Design Protocol for Wood in Rivers

Tim Abbe, Ph.D., R.G.,
Michael Spillane, P.E., Mark Ewbank, P.E.,
Maeve McBride, Ardith Lanstra-Nothdurft, R.L.A.,
José Carrasquero, M.S., Al Wald¹, R.G., and Janine Castro², Ph.D.

¹ Washington State Department of Transportation, Olympia, WA
² U.S. Department of Fish and Wildlife, Portland, OR

PRESENTATION OUTLINE

• Introduction –
  *Wood in rivers: differing perspectives*

• Design Protocol
  *Development of a standard of practice*

• Testing New Technologies
  *Results of engineered logjams thus far*
INTRODUCTION

Conflicting perspectives that persist

Traditional engineering perspective:
wood is a hazard to infrastructure
and property

Current ecological perspective:
wood is a crucial component of fluvial
environments, providing habitat diversity,
protecting endangered species, enhancing
water quality, and sustaining ecosystems

Snags and Logjams posed a major
impediment to agricultural and industrial
development of the United States

Missouri River 1843
INTRODUCTION

Traditional River Management:
1. Channel clearing through snag/jam removal.
2. Loss of riparian sources through channelization.

INTRODUCTION

Wood removal remains a significant part of river management in much of the U.S.

“This logjam caused a portion of Hwy 77 to flood that had never flooded before.”

“Those blockages also cause the Guadalup to change its course…” “The dam is made up of large trees and logs… removal is expected to cost about $250,000. Removal of the five logjams on the Guadalupe is expected to cost another $450,000.” - Corpus Christie Caller Times 12/11/98 (Texas)
Current Ecological Understanding of Wood in Rivers

Snags and logjams played an important role in creating the complex array of habitat once found in many forested river valleys.
INTRODUCTION

Traditional management has converted complex rivers to simple channels.

(b) Degraded Forest River Corridors

*Channelized and Braided Systems:*

- single wide, shallow channel with high width to depth ratio

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Logjams may have been impediments to development, but they were also ecological hotspots...

“For there, straight ahead they saw it, with the river clenched deep in its grip: rich with the smell of new flowers, and old rot, alive with flashes of bright birds, and mosquitoes, throbbing with hidden fish, and mink, and bear, and puma,...”

*an 1800's perspective of logjams in the Red River, LA*
INTRODUCTION

Wood is an important mechanism in creating and sustaining pools.

Side Channels of Lower Elwha River

- 42% LWD or logjams
- 39% Other or unknown
- 15% Boulders
- 4% Roots

INTRODUCTION

Engineered logjam fish monitoring results

Pess et al. 2002....

Organic Matter Collected From Various Substrates

Elwha River – October 2002
INTRODUCTION

Engineered logjam fish monitoring results
Pess et al. 2002....

Species richness

min
mean
max

backwater pools w/ logjams
backwater pools w/o logjams
main pools with logjams
main pools w/o logjams
riffles
glides
edge

Density of Juvenile Salmon
(Lower Elwha all seasons, Pess et al. 2002)

units with ELJs
units without ELJs

density when fish present

chinook < 50
chinook 50–100
chinook 100+
coho fry
coho +
Advances in fluvial geomorphology and ecology have been integrated into regulatory requirements to protect natural resources.

Regulations now discourage or even preclude some traditional practices in river engineering.

Native, local, state, and federal laws, regulations, and policies affecting river management.

1. Flood protection (FEMA)
2. Zoning/Shoreline Management (SMA)
3. Fish & wildlife (WDFW hydraulic permits)
4. Water quality (TMDLs)
5. Wetlands (Clean Water Act)
6. Endangered species (ESA)
7. Tribal rights.

Keep in mind that the intent of most laws and policies are to protect our own health and environment. Striving to meet this intent will improve regulatory relationships and the permitting process.
INTRODUCTION

Moving forward...

Opposing perspectives must be respected

Wood re-introduction in streams and rivers is not a passing fad but a scientifically recognized component of Pacific Northwest river ecosystems essential to salmon recovery.

Human infrastructure must be protected, how is the key

Wood can be a tool for restoring habitat and protecting infrastructure

How? Appropriate designs for appropriate locations

But what is appropriate?

This highlights the need for standards of practice

INTRODUCTION

Are there sustainable solutions that can meet these dual mandates to protect human communities and fluvial ecosystems?

This question is particularly important for the complex and controversial issue of wood in rivers.
INTRODUCTION

Blanket rock revetments are a common traditional treatment that is no longer an acceptable solution many northwest rivers.

Yes. In appropriate settings, well designed wood structures can be part of “self-mitigating” solutions.
Successful long-term restoration of river and stream ecosystems will depend on how well designs for bank protection and habitat enhancement are incorporated into standard engineering practice.

INTRODUCTION

Wood re-introduction to rivers will be accepted into standard engineering practice only after a standard of practice based on sound science and engineering is developed, implemented, and proven.
A Design Protocol for wood in rivers

Elements of Standard Practice for Wood Structures

Objectives
- Type of habitat
- Infrastructure protection

Reach Analysis
- Geomorphology
- Hydrology
- Habitat (instream and riparian)
- Wood drift characteristics

Feasibility
- Opportunities
- Constraints
- Conceptual Design Alternatives

Risk Assessment
- Risk to habitat and humans
- Factor of Safety
- Engineering Analysis
Elements of Standard Practice for Wood Structures (continued)

Design
- Type of structure and architecture
- Number of structures, size and location
- Force balance
  - Buoyancy, drag impacts and moments
  - Resistance (passive earth pressures, skin friction)
- Scour and deposition
- Flood inundation, backwater
- Design life
- Human safety
- Bio-engineering/Re-vegetation

- Maintenance recommendations
  - Culling or repair
  - Re-vegetation
Selected aspects of design and analysis protocol ....

Reach Analysis

Develop an understanding of the surrounding area:

• Channel dynamics and geomorphic characteristics
• Bank characteristics
• Disturbance history in reach and watershed
• Hydrology and hydraulics
• Ecological/biological conditions and opportunities
• Riparian conditions
• Infrastructure constraints
Reach Analysis: *Know your river!*

**Historic channel dynamics:** erosion rates, planform changes.

**Historic disturbances:** how conditions have changed, e.g., levees, urbanization, incision, sediment and wood debris supply.

**Habitat change over time.**

**Identify opportunities and constraints.**

**Current boundary conditions and hydraulics.**

The reach analysis should provide the information necessary to make predictions about the future under different scenarios and develop sustainable designs that emulate natural conditions and processes.

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**Feasibility**

*Considerations Before Design Begins*

**Identify opportunities such as:**

- Can threatened infrastructure be moved out of harms way?
- How much of the channel migration zone can be preserved?
- Can habitat be enhanced as part solving traditional problems such as bank protection and flood control? *e.g., where increasing inundation is acceptable it will enhance habitat and contribute to downstream flood protection.*
- Are solutions limited to the site, e.g., could flow diversion into secondary or historic channels upstream of site help?
- Are local construction materials available?
- Will partnerships with other stakeholders benefit the project?
Feasibility
Considerations Before Design Begins

Assess constraints such as:

• Is existing background information sufficient for design and risk assessment?
• What are stakeholder objectives and relationships?
• What are the limits on channel migration?
• Bed materials: e.g., grain size, cohesion, bedrock?
• Current and future watershed and riparian conditions?
• What are structural factor of safety requirements?
• Cost of materials, limitations on construction access?
• Are de-watering and temporary diversions necessary?
• What are the probable permitting restrictions?
• Are there legal considerations?

Feasibility Example: Rickreall Creek, OR
Feasibility Example: Rickreall Creek, OR

Opportunities:
- Conversion of bedrock channel to an alluvial channel
- Bank setback acceptable along left bank.
- Lowered flood elevations resulting from incision offer opportunity to raise stage without exceeding FIRM.
- Community support.
- Public education in an urban setting.
- Easy construction access.

Constraints:
- Urban stream with adjacent residential property.
- Channelized stream with steep hydrographs and super-critical flows through project reach.
- Bedrock channel limiting in-stream burial of structures.
- Human safety in urban park setting.
- Regulatory flood level cannot be affected.
Risk assessment for river projects

- Accuracy of available data on soils, hydrology, topography and hydraulics on which design is based.
- Potential effects on channel change at project, upstream, downstream and on opposite banks:
  - Flood levels
  - Scour
  - Sedimentation
  - Bank erosion
- Potential short and long-term impacts to habitat.
- Potential hazards to humans.
- Potential for damage to infrastructure
- Potential magnitude of drift collection
- Accessibility for maintenance

Example of risks: large logjams can impound rivers

Deschutes River, Thurston County, February 2002
**DESIGN PROTOCOL**

**Elevated river stage, \(\Delta H\), associated with Deschutes logjam, winter 2002**

![Graph showing head differential and river discharge over time.](image)

**DESIGN PROTOCOL**

**Developing tools, e.g., \(\Delta H = f(Q)\)**

![Graph showing depth and discharge ratio.](image)
Hydraulic modeling of logjams: Ozette River

Remember that in many situations large accumulations of wood pose little or no risk, create outstanding habitat, and reduce drift and flood problems downstream.

Floodplain side channel forming at large logjam in Green River, WA
Risk Assessment - Factor of Safety

Design tailored to site requirements and risks:

- Type of structure
- Location of structure
- Size of structure
- Structural integrity

**Factor of safety is a big deal** – need to incorporate in wood structure design the same as is done for other civil engineering designs

Increase factor of safety commensurate with risks of structure failure: higher factor of safety for infrastructure protection situations

### DESIGN PROTOCOL

#### Wood properties, e.g., strength, elasticity, density, …

- *Thuja plicata*, $\gamma \approx 0.385$
- *Pseudotsuga menziesii*, $\gamma \approx 0.500$
- *Prunus serotina*, $\gamma \approx 0.540$

Why does some wood sink – even “light woods”? The cellulose comprising the cell walls of wood has a specific gravity of 1.5, so if a piece of wood were completely saturated:

$$1000 \text{ kg/m}^3 < \text{effective density} < 1500 \text{ kg/m}^3$$

Driving Forces: Buoyancy

- Wood density
- Wood shape
- Wood size
- Water depth

Displacement
Draft
Normal forces

Driving Forces: Drag and Incipient motion

\[ F_D = C_D A_o \rho U^2 / 2 \]
Resisting Forces: **Skin Friction**

<table>
<thead>
<tr>
<th>Earth Material</th>
<th>Frictional Resistance</th>
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<tbody>
<tr>
<td>Marsh</td>
<td>144 lbs force/ft²</td>
</tr>
<tr>
<td>Silty clay</td>
<td>361 lbs force/ft²</td>
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<tr>
<td>Sandy clay</td>
<td>605 lbs force/ft²</td>
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<tr>
<td>Gravel</td>
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<tr>
<td>Gravel</td>
<td>1500 lbs force/ft²</td>
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<td>Gravel</td>
<td>2200 lbs force/ft²</td>
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<tr>
<td>Gravel</td>
<td>3113.7 N/m²</td>
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<tr>
<td>Gravel</td>
<td>9786.0 N/m²</td>
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</tbody>
</table>

Input:
- Pile diameter = 2 ft (0.6m)
- Length of pile = 30 ft (9.1m)
- Buried depth of pile = 16 ft (4.9m)
- Depth of water = 30 ft (9.1m)
- Wood density = 31 lb/ft³ (500 kg/m³)
- Frictional resistance of ground = 2000 lbs force/ft⁷ (8896.4 N/m⁷)

Output:
- Pile length exposed above ground = 14 ft (4.3m)
- Pile length exposed above water = 0 ft (0.0m)
- Submerged length of pile = 30 ft (9.1m)
- Cross-sectional area of pile = 3.1 ft² (0.29 m²)
- Lateral surface area of pile in ground = 100.5 ft² (9.34 m²)
- Total volume of pile = 94.2 ft³ (2.67 m³)
- Submerged volume of pile = 94.2 ft³ (2.67 m³)
- Buoyant force = -28859 lb (13090.5 N)
- Frictional resistance = 201062 lb (83089.1 N)
- Net load (buoyant force if negative) = 172203 lb (69998.6 N)
- Factor of safety = 76

**Resisting Forces: Surcharge**

<table>
<thead>
<tr>
<th>Burial Depth (m)</th>
<th>Log Volume (m³)</th>
<th>Buoyant Force of Log (N)</th>
<th>Normal Force of Sediment (N)</th>
<th>Factor of Safety</th>
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<tbody>
<tr>
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<td>7.85</td>
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<td>7.85</td>
<td>15.50</td>
<td>-38624</td>
<td>152055</td>
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</table>

Dimensionless burial depth: burial depth / log diameter

Factor of Safety: 10 m log, horizontal inclination, 50% of length buried in dense sand
Resisting Forces: Passive Earth Pressures

\[ P_p = \frac{(K_p \gamma' h^2)}{2} \]

\[ K_p = \frac{(1+\sin \phi')}{(1-\sin \phi')} \]

**Design Life:** wood can be quite resilient...

"Foundation piles, when cut off below the ground-water level, apparently have an indefinite life. The piles in the foundation (St. Mark’s in Venice), which had been in service for 1,002 years, were found to be in such a good state of preservation that they were allowed to remain to support the reconstructed tower."

The type, location, and size of structures

This may be the most important aspect of a design.

Wood budget: what is the predicted influx of drift and how will it influence project performance and maintenance?
Increasing Factor of Safety Values

- **Force balance:** Increase burial depth, add inclined piles, consider addition of ballast. Add redundancy with additional elements and structures.
- **Scour:** Increase excavation depth
- **Backwater:** Reduce blockage coefficient protrusion.
- **Effects on opposite bank:** Reduce magnitude of flow deflection.
- **Boater Safety:** Prevent scour undercutting structure and protrusion into flow.

Plans, Specifications and Construction

Plans often require greater detail and explanations than traditional structures since many contractors are not familiar with complex wood structures.

Because of the natural variability of wood, plans and specifications should provide minimum values and guidelines for variation, e.g., species, wood quality, rootwad size & shape, branch structure, …

De-watering and flow diversions for predicted range of flows during construction period must be included in plan details and specifications.

Equipment should be adequate to move large volumes of alluvium and logs quickly and efficiently.
Construction:
Equipment, access, diversions, excavation, …

**Cispus River Site A**

- August 27, 2001
- September 14, 2001
- September 27, 2001

Wood and Human Safety:
Often a Major Consideration

*Queets River, 1994*

*Elwha River, 2002*
Communicating Safety Risks

Potential concerns communicated early in design phase.
Ensure appropriate measures are taken in design and post-construction:
• Informational/educational signage
• Inspections and maintenance
• Managing wood accumulation

Tolerate natural dynamics wherever possible

e.g., the Yakima River near Easton, WA, directly north of I-90 has numerous large logjams and a very complex channel system.
Establishing a Standard of Practice for Re-introduction of Wood in Rivers

Conception of New Alternatives
- Develop
- Implement
- Test

Design, Construction, and Management Standards
- Develop
- Implement
- Test
- Acceptance

Testing the performance of engineered logjam technology: have test structures been successful?

Here are some examples...
## ELJ Projects*

<table>
<thead>
<tr>
<th>Year</th>
<th>River</th>
<th>Sponsor</th>
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<tbody>
<tr>
<td>1995</td>
<td>Cowlitz</td>
<td>Private landowner</td>
</tr>
<tr>
<td>1998</td>
<td>N.F. Stillaguamish</td>
<td>State, County, Federal</td>
</tr>
<tr>
<td>1998/2001</td>
<td>North Creek</td>
<td>State</td>
</tr>
<tr>
<td>1999-2002</td>
<td>Elwha</td>
<td>Tribe, State</td>
</tr>
<tr>
<td>1999</td>
<td>Cispus B &amp; C</td>
<td>Federal</td>
</tr>
<tr>
<td>2000</td>
<td>Williams River**</td>
<td>Local district, landowner</td>
</tr>
<tr>
<td>2000</td>
<td>S.F. Nooksack</td>
<td>Tribe, State</td>
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<tr>
<td>2001</td>
<td>Cispus A</td>
<td>Federal</td>
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<tr>
<td>2002</td>
<td>Methow</td>
<td>Private landowner</td>
</tr>
<tr>
<td>2002</td>
<td>Quilcene</td>
<td>Tribe, Private landowner</td>
</tr>
</tbody>
</table>

* Washington State projects, ELJ-type structures have also been constructed in Mississippi by F.D. Shields, National Sedimentation Laboratory, Oxford, MS

** New South Wales, Australia,
TESTING NEW TECHNOLOGIES

Williams River ELJ #2 pre-existing conditions
September 2000

TESTING NEW TECHNOLOGIES

Williams River ELJ #2 during construction
September 2000
TESTING NEW TECHNOLOGIES

Williams River ELJ #2 as-built
September 2000

TESTING NEW TECHNOLOGIES

Williams River ELJ #2 after 6 overtopping flows
November 2002
TESTING NEW TECHNOLOGIES

Williams River As-built, September 2000

Herrera Environmental Consultants
Seattle, Portland, Missoula, Sequim

TESTING NEW TECHNOLOGIES

Williams River example of over-topping flow, March 2001

Herrera Environmental Consultants
Seattle, Portland, Missoula, Sequim
TESTING NEW TECHNOLOGIES

Williams River after flood peak, March 2001

Williams River after 6 over-topping flows, November 2002
Washington ELJ Project Sites: 1995-2002

North Fork Stillaguamish River 1998 ELJ Project

March 2000
TESTING NEW TECHNOLOGIES

Bridges and wood: success of 1998
North Fork Stillaguamish River ELJ Project

1998: pre-existing conditions

1999: 8 peak flows >= bkf
2000: 16 peak flows $\geq$ bkf

2001: 17 peak flows $\geq$ bkf
2002: 24 peak flows >= bkf

Thanks to all of you working toward sustainable river management.

2003 Northwest River Restoration Symposium, Skamania, WA