

Engineering With Nature®

Introducing the Riverine Engineering Practice Guide for Wood-Based Bank Toe Protection

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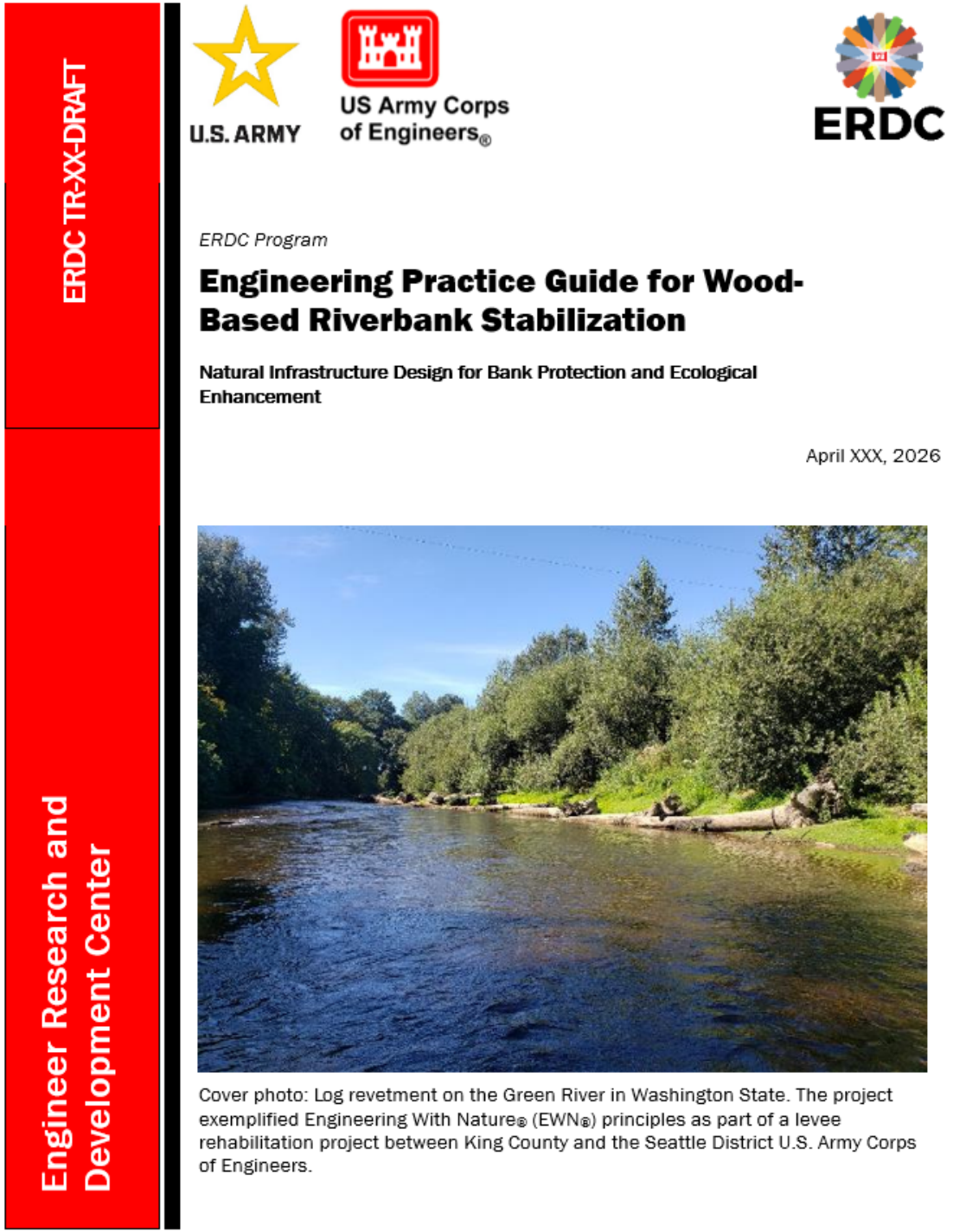
https://riverrangers.org/

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US Army Corps of Engineers

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https://ewn.erdc.dren.mil/engineering-practice-guides/

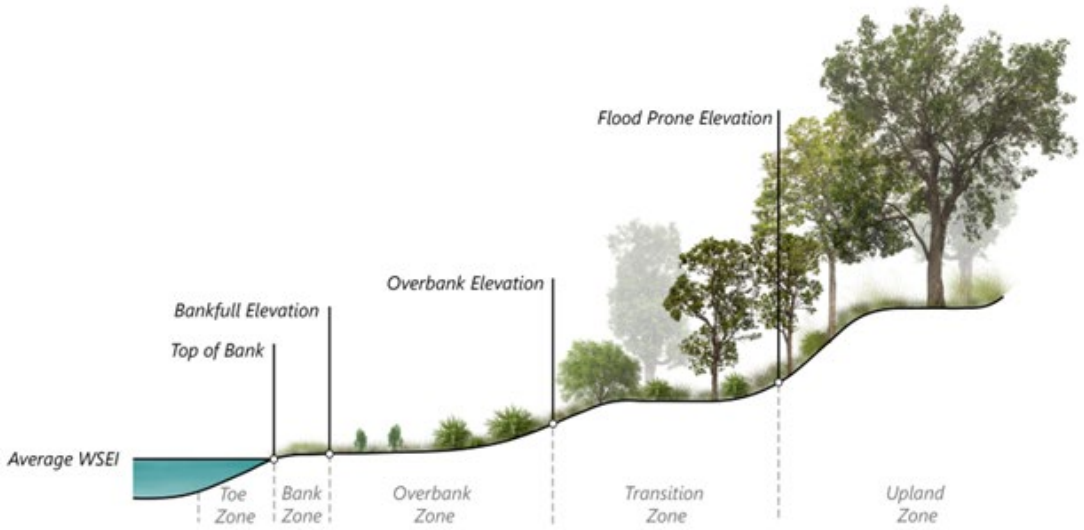


Practice Guide Details the Workflow for Designing Bank Toe Protection Using Wood

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- Define project goals around flood risk management, geomorphic processes, and ecological uplift (1.1 and 1.2)
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Iterative design and refinement

Long-term cycles of assessment

Additional Considerations (Section 4)
- Permitting and compliance (4.1)
- O&M requirements (4.2)
- Monitoring and adaptive management (4.3)

Other USACE Guidance
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- National Large Wood Manual
- Cost Effectiveness and Incremental Cost Analysis

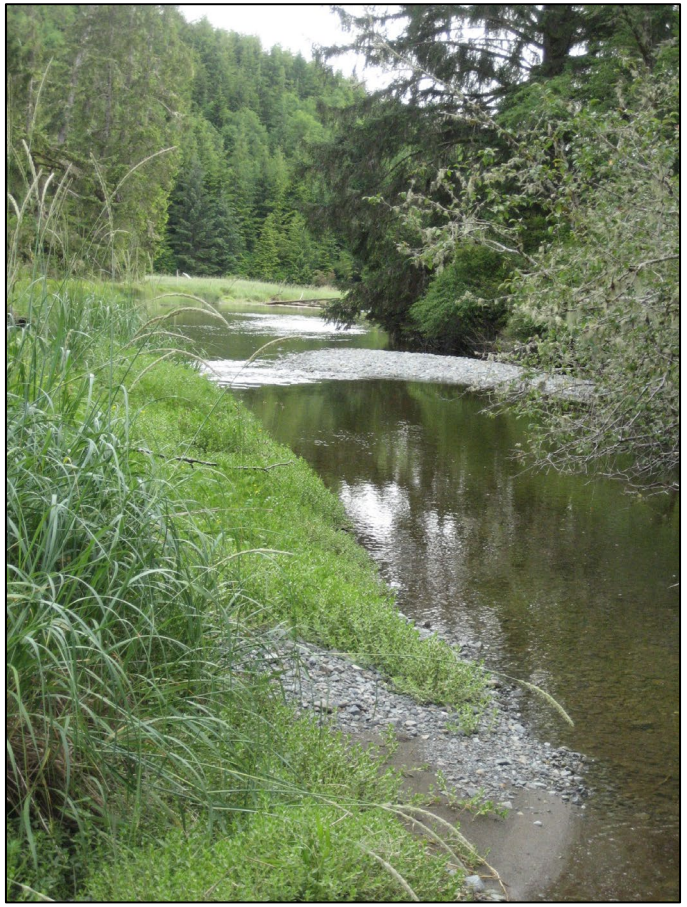
Set Project Goals, Define Success Metrics, Collect Data, Initiate Design, and Refine to a Final Design

Section 1.1:
Define Equal Project Goals around Flood Risk Management, Geomorphic Processes, and Ecological Uplift

Bank Stabilization:
Intentionally modify the bank profile, which alters near bank hydraulics in a manner that reduces the erosive forces acting on bank sediment, stabilizes the bank, and reduces rates of fluvial erosion further erosion

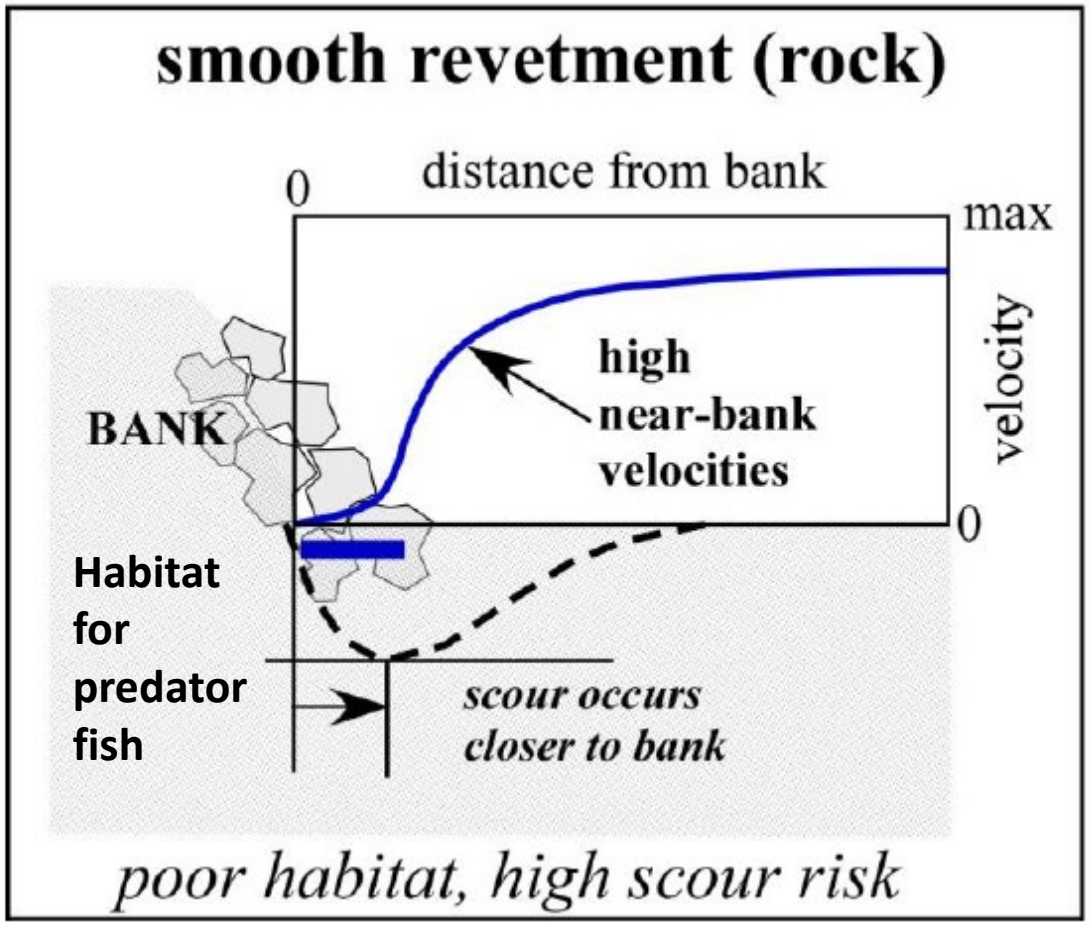
Geomorphic Processes:
Alters turbulent flow patterns and local roughness, which create backwater or pool areas or combine to reduce near-bank flow velocities, increase deposition, and encourage vegetation growth

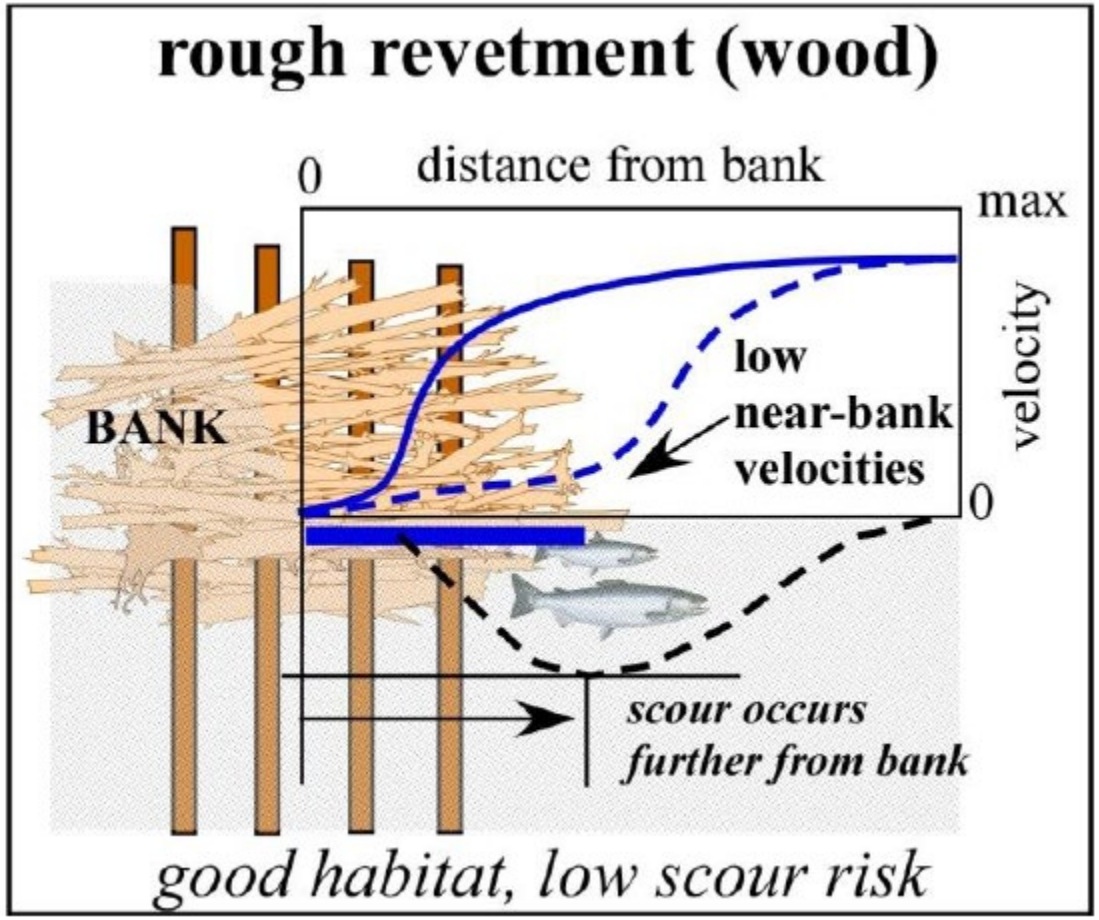
Water Quality Impacts:
Wood and wood surface biofilms regulates nutrient, organic matter, and fine sediment inputs and control rate of nutrient export; a food source for grazing invertebrates



Wood designs can mimic natural bank processes — combined with engineering analysis, it can stabilize and enhance

Section 1.1:
Equal Goal Consideration Creates a Multiple Purpose Project
EPG Focuses Solution on Use of Wood in Bank Protection





Conventional hard armoring protects infrastructure — but sacrifices the ecological functions that keep rivers resilient.

Consider the Local Situation For Appropriateness

- Is the river actively eroding at a rate faster than project can take effect
- Is critical infrastructure adjacent - wood may be part of a larger stabilization effort but unlikely the sole support
- Are flow velocities and energy so high that wood will either wash downstream or require very expensive ballasting
- Are appropriate wood materials need to be available nearby
- Ensure any recreational safety needs can be addressed through design

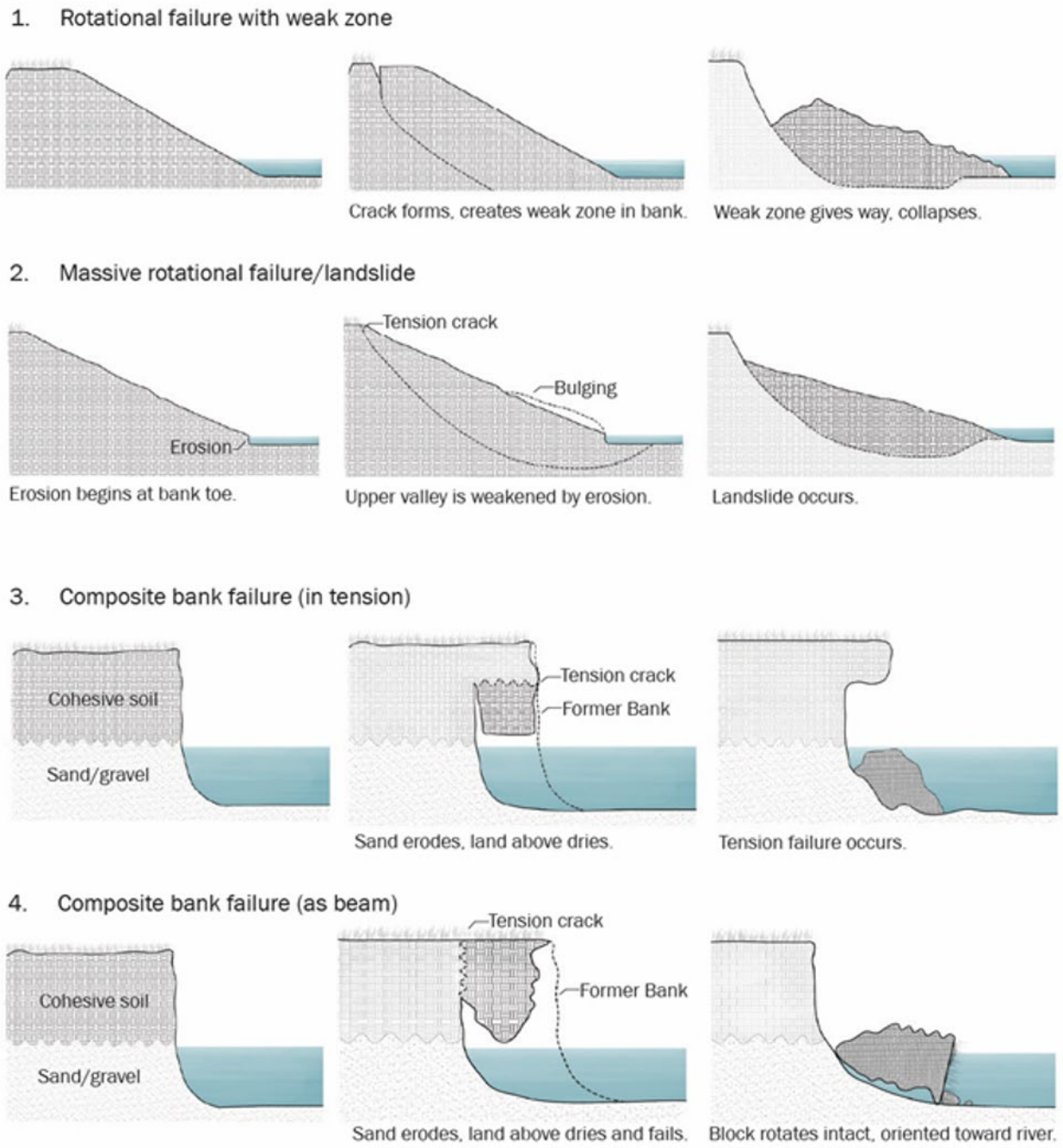




Wood may not always be appropriate for the location

Section 1.3: Determine Dominant Erosional Process

Can it be alleviated with toe structures?



Section 1.3:
Determine Dominant Erosional Process:
Natural Variability or Watershed Alteration

Natural process and beneficial for channel planform shape and complexity



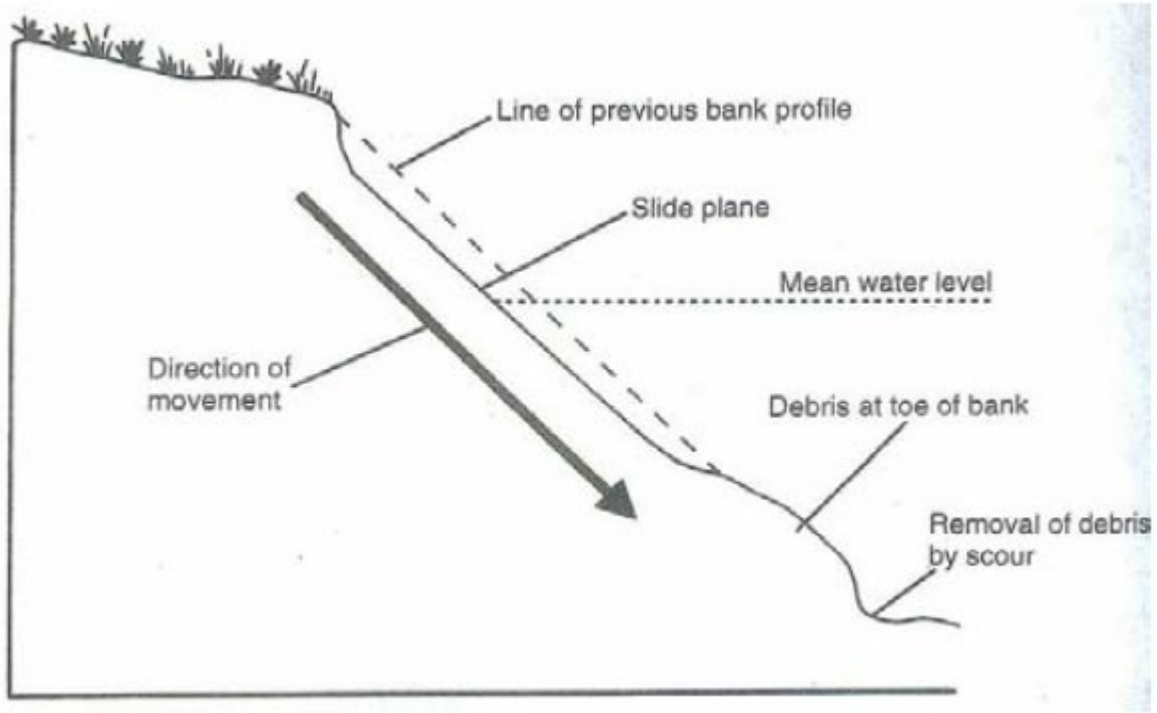
Erosion may be driven by hydromodification or undesirable due to nearby structures



Section 1.3:
Determine Dominant Erosional Process:
Shallow Landslide or Translational Slide

Occurs where there is a change in shear strength within the bank, which creates an eventual failure plane. This can be a change in bank material and formation of a seepage plane within the bank or a granular flow process.



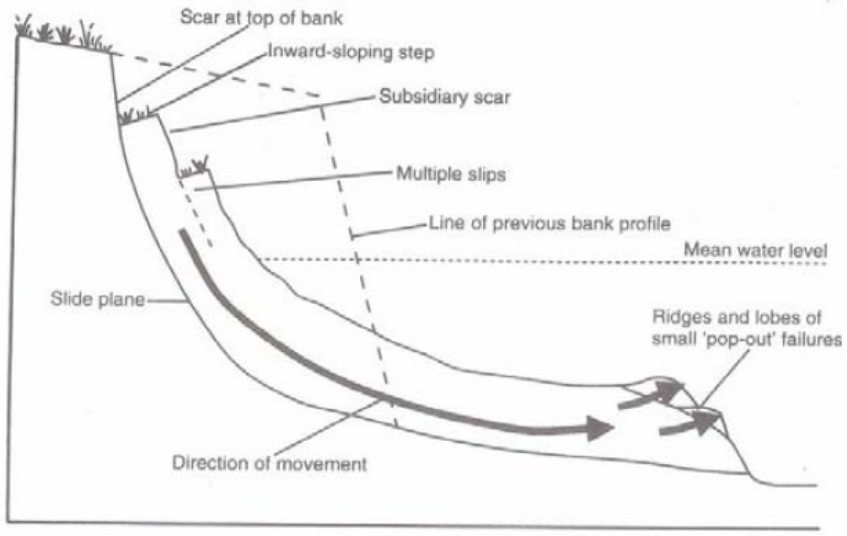


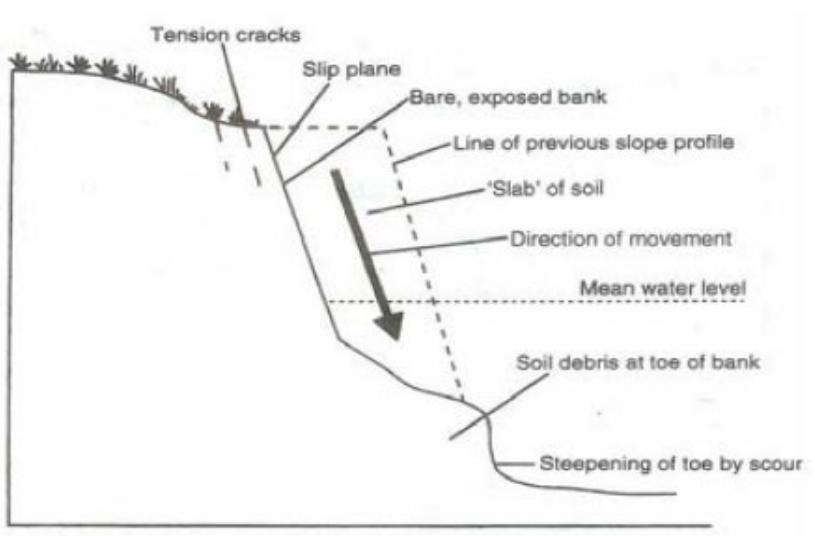
Projects at the toe will not address bank erosion processes

Section 1.3:
Determine Dominant Erosional Process:
Rotational Failure

Occurs when hydraulically driven toe erosion intersects an internal structural failure plane and bank slides downward and outward OR evaporation from the surface soils generates tension cracks at the top of the bank tension cracks at the top and bank separation







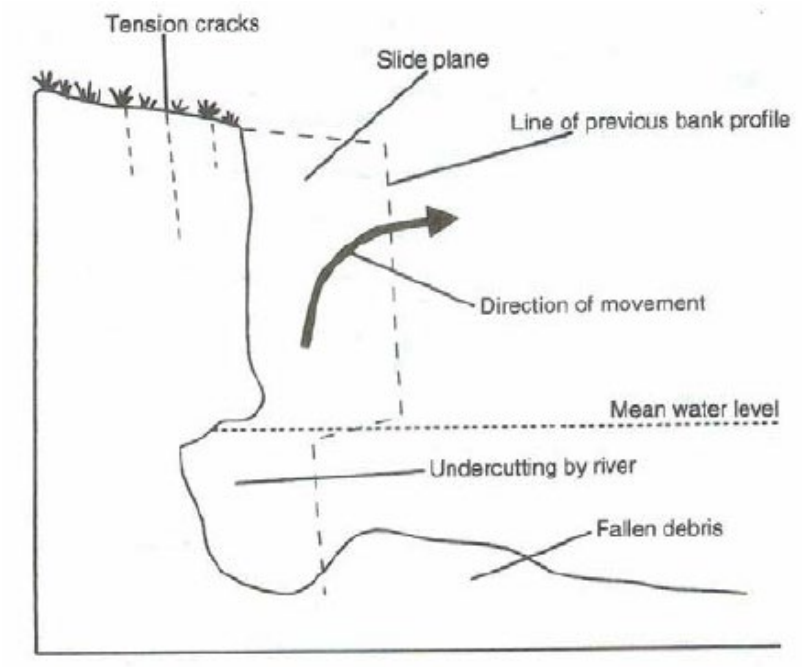


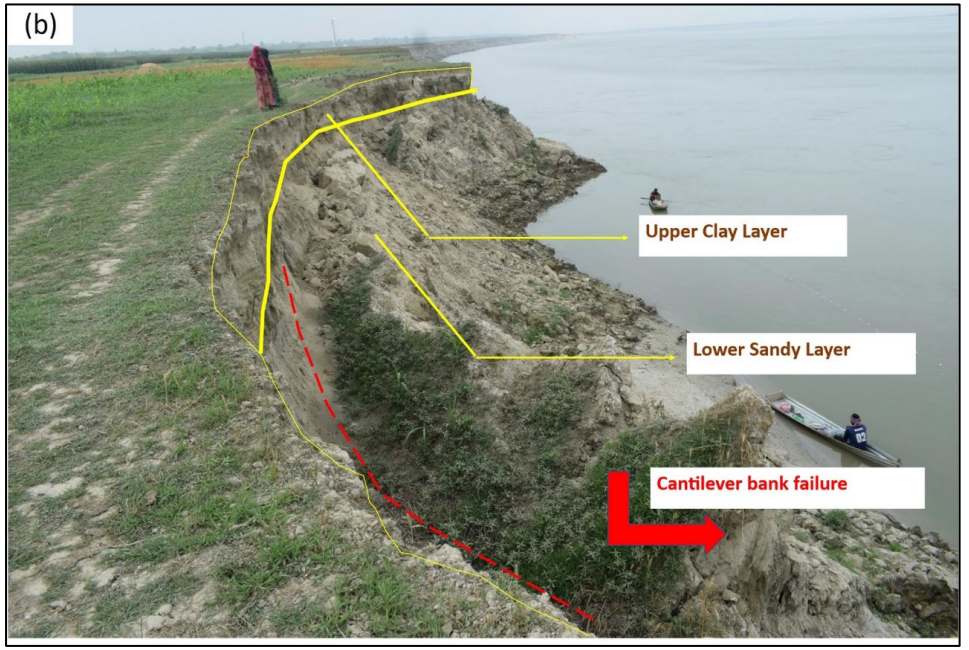
Toe stabilization can reduce risk of slab and rotational bank failure

Section 1.3:
Determine Dominant Erosional Process:
Cantilever Failure and Bank Undercutting

Common where there is a change in bank composition and the base is more easily eroded. Failure is triggered by hydraulic erosion of the more erodible base layer, leaving an overhanging block that can fail by shear or tensile







Toe stabilization can reduce risk of bank undercutting, particularly when cause of hydraulics is countered

EPG Focuses on Bank Toe











Section 1.4: Select General Design Approach









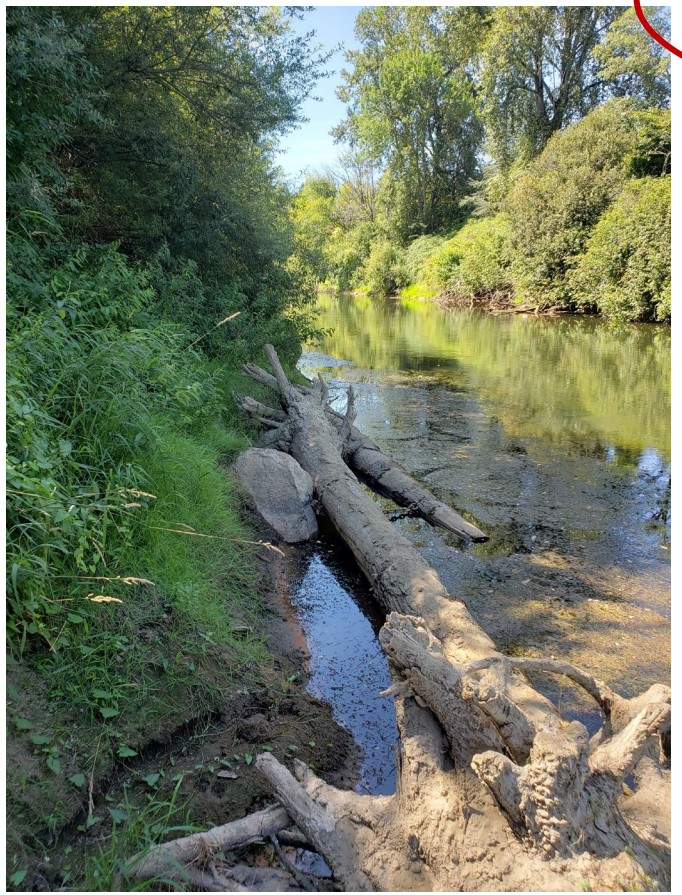
EPG includes methods that can be employed in a range of physiographic regions

Section 1.4:
Select General Design to Counter Erosional Process

Each technique differs in installation requirements, structural performance, ecological benefits, and long-term maintenance considerations, making proper method selection critical to project success.

Process Causing Erosion	Intervention
Reduction in sediment supply and increase in extended duration low flows	Log revetment Bank embedded logs - with and without rootwads
Persistent change in flow patterns and rates (for example, from an increase in the number of large flow events each year) has led to lower bank or bank toe erosion and overall bank collapse	Bank embedded logs - with and without rootwads
Increased overland flow due to change in local land use has led to bank collapse and channel widening	Log deflectors –logs can extend into the channel Log revetment –logs need to remain aligned with the bank
Persistent reduction in sediment supply or increase in flow rate has eroded the bank face as well as the toe. Often caused by boat wakes or nearby infrastructure causing expansion and contraction of flows and altering sediment transport processes	Timber bank crib –logs cannot extend into the channel Log deflectors– boat wakes have concentrated erosion closer to the toe and logs can extend in the channel

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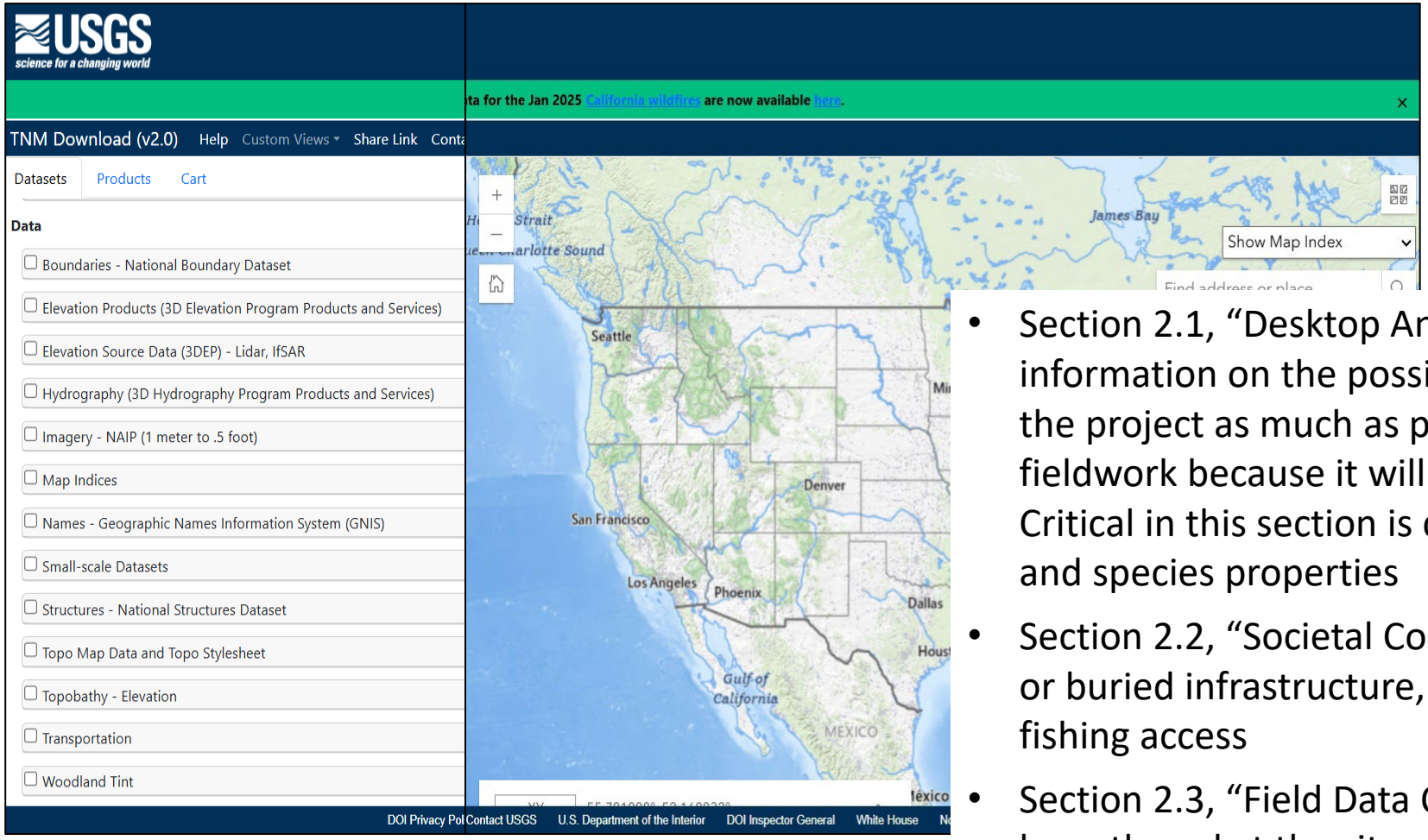
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Section 2:
Gather the Data Needed to Develop a Design

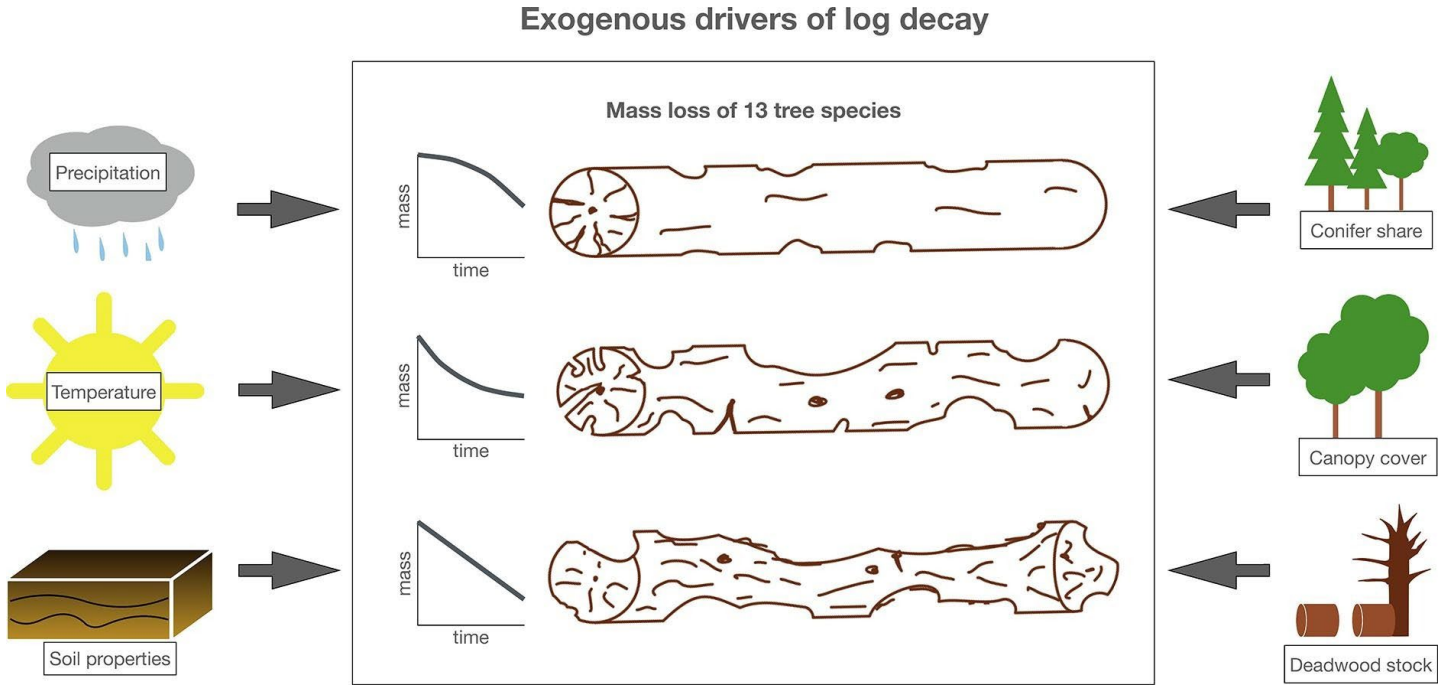




- Section 2.1, “Desktop Analysis,” focuses on gathering existing information on the possible project reaches and using it to define the project as much as possible. It should occur prior to the fieldwork because it will inform and focus the data collection. Critical in this section is determining the wood species available and species properties
- Section 2.2, “Societal Context,” focuses on land use, river adjacent or buried infrastructure, boater use and safety, and need for fishing access
- Section 2.3, “Field Data Collection,” describes the data that has to be gathered at the site on wood and ecosystem and describes or references collection methods.

Section 2.1: Desktop Analysis

- Gather existing information on the possible project reaches and use it to define the project as much as possible.
- Occurs prior to the fieldwork because it will inform and focus the data collection.
- Includes determining the wood species available and species properties



Edelmann et al., 2023

Appendix A: Table of wood species specifics.

Wood Species (Scientific Name)	Common Name	Decay Rate (years to 50% loss)	Climate	Average Log Diameter (in)	Source Document
Acer rubrum	Red Maple, Swamp Maple, Scarlet Maple	10	Temperate	7.2	Russell et al., 2014
Acer saccharinum	Silver Maple	9	Temperate	7.2	Russell et al., 2014
Acer saccharum	Sugar Maple	10	Temperate	7.2	Russell et al., 2014
Alnus incana	Speckled Alder, European Gray Alder	6.8	Subarctic	2	Freschet et al., 2011
Betula alleghaniensis	Yellow Birch, Golden Birch, Swamp Birch	11	Temperate	7.2	Russell et al., 2014
Carpinus betulus	European Hornbeam	~5	Temperate	12.2	Kahl et al., 2017

Decay rates depend on species and local climate

Section 2.3: Field Data Collection

From aerial image analysis during desktop work

- identified bankline at different points in time
- determined if erosion is episodic or continual

While at the Site

- Focus survey on reaches with greatest and least change in bankline for causal indicators
- Characterize bank soil layers
- Generate detailed bank survey data to use in design
- Verify presence or absence of adjacent infrastructure



Describes field data needed and describes or references collection methods

End of Section 2 has a table to check through during data collection

Question to Answer from Collected Data	Desktop	Field
Is there a nearby source for wood and ballast rock?	2.1.2, 2.1.4	
How does site physiography matter for project design?	2.1.2, 2.1.4	
Does the channel have floodplain access or is the channel incised?	2.1.2, 2.1.3	
Are wood-based structures appropriate for the site?	1.5	
How has the channel changed over recent history (10 years, 100 years)?	2.1.1, 2.1.2, 2.1.3	
What are the channel and reach planform patterns and are they the same?	2.1.2	
What are current uses of the channel? Are there current channel uses that could impact design?	2.2.3, 2.2.4, 2.2.5	2.3 (verify)
Is there infrastructure in the area that could impact design or the amount of acceptable risk?	2.2.1, 2.2.2	2.3 (verify)
What is the bank profile geometry in eroded and non-eroded reaches?	2.1.2	2.3.1
What is the primary mechanism of bank erosion at the site?	1.3, 2.1.2	2.3.1
Are bank soils consistent? Are they cohesive, non-cohesive, or a mix?		2.3.5
What are the bank soil layer and soil properties?	2.1.1	2.3.5
What are the range of flows at the site and the different flow frequencies (10%, 50%, 90% flow exceedance probability flows)?	2.1.3	
What are the top of bank and bankfull flows?		2.3.1
Are there plant or animal species of concern or interest in the area?	2.1.5	2.3.6
What are the native forms of vegetation in the region?	2.1.5	2.3.6
What is the grain size distribution of sediment on the channel bed?		2.3.2
What is the sediment supply (if applicable)?		2.3.4
Is there a need to create scour pools?	2.1.5	2.3.6
Is there a need to narrow the channel?	2.2.1	2.3.1
Has anyone already built a hydraulic model of the area?	2.1.1	
Is there wood present in the channel and riparian area?	2.1.2	2.3.3

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Section 3.1:
Design Objectives are Defined to Project Meets Design Goals

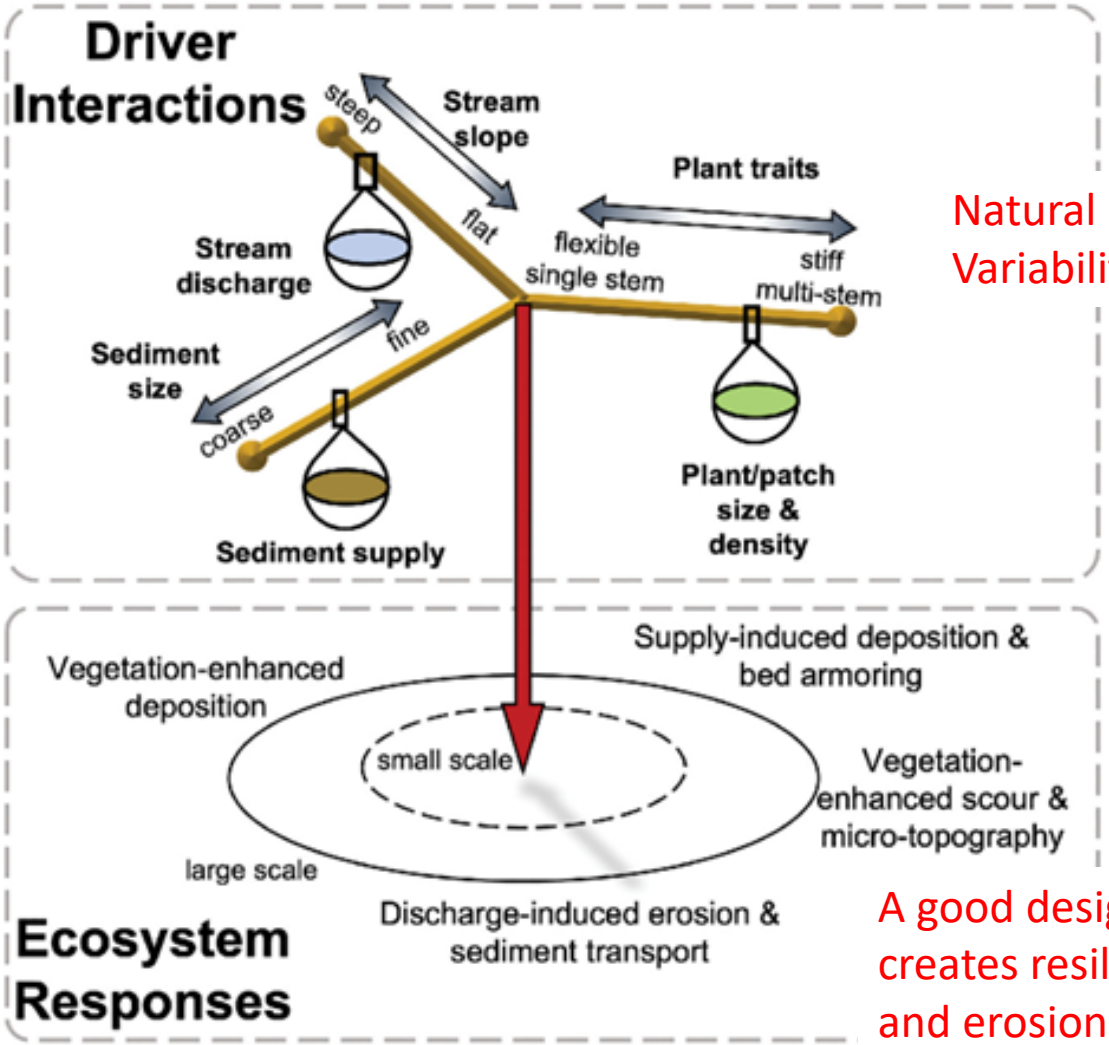


Image from Bywater-Reyes, Diehl, Wilcox, Stella, and Kui. 2022. ESP&L, 47 (10): 2410–36. https://doi.org/10.1002/esp.5385.

What could happen to risk long-term success of project goals?

- Excessive amounts of sediment are deposited, burying the wood and aggrading the lower bank to a higher elevation
- Excessive amounts of organic matter and wood are deposited on the structure, increasing hydraulic stresses on the structure
- Wood is not appropriately ballasted and transports downstream
- Project alters the hydraulics and the bank upstream or downstream of the site erodes
- Bank erosion continues due to processes not associated with fluvial erosion and bank line retreat eventually strands the wood structure in the channel
- Changes to land use upstream alter hydraulics and sediment supply leading to erosion that threatens existing infrastructure or private property

Section 3.1:
Metrics Quantify Project Objectives and Build in Resilience

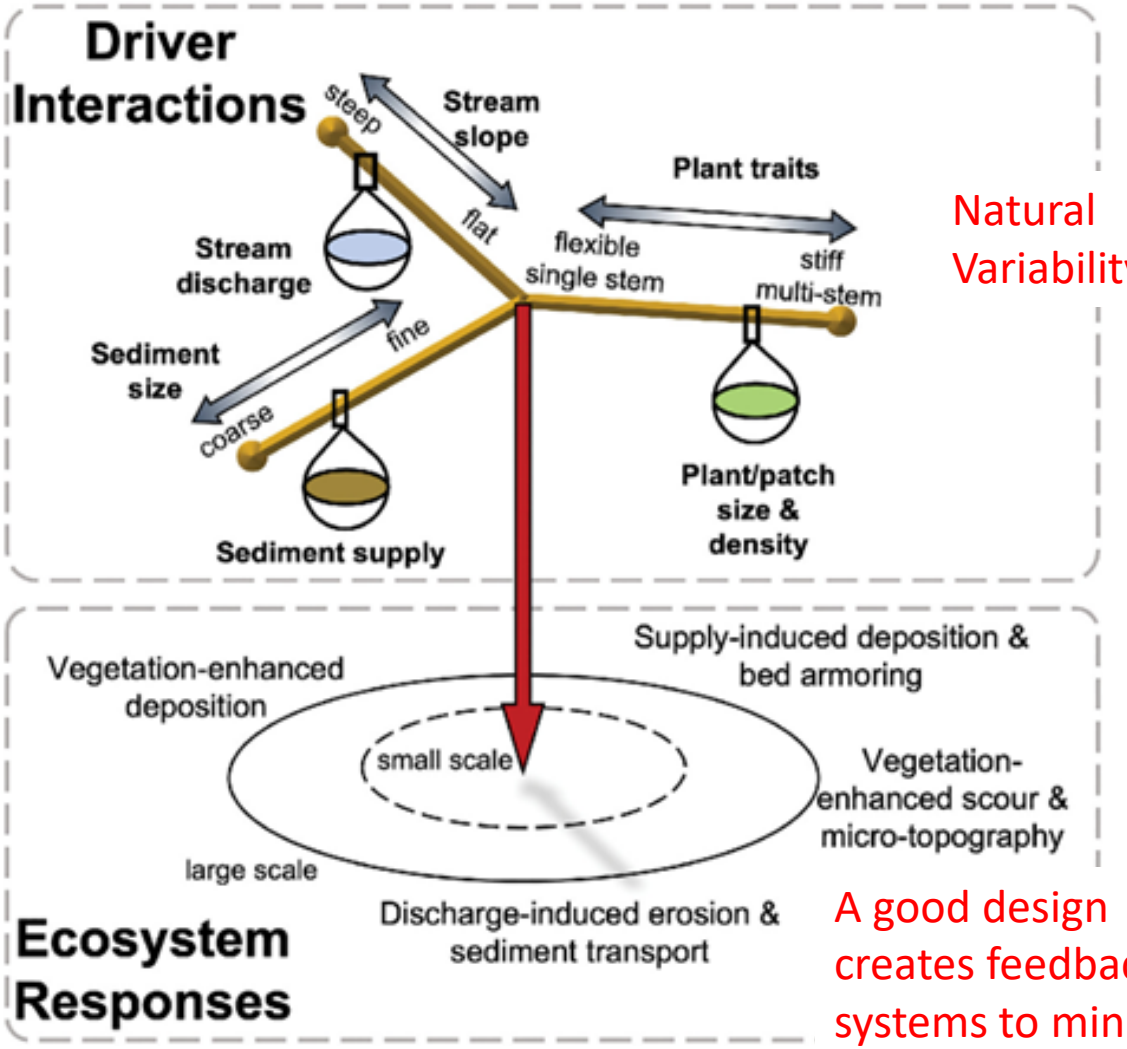


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Define how much change is acceptable
The criteria should include natural variability within the range of acceptable adjustment

- What is the tolerance level for bank erosion or near-bank deposition before risking project goals?
- How much of the structure can be non-functional (eroded logs or ballast rock, log or rootwad burial, log or rootwad not engaged with flow) before risking project goals?
- Are the vegetation species diverse?
- What is the minimum decrease in organic matter or nutrient input the to river?
- Is the project sustaining the minimum expected level of ecosystem diversity and abundance?

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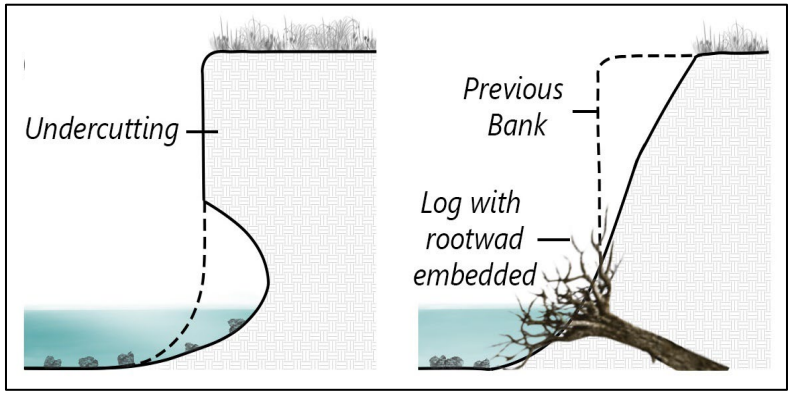
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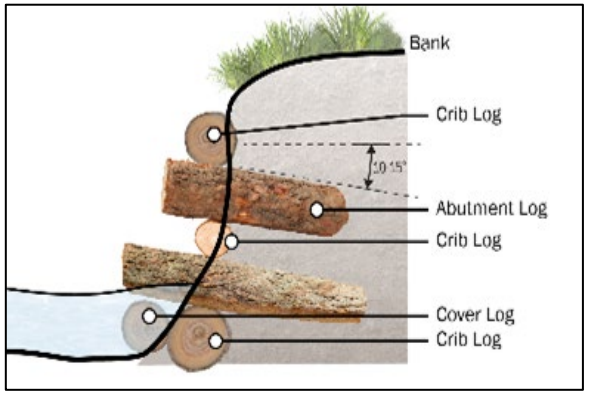
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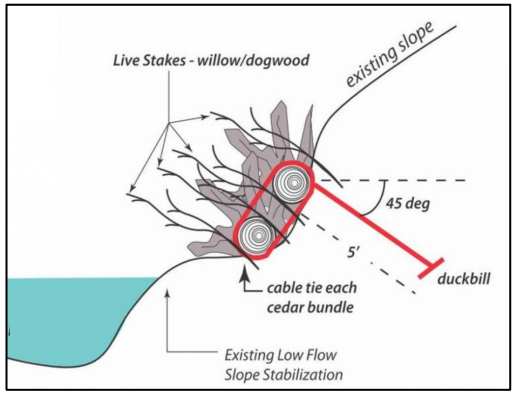
Section 3.3 Select Design Type

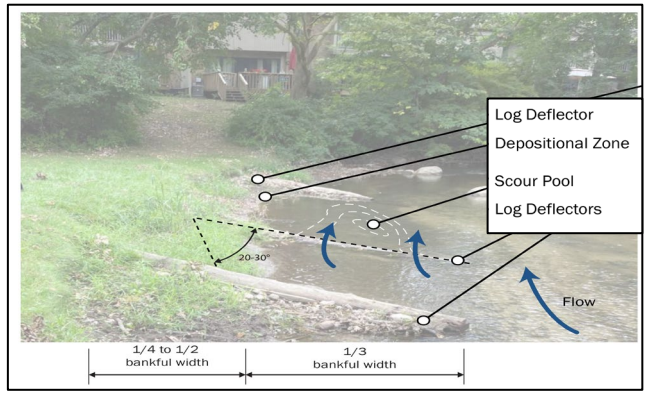
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Design Phase	Design Aspect	Specific Criteria	Data	Design
Section 3.3: Develop Initial Design	Identify Design Type	Determine the dominant process responsible for bank erosion and the appropriate type of protection design	1.3	3.3
	Bank Embedded Log	Determine use of rootwads, log spacing, and log location in bank profile	1.4.2	3.3.1
	Timber Bank Crib	Determine length and height, appropriate planting	1.4.3	3.3.2
	Log Revetment	Determine location relative to bank toe, height and complexity of structure, and inclusion of any rootwads	1.4.4	3.3.3
	Log Deflector	Determine orientation, length, and distance of log into the flow. Orient deflector to create one or two scour and deposition locations	1.4.5	3.3.4









Ensure that initial design from planning is appropriate intervention for erosional drivers
(e.g. overland flow widened bank, boat wave action, reduced sediment supply, upstream flow control)

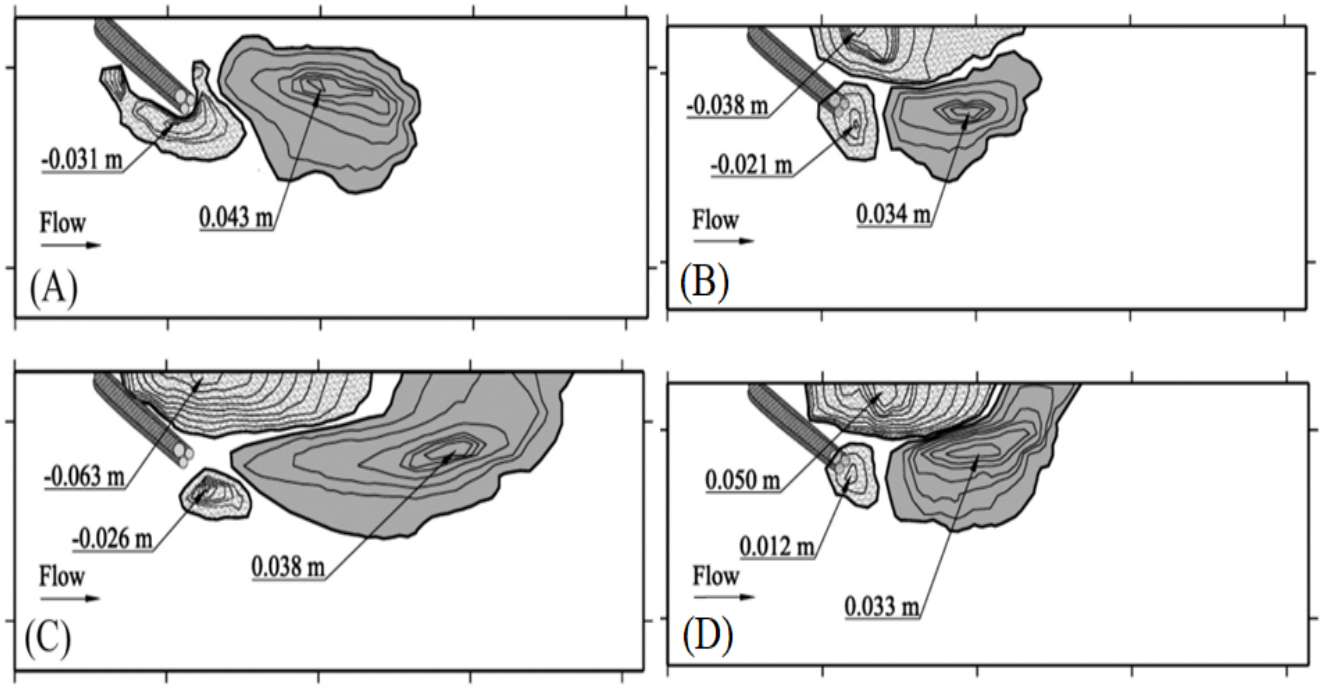
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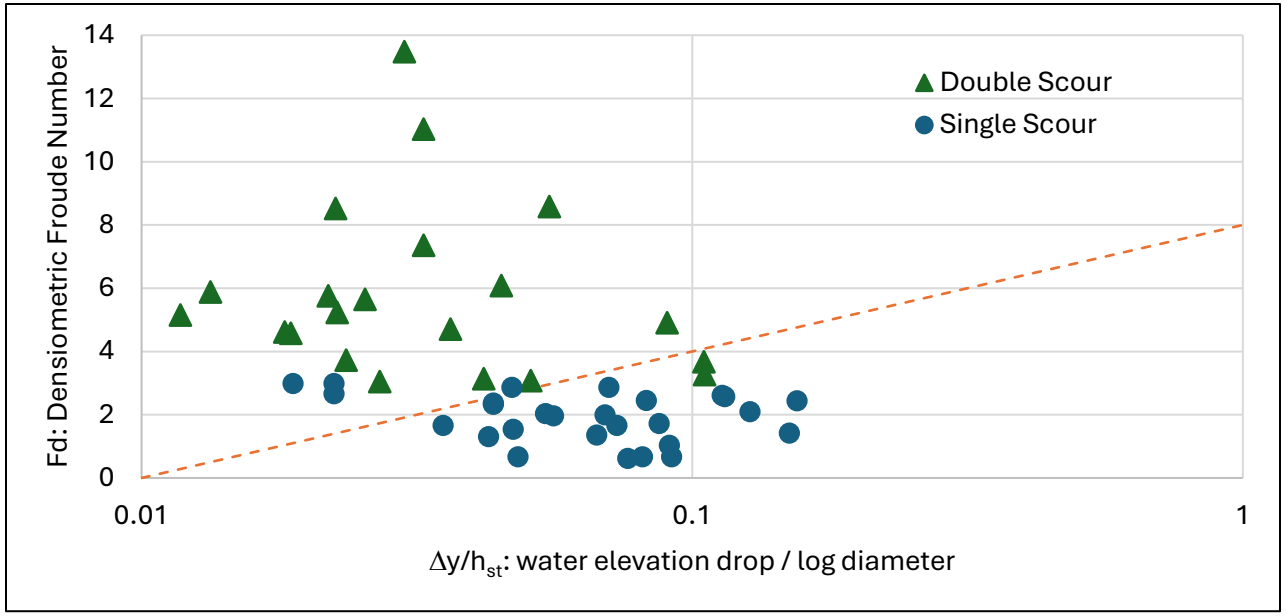
Can design to create single or double scour holes and for deposition as well as scour



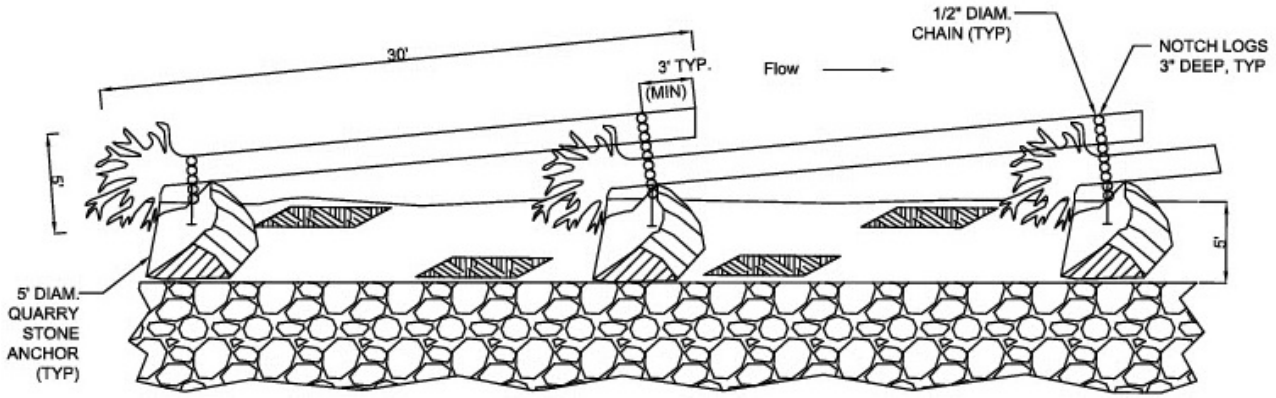
The maximum scour depth expected at a log deflector is predicted using information on the structure size, densimetric Froude number, and water depths for the design flows

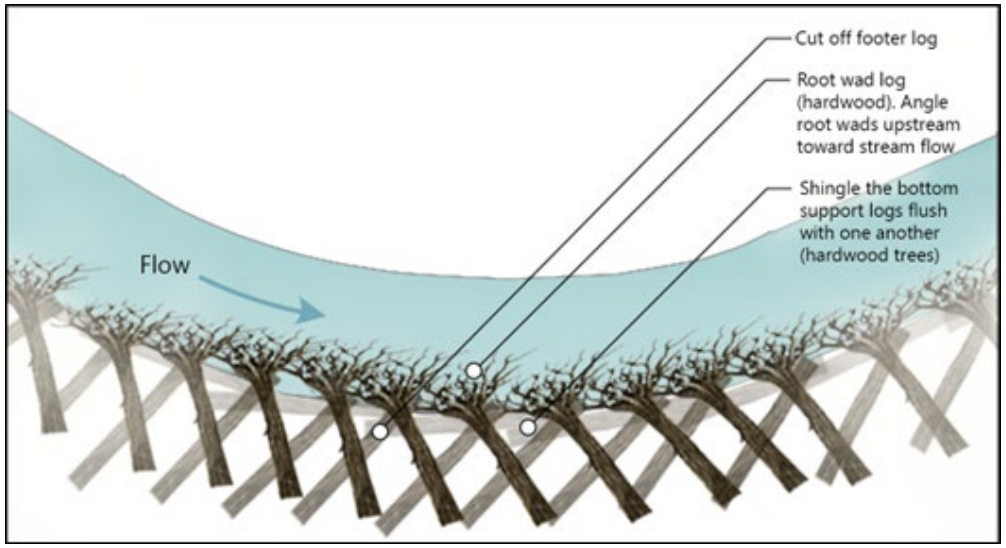
$$z_{max} = \frac{h_{st} l_{st}}{B h_{tw}} 6.6 F_d^2 \Delta y$$

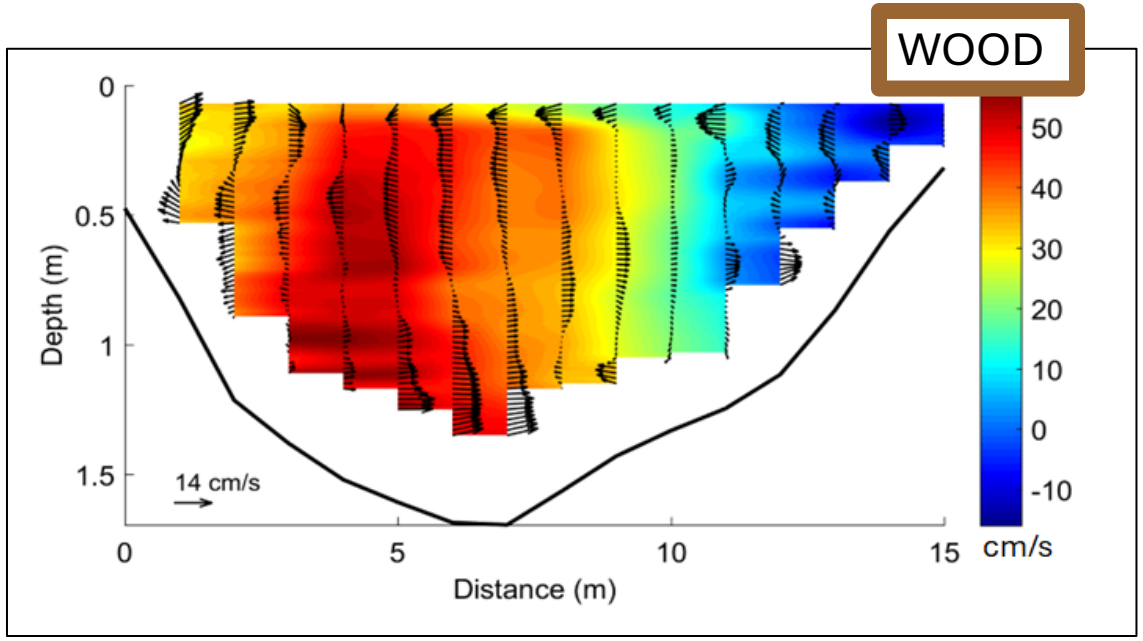




Design to Alter Near Bank Hydraulics







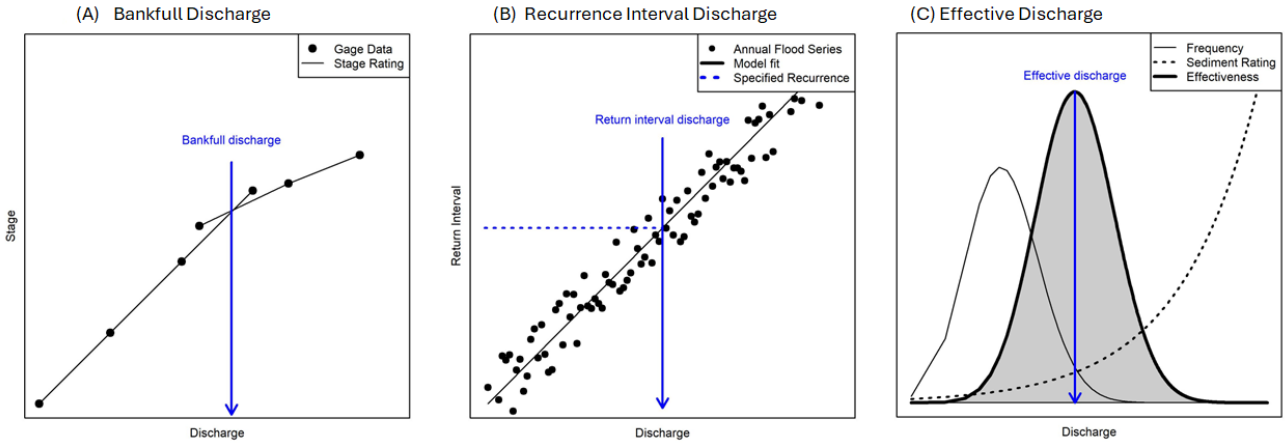
Cross-sectional flow fields from a straight reach of a river with wood along the right bank. Shows downstream and transverse velocity magnitudes with band color and arrows, respectively.

Design Phase	Design Aspect	Specific Criteria	Data	Design
Section 3.4 Evaluate Design	Design Discharge	Determine the discharges to use in design	2.1.3	3.4.1
	Hydraulic performance	Calibrate to the events that created erosion. Then, evaluate over multiple hydrographs and design flows that reflect existing and anticipated flow rates	2.1.3	3.4.2
	Bank Process	Evaluate risk of bank failure under a range of flows and designs	2.3.1, 2.3.4	3.4.2
	Project Stability	Evaluate forces acting on design and adjust for needed anchoring and/or ballast to fulfill structural stability goals. Evaluate design over multiple hydrographs and future bank lines	—	3.4.3
	Sediment transport	Evaluate impact of bank embedded log design on near-bank aggradation and erosion, including the potential for scour. Use either a sediment transport rating curve or sediment transport model, depending on project risk.	2.3.2, 2.3.4	3.4.4

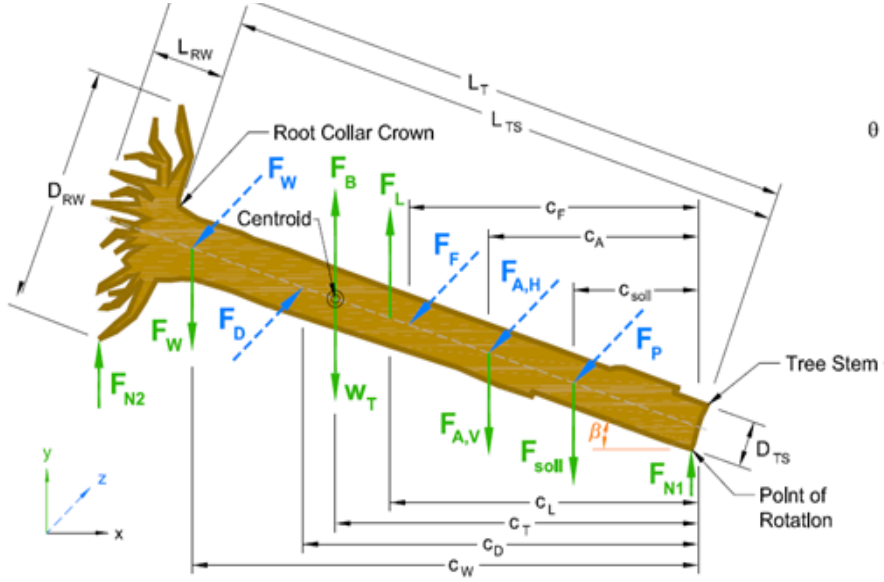
Choose multiple design discharges
Model to the degree needed for the risk

Drag force acting on the wood

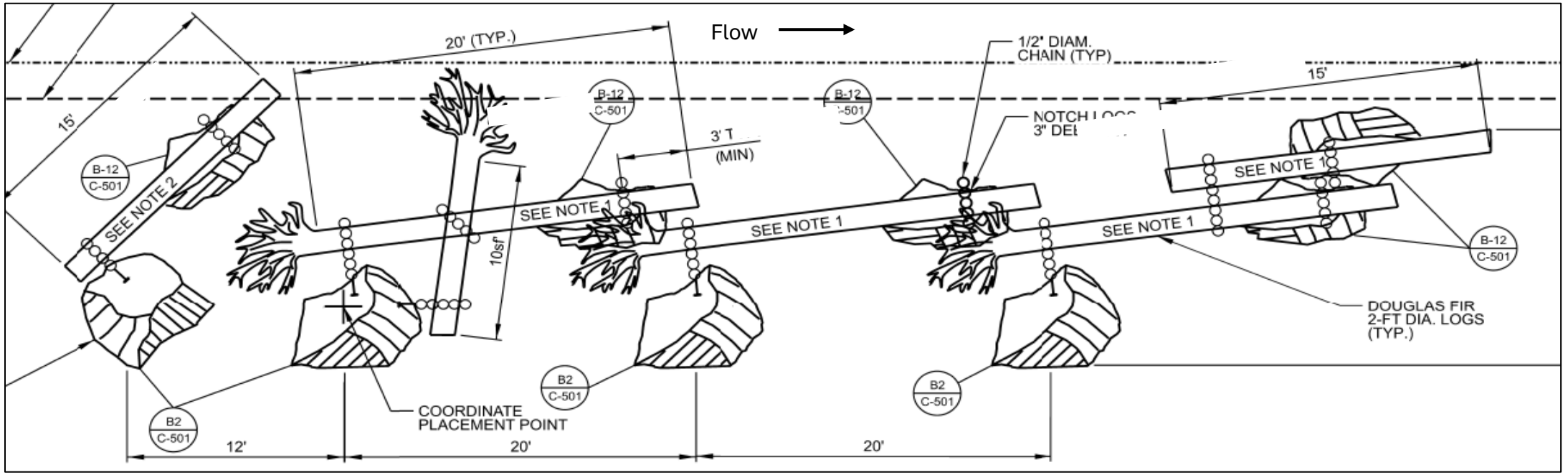
$$F_D = \frac{1}{2}\rho C_D^{app} u^2 A \sin\Theta$$



Force diagram from Rafferty (2017) tool

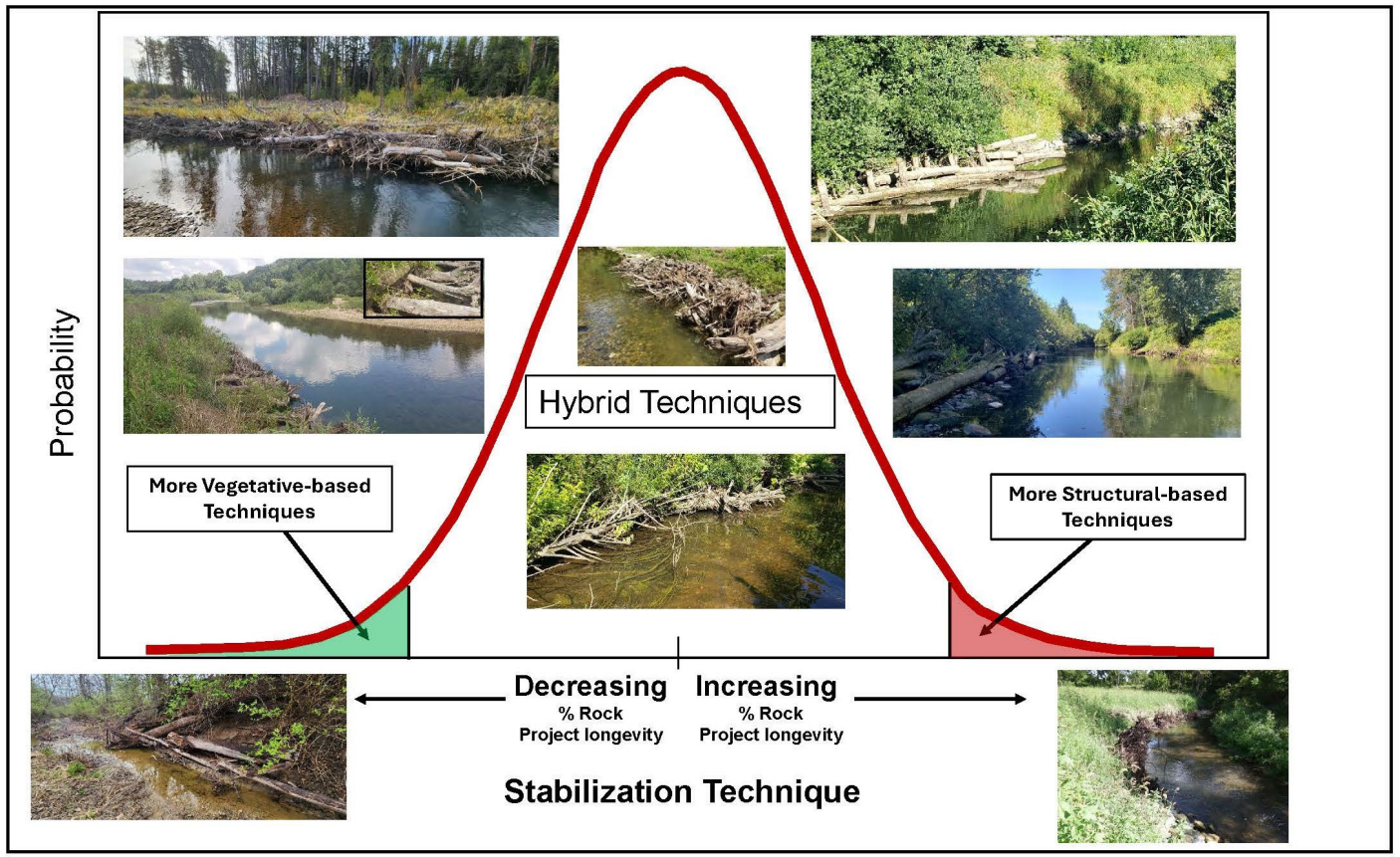


Design Phase	Design Aspect	Specific Criteria	Data	Design
Sections 3.4-3.5: Refine Design	Ecosystem Uplift	Adjust log orientations, angles, and other details to ensure plans for generating shade, increasing organic matter, and altering near-bank hydraulics will have the anticipated increase in ecological benefits	2.1.5, 2.3.6	3.4.5
	Structure stability	Ensure stability as design becomes finalized with species and orientations		3.4.3
	Anticipate Vegetation	Select plants beneficial to the local ecosystem where part of design and set O&M expectations for opportunistic vegetation at the bank, particularly where deposition is expected	2.1.5	3.5.2
	Community Benefits	Adjust design to accommodate recreational, access, or cultural uses of the site	2.2.5	3.5.1
	Safety	Adjust to ensure recreational safety	2.2.4	3.5.3
	Design Resilience	Evaluate proposed design for resilience against expected changes with seasonality, and potential changes in upstream landuse.	—	3.5.4



Techniques Can Combine EPGs

Examples:
Wood Toe + Benching EPGs
Wood Toe + Upper Bank EPGs

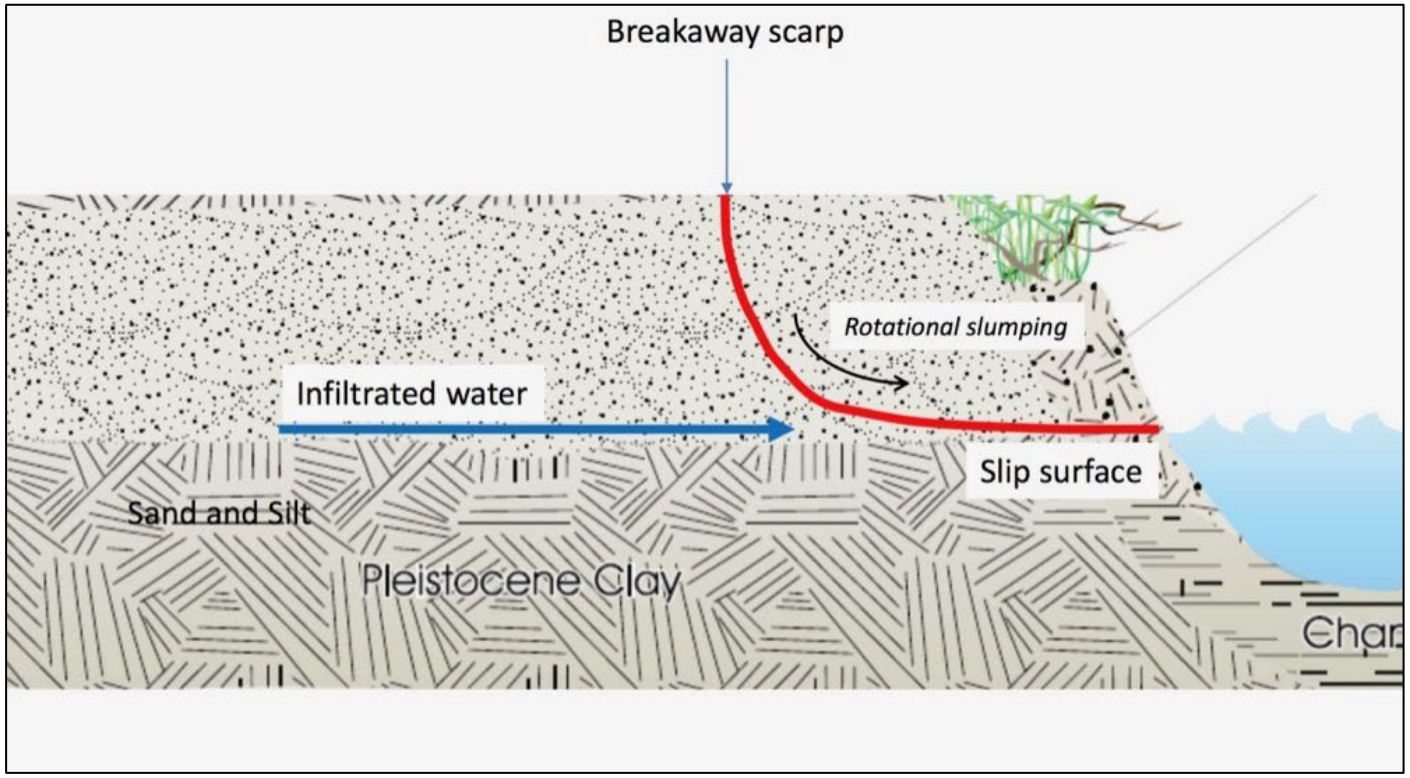


Wood based toe stabilization methods may be applied in combination with conventional and natural infrastructure using ballast rock, riprap, anchors, biopolymers, vegetation, and other natural materials to meet site and bank stabilization needs

Hybrid applications combine approaches to provide a robust and sustainable engineering design

Remember to Check that Toe Erosion is the Cause of Bank Erosion at the SIte

Slumping due to flow on an unconformity in the subsurface and increased overland flow





Water from overbank flooding after big storms but also from heavy lawn watering or even heavy rains saturates the loose, permeable sandy-clay layers. This loose sandy clay sits on top of an impermeable layer of hard, red clay of the very old Beaumont formation. When it hits the hard Beaumont clay, water percolating down from above travels sideways over the Beaumont clay into the bayou. When wet this very old layer of hard clay serves as a glide plane.

Buffalo Bayou in Houston https://www.savebuffalobayou.org/

Remember to Check that Toe Erosion is the Cause of Bank Erosion at the SIte

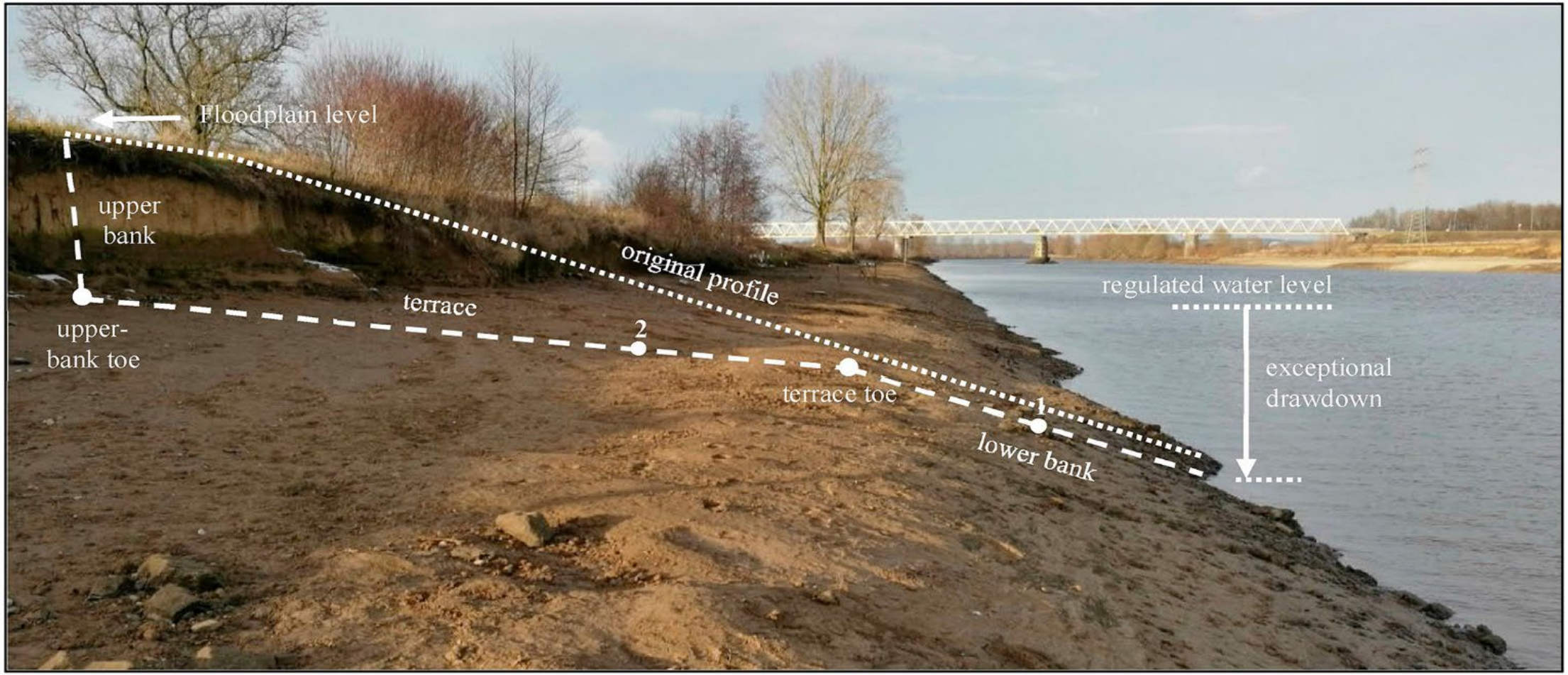


Freeze-thaw cycles are the dominant erosional process.

Field monitoring and data gathering at the bank site revealed bank retreat was greatest during December, January, and February and dominated by subaerial processes.
Erosional notches formed as warmer water eroded the frozen sediments.

Wynn, Theresa M.. “Modeling Channel Erosion at the Watershed Scale: Model Review and Case Study.” (2006).

Remember to Check that Toe Erosion is the Cause of Bank Erosion at the SIte



Bank terrace of Meuse River (km 154.1), visible after a ship accident that lowered the water level by 2.6 m from the regulated stage.

JGR Earth Surface, Volume: 125, Issue: 7, First published: 20 July 2020, DOI: (10.1029/2019JF005441)

Remember to Check that Toe Erosion is the Cause of Bank Erosion at the SIte



the presence of signal crayfish burrows significantly increases rates of bank retreat for the first time. Burrowing steepened banks, significantly increased the rate of diffuse erosion and increased the spatial extent of mass collapses. Animal burrows can alter riverbank erosion processes by promoting geotechnical failures and altering hydraulics at the bank face.

Earth Surf Processes Landf, Volume: 46, Issue: 4, Pages: 837-852, First published: 15 January 2021, DOI: (10.1002/esp.5070)

Remember to Check that Toe Erosion is the Cause of Bank Erosion at the SIte

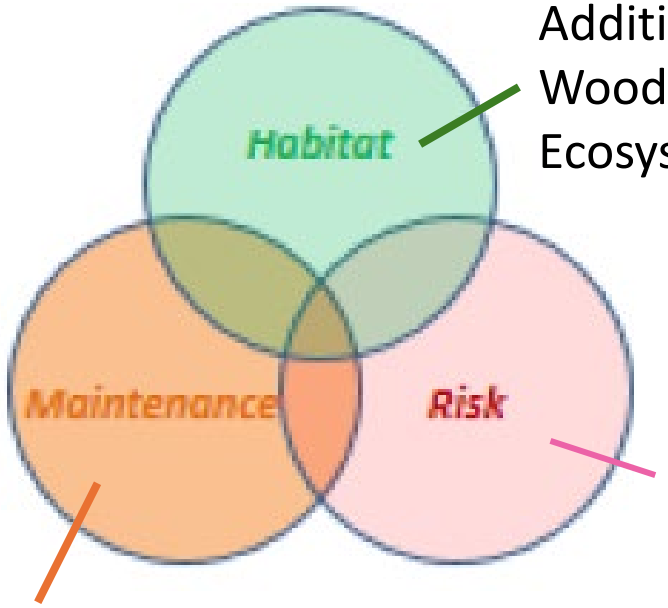


Figure 10. A large rotational slump in Middleton, Nova Scotia. This landslide was associated with fluvial erosion of 20 m-high slope along the Annapolis River when the water table was elevated activating a failure plane between impermeable clay-rich till and overlying outwash sediment.

Spooner, I., Batterson, M., Catto, N., Liverman, D., Broster, B., Kearns, K., ... MacAskill, W. (2013). Slope Failure Hazard in the Atlantic Provinces: A Review. *Atlantic Geoscience*, *49*, 1–14. https://doi.org/10.4138/atlgeol.2013.001

Key Take Aways

Wood-based bank stabilization can arrest erosion in altered channels in a manner that provides stability, creates ecological uplift to the benefit of riparian and aquatic habitat, and benefits the surrounding community.



Addition of Wood to Ecosystem

Reduces Risk of Bank Erosion and Bankline Retreat

Require Equal or Less Maintenance



- Match the structure to the dominant erosional process at your site.
- Spend time on desktop work before field work to make the most of field time
- Use the iterative design process to ensure all risk, geomorphic, and ecological objectives are met
- Ensure long term success by working with the sponsor on O&M plans
- Work with the sponsor to fulfill local goals and create community benefits
- Use the defined metrics to identify if, when, and what adaptive management is needed