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Functional Performance of Engineered LWD for Fish and Wildlife Habitat Enhancement

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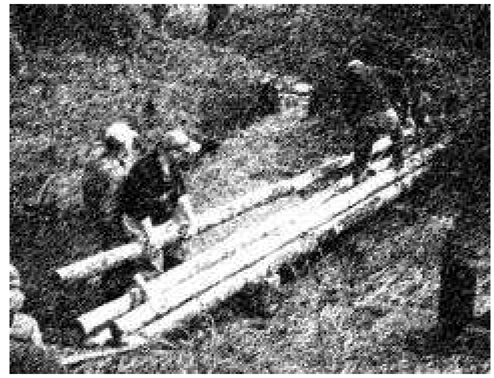
Summary: An engineered large woody debris structure has been designed and developed for use in habitat and watershed restoration projects. The ELWd® structure was designed according to the Appreciative Design method to accommodate readily available wood materials, low-tech manufacturing methods, and volunteer-based installation. Technical features include a high organic surface area, structural integrity in an all-wood product, length proportional to channel properties and diameter proportional to flow depth. Equations for appropriate structure length and diameter as functions of channel properties were derived from the literature. The ELWd® structures have now been installed to provide a number of different functionalities including: scour pool formation, complex cover features, bank protection, flow routing, sediment storage and high flow refuge. The paper describes the design rationale and critical assumptions that resulted in the present configuration for ELWd® structures, and results of the first three years of in-stream use.

Keywords: Habitat, wildlife, fisheries, restoration

Engineered large woody debris are large diameter functional habitat and bioengineering "logs" assembled from readily available small diameter poles. Engineered LWD enables new design options for habitat and stream restoration engineers. This paper includes a survey of how engineered LWD has been applied for habitat, geomorphic, hydraulic and bank stabilization in the three years since the structural concept was introduced. Current performance of 43 installed structures is summarized.



FUNCTIONALITY OF LARGE WOODY DEBRIS

Efforts to improve stream habitat date from the early 1900's (Hubbs, Greeley, and Tarzwell 1932; White 1996). Wood, whether dimension lumber or round wood, has been the preferred material for habitat structures from the earliest days. Early practitioners in the Midwest appear to have given careful consideration to functional requirements of their target species and applied a disciplined design to habitat enhancement structures. Hubbs, Greeley and Tarzwell (1932) identified six essential factors that are required for healthy trout populations.

1. Pure water, free of industrial, sanitary and natural pollution
2. Cold water
3. Adequate spawning conditions
4. Good Shelter
5. Sufficient food for each age class of trout
6. Protection from depletion by natural enemies, disease and over-fishing

Woody features are instrumental for gravel sorting necessary for spawning beds. "Lunker cover" and similar complex structures provide shelter from the current and protection from predators. Organic materials such as wood provide substrate for important macro and micro foods. From early in the century to today, stream restoration and improvement projects almost universally include large woody debris elements (Seehorn 1992).

By the early 1980's the broader role of large woody debris (LWD) within fluvial systems became the focal point for intense study. While organic debris of all sizes is generally recognized as important for maintaining the biotic and abiotic functions of stream channels, functional large woody debris is critical (Bilby and Ward 1989; Sedell and Beschta 1991; White 1996). LWD has a major influence on channel form, sediment transport and deposit patterns, as well as contributes to organic cycling (Bilby and Ward 1991). Yet, the amount of large wood in most coastal streams is a small fraction of historic levels (Bilby and Ward 1991; Bisson et al. 1997). Current efforts to protect riparian vegetation (Washington State Forest Practices Board 1994) are expected to yield significant quantities of woody debris at some time in the future (Peterson and Klimas 1996). Cederholm (1997) estimates that it will take approximately 100 years for coniferous streams to achieve minimal recovery. Until such time as natural processes come into play, it will be necessary to continuously add large woody debris from other sources if we are to maintain or restore adequate levels of salmonid habitat (Gregory and Ashkenas 1990).

Today, the functions of LWD are generally accepted to include the following:

1. Provide shelter and low velocity refuge for fry and juvenile fish (Gregory and Bisson 1997)
2. Facilitate in-channel storage of sediment through creation of dams, bars or islands (Abbe and Montgomery 1996) (Chesney 2000)
3. Modify stream flow to create pool structure (Cherry and Beschta 1989)
4. Direct high-water flow to support hydraulic routing (Gippel 1995; Gregory and Bisson 1997)
5. Trap and hold small organic materials (leaves, needles, carcasses, etc.) (Culp, Scrimgeour, and Townsend 1996)
6. Provide hydraulic roughness to the stream during high flow conditions (Abbe and Montgomery 1996)
7. Provide bank stabilization by reducing erosive action (Donat 1995)
8. Provide visual aesthetics suggesting natural stream conditions (Bisson et al. 1997)
9. Provide habitat and perches for aquatic insects, amphibians, birds and riparian mammals (Borchardt 1993)
10. Provide complex surface and nutrients for microbiological organisms important to the aquatic ecosystem (Bilby and Ward 1989)
11. Feed the "wood budget" to provide a flux of woody organic matter in the stream channel (Chesney 2000)

DESIGN OF ENGINEERED LARGE WOODY DEBRIS

The Appreciative Design process (Dooley and Fridley 1996) was followed to create a LWD solution that may be preferred for many stream, wetland, lake and upland situations. Appreciative Design is a structured process to search for a best-set solution to technical and organizational problems. The Appreciative Design process is a significant extension of the hierarchical axiomatic design methodology of Suh (1990; 1995). Suh's axiomatic design was modified through the addition of stakeholder ownership of constraints (McIntyre and Higgins 1989), and inclusion of many features of the Soft Systems Methodology developed by Checkland (1990).

In order to perform identified <u>functional requirements</u>, any specified native or engineered LWD solution would need to have <u>design attributes</u> such as the following:

- Cross-section and length that are proportional to stream channel and high flow conditions
- Mass, specific gravity or other features to keep LWD in place during all but most severe flows
- High hydraulic roughness
- High physical surface roughness to trap sediments, debris, etc.
- Maximum surface area to cross-section area ratio
- Natural appearance after placement to blend with the stream corridor scene
- Natural appearance of components and debris when the structure fails, breaks-up or decays
- Small debris size when structure fails, to minimize impact on downstream public works

In addition to physical parameter constraints there are a number of stakeholders who contribute constraints to the design process. Such stakeholders are termed "constraint owners."

<u>Client Constraints</u>

- Competitive installed cost compared to native LWD
- Low cost for placement (less equipment rental cost is better)
- Lasts long time (lower maintenance cost is better) (lasts until riparian silviculture begins to deliver)
- Applicable to sites with difficult access for large equipment (install with hand crews is better)
- Does not increase risk of damaging downstream resources (lower risk of damage is better)

Fisheries Enhancement Contractor Constraints

- Manufacture from readily available materials (smaller diameter components is better)
- Low tech manufacture (product value does not warrant expensive manufacturing process)
- Easy to train crews to install (lower information content is better)
- Minimize risk liability claim from high water failure (less risk of damage to property & public works)

Volunteer Coordinator Constraints

- Maximum number of structures per grant dollar (lower requirement for rental equipment and operators is better)
- Need to separate volunteers from mechanized equipment operations (install with all hand labor is best)
- Maximize volunteer participation in meaningful part of projects (volunteers putting structures in stream is better than volunteers doing cleanup after machines do the habitat work)
- Easy logistics to prepare for volunteer events and work days (stage kits of lightweight materials is better)

Environmental and Recreational Special Interests

- Materials are all organic and similar to native materials
- Avoid steel, plastics and other unnatural materials
- Structures look like they belong in the natural environment (better aesthetics)
- Debris from failed structures looks natural in the streamside environment

Materials Supplier Constraints

- Utilize non-merchantable or low value raw materials
- Utilize readily available raw materials

Regulator and Public Agency Constraints

- Amenable to meeting the requirements of WAC 220-110
- Natural materials (no car bodies, concrete, tires, asphalt, etc.)
- Does not increase flood height (less flood impact is better)
- Does not increase risk to public works (bridges & culverts) over native LWD risks (lower risk is better)

The current design of engineered large woody debris as manufactured by ELWd Systems company is an "optimal" solution to the design problem as characterized above. The fundamental element of an ELWd® (pronounced "elwood") brand engineered LWD structure is to create a hollow cylinder by assembling even numbers (pairs) of small diameter logs into a hollow tube or truncated cone (Dooley 1998; Dooley and Paulson 1998). The central cavity inside the ELWd® structure can be filled with cobbles or gravel to decrease buoyancy, increase effective specific gravity, and help the structure stay in place during high water and floods.

Assessment of Installed Projects

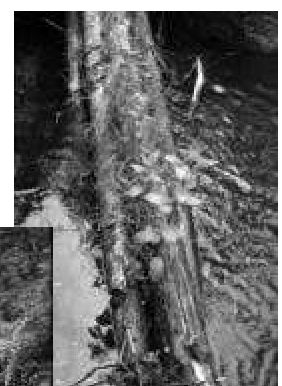
We recently assessed the functional performance of 43 engineered LWD structures installed in seven projects completed during the years 1997 through 1999. Of the 43 structures installed, only one has moved outside of the project reach. That structure was lost in a high water event due to an anchor cable failure. All project sites were visited at least once after project completion, most have been visited two or three times. At each visit photographs were taken to compare structure position and condition to the installed conditions. Notes were made of any unusual observations, such as anchoring problems, bank scour, unanticipated habitat or ecological benefits, etc. The long-term record for each structure includes species, wood source, detailed design and manufacturing information, customer, watershed, date of installation and other base data.

The table below summarizes the observed functionality of 43 in-stream structures. For each project, the primary functional objective(s) are identified with a "P" symbol. Secondary and/or unanticipated positive functionalities that are provided by installed structures are identified by an "X" symbol.

Table 1. Functional Performance of Engineered LWD Structures

Project	Bank Full Width (m)	No. of Engr. LWD Installed	Functional Objective(s) Achieved by Installed Structures										
			Provide Bank Protection	Provide Fish Shelter	Store or Sort Sediment	Form Pools	Redirect Current	Store Fine Organic Debris	Increase Channel Roughness	Provide Natural Look to Stream	Perches for Amphib., Birds, Mammals	Organic Substrate for Macro/Micro Organisms	Feed Wood Budget
Griffin 1	10	5		X	X	P	X	X	P	X	X	X	P
Mashel	40	4	X	X	P		X				X	X	X
Griffin 2	10	5		X	P	X			X		X	X	X
Samish	20	2	P	X			P		X				
Thornton	5	1	P	X				X		X		X	
Newaukum 1	7	13	X	P	P	X	P	X	P	X	X	X	P
Newaukum 2	3	8	X	P		X	X	X	P	X	X	X	X
Total		43											

Most projects used LWD to achieve multiple primary and secondary objectives. The fact that multiple functionalities are desired is consistent with the findings of other studies of habitat enhancement and watershed restoration projects by the lead author (Dooley 2000).



The Griffin 1 project included five engineered LWD as part of a large wood-loading program. Over 125 pieces of LWD were added to a relatively short reach to restore the wood load to approximately one log per channel width. None of the wood was anchored, thus was free to move to stable locations and configurations during winter high water. All of the engineered LWD moved at least 30 meters during the first winter. One 7 meter long, .6 meter diameter engineered LWD structure became trapped under a large log where it collected sediment upstream and formed a large scour pool downstream. The log and pool appear stable after two seasons. All other engineered LWD structures moved with other placed LWD into relatively stable debris jams. An important observation is that engineered LWD that has remained in a stable location for more than one season has accumulated significant fine organic debris within the structure and now has vegetation growing from its surface, much like remnant ancient LWD.

The Mashel and Griffin 2 projects were part of a large hydrology and fisheries study conducted by the Center for Streamside Studies at the University of Washington. The structures have been intensively monitored, with results reported elsewhere (O'Neal et al. 1999). The primary functional objective was to use digger logs along a plane-bed reach to create scour pools and sort gravels. Scour pools were expected to provide low-water refugia. Accumulated gravels were expected to provide additional spawning habitat.

The Samish project used two engineered LWD in a large pool on the outside of a river bend to quiet surface flow against an eroding bank and to provide floating complex cover for juvenile salmonids.

An engineered LWD structure 5 meters long and 0.6 meters diameter was used in Thornton creek for bioengineering bank protection. The large diameter of the structure allowed an effective lateral scour pool to form along the log without compromising its bank protection functionality. The structure was filled with gravel ballast as part of the anchoring specification. High winter flows added silt and fine organic debris to the structure. In the spring of 2000, vegetation sprouted from gaps in the structure, effectively blending the bank structure with the surrounding area.

The Newaukum 1 project included thirteen engineered LWD structures that were installed in a variety of orientations to achieve multiple objectives. The site is a plane-bed reach of a low-gradient stream that was straightened and channelized approximately 70 years ago. After one season, the installed structures already have triggered gravel sorting and minor pool formation.

Newaukum 2 project is on a small fork of the main stream. The installed structures have a length that is more than twice the bank-full width, and a diameter more than three times the typical flow depth. Although the structures appear oversized for the location (given current notions of habitat enhancement), they are of the size and scale of trees native to the area. The project was installed during early 2000, so long-term performance is yet to be assessed.

After 1-3 years of service, all engineered LWD structures that have been assessed are in good structural condition. Many still have intact bark. All that are wetted show signs of colonization by aquatic microflora and invertebrates.

Conclusions

Engineered LWD has proven to be a functionally effective alternative to native solid LWD for habitat enhancement, watershed restoration and bioengineering projects. An evaluation of 43 engineered LWD structures across seven projects suggests that engineered LWD captures organic matter and supports vegetation much more like old remnant LWD than does recently-placed solid LWD. Engineered LWD has proven effective for bank protection and bioengineering stabilization, with a particular benefit as vegetation roots into the structure and binds it to the bank. Ballasting engineered LWD substantially reduces the need for cable anchors. In all other respects, the engineered large woody debris appear to be performing similarly to solid large woody debris.

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