U.S.D.A FOREST SERVICE & NATURAL RESOURCE CONSERVATION SERVICE
LARGE WOOD WORKSHOP
(September 2023 Craig, Alaska)

Engineering Analysis Required for Large Wood Projects

LARGE WOOD MEANDER BEND JAM - MONONGAHELA N.F. WV.

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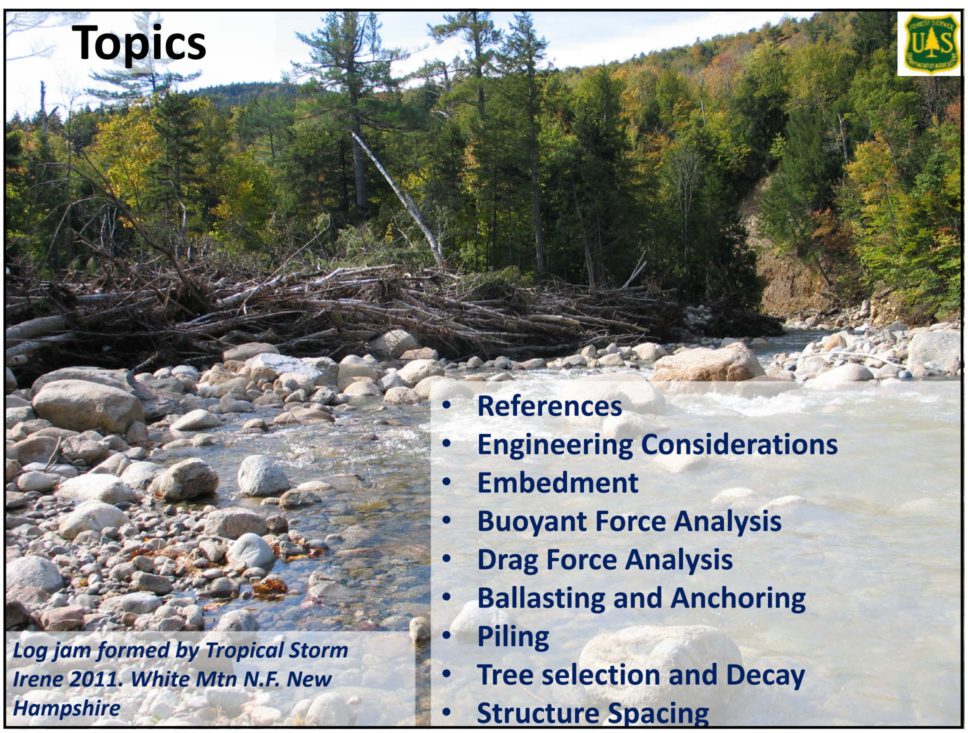
Topics



Log jam formed by Tropical Storm Irene 2011. White Mtn N.F. New Hampshire

- References
- Engineering Considerations
- Embedment
- Buoyant Force Analysis
- Drag Force Analysis
- Ballasting and Anchoring
- Piling
- Tree selection and Decay
- Structure Spacing

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Acknowledgements for Slides and Photos

Tim Abbe PhD– Natural System Design
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Scott Wright P.E. – River Design Group
Mark Jordan – Jordan Environmental Engineering

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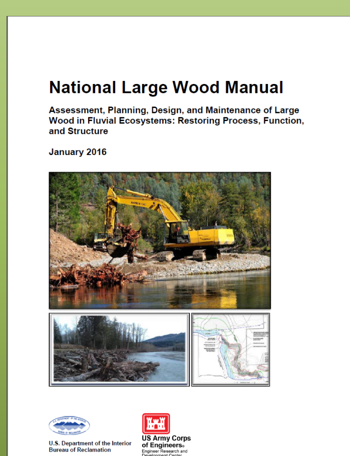
Design References



National Large Wood Manual

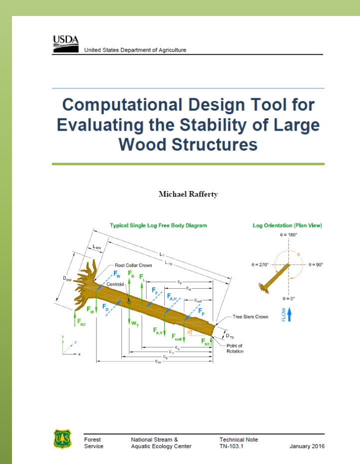
Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure

January 2016

U.S. Department of the Interior
Bureau of Reclamation

US Army Corps of Engineers

http://www.naturaldes.com/pdf/Large_Wood_National_Manual_final.pdf



USDA United States Department of Agriculture

Computational Design Tool for Evaluating the Stability of Large Wood Structures

Michael Rafferty

Forest Service | National Stream & Aquatic Ecology Center | Technical Note TN-103.1 | January 2016

http://www.fs.fed.us/biology/nsaec/products-publications-technotes.html

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Key Engineering Considerations (From NLWM 2016)

Category	Decisions
Hydrology	What is the design event? How will the structures affect/interact with smaller and larger flows? Should ice be considered in the design?
Reach layout	How many structures will be placed and where?
Materials	What types and sizes of logs and other materials will be used? Sources?
Structure dimensions and details	What type/shape of structures will be employed? What will their dimensions be?
Hydraulics	How will the project affect habitat quality and high flow stages?
Sediment	What effect will the project have on local scour and deposition, bank erosion, reach scale morphology, channel response, habitat value, and terrestrial plant colonization?
Vegetation	How much effort should be devoted to planting vegetation? Should effects of vegetation on structural stability (surcharge, sediment cohesion), erosion, and bank stability be included in analysis, and, if so, how?
Anchoring	What is the magnitude of forces that the structures must be designed to resist? Will anchoring involve passive or active restraints? What factors of safety will be used?
Construction	What construction methods will be utilized? Will channel be de-watered or large wood placed in the "wet"? What adverse impacts will be created by construction, and how can they be controlled? What time windows (seasons) will be used for construction?
Economics	Can the project be delivered within budget? How can value be increased?

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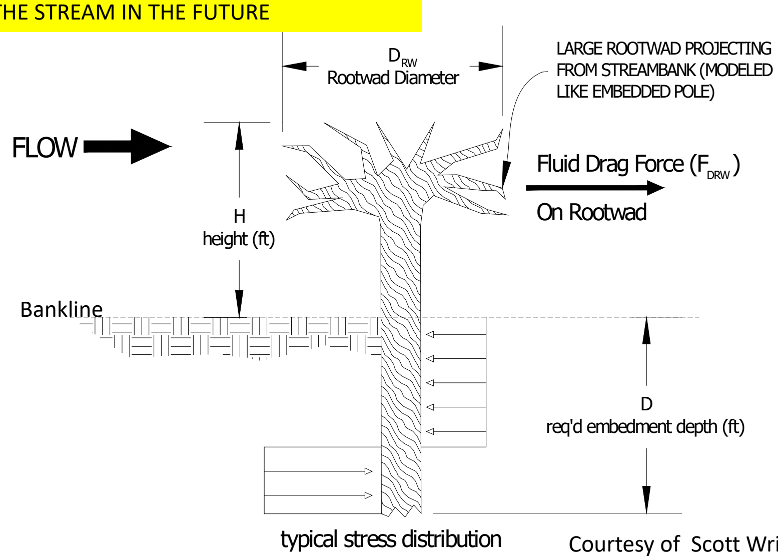
Embedment – Analytical method

THINK ABOUT LONG TERM BANK SCOUR!
WILL YOUR STRUCTERE STICK OUT FARTHER
IN THE STREAM IN THE FUTURE



Courtesy of Scott Wright

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Embedment

Rule of Thumb (Oregon DOT 2011)

- Bury at least 2/3 of the log / structure length into the bank.

This is a starting point. Check with Analysis (Buoyancy and Drag)

Analytical Method (single log)

Where:

F_{DRW} = Drag force
C_{DRW} = Rootwad Drag Coefficent
D_{RW} = Projecting rootwad diameter
L_{RW} = Rootwad length
H = Distance from Stream bank
D_l = Tree stem diameter
V = Max. stream velocity @LW
S_l = Allowable soil stress

$$F_{DRW} = C_{DRW} \cdot (D_{RW} \cdot L_{RW}) \cdot \frac{V^2}{2} \cdot \rho_w$$

$$D = \frac{1.18 \cdot F_{DRW}}{D_L \cdot S_1} \cdot \left(1 + \sqrt{1 + \frac{1.88 \cdot D_L \cdot S_1 \cdot H}{F_{DRW}}}\right)$$

NOTE: Avoid embedding logs under roads or facilities

Rootwad Drag Coefficents

0.7 to 0.9	Shields and Gippel (1995)
Up to 1.5	Alonso (2004)
0.4 to 1.2	Gippel et al. (1996)
1.0	Fischenich and Morrow (2000)
1.2 to 0.3 (tree)	D'Aoust and Millar (2000)
1.2 (rootwad)	D'Aoust and Millar (1999)
From NRCS 14J	D'Aoust and Millar (1999)

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Embedment

This is a starting point. Check with Analysis (Buoyancy and Drag)

$$F_{DRW} = C_{DRW} \cdot (D_{RW} \cdot L_{RW}) \cdot \frac{V^2}{2} \cdot \rho_w$$

Analytical Method (single log)

Where:

F_{DRW} = Drag force
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D_{RW} = Projecting rootwad diameter
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H = Distance from Stream bank
D_l = Tree stem diameter
V = Max. stream velocity @LW
S_l = Allowable soil stress

From NRCS 14J

Source:Chapter 18 of the 2003 International Building Code (IBC, 2002)

CLASS OF MATERIALS	LATERAL BEARING PRESSURE	LATERAL BEARING	LATERAL SLIDING RESISTANCE
	PRESSURE (psf/ft below natural grade)	Coefficient of friction[a]	Cohesion (psf)[b]
1.Crystalline bedrock	1,200	0.7	-
2.Sedimentary and foliated rock	400	0.35	-
3.Sandy gravel and/or gravel (GW and GP)	200	0.35	-
4.Sand, silty sand, clayey sand, silty gravel and clayey gravel (SW, SP, SM, SC, GM and GC)	150	0.25	-
5.Clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH)	100	-	130

For SI: 1 pound per square foot = 0.0479 kPa, 1 pound per square foot per foot = 0.157 kPa/m.

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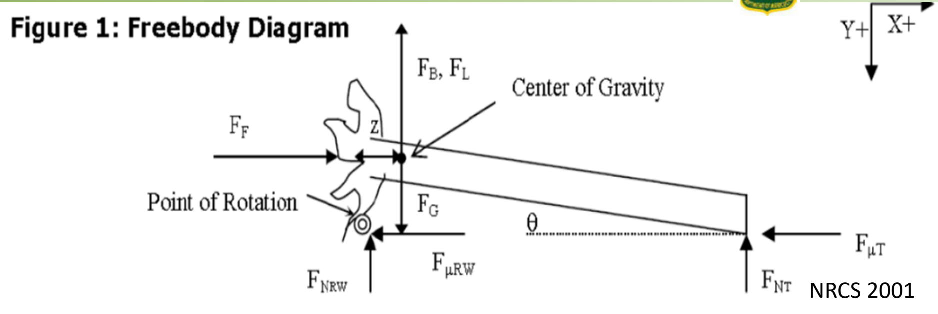
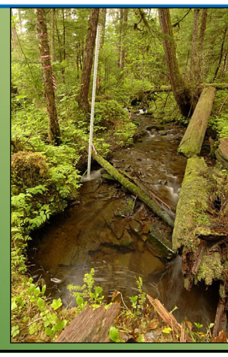
Forces Acting on Large Wood Structures



- F_B = Force due to buoyancy
- F_G = Force due to gravity
- F_F = Force due to flow
- F_μ = Force due to friction between LW and the bed
- F_L = Force due to lift
- F_N = Force normal to LW at the tip and the rootwad



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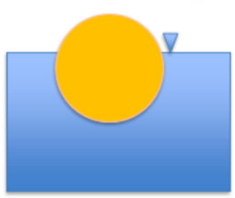
Buoyant Force Balance

Analysis outlined in NRCS Technical Supplement 14J 2007

Slide by R.Hrachovec

Un-ballasted log in water

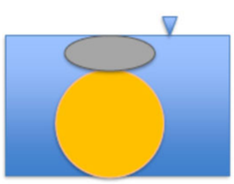


Fl (force of lift) = 35 lb @ 0.56 cf water displaced

Wl (weight of log) = 35 lb

Fbl (net buoyant force) = Fl (35 lb) – W 35 lb = 0 lb

Ballasted log in water



Fl (force of lift) = 80 lb (1.3 cf water displaced)

Wl (weight of log) = 35 lb (1 cf wood submerged)

Wb (weight of ballast) = 45 lb (0.3 cf rock submerged)

Fbl = - Fl (80 lb) + (Wl) 35 lb + Wb (45 lb)= 0 lb

W' = Wl + Wb

Safety Factor = W' / Fl (recc > 1.5)

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Buoyant Force Analysis

Analysis outlined in NRCS Technical Supplement 14J 2007

The Buoyant Force is equal to the displaced water volume

The net buoyant force ($\vec{F}_B$) difference between the weight of the structure and the weight of displaced water

$$\vec{F}_B = ([\rho_{wood*} V_{wood}] - [\rho_{water*} V_{water}])*\vec{g}$$

Where:
- ρ = density
- V = volume
- $\vec{g}$ = the gravitational acceleration vector in the vertical direction ($32.2\ ft/sec^2$)

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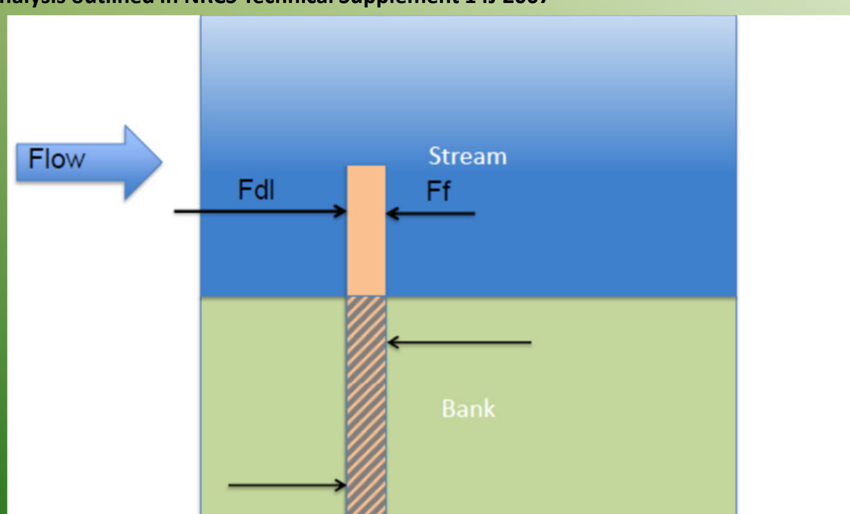
Drag Force – Plan View

Analysis outlined in NRCS Technical Supplement 14J 2007



Slide by R.Hrachovec

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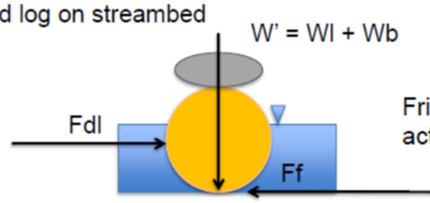
Drag and Resistant Forces

Slide by R.Hrachovec

Un-ballasted log on streambed

Ballasted log on streambed



Friction increases with weight acting on streambed

Safety Factor = Fdl / Ff (recc > 1.5)

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Drag Force Analysis

Analysis outlined in NRCS Technical Supplement 14J 2007

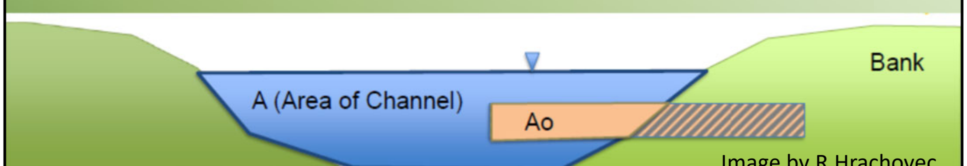


Image by R.Hrachovec

Drag Force $F_D = C_{Dapp} * A_o * (V^2/2*g)*\rho_w$

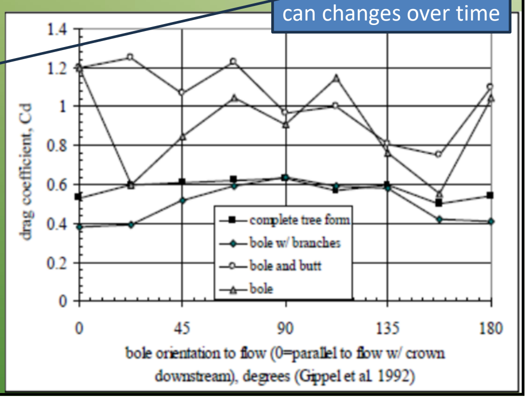
Note: permeability can changes over time

Where:

- C_D = Drag Coeff. function of permeability
- A_o = XS area of structure
- V = Max. water velocity
- ρ_w = Density of water
- g = Acceleration due to

$C_{Dapp} = C_D/(1\text{-}B)^{\wedge}2$

Blockage ratio (B) = Ao / A



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Engineering Properties of Bank Sediments for Buoyancy and Drag Calculations

Table 5-17. Typical compacted densities and optimum moisture contents for USCS soil types (after Carter and Bentley, 1991).

Soil Description	USCS Class	Compacted Dry Unit Weight (lb/ft3)	Compacted Dry Unit Weight (kN/m3)	Optimum Moisture Content (%)
Gravel/sand mixtures:				
well-graded, clean	GW	125-134	19.6-21.1	8-11
poorly-graded, clean	GP	115-125	18.1-19.6	11-14
well-graded, small silt content	GM	119-134	18.6-21.1	8-12
well-graded, small clay content	GC	115-125	18.1-19.6	9-14
Sands and sandy soils:				
well-graded, clean	SW	109-131	17.2-20.6	9-16
poorly-graded, small silt content	SP	94-119	15.7-18.6	12-21
well-graded, small silt content	SM	109-125	17.2-19.6	11-16
well-graded, small clay content	SC	106-125	16.7-19.6	11-19
Fined-grained soils of low plasticity:				
silts	ML	94-119	14.7-18.6	12-24
clays	CL	94-119	14.7-18.6	12-24
organic silts	OL	81-100	12.7-15.7	21-33
Fine-grained soils of high plasticity:				
silts	MH	69-94	10.8-14.7	24-40
clays	CH	81-106	12.7-18.6	19-36
organic clays	OH	66-100	10.3-15.7	21-45

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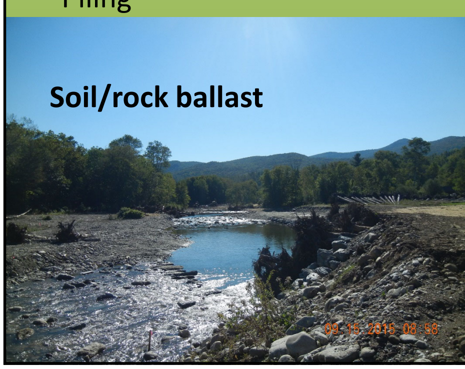
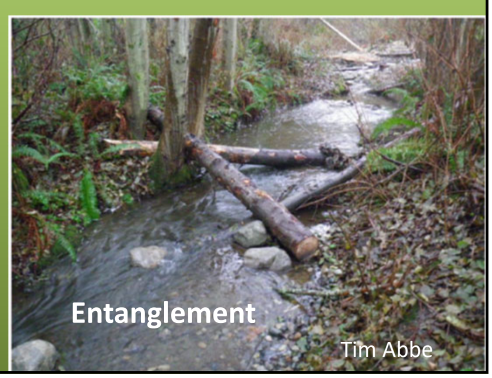
Ballasting and Anchoring

Ballasting and Anchoring is accomplished by:

- Soil, rock, & wood ballast (weight) over buried key pieces overcoming buoyancy and drag
- Entanglement – wood pieces woven into live trees
- Mechanical anchoring – soil anchors (manta ray or duckbill) or deadmen (buried log) with cable attachment to structure
- Piling





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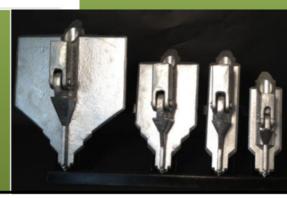
Mechanical Anchoring

Require cable attachment to key structural pieces and special equipment for installation. Deadmen composed of buried logs and cable attaching key pieces to deadmen also work

General Holding Capacities >>>

Soil Description	Blow Count (N)	MR-68 Ultimate: 5 kips	MR-88 Ultimate: 10 kips	MR-4 Ultimate: 16 kips	MR-3 Ultimate: 20 kips	MR-2 Ultimate: 40 kips	MR-1 Ultimate: 40 kips	MR-SR Ultimate: 40 kips
Very dense/cemented sands Coarse gravel and cobbles	60-100+	5 (1,3)	10 (1,3)	16 (1,3)	20 (1,3)	28-40 (1,3,4)	40 (1,3)	40 (1,3,5)
Dense fine compacted sands very hard silts or clays	45-60	3-4 (2,3,4)	6-10 (2,3,4)	9-16 (2,3,4)	17-20 (2,3,4)	21-28 (2,4)	36-40 (1,3,4)	40 (1,3)
Dense clays, sands and gravels hard silts and clays	35-50	2.2-3 (4)	4-6 (4)	6-9 (4)	12-18 (2,4)	15-22 (2,4)	24-36 (2,4)	32-40 (2,3,4)
Medium dense sandy gravel stiff to hard silts and clays	24-40	1.5-2 (4)	3-4 (4)	4.5-5.5 (4)	9-14 (4)	12-18 (4)	18-20 (2,4)	24-34 (2,4)
Medium dense coarse sand and sandy gravel stiff to very stiff silts and clays	14-25	1.1-1.5 (4)	2-3 (4)	3.5-4.5 (4)	7-9 (4)	9-12 (4)	15-20 (4)	18-24 (4)
Loose to medium dense fine to coarse sand firm to stiff clays and silts	7-14	0.9-1.2 (4)	1.5-2.5 (4)	2.5-4 (4)	5-8 (4)	7-10 (4)	10-15 (4)	14-18 (4)
Loose find sand, alluvium, soft clays fine saturated silty sand	4-8	0.6-1.0 (4)	0.9-1.5 (4,6)	1.5-2.5 (4)	3-5 (4,6)	5-8 (4,6)	8-12 (4,6)	9-14 (4,6)
Peat, organic silts; Inundates silts fly ash	0-5	-5	0.2-0.9 (4,6)	0.3-1.5 (4,6)	0.8-3 (4,6)	2-5 (4,6)	3-8 (4,6)	4-12 (4,6)

1. Drilled pilot hole required for efficient installation
2. Ease of installation may be improved by drilling a pilot hole
3. Holding capacity limited by ultimate strength of anchors
4. Holding capacity limited by soil structure
5. Not recommended in these soils
6. Wide variation in soil properties reduces prediction accuracy. Pre construction field test is recommended



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Piling

- Can provide complete or partial fixity
- Scour susceptible – Need to be deep and many for lateral stability
- Driving can be achieved with excavator bucket, vibrator attachment to excavator, excavating and burying rootwad trees deeply.
- Easily driven in clays, sand, and fine gravel.
- Time consuming and expensive in coarse gravel, cobble and boulder substrates. Excavation will be wide due to cave-in's

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Piling Analysis (Trial and Error Method)

$$F_{gh(piles)} = N\left(\frac{\frac{1}{2}L_{em}^{3}d_{p}K_{p}(\gamma_{s}-\gamma_{w})}{(h_{load}+L_{em})}\right)$$

- F_{gh} = Restraint force provided by geotechnical processes (piling/embedding)
- N = number of piles
- L_{em} = Length of the pile below the bed allowing for scour
- d_p = Pile diameter
- H_{load} = Distance above the scoured bed the load is applied
- K_p = Rankine coefficient for passive earth pressure
- $\Upsilon_{s\ or\ w}$ = Unit weights of sediment and water

If you need a structure that will rely solely on piling for stability get a Geotechnical Engineer to help!

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Rankine coefficient for passive earth pressure (Kp) at rest

Rakine passive earth pressure coefficient:

$$K_p = cos\beta\frac{cos\beta + (cos^2\beta - cos^2\phi)^{1/2}}{cos\beta - (cos^2\beta - cos^2\phi)^{1/2}}$$

For the case where beta = 0

$$K_p = tan^2(45 + \frac{\phi}{2})$$

Where:
Φ = is the internal friction angle of the soil
(β = is the slope of the backfill

β	ϕ = 26	28	30	32	34	36	38	40	42
0	2.5611	2.7698	3.0000	3.2546	3.5371	3.8518	4.2037	4.5989	5.0447
5	2.5070	2.7145	2.9431	3.1957	3.4757	3.7875	4.1360	4.5272	4.9684
10	2.3463	2.5507	2.7748	3.0216	3.2946	3.5980	3.9365	4.3161	4.7437
15	2.0826	2.2836	2.5017	2.7401	3.0024	3.2926	3.6154	3.9766	4.3827
20	1.7141	1.9176	2.1318	2.3618	2.6116	2.8857	3.1888	3.5262	3.9044
25	1.1736	1.4343	1.6641	1.8942	2.1352	2.3938	2.6758	2.9867	3.3328
30	—	—	0.8660	1.3064	1.5705	1.8269	2.0937	2.3802	2.6940
35	—	—	—	—	—	1.1239	1.4347	1.7177	2.0088
40	—	—	—	—	—	—	—	0.7660	1.2570

Empirical values for ϕ, of granular soils based on the standard penetration number, (from Bowels, *Foundation Analysis*).

SPT Penetration, N-Value (granular soil) (blows/ foot)	ϕ (degrees)
0	**25 - 30**
4	**27 - 32**
10	**30 - 35**
30	**35 - 40**
50	**38 - 43**

Relationship between ϕ, and standard penetration number for sands, (from Peck 1974, *Foundation Engineering Handbook*).

SPT Penetration, N-Value (blows/ foot)	**Density of Sand**	ϕ (degrees)
<4	Very loose	<29
4 - 10	Loose	29 - 30
10 - 30	Medium	30 - 36
30 - 50	Dense	36 - 41
>50	Very dense	>41

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Piling – Driven/ Vibrated

Customized pile driver made of plate compactor and weld steel hoop.

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Large Wood Structure Spacing

- Spacing is dependent on function of the structure and where they would likely be located (terrain dependent) and determined during site assessment.
- Structures can be individual log jams or groups of structures. For extensive bank stabilization, a series of discreet individual structures can be used.

Table 6-6. Criteria for Spacing Intermittent Large Wood Structures along the Outside of Meander Bends[a]

From NLWM 2016

Channel Planform	Large Wood Structure Spacing	Source
Rc/W > 3	3 to 5 x projected crest length	Sylte and Fischenich (2000)
Rc/W < 2.5	Spacing goes to zero—use continuous type structure	
Tight bends	3 x projected crest length	Drury et al. (1999), Brooks (2006)
Straight reaches	5 x projected crest length	
All	1.5 to 2.0 x crest length	Petersen (1986) in Shields et al. (2004)
All	2/3 to 2.5 times the length of the upstream structure	Pokrefke (2013)

Rc/W = bend radius of curvature divided by channel top width

[a] These design criteria are extracted from works guiding placement of river training and bank protection structures designed to produce channel stability. If higher levels of dynamism are desired or tolerable, spacing should be increased. Erosion between widely spaced structures may lead to flanking (river avulsion around the land side of structure).

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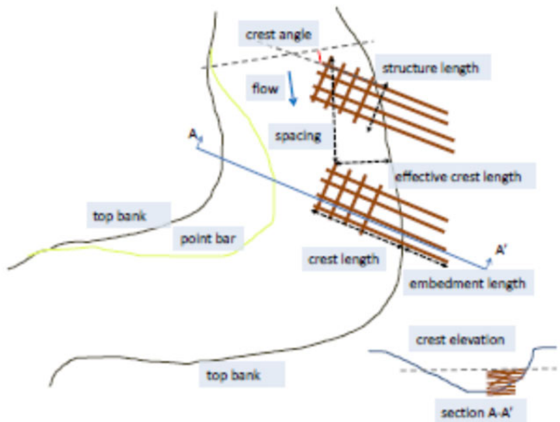
Large Wood Geometric Variables

Figure 6-12. Definition Sketch for Large Wood Geometric Variables



From NLWM 2016

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Other Structure Consideration

- **Structure height**
  - **Variable, however, if you can go up to or close to Q100 flow will route around the structure (especially Meander bend and lateral bar jams) versus over the top which causes much more erosion and eventually erodes behind the wood.**
- **Embedding trees**
  - **In coarse gravel and cobbles – trench in logs**
  - **In dense silt and sands – can trench or vibrate logs in**
  - **In saturated silts and clays – Can push trees in vertically or horizontally**

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Scour Analysis

- Scour is a significant causal mechanism for log structure failure either by lateral scour or vertical scour removing ballast or eroding banks increasing drag force
- Scour depth is difficult to determine exactly
- Understanding the relations with material composition and controls on pools (bends, obstructions, etc) in the stream is critical
- Empirical and field based methods can be used to determine an approximate design scour depth

Natural apex jam
Southern Missouri

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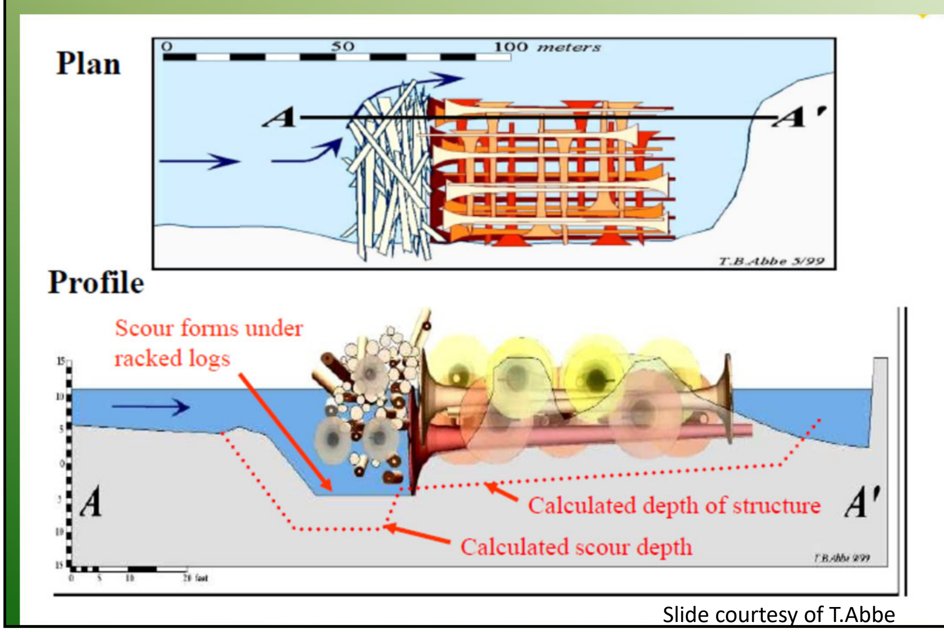
Scour Effect on Structural Integrity



Slide courtesy of T.Abbe

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Scour Analysis by Longitudinal Profile Assessment

Delineate the lower vertical adjustment potential (scour) line.

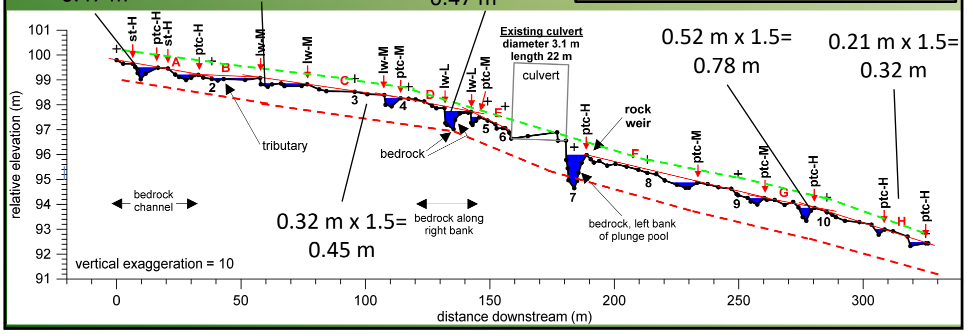
- Choose deepest pool along channel and measure max depth.
- Adjust line to reflect scour/fill processes that occur during floods. Recommended criteria:
  - 1.00 x Pool Max Depth (PMD): Step-pool channels, S > 5%, boulder-cobble boundaries.
  - 1.25 x PMD: Step-pool channels with S < 5%, cobble-gravel boundaries.
  - 1.50 x PMD: Steep riffles with ribs, cobble-gravel boundaries.
  - 1.75 x PMD: Riffles, gravel-cobble boundaries.
  - 2.00 x PMD: Riffles, sand-fine gravel boundaries.
  - No adjustment for bedrock.

If your constriction for the log jam is not found in the stream …
SCOUR WILL BE DEEPER

0.47 m x ~~1.5~~= 0.47 m

0.10 m x 1.5= 0.15 m

0.47 m x ~~1.5~~= 0.47 m



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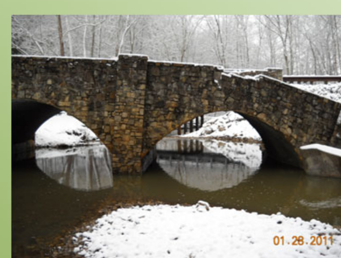
Scour Analysis – Empirical Methods

Pierre Julien (River Mechanics p. 313) after Karaki's & Richardson's equation for scour at an abutment

$$d_s = 1.1 \cdot \left(\frac{L_e}{d_1} \right)^{0.4} \cdot Fr^{0.33} \cdot d_1$$



Where:

- **Le – Effective length (ft) of the single log protruding into the flow or projected crest length for log jam structures**
- **D1 – Average upstream flow depth (ft)**
- **Fr – Froude number upstream of the log jam (from HEC-RAS output or computation**

SCOUR EQUATIONS IN HEC-RAS CAN ALSO BE USED AND ARE USUALLY VERY CONSERVATIVE

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Ice Analysis and Risk (Northern Rivers – lower 48 and Ak)

Ice that cause flooding are formed in two ways:

1. Mechanical ice jams - that are formed during ice break up during warming spells or at the end of winter with ice out. This forms a dam that backs up water and produces a dam break event/flash flood during release.
2. Frazil ice and Anchor Ice accumulation in pools and runs reduce available cross section area and produce flooding and risk to infrastructure in Northern rivers

Lehmi River, Idaho after restoration project

https://www.eastidahonews.com/2023/01/ice-jam-on-lemhi-river-causes-flooding-in-salmon-neighborhood/

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Ice Analysis and Risk

Accumulated Freezing Degree Days (AFDD)

https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1612.pdf

$$t_i = C\,(\text{AFDD})^{0.5}$$

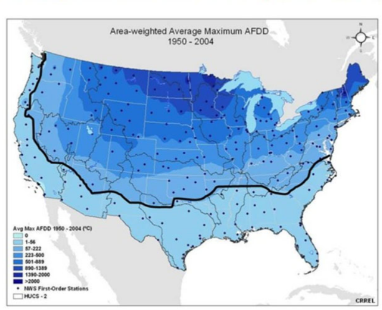
where C is a coefficient, usually ranging between 0.3 and 0.6 and AFDD is in °F days (Table 1).

Table 1. Coefficient for use in modified Stefan equation with ice thickness in inches, AFDD in °F days (from USACE 2002).

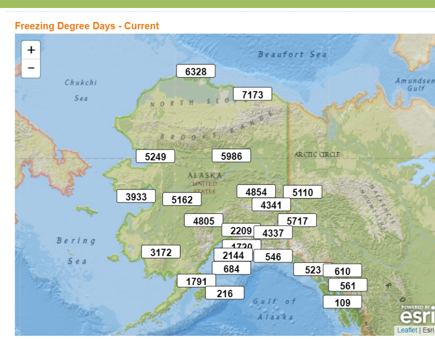
Condition	Typical value of C
Windy lake with no snow	0.8
Average lake with snow	0.5 to 0.7
Average river with snow	0.12 to 0.15
Sheltered small river	0.21 to 0.41

Source https://faculty.babson.edu/goldstein/goldsteingroup/TN04-3.pdf

Average Maximum AFDD (1950-2004)



(AFDD = Accumulated freezing degree days)



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Ice Analysis and Risk

Frazil Ice Deposition

- **Where to Look for it:**
  - Change in slope from steep to mild
  - Upstream end of impoundments and large pools
  - Confluence of smaller and larger tributaries
  - Downstream from locations that are turbulent enough to remain open all winter

When to be concerned about thicker than normal frazil ice deposition

- Sudden period of intense cold when there is little to nice cover to insulate the water surface

https://download.comet.ucar.edu/memory-stick/hydro/basic_int/river_ice/navmenu.php_tab_1_page_16.0.0.htm

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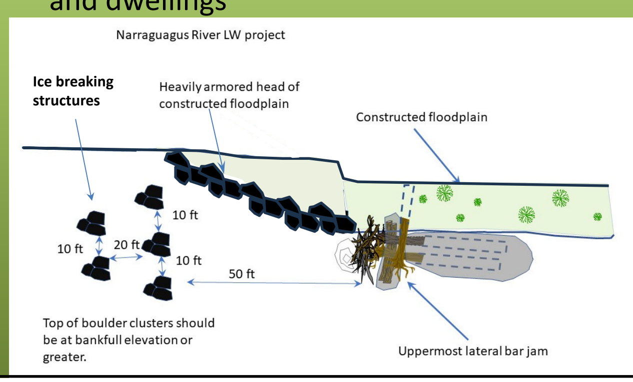
Ice Analysis and Risk

Mechanical Ice Jams

- **Where to Look for it:**
  - Significant constrictions caused by bridges or wood in low to moderate gradient rivers
  - Constrictions at the downstream end of impoundments

When to be concerned mechanical ice jams

- Usually not a concern in most location where we place large wood structures
- When causing constrictions adjacent to infrastructure and dwellings
- When creating large amounts of still water by restoration upstream of infrastructure and dwellings



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Tree Selection – Size and Species

Cramer 2002 Recommendations

Dimension	Minimum size
Rootwad diameter	Bankfull discharge depth
Trunk diameter	0.5 × bankfull discharge depth
Tree length	0.25 × bankfull discharge width

Can use smaller trees for structures. Think about life cycle of the structure

Species	Durability (assuming wetting and drying)	Source of information[1]
Cottonwood (*Populus* spp.)	Poor	Johnson and Stypula (1993)
Alder (*Alnus* spp.)	Poor	Johnson and Stypula (1993)
Maple (*Acer* spp.)	Fair (will survive 5 to 10 yr)	Johnson and Stypula (1993)
Hemlock (*Tsuga* spp.)	Least durable of conifers	Johnson and Stypula (1993)
Sitka spruce (*Picea sitchensis*)	Excellent	Johnson and Stypula (1993)
Douglas-fir (*Pseudotsuga* spp.)	Excellent (will survive 25 to 60 yr) 32–56 yr	Johnson and Stypula 1993); Harmon et al. (1986)
Western red cedar (*Thuja plicata*)	Most desirable (will survive 50 to 100 yr)	Johnson and Stypula (1993)
Yellow-poplar (*Liriodendron tulipifera*)	0.4 yr	Harmon et al. (1986)
Aspen (*P. tremuloides*)	5 yr	Harmon et al. (1986)
White fir (*A. concolor*)	4 yr	Harmon et al. (1986)
Norway spruce (*Picea abies*)	~30 yr	Kruys, Jonsson, and Stahl (2002)
Conifers (*P. sitchensis, T. heterophylla, P. menziesii, T. plicata*)	Half-life of ~20 yr	Hyatt and Naiman (2001)

From NRCS 14J

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Tree Selection –Species and Weights

Table 1B.—Average oven-dry and green weight of wood and bark when only wood volume is known for tree species in North America. Reference numbers in this table refer to numbered citations found in Literature Cited section of this report.

							Total oven-dry and green weight of wood and bark per cubic foot of wood *			
Common name	Genus	Species	FIA code	Wood reference	Bark reference	Bark % reference (Tab 3)	Avg. oven-dry weight of wood and bark (lb/cf)	Avg. oven-dry weight of wood and bark (kg/m3)	Avg. green weight of wood and bark (lb/cf)	Avg. green weight of wood and bark (kg/m3)
Pacific silver fir	Abies	amabilis	11	25	30	30	29	461	49	781
Balsam fir	Abies	balsamea	12	25	12	9	24	378	51	817
White fir	Abies	concolor	15	25	12	a	27	437	54	862
Grand fir	Abies	grandis	17	25	12	a	26	418	52	832
Subalpine fir	Abies	lasiocarpa	19	25	12	21	23	364	33	536
California red fir	Abies	magnifica	20	25	12	a	25	407	52	826
Noble fir	Abies	procera	22	25	12	a	26	423	35	567
Port-Orford-cedar	Chamaecyparis	lawsoniana	41	25	25	a	27	436	47	754
Alaska yellow-cedar	Chamaecyparis	nootkatensis	42	25	29	21	29	466	51	819
Atlantic white-cedar	Chamaecyparis	thyoides	43	25	29	a	22	356	42	669
Alligator juniper	Juniperus	deppeana	63	2	28	a	33	528	45	718
Utah juniper	Juniperus	osteosperma	65	3	b	a	46	730	62	997
Southern redcedar	Juniperus	virginiana	67	2	b	a	29	468	42	670
Eastern redcedar	Juniperus	virginiana	68	25	29	23	30	488	42	670
Tamarack (native)	Larix	laricina	71	25	12	23	33	532	52	836
Western larch	Larix	occidentalis	73	25	12	a	33	526	53	845
Incense-cedar	Calocedrus	decurrens	81	25	30	a	24	392	48	775
Engelmann spruce	Picea	engelmannii	93	25	12	21	24	387	45	727
White spruce	Picea	glauca	94	25	12	a	26	421	41	650
Black spruce	Picea	mariana	95	25	12	a	27	434	42	665
Red spruce	Picea	rubens	97	25	12	a	26	411	39	618
Sitka spruce	Picea	sitchensis	98	25	12	21	25	399	41	653
Knobcone pine	Pinus	attenuata	103	30	b	30	27	435	55	878
Jack pine	Pinus	banksiana	105	25	12	9	29	457	57	911
Common or two-needle pinyon	Pinus	edulis	106	2	b	a	35	553	45	727
Sand pine	Pinus	clausa	107	25	12	26	33	527	46	736
Lodgepole pine	Pinus	contorta	108	25	12	21	26	413	42	680
Shortleaf pine	Pinus	echinata	110	25	12	26	33	526	58	923

- **Unit weights are required to perform buoyancy and drag force analyses.**
- **Also need to estimate equipment sizes and helicopter loads**

From: Miles, Patrick D.; Smith, W. Brad. 2009. Specific gravity and other properties f wood and bark for 156 tree species found in North America. Res. Note NRS-38. U.S. Department of Agriculture, Forest Service, Northern Research Station. 35 p.

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Spreadsheet Example

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Questions?

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