Streambank Habitat Enhancement with Large Woody Debris

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Complexity	Environmental Value	Cost
Low – Moderate – High	Low – Moderate – High	Low – Moderate – High

Overview

Naturally occurring large woody debris (LWD) (i.e., > 10 cm diameter and 2 m in length) is an important component of many lotic systems. It provides velocity refuge and overhead cover for fishes, substrate for aquatic invertebrates, and can be an important source of particulate organic matter adding to primary productivity of a stream.

Large woody debris also plays a major role in stream channel morphology, contributing to formation of pool habitat, increasing meandering, and increasing sediment capacity. Large woody debris dissipates flow energy, resulting in improved fish migration and channel stability. It also provide basking and perching sites for reptiles and birds. Positive effects of LWD are well- documented in high-gradient streams, and recent studies show that LWD is an important habitat component of low-gradient streams with fine substrates.

The amount of LWD in streams is affected by anthropogenic factors. Large woody debris has been removed from streams for a variety of reasons including improved navigation, reduction of flow resistance, flood control, and perceived fish passage problems. Large woody debris is usually removed during channelization operations. Clearing of riparian vegetation whether due to channelization operations, agriculture, forestry practices, or urbanization reduces LWD recruitment. Alternately, urbanization, channelization and other actions that lead to channel incision can initiate systemic channel instabilities that lead to a significant introduction of LWD into a stream.

Figure 1. Stream in southeast U.S. with several types of LWD

Placing LWD into streams is an increasingly popular technique to improve fish and wildlife habitat. Large woody debris projects can be divided into two categories based on project goals, hereafter referred to as category 1 and category 2 projects. The main goal of category 1 projects (Figure 2) is to improve habitat by increasing LWD quantities in the stream. In category 2 projects (Figure 3), the main goal is to alter flows in some way to improve aquatic habitat. This is not to imply that category 1 projects will not alter flow, only that this is not the main goal. Flows will be altered in predictable ways any time LWD is added to a stream and effects of the altered flows should be carefully considered during the planning stage. Some specific objectives that can be accomplished with category 2 projects are listed below:

1. Create pool habitat.
2. Generate scour.
3. Increase depths through shallow reaches.
4. Divert flows away from a bank to reduce erosion.
5. Armor stream banks to reduce erosion.
6. Promote bar formation through induced sediment deposition.
7. Increase instream cover and refugia.

Figure 2. Category 1 LWD structure

Large woody debris commonly placed into streams can be categorized as three types: whole trees, logs, and root wads. A whole tree is a tree cut off at the stump with all or most of the limbs attached, including terminal branches. Logs are sections of the bole with all limbs removed. Root wads consist of the root portion of the tree and a section of the bole. A fourth category including brush mattressing and brush revetments will be covered in EMRRP Technical Note SR-22.

The many small terminal lateral branches on whole trees provide a large surface area and many interstitial spaces - ideal habitat for aquatic invertebrates and fishes. Thus, whole trees are desirable for category 1 projects. The many small branches also cause whole trees to have more flow resistance than other types of LWD, restricting choices of orientation in the current, so it is often not feasible to use whole trees for category 2 projects when flooding is a concern.

Logs have little surface area and flow resistance and are very rigid compared to whole trees. They may have little value as fish habitat unless they are positioned so as to alter flow in some way (i.e., perpendicular or diagonal to current). Logs are therefore more useful for category 2 than category 1 projects.

Compared to whole trees, root wads are rigid, but have more surface area and provide better fish habitat than logs. Root wads are useful for category 1 projects where high flow velocities preclude placement of whole trees and large branches and in category 2 projects that have a secondary goal of providing LWD habitat for aquatic organisms.

The primary purpose of this paper is to discuss problems and techniques associated with placing LWD in stream habitats. Category 2 projects require site-specific plans beyond the scope of this paper, but many of the problems and techniques discussed here have application in category 2 projects.

Planning

Category 2 projects are more difficult to successfully implement and have higher failure rates than category 1 projects because slight damage to category 2 structures can alter flow characteristics enough to render the structure ineffective. Thus, category 2 projects require very specific and detailed construction plans that take into consideration channel morphology and stability, sediment transport, anchoring techniques, construction materials, and site sonditions. A much simpler plan will usually suffice for category 1 projects where the primary engineering concern is to ensure that anchoring is adequate to hold the structure in place during the most extreme flow conditions.

Figure 3. Category 2 LWD structure used to stabilize a stream bank

The amount of LWD in streams, especially middle- and high-order streams, is often underestimated with a resultant overestimation of the need to add more. Thus, category 1 project streams should be examined during low flow conditions to determine the quantity and distribution of LWD using modified forestry techniques. These can be compared to values from relatively pristine streams obtained from the scientific literature. Assessing the need for a category 2 project requires a determination of limiting factors. This may be readily apparent in highly degraded streams but may require surveys and comparisons to pristine streams for healthier systems.

After determining goals and assessing need, the logistical problems of the project must be solved. An adequate supply of LWD materials, transport to the site, and means of positioning materials in the stream will be necessary. Trees that can be acquired near the site are preferred, reducing or eliminating transport cost and ensuring that whole trees with branches attached can be used. Heavy equipment will probably be necessary for positioning and anchoring materials. Site-access plans should consider the need for heavy equipment and transport of materials and should be designed to minimize damage to riparian and in-stream habitats.

Estimated life of the structure may be required to complete a cost benefit analysis. Life spans of LWD structures are often underestimated by at least 25 to 50 percent (Frissell and Nawa 1992). Evaluation studies of LWD structures suggest that a realistic life span for LWD structures is 5 to 15 years, barring failure. Factors influencing LWD structure life include:

- Tree species (cypress, cedar, redwood, and oak last longest)
- Climate (dry and cool climates prolong life)
- Position relative to water surface (frequent wetting and drying reduces life - continuously submerged wood lasts longest)
- Soil contact (microbial digestion in soils limits life, but burial in anaerobic soils prolongs life almost indefinitely)

The negative impacts of adding LWD should be carefully assessed. Heavy equipment can damage riparian habitat, and felling or uprooting streamside trees for construction materials can cause loss of shade and decreased bank stability. Large woody debris can increase flow resistance and thus, flooding potential. Studies by the authors have shown increases in resistance coefficient values of greater than 50 percent due to LWD (Fischenich 1996).

Loosely anchored or improperly placed LWD can increase bank erosion. Large woody debris structures can also impede navigation and can be a safety hazard under certain conditions. Failure to consider negative impacts can lead to extremely undesirable and possibly hazardous conditions.

Cost

The cost of LWD projects varies with the complexity of the design, site accessibility, flow conditions, and cost of LWD materials, cables, anchors, etc. One of the few published studies that analyzed cost of LWD projects found that cost could vary by an order of magnitude ($12.90 vs. $164.50 per meter of channel length) due to differences in design complexity alone (Cederholm et al. 1997).

Hourly cost of heavy equipment operation can be estimated with the microcomputer-aided cost estimate system (MCASES) database. Cost of anchors is available from the manufacturers (Appendix I) and cost of materials, other than the woody debris, can be obtained from a well-equipped hardware store.

Estimating the labor and heavy equipment requirements is difficult because these items tend to be very site-specific. Constructing a few representative LWD structures during the planning stage may be necessary so that labor and heavy equipment requirements can be extrapolated to the whole project.

The commercial value of trees used for LWD structures is often overlooked as a project cost. Tree values can be substantial and depend on species and tree size. Board foot costs of some common marketable trees are given in Table 1. A tree with a 12-in. base diameter will contain approximately 150 to 200 board feet, depending on species and taper of the bole.

Site Selection

In most cases, logistical considerations and need based on distribution of existing LWD should determine site location of category 1 projects. Site location of category 2 projects will be dictated by local site conditions and specific objectives of the project. Some factors that should be considered when selecting sites for category 1 and category 2 projects are given in Table 2.

Table 1. Approximate Cost (1999 dollars) for Common Varieties of Saw Timber

Variety of wood	Price per 1000 board feet[5]
Southern yellow pine[1]	\$ 432 - \$ 461
Mixed hardwood[1]	\$ 170 - \$ 220
Oak[1]	\$ 290 - \$ 385
Douglas fir and western hemlock[2] 8–9 inch dbh.	\$ 100 - \$ 125
Western red cedar[2], 13–16 inch dbh.	\$ 650 - \$ 800
Aspen[3]	\$ 93.83
Birch[3]	\$ 37.60
Basswood[3]	\$ 117.00
White spruce[3]	\$ 83.20
Black spruce[3]	\$ 123.20
Jack pine[3]	\$ 123.36
Red and white pine[3]	\$ 174.34
Coastal redwood[4]	\$ 510 - \$ 580
Cypress	\$ 250 - \$450

[1]Mississippi timber price report, Nov/Dec 1998.
[2]Washington Department of Natural Resources.
[3]Minnesota timber price report, 1997.
[4]California harvest value schedules.
[5]In 1999 dollars.

Table 2. Factors to Consider When Selecting a Site for Adding LWD to Streams

Variable	*Factors to consider*
Stream size	Category 1 projects can be successfully implemented in any sized stream as long as a stable bank is available. Category 2 projects will be difficult to successfully implement in streams with flows greater than 5 m^3/sec.
Sediment load	High sediment loads can quickly bury LWD structures, reducing their effectiveness. This is most often a problem with category 2 projects.
Substrate	Anchoring will be difficult in very hard substrates such as cobble, boulder, or bedrock without specialized equipment. Soft substrates allow use of screw type and driven in anchors and allow the debris to be partially buried in the substrates increasing stability.
Channel stability	Large woody debris should never be anchored to an actively eroding bank or an actively incising channel bed.
Flow velocity	Anchoring LWD will be easier in low-velocity sites such as inside bendways.
Site access	Sites that allow use of heavy equipment without damaging riparian and instream habitat are the most suitable. Stream reaches with a road along the top bank are ideal.
Distribution of existing LWD	Large woody debris should be added to areas where existing LWD is rare or absent.
Flow resistance	Both category 1 and category 2 projects can increase flow resistance in a stream and should not be implemented in stream reaches where existing flood hazard is high.
Navigation	Large woody debris structures should not be located where they will be a hazard to recreational and commercial boating. Structures that may be a hazard should be clearly marked.
Location of raw materials	When possible, sites should be located near trees that can be used for raw materials.

General Considerations for Implementation of Category 1 Projects

Size and types of trees

Whether large or small trees provide better habitat for aquatic organisms is unknown; thus, the size that can be most efficiently placed and anchored with the available labor and heavy equipment should be used. Trees used for LWD projects should have as many limbs left in place as possible to maximize the surface area and interstitial spaces that provide the best habitat for fish and invertebrates.

Trees with many small branches can also have beneficial effects on stream morphology by trapping sediments and reducing bed degradation. However, some limbs should be removed from the side of the tree that is anchored to the bank. In some cases transport and placement constraints of the LWD will necessitate removal of more limbs. Contractors employed to place LWD in streams should be made fully aware of these requirements.

The LWD unit should be clearly defined in the contract. This definition should include a minimum crown width or a minimum number of limbs that have not been trimmed in any way. If this is not done, the contractor will very likely trim all limbs from the bole to facilitate movement and anchoring (Figure 5).

The most durable tree species available should be used. Species that are most often used for decking or other outside construction, such as cypress *Taxodium distichum,* western red cedar *Thuja plicata,* coastal redwood *Sequioa sempervirens.* and red and white oaks *Quercus spp*., are most desirable.

However, these species are usually the most desirable for lumber and, therefore, the most expensive, so compromise will often be necessary.

Figure 4. Deadman anchor that failed due to bank erosion

Figure 5. Large woody debris placed by a contractor that has had all limbs removed prior to placement

Placement

In general, LWD should not be anchored in mid-channel. Except in very shallow streams, LWD will of necessity be anchored to the streambank rather than the streambed. The bole of the tree should be anchored securely to the bank with no possibility of movement. The individual LWD components should be anchored at a minimum of two points The distance from the LWD to the anchors should be as small as feasible. When some distance must separate the anchor and the debris, there should be a straight line between the two. For example, cable should not be run over the curve of a bank to secure LWD to an anchor on the top of the bank.

For anchors placed on the top bank, a ditch may be required between the LWD and the anchor so that the cable can be tightened sufficiently to secure the structure (Figure 6). Failure to adequately anchor the LWD to the bank can result in scour between the tree bole and the bank that can destabilize the structure and in severe cases, can destabilize the bank. Loose structures will also oscillate in the current and can result in failure of anchors or attachment materials and loss of the structure.

Figure 6. Ditches used to run cables from LWD to anchors on the top bank

When possible, trees should be anchored so that they are continually submerged as alternate wetting and drying accelerates deterioration. Ice has a great potential for straining anchoring systems and damaging LWD structures. Unless they can be placed entirely beneath the level of the flows, adding LWD to streams with heavy ice flows is not recommended.

Stability

Due to their low specific weight (usually less than one) and large surface area, lift forces on LWD can place a heavy strain on anchoring systems. This condition is exacerbated by the tendency of LWD structures to capture floating debris, increasing the drag force on the anchors during high flows. The force on the anchors should be calculated by estimating the surface area of the debris structure exposed to current (perpendicular to the flow), using the following equation for the force:

$$F_d = 0.95A(V)^2 \qquad (1)$$

where A is the LWD area (ft^2), and V is the expected stream velocity (ft/sec). The total drag can be divided by the number of anchors to determine the per-anchor force. A good rule of thumb is to multiply this by a factor of four to account for capture of additional debris, weakening of anchoring materials, and uncertainty.

Materials for Attaching LWD to Anchors

Some material will be necessary to secure the tree to an anchor. Cable is most often used but chain and rope are also useful. The main considerations are strength, corrosion resistance, ease of pulling tightly, and ease of clamping or tying. The material should be strong enough to hold the LWD for the highest flows expected during the life of the project. Loss of strength through corrosion or rot should be taken into consideration. Use of corrosion-resistant coatings, stainless steel, or nonferrous materials such as bronze, brass, or synthetics, may be necessary. Specific materials used to secure LWD to anchors are discussed below.

Cables

Steel cables are most often used to attach LWD to anchors. These are available with both standard carbon steel and stainless steel elements. Smaller cables are often coated with plastic or nylon to prevent injury during handling.
Stainless steel cables are the most desirable because of corrosion resistance. Stainless steel cables do not weaken over time from corrosion as much as standard steel cables and thus, smaller sizes can often be used, offsetting the higher cost. Standard steel cables should always be coated with a corrosion-resistant material.

Cables can be secured with cable crimp links or wire rope clips. The cable crimp link is a piece of aluminum (sometimes brass) with a hole shaped to accommodate two lengths of a specific- sized cable. A permanent joint is formed when the link is crushed, best accomplished with a specialized tool; however, a hammer will suffice. Cable crimp links are available for 3/8-in. and smaller cables and using the proper sized link for the cable is absolutely necessary. Wire rope clips, also known as cable clamps, consist of a U-bolt and a saddle. They are available for all sizes of cable and proper size should always be used. The saddle should always go on the load-bearing side and if coated cable is used, the coating should be stripped from the portion being clamped. Two clamps are recommended as a safety factor to better ensure non-slippage. Cables should never be secured by knotting.

Chain

Chain can be a useful material for attaching LWD to anchors. It is more flexible than cable but is also heavier and costs more than cable of comparable strength. Although most chain sold through retailers is coated with a corrosion-resistant material, the most durable are those that are hot-dip galvanized, available from marine supply dealers. Specialized materials are available for securing chains but they are also easily secured by bolting links together. Bolts should be the maximum size that will fit through the link and washers and should be placed at the head and the nut end. Lock nuts or washers are recommended.

Rope

Rope may be especially desirable where attachments are visible and thus aesthetics are important. A variety of rope types are available, but those made specifically for marine use are usually strongest and most durable. Ropes can be secured with a variety of knots but most situations can probably be addressed using bowline, slipknots, and square knots.

Whatever material is used, the importance for a tight connection, with no play, between the anchor and the debris cannot be overstated. Mechanical devices such as turnbuckles or come-alongs will usually be helpful in achieving this.

Anchoring Techniques for Category 1 Projects

A variety of techniques can be used to anchor LWD. Some of the most common and some of the most useful are discussed below.

Live Tree Stump

On some occasions, live trees are positioned perfectly so that the trunk can be partially cut, allowing the tree to fall directly into the stream and remain sufficiently attached to the stump so that no further anchoring is needed. This method is the least labor-intensive for adding LWD to streams, but its success requires that all of the following conditions are met. The tree must be located adjacent to a reach in which LWD is limited. The tree must be sufficiently close to the stream and it must not be leaning away from the stream. Finally, the stream must have sufficient riparian vegetation so that cutting the tree does not pose a severe negative impact. Meeting all of these conditions is rare.

Tree Stump

Tree stumps close to the stream can be used as anchors and they are often readily available where one or both banks have been recently cleared. The cable (or other material) can be looped around the stump or bolted to it by drilling a hole completely through the stump and placing a nut and washer on the opposite side. Lag bolts and wood screws should never be used. If the cable is looped around the stump, measures should be taken to ensure that it does not come off if the debris floats above the anchor during high water.

There are two major concerns with tree stumps. The first is the lack of knowledge of strength. It is difficult or impossible to accurately estimate the amount of strain that a tree stump will withstand. The second concern is erosion. Tree stumps are often an indicator that a bank has recently been cleared and may be beginning to actively erode. This may be especially true in areas that have been recently channelized (Figure 7). Placing LWD in such areas may not succeed.

Figure 7. Tree stumps and a deadman anchor, exposed by erosion on a recently channelized river

Live Trees

Live trees close to the stream can also be used as anchors. The main concern here is injury to the tree. The cable should be looped around the tree trunk for maximum strength; however, the cable should not be allowed to come in direct contact with the bark or the tree may be girdled and killed. This can be accomplished by protecting the trunk with wooden blocks, a used conveyor belt, or some other durable but relatively soft material. The strength of the tree is also a concern. When a choice is available, the largest tree should be used. Small trees have been uprooted when used as anchors for LWD.

Reinforcing Rod (Rebar)

Three-quarter inch reinforcing rod is probably most useful for attaching logs directly to other logs, but it can also be used to anchor LWD to the substrate. Reinforcing rod has very little holding power in soil and thus is best suited for small streams that are not prone to flooding. Advantages of reinforcing rod are low cost and ease of driving into relatively coarse substrates such as large gravel and small cobble.

Weighted Anchor

Containers, ranging in size from a 5-gal bucket for small structures, up to a 55-gallon drum for whole trees, can be filled with concrete and used as anchors. Weighted anchors are best when used in low-gradient streams with fine substrates where they can become partially buried. However, even under ideal conditions, weighted anchors should not be relied upon to withstand high flows. They should be used in conjunction with another anchoring method, or not used at all.

Dead Man

Dead man is a term that usually refers to a buried anchor. It often consists of a reinforced concrete post that is partially buried with an attachment point on the protruding portion. Heavy equipment is usually required to install dead men, but where installation is feasible, they can be useful for anchoring LWD to stream banks.

Commercially Manufactured Anchors

These are usually the most desirable anchors because they are easy to install, estimates of approximate holding power are usually available from the manufacturer, and most are designed to have cables attached directly to them. There are a variety of commercially manufactured anchors that can be easily installed in soft substrates (Appendix I). Most of these are variations of screw-type or "duckbill" anchors, although other types that require digging and backfilling are available. Screw-type anchors are available for soft or rocky soils and most can be installed by hand, but heavy equipment will usually make the job much easier. Duckbill anchors can be driven easily with hand tools. Commercial anchors are also available that are designed for solid rock substrate but most require a means of drilling a hole in the rock and may require grouting for best results.

Partial Burial

When feasible, it is desirable to partially bury the LWD to increase stability. Partial burial can sometimes be achieved by sharpening the butt of the tree (or the trunk portion of a rootwad) with a chainsaw and driving it into the bank with heavy equipment, or with hand tools for smaller debris. Alternatively, a backhoe or extractor can be used to excavate a trench in the bed or bank into which part of the trunk can be placed and then buried with backfill or stone. The partially buried log can sometimes be used as an anchor for other LWD.

Construction

Most category 1 and category 2 projects will require use of heavy equipment. An extractor with a "thumb" will be most useful for moving and positioning LWD in the stream (Figure 8). Often the log will have to be "pinned down" (i.e., held tightly to the substrate, with heavy equipment to be anchored securely). Other uses of heavy equipment include installation of screw anchors with a hole-boring machine, excavation and backfilling to bury anchors and LWD, and boring holes in rocks for installation of rock anchors.

A mechanical means of puling cables, chains, or ropes tight will often be necessary. Turnbuckles, and come- alongs are usually the most practical, but under certain conditions, electric winches or other devices may be useful.

Operation and Maintenance

Monitoring and maintenance are critical for projects incorporating LWD. Most structures should be examined after the first high-flow event, the first ice-out (if applicable), and after one year to determine performance. Maintenance needs that should be anticipated include replacement, reanchoring, and removal of failed material. Realistic maintenance budgets should account for full replacement every ten years.

Applicability and Limitations

Techniques described in this technical note are generally applicable to stream restoration projects that include an increase of LWD for fish habitat improvement as an objective. Although useful in many situations, addition of LWD will probably be most beneficial in low-gradient streams that lack hard substrate and cover. Best results will be obtained when LWD is used in conjunction with other stream

Figure 8. An excavator with a "thumb" used to place LWD

rehabilitation techniques, such as reforestation of riparian zones and stabilization of sediment sources in the watershed. The use of large woody debris for stabilizing actively eroding streambanks on large rivers, particularly those with ice formation, is questionable. Incorporation of LWD into more conventional stabilization projects on such rivers should be considered for habitat enhancement, but the benefits may not justify the risks.

Possible negative impacts of the addition of LWD should be carefully considered before work is undertaken. Large woody debris structures can increase erosion and bank failure, present a navigation hazard, increase flow resistance, and increase flooding potential. Large woody debris structures that break free from their anchors can become safety hazards and aesthetic liabilities and can damage downstream structures. Construction of LWD structures and removal of trees for building materials can also damage riparian habitats. In short, considerable caution should be exercised when including LWD as a stream restoration component. Benefits should clearly outweigh risk.

Table 3. Sources of Information for Large Woody Debris in Streams

Type of Information	*Source*[1]
Techniques for altering flows with log structures	Seehorn 1992
Techniques for placing LWD in streams.	Seehorn 1992
	Cederholm et al. 1997
Methods to quantify LWD in streams.	Wallace and Benke 1984
Information on ecological benefits of LWD in stream environments	Benke et al. 1985
	Ward and Aumen 1986
	Angermeier and Karr1984
	Bryant 1983
	Flebbe and Dolloff 1995
Information on effects of woody debris on flow resistance	Dudley et al. 1998
	Young 1991
	Shields and Smith 1992
	Gippel 1995
	Shields and Gippel 1995
Effects of LWD on stream morphology.	Beechie and Sibley 1997
	Diehl 1997
	Wallerstein et al. 1997
	Wood-Smith and Swanson 1997
Long term effects of logging on LWD in streams	Ralph et al. 1994
	Bilby and Ward 1991
	Murphy and Koski 1989
Causes of failure of various types of habitat improvement structures.	Frissell and Nawa 1992
Estimation of life span of stream habitat improvement structures.	Frissell and Nawa 1992
Incremental effects of LWD removal on habitat	Smith et al. 1992

[1]Expanded versions of references are found in the References section.

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Appendix I. Manufacturers of Anchors

Affordable Instant Storage Shelters & Greenhouses, P. O. Box 260037, Tampa, FL 33685-0037. Phone (800)747-4434, Fax (813)806-0122. E-mail Shelters@gte.net Web address www.instantshelters.com/anchor.html

A. B. Chance Company, 210 North Allen St., Centralia, MO 65240. Phone (573)682- 8543. Fax (573)682-8714.

Earth Anchors, 15 Campbell Road, Croydon Surrey, United Kingdom. Phone 44 181 684 9661. Fax 44 181 684 2230

Royal Anchoring Systems, Inc., 30630 Forest Boulevard, P. O. Box 119, Stacy, MN 55079. Phone (612)462-1766. Fax (612)462-1693. http://www.ICES.com

Sladek Corp., RR #2, Box 449E. Battle Lake, MN 56515. Phone (877)864-8836. E-mail Sladekcorp@yahoo.com Web location www.sladekcorp.com

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