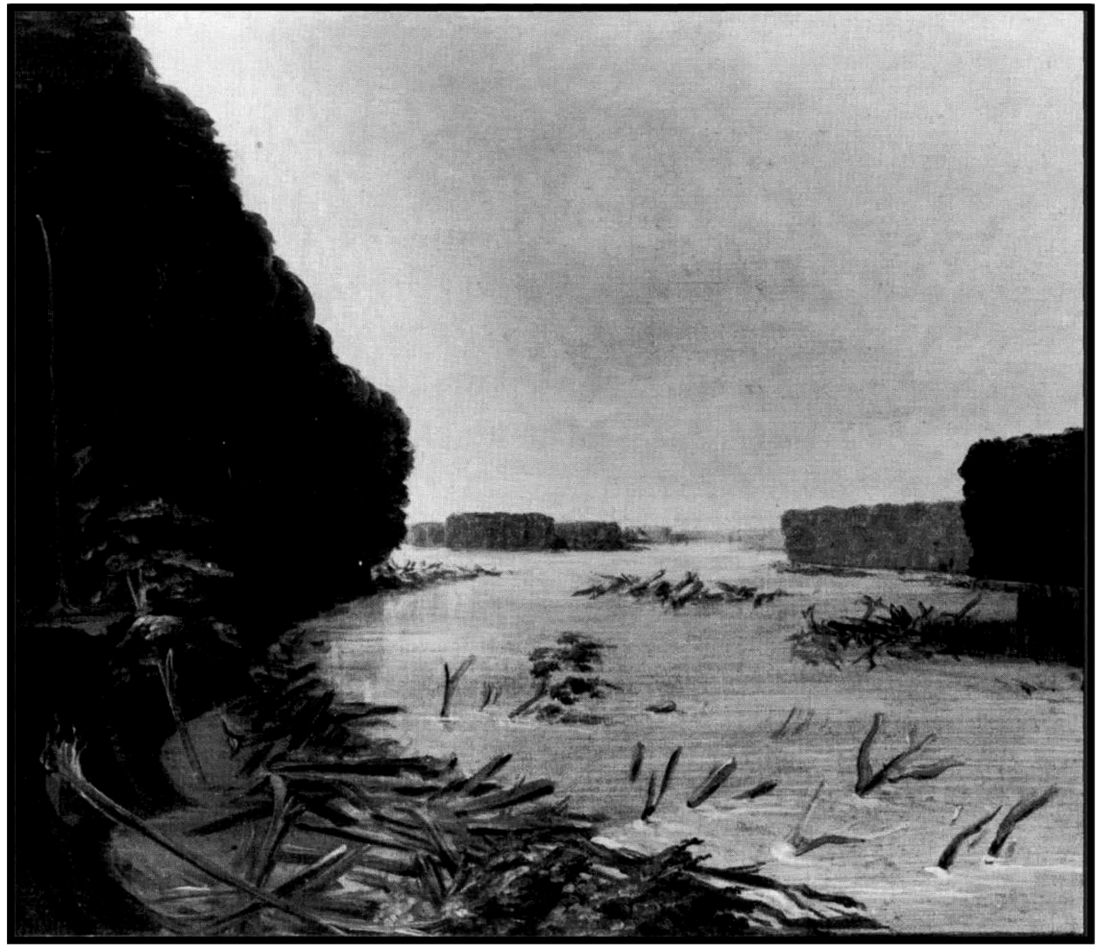


Model Results



Influence of vegetation on bank erosion



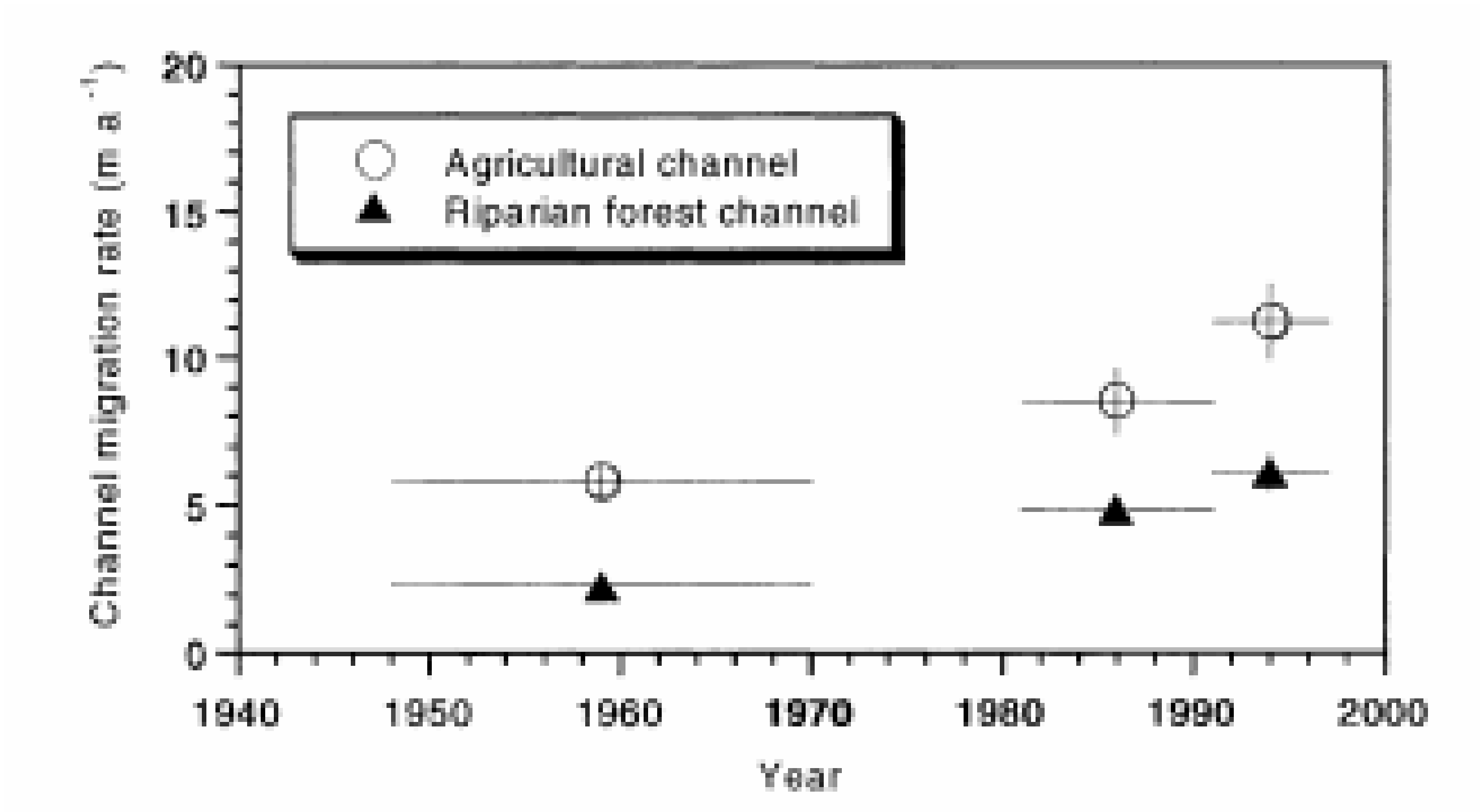


"View on the Missouri, Alluvial Banks Falling in, 600 Miles above St. Louis"
George Catlin, 1832. National Museum of American Art, Smithsonian Institution.

Missouri River

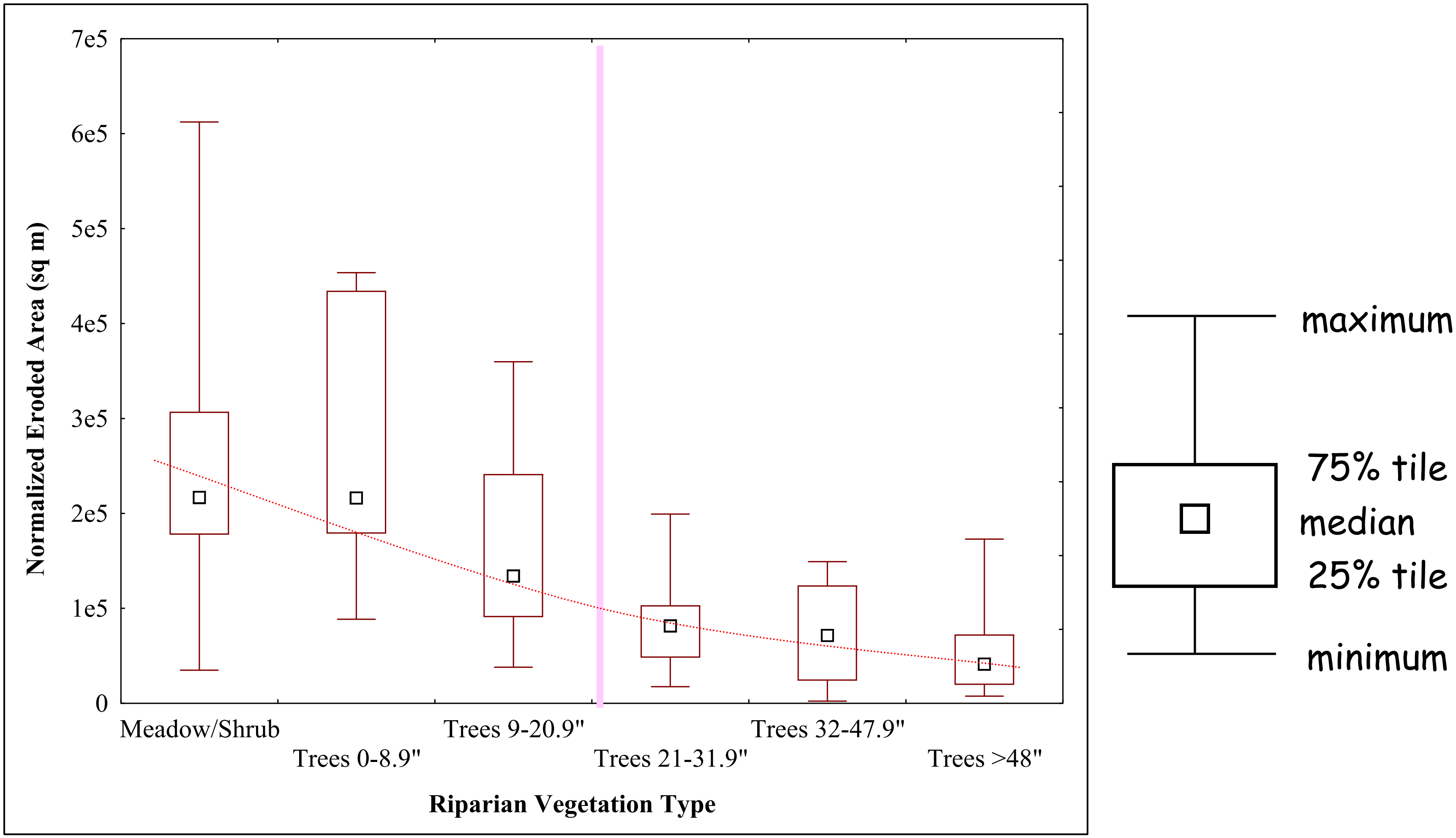
Central Sacramento River channel migration rates

(Agricultural erosion rates) = **2** * (Forest erosion rates)



Micheli, E.R., J.W. Kirschner, and E.W. Larsen 2003. Quantifying the effect of riparian forest versus agricultural vegetation on river meander migrations rates, Central Sacramento River, California, USA. River Research and Applications. 19. 1-12.

Normalized Eroded Areas by Riparian Vegetation Type

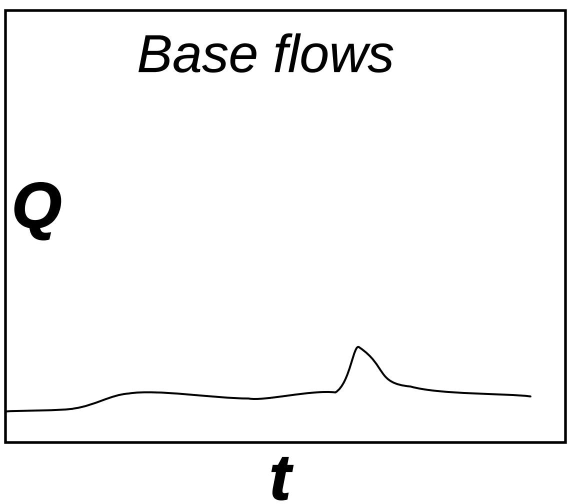


Abbe et al. 2003. **Forest Influence on floodplain development and channel migration zones. Geological Society of America Abstracts**

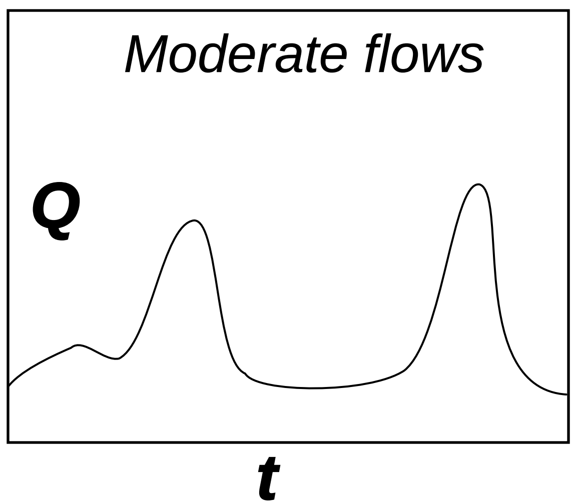
Vegetation influences fluvial ecosystems across multiple scales

cm km

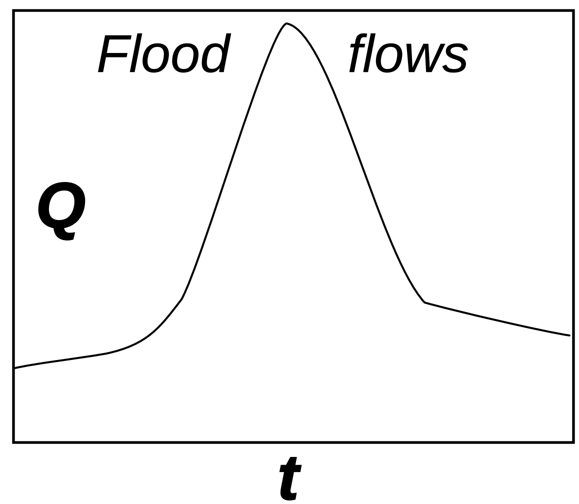
substrate & cover



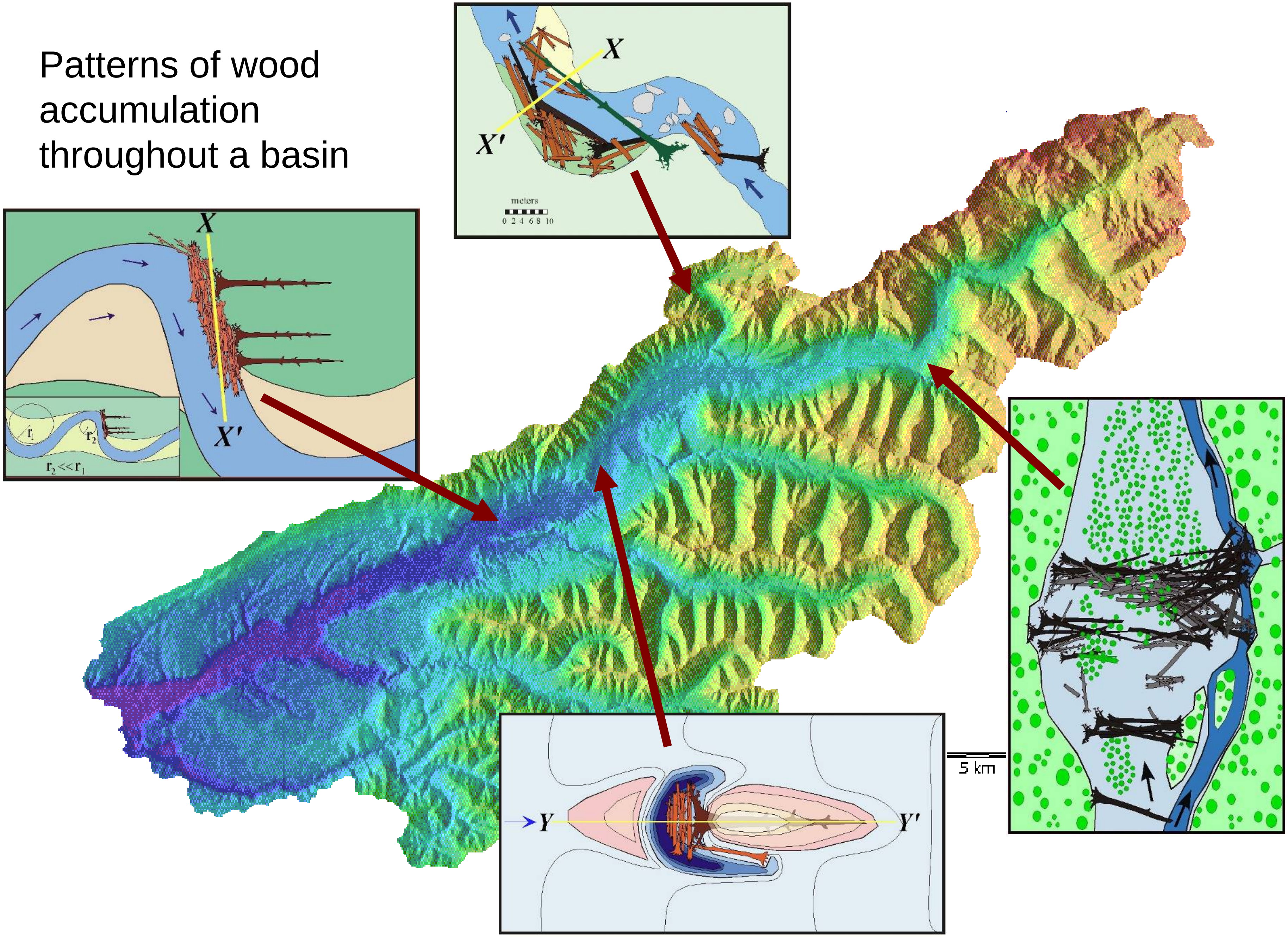
Bedforms & gradients



planform & floodplain



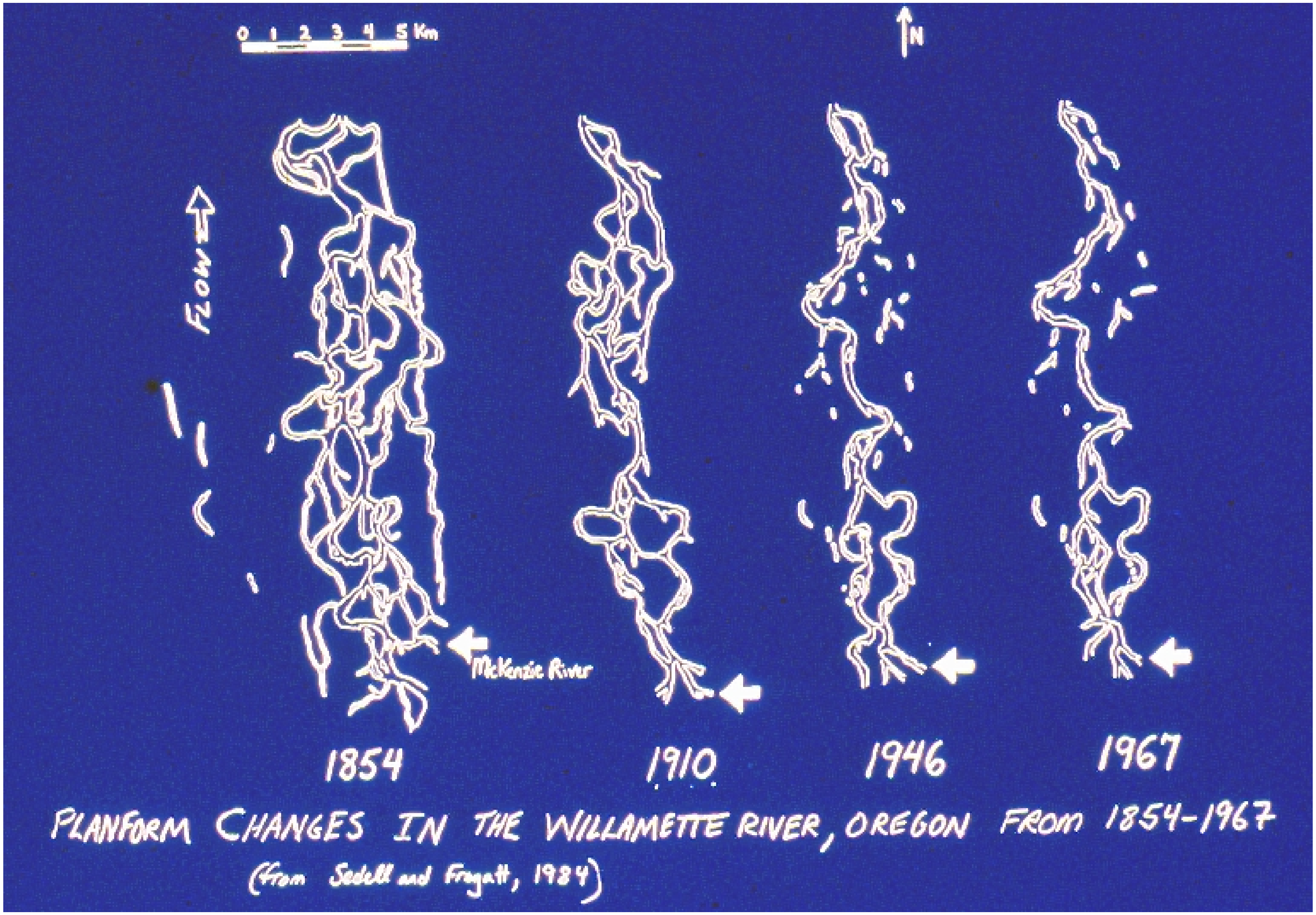
Patterns of wood accumulation throughout a basin



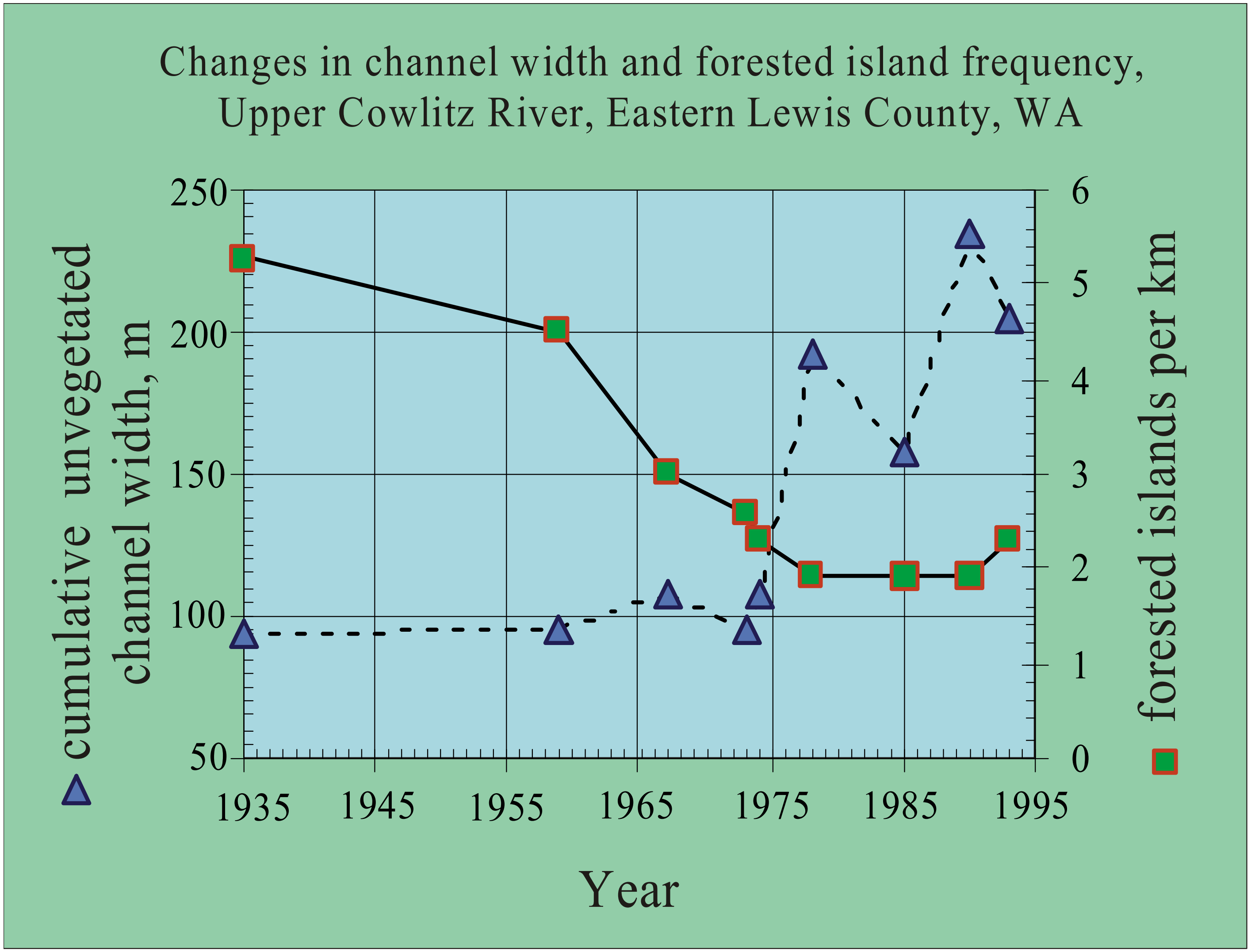
Bar Apex Jam, Allyn River, New South Wales, Australia

An anabranching channel system loaded with wood

Removing wood reverses the morphologic complexity created by wood and simplifies rivers.



Human development has dramatically reduced the size and quantity of wood debris. The result is a significant change in channel geomorphology.



Sediment discharge resulting from channel clearing

Consequences of removing wood debris from Colorado River of Texas

Sediment deposited in Matagorda Bay between 1909 and 1941 = 42,809,700 m^3

An average sediment discharge of 1,297,264 $m^3\ yr^{-1}$

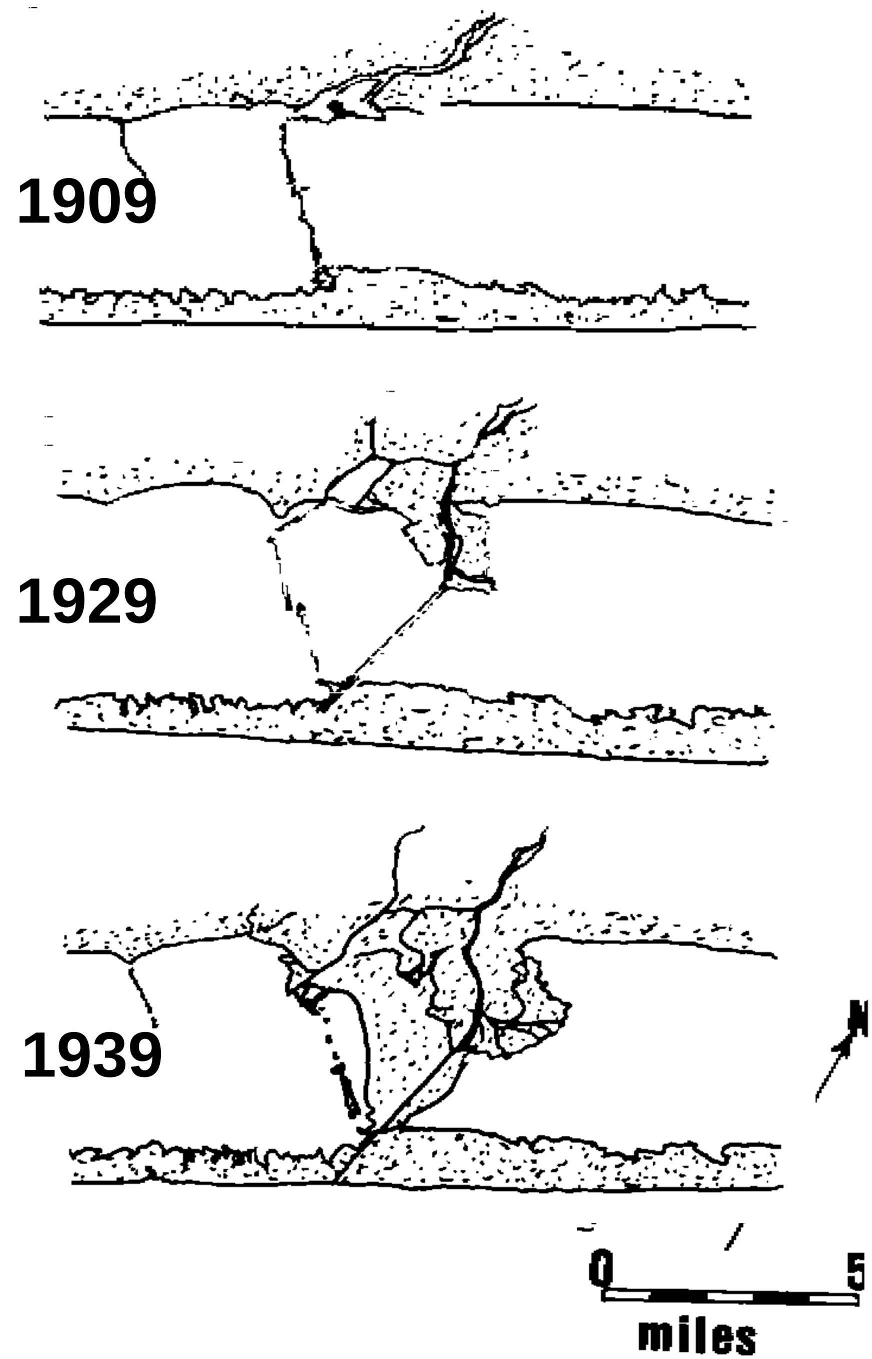
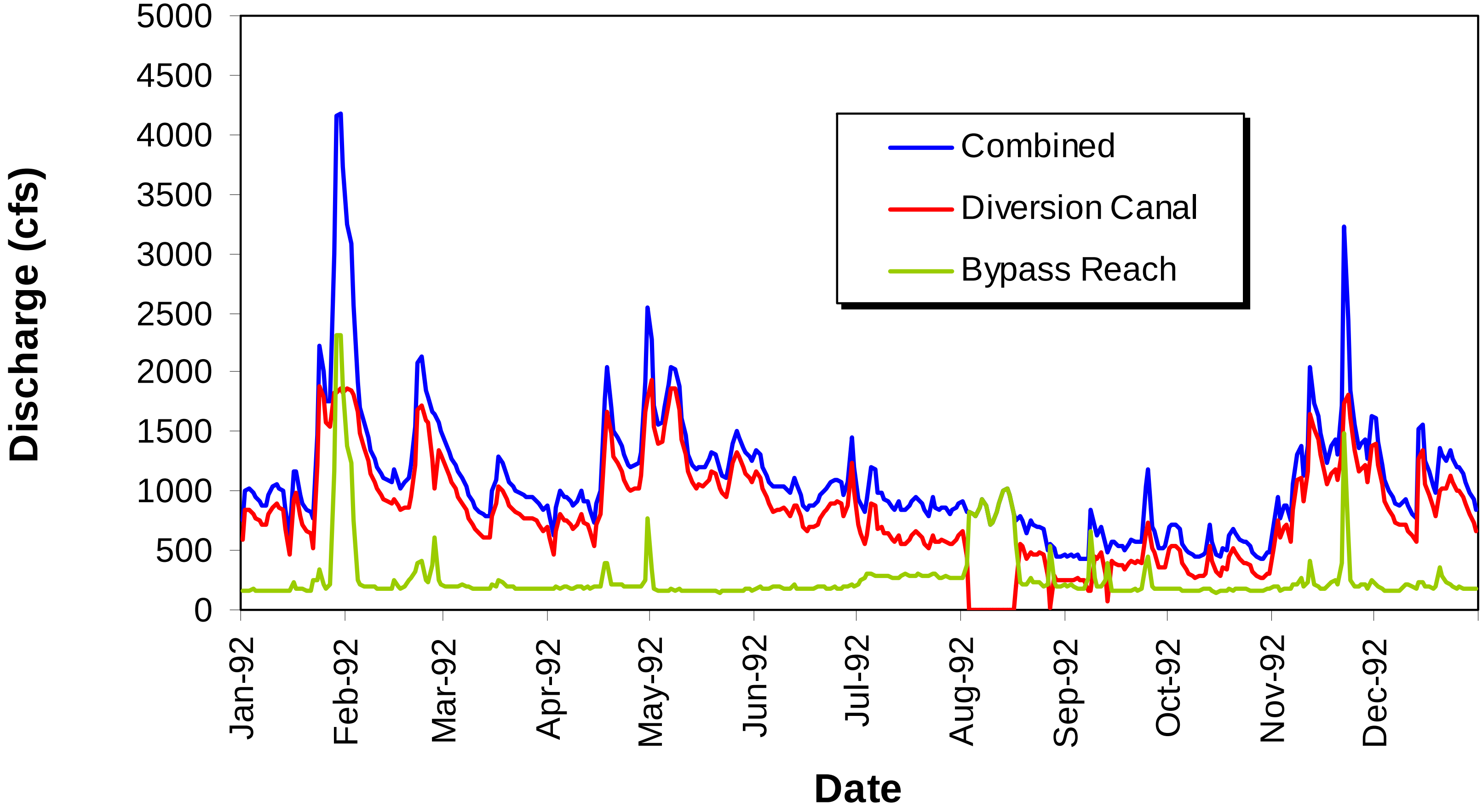
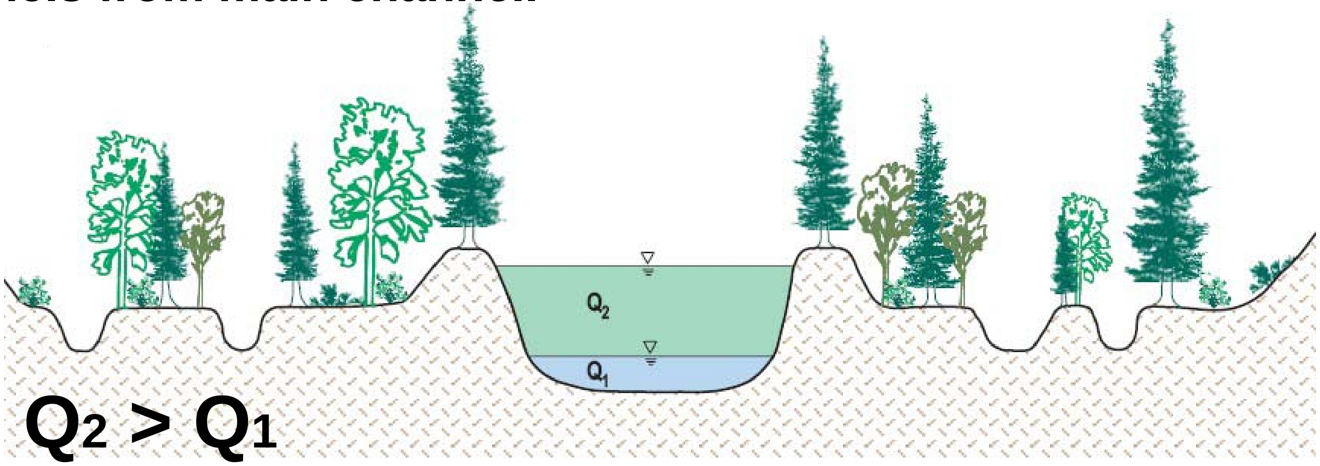


Illustration of the importance of channel roughness versus discharge in creating habitat within a channel reach downstream of a major flow diversion

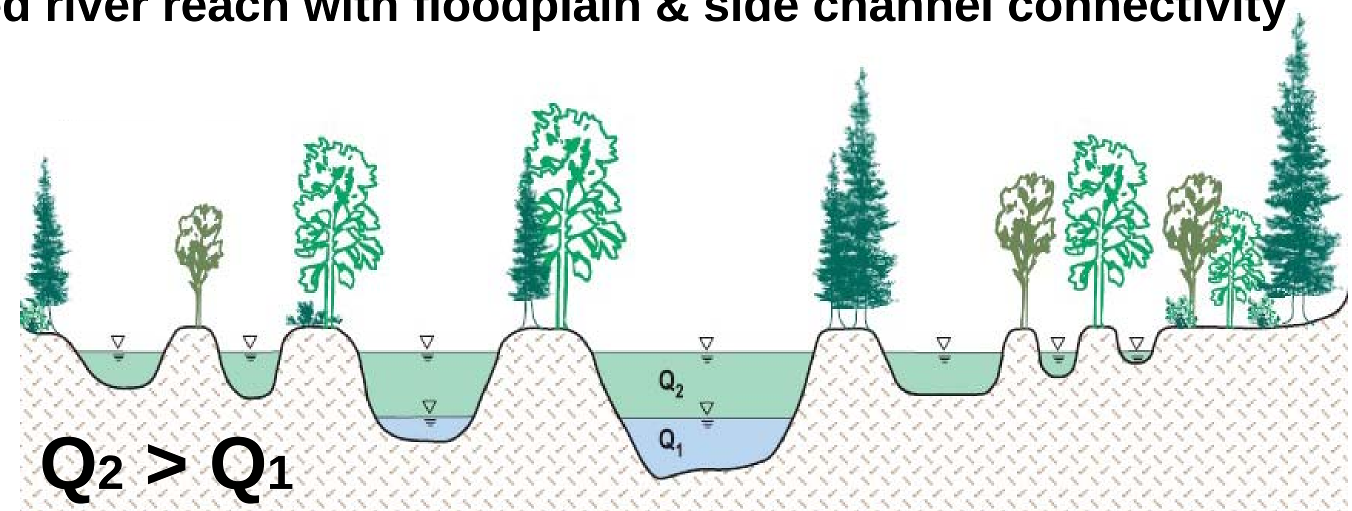
Flow Regulation in Bypass Reach

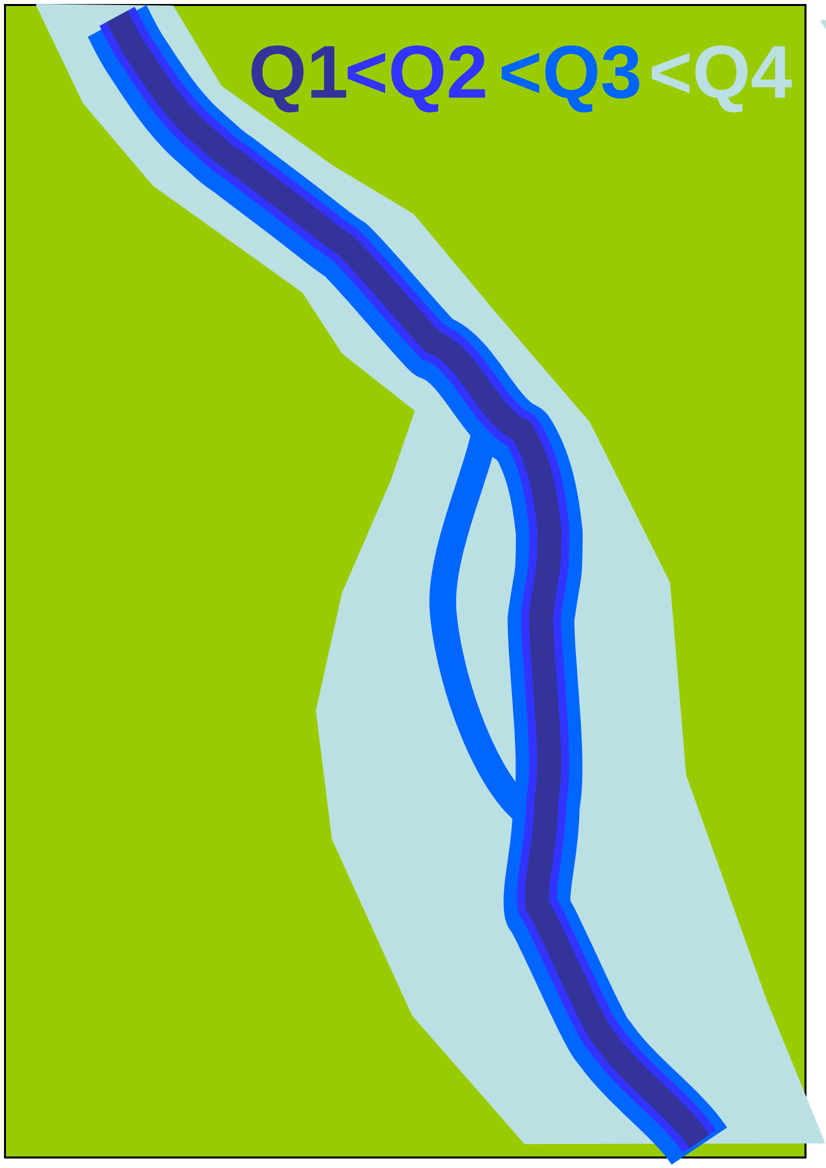


River confinement due to levees or incision disconnects floodplain and side channels from main channel.

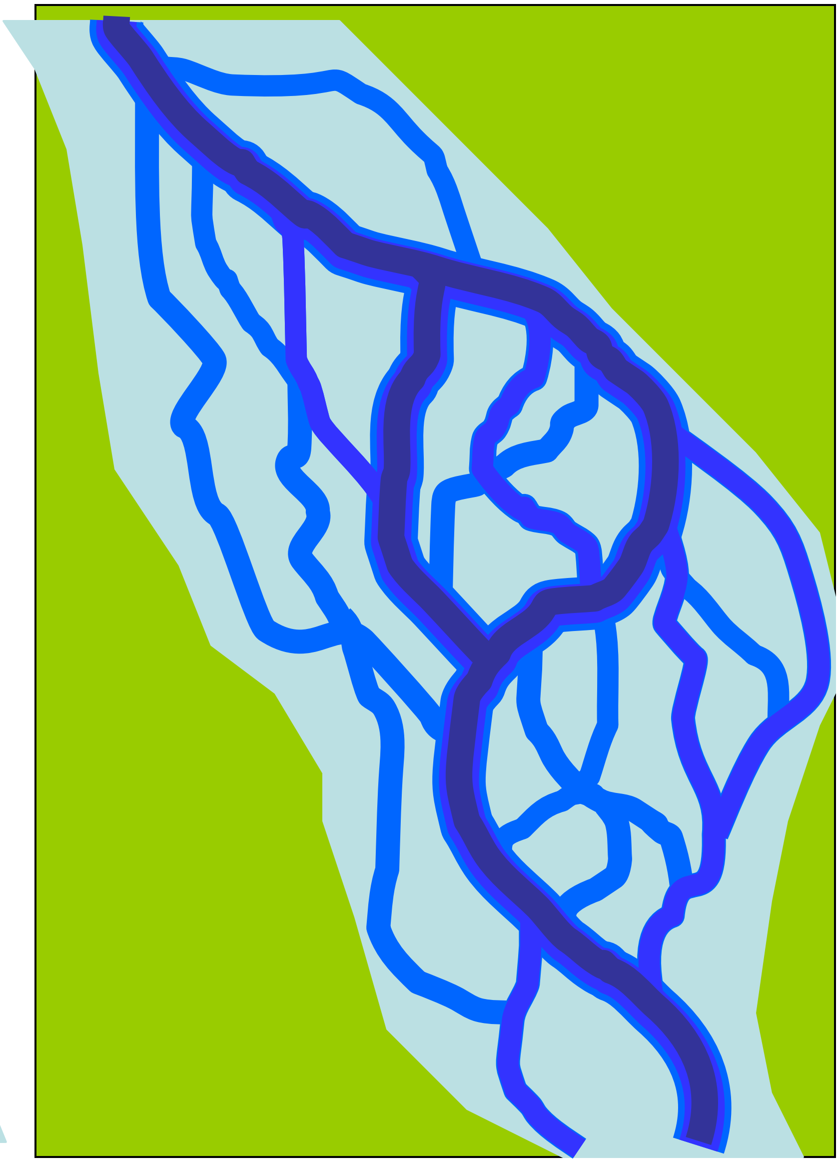


Unconfined river reach with floodplain & side channel connectivity



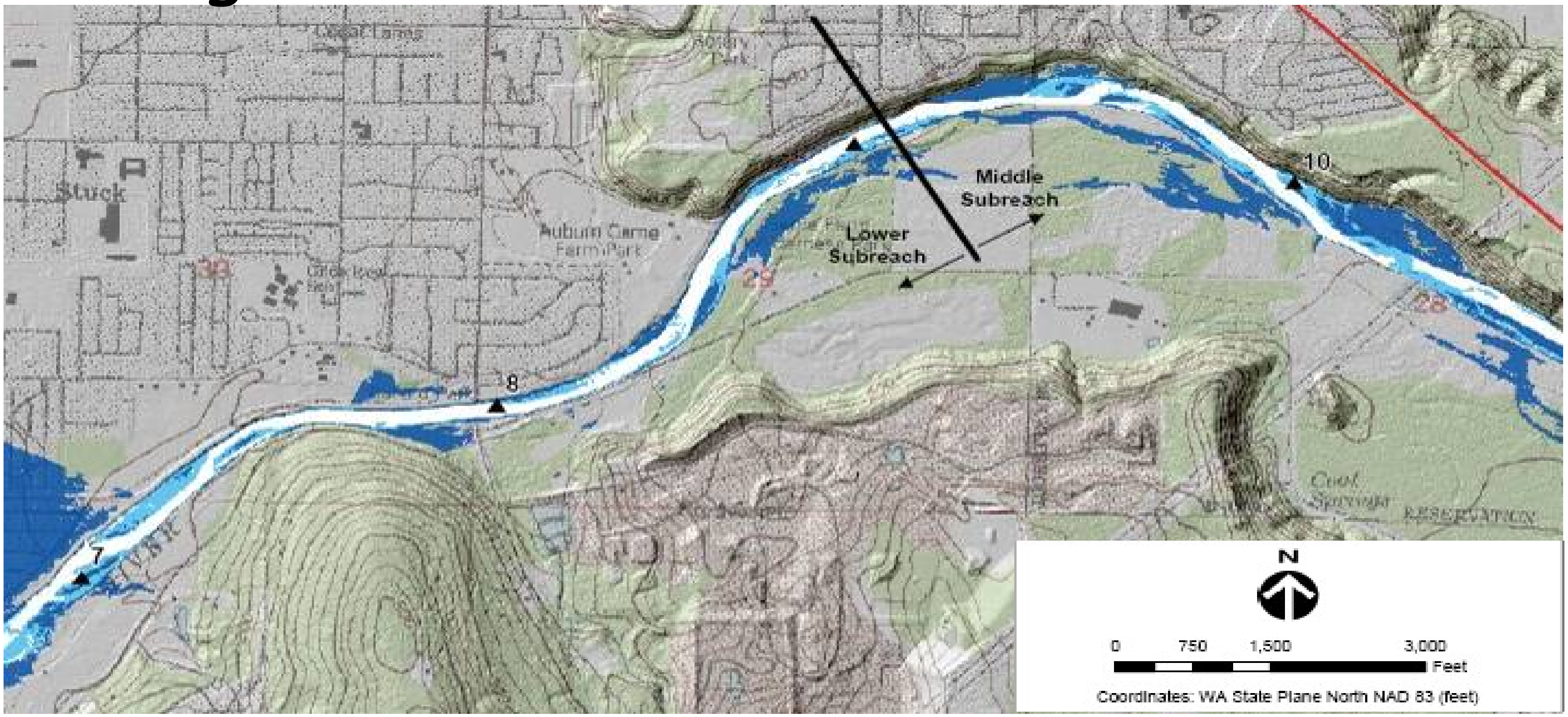


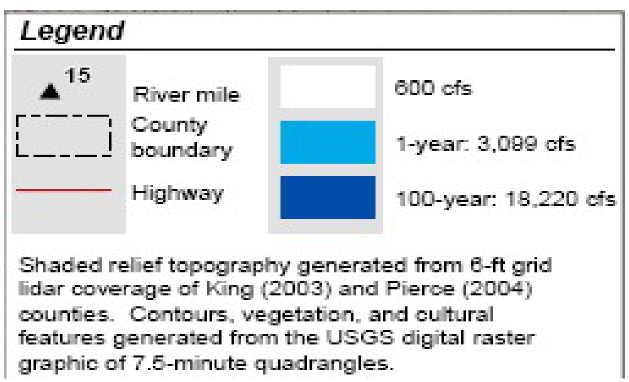
Levee constrained or incised river



Unconstrained river

Straightened channelized reach

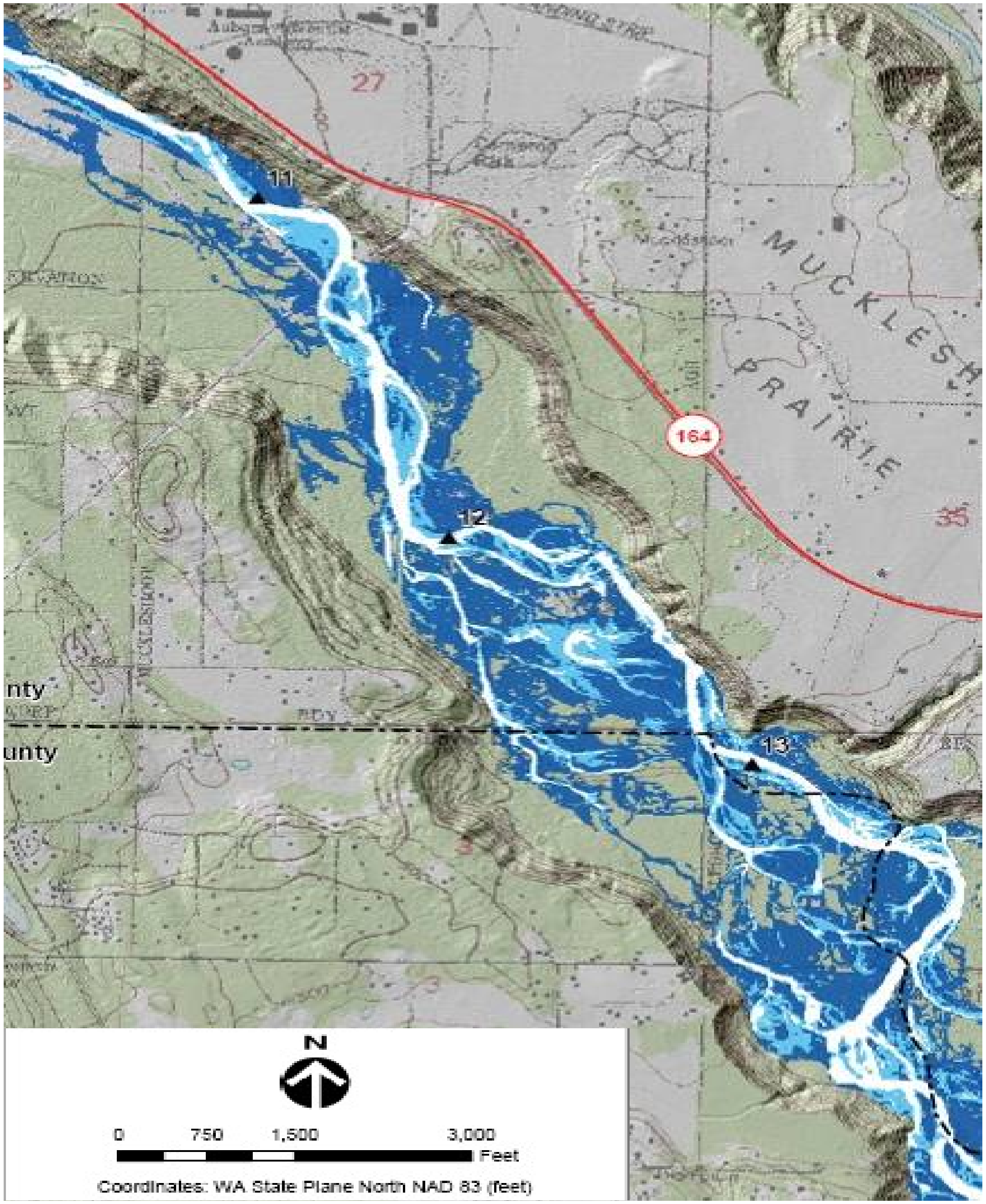




Simulated flow inundation areas Lower Reach,

RM 7 to RM 10.

Intact unconfined reach



Simulated flow inundation areas in Middle Reach,

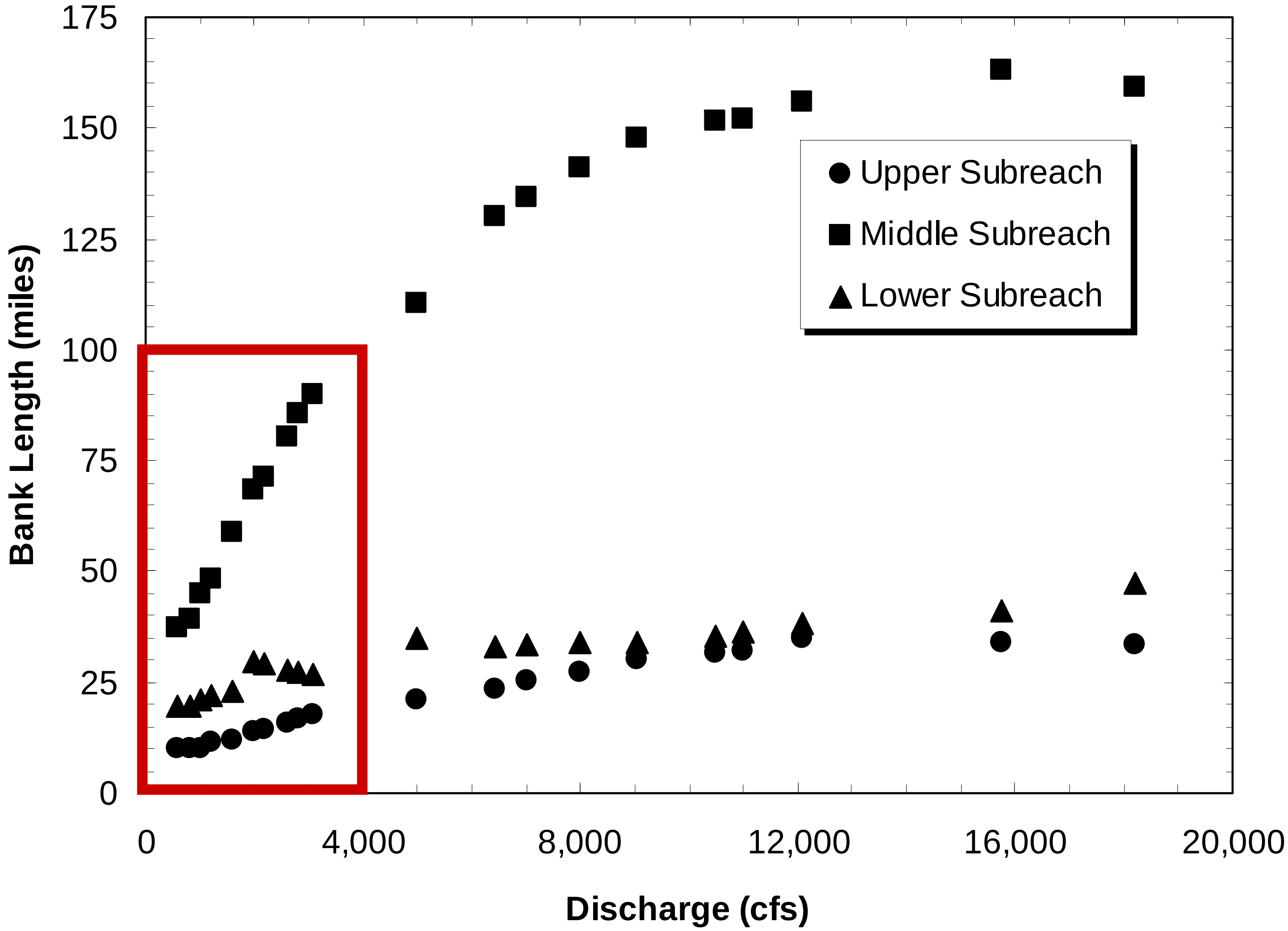
RM 10 to RM 13.

Legend

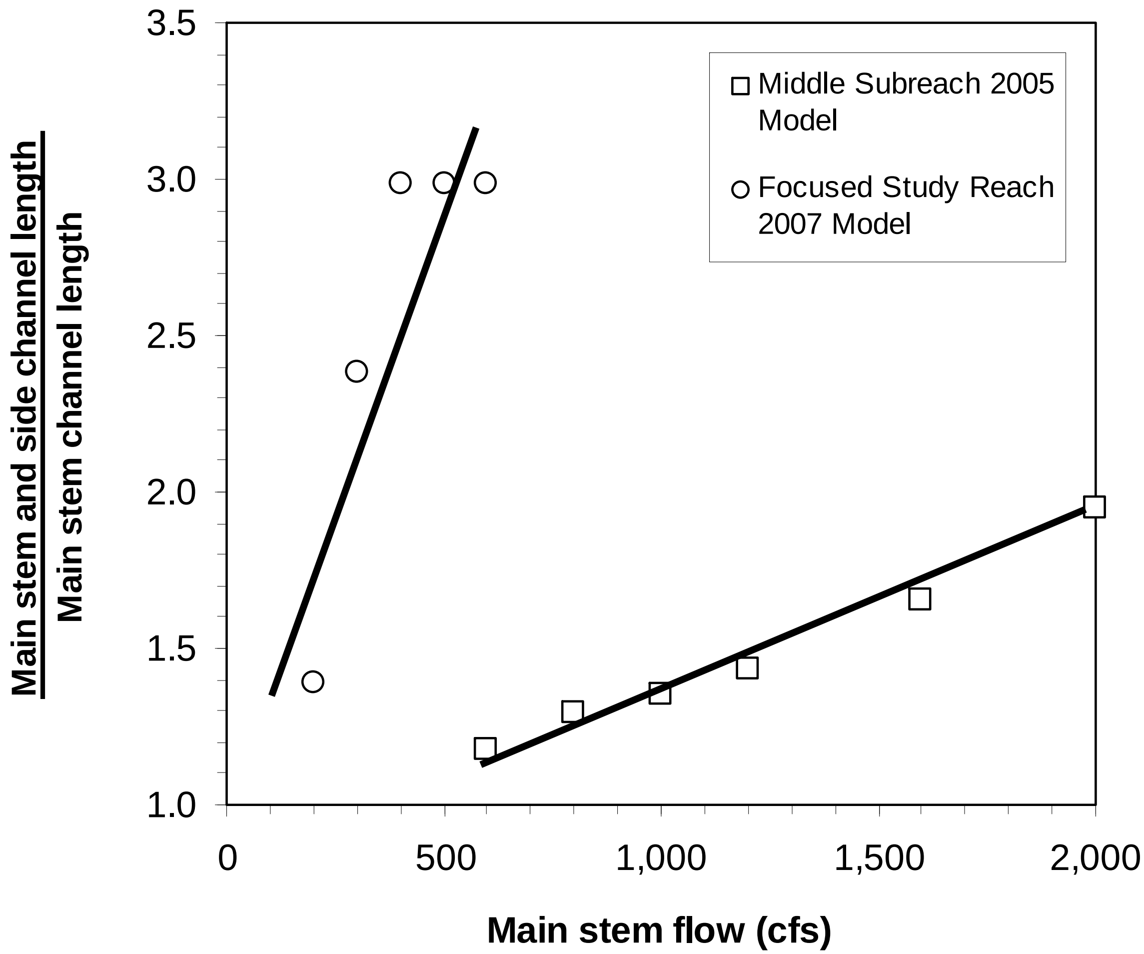
▲ 15	River mile		600 cfs
	County boundary		1-year: 3,099 cfs
	Highway		100-year: 18,220 cfs

Shaded relief topography generated from 6-ft grid lidar coverage of King (2003) and Pierce (2004) counties. Contours, vegetation, and cultural features generated from the USGS digital raster graphic of 7.5-minute quadrangles.

Model results showing relations between bank length and discharge in the three subreaches



Model Results (field calibrated)



Change in habitat quantity per 100 cfs of diverted water for low-flow conditions in the bypass reach

Subreach	Change in channel length/100 cfs	Flow range (cfs)
Upper & Middle (uncalibrated)	1 mile (6%)	600 - 3,100
Middle (field calibrated)*	6 miles (38%)	200 - 600

*Even more side channels observed in field than predicted by model.

What about downstream discharge and stage?

a) Relief

b) Vegetation

c) Type of input hydrograph

d) Channel form

e) Channel slope

Recent work by Gordon B. Anderson provides new perspective on the influence of vegetation on flood routing.

(Anderson, G.B. 2006. Quantifying the interaction between riparian vegetation and flooding from cross-section to catchment scale. University of Melbourne, Australia)

Flood wave celerity

$$c = \frac{dQ}{dA} = \frac{1}{B}\frac{dQ}{dy}$$

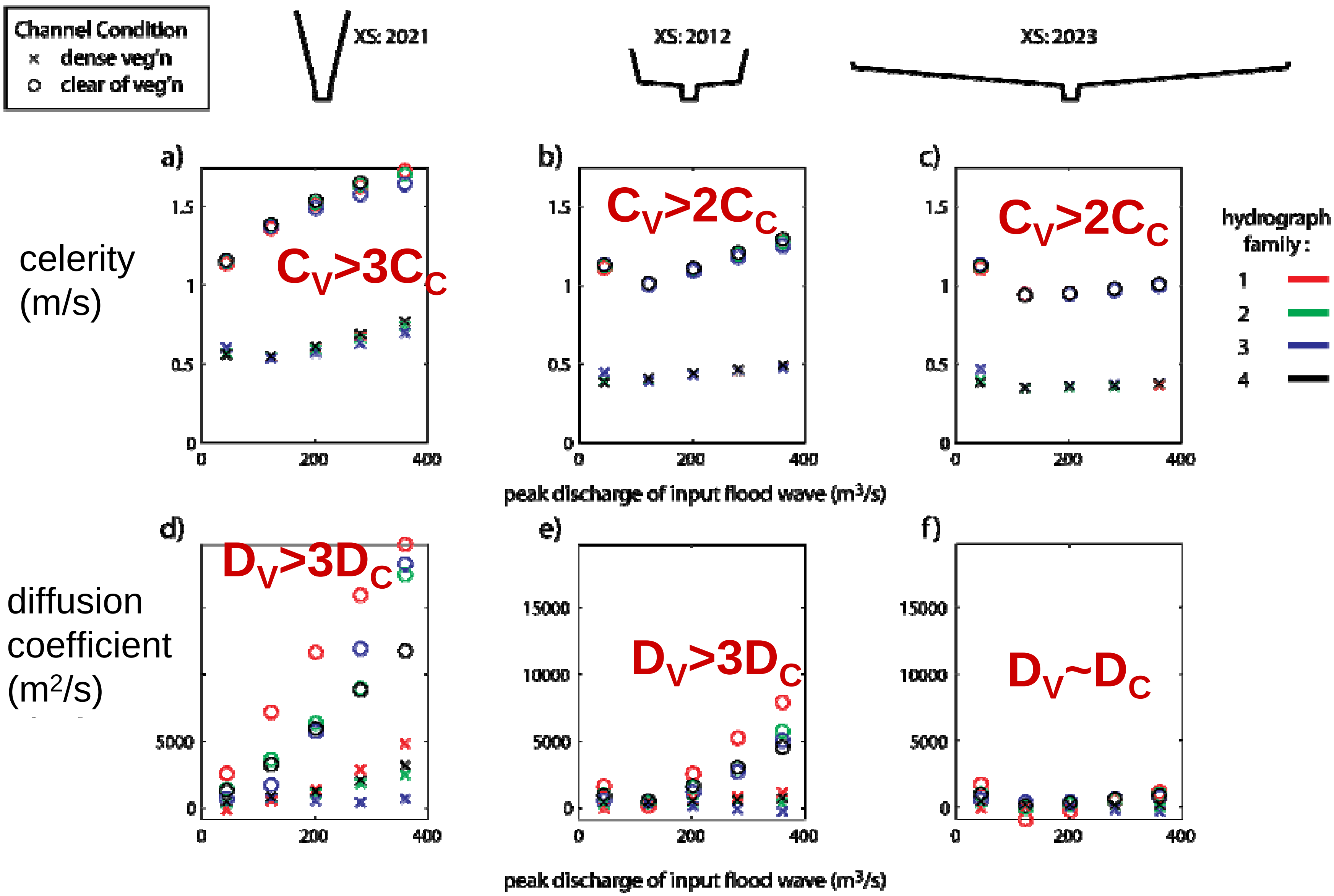
Hydraulic diffusion

$$D = \frac{Q}{2BS_o}$$

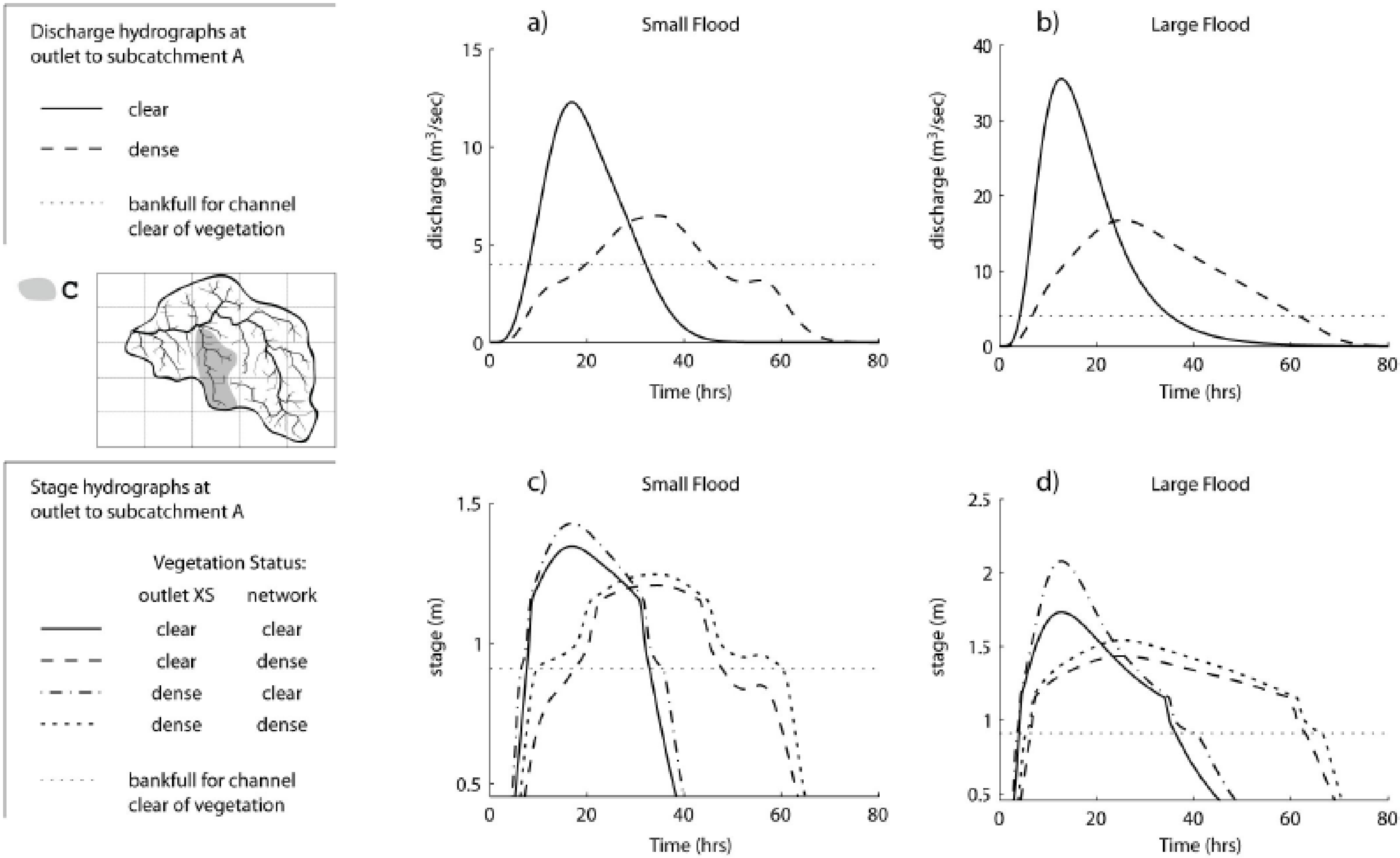
Applying Manning Equation to link discharge to stage:

$$c_A = \frac{5}{3}\frac{R^{2/3}S_o^{\,1/2}}{n}$$

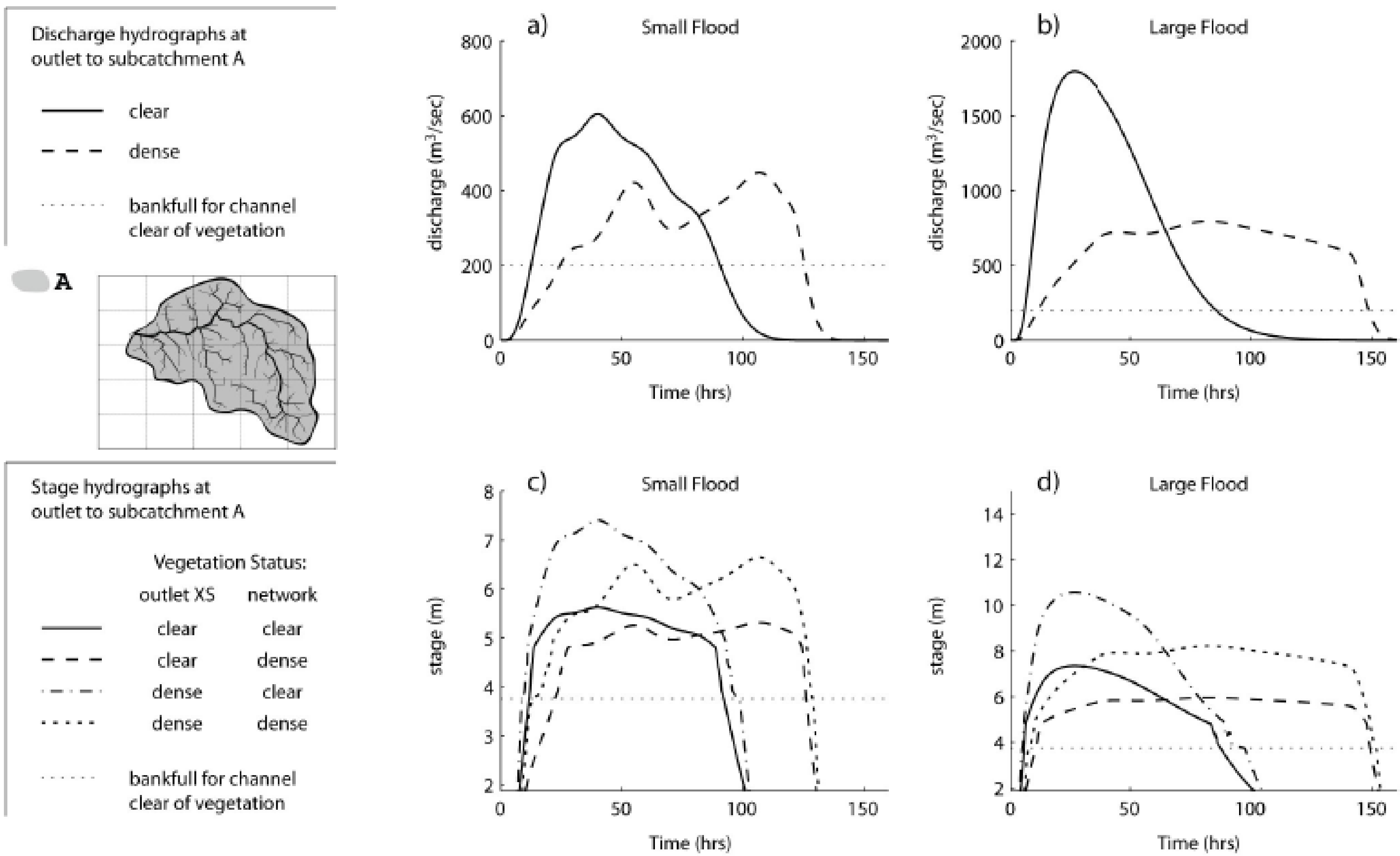
$$D_A = \frac{1}{2}\frac{R^{5/3}}{nS_o^{\,1/2}}$$



Varying channel geometry (Anderson, BG. 2006 Figure 6.13)



Anderson, BG. 2006.



Anderson, BG. 2006.

Anderson (2006, p.417) concludes:

This research shows that the impact of riparian vegetation on flooding has been overstated in the past as the impact of catchment-scale flood wave attenuation was not considered. Therefore, the argument for blocking riparian rehabilitation for fear of exacerbating flooding is flawed.”

Flooding in Manoa Stream
O’ahu, HI

Manoa Stream, O’ahu 5-19-08

Manoa Stream, O’ahu 10-31-04

Manoa Stream, O’ahu 10-31-04

Tree removal off right bank of Manoa Creek after Halloween Flood of 2004

Manoa Stream, O’ahu 5-19-08

Putting roughness back

July 2003

January 2004

Upstream grade control site
July 2003

August 2003

November 2003

Looking upstream at downstream end of project reach

Before

After


Mahalo