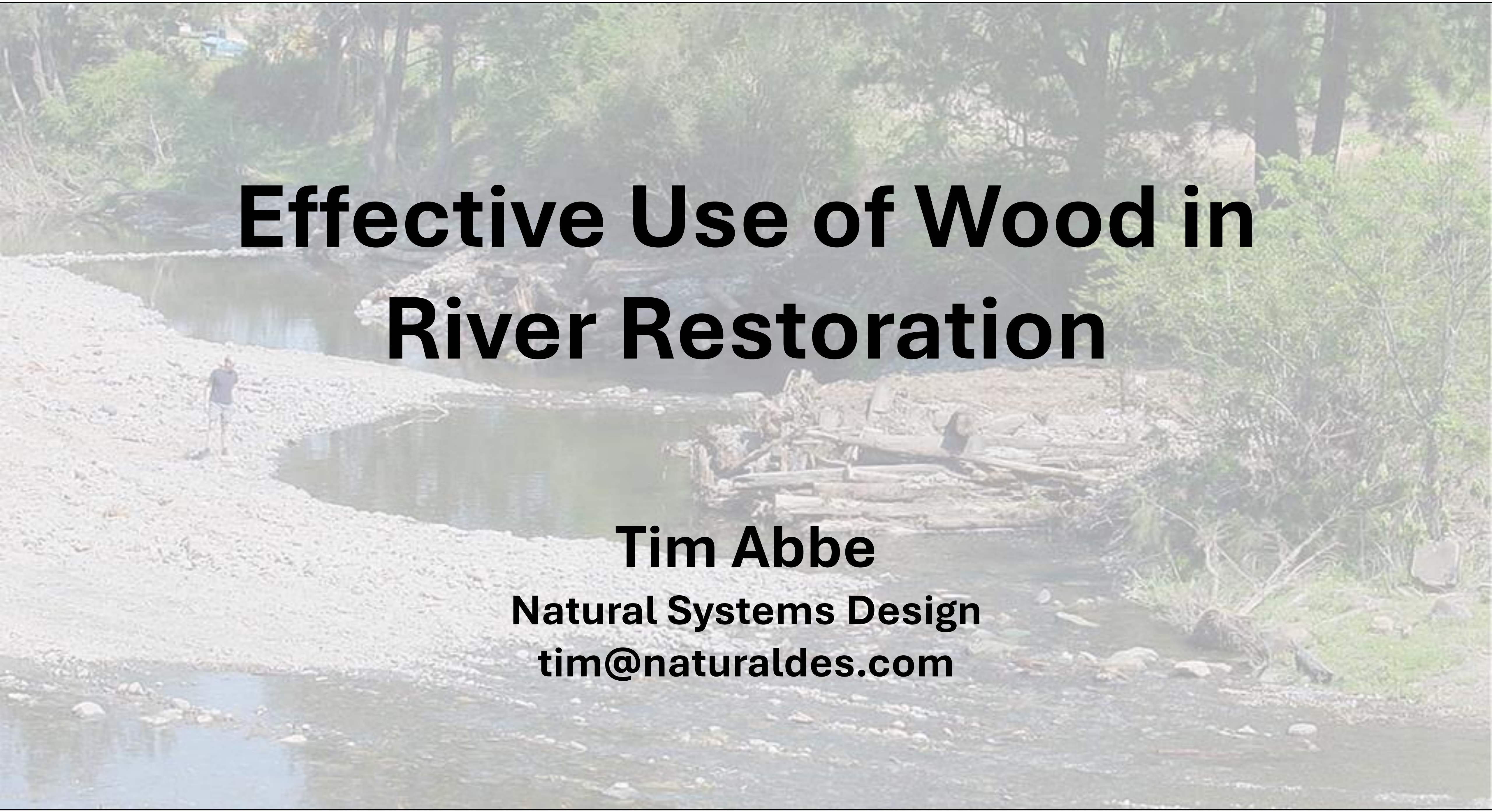


Effective Use of Wood in River Restoration

Tim Abbe
Natural Systems Design
tim@naturaldes.com

What is wood effective at?

- Pools
- Cover
- Bars and islands
- Trapping alluvium
- Trapping small wood
- Decreasing substrate grain size
- Water retention
- Hyporheic exchange
- Floodplain connectivity

Physical Habitat

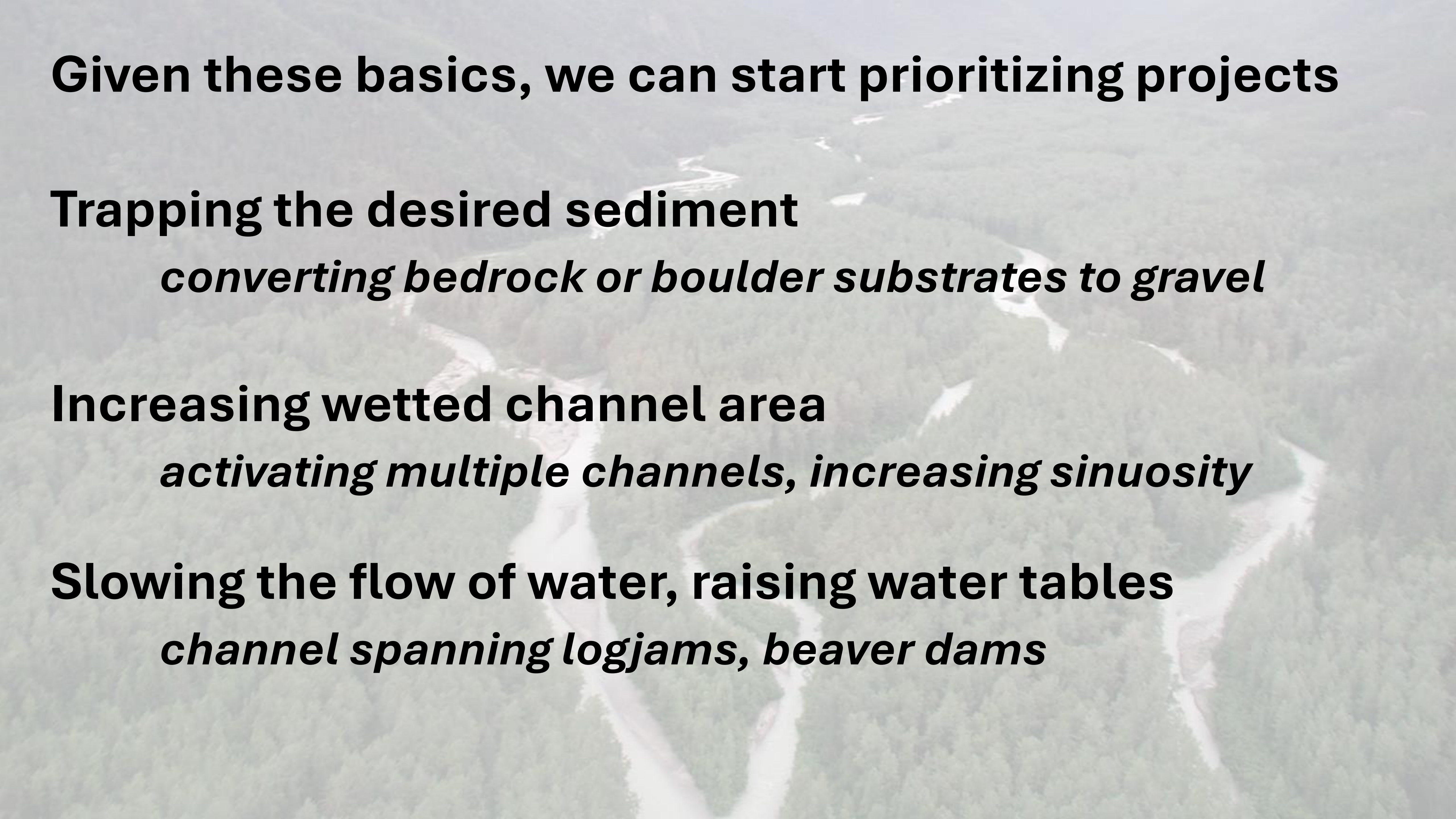
What do fish need?

Starting with the basics

More than any other variables, fish need <u>water and alluvium</u>

Water in the right places at the right times and right temperatures

Sediment that provides spawning habitat (right grain sizes and not subject to excess scour)



Given these basics, we can start prioritizing projects

Trapping the desired sediment

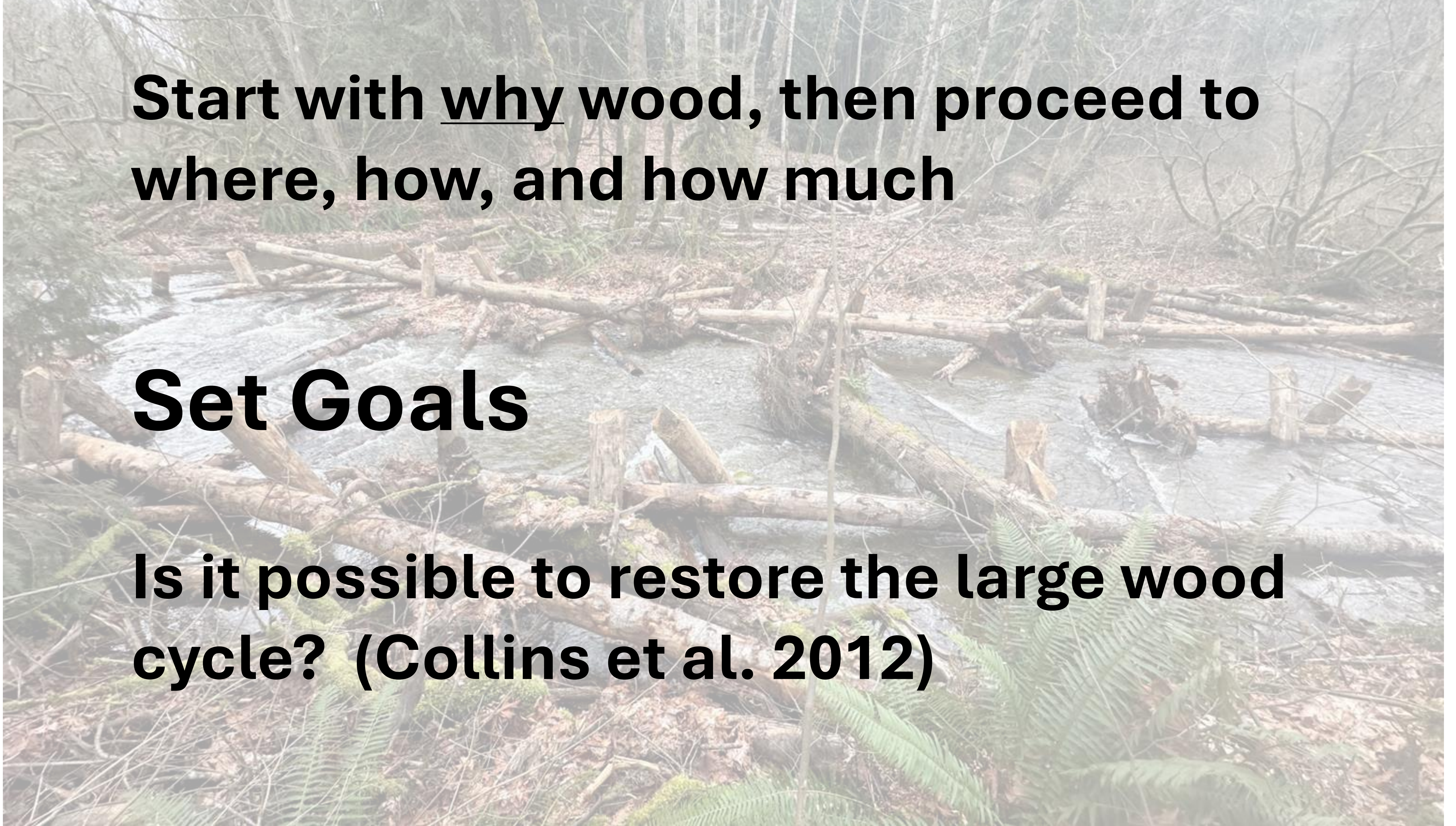
converting bedrock or boulder substrates to gravel

Increasing wetted channel area

activating multiple channels, increasing sinuosity

Slowing the flow of water, raising water tables

channel spanning logjams, beaver dams



Start with why wood, then proceed to where, how, and how much

Set Goals

Is it possible to restore the large wood cycle? (Collins et al. 2012)

Historical Context:

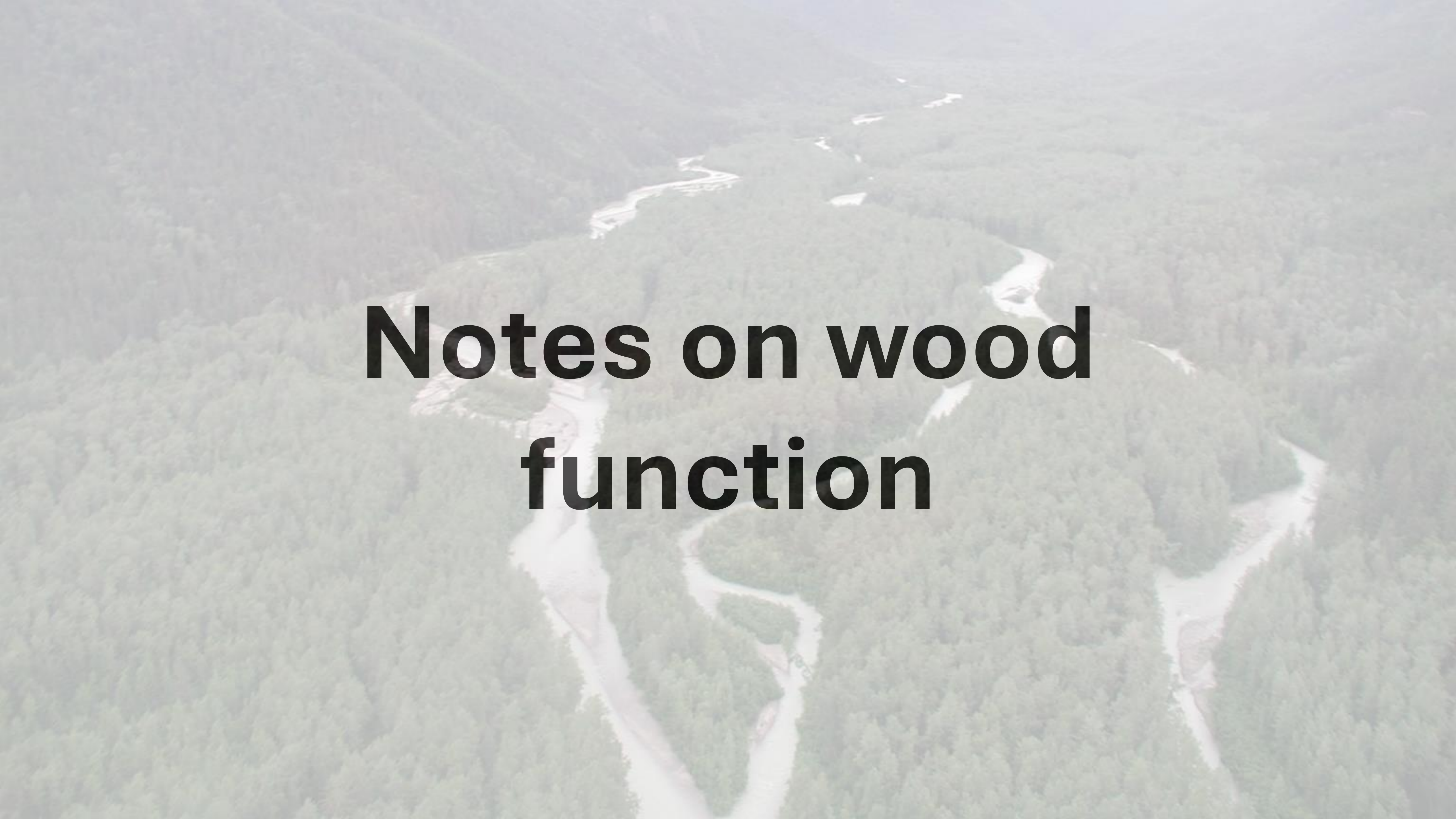
Few places have 'natural' wood loading

Sandy River, Oregon 1965

Clearing
Dredging
Deforestation
Confinement
Splash damming

Millions of pieces of wood removed from North American Streams

Notes on wood function



Wood increases bed complexity and pool frequency by introducing **large roughness elements**

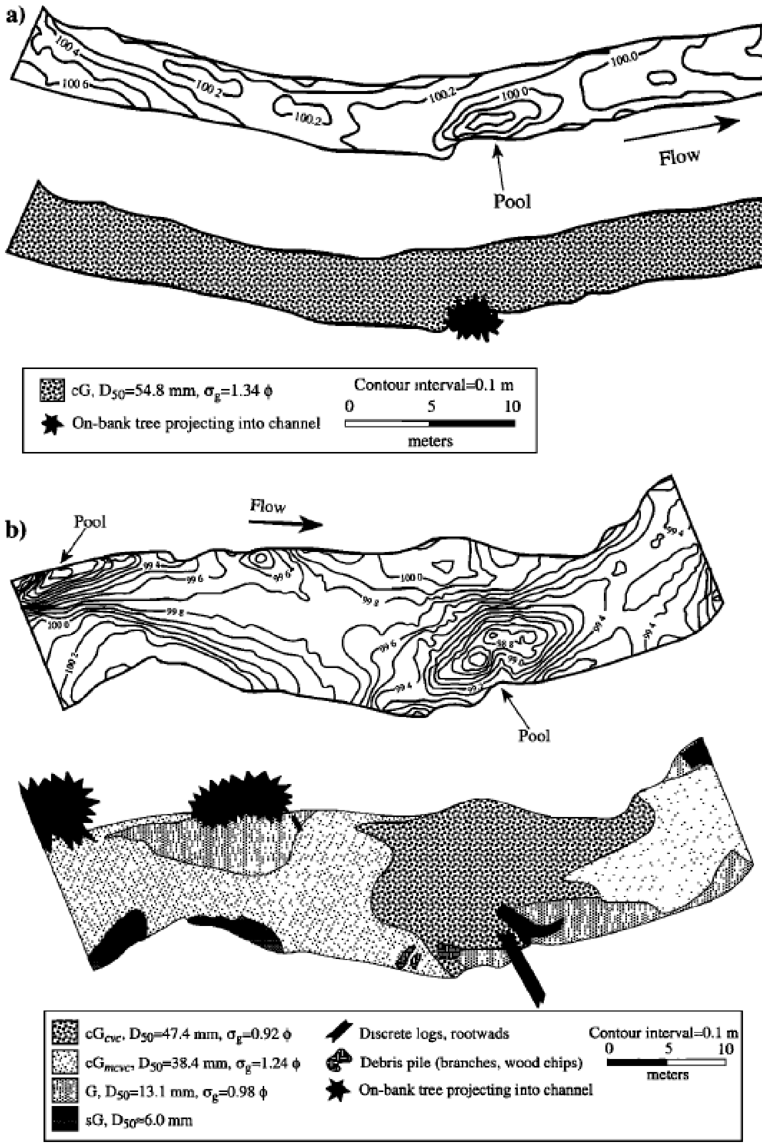


Figure 8. Morphologic and textural plan maps of typical (a) plane-bed (Hoko River 2), (b) wood-poor pool-riffle (Hoko River 1), and (c) wood-rich pool-riffle (Mill Creek) channels studied on the Olympic Peninsula [from *Buffington and Montgomery*, 1999]. See Table 3 for texture definitions. Boundary between channel bed and walls defines the lateral margin of the maps.

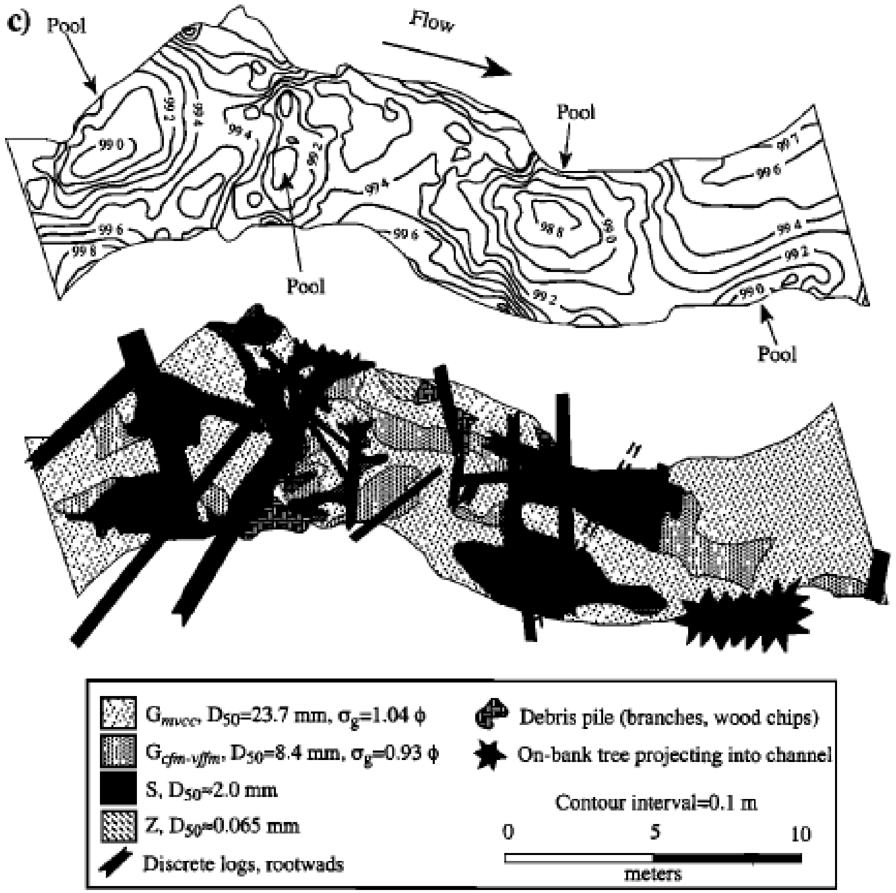
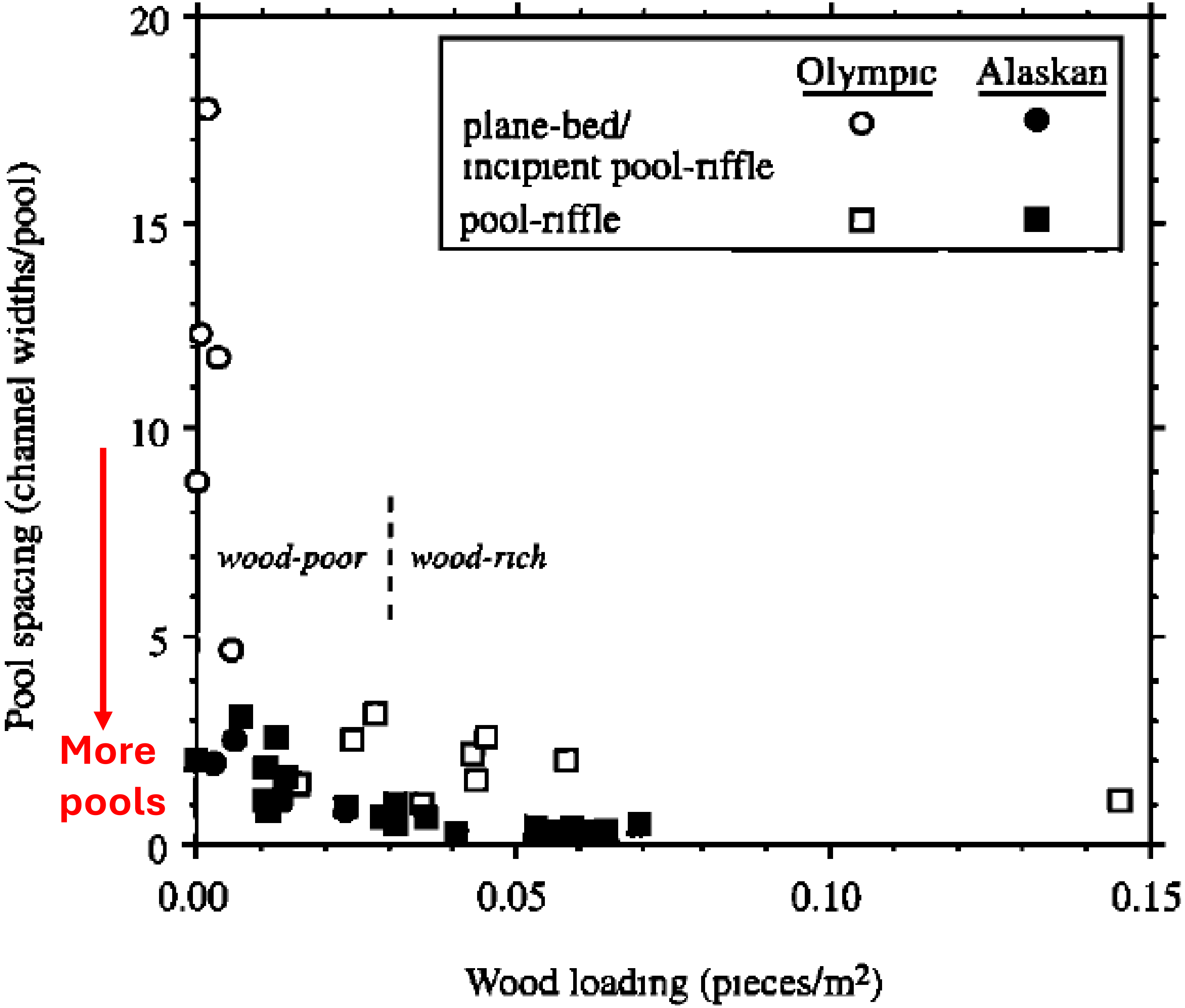


Figure 8c. (continued)

Buffington, J. and Montgomery, D. 1999



Buffington, J. and Montgomery, D. 1999

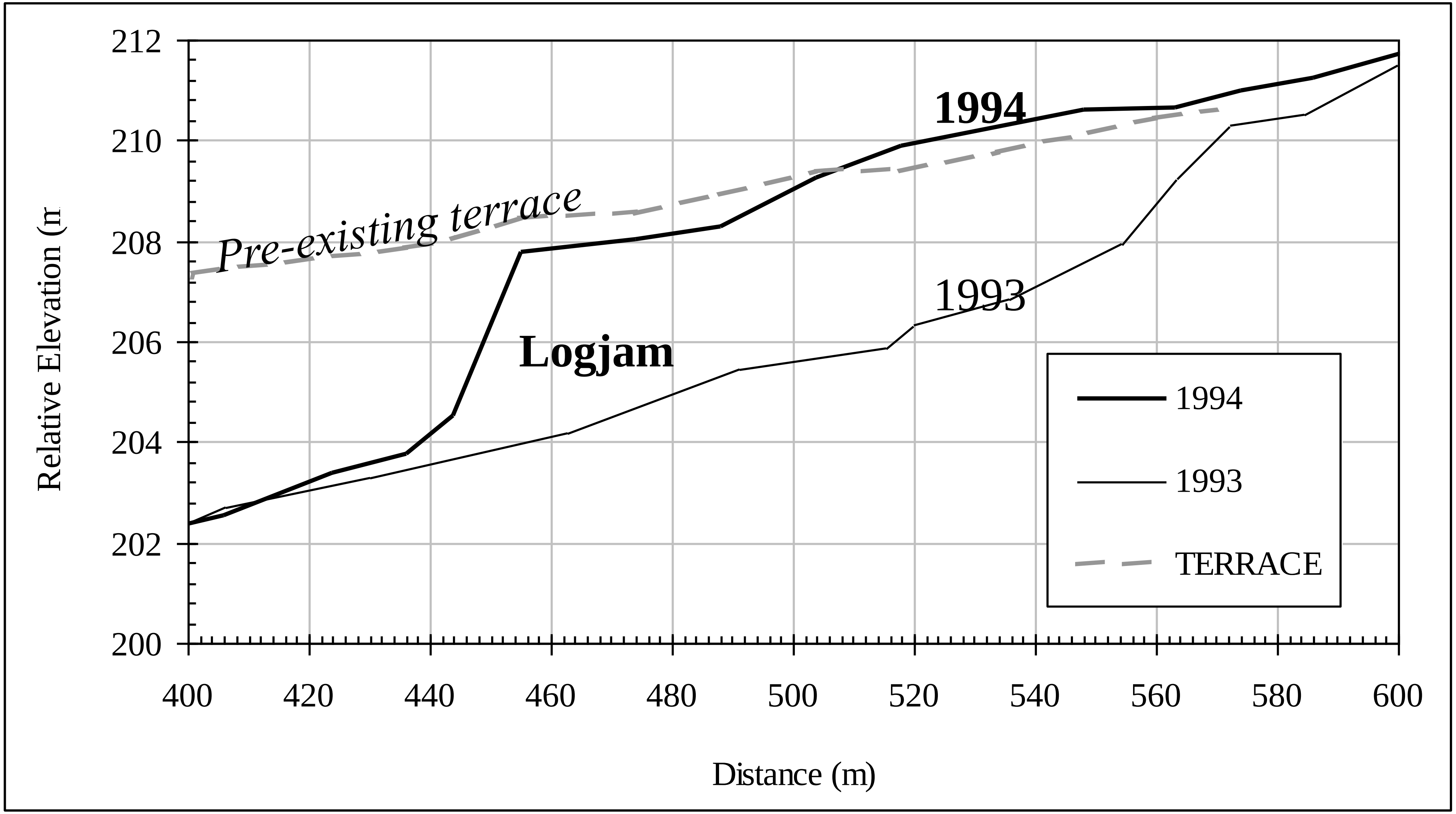
Wood rich streams have pool spacings ranging from 0.2 to 3 channel widths.

Wood poor streams have pool spacings from 1 to 17 channel widths

Channel profile and valley influences

Bed aggradation associated with logjams:

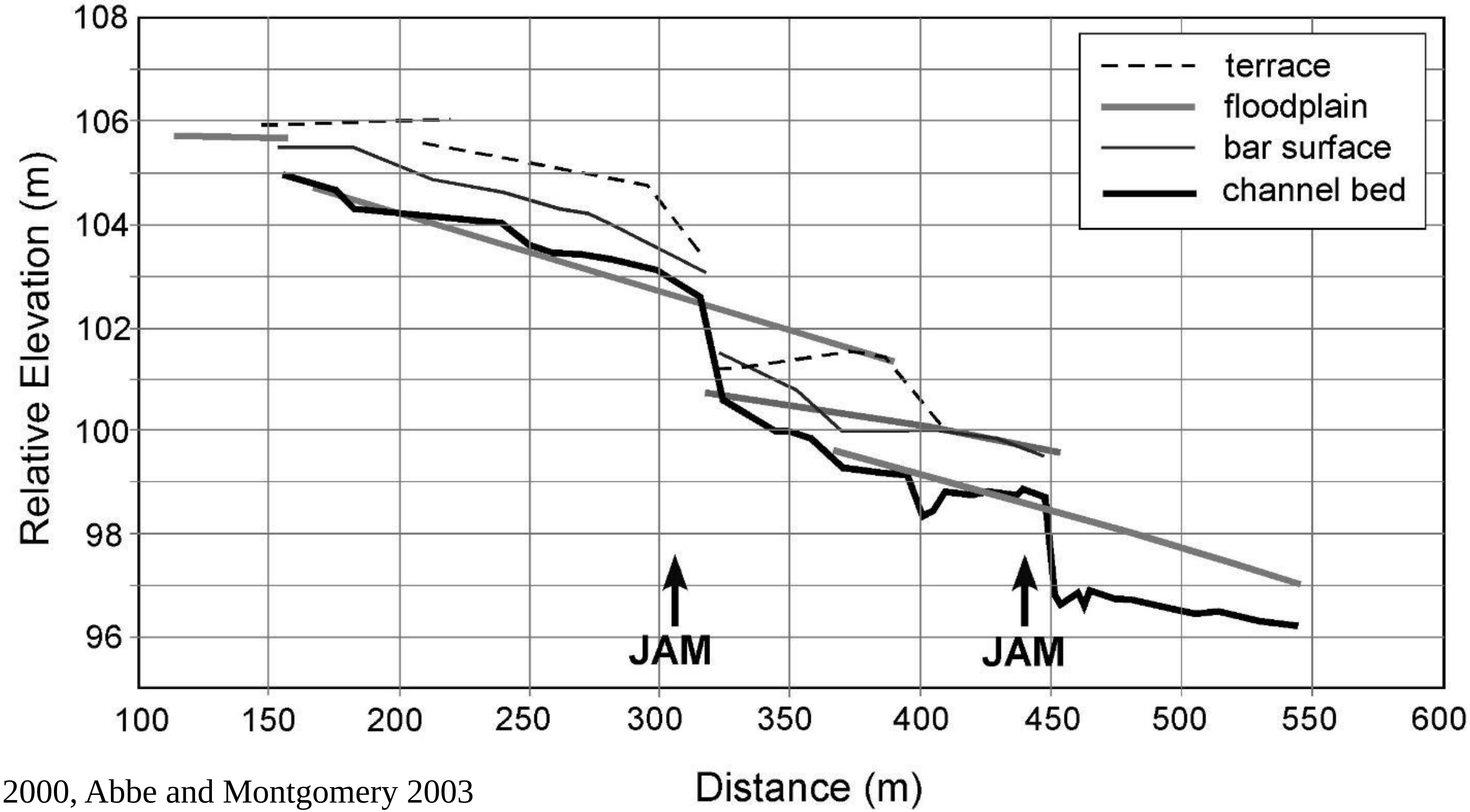
Alta Creek, Queets River Basin



Abbe 2000, Abbe and Montgomery 2003

Discontinuous, oblique alluvial surfaces create complex floodplains,

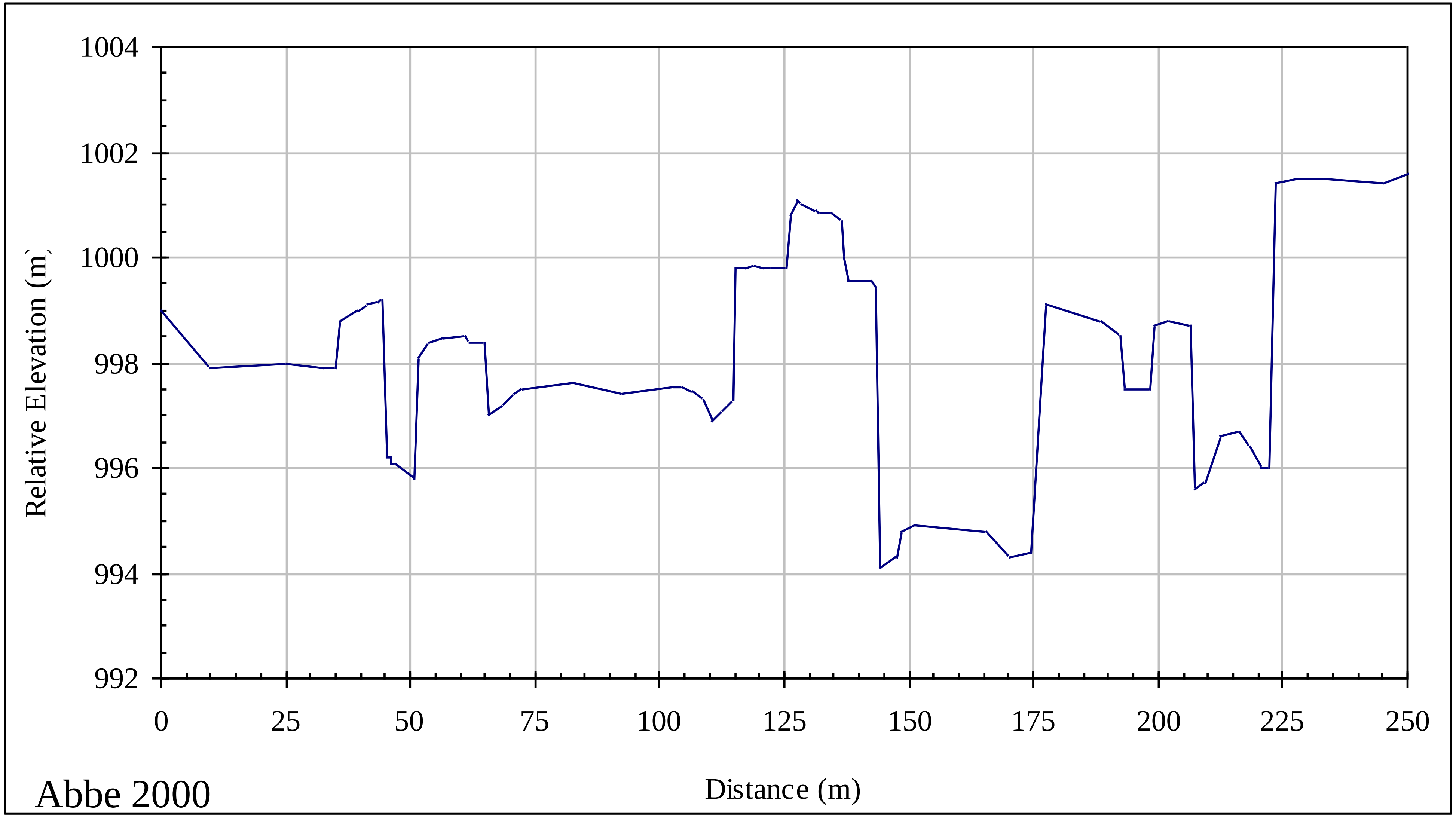
Queets River mainstem



Abbe 2000, Abbe and Montgomery 2003

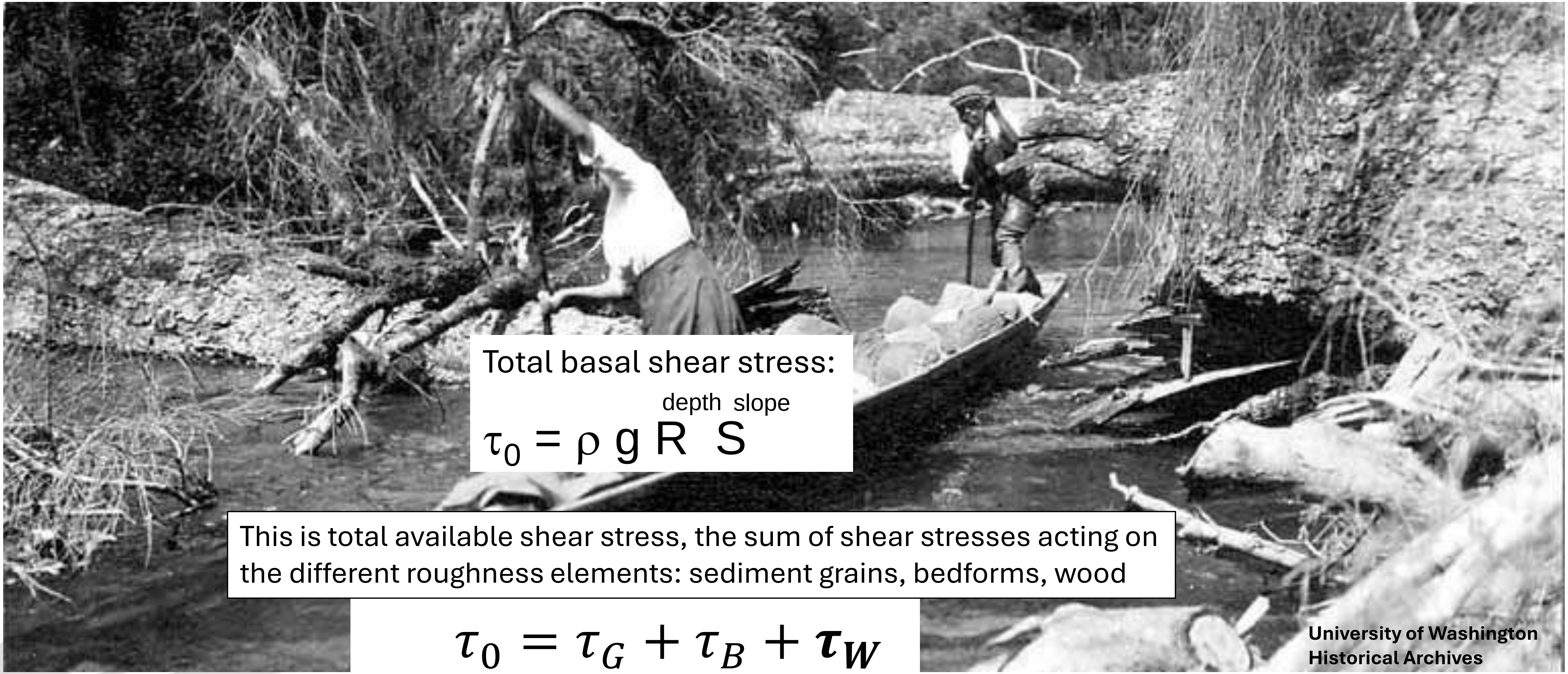
Wood creates more complex valley bottoms

Alta Creek, Queets River Basin



Abbe 2000

Engineered Logjams: Stress partitioning by wood



Total basal shear stress:

$$\tau_0 = \rho\, g\, \overset{\text{depth}}{R}\ \overset{\text{slope}}{S}$$

This is total available shear stress, the sum of shear stresses acting on the different roughness elements: sediment grains, bedforms, wood

$$\tau_0 = \tau_G + \tau_B + \boldsymbol{\tau_W}$$

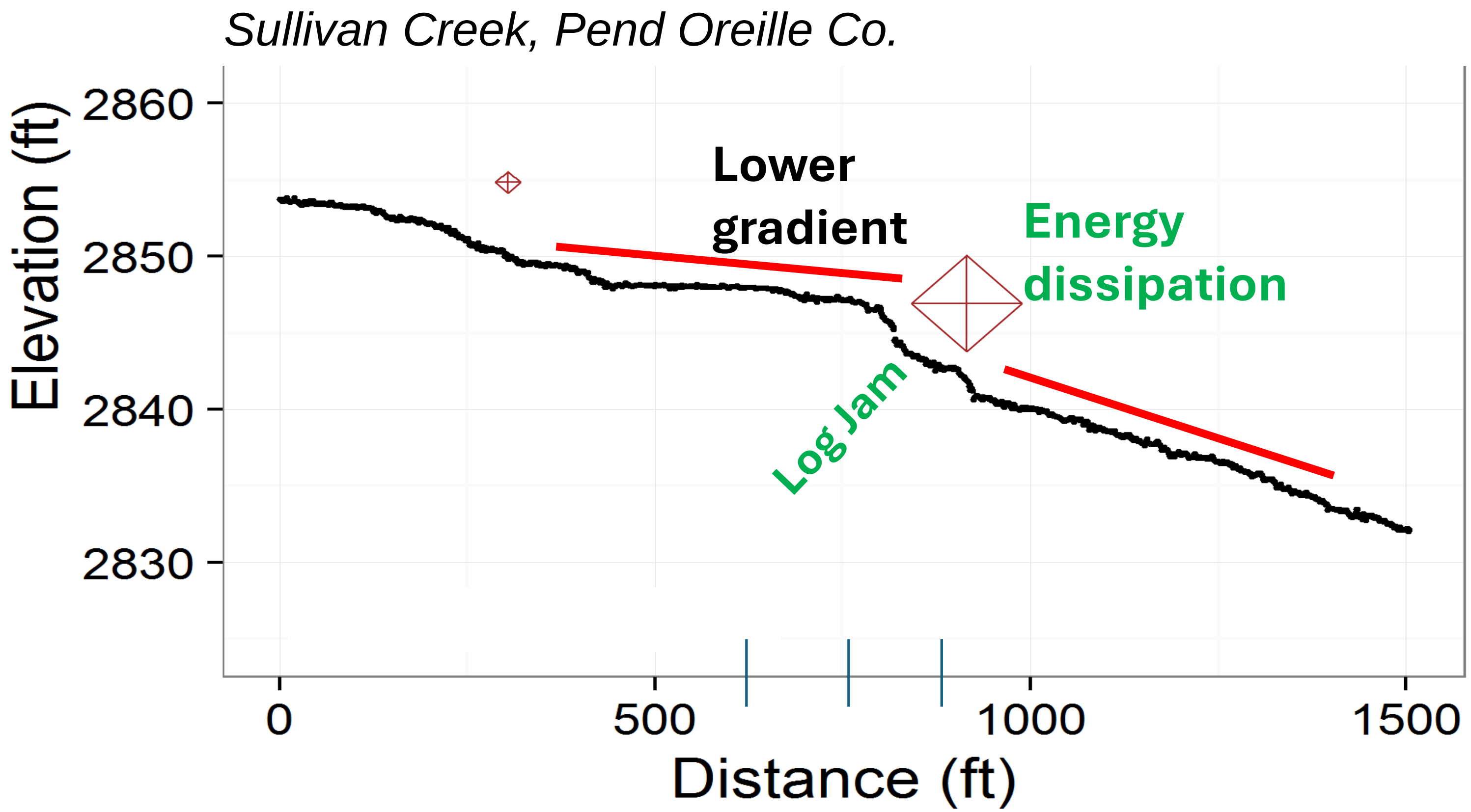
University of Washington Historical Archives

τ_G = *grain shear stress (responsible for sediment transport)*

τ_B = *bedform shear stress*

τ_W = *wood shear stress*

Engineered Logjams: Stress partitioning by wood



By reducing channel slope wood reduces grain shear stress, captures bed material and reduces D_{50}

τ_0 = 140 Pa

τ_w = 105 Pa

τ_{gr} = 35 Pa **a 4-fold reduction in sediment transport capacity**

Engineered Logjams: Stress partitioning by wood

Q2   = 820 cfs
Q100 = 1,280 cfs

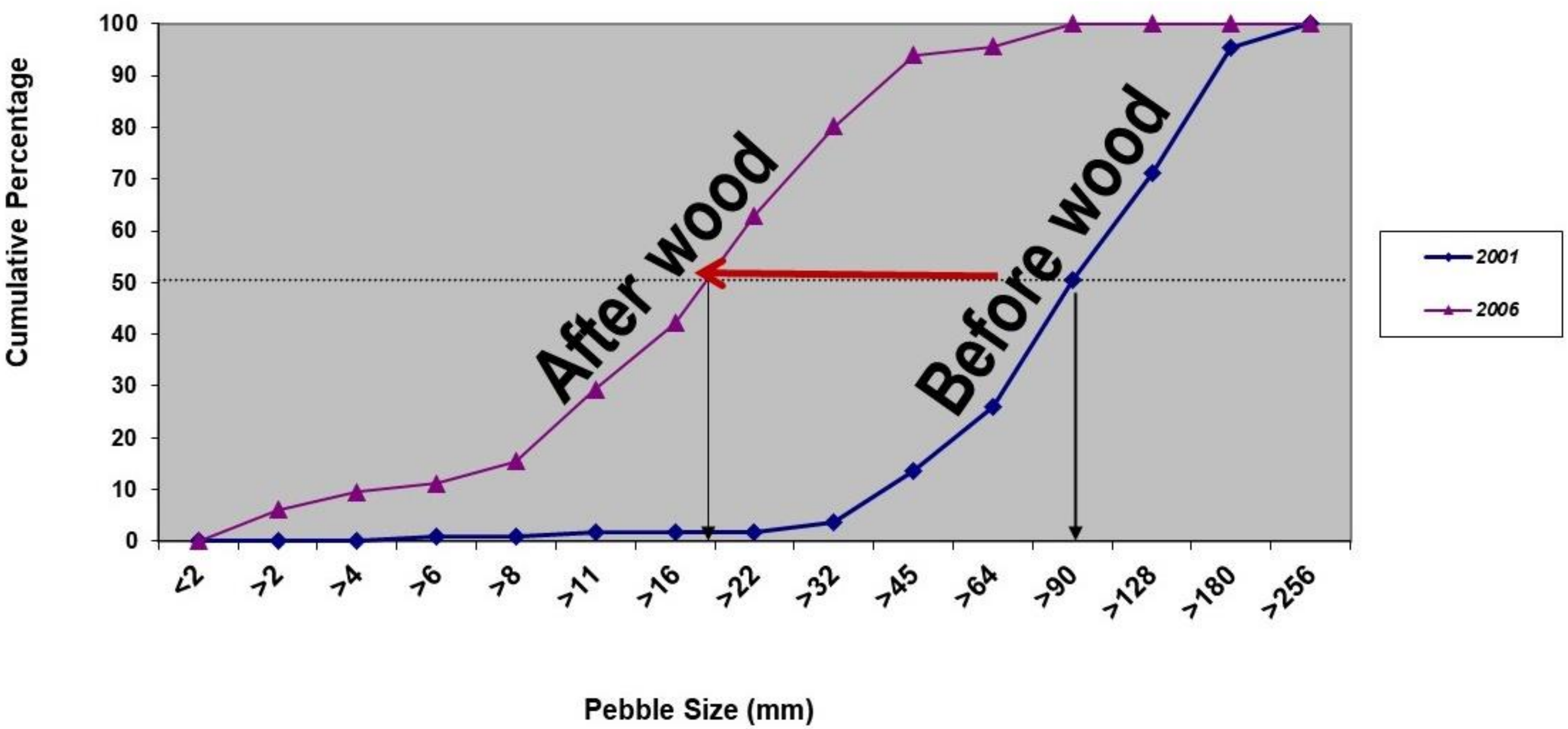
Sullivan Creek, WA   2018 PRE-PROJECT

Engineered Logjams: Stress partitioning by wood

Sullivan Creek, WA   2020 - TWO YEARS POST PROJECT

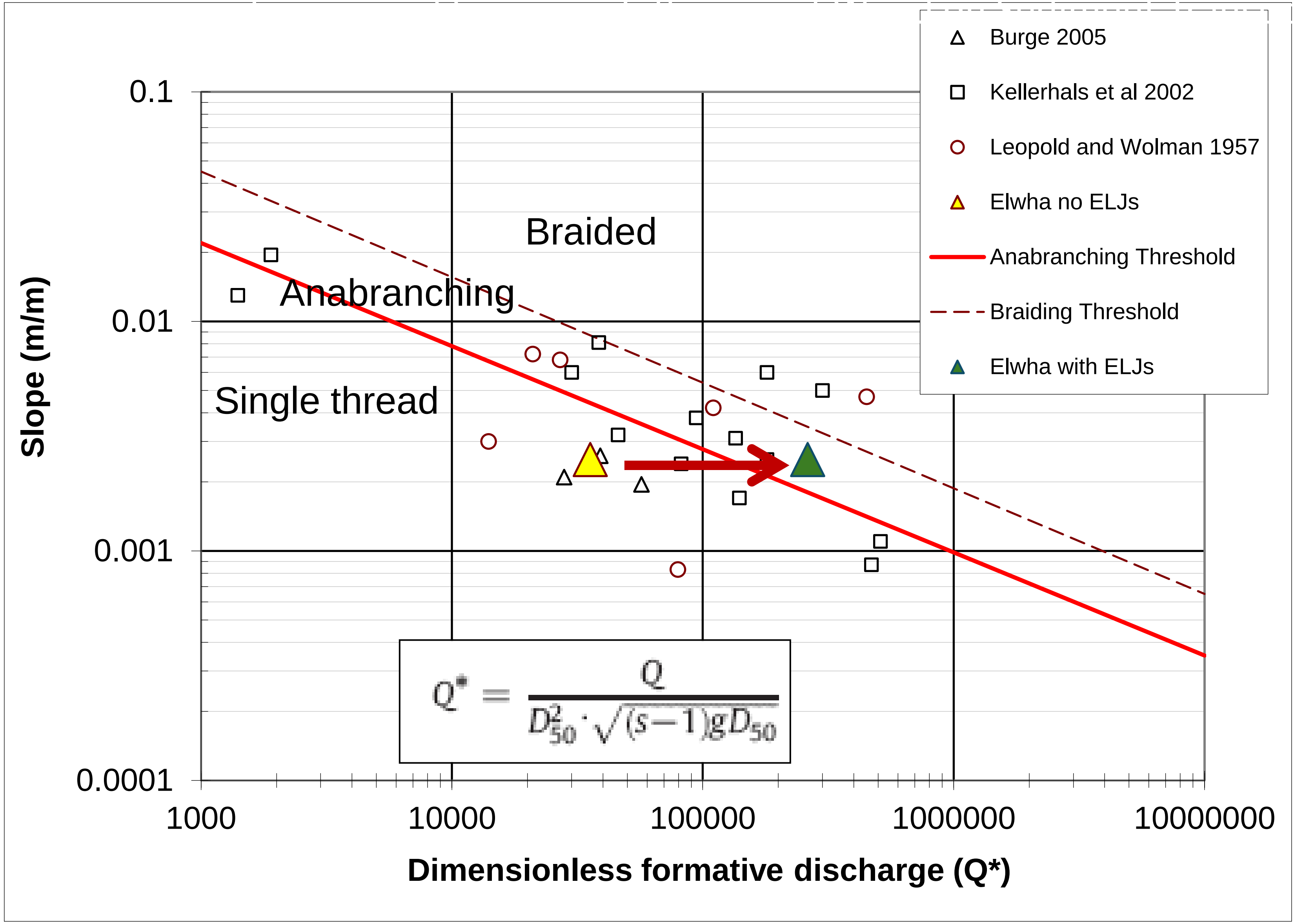
Lower Elwha River response to engineered logjams

As wood partitioning more shear stress grain size diminishes



D50 of bed decreased almost 5 fold after ELJs were installed.
D50(before) = 90 mm, D50 (after) = 19 mm

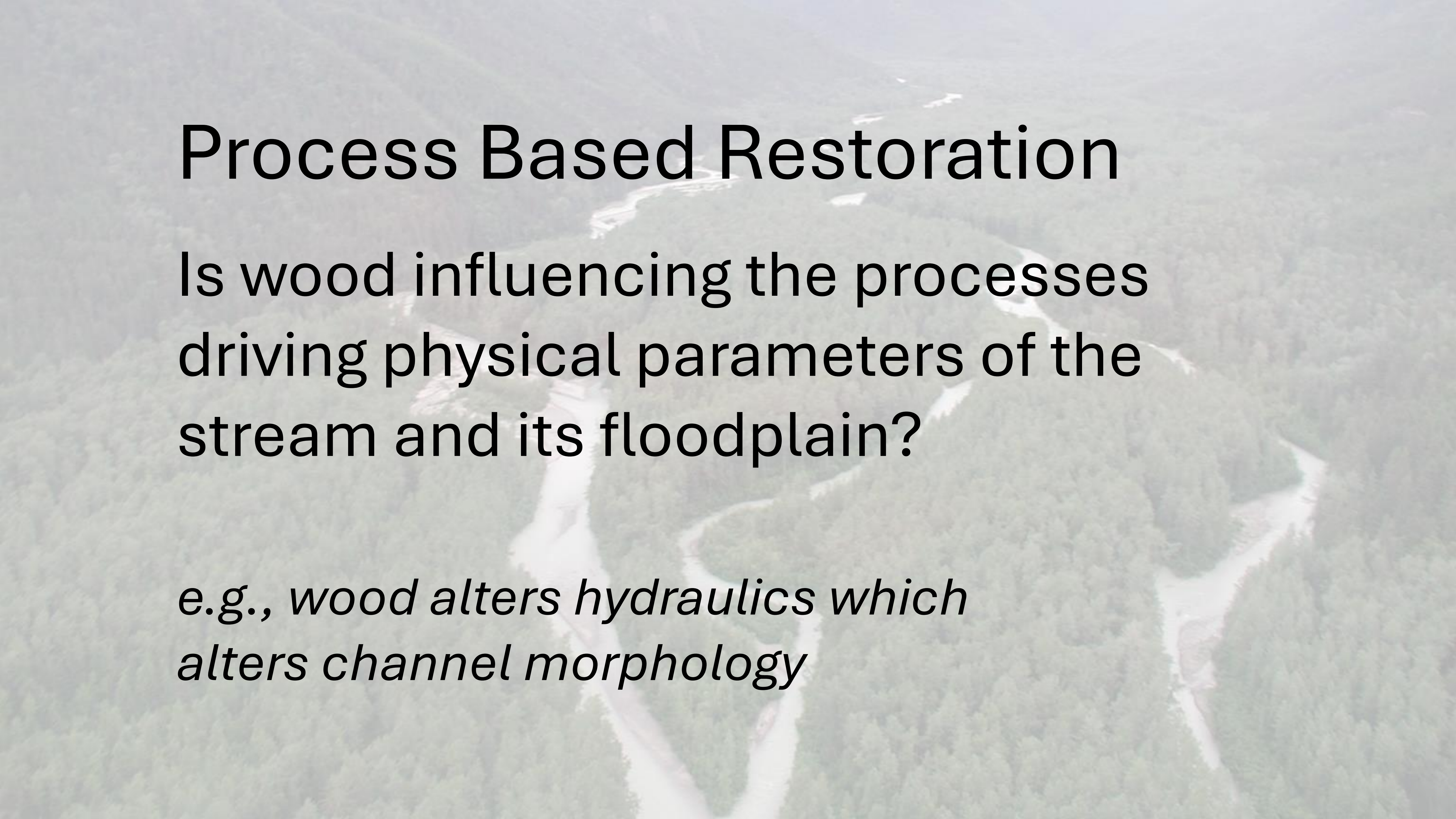
Engineered Logjams: Influence of Channel Form



$$Q^* = \frac{Q}{D_{50}^2 \cdot \sqrt{(s-1)gD_{50}}}$$

Reducing substrate grain size can change channel planform

(adapted from Eaton et al. 2010)



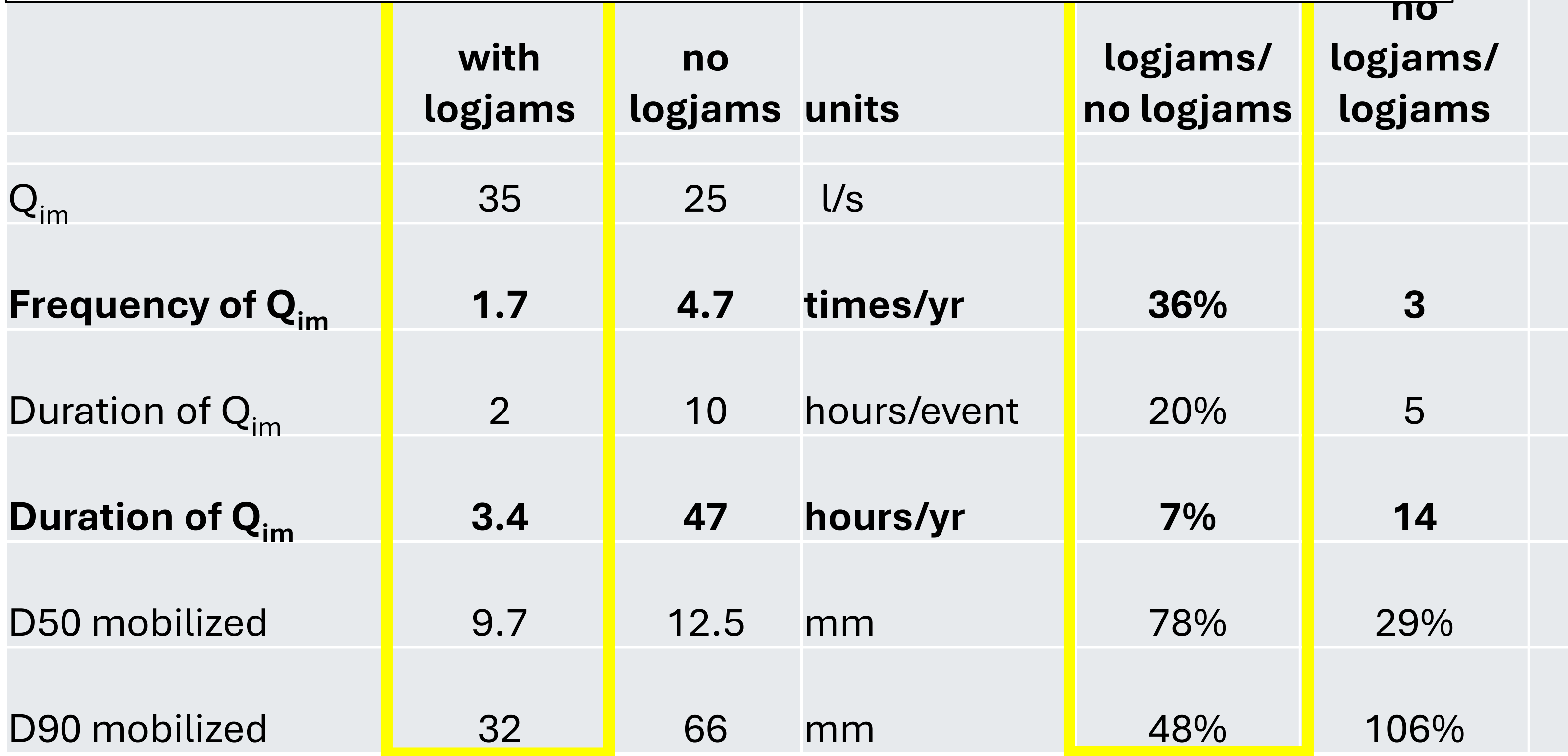
Process Based Restoration

Is wood influencing the processes driving physical parameters of the stream and its floodplain?

e.g., wood alters hydraulics which alters channel morphology

Engineered Logjams: Process influence of wood

Assani and Petit 1995 study of wood and bed mobility

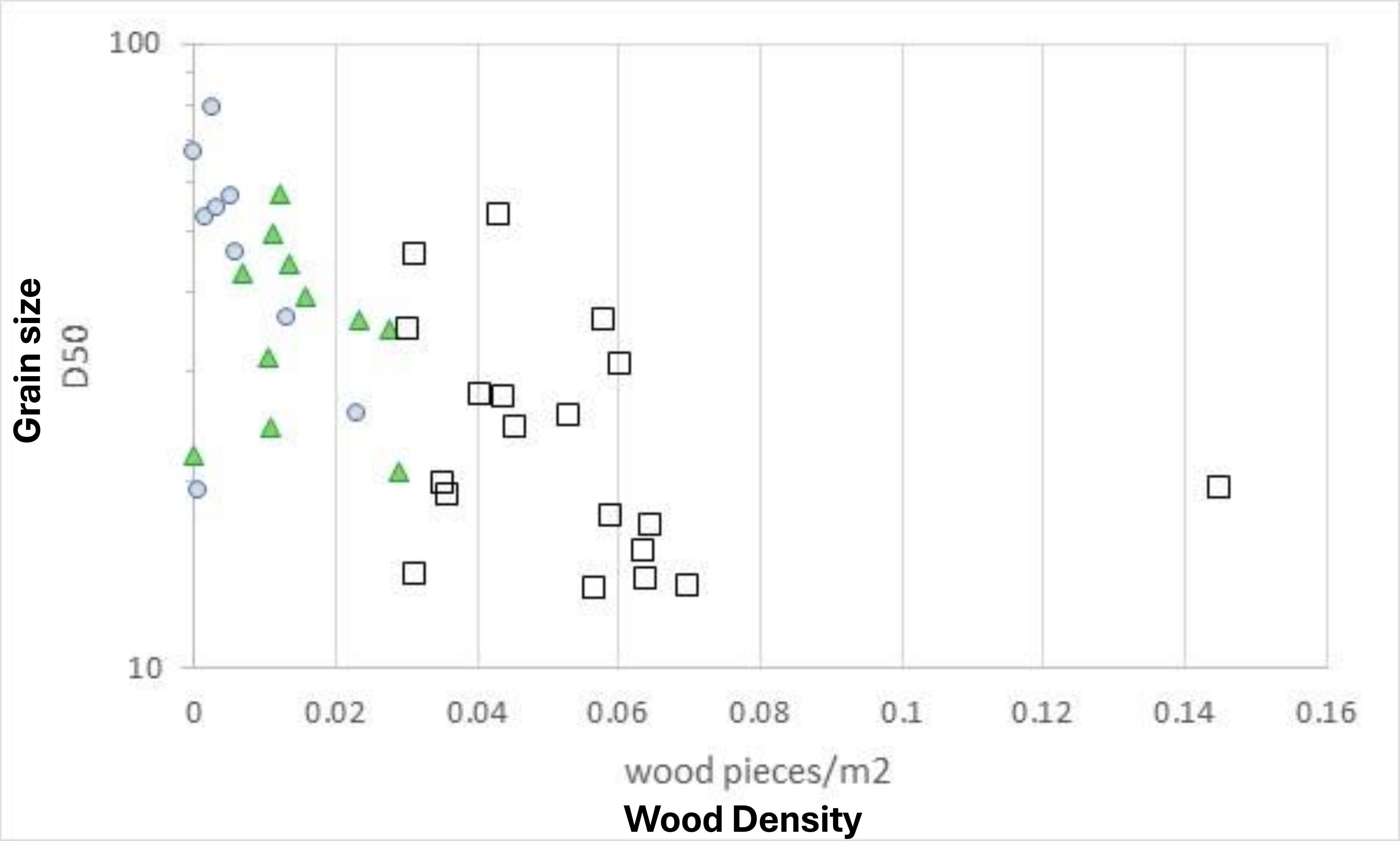


	with logjams	no logjams	units	logjams/ no logjams	no logjams/ logjams
Q_{im}	35	25	l/s		
Frequency of Q_{im}	**1.7**	**4.7**	**times/yr**	**36%**	**3**
Duration of Q_{im}	2	10	hours/event	20%	5
Duration of Q_{im}	**3.4**	**47**	**hours/yr**	**7%**	**14**
D50 mobilized	9.7	12.5	mm	78%	29%
D90 mobilized	32	66	mm	48%	106%

Q_{im} = Q at initiation of bed load motion (~50% of marked pebbles in motion)

Bedload Mobilization	**Effect of wood removal**
Frequency	3x increase
Duration	14x increase
D50	1.3x increase in size
D90	2.1x increase in size

Engineered Logjams: Process influence of wood

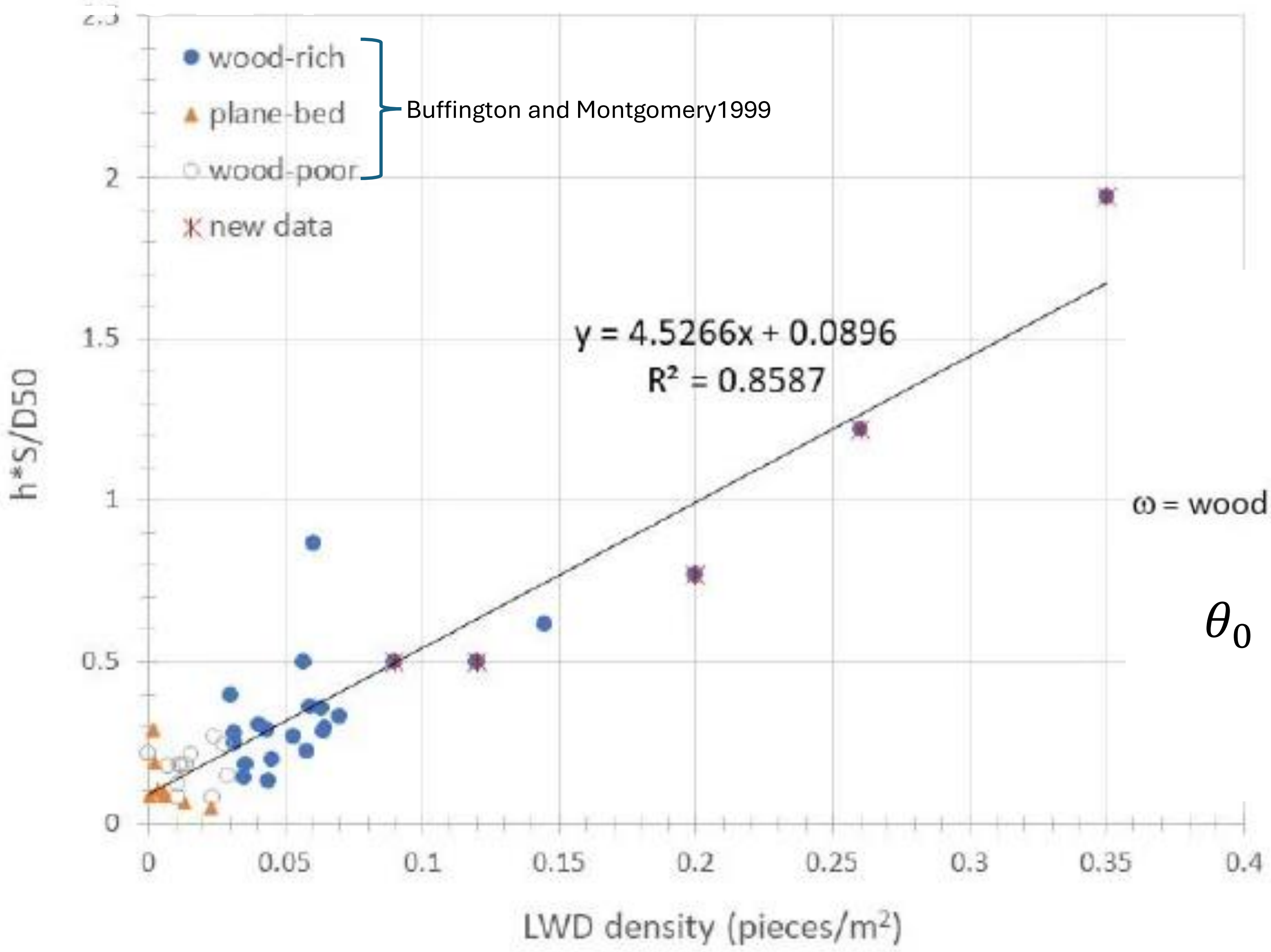


Grain size

Wood Density

Buffington, J. and Montgomery, D. 1999

Engineered Logjams: Process influence of wood



Buffington and Montgomery1999

Wood Density

$$\frac{hS}{D_{50}} = 4.5266\omega + 0.0896$$

ω = wood density (pieces/m2)

$$\theta_0 = \frac{\rho}{(\rho_s - \rho)}(4.5266\omega + 0.0896)$$

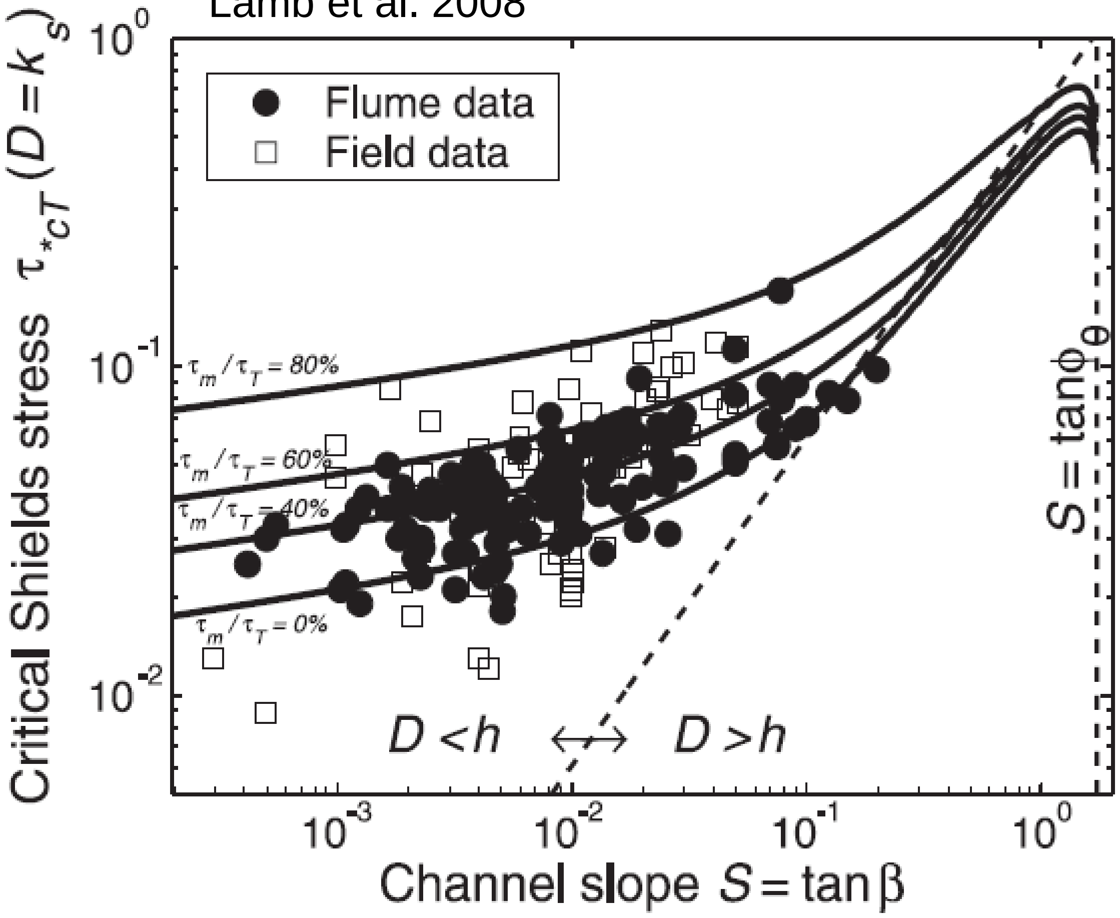
$$\theta_0 = 2.7436\omega + 0.0543$$

Engineered Logjams: Influence of Wood on Scour

Scour depth derivation of Haschenburger (1999):

$$d_s = \frac{1}{3.33^{-1.52\,\theta_0/\theta_c}}$$

Lamb et al. 2008



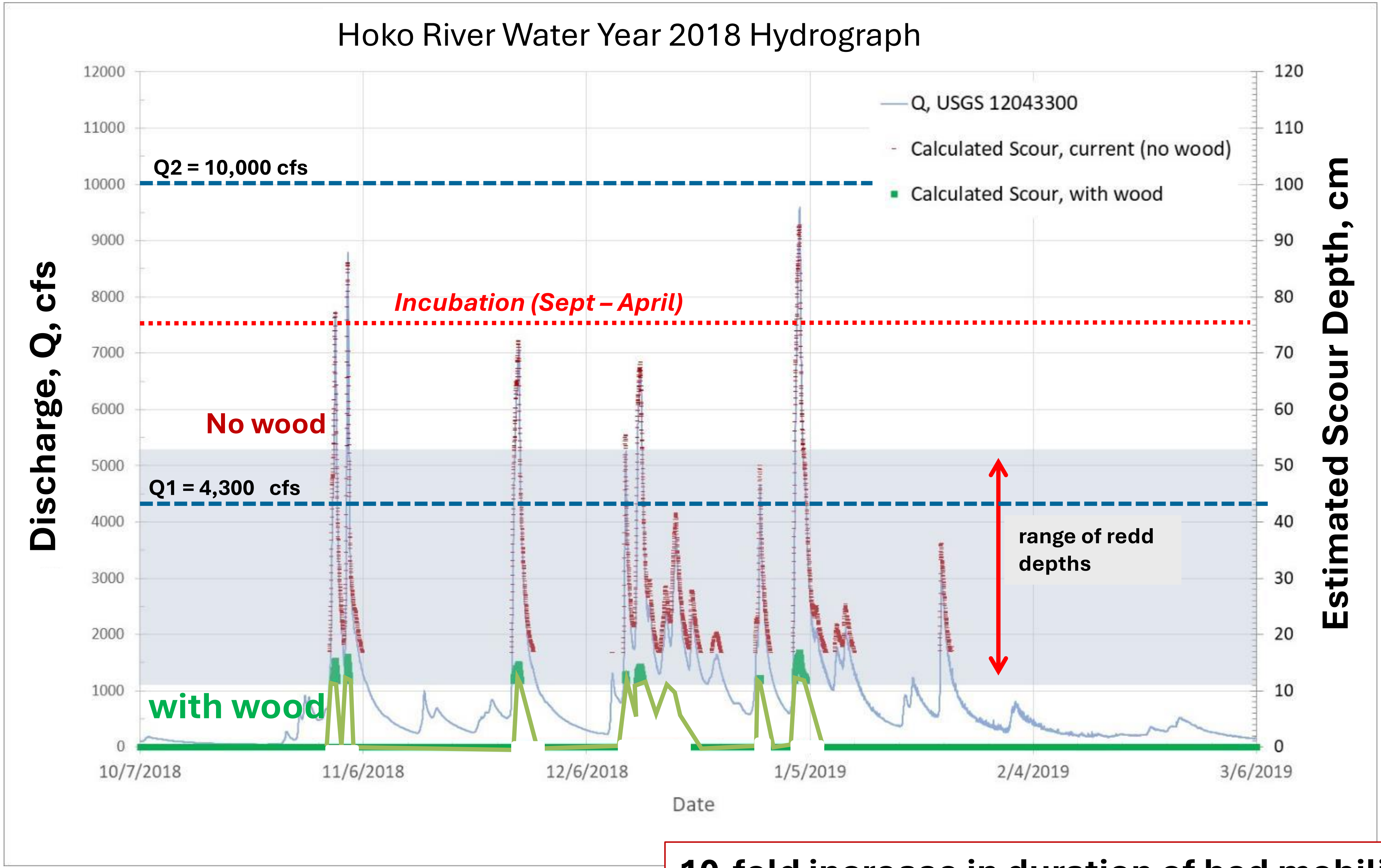
$$\theta_0 = \frac{\tau_o}{(\rho_s-\rho)\,g\,D_{50}}$$

$$\theta_c = 0.15S^{0.25}$$

Critical Shields stress increases with morphologic drag

τ_m / τ_T = shear stress associated with morphologic structures / total stress

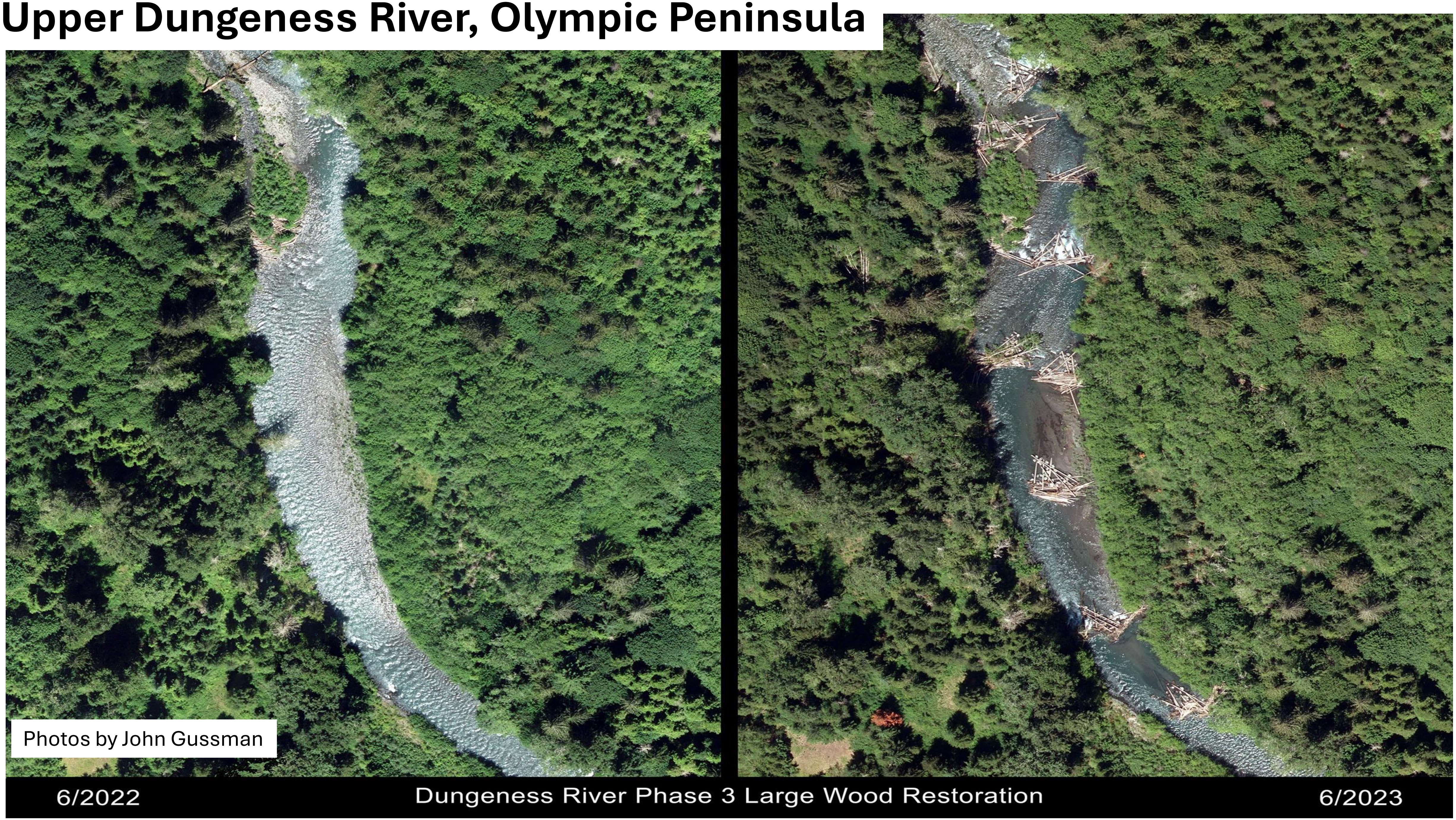
Scour modeling example, Lower Hoko River, WA



10-fold increase in duration of bed mobilization
5-fold increase in magnitude of scour

Project Examples

Upper Dungeness River, Olympic Peninsula



Photos by John Gussman

6/2022

Dungeness River Phase 3 Large Wood Restoration

6/2023

Upper Dungeness River

01-31-25
Photo by John Gussman

Upper Dungeness River


01-25-25

Upper Dungeness River: pre-project representative substrate

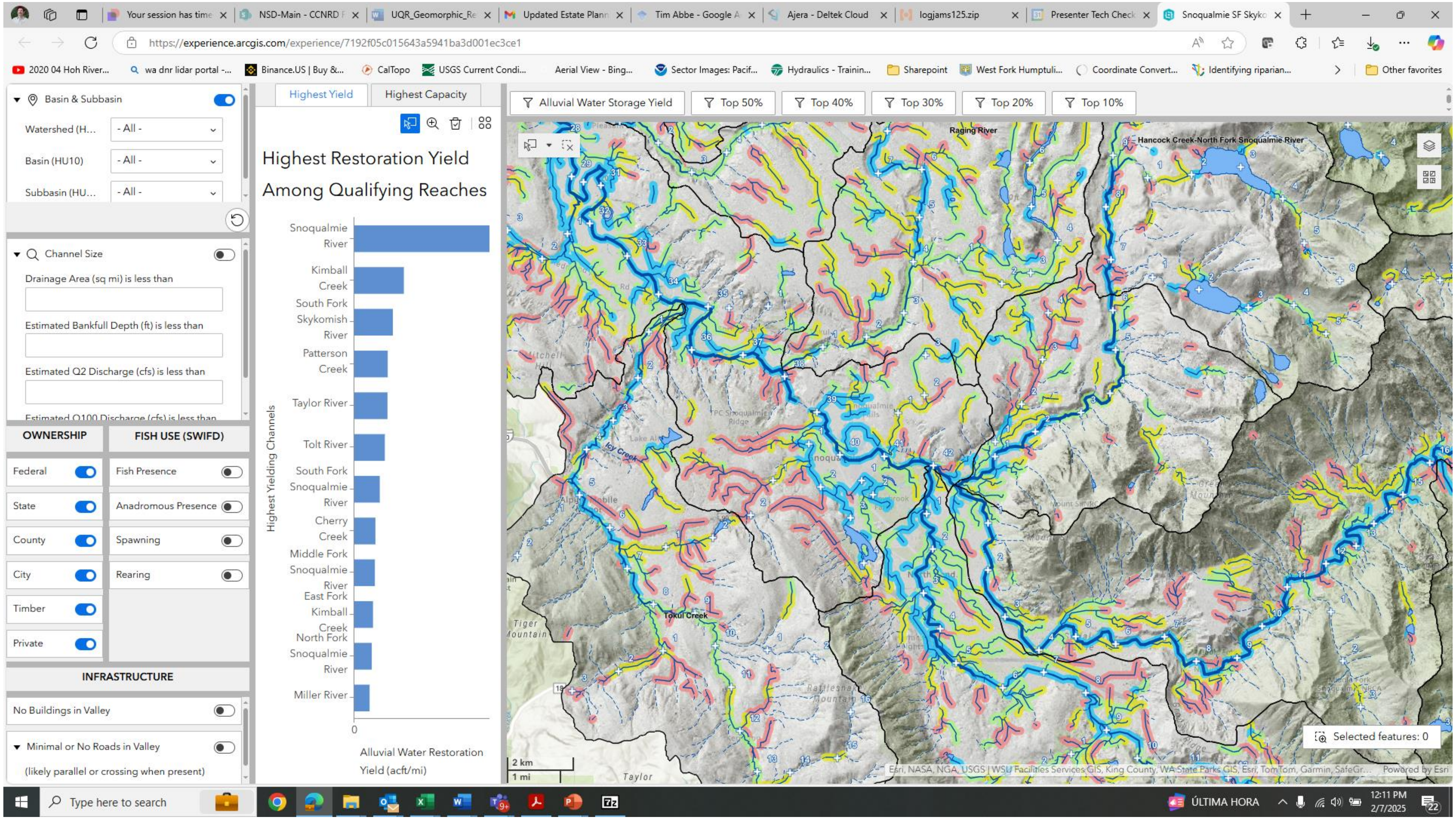
Upper Dungeness River: Post-project substrate

Upper Dungeness River

09-22-23

Restoring Incised Channels

Development of New Tools: DEM models for alluvial water storage and restoration potential



https://experience.arcgis.com/experience/7192f05c015643a5941ba3d001ec3ce1

Basin & Subbasin ●

Watershed (H... - All -

Basin (HU10) - All -

Subbasin (HU... - All -

Channel Size ○

Drainage Area (sq mi) is less than

Estimated Bankfull Depth (ft) is less than

Estimated Q2 Discharge (cfs) is less than

Estimated Q100 Discharge (cfs) is less than

OWNERSHIP		FISH USE (SWIFD)	
Federal	●	Fish Presence	○
State	●	Anadromous Presence	○
County	●	Spawning	○
City	●	Rearing	○
Timber	●		
Private	●		

INFRASTRUCTURE

No Buildings in Valley ○

Minimal or No Roads in Valley ○

(likely parallel or crossing when present)

Selected features: 0

Shale Creek
Olympic Peninsula

Shale Creek – helicopter construction

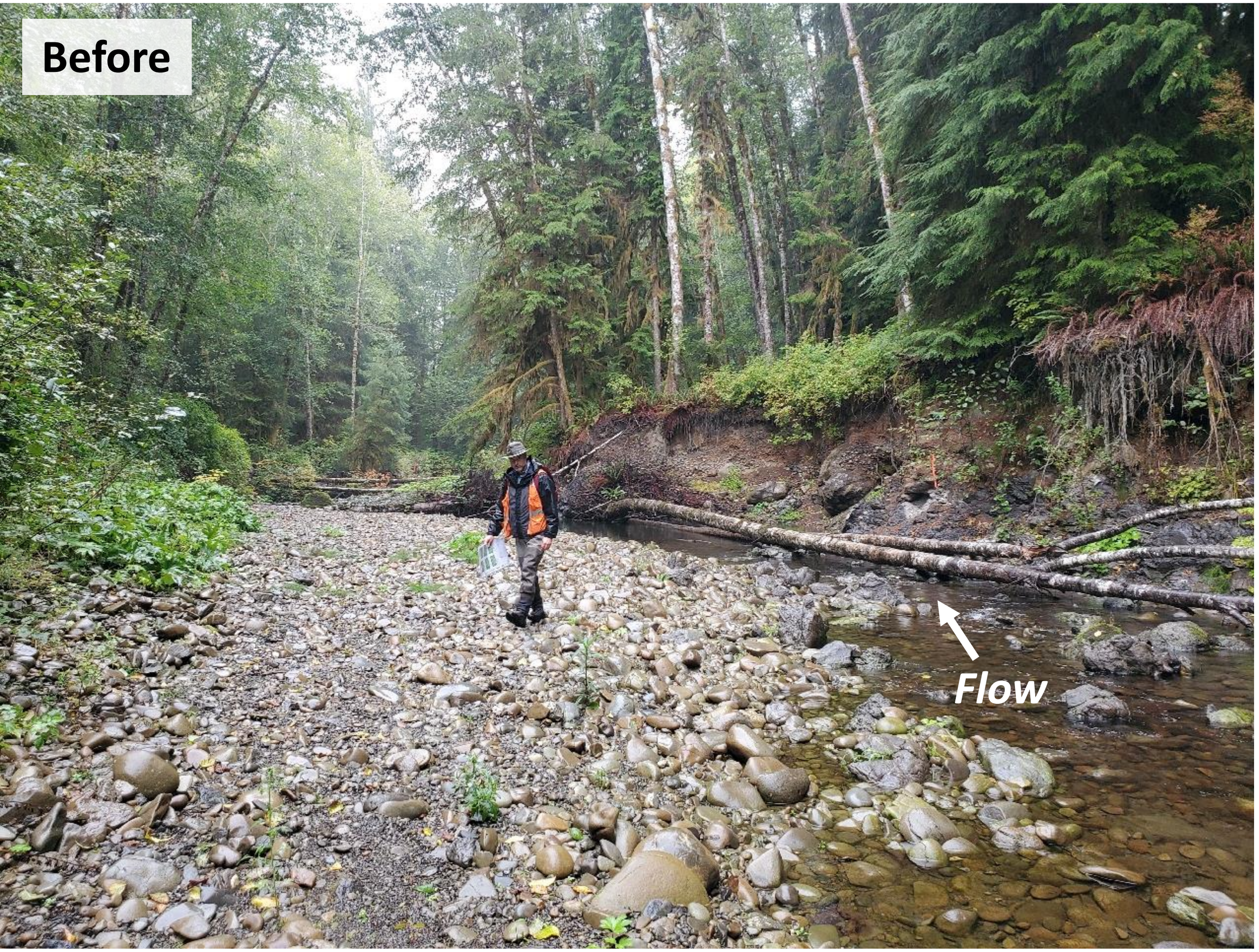
Shale Creek

Shale Creek

Structure 2

Shale Creek

Structure 12


Before

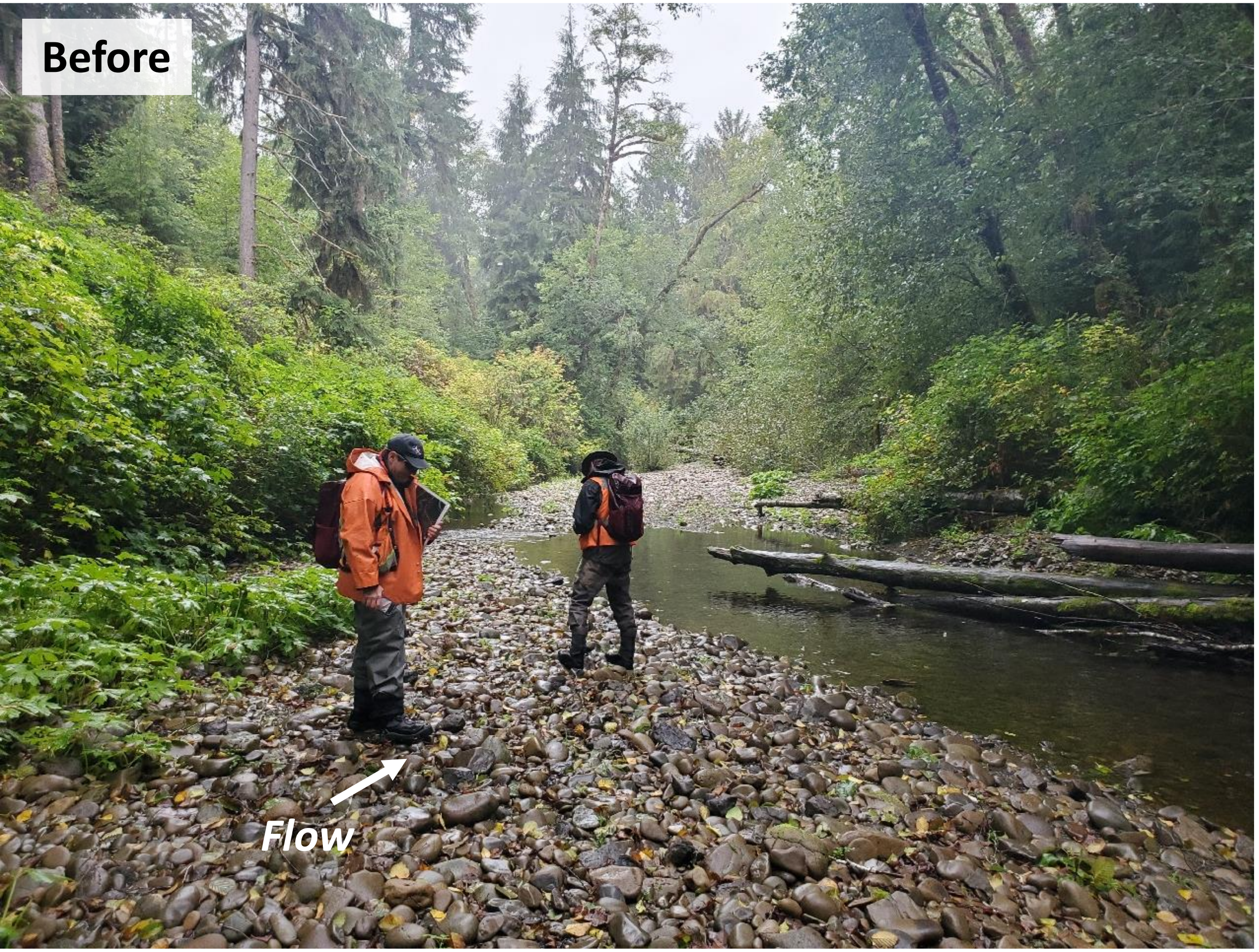

After (10/17/2023)

Shale Creek

Structure 13 (looking downstream)

Shale Creek

Structure 15


Before


After (5/2/2024)

South Prairie Creek
Puget Sound

South Prairie Creek -

Entrenched boulder plane-bed channel

New floodplain anabranch channel

Pre-existing straightened and incised channel

Engineered grade control structure CSS-3

February 9, 2022

Upstream of engineered grade control #2 - channel aggradation, wood accumulation, rise in water surface elevation

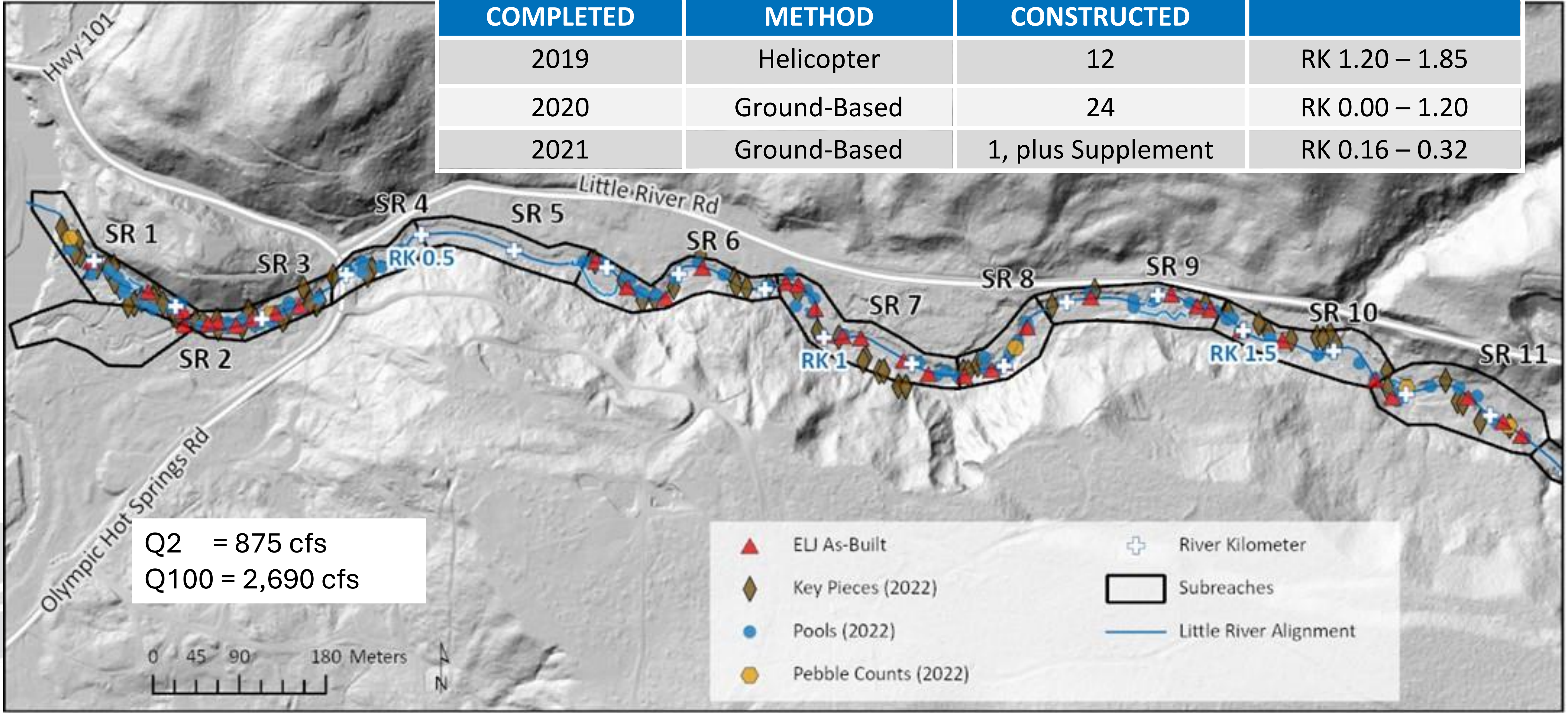
Little River

North Olympic Peninsula

Restoration of an incised channel

Little River, WA

YEAR COMPLETED	CONSTRUCTION METHOD	STRUCTURES CONSTRUCTED	LOCATION
2019	Helicopter	12	RK 1.20 – 1.85
2020	Ground-Based	24	RK 0.00 – 1.20
2021	Ground-Based	1, plus Supplement	RK 0.16 – 0.32



Q2 = 875 cfs
Q100 = 2,690 cfs

Engineered Logjams: Incision Restoration in Little River

River Kilometer: 1.68

Pre-Restoration (8/7/2019)

Post-Restoration (8/10/2022)

View: Upstream

View: Upstream

High-velocity riffle, cobble-boulder substrate plane bed channel.

→

Reduced flow velocity due to ELJ backwater, deposition of spawning gravels, pool-riffle channel

Engineered Logjams: Incision Restoration in Little River

River Kilometer: 1.13

Pre-Restoration (7/10/2020)

View: Downstream

Post-Restoration (8/10/2022)

View: Downstream

High-velocity riffle, cobble-boulder substrate. → Reduced flow velocity, increase in wetted width, deposition of gravels throughout, cobbles partially buried.

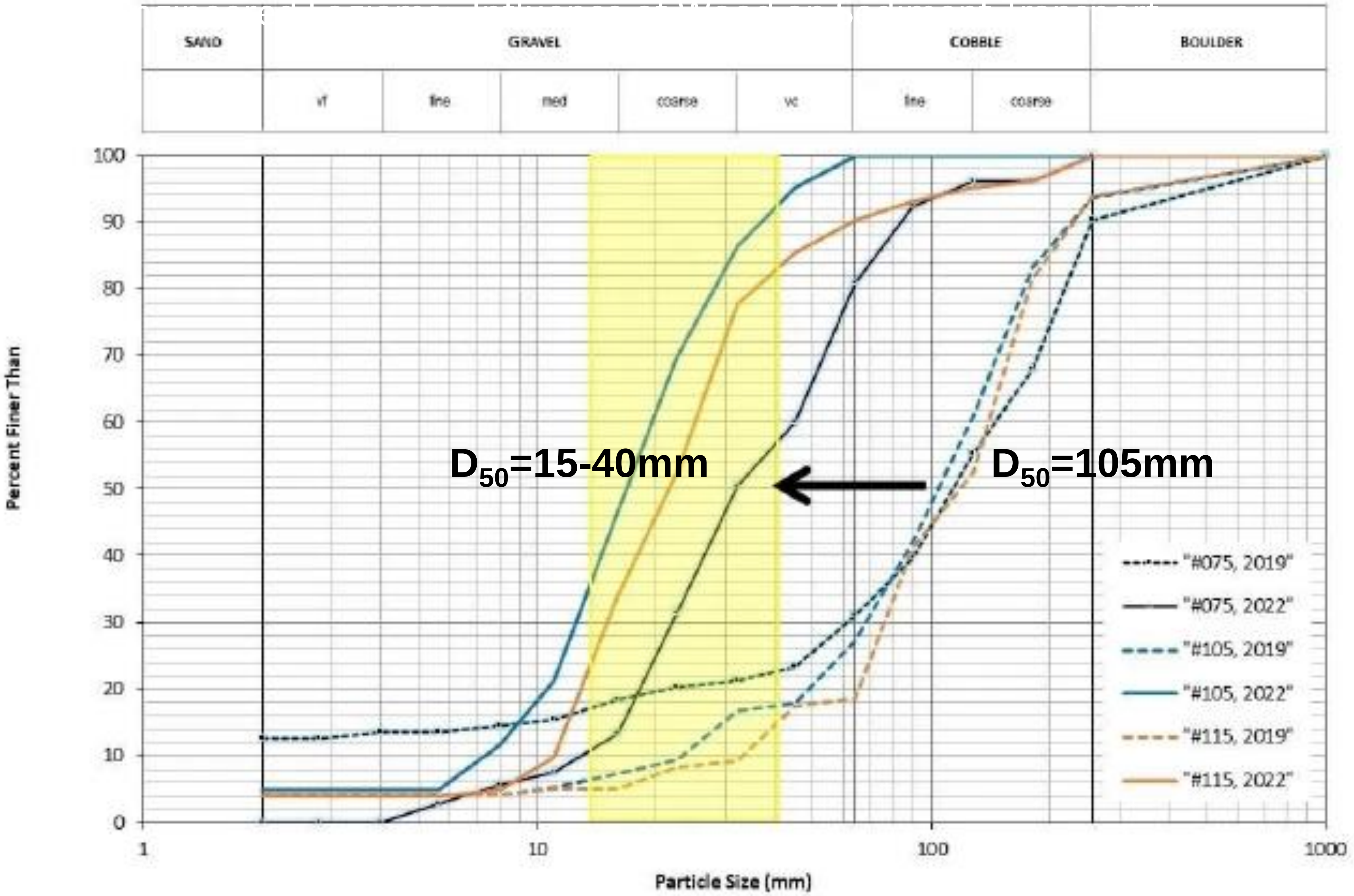
Engineered Logjams: Incision Restoration in Little River

Low flow, 07-05-23

Five layer log and rock-collar design

~Bankfull flow, 01-11-22

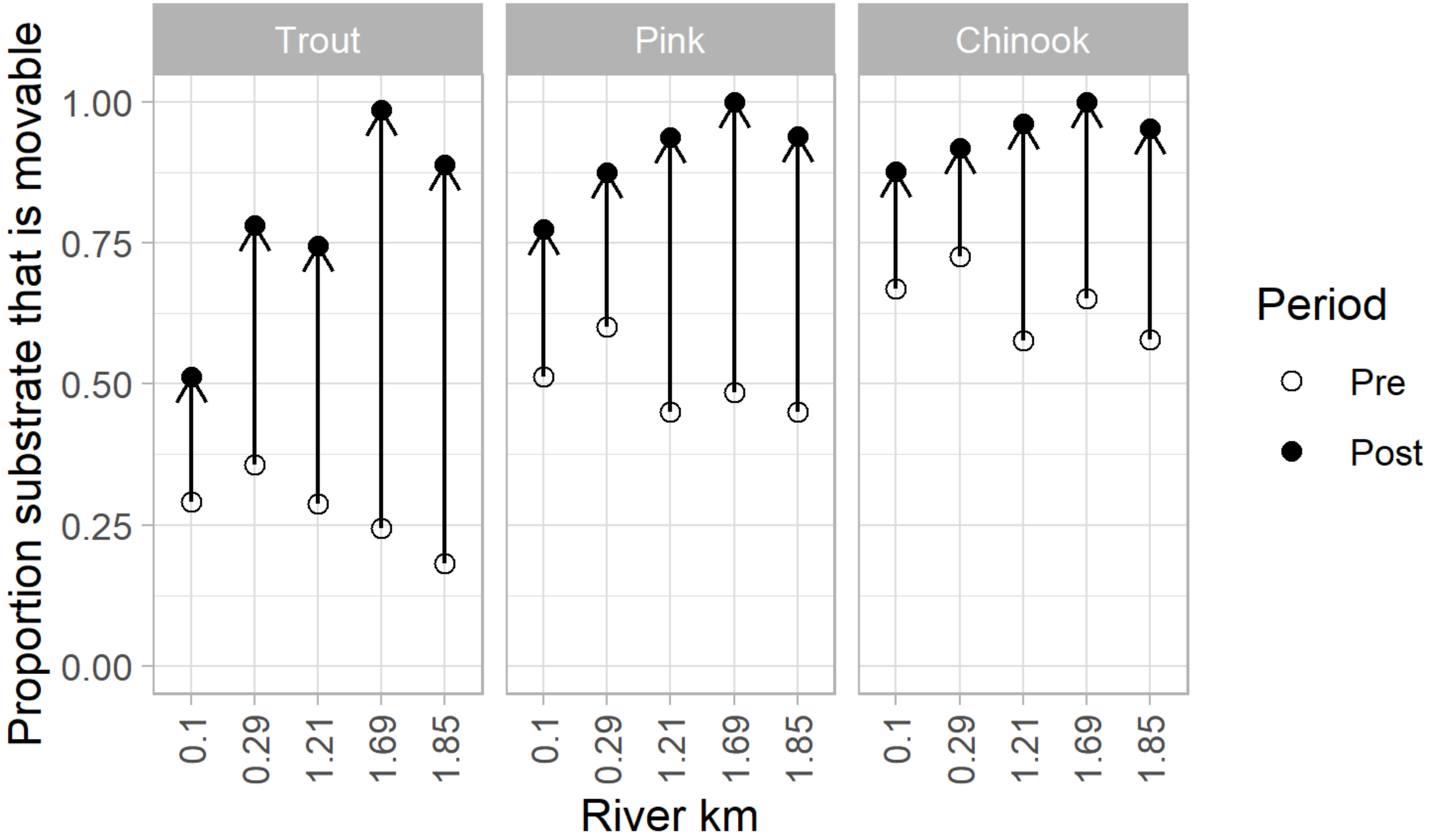
Little River response to engineered logjams



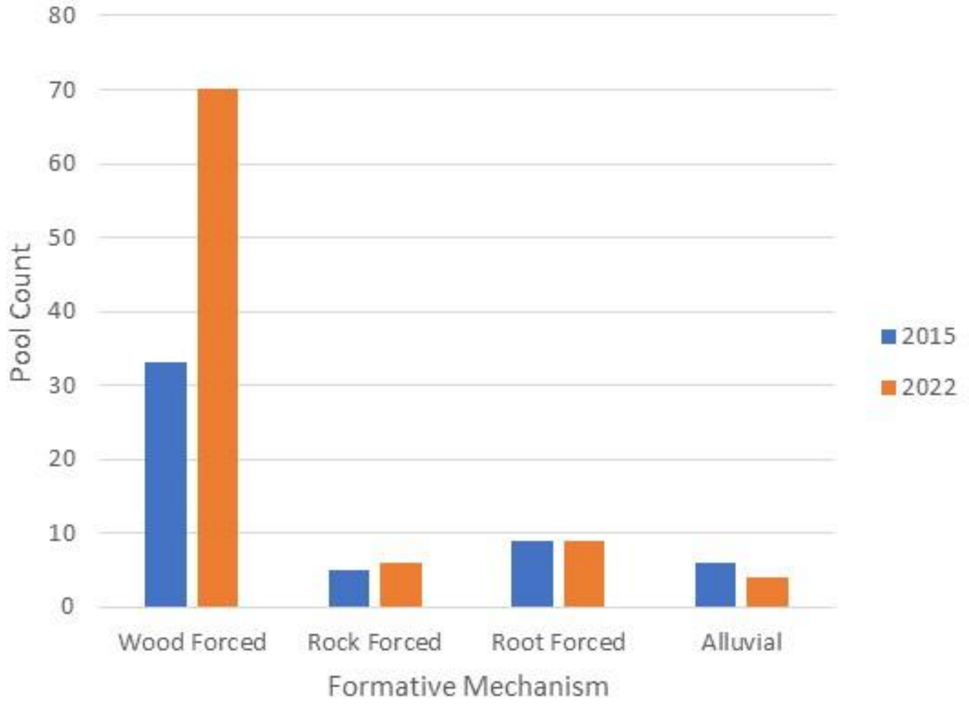
D$_{50}$=15-40mm

D$_{50}$=105mm

Fish and Substrate

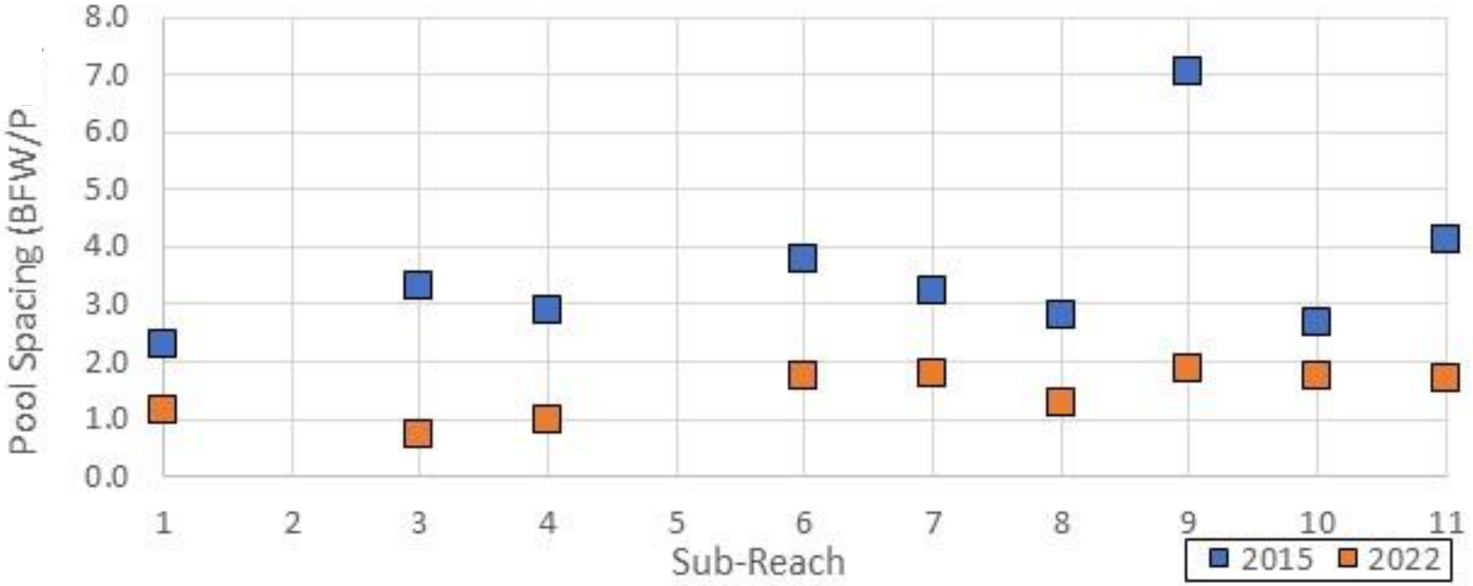


Engineered Logjams: Incision Restoration in Little River



# of wood forced pools more than doubled

Spacing between pools diminished



Little River Summary

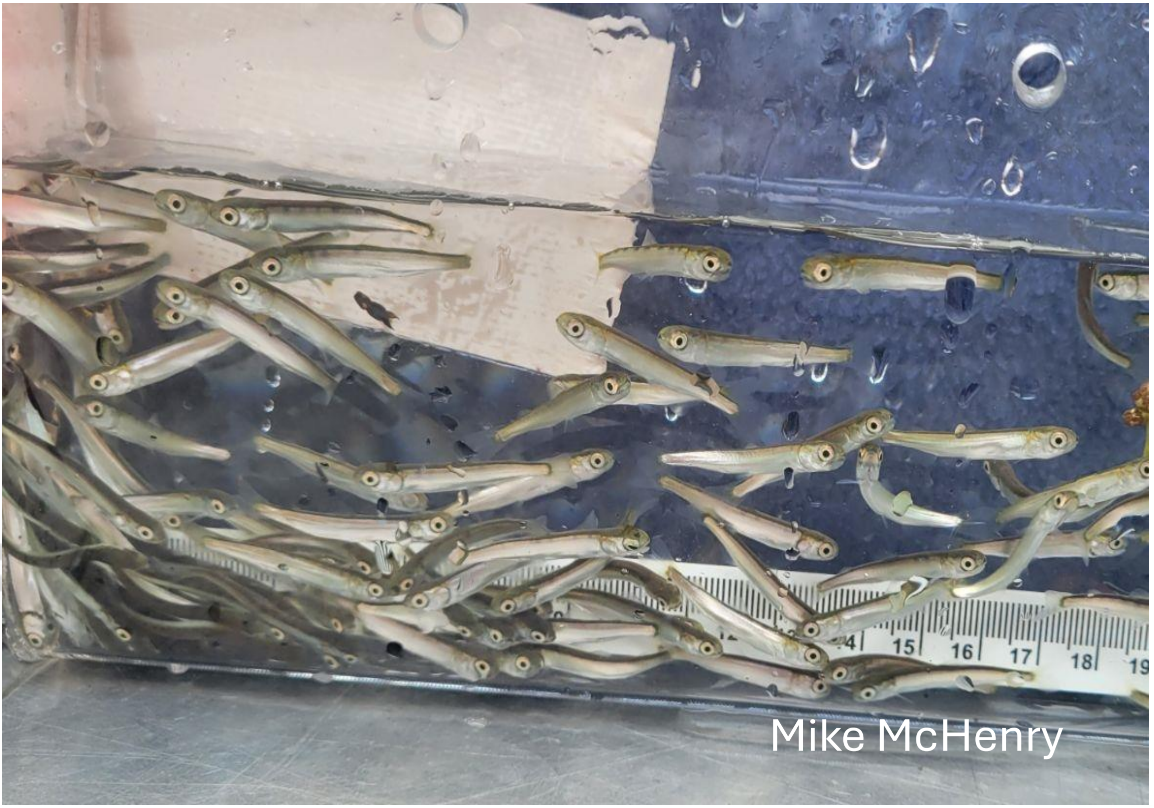
- > 2-fold increase in pool frequency
- Stabilization of previously incising channel profile
- 60-80% reduction in substrate grain size
- Total side channel length increased from 82 to 331 m
- Six of nine treatment reaches gained a new side channel

Engineered Logjams: Incision Restoration in Little River

- 2023 1,000 Pink spawners
- Spawned on sediment accumulated upstream of structures
- Spring 2024 captured 45,000 out-migrating spring smolts
    - Capture is approximately 10-15% of total smolts

Take Home: ***high numbers attributed to low mortality of eggs and high survival rates of emerging fish due to habitat improvements***


Mike McHenry



Mike McHenry

Large River Restoration

Restoring the Large Wood Cycle in large rivers

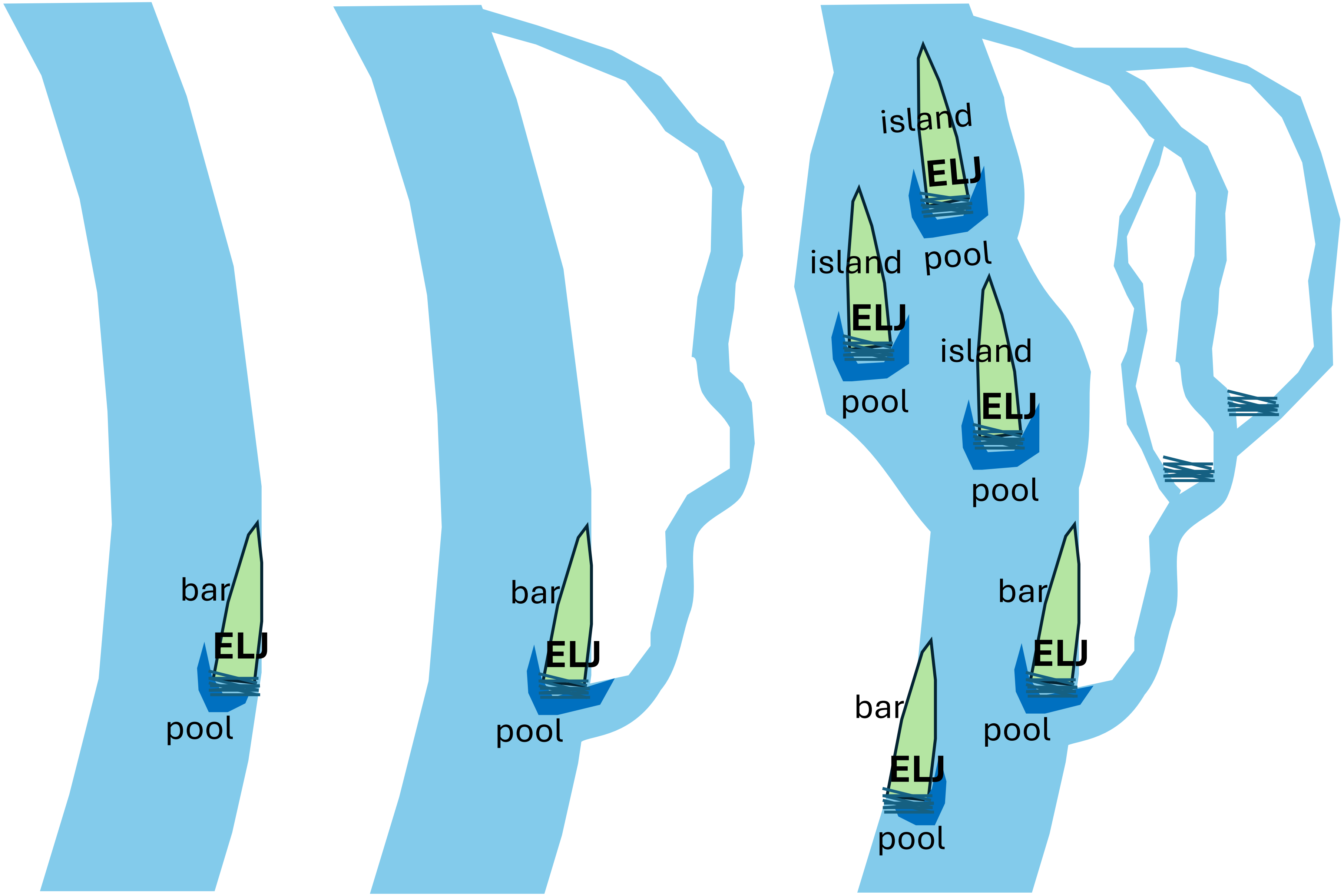
The Large Wood Cycle

Big Trees → Big Wood → Stable Logjams → Stable Forest Islands → Increased Channel Length → Pools, Stable Spawning Beds, Cover, Off-channel Refugia

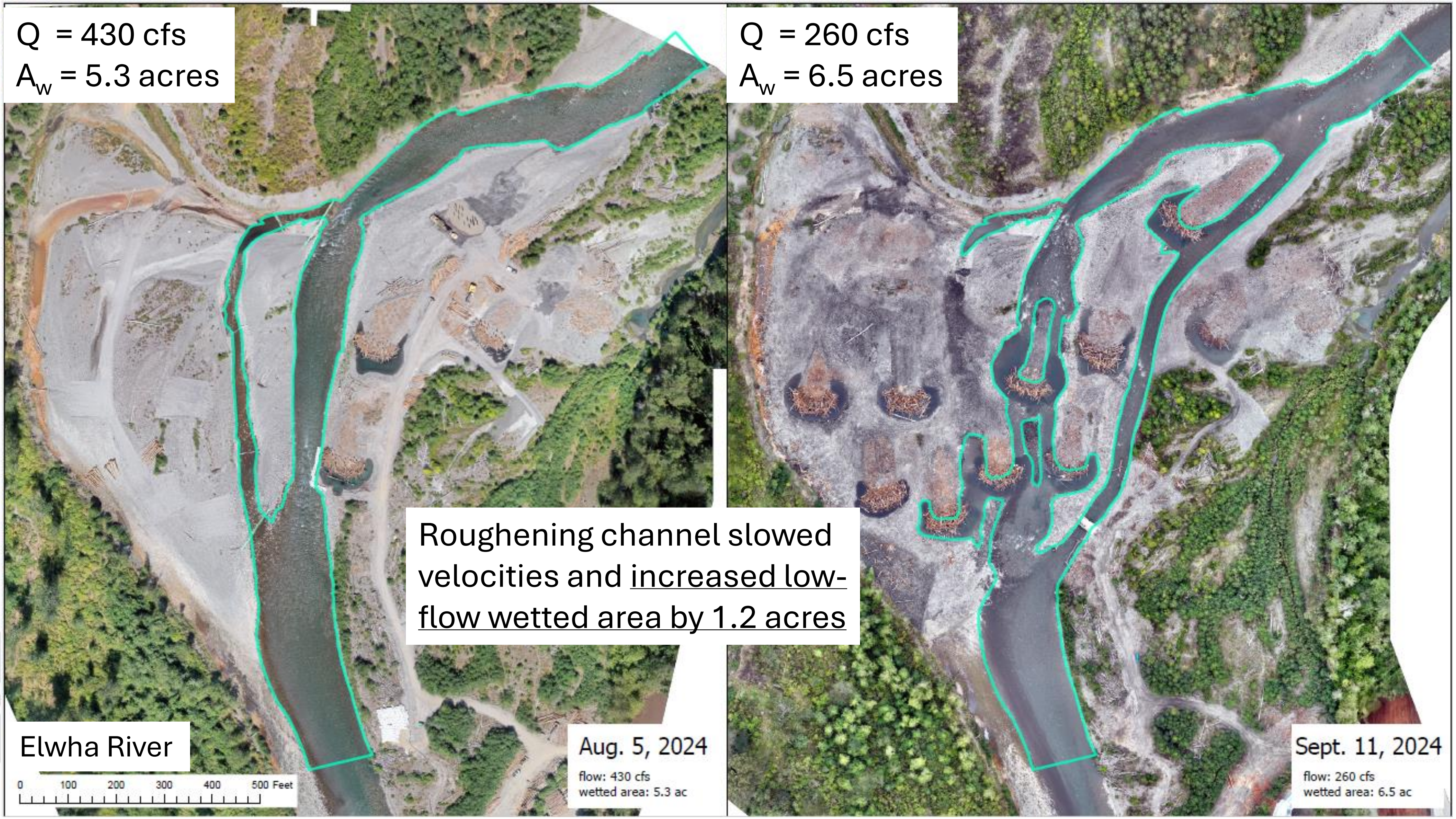
Habitat Quantity: Increased Channel Length

Habitat Quality: Pools, Stable Spawning Beds, Cover, Off-channel Refugia

Minimal	High	Very High	**Habitat Benefit**
Low	Moderate	High	**Benefit/Cost**



Large River Engineered Logjam Design: Wetted Area



$Q = 430$ cfs
$A_w = 5.3$ acres

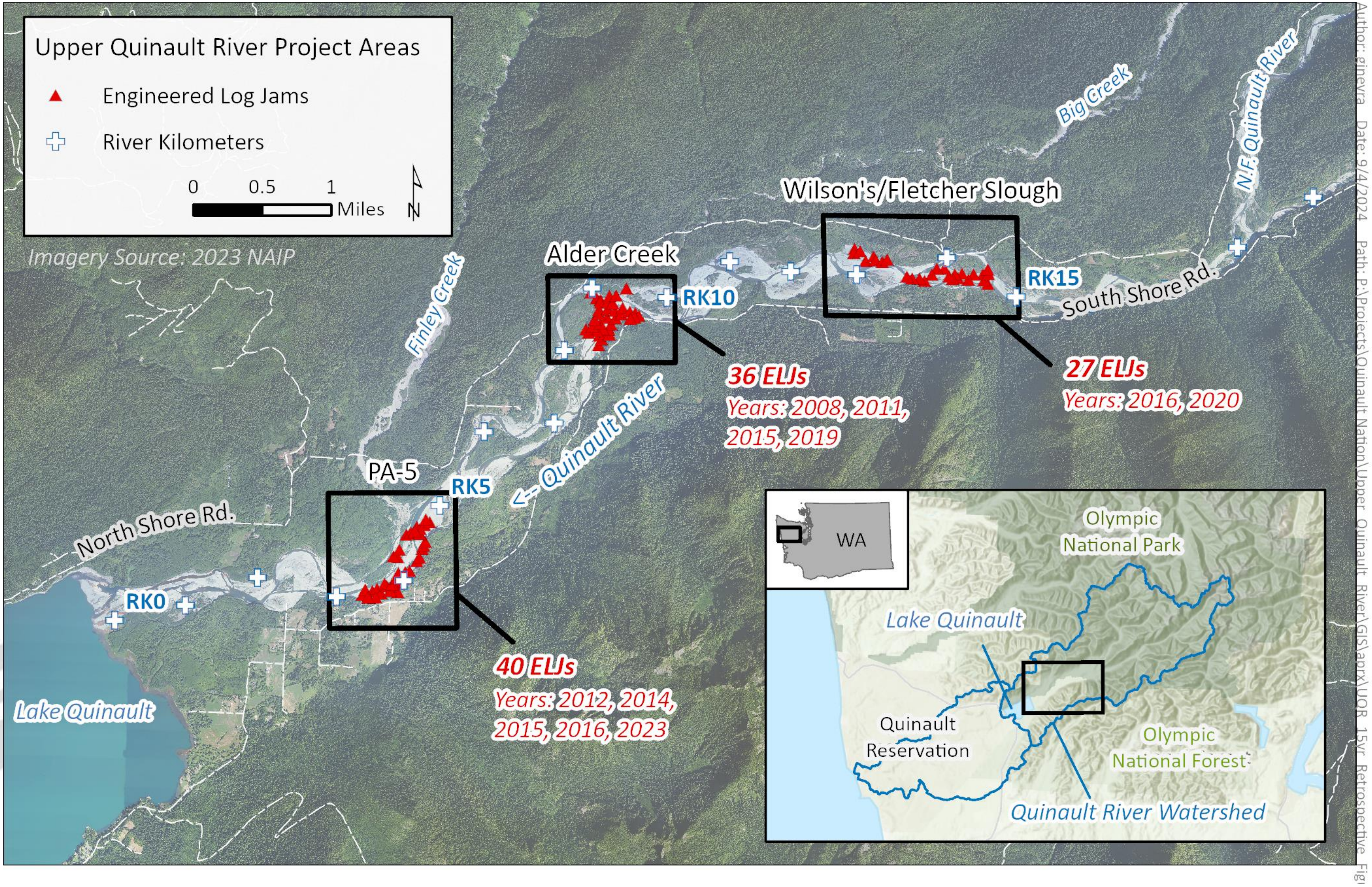
$Q = 260$ cfs
$A_w = 6.5$ acres

Roughening channel slowed velocities and <u>increased low-flow wetted area by 1.2 acres</u>

Upper Quinault River

Southwest Olympic Peninsula

Engineered Logjams: Upper Quinault River



Upper Quinault River Valley Restoration

Goals:

- Restore Large Wood Cycle
  - Protect existing forested floodplain and side channels
  - Restore an anabranching channel system
  - Create stable forested islands
- Protect infrastructure and property

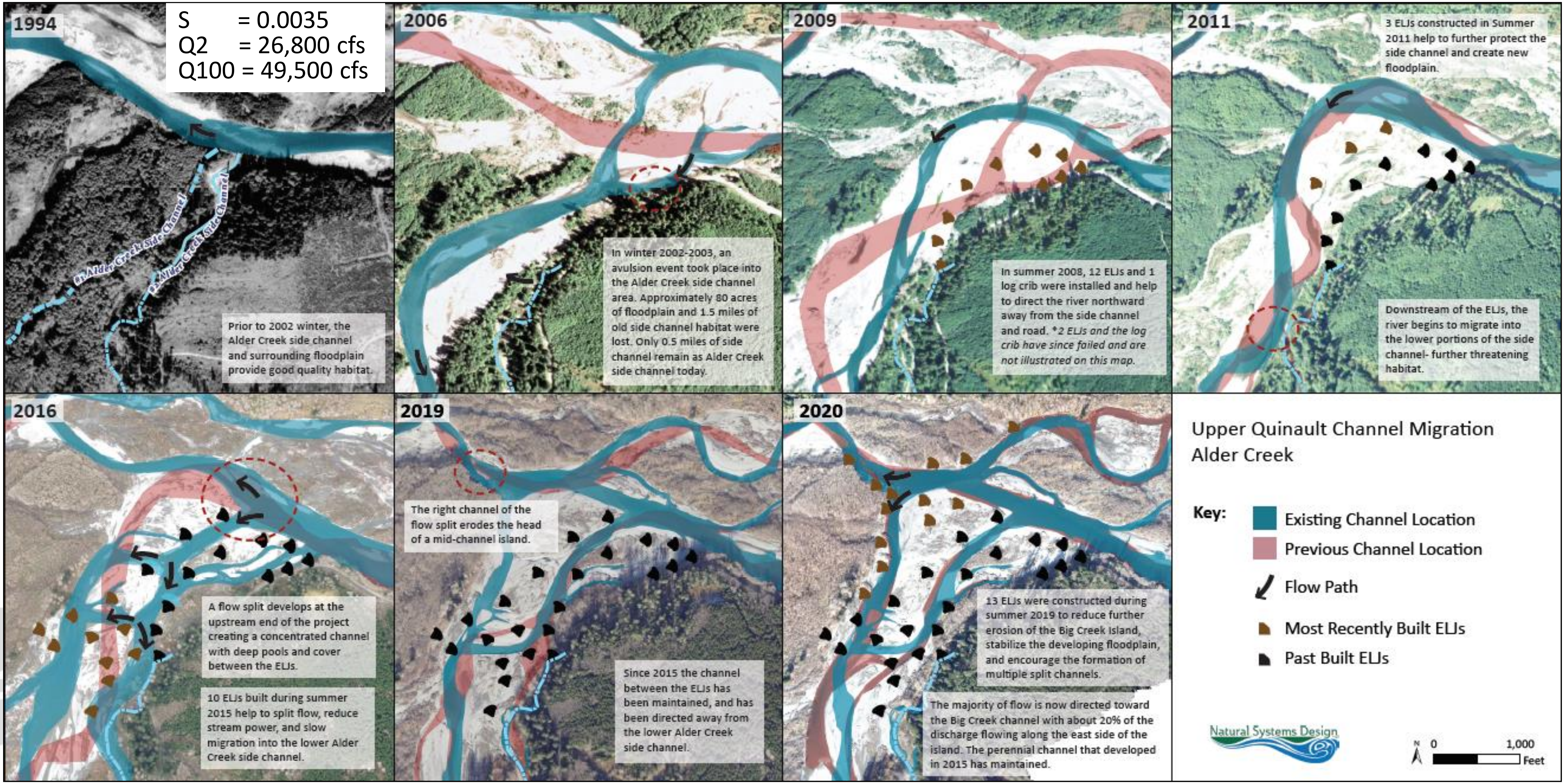
103 ELJs have been constructed in the Upper Quinault from 2008 to 2023. **94% remaining** (6 ELJs failed).
Six different types of ELJs constructed between 2008 and 2023.

Large River Engineered Logjam Performance

Upper Quinault River Valley Restoration 2008-2023

PROJECT AREA	CONSTRUCTION YEAR	ELJS	STABILIZED WOOD	TIMBER REVETMENT
Alder Creek	2008	10	0	0
	2011	3	0	0
	2015	10	0	0
	2019	13	5	0
	Total Installed	**36**	**5**	**0**
PA-5	2012	6	2	0
	2014	13	5	0
	2015	2	0	0
	2016	9	4	1
	2023	10	1	0
	Total Installed	**40**	**12**	**1**
Fletcher and Wilson's	2016	8	10	0
	2020	19	8	0
	Total Installed	**27**	**18**	**0**
All	**Total Installed**	**103**	**38**	**1**

Engineered Logjams: Upper Quinault River



S = 0.0035
Q2 = 26,800 cfs
Q100 = 49,500 cfs

1994

Prior to 2002 winter, the Alder Creek side channel and surrounding floodplain provide good quality habitat.

2006

In winter 2002-2003, an avulsion event took place into the Alder Creek side channel area. Approximately 80 acres of floodplain and 1.5 miles of old side channel habitat were lost. Only 0.5 miles of side channel remain as Alder Creek side channel today.

2009

In summer 2008, 12 ELJs and 1 log crib were installed and help to direct the river northward away from the side channel and road. **2 ELJs and the log crib have since failed and are not illustrated on this map.*

2011

3 ELJs constructed in Summer 2011 help to further protect the side channel and create new floodplain.

Downstream of the ELJs, the river begins to migrate into the lower portions of the side channel- further threatening habitat.

2016

A flow split develops at the upstream end of the project creating a concentrated channel with deep pools and cover between the ELJs.

10 ELJs built during summer 2015 help to split flow, reduce stream power, and slow migration into the lower Alder Creek side channel.

2019

The right channel of the flow split erodes the head of a mid-channel island.

Since 2015 the channel between the ELJs has been maintained, and has been directed away from the lower Alder Creek side channel.

2020

13 ELJs were constructed during summer 2019 to reduce further erosion of the Big Creek Island, stabilize the developing floodplain, and encourage the formation of multiple split channels.

The majority of flow is now directed toward the Big Creek channel with about 20% of the discharge flowing along the east side of the island. The perennial channel that developed in 2015 has maintained.

Upper Quinault Channel Migration
Alder Creek

Key:

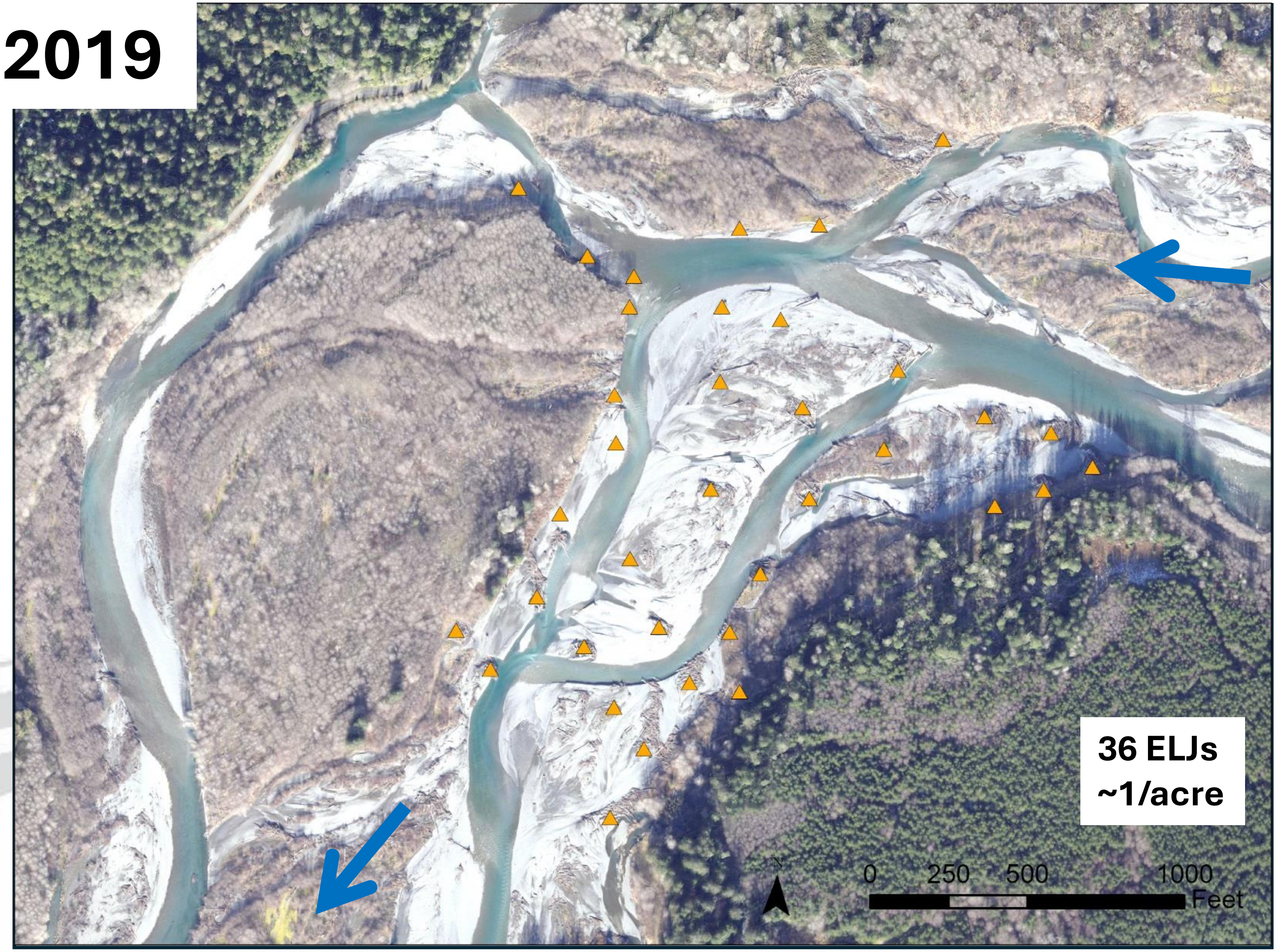
- 🟦 Existing Channel Location
- 🟥 Previous Channel Location
- ↙ Flow Path
- ▲ Most Recently Built ELJs
- ▲ Past Built ELJs

Natural Systems Design

Engineered Logjams: Upper Quinault River

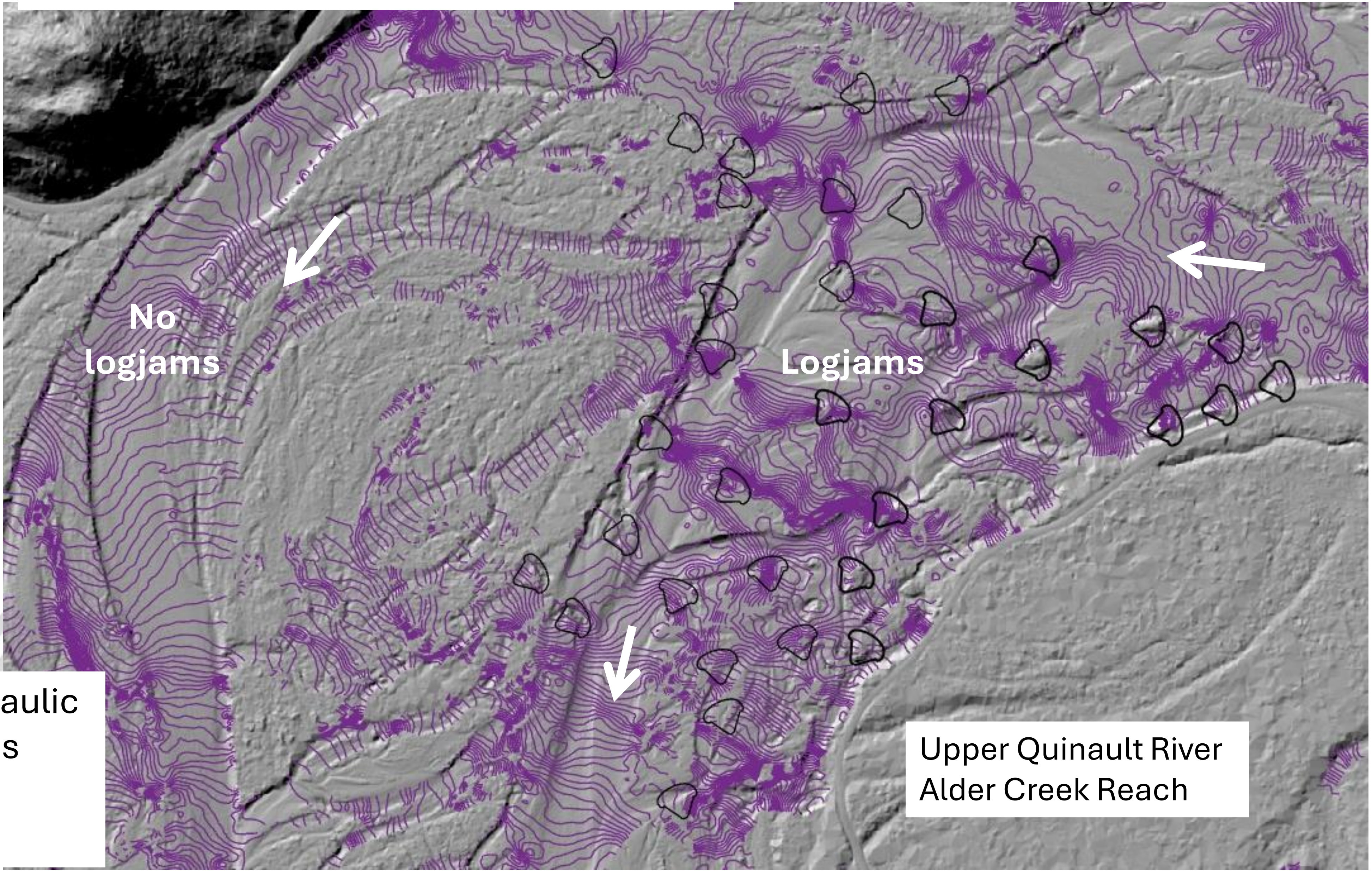
2009

Engineered Logjams: Upper Quinault River



Engineered Logjams: Influence on water surface elevations

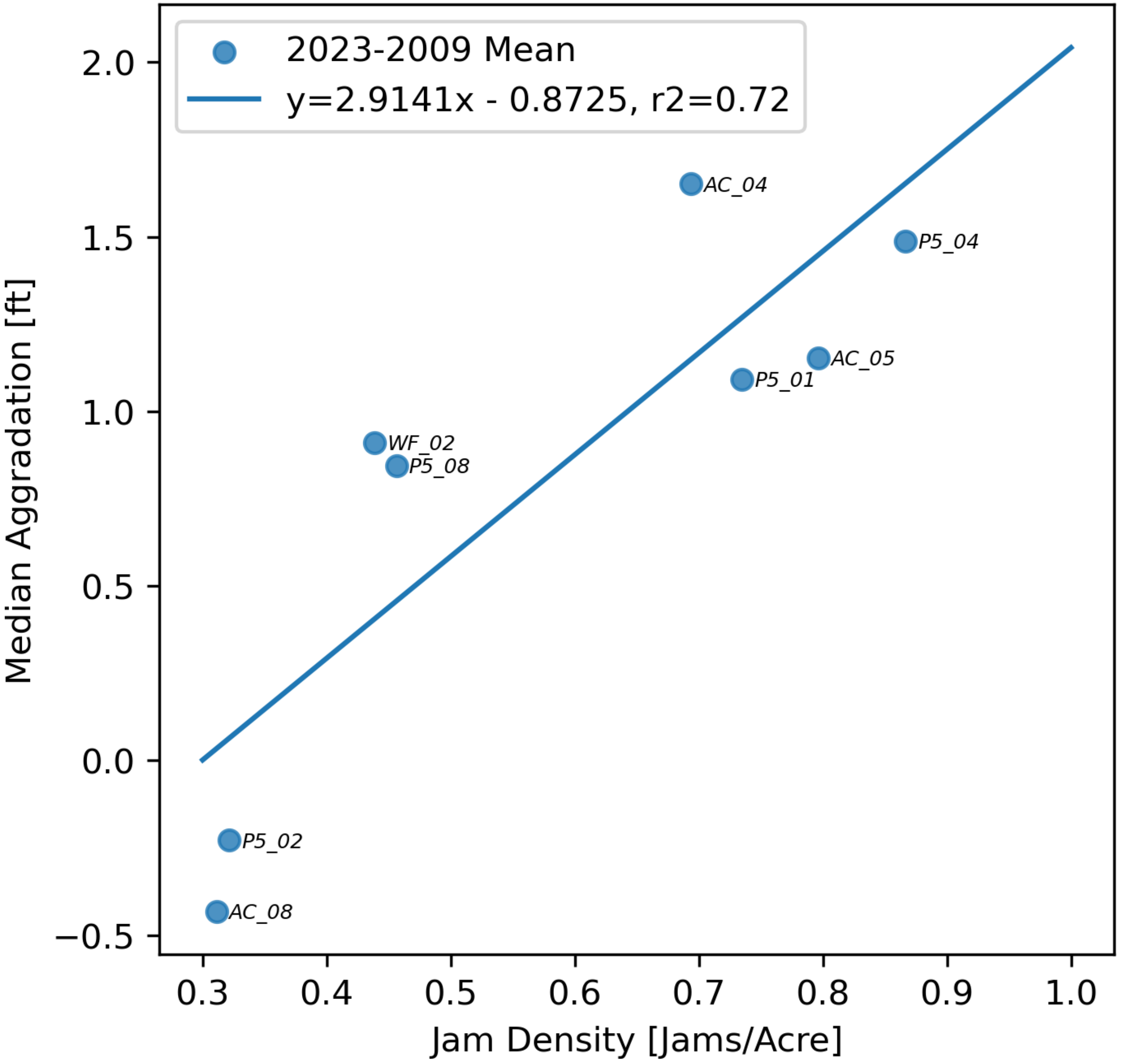
Water surface elevation contours (0.1 ft)



Local hydraulic head drives hyporheic exchange

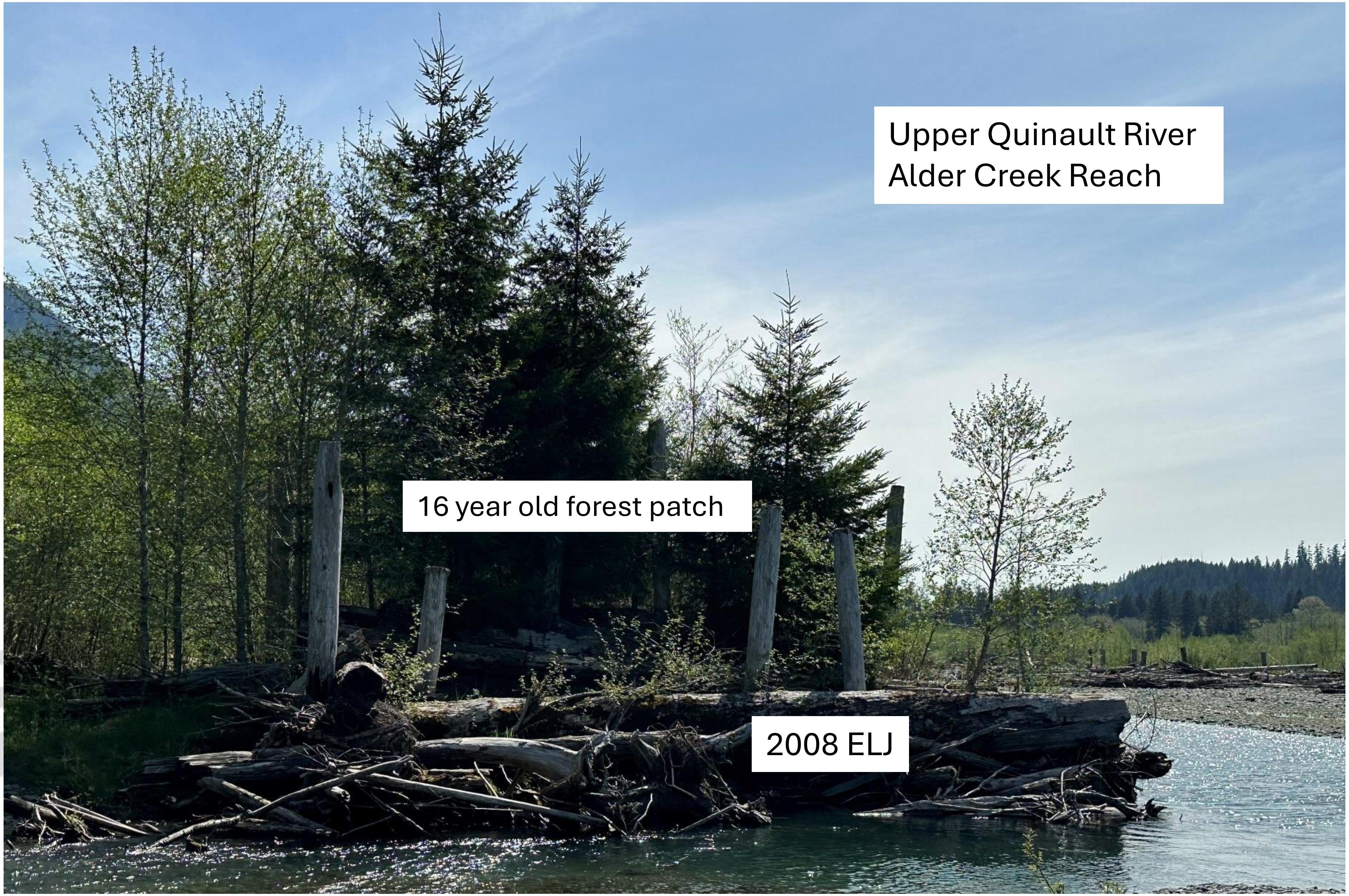
Upper Quinault River
Alder Creek Reach

Engineered Logjams: Upper Quinault River



Preliminary landform analysis showing a possible trend between jam density and gravel bar aggradation (floodplain development)

Large River Engineered Logjam Design: Forest Islands

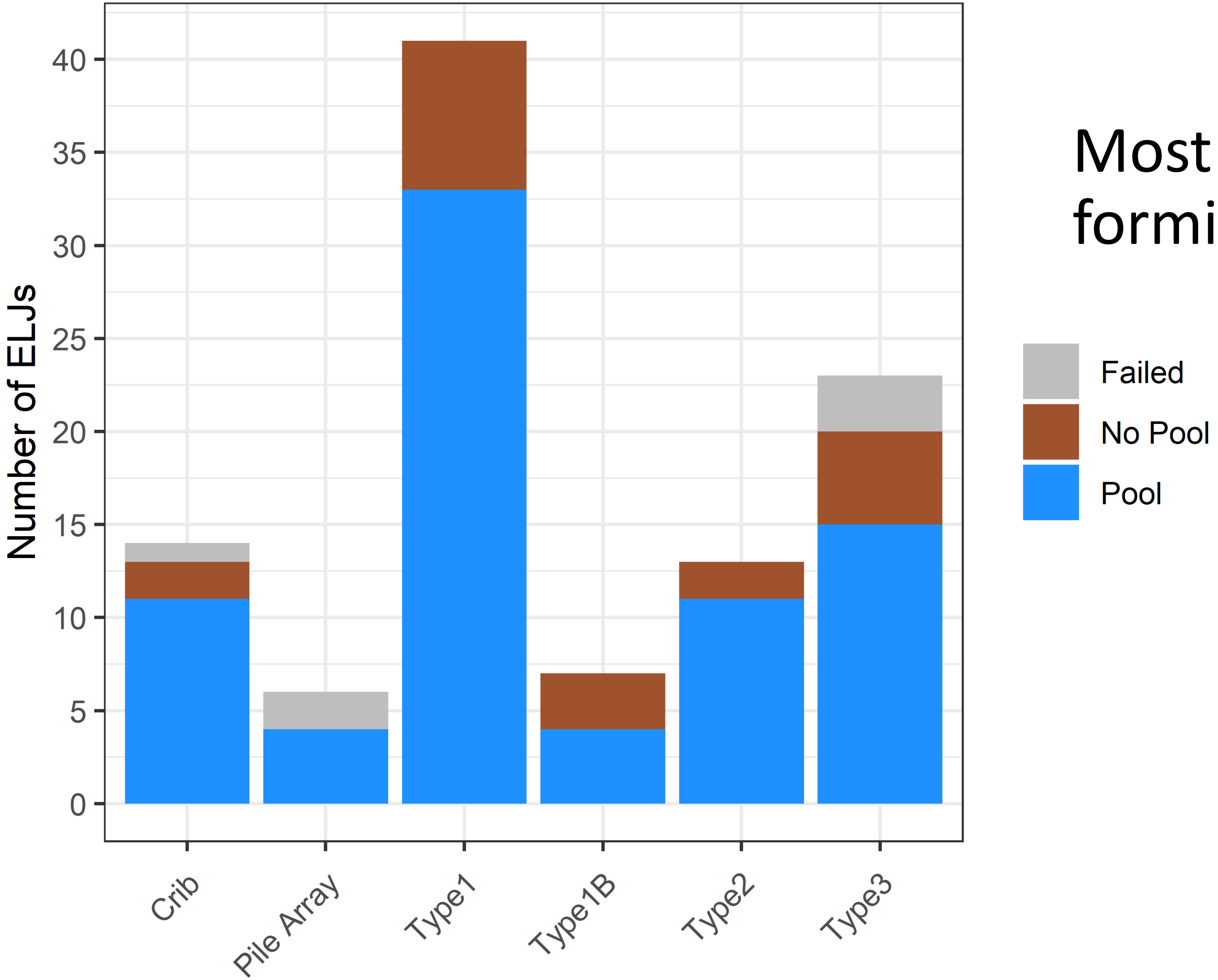


Upper Quinault River
Alder Creek Reach

16 year old forest patch

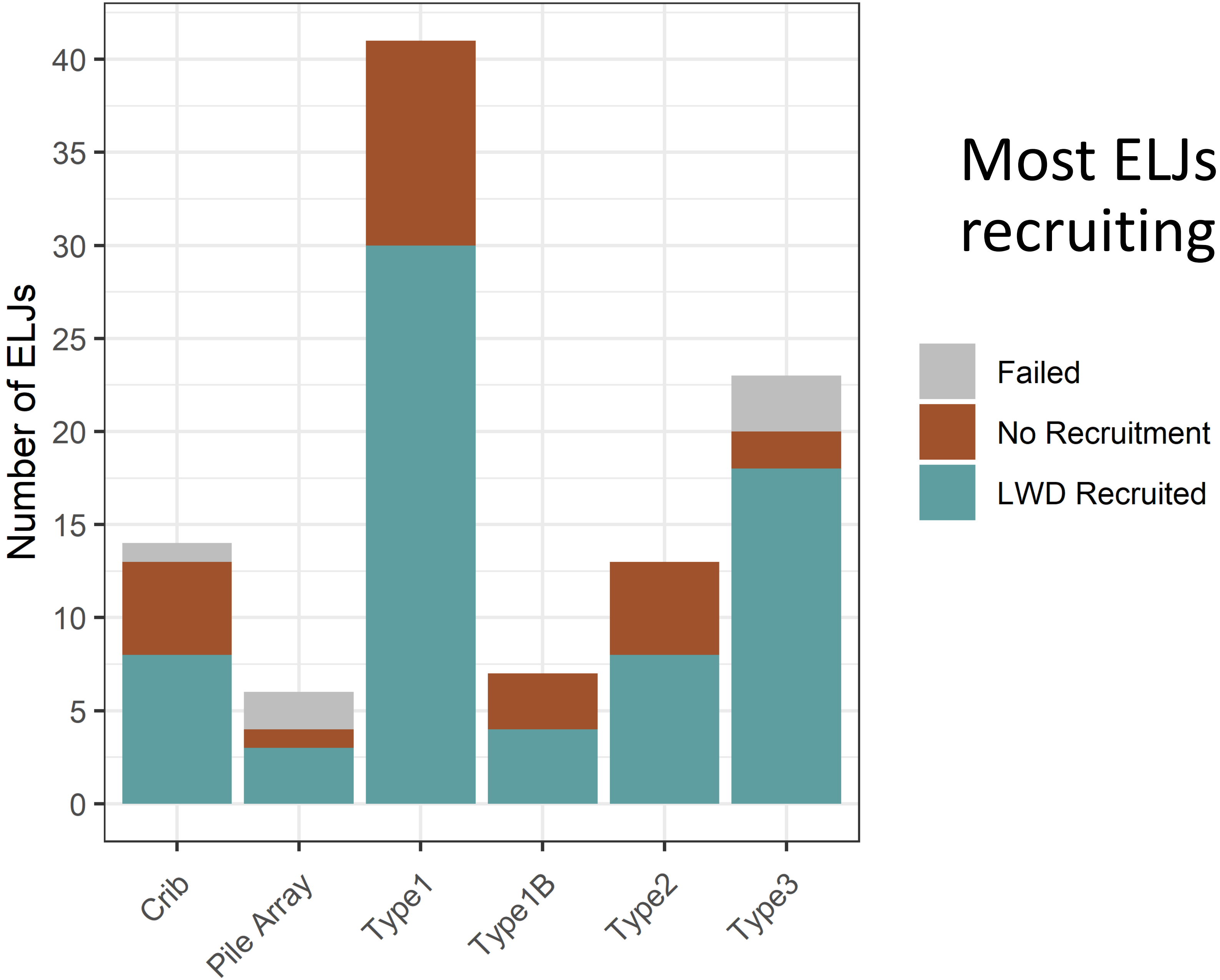
2008 ELJ

Engineered Logjams: Upper Quinault River



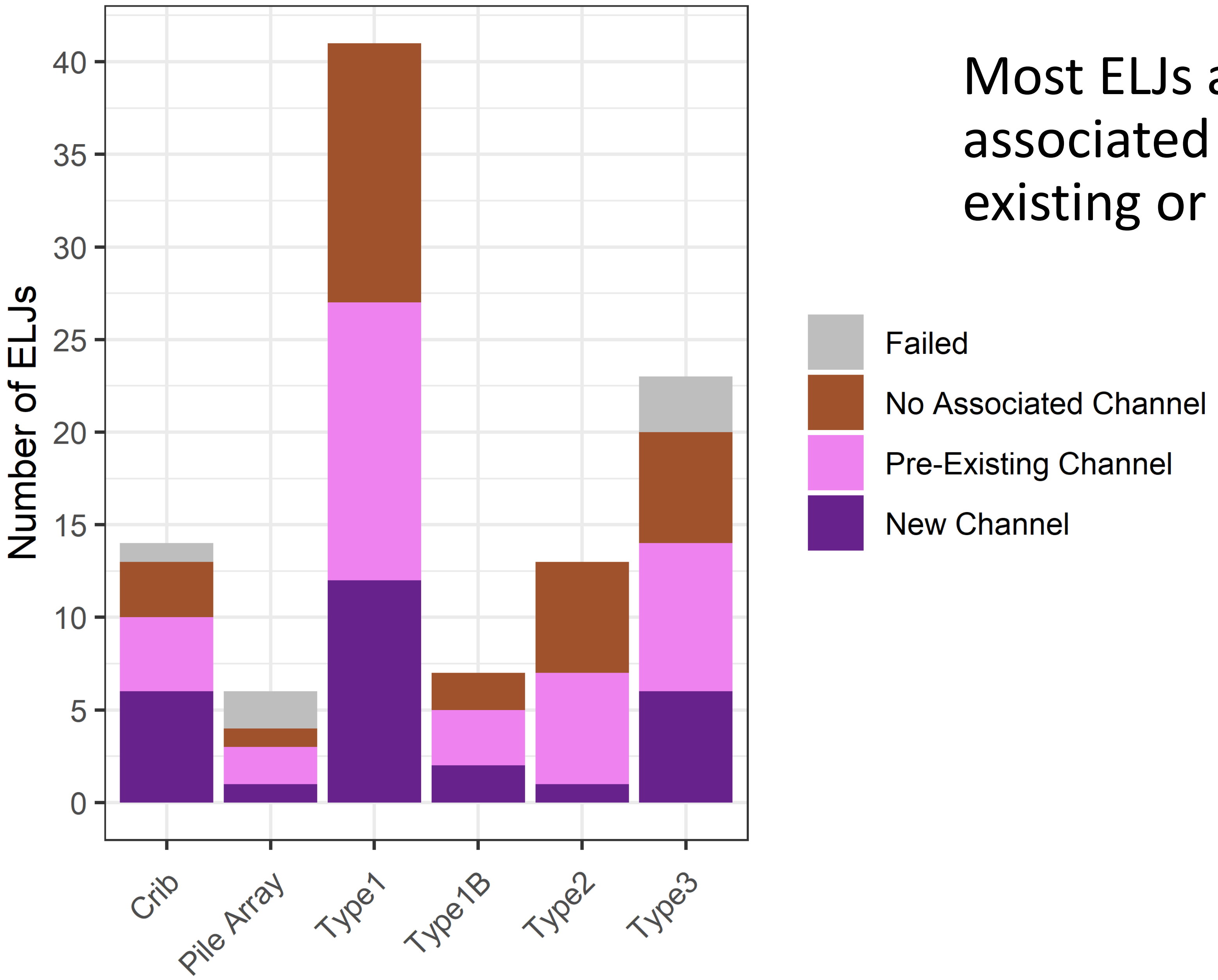
Most ELJs are forming pools

Engineered Logjams: Upper Quinault River



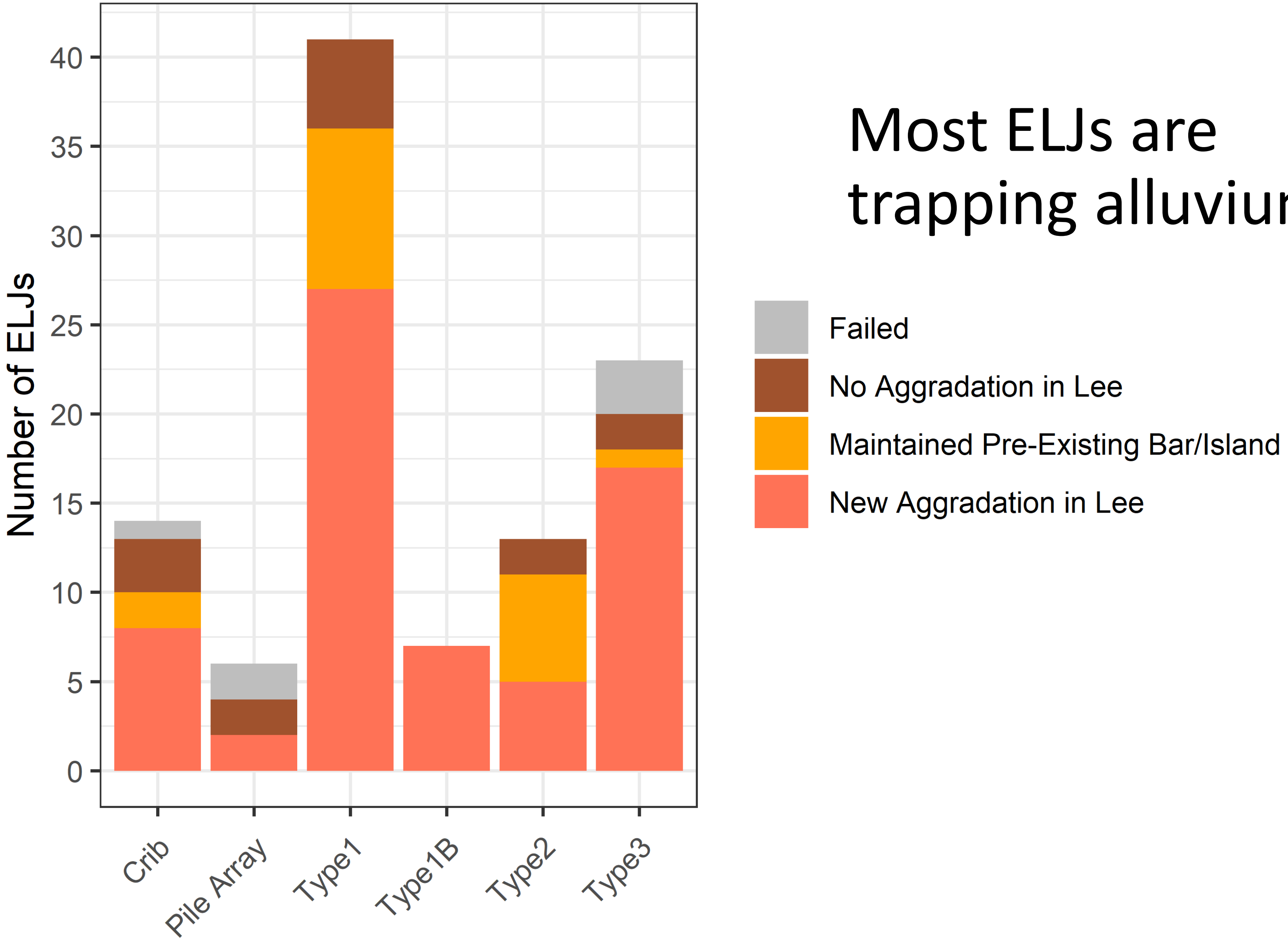
Most ELJs are recruiting wood

Engineered Logjams: Upper Quinault River



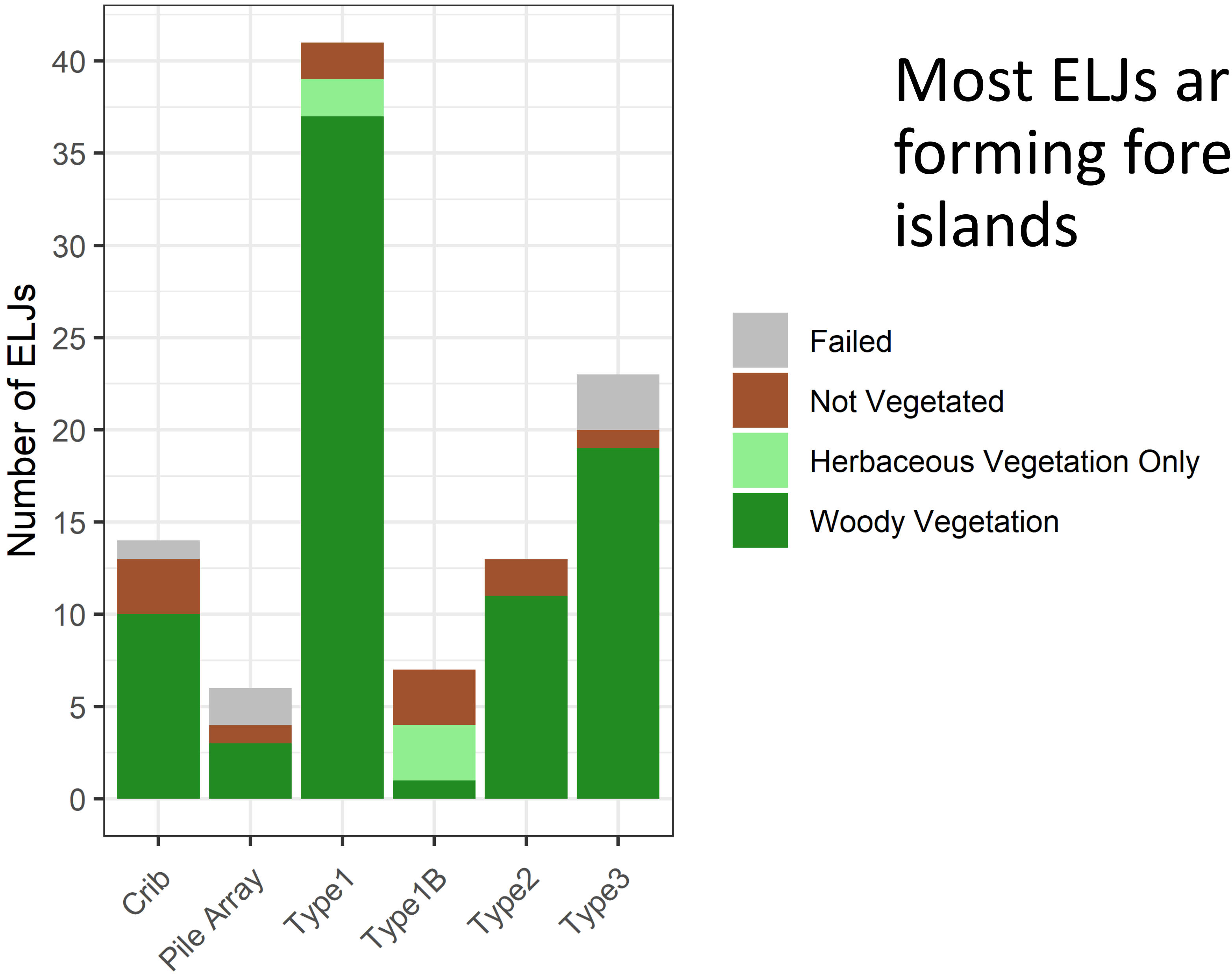
Most ELJs are associated with a pre-existing or new channel

Engineered Logjams: Upper Quinault River

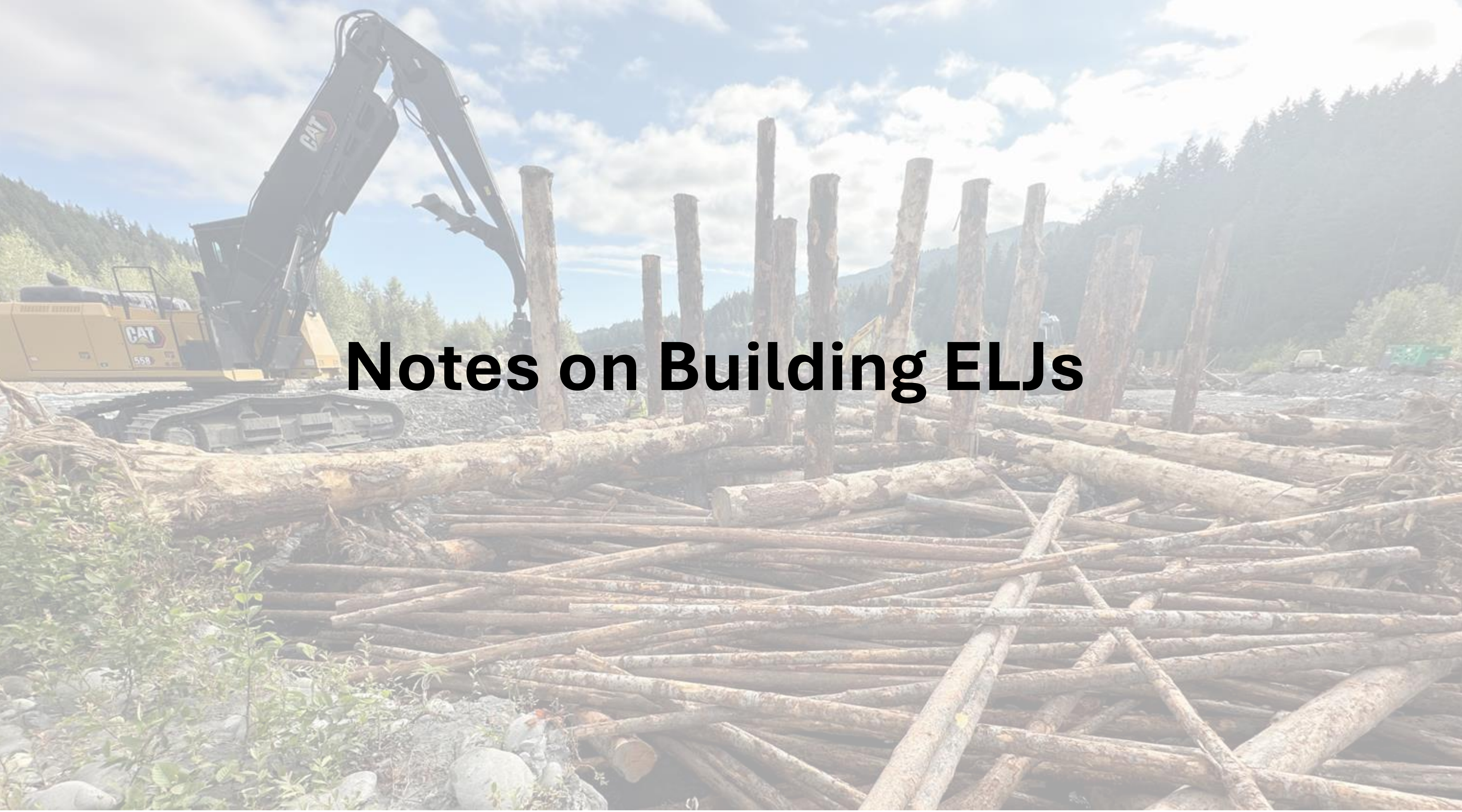


Most ELJs are trapping alluvium

Engineered Logjams: Upper Quinault River



Most ELJs are forming forested islands



Notes on Building ELJs

All forest products are valuable in restoration

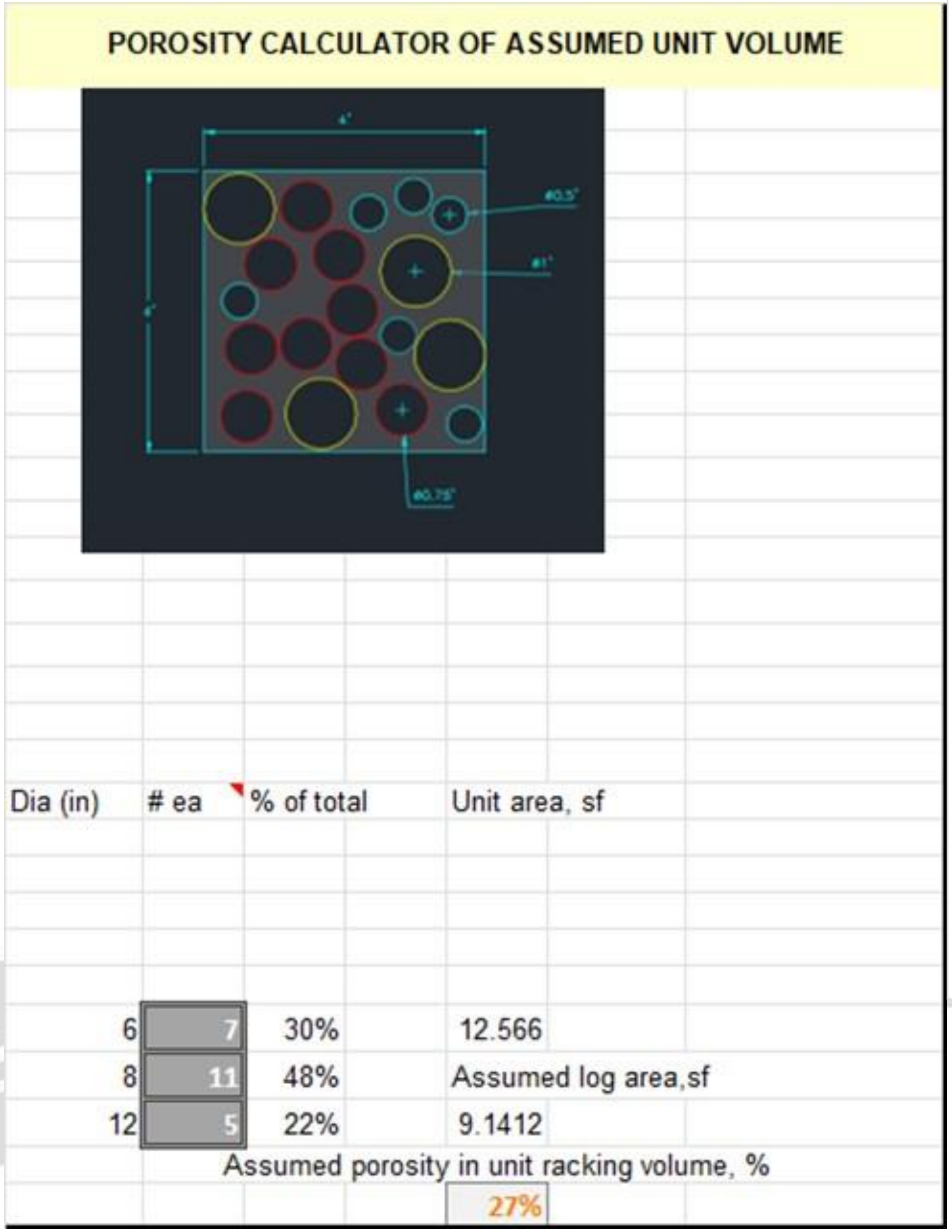
- **Rootwad and bole**
  - **Key pieces**
  - **Buried posts**
  - **Beams in ELJ core**
  - **Racking wood retention**
- **Tree boles**
  - **Beams in ELJ core**
  - **Racking wood**
- **Slash**
  - **Soil amendment when backfilling**
  - **Erosion control on finished grades**
  - **Supplement to slash**
- **Secondary Species (Cottonwood, alder, hemlock)**
  - **Racking wood and slash**

Large River Engineered Logjam Design: Structure Core

Large River Engineered Logjam Design: Structure Core

Completed Structure Elwha River 101 Reach 2024
~600 racking logs

Large River Engineered Logjam Design: Racking Wood

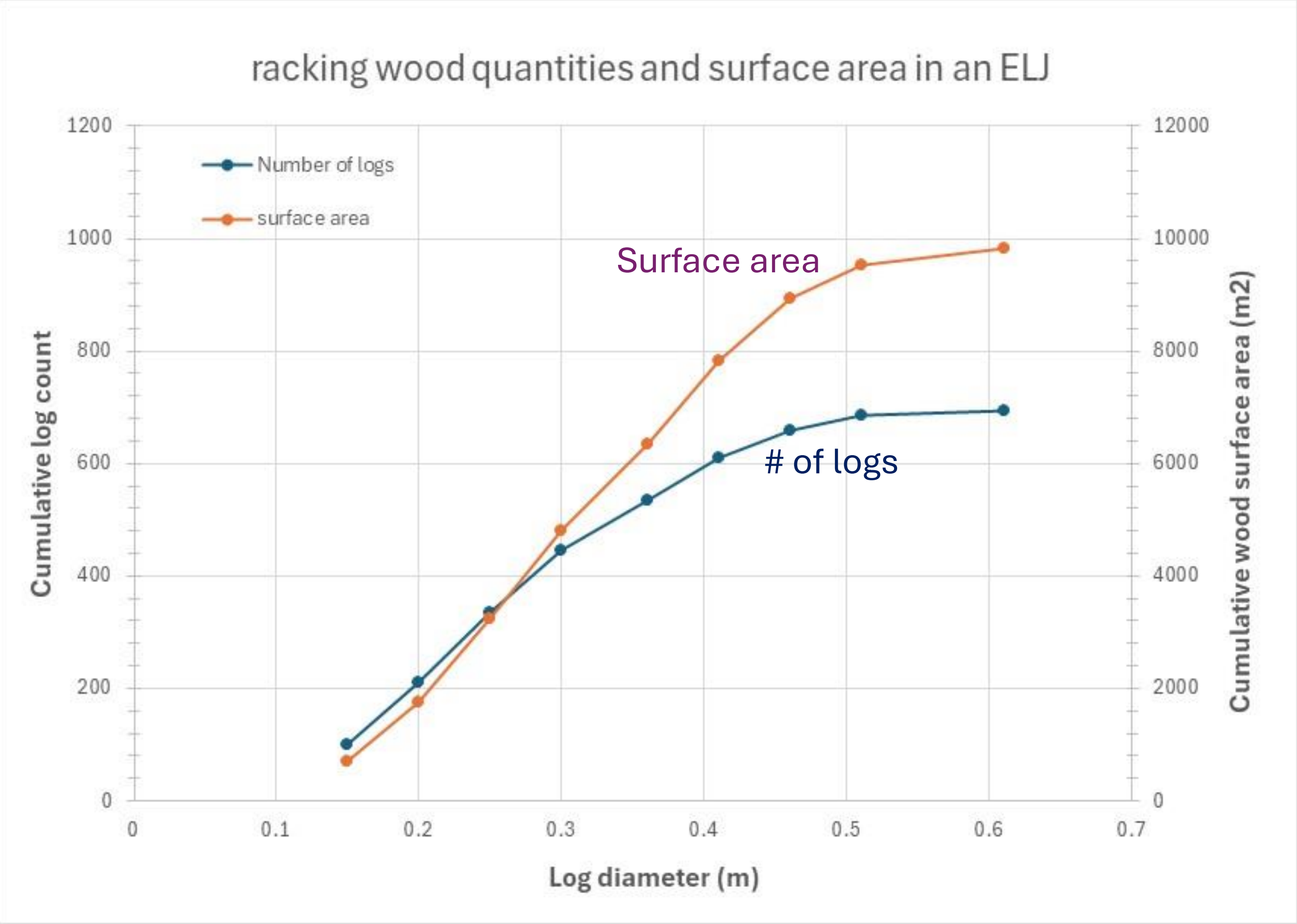


POROSITY CALCULATOR OF ASSUMED UNIT VOLUME

Dia (in)	# ea	% of total	Unit area, sf
6	7	30%	12.566
8	11	48%	Assumed log area,sf
12	5	22%	9.1412

Assumed porosity in unit racking volume, %

27%



17 Elwha Ranney Reach ELJs introduced ~170,000 m^2 of wood surface area to the river – not including added slash

Large River Engineered Logjam Design: Slash

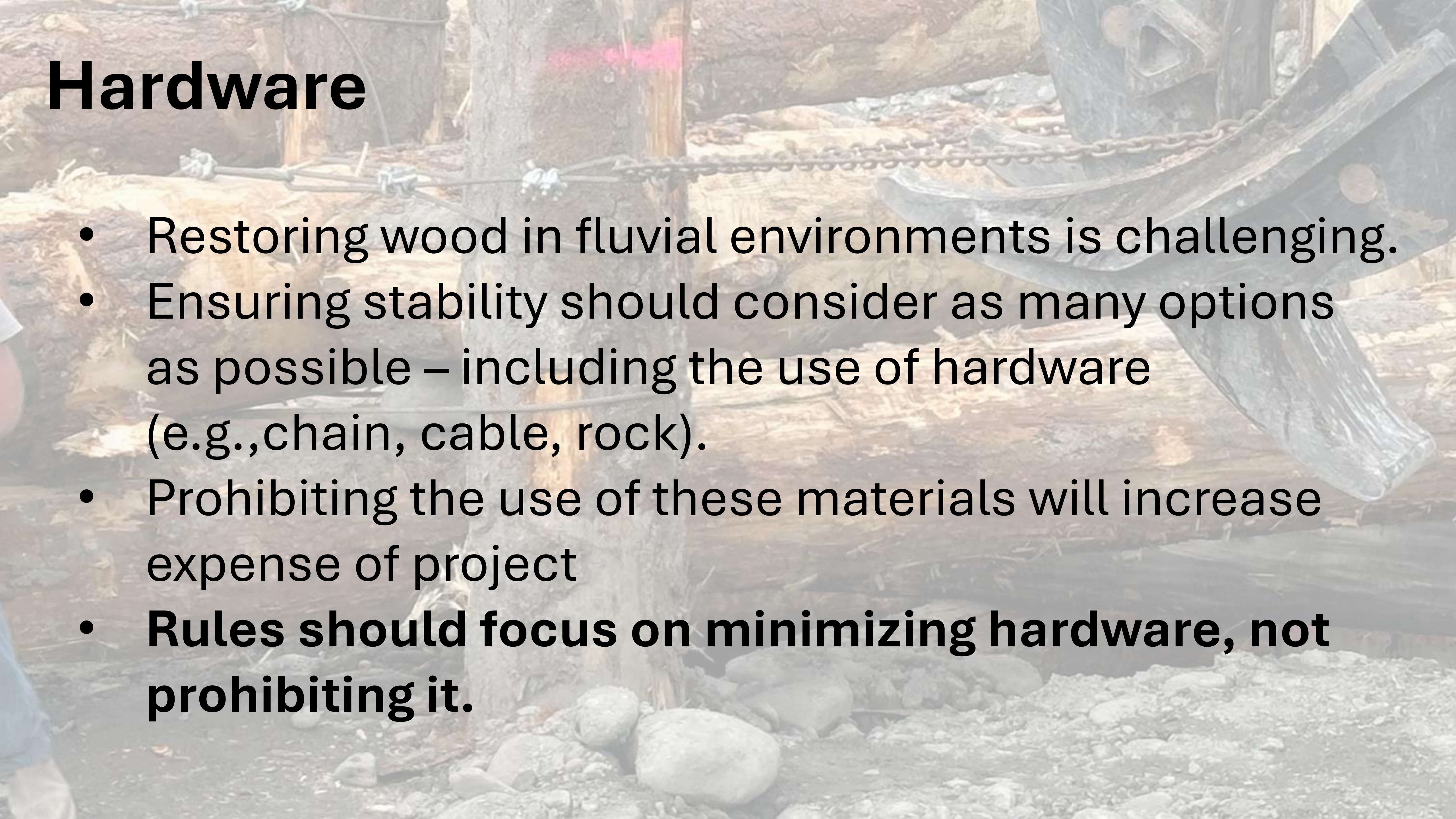
- Adding slash to racking wood increases wood surface area, reduces permeability upstream of ELJ core

Large River Engineered Logjam Design: Slash

Slash

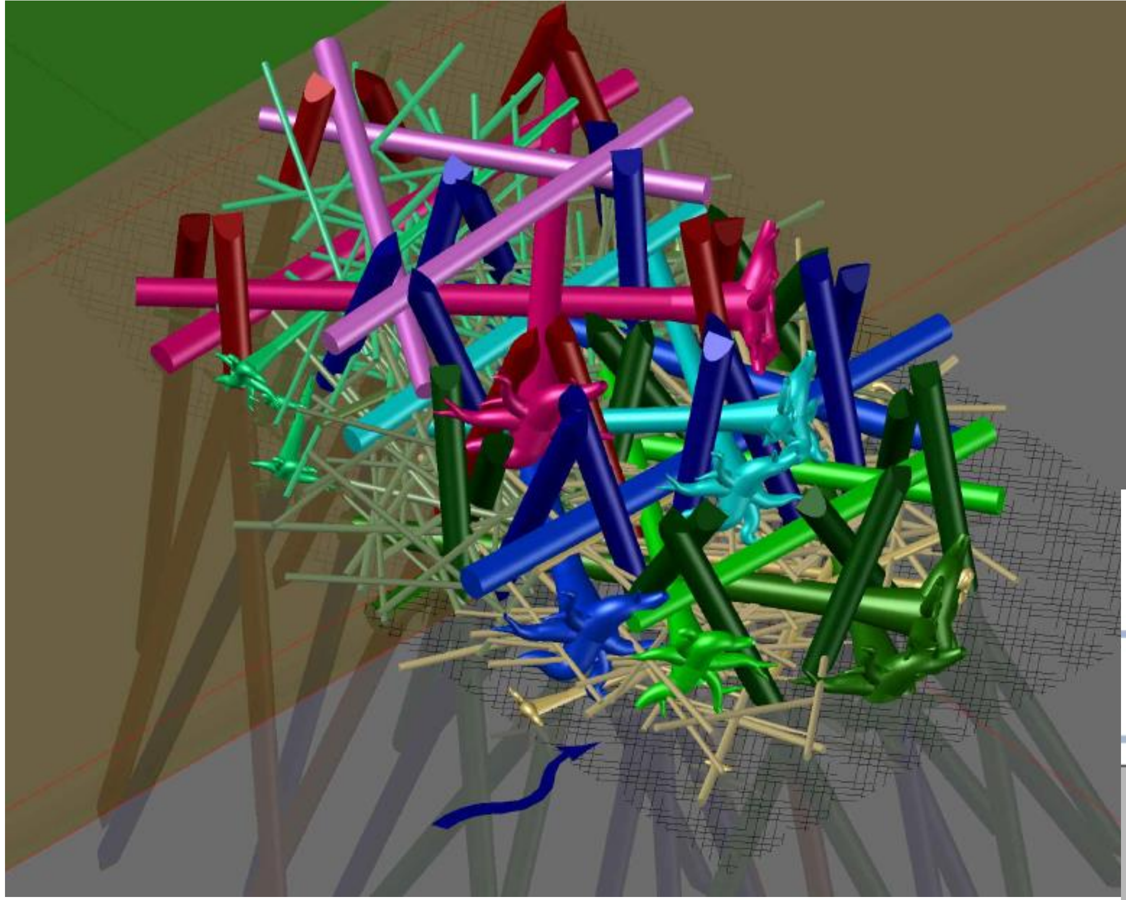
- Adding slash to backfill increases **nitrogen** and **moisture**.
- It also simulates root structure until vegetation takes hold.

Hardware



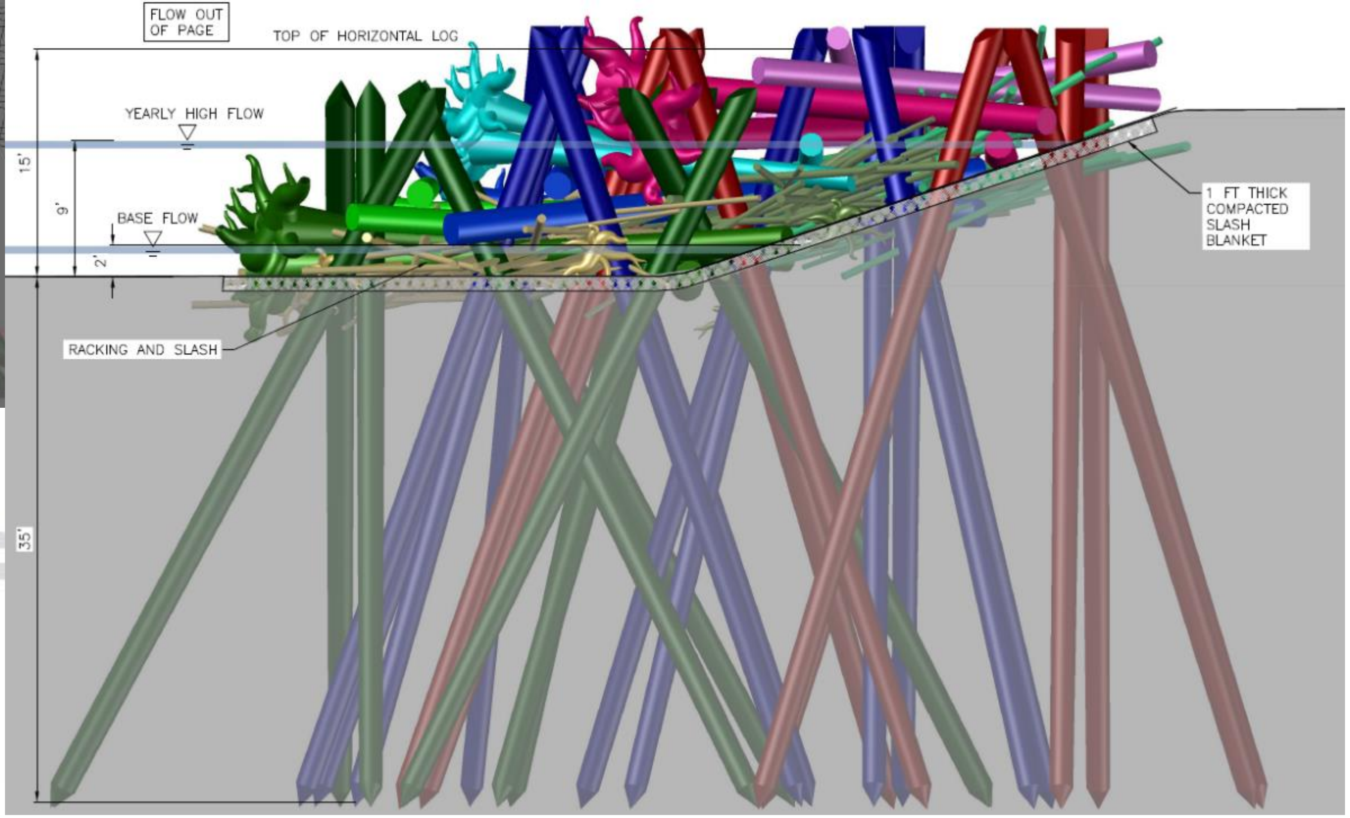
- Restoring wood in fluvial environments is challenging.
- Ensuring stability should consider as many options as possible – including the use of hardware (e.g.,chain, cable, rock).
- Prohibiting the use of these materials will increase expense of project
- **Rules should focus on minimizing hardware, not prohibiting it.**

Advancements in ELJ Design:



Batter pile structures

- **Don’t need hardware**
- Require adequate excavation for scour
- Geotech analysis essential to ensure pile driving

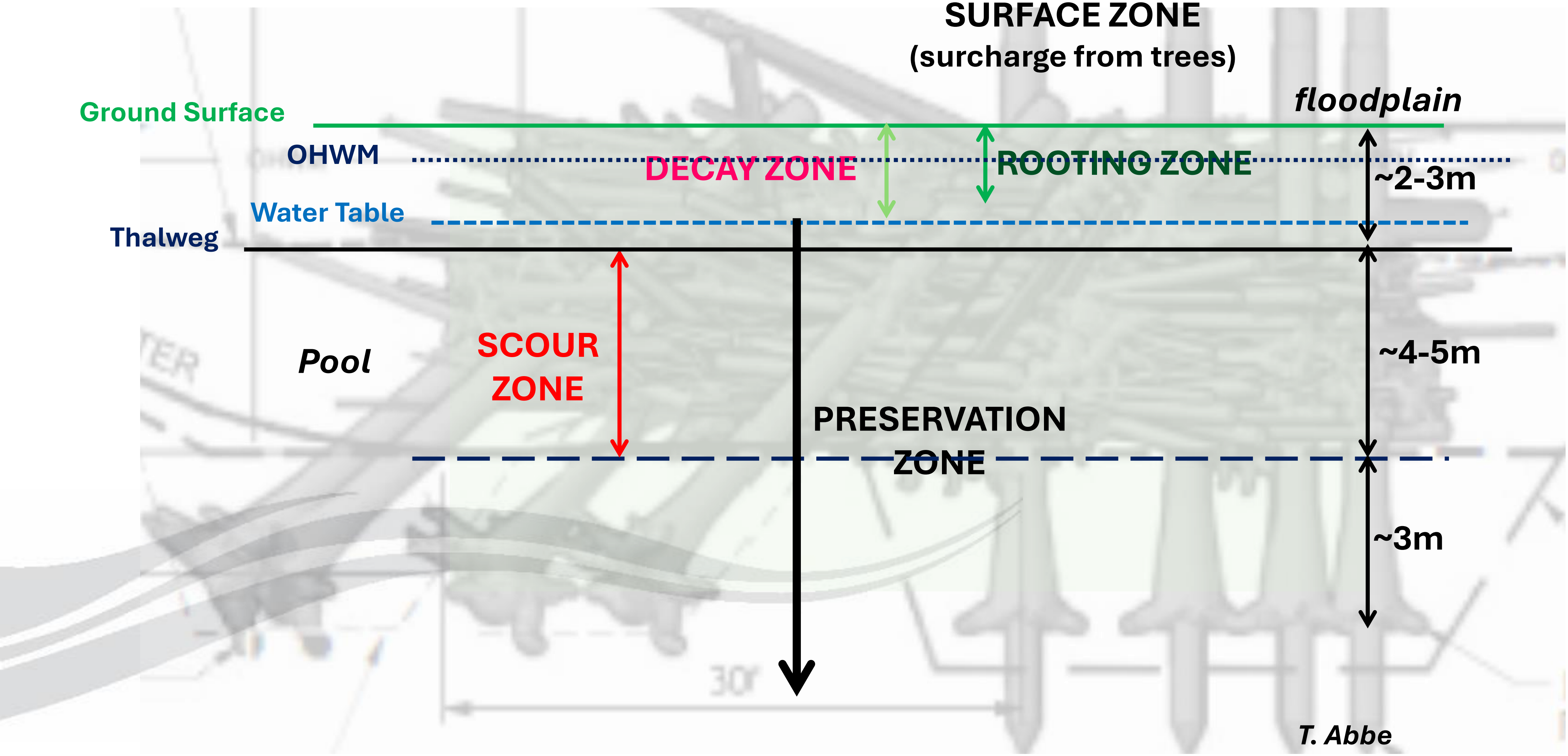


Large River Engineered Logjam Design: Batter Piles

Lower White prototype structure
City of Sumner, WA

Large River Engineered Logjam Design: Structural Elements

Design life should be sufficient to restore key sized wood for large wood cycle



OHWM – ordinary high water mark

Engineered Logjams: Structure Failure

Failure Mechanisms

1. Undermining (scour)
2. Pile collapse (scour)
3. Pile rupture

All these are exasperated by lack of racking wood

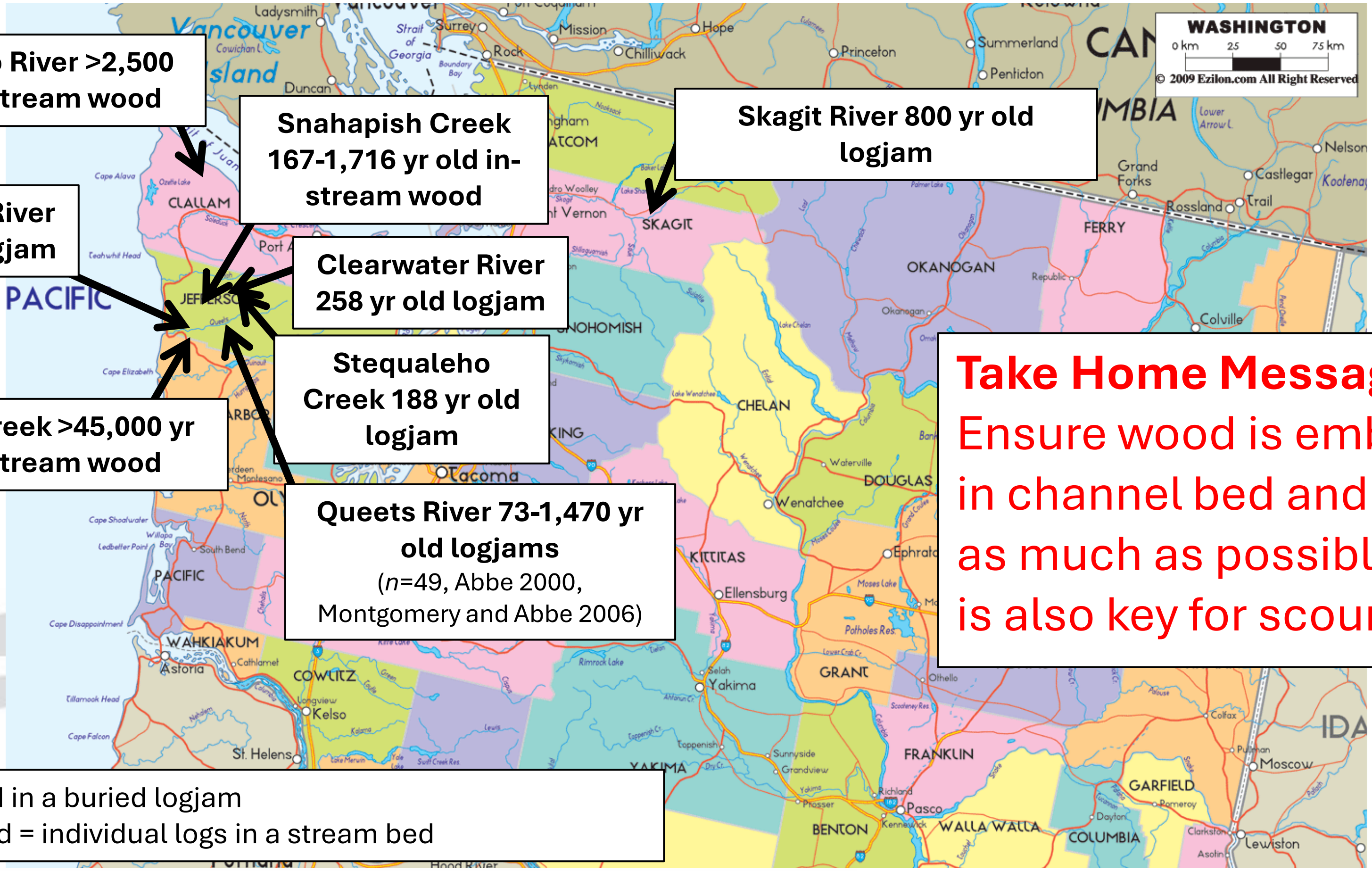

Upper Quinault 2024

Engineered Logjams: Wood Longevity

26 year old ELJ,
Cispus River

Engineered Logjams: Wood Longevity

NSD fluvial wood ^{14}C radiocarbon dates in Washington State



Little Hoko River >2,500 yr old in-stream wood

Snahapish Creek 167-1,716 yr old in-stream wood

Skagit River 800 yr old logjam

Clearwater River 273 yr old logjam

Clearwater River 258 yr old logjam

Stequaleho Creek 188 yr old logjam

Harlow Creek >45,000 yr old in-stream wood

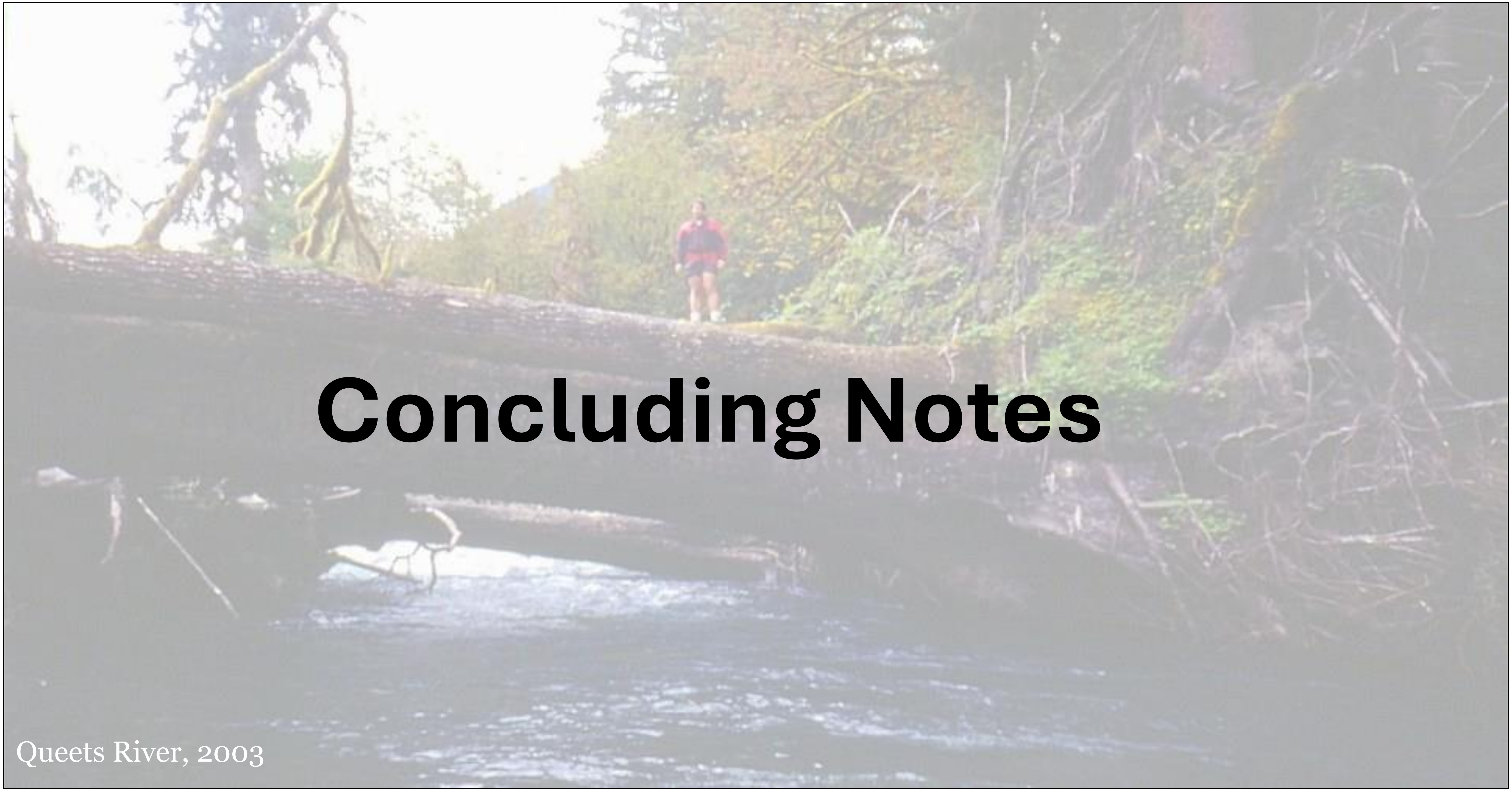
Queets River 73-1,470 yr old logjams
(*n*=49, Abbe 2000, Montgomery and Abbe 2006)

Take Home Message

Ensure wood is embedded in channel bed and wetted as much as possible – this is also key for scour.

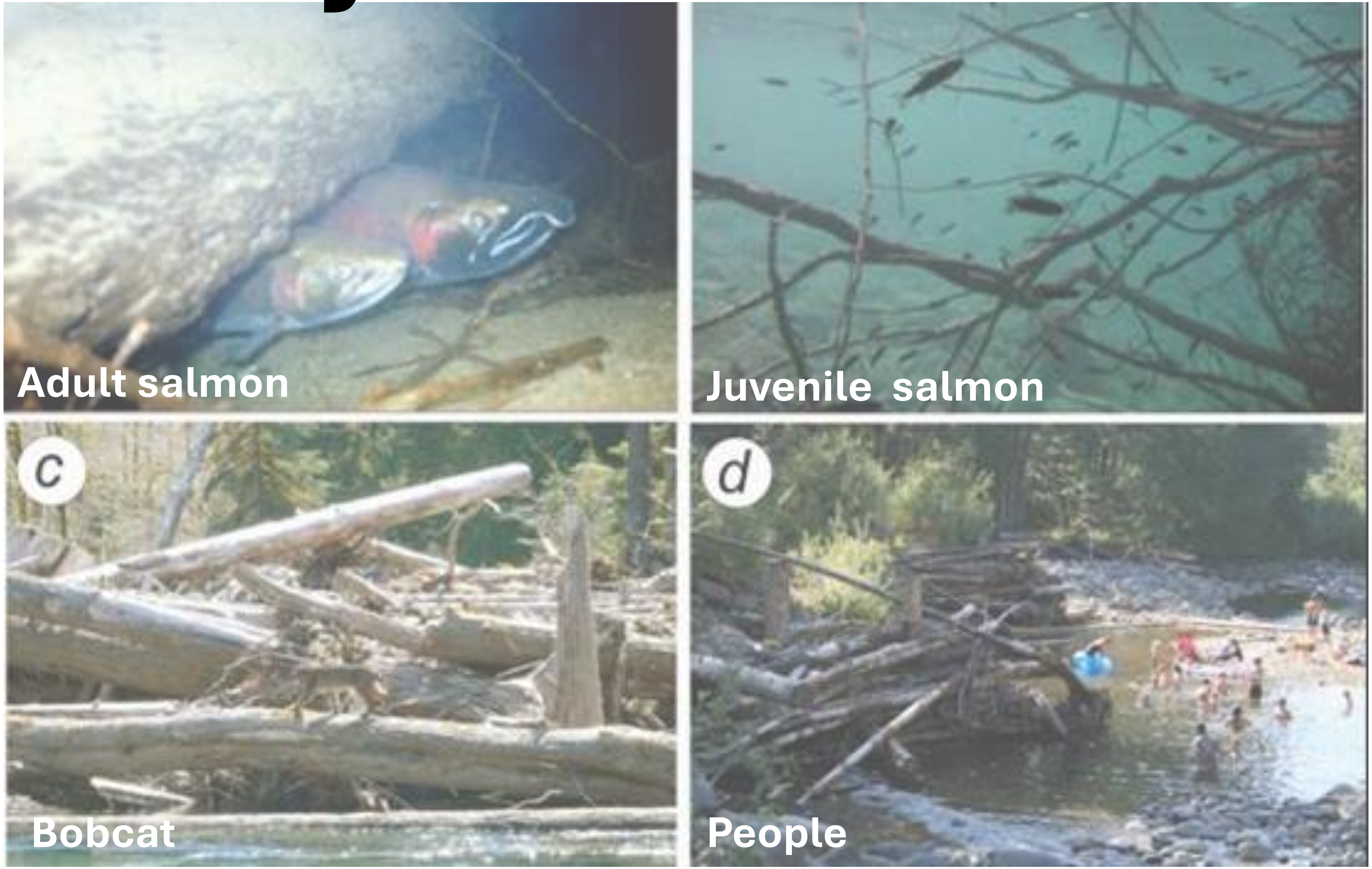
Logjam = wood in a buried logjam
In-stream wood = individual logs in a stream bed

Concluding Notes

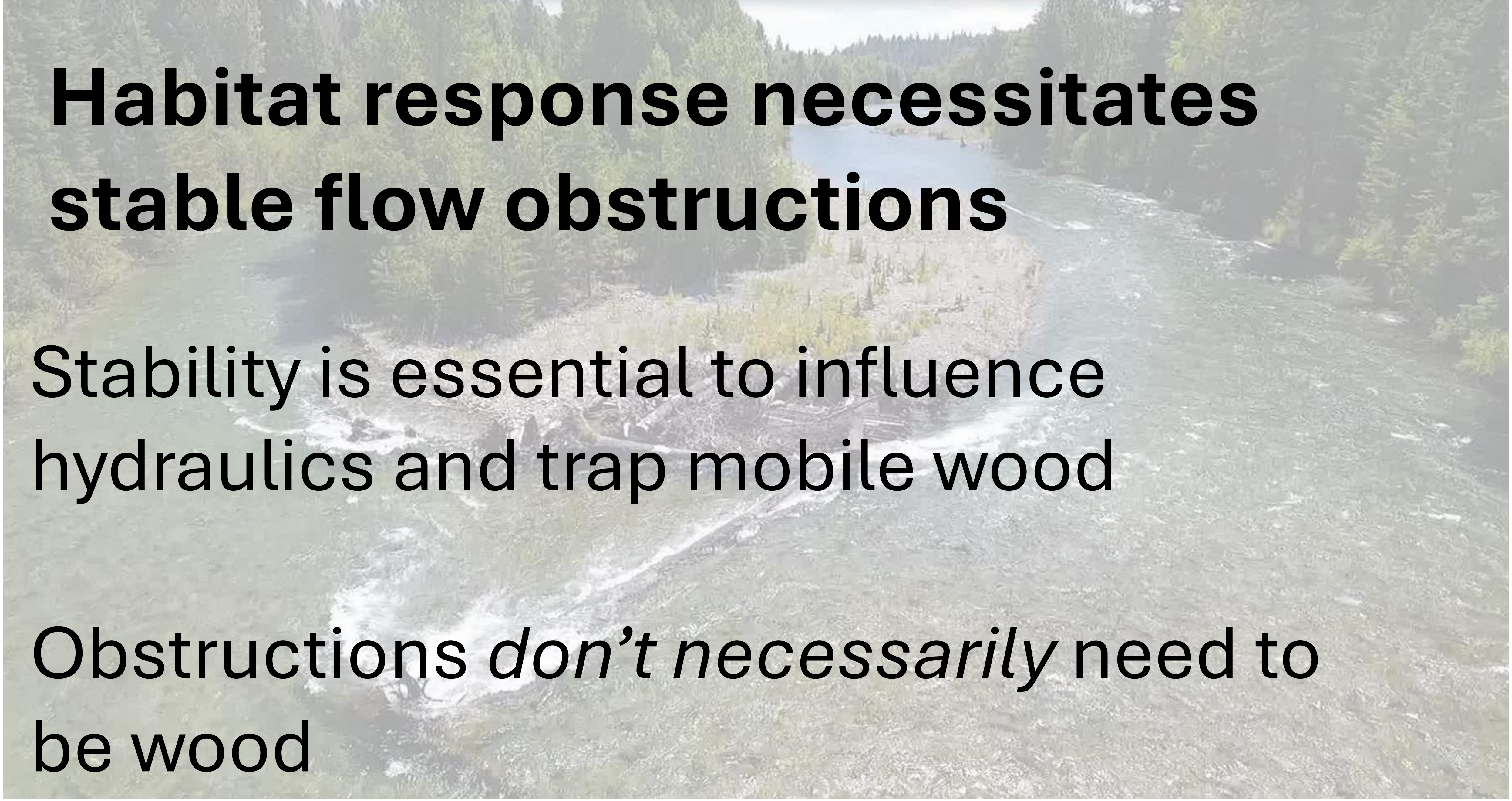


Queets River, 2003

Ecosystem Benefits



Habitat response necessitates stable flow obstructions



Stability is essential to influence hydraulics and trap mobile wood

Obstructions *don’t necessarily* need to be wood

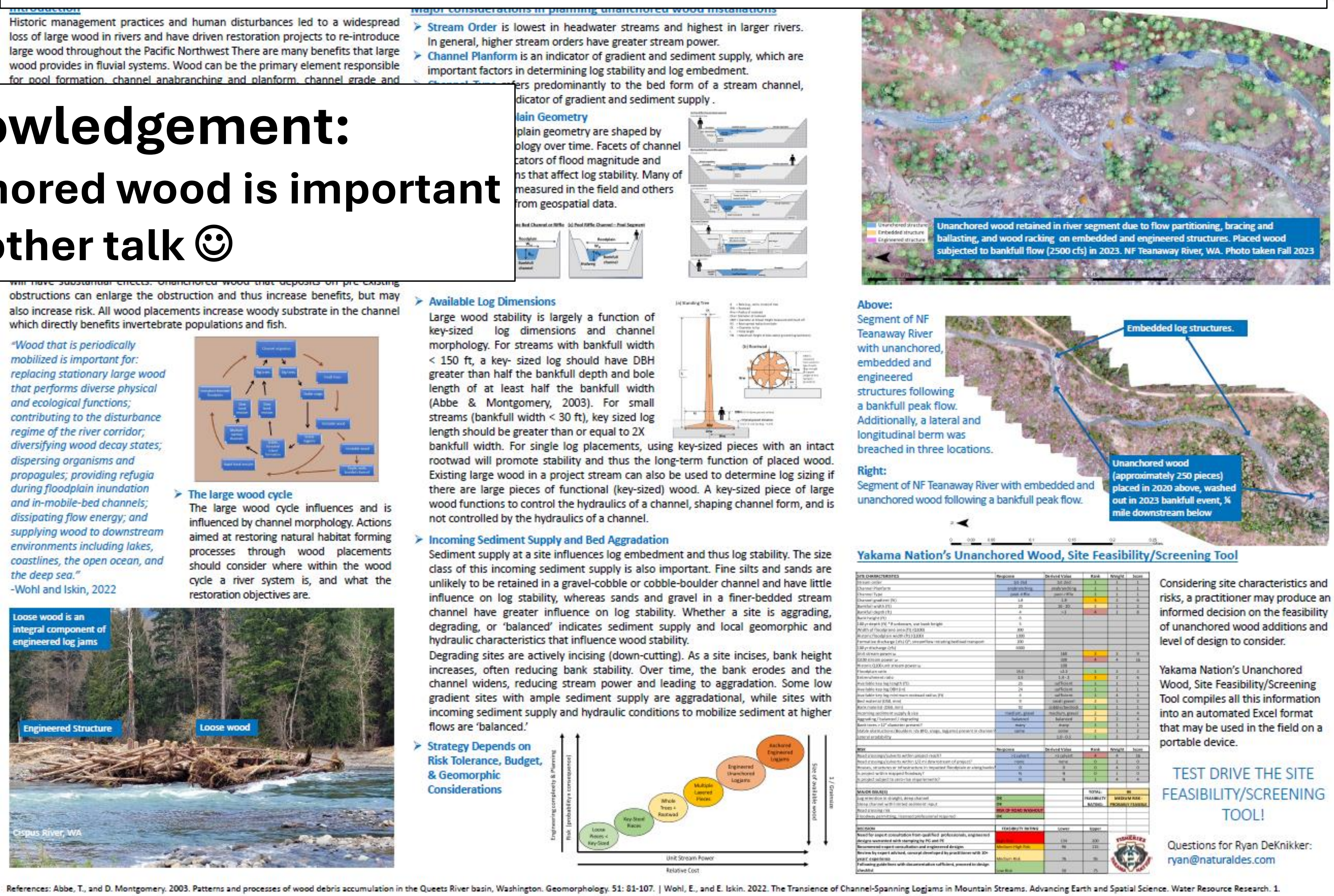
Functions and Guidelines of Unanchored Wood Placements in Stream Restoration

Ryan DeKnikker, Davey French, Tim Abbe

Acknowledgement:

Unanchored wood is important

But another talk ☺



Historic management practices and human disturbances led to a widespread loss of large wood in rivers and have driven restoration projects to re-introduce large wood throughout the Pacific Northwest There are many benefits that large wood provides in fluvial systems. Wood can be the primary element responsible for pool formation, channel anabranching and planform, channel grade and

obstructions can enlarge the obstruction and thus increase benefits, but may also increase risk. All wood placements increase woody substrate in the channel which directly benefits invertebrate populations and fish.

"Wood that is periodically mobilized is important for: replacing stationary large wood that performs diverse physical and ecological functions; contributing to the disturbance regime of the river corridor; diversifying wood decay states; dispersing organisms and propagules; providing refugia during floodplain inundation and in-mobile-bed channels; dissipating flow energy; and supplying wood to downstream environments including lakes, coastlines, the open ocean, and the deep sea."

-Wohl and Iskin, 2022

- **The large wood cycle**
  The large wood cycle influences and is influenced by channel morphology. Actions aimed at restoring natural habitat forming processes through wood placements should consider where within the wood cycle a river system is, and what the restoration objectives are.

Loose wood is an integral component of engineered log jams

Engineered Structure

Loose wood

Cispus River, WA

- **Stream Order** is lowest in headwater streams and highest in larger rivers. In general, higher stream orders have greater stream power.
- **Channel Planform** is an indicator of gradient and sediment supply, which are important factors in determining log stability and log embedment.
- …ers predominantly to the bed form of a stream channel, …dicator of gradient and sediment supply .
- **…lain Geometry**
  …plain geometry are shaped by …ology over time. Facets of channel …cators of flood magnitude and …ns that affect log stability. Many of …measured in the field and others …from geospatial data.
- **Available Log Dimensions**
  Large wood stability is largely a function of key-sized log dimensions and channel morphology. For streams with bankfull width < 150 ft, a key- sized log should have DBH greater than half the bankfull depth and bole length of at least half the bankfull width (Abbe & Montgomery, 2003). For small streams (bankfull width < 30 ft), key sized log length should be greater than or equal to 2X bankfull width. For single log placements, using key-sized pieces with an intact rootwad will promote stability and thus the long-term function of placed wood. Existing large wood in a project stream can also be used to determine log sizing if there are large pieces of functional (key-sized) wood. A key-sized piece of large wood functions to control the hydraulics of a channel, shaping channel form, and is not controlled by the hydraulics of a channel.
- **Incoming Sediment Supply and Bed Aggradation**
  Sediment supply at a site influences log embedment and thus log stability. The size class of this incoming sediment supply is also important. Fine silts and sands are unlikely to be retained in a gravel-cobble or cobble-boulder channel and have little influence on log stability, whereas sands and gravel in a finer-bedded stream channel have greater influence on log stability. Whether a site is aggrading, degrading, or 'balanced' indicates sediment supply and local geomorphic and hydraulic characteristics that influence wood stability.
  Degrading sites are actively incising (down-cutting). As a site incises, bank height increases, often reducing bank stability. Over time, the bank erodes and the channel widens, reducing stream power and leading to aggradation. Some low gradient sites with ample sediment supply are aggradational, while sites with incoming sediment supply and hydraulic conditions to mobilize sediment at higher flows are 'balanced.'
- **Strategy Depends on Risk Tolerance, Budget, & Geomorphic Considerations**

Unanchored wood retained in river segment due to flow partitioning, bracing and ballasting, and wood racking on embedded and engineered structures. Placed wood subjected to bankfull flow (2500 cfs) in 2023. NF Teanaway River, WA. Photo taken Fall 2023

Above:
Segment of NF Teanaway River with unanchored, embedded and engineered structures following a bankfull peak flow. Additionally, a lateral and longitudinal berm was breached in three locations.

Right:
Segment of NF Teanaway River with embedded and unanchored wood following a bankfull peak flow.

Embedded log structures.

Unanchored wood (approximately 250 pieces) placed in 2020 above, washed out in 2023 bankfull event, ¼ mile downstream below

Yakama Nation's Unanchored Wood, Site Feasibility/Screening Tool

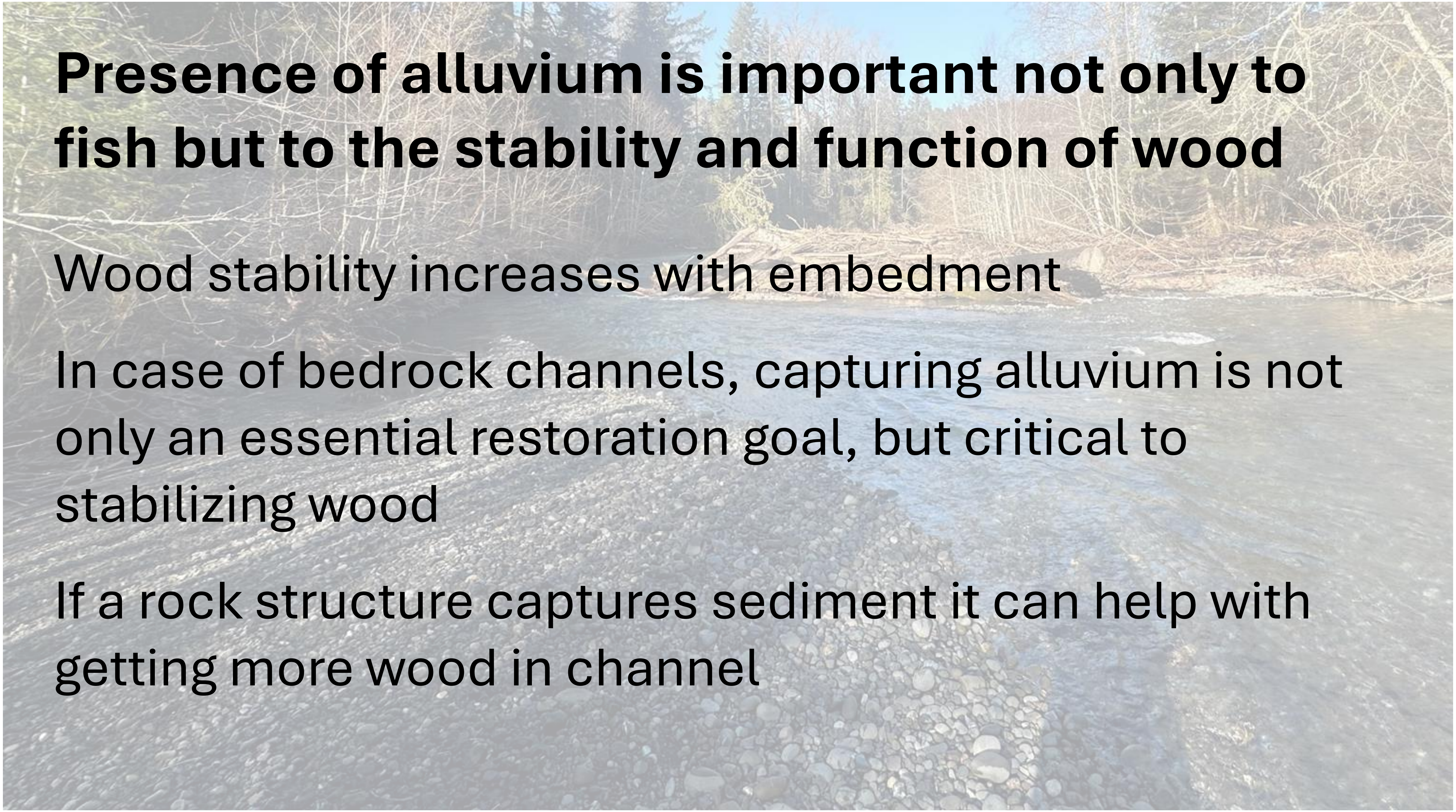
Considering site characteristics and risks, a practitioner may produce an informed decision on the feasibility of unanchored wood additions and level of design to consider.

Yakama Nation's Unanchored Wood, Site Feasibility/Screening Tool compiles all this information into an automated Excel format that may be used in the field on a portable device.

TEST DRIVE THE SITE FEASIBILITY/SCREENING TOOL!

Questions for Ryan DeKnikker:
ryan@naturaldes.com

References: Abbe, T., and D. Montgomery. 2003. Patterns and processes of wood debris accumulation in the Queets River basin, Washington. Geomorphology. 51: 81-107. | Wohl, E., and E. Iskin. 2022. The Transience of Channel-Spanning Logjams in Mountain Streams. Advancing Earth and Spatial Science. Water Resource Research. 1.

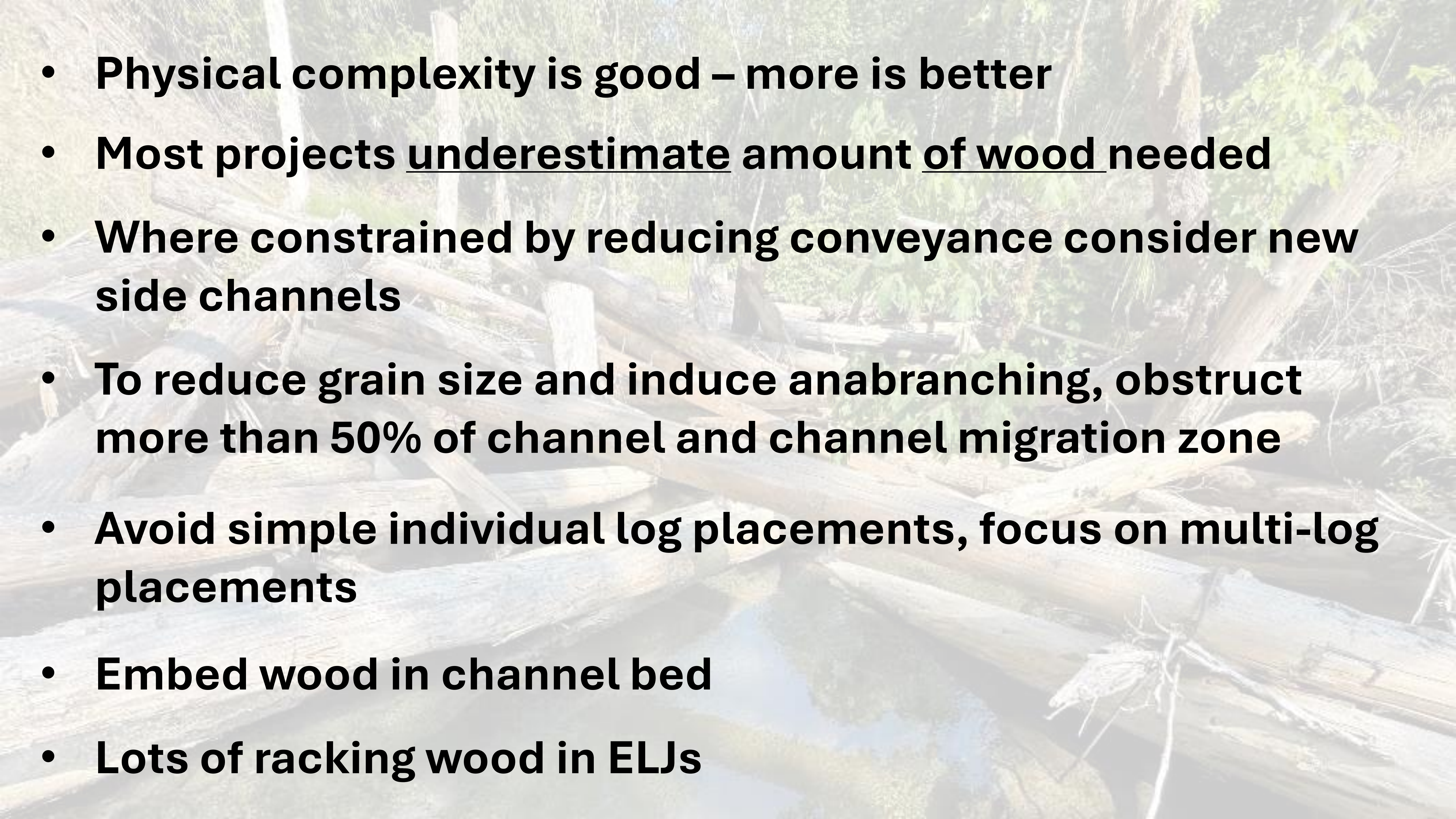


Presence of alluvium is important not only to fish but to the stability and function of wood

Wood stability increases with embedment

In case of bedrock channels, capturing alluvium is not only an essential restoration goal, but critical to stabilizing wood

If a rock structure captures sediment it can help with getting more wood in channel



- Physical complexity is good – more is better
- Most projects underestimate amount of wood needed
- Where constrained by reducing conveyance consider new side channels
- To reduce grain size and induce anabranching, obstruct more than 50% of channel and channel migration zone
- Avoid simple individual log placements, focus on multi-log placements
- Embed wood in channel bed
- Lots of racking wood in ELJs

Wood placement is best low in channel

- most effective stress partitioning
- greatest longevity
- highest engagement with fish

Identifying Wood Treatments

Problems	Channel incision	Bank erosion	Lack of pools	Lack of spawning gravel (cobble/bedrock substrate)	High temperature	Lack of side channels	Poor floodplain connectivity	Channel overwidening	Lack of cover	
Disturbance Process	Increased basal shear stress	Loss of shear strength of bank material, high near-bank shear stress, elevated sediment supply	Lack of stable in-stream wood	Simplification of stress partitioning (lack of roughness elements in channel)	Lack of shade (wide channels, immature riparian trees), lack of deep pools	Lack of stable in-stream wood	Lack of stable in-stream wood	Loss of shear strength of bank material, high near-bank shear stress, elevated sediment supply	Lack of stable in-stream wood	
Treatments	Wood and/or rock grade control, ELJ arrays	Stable toe roughness, ELJ flow deflectors or complex timber revetments along bank, ELJ arrays to dissipate flow before reaching sensitive areas	Stable in-stream wood, wood and/or rock grade control, ELJ arrays	Stable in-stream wood, wood and/or rock grade control, ELJ arrays	ELJ arrays splitting channel to create narrower channels	ELJ arrays splitting channel to create narrower channels	Stable in-stream wood, wood and/or rock grade control, ELJ arrays	Stable toe roughness, ELJ flow deflectors or complex timber revetments along bank, ELJ arrays to dissipate flow before reaching sensitive areas	ELJs with abundant racking wood	Riparian reforestation

Questions

tim@naturaldes.com

206-681-8697

Queets River, 2003

Engineered Logjams: References

Some ELJ references can be found on our website:
https://naturaldes.com/resources/

Abbe, T. and Montgomery, D. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management 12, 201-221.

Abbe, T. and Montgomery, D. 2003. Patterns and processes of wood debris accumulation in the Queets River Basin, Washington. Geomorphology 51(1-3), 81-107.

Abbe, T., Montgomery, D.R. and Petroff, C. 1997. Design of stable in-channel wood debris structures for bank protection and habitat restoration: an example from the Cowlitz River, WA. In Wang, S.S.Y., Langendoen, E.J. and Shields, F.D. (editors), Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision. 809-816.

Abbe, T. and Brooks, A.P. 2011. Geomorphic, engineering and ecological considerations when using wood in river restoration. In Simon, A., Bennett, S. and Castro, J. (editors), Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses and Tools. Geophysical Monograph Series 194. American Geophysical Union, Washington D.C., 419-451.

Abbe, T., Hrachovec, M. and Winter, S. 2018. Enginereed log jams: recent developments in their design and placement with examples from the Pacific Northwest, U.S.A. Earth Systems and Environmental Sciences. Elsevier. http://loi.or/10.1016/B978-0-12-409548-9.11031-0

Assani, A.A. and Petit, F. 1995. Log-jam effects on bed-load mobility from experiments conducted in a small gravel-bed forest ditch. Catena 25, 117-126.

Buffington, J.M. and Montgomery, D.R. 1999. Effects of hydraulic roughness on surface textures of gravel-bed rivers. *Water Resources Research* 35(11), 3501-3521.

Collins, B.D., Montgomery, D.R., Fetherston, K.L. and Abbe, T. 2012. The floodplain large-wood cycle hypothesis: a mechanism for the physical and biotic structuring of temperate forested alluvial valleys in the North Pacific Coastal Ecoregion. Geomorphology 139/140, 460-470.

Dobson, A. and Rixon, T.F. 1902. Forest conditions of the Olympic Forest Reserve, Washington. U.S. Geol. Survey Prof. Paper No.7. Washington D.C.

Eaton, B.C., Millar, R.G. and Davidson, S., 2010. Channel patterns: Braided, anabranching, and single-thread. *Geomorphology*, *120*(3-4), pp.353-364.

Haschenburger, J.K. 1999. A probabilistic model of scour and fill depths in gravel-bed channels. Water Resources Research 35, 2857-2869

Lamb, M.P., Dietrich, W.E. and Venditti, J.G. 2008. Is the critical Shields stress for incipient sediment motion dependent on channel-bed slope? Journal of Geophysical Research, 113, F02008, doi: 10.1029/2007JF000831.

Manga, M. and J. Kirchner. 2000. Stress partitioning in streams by large woody debris. *Water Resource Research* 36, 2373-2379

Sedell, J.R. and Froggatt, J.L., 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, USA, from its floodplain by snagging and streamside forest removal: With 2 figures and 1 table in the text. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen*, *22*(3), pp.1828-1834..

Extras

Working with Constraints

Large River Engineered Logjam Design: Structure Layout

Elwha River
Ranney Reach 2023
NAIP Aerial Image (USGS)

Project Goals

- Increase pool frequency & cover
- Increase retention of spawning gravels
- Create stable forested island and anabranching channel
- Benefit municipal water source by limiting westward migration of river channel

Port Angeles municipal water supply

Working with Constraints

Large River Engineered Logjam Design: Structure Layout

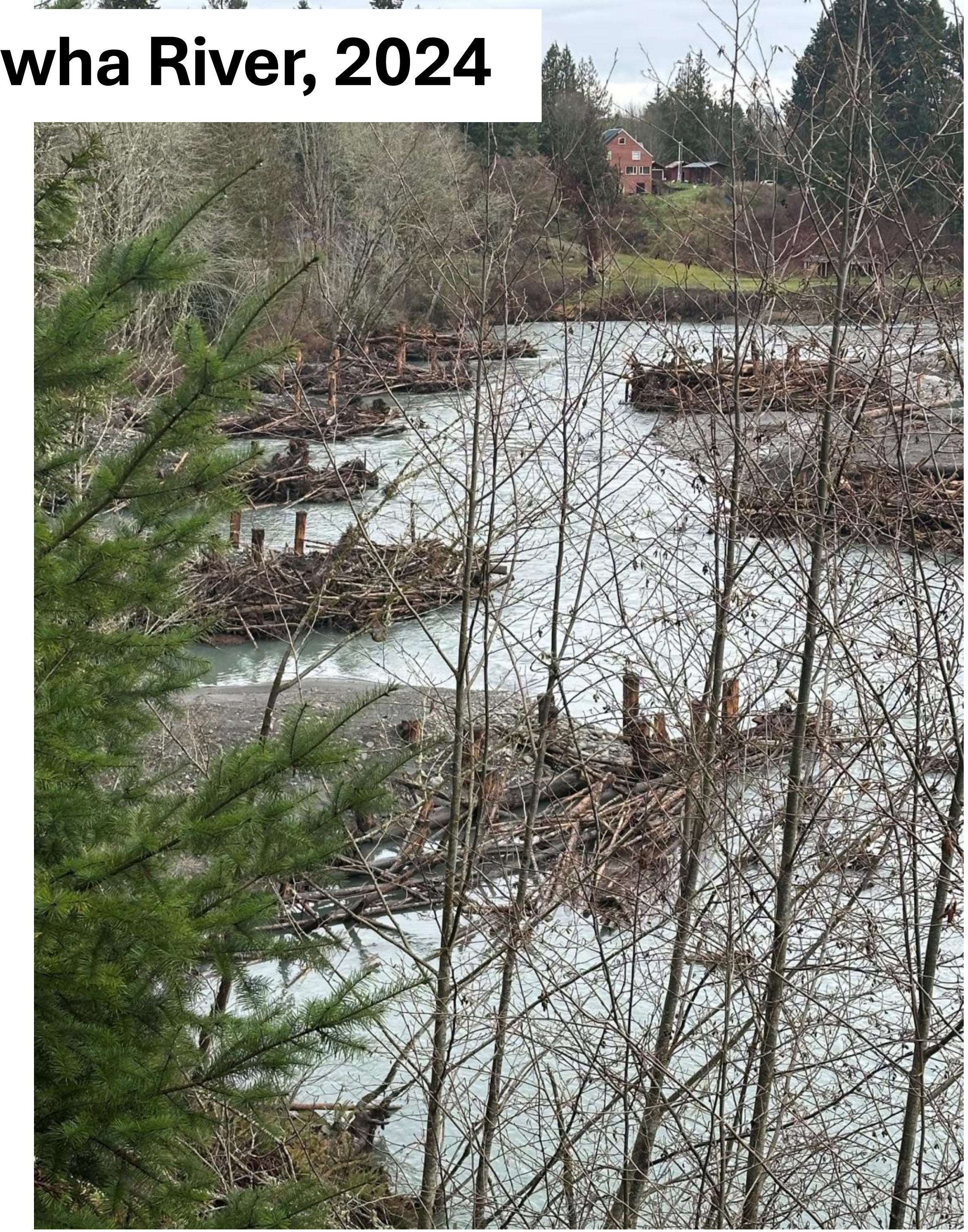
Elwha River
Ranney Reach 2024
Drone image just after restoration (NSD)

Project Goals

- Increase pool frequency & cover
- Increase retention of spawning gravels
- Create stable forested island and anabranching channel
- Benefit municipal water source by limiting westward migration of river channel

Port Angeles municipal water supply

Working with Constraints Lower Elwha River, 2024



Bank Erosion

Erosion is a natural and beneficial process where mature riparian forests are present.

- Restoration actions should accommodate erosion in these situations

Erosion can be problematic where it occurs into immature forests, pastures, fields or developed areas

- Erosion results in no recruitment of functional wood
- Erosion can lead to over-widened channels and elevated solar radiation (higher temperatures).
- Erosion can deliver elevated supply of fine sediment
- Erosion can deliver undesired materials into channel

Simple vs Complex Banks

South Fork Nooksack River

Simple vs Complex Banks

South Fork Nooksack River 2015

Simple vs Complex Banks

South Fork Nooksack River 2020