Chapter 10 Woody Material in the Riparian Zone

10-1 Introduction

Woody material plays a critical role in many Washington streams through its influence on aquatic habitat and stream geomorphic processes. In many forested streams, wood is a fundamental driver of fluvial geomorphology—the shape of the stream channel and how it changes over time. The quantity, size, and function of woody material, particularly large woody material (LWM, also referred to as "large woody debris") in many of these stream systems have been altered through decades of timber harvesting, channel clearing, snag removal, and human alteration to stream channels and riparian zones, resulting in changes to stream channel form and function and degradation of aquatic habitat. Restoration of instream LWM has therefore become a common restoration practice in Washington State and throughout the Pacific Northwest. Placement of LWM can achieve a variety of physical and biological benefits to stream morphology and aquatic habitat. LWM projects can be used to directly provide habitat cover, complexity, and natural levels of streambank stability, or may provide indirect benefits through their influence on pool development, sediment trapping, hydraulic roughness, lateral channel dynamics, and maintenance of channel bedform.

This chapter provides guidance on designing projects that use wood in all water bodies—streams, rivers, lakes, and marine shorelines. Section 10-2 gives an overview of the design process, including reach assessments (which are described in greater detail in Section 10-3), recreational safety considerations (which are described in greater detail in Section 10-4), and developing and understanding clear project objectives (which are described in greater detail in Section 10-5). Design criteria, including using mobile wood, are discussed in Sections 10-6 and 10-7. Sections 10-8 and 10-9 discuss mobile woody material (MWM) and SWM, respectively. Section 10-10 provides guidance on inspection and maintenance, and Section 10-11 provides the appendices.

Until relatively recently, the role of LWM in forming and maintaining stream habitat was not understood or was largely ignored. As settlement and development increased, so did the removal of LWM and boulders from the state's waterways. Past logging practices often removed trees to the edge of the stream, limiting future wood input to the stream. In many cases, streams were also cleared of wood for conveyance or fish migration. Over time, these and other activities resulted in depletion of aquatic habitat and channel-forming processes in many streams. The removal of instream LWM has dramatically altered channel form, and how LWM, sediment, and fish moved through the river system. LWM can be used effectively to provide infrastructure protection as well as aquatic habitat.

WSDOT is actively monitoring completed fish passage projects and will update this chapter as new information becomes available. Contact the State Hydraulics Office for additional or updated guidance.

10-1.1 *Purpose and Need*

Aquatic habitat enhancement and restoration is an important environmental stewardship function in all work within riverine corridors, including eliminating fish passage barriers at stream crossings of the state highway system (see Chapter 7). Fish barriers have functioned to hold stream grade, so replacing these barriers can trigger channel incision. Wood placement in reconstructed channels reduces the risk of future channel incision by improving sediment storage and flow complexity. Furthermore, the addition of LWM for bank stabilization that contains rock can be self-mitigating (determined on a case-by-case basis). Incorporating LWM into bank stability and scour protection projects as sustainable habitat features is encouraged.

The purpose of this guidance is to assist in determining when LWM is appropriate, and how to design LWM features that meet habitat and stability objectives. Because processes associated with LWM have been impaired on almost all streams, aquatic habitat restoration activities are an important method for reintroducing the necessary structure to stream channels. Frequently, the best approach for habitat restoration is to mimic natural conditions to which salmon and other aquatic species have adapted. Natural wood loading conditions provide a reference to guide quantities, sizes, and placement of LWM as a component of restoration. This approach is most effective when the adjacent riparian forest also mimics natural conditions (or is on a trajectory to reach these conditions) so that instream wood recruitment and other riparian processes can be maintained.

10-1.2 *Guidance for Emergency Large Woody Material Placement*

Generally, failure of a water crossing or a streambank requires rapid response to stabilize and prevent additional damage to WSDOT facilities and to restore a safe travel corridor. In these cases, regional maintenance staff likely need to act without the benefit of a reach assessment and an engineering design to replace damaged facilities. Maintenance staff are left to stabilize or restore the site to the previous design specifications, in likely adverse environmental conditions. Engineering judgment calls are needed during such situations; LWM should be placed during emergency repairs only in consultation with the State Hydraulics Office. The maintenance or project office in charge of emergency repairs must also consult with WDFW and the appropriate tribal contacts for the area.

Emergency actions still require permits from regulatory agencies, and those permits may be conditioned with mitigation requirements. In these cases, LWM placement should be included as a mitigation element for aquatic habitat impacts. LWM must be incorporated in emergency stabilizations whenever conditions allow.

10-1.3 *Design Oversight*

Project designs that include LWM or engineered log jams (ELJs) require expertise in hydrology, hydraulics, geomorphology, riparian ecology, biology, and civil engineering. Because of the risks involved, all LWM placements in bank protection and stream restoration projects shall be designed under the supervision of the State Hydraulics

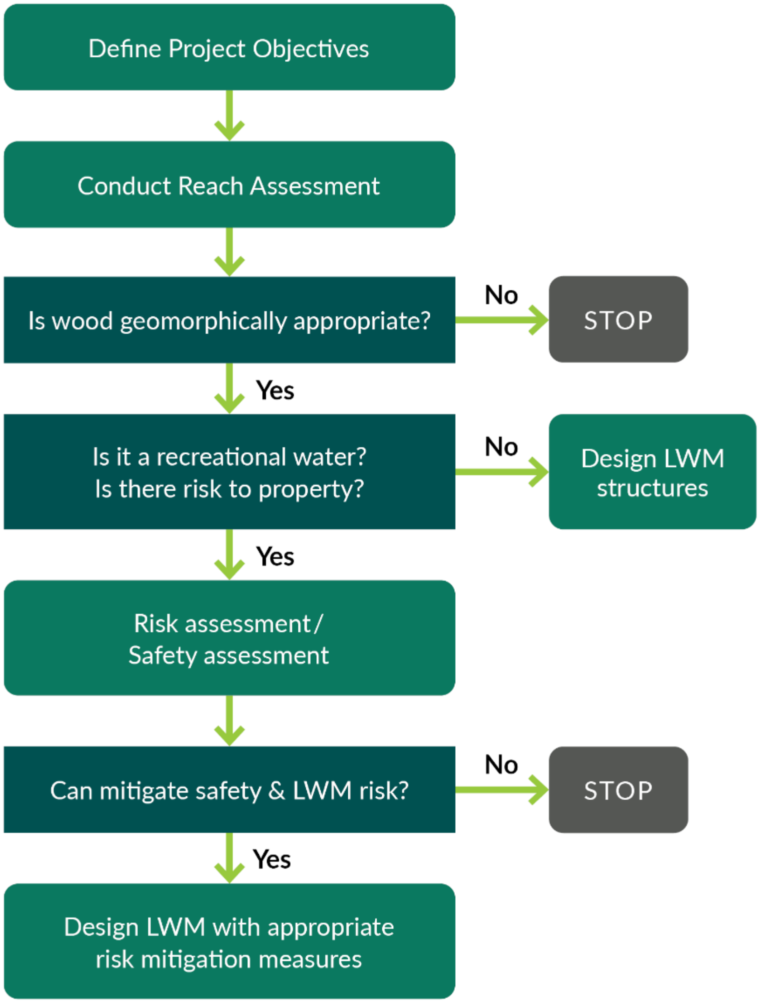
Office, as described in Chapter 1. Placement of all LWM, including MWM, below the 100-year flood elevation must be approved by the State Hydraulics Office.

10-2 Design Process

Design and placement of LWM structures shall follow a geomorphic and ecological assessment of the watershed and a similar, more detailed assessment of the river reach or site to be treated, including an analysis of existing conditions and anticipated responses related to stability. The following multi-step LWM design process is shown in Figure 10-1:

1. A reach assessment is prepared to describe the geomorphic and habitat conditions of the site, the constraints, and the existing LWM in the system and to determine that the use of LWM is suitable for the site conditions.
2. A recreational water safety assessment is made to identify potential risks to the public and to provide guidance to reduce potential risks.
3. The design-based project objectives are identified.
4. The design is created using general and project-specific design criteria.

Figure 10-1 LWM Design Process



10-3 Reach Assessments

A reach assessment is required for all in-water projects that change channel planform or cross-section (see Chapter 7). A reach assessment is a scalable report and, based on the conditions at a site, may range from a few paragraphs in the Hydraulic Design Report to a standalone report. The level of effort for the reach assessment will be determined by the State Hydraulics Office. Reach assessments provide important geomorphic and habitat information that is critical to the successful design of LWM projects.

A reach assessment should follow the ISPG outline (WDFW 2002) and characterize the project site conditions and the larger representative reach of the channel and the watershed. In addition to identifying problems at a site and possible solutions, the reach assessment should include the following:

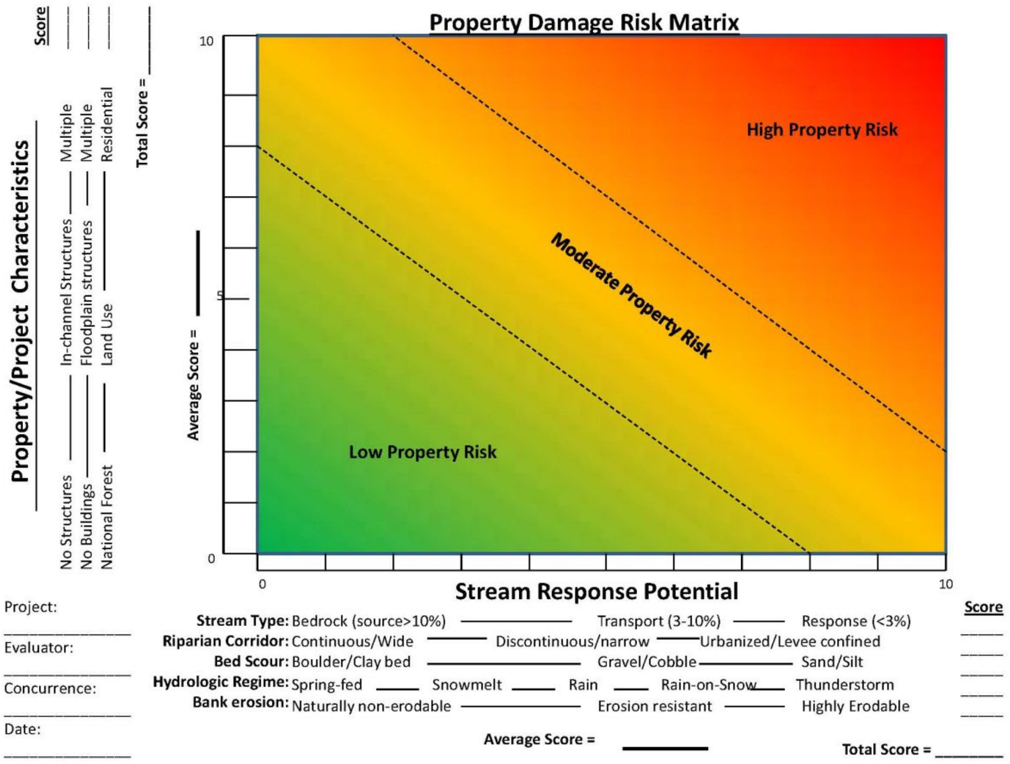
- A description of LWM found at the project site and within the representative reach including the LWM's likely sources and functions in the channel
- A discussion of the potential for LWM to be recruited: bank erosion, mass wasting, windthrow, etc.
- A discussion of the ability of the water course to transport LWM to the project site
- A description of adjacent and downstream property or infrastructure that could be affected by the project

The reach assessment should determine if the use of LWM is suited to the conditions at the project site. In addition, if LWM is proposed in the following locations (and if there is infrastructure or property in the downstream reach), a risk assessment must be completed:

- Channels that are subject to debris flows and other mass-wasting activity
- Locations within culverts or under bridges
- Alluvial streams with a gradient of more than 4 percent
- Non-alluvial streams with a gradient of more than 2 percent

The risk assessment should be included within the reach assessment. The risk assessment should characterize the risk of debris (sediment and recruited wood) and water affecting LWM structures and thus other infrastructure or property, and provide guidance for mitigating the risks. If the risks cannot be mitigated, then use of LWM is prohibited in the reach. USBR produced guidance on conducting risk assessments for LWM placement (USBR 2014). In this document, USBR presents a risk matrix, which is helpful in categorizing risk to infrastructure, even when risk cannot be quantified. This matrix is presented in Figure 10-2. USBR (2014) discusses how to fill out the inputs on the X axis (stream response potential) and the inputs on the Y axis (property/project characteristics). These inputs are combined to determine the property damage risk in the main field of the graph.

Figure 10-2 Property Damage Risk Matrix



NRCS's *National Engineering Handbook* (Technical Supplement 14J: Use of LWM for habitat and bank protection) provides additional discussion of the limitations on using LWM (NRCS 2010). The *National Large Wood Manual*, produced by USBR and ERDC (2016), provides additional discussion on projects involving woody material.

10-4 Recreational Waters Safety Assessment

Like a reach assessment, a recreational waters safety assessment is a scalable report that, based on the unique conditions at a site, may range from a few paragraphs in the Hydraulic Design Report to a standalone report. The assessment should identify the water body, likely recreational activities that could occur at the site or in the project reach, and risks or hazards that LWM may pose to recreational users and determine if LWM can be used with an acceptable level of risk. This type of assessment is often required by the Washington State Department of Natural Resources for aquatic land use permits and should include an inventory of nearby public access points, such as WDFW and USFS boating access sites. A review of regional paddling guidebooks will also help identify recreational water use. The American Whitewater Association (www.americanwhitewater.org) has a searchable database of recreational river runs.

The following types of water bodies are considered "recreational" by WSDOT for the purposes of this guidance:

- All rivers designated as "Wild and Scenic" rivers.

- All rivers and streams designated as navigational waters by the U.S. Coast Guard.
- All rivers and streams within state and national parks, national monuments, national recreation areas, and wilderness areas.
- Rivers, streams, and other water bodies known to local law enforcement, fire departments, and other river rescue organizations to receive heavy recreational (boating/swimming) use. These organizations can be very helpful in determining the degree of recreational use and relative hazard.
- All streams with a BFW greater than 30 feet.
- All rivers and streams designated as State-Owned Aquatic Land by the Washington State Department of Natural Resources (DNR).

LWM may present risks to recreational users and these risks should be considered in the assessment and later in the planning and design phases of project development. In general, for channels with recreational boating/floating activities:

- LWM placement in confined channels should be limited to grade control on the streambed and not structures obstructing flow.
- LWM structures shall not be placed where there is poor visibility from upstream.
- LWM structures shall not be put in channels that do not allow for circumnavigation.
- Larger LWM structures shall not be constructed downstream, or within 100 feet upstream, of boat ramps.

Basic engineering standards require consideration of safety and risk and, ultimately, design decisions regarding the use of LWM in recreational waters must be left to the State Hydraulics Office. The methods and assumptions used for the recreational water safety assessment analysis will be fully documented in the project's Hydraulic Design Report.

10-5 Project Objectives

A type of LWM structure or placement should be selected using similar criteria employed for selecting any approach for stream stabilization or habitat rehabilitation:

- LWM structure or placement should address the dominant erosion processes operating on the site.
- Key habitat deficiencies (e.g., lack of pools, cover, woody substrate) should be addressed.
- The completed project should function in harmony with the anticipated future geomorphic response of the reach (e.g., erosive reaches should incorporate the potential for erosion and consider increasing overburden or anchoring forces; transport reaches should evaluate the sediment balance within the reach and determine whether LWM would be beneficial to the sediment balance; depositional reaches should consider if accumulation rates will negatively impact the structure or encourage lateral channel migration, etc.).

- Risks to safety for recreational use of the completed project should be minimized.
- LWM shall not be placed in locations or orientations that could generate additional scour risks for structures or roadway embankments.

FHWA has published several references that can aid in the selection of appropriate structures for scour and bank protection: Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance (HEC-23 Volume 1 and Volume 2) and two companion documents—Evaluating Scour at Bridges (EC-188 and Stream Stability at Highway Structures ((HEC-20).

The Washington State aquatic guidelines Program has published the ISPG and *Stream Habitat Restoration Guidelines* (Cramer 2012), which provide more detailed guidance for using LWM. In addition, the NRCS's *National Engineering Handbook* (Technical Supplement 14J) (2007) and the *National Large Wood Manual* (USBR and ERDC 2016) provide similar discussion.

The balance of this chapter provides general design criteria that apply to all projects with LWM. In addition, Appendix 10A provides photographs and illustrations of LWM configurations as well as brief narratives on their applications and limitations.

10-6 General Design Criteria

The following sections provide design criteria that apply to all LWM projects. The criteria cover:

- Design life
- Wood selection
- Design flow
- Placement
- Stability and anchoring
- Scour
- FEMA floodplains and floodways

10-6.1 *Design Life*

One of the key elements in any project design is identifying the design life. Projects that include LWM are no different; however, LWM decays over time. The project objectives need to be considered when selecting LWM as a design element. LWM used to protect banks or to redirect flow to protect critical infrastructure are usually intended to be functional for an extended period. LWM used primarily for habitat may have a considerable shorter design life as it is anticipated that the riparian corridor will contribute LWM in the future. LWM can last indefinitely if it remains wet or is buried in substrate that is frequently saturated (e.g., streambanks).

LWM varies by species in its durability and decay-resistant properties. Decay is also linked directly to the size of wood used—the larger it is, the longer it will last. It is unlikely that deciduous wood would last for more than 10 years. Cottonwood and alder, even in the large sizes needed for installations along major rivers, are the most rapidly decaying tree species. While maple will also decay fairly quickly, it is more durable than the other deciduous tree species; water-saturated maple may last 10 to 20 years. For maximum longevity, it is best to use decay-resistant coniferous species whenever possible. Well-designed LWM structures can last 50 years or longer.

Of the conifers, hemlock is poorly suited because of its rapid decay rate. While very durable, Sitka spruce and western red cedar have low densities (i.e., are more buoyant) and require more anchoring than other softwoods.

Douglas fir has excellent durability, especially when maintained in a saturated condition; it is also the most abundant of the commercially managed softwoods. Douglas fir generally survives for at least 25 to 50 years. Such longevity puts this species within the normal estimates of the functional design lifetime expected for conventional riverbank stabilization installations (Johnson and Stypula 1993). Cedar has the most longevity of any Northwest species but is more susceptible to mechanical damage.

The longevity of any wood will be greatly enhanced if it remains fully saturated (i.e., waterlogged). The maximum decay rate occurs with alternate wetting and drying, or consistently damp condition, rather than full saturation. Logs that are buried or submerged in fresh water can last for decades or even centuries. Consequently, LWM structural elements should be placed as low as possible, preferably in locations where they remain submerged. This is also preferable for habitat logs.

10-6.2 *Wood Selection*

Both the strength and relative buoyancy of logs is determined chiefly by wood density. The physical characteristics of various tree species are presented in Table 10-1. The denser the wood used in the structure is, the more strength and resilience the structure has. Conifers are generally specified as preferable for use in LWM structures because of the following factors:

- Density and resultant strength
- Relative uniformity of trunk shape (which makes them easier to construct with than deciduous species)
- Large ratio between the trunk diameter at breast height (DBH) and rootwad diameter (roots are shallow and radiate from the stem)

Of the conifer species that occur and are readily available in the Pacific Northwest, Douglas fir has the highest density and the best geometric properties for LWM structures. Other conifers such as western red cedar and Sitka spruce have lower specific gravities and strengths (Table 10-1). These species can be used for cribbing structural members but used only as posts if large enough to exceed strength requirements. Deciduous species generally have lower densities and should only be used for non-structural elements of LWM structures. As described previously, the longevity of any wood will be greatly enhanced if it remains fully saturated (i.e., waterlogged). The stream designer should use species best suited for the project location and objectives. Table 10-1 shows physical characteristics of woods found in the Pacific Northwest.

Table 10-1 Physical Characteristics of Woods Found in the Pacific Northwest

Common Name	Genus	Species	Green Wood (moisture content ~ 30%)			Dry Wood (moisture content ~ 12%)		
			Specific Gravity[a]	Modulus of Rupture N/m^2	Modulus of Elasticity N/m^2	Specific Gravity[a]	Modulus of Rupture N/m^2	Modulus of Elasticity N/m^2
Subalpine fir	*Abies*	*lasiocarpa*	0.31	3.40E+07	7.20E+06	0.32	5.90E+07	8.90E+06
Western red cedar	*Thuja*	*plicata*	0.31	3.59E+07	6.50E+06	0.32	5.17E+07	7.70E+06
Black cottonwood	*Populus*	*trichocarpa*	0.31	3.40E+07	7.40E+06	0.35	5.90E+07	8.80E+06
Engelmann spruce	*Picea*	*engelmannii*	0.33	3.20E+07	7.10E+06	0.35	6.40E+07	8.90E+06
Grand fir	*Abies*	*grandis*	0.35	4.00E+07	8.60E+06	0.37	6.10E+07	1.08E+07
Sitka spruce	*Picea*	*sitchensis*	0.37	3.90E+07	7.40E+06	0.40	7.00E+07	1.08E+07
Ponderosa pine	*Pinus*	*ponderosa*	0.38	3.50E+07	6.90E+06	0.40	6.50E+07	8.90E+06
Red alder	*Alnus*	*rubra*	0.37	4.50E+07	8.10E+06	0.41	6.80E+07	9.50E+06
Silver fir	*Abies*	*amabilis*	0.40	4.40E+07	9.80E+06	0.43	7.30E+07	1.19E+07
Yellow cedar	*Chamaecyparis*	*nootkatensis*	0.42	4.40E+07	7.90E+06	0.44	7.70E+07	9.80E+06
Mountain hemlock	*Tsuga*	*mertensiana*	0.42	4.30E+07	7.20E+06	0.45	7.90E+07	9.20E+06
Western hemlock	*Tsuga*	*heterophylla*	0.42	4.60E+07	9.00E+06	0.45	7.80E+07	1.13E+07
Bigleaf maple	*Acer*	*macrophyllu*	0.44	5.10E+07	7.60E+06	0.48	7.40E+07	1.00E+07
Douglas fir	*Pseudotsuga*	*menziesii*	0.45	5.30E+07	1.08E+07	0.48	8.50E+07	1.34E+07

Notes:

N/m^2 = newton per square meter.

a. Specific gravity computed from oven-dry weight (0% moisture) and volume at 12% moisture content.

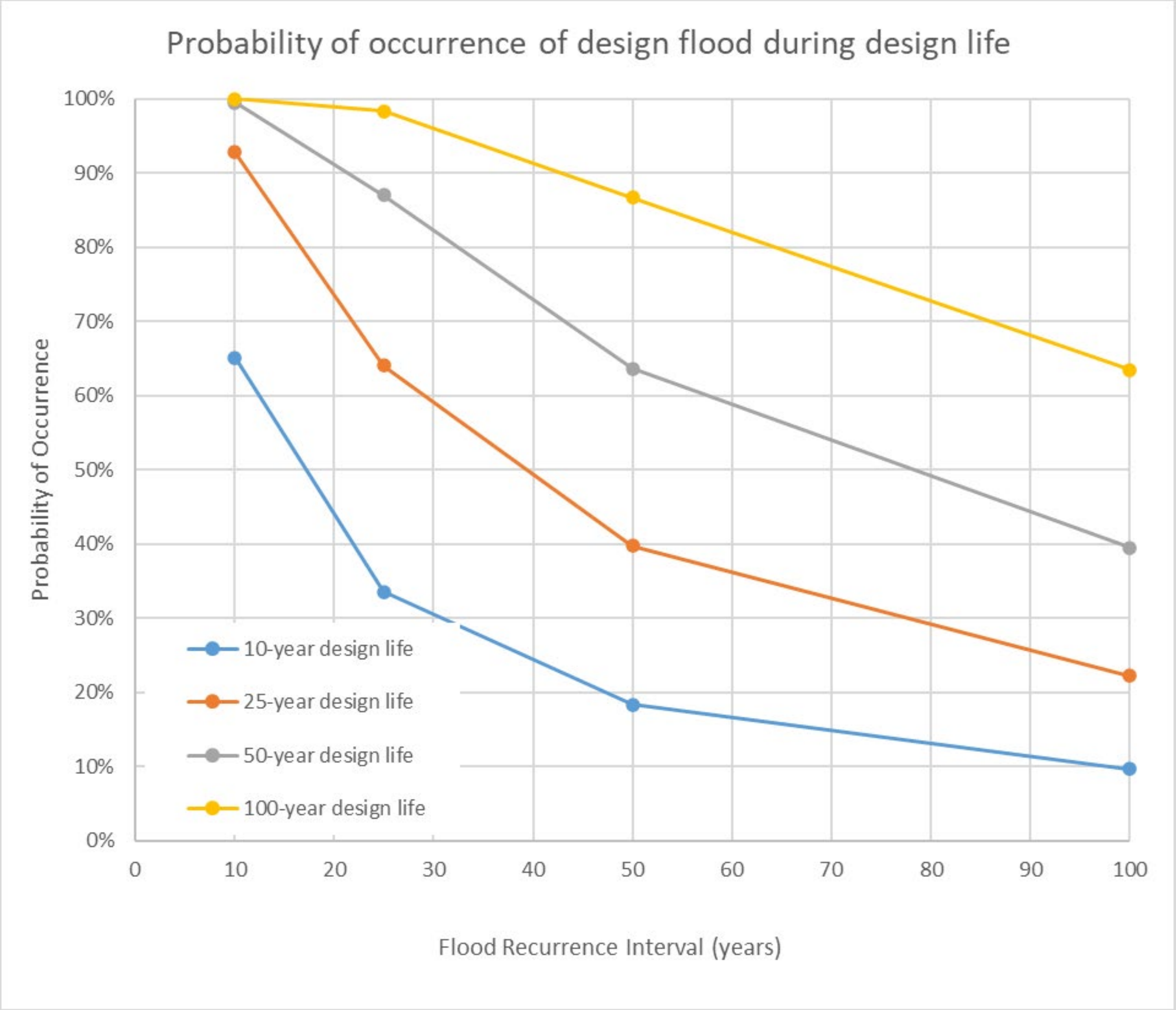
10-6.3 *Design Flow*

When designing LWM placement, several factors must be considered. Because most LWM bank stabilization and flow-directing structures are intended to function over a long project design life (50 years or longer), design flows equivalent to the 100-year discharge must be used to estimate depth and channel velocity to estimate buoyancy and drag loads to ensure that they do not become mobilized during extreme floods to the detriment of the project or other facilities. However, wood for habitat should be placed in the channel to interact with water at low flow conditions.

Although LWM for habitat projects may have a shorter design life, to reduce risks to WSDOT and other infrastructure and property, the 100-year discharge shall be used for stability. Climate resilience should also be considered as current science suggests that both the magnitude and frequency of peak flows are expected to increase (WDFW 2016) and therefore, the 2080 projected 100-year discharge evaluation shall be discussed with the State Hydraulics Office for inclusion in this application. The mean annual discharge or more frequent flows should be considered for the purpose of placing LWM in the channel so that it regularly interacts with the low-flow channel to enhance or create habitat. Mobile woody material (MWM; see Section 10-8) may use a lower recurrence interval design flow, based on habitat and stream restoration objectives.

Figure 10-3 shows that for a project design life, a design flow of the same recurrence has about a 63 percent chance of occurring during the project life, regardless of the flow. It also shows that the likelihood of a project experiencing a design flood increases somewhat as the recurrence interval increases.

Figure 10-3 Design Flow Risks Occurring during Project Life



Note:
Probability of a single exceedance over design life: P = 1 - (1 - 1/RI)^N

As described in Chapter 2, design flows can be determined from gage data (preferred), regional regression analyses, or hydrologic models (e.g., MGSFlood). The USGS StreamStats website has links to gage- and regression-based flow data.

10-6.4 *Placement*

Aspects of LWM placement include orientation, dip angle, and spacing. When the function of LWM is primarily for habitat benefit, placement should emulate natural LWM recruitment style and process, subject to the constraints of the site and stability requirements.

The weight of the log on the bank increases stability and reduces downstream movement. In addition, one or more logs can be placed on top of another, so the weight of the top log pins the lower log. Complex placements with multiple logs with interlocking pieces of wood provide better habitat and mimic wood accumulation (log jams) over time.

Channel migration in alluvial stream valleys is the principal mechanism of wood recruitment to channels. Numerous studies have shown that erosion rates in areas with mature timber are half or lower those of the rate in areas with small trees or pasture (Abbe and Brooks 2011; USBR and USACE 2016). LWM can be a significant factor in reducing erosion rates, though isolated key pieces can locally increase rates. Log jams can also trigger channel avulsions, which can then result in large inputs of LWM. ELJ projects have been proved effective in limiting channel migration and in improving channel alignment at bridge crossings.

10-6.5 *Stability and Anchoring*

A force balance analysis will identify the potential for incipient motion of LWM. The ultimate mobility of the wood will then depend on the stream's ability to transport the wood based on flow depth and power and riparian features such as established trees that will resist wood transport (mobility resistance).

10-6.5.1 Incipient Motion

LWM is subjected to a combination of hydrodynamic, frictional, and gravitational forces that act either on the LWM or on its anchors. The principal forces are listed below:

- Vertical buoyancy force acting on the LWM and transferred to its anchors
- Horizontal fluid drag force acting on the LWM and transferred to the anchors
- Horizontal fluid drag force acting directly on the anchors
- Vertical lift force acting directly on the anchors
- Immersed weight of the anchor (if boulders are used as anchors)
- Frictional forces at the base of the anchor that resist sliding (if boulders are used as anchors) or being pulled out (if posts or pilings are used as anchors)

At a site where the objective is primarily habitat enhancement, it is preferable to not have artificial anchors for LWM, but this must be carefully considered. LWM can, if sized and positioned correctly, be "self-ballasting" during the design flow. This means that enough mass of the wood is above water to counteract the buoyant and drag forces of the wood below water. In addition, a mobility analysis/risk analysis (see below) should be conducted to show that the wood, if mobilized, would not move a significant distance, and/or that there is little or no risk to property or infrastructure downstream.

When using soil ballast, consideration shall be given such that the overall bank material is stable in the vicinity of the structures so that the ballast material can be relied upon for the intended design life.

There are numerous techniques for anchoring LWM. In order of preference, below are some commonly used anchoring techniques:

- Natural existing vegetation

- Self-ballasting
- Wood ballast
- Soil ballast
- Wood piles/racking
- Boulder ballast
- Boulder anchors
- Dolosse-timber or log jacks
- Deadman anchors

LWM can be attached to anchors primarily with steel cable for WSDOT projects. However, other attachment applications include steel chain, rebar pins, or threaded bolts and nuts. The fewer components that are in the anchoring system, the better to minimize failure points. USBR (2014) provides extensive guidance on and examples of anchoring systems.

Wherever possible, redundant anchoring systems should be used. Examples of this include combining pilings or anchors with bank overburden partially burying the LWM in the bank. Anchoring systems should be designed with an appropriate FOS to account for uncertainty and risk, where the FOS is defined as the ratio of the resisting forces divided by the driving forces. WSDOT generally uses FOSs of 1.5, higher if there is greater uncertainty in force balance calculations and if the wood mobility could pose a high threat to infrastructure. The 100-year discharge or 2080 projected 100-year discharge is used as the design flow. More frequent design flows may be used if the wood function is primarily for habitat. All LWM including MWM placement below the 100-year flood elevation must be approved by the State Hydraulics Office.

USBR (2014) has developed guidance on selecting FOSs to use for each of the forces described previously (*Large Woody Material—Risk Based Design Guidelines*) that considers the risks to public safety and property damage. A design that proposes FOSs less than 1.5 shall be approved by the State Hydraulics Office.

Numerous guidance documents deal with the stability analysis equations for estimating these forces. A description of applicable equations and their use can be found in NRCS (2007) and D'Aoust's *Large Woody Debris Fish Habitat Structure Performance and Ballasting Requirements* (1991). More recently, USFS has published the *Computational Design Tool for Evaluating the Stability of Large Wood Structures* (Rafferty 2016), which is the accepted reference for such calculations. Other methods may be acceptable upon review by the State Hydraulics Office.

The buoyancy force FOS calculation is based on Equation 10-1 below.

$$FOS_{buoyancy} = F_D/F_U \tag{10-1}$$

where:

F_D = total downward force F_U = total upward force

and where:

$F_D = W_O + W_{anchor}$

and:

W_O = weight of overburden W_{anchor} = weight of anchor

and where:

$F_U = B_{root} + Bbole$

and:

B_{root} = buoyancy of rootwad B_{bole} = buoyancy of log bole

Appendix 10A contains the parameters and equations for calculating weight and buoyancy of the objects in an LWM structure. Note that this is just a framework and that the specific design of a structure may necessitate inclusion of calculations for logs that interact with each other (e.g., a structure with a footer log and a rack log). More complex structures will require multiple interrelated FOS calculations.

The FOS_{drag} (same as USBR's $FOS_{sliding}$), is based on Equation 10-2 below.

$$FOS_{drag} = F_f/F_{Dr} \tag{10-2}$$

where:

F_f = total friction force F_{dr} = total drag force

and where:

$F_f = -(F_D - F_U)*C_{rl}$ riverbed-log friction coefficient

and:

C_{rl} = riverbed-log friction coefficient

and where:

$F_{Dr} = C_{dr}(y/g)*(v){}^{\wedge 2}*(A_{rtwd}){}^{\wedge 0.5}$

and:

C_{dr} = unitless drag

coefficient y = specific

weight of water

g = gravitational

acceleration v =

computed water

velocity

A_{rtwd} = projected area of rootwad

Moment force is not a concern for LWM structures in Washington streams because the structures are usually long in the direction of flow, narrow in the direction perpendicular to flow, and not very tall (USBR 2014). Nonetheless, the LWM spreadsheet tool calculates the moment forces. See Appendix 10A for more information. The methods and assumptions used for stability analysis will be fully documented in the project's Hydraulic Design Report.

10-6.5.2 Mobility Analysis

By default, the risk associated with movement is equated with incipient motion—essentially equating failure with any movement of placed wood. However, there are cases when considering the risk of LWM mobility, once moved, can help achieve project objectives. This is primarily when the project objective is exclusively habitat restoration or enhancement. Many natural stream corridors also have riparian trees and other features that may resist transporting wood downstream, especially in smaller streams where the wood is large relative to the flow depth.

In such cases, an LWM mobility analysis may be conducted that assesses the likelihood of LWM movement in a stream reach as well as the potential impact to property and infrastructure. Currently there is no well-established methodology for conducting such an analysis, but certain references may be helpful (Braudrick and Grant 2000; Kramer and Wohl 2016; Ruiz-Villanueva et al. 2016). The State Hydraulics Office will review and approve any mobility analysis. It is helpful to contact the State Hydraulics Office before beginning the mobility analysis work.

10-6.6 *Scour*

Scour is the principal failure mechanism of many instream structures, such as bridge piers, abutments, rock revetments, levees, and floodwalls. It is also a primary threat to LWM structures, from simple log weirs to large ELJs. Scour at LWM placements creates important habitat features but can also cause undesirable movement or destabilization of logs and/or streambanks. LWM placements must be designed to accommodate anticipated scour conditions, including long-term degradation, particularly if the LWM is for streambed stability objectives. The destabilizing effects of scour can be minimized by substantial embedment of rack logs in the streambank; this can be done in a way that ensures continued engagement of the wood with low flows. LWM shall be located so that it does not create scour that could undermine bridge members (e.g., piers, abutments) or road embankments. Bioengineering techniques should be considered whenever the bank opposite the LWM is made of fill or is unconsolidated natural material, and the LWM is expected to direct flow toward the opposite bank.

Reliable methods for estimating scour at LWM placements have not yet been developed in either the engineering or scientific communities. In some cases, equations developed for bridge piers and abutments have been used to predict scour, but these are overly conservative for gravel bed streams found in much of Washington and may not accurately represent the unique geometry of LWM. Scour analysis for LWM projects will therefore often rely heavily on engineering judgment and lessons learned from practical experience. It is always worthwhile to measure residual pool depths (the difference in depth or bed elevation between a pool and the downstream riffle crest) in a project reach to get minimum estimates (during flood flows these pools may deepen). The methods and assumptions used for this analysis will be fully documented in the project's Hydraulic Design Report. Additional guidance may be found in Chapter 6 of the *National Large Wood Manual* (USBR 2016). This document also cites the following references as being useful for specific situations:

- Empirical formulas for scour: WDFW (2012), Arneson et al. (2012), Shields (2007)
- Scour analysis applied to LWM: Brooks et al. (2006), Abbe and Brooks (2011)
- Scour computations for engineered log jams: Drury (1999)

10-6.7 *FEMA Floodplain and Floodways*

See Chapter 7 for information on flood risk assessment and analysis. See the WSDOT *Environmental Manual* for information on FEMA Floodplain permits.

10-6.8 *Recreational Safety in Navigable Waters*

It is recognized that river recreation, including swimming, boating, and fishing, carries varying degrees of risk. The level of risk is influenced by many factors, including the person's level of experience, skill, and judgment; conditions in the watercourse, such as depth, turbulence, velocity, temperature, and bank form (steep banks or beach); and instream elements, such as LWM.

Given that the planning-level recreational waters safety assessment (Section 10-4) indicated that LWM would be an acceptable risk, LWM may still present residual risks to recreational users and these risks should be considered in design:

- LWM structures shall not be constructed in confined channels except as grade control on the streambed and not obstructing the channel.
- LWM structures shall be placed where there is good visibility from upstream (50 feet or three BFWs, whichever is larger).
- LWM structures shall not be put in channels that do not allow for circumnavigation. Locations that include features such as gravel bars allow recreational users to land, walk around, and avoid the LWM structures.
- Larger LWM structures, such as ELJs, shall not be placed on the outside of a meander bend where the curve ("tortuosity") of the bend is less than 3 using the formula Rc/W<3, where Rc is the radius of the meander curve, and W is the BFW in the upstream riffle.
- Larger LWM structures shall not be constructed in close proximity downstream from boat ramps (100 feet or three BFWs, whichever is larger).
- Signage should be addressed on a case-by-case basis, particularly where upstream visibility is limited because of meandering channels, etc.

In addition to the safety considerations regarding placement of LWM structures, LWM structures should be designed to limit flow-through characteristics by including an impermeable core to prevent "straining." Straining is a phenomenon by which swift water flowing through an LWM structure tends to draw floating objects toward and into it. The denser the core of the structure is, the less this tends to occur.

At sites with heavy recreational use, public notification and involvement may be desired to minimize the risks of LWM structures. Public notification should be handled on a case-by-case basis depending on the size and complexity of the project and the degree of public use of the water body. The public involvement procedures under the National Environmental Policy Act and State Environmental Policy Act should be used as the primary mechanism for informing the public about WSDOT LWM projects.

Guidance for these processes can be found in the *Environmental Manual*, Chapter 400. Additional guidance for public involvement can be found in WSDOT's *Design Manual*.

10-7 Project-Specific Design Criteria

This section presents project-specific design criteria and design references for bridge scour and bank stabilization, stream habitat restoration, and habitat design.

10-7.1 *Bridge Scour and Bank Stabilization*

Placing wood in the vicinity of or underneath structures generates a high probability of risk and impacts to the structure and approaching roadway and has a high probability of requiring future maintenance or emergency repairs.

Public safety concerns for recreational users also pose additional risk in utilization of LWM. This is particularly true with regard to bridges for the following three reasons:

- Loading of LWM on bridge piers can place immense force against the structure that can increase the likelihood of damage or failure. If a bridge is also experiencing scour problems, then these risks can mutually reinforce the effects, dramatically increasing the threat to the structure and the safety of the traveling public.
- Bridges often present preexisting obstructions to flow (such as piers, abutments, etc.), that affect various aspects of flow and sediment dynamics including velocity, flow direction, and backwater effects.
- Bridges located at the intersections of highways and rivers, and highways adjacent to rivers often present the easiest way for the public to access the river for boat launches, fishing and swimming access, trails, etc. The public is naturally drawn to these highway/river interfaces; therefore, public safety concerns are heightened.

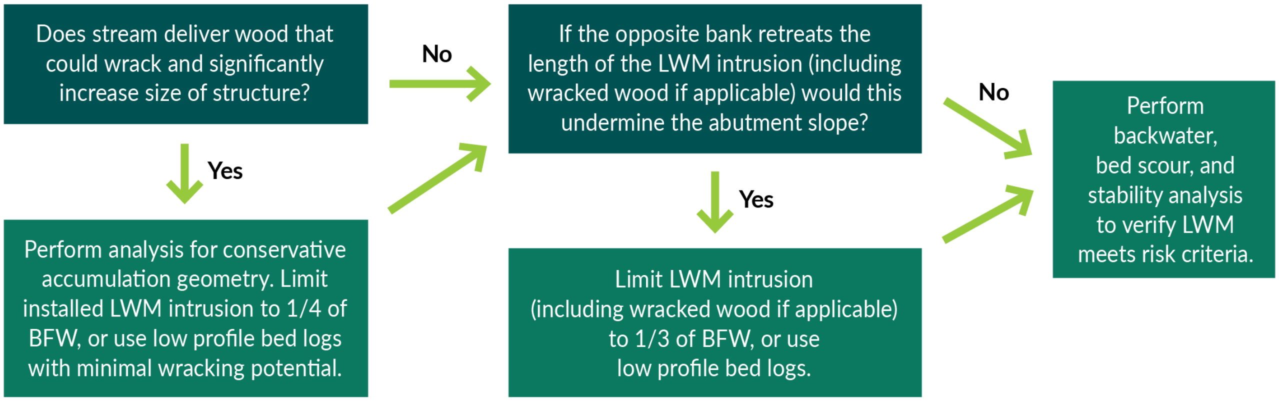
Figure 10-4 shows a decision tree for consideration of LWM under or adjacent to bridges.

Figure 10-4 Decision Tree for Consideration of LWM under or adjacent to Bridges

ALL LWM DESIGNS UNDER BRIDGES SHALL ADDRESS THE FOLLOWING RISKS:

- **Undermining of abutment slopes:** See decision tree below for allowable LWM intrusion into channel.
- **Backwater:** Demonstrate adequate freeboard with a hydraulic model that reflects obstructive effects of LWM.
- **Bed scour:** Foundations should be deep enough to accommodate increased bed scour. This will typically be only a few feet for single logs in gravel beds, but will be much more significant in sand beds or with wracked structures.
- **Stability:** Minimum factor of safety of 2 for buoyant and drag forces.

DECISION TREE FOR ALLOWABLE LWM GEOMETRY TO AVOID BRIDGE ABUTMENT EROSION:



To ensure adequate public safety and the stability of ELJ and other LWM structures for projects, it must be emphasized that the design shall be coordinated through the State Hydraulics Office. The project objective, and the surrounding infrastructure, shall be considered. Where LWM is to be incorporated into bank stability design, the decay and degradation of the wood over time shall be considered. Where needed, bank stabilization measures should contain redundancies (such as traditional “hard” structural measures). LWM shall be placed outside of any scour countermeasure footprint. LWM shall be placed such that it does not conflict with the scour policies presented in the *Bridge Design Manual*, nor with Chapter 7 of this *Hydraulics Manual*.

Appendix 10A provides photographs and brief narratives of various types of LWM installations. While the primary intent of the appendix is as a guideline for siting and structure design, it may also help define parameters for permit conditions and for carrying out due diligence with regard to public safety concerns expressed by some recreational river users. In addition, resources such as the ISPG and HEC-23 Volume 1 and Volume 2 are available to help guide selection of appropriate bridge scour and bank instability countermeasures.

10-7.2 *Stream Habitat Restoration*

WSDOT performs stream habitat restoration to reconstruct stream corridors through new water crossings. Stream habitat restoration may also occur in road widening or realignment projects or as an element of wetland or aquatic habitat mitigation projects. Permitting agencies will often require WSDOT to incorporate LWM into these projects as sustainable habitat features. These features increase channel complexity and diversity of habitat necessary to support a healthy aquatic ecosystem.

The concept of stream restoration refers to returning degraded ecosystems to a more stable, healthier condition. In some systems this includes allowance for processes such as channel migration. All crossing designs should not consider just flow conveyance, but also the passage of sediment and wood. Many streams have been severely impacted by land clearing and urbanization, resulting in changes to their hydrologic and sediment regimes, loss of streambank vegetation, and channel alterations. Restoration upstream of crossings can help to reduce risks by capturing mobile wood that might otherwise cause blockages. Restoration also can be instrumental in preventing channel incision through a new crossing.

Stream restoration activities include the following:

- Constructing channels with the appropriate planform, grade, width, and depth, and channel substrate, as discussed in Chapter 4 and Chapter 7
- Constructing overbank and floodplain areas, where appropriate
- Stabilizing the channel banks and disturbed floodplain and upland areas with revegetation and bioengineering according to WSDOT's *Roadside Manual*

LWM provides habitat and geomorphic functions, including "key pieces" and non-key pieces. Key pieces are logs that are large enough to persist and influence hydraulics and bed topography in a stream through a wide range of flow conditions. Non-key pieces are other pieces of LWM that provide habitat functions in addition to key pieces, but are smaller, and thus not as persistent in the aquatic environment. Both key and non-key pieces provide the following functions, either directly or indirectly:

- Creation of stable obstructions that capture organic debris and form log jams
- Pool formation
- Eddy creation and flow complexity
- Deposition of finer sediments to create substrate diversity
- Enhance hyporheic flow by locally increasing hydraulic head
- Cover for aquatic organisms
- Woody substrate for invertebrates and other aquatic species
- Accumulation of mobile wood and other organic debris
- Help activate side channels with flood flows

WSDOT may install LWM to provide these functions where infrastructure or land use limits natural delivery of LWM, or where replanted riparian zones are not expected to deliver LWM for many decades. Note that all vegetation to be cleared on a site must be evaluated for use for habitat purposes and so used if determined to be acceptable quality.

Reconstructed channels near WSDOT infrastructure require a level of predictability that will often limit the ability to place wood in a fully natural manner. In these cases, wood will be placed with anchoring systems that emulate natural key piece functions while limiting wood movement and hydraulic effects that would threaten public safety, infrastructure, or other resources.

LWM can enhance stream stability by dissipating energy, reducing basal shear stress, deflecting erosive forces, and encouraging deposition of bed material. LWM may also be strategically placed to improve stability and facilitate establishment of the designed channel banks and bed. All LWM, including MWM placement below the 100-year flood elevation, must be approved by the State Hydraulics Office.

10-7.3 *Habitat Design Process*

The LWM habitat design process is multi-stepped. Assuming that a reach assessment and the recreational water safety assessments indicate that LWM is suitable for a project site, the next steps are listed below:

1. Determine the BFW, depth, and gradient, as described in Chapter 7
2. Identify the characteristics of LWM
3. Identify the quantity of LWM
4. Configure the key and non-key LWM pieces and determine the use of small wood and slash

BFW is a determining factor in identifying the size and number of LWM pieces that should be used. As described in Chapter 7, WDFW's WCDG (Appendix C) describes in detail the procedures for determining BFW.

The following sections provide narratives of LWM characteristics, quantities, and configurations.

10-7.3.1 LWM Characteristics

Key pieces must be logs with sufficient structural integrity to resist decay, abrasion, and breakage. Although conifers are strongly preferred because of their higher resistance to decay, deciduous species may be considered if they naturally act as key pieces in the riparian community in the project area. All key pieces are required to include the rootwad. Rootwads significantly improve the stability and habitat benefits of key pieces (e.g., Abbe and Montgomery 1996; Abbe and Brooks 2011). Rootwads for key and non-key LWM pieces shall not be cut or broken off. Logs should arrive at the staging area with the rootwad fully intact.

The size of key pieces shall be sufficient to provide the mass needed for persistence and habitat formation. This is achieved by matching the key piece volume targets, described below.

Non-key pieces of LWM are important to meeting overall LWM targets (discussed below). These pieces should have rootwads, as it is generally better habitat and promotes more stability. However, logs without rootwads may be appropriate. Like key pieces, these LWM pieces should also be structurally intact, with as much bark retained as practicable. For both key and non-key pieces, conifer species are preferred, because they do not decay as quickly as deciduous species. It is also critical to the habitat objective that stream restoration include the use of slash and small wood, especially within the LWM structures.

10-7.3.2 LWM Targets

For WSDOT projects involving regrading or realignment of stream channels, LWM targets apply. These targets are adopted from the recommendations in Fox and Bolton (2007). It should be emphasized that being targets, they are goals or a baseline, and as such are subject to specific site constraints and considerations. Differences between baseline or target and the proposed wood layout shall be justified based on specific site constraints and considerations and documented in the PHD/final hydraulic design (FHD) report.

Fox and Bolton (2007) measured several parameters of wood in streams of various widths and in various environments. Because this is the most detailed study of LWM in Washington, the *Hydraulics Manual* uses it as a reference. Additionally, when LWM is being used to emulate habitat functions in a newly created reach of stream, the 75th percentile of four key metrics found by Fox and Bolton (2007) is the target. This was identified by the authors of that study to compensate for cumulative deficits of wood loading due to development. The four metrics are:

- Key piece volume
- Key piece density
- Total number of LWM pieces (key and non-key)
- Total volume of LWM (key and non-key)

Table 10-2 shows the LWM targets for each of the four metrics, by BFW, and forest zone of the categories of streams. A "log metrics calculator," a spreadsheet tool supplied by the State Hydraulics Office, is available and shall be used to design LWM that meets these targets.

To account for portions of the channel where infrastructure limits LWM placement (e.g., under a bridge or in a culvert), a higher density may be needed in some channel segments to achieve the target density for the entire restored segment.

Density targets assume that the LWM will be engaged with instream flows so that it functions to create habitat such as pools, low-velocity refugia, cover, capture sediment, or sediment retention. To best achieve these functions, LWM should be placed within the low-flow channel.

Table 10-2 Large Wood Target Metrics

KEY PIECE VOLUME		KEY PIECE DENSITY			TOTAL LWM VOLUME			TOTAL PIECES OF LWM		
BFW class (ft)	volume (yd3)	**Forest zone**	BFW class (feet)	75th percentile (per/ft stream)	**Forest zone**	BFW class (feet)	75th percentile (yd3/ft stream)	**Forest zone**	BFW class (feet)	75th percentile (yd3/ft stream)
0-16	1.31	**Western WA**	0-33	0.0335	**Western WA**	0-98	0.3948	**Western WA**	0-20	0.1159
17-33	3.28		34-328	0.0122		99-328	1.2641		21-98	0.1921
									99-328	0.6341
34-49	7.86	**Alpine**	0-49	0.0122	**Alpine**	0-10	0.0399	**Alpine**	0-10	0.0854
50-66	11.79		50-164	0.0030		11-164	0.1196		11-98	0.1707
									99-164	0.1921
67-98	12.77	**Douglas Fir/Pond. Pine (much of eastern WA)**	0-98	0.0061	**Douglas Fir/Pond. Pine**	0-98	0.0598	**Douglas Fir/Pond. Pine**	0-20	0.0884
									21-98	0.1067
99-164	13.76									
165-328	14.08									

Using the BFW, the LWM designer first selects the corresponding 75th percentile key piece volume, then the 75th percentile key piece density, and 75th percentile total LWM volume. When using the log metrics calculator, when BFW, length of regrade, and forest zone are entered, the target metrics for the project reach are automatically calculated.

When the LWM targets are determined, the LWM designer then enters log dimensions (midpoint diameter and length) and number for each log type, and adjusts as needed to meet the LWM targets. The log metrics calculator helps the designer quickly determine target numbers and easily adjust log dimensions to meet the LWM targets while also designing for specific project configuration. Contact the State Hydraulics Office for additional or updated guidance.

10-7.3.3 Configuration

The configuration of LWM will depend on the project objectives. Configuration of LWM for bank protection is different from that for aquatic or floodplain habitat enhancement. To provide the best certainty for fish habitat, natural configurations and spatial organizations known to foster adaptations by salmonids shall be mimicked. For example, see Fox (2003) and Abbe and Montgomery (1996).

WSDOT expects a diversity of wood sizes, orientations, and elevations. Wood can be placed in single logs or multiple-log groupings, depending on habitat or stabilization objectives.

Many LWM structures are gravity-based, meaning that they rely on the weight of the structures and overburden to remain stable. Structures can also be stabilized using vertical elements such as driven piles or excavated vertical and batter (inclined) posts (Abbe and Brooks 2011). These structures rely on passive earth pressure and skin friction acting on vertical timbers. These structures can also include horizontal elements such as beams or cribbing. Cable can be used to secure horizontal logs to structural piles or posts. Large and complex LWM designs are generally better suited to larger streams (greater than 30 feet BFW). This includes structures such as high crib walls, flow deflection jams, apex bar jams, and dolotimbers (concrete dolo and timber assemblage (Abbe and Brooks 2011).

10-7.3.3.1 Large Woody Material for Bank Stabilization/Protection

In most water-crossing projects, there is a need to protect newly constructed streambanks composed of unconsolidated fill, until revegetation provides enough root strength. Logs with rootwads still attached can be used to absorb energy from high flows, break up turbulence, and deflect momentum of the water away from the streambank. The size of wood, elevation of placement, angle of placement, and height of structure are all site-specific elements that depend on channel geometry and anticipated depth and shear stress of the design flow.

Numerous guidance documents are available to assist in determining configuration of LWM for streambank stabilization. These include the ISPG (WDFW 2002), NRCS (2007), and USBR and ERDC (2016). Some examples of configuration can be seen in Appendix 10A.

10-7.3.3.2 Large Woody Material for Aquatic Habitat Enhancement

Before laying out the LWM design for aquatic habitat enhancement, it is important to have some understanding of the species that use the stream and what habitat features the design will provide. The stream designer needs to know what kind of fish and habitat is needed and how the channel has been impacted by the loss of functional wood. For example, many channels experience incision or downcutting after wood is removed, which can impact water crossings. Therefore, restoring functional wood is not simply just for habitat, but can be important in protecting infrastructure. The stream designer should seek the input of a habitat biologist and, if possible, a fisheries biologist. The stream designer should consider the following:

1. Is the stream fish bearing?

   The Washington State Department of Natural Resources Forest Practices Application Mapping Tool identifies fish-bearing streams. It is helpful to determine fish species in the reach because different species have different habitat preferences or needs. The WDFW SalmonScape web mapping tool identifies the presence of various salmonid species.

2. What is the habitat-limiting factor that the project would address?

   Common limiting factors in Washington's waterways include water quality (temperature, sediment), stream flow, instream structure and complexity, pool size and/or frequency, spawning habitat, overwinter habitat, rearing habitat, and interaction with floodplain. Assessments identifying the limiting factors for a stream or basin have been completed for about half of Washington's watersheds in accordance with the 1998 Washington State Watershed Management Act. Links to studies and reports for each WRIA can be found at Ecology's website.

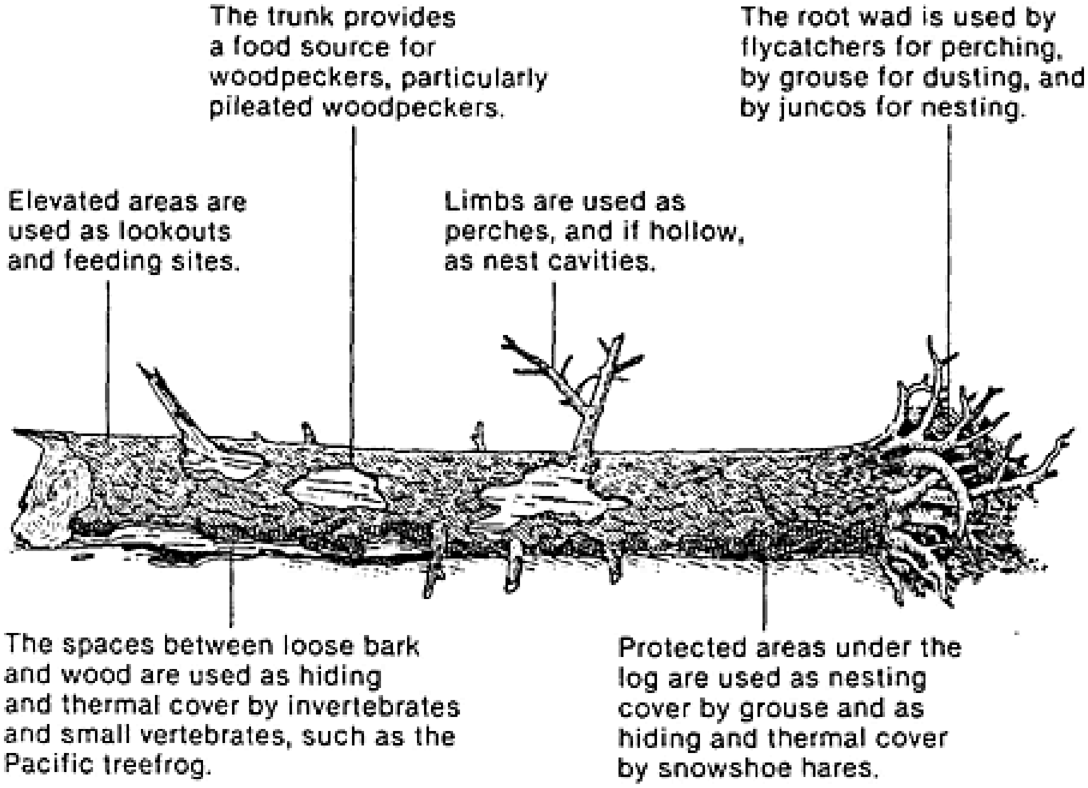
Knowing the species life history and habitat needs, as well as an understanding of the stream system, helps to identify an appropriate LWM configuration. For example, LWM located at the outer limits of the bankfull channel may provide high flow refuge but provide little rearing habitat or summer thermal refugia as it may be well away from the active low-flow channel. Conversely, LWM placements low in the channel to enhance low-flow habitat values may not provide high-flow refuge.

Logs with rootwads can offer more habitat function than those without. The roots create excellent hiding habitat for juvenile fish. The roots also add to the stability of the structure by maintaining contact with the stream bottom over a wider range of stream flows. LWM for habitat must be engaged at all flow levels, wherever possible. A habitat biologist should be consulted to help maximize habitat value of placed LWM.

10-7.3.3.3 Large Woody Material for Floodplain and Wetland (Low Energy) Environments

Dead and down woody materials are important components of wildlife habitats in western forests (Figure 10-5). These materials furnish cover and serve as sites for feeding, reproducing, and resting for many wildlife species. LWM can be placed in low-energy aquatic environments such as wetlands and floodplain fringes where flooding is so shallow and slow moving that the LWM cannot be mobilized. Figure 10-5 shows habitat benefits of LWM in low-energy environments.

Figure 10-5 Habitat Benefits of LWM in Low-Energy Environments



10-7.3.3.4 Large Woody Material for Grade Control and Forced Aggradation

Many WSDOT stream crossings were not originally designed with fish passage or sediment transport in mind. As a result, in the process of either correcting passage barriers or restoring sediment transport capacity, designers may be faced with incision potential following reconstruction. Use of wood for grade control is one tool that could be considered and is therefore described briefly here. Additional references include Abbe 2000, Abbe and Brooks 2011, Micheli et al. 2004, and Abbe et al. 2019.

The following points describe the considerations in design of LWM grade control:

- Grade-controlling wood in small channels (less than 60 feet):
    - Wood should be angled into the streambed and avoid level logs crossing the channel.
    - Logs shall be placed in a way that does not impact fish passage.
    - Multiple logs should be used to define low-flow pathways and dissipate energy.
    - Logs should extend into the streambed and up through high flow water column (both multiple layers and by vertical angles of the logs.
- Grade-controlling wood in large channels (greater than 60 feet):
    - Channel-spanning wood should be considered for incising channels. This would consist of an interlocking assemblage of multiple low-profile structures in the

  stream (examples from South Fork Nooksack and South Prairie Creek).
  - Wood structures should obstruct a large portion of the bankfull channel (approximately 50 percent).
  - Structures should be placed across the active channel migration zone with spacing of approximately 1/2–2/3 the active BFW.
  - Structures should be embedded at or below the total scour elevation unless they have a “self-settling” design. They should not extend higher than bankfull elevation.
- Bank treatments should include a complex assemblage of multiple logs to maximize roughness.

Figure 10-6 provides an example of small-channel complex log grade control. Figure 10-7 provides an example of grade-control wood used in conjunction with rock. Figure 10-8 provides an example of large-channel wood grade control.

Figure 10-6 Example of Small-Channel Complex Log Grade Control

Image taken from a project in the Little River, Clallam County. The structure consists of up to five layers of logs at different vertical and horizontal angles over a 50-foot length of channel. The structure raised the streambed 3 to 4 feet and aggraded the channel upstream.

Figure 10-7 Example of Grade-Control Wood Used in Conjunction with Rock

Image taken from a project in Centennial Creek, Snohomish County. This was a fish passage barrier correction.

Figure 10-8 Example of Large-Channel Wood Grade Control

Image taken from a project in South Prairie Creek, Pierce County. Interlocking assemblage of rock-ballasted log structures raise the creek bed by more than 4 feet.

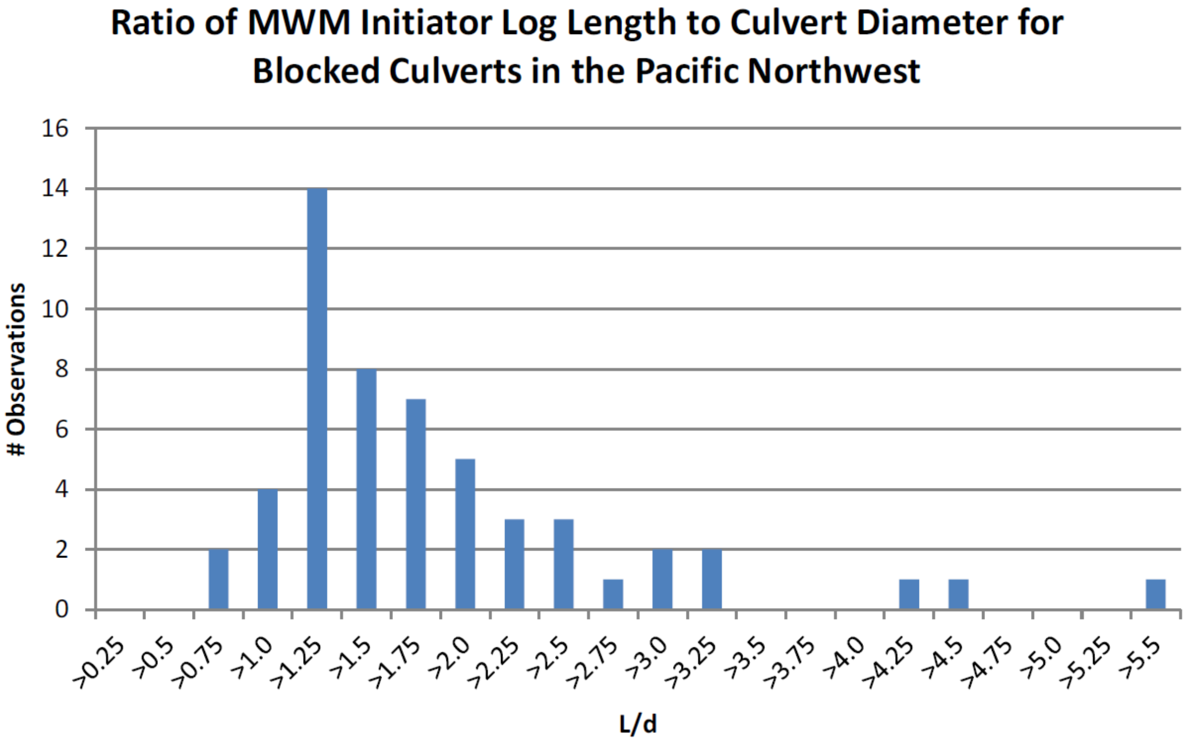
10-8 Mobile Woody Material

MWM is used for habitat restoration or enhancement, recognizing that wood moves through aquatic systems across a continuum of flow levels. When calculating the stability of MWM, the FOS should be 1.0, because it is desired for the wood to get mobilized at a specific discharge. MWM supports various habitat processes, and includes wood that is considered LWM and smaller. Woody debris is an important component of aquatic and terrestrial habitats with many crucial ecological functions: habitat for organisms, energy flow, and nutrient cycling. Additionally, MWM is used to help meet LWM targets in projects where there are constraints.

Studies on the transport of MWM in streams in the Pacific Northwest and northern California emphasize the differences between two distinct wood transport regimes: uncongested and congested (Braudrick et al. 1997). During uncongested transport, individual logs move without piece-to-piece interactions and generally occupy less than 10 percent of the active channel area. In congested transport, logs move together as a single coordinated mass or “raft” and can occupy more than 33 percent of the active channel area. Congested wood transport can result in stream channel blockages because of its large effective size relative to its individual members and can result in channel migration, bank erosion, and blockages of downstream road-stream crossings. Congested wood transport is relatively rare; most accumulations of MWM tend to break apart and the pieces move individually (e.g., Diehl and Bryan 1993).

Studies of MWM blockages at culverts in small streams indicate that the plugging of culverts by MWM is initiated by one or more "initiator pieces" lodging across the culvert inlet during high flows (Furniss et al. 1998; Flanagan 2005; Figure 10-9). The point of contact with the edge of the culvert barrel then becomes a nucleation site for the continued accumulation of finer material—both wood and sediment. Wood accumulating over multiple floods will eventually result in diminished culvert capacity or complete blockage. Only 3.7 percent (2 out of 54) of initiator pieces in plugged culverts had lengths that were between 75 and 100 percent of the culvert width, and in both of those instances the initiator pieces had substantial rootwads attached that had lodged themselves on the barrel edges of the culverts. An additional study (Flanagan 2003) indicates that 99.5 percent of fluvially transported pieces of MWM through low-order channels are shorter than the BFW of the stream.

Figure 10-9 Ratio of MWM Initiator Log Length to Culvert Diameter



Source: Flanagan 2005.

10-8.1 Design Criteria

This section provides design criteria for using MWM to improve ecologic functions in the riparian corridor while minimizing downstream disturbances that could lead to property damage, flooding, or other downstream impacts. The following summarizes key criteria to placement of MWM:

- MWM can be placed as “racking” material in front of stable log jams.
- MWM can be placed on top of stable log jams to improve revegetation.
- The MWM should be distributed at a wide range of elevations in the impacted area to prevent mass mobilization of MWM in a single high-flow event.
- Downstream infrastructure or constraints must be evaluated before designing MWM, including a detailed risk assessment if warranted. Based on the above research, individual logs with rootwads should be no longer than 75 percent of the downstream culvert diameter and MWM without rootwads should be no longer than 100 percent of the downstream culvert diameter.

The use of MWM must be evaluated on a site-specific basis—the degree of mobility with the riparian corridor, the amount of natural wood recruitment, and the distance to the next downstream culvert are all factors.

All LWM including MWM placement below the 100-year flood elevation must be approved by the State Hydraulics Office.

10-8.2 Design Flows for MWM

MWM should be designed and placed with specific objectives in mind. The appropriate design flow or flows must be determined from habitat objectives, hydraulic opening width, and on-site constraints.

10-9 Small Woody Material and Slash

Woody material that is too small to be considered LWM shall be used in stream restoration design. Clearing riparian areas for construction access will often result in the accumulation of downed woody material that shall be used within complexity features, such as filling void spaces with LWM structures, incorporating into the streambed for enhanced stability and biological function, and racking on the upstream face of the boulder or wood structures. Additional guidance on specific locations and amounts of slash will be included in future hydraulic manual updates.

This material, referred to as SWM, is commonly left in slash piles or disposed of by the construction contractor. Consequently, permitting agencies often require redistribution of this material as SWM within the stream corridor after construction is completed. Therefore, all SWM generated on site as part of stream restoration construction will be reused for habitat. SWM can be used to fill void spaces in multi-log structures, or distributed randomly in the newly constructed channel and floodplain.

In some cases, the clearing limits of a constructed channel may extend farther above the 100-year WSEL. Downed woody material can also be placed in those areas for habitat purposes, in accordance with landscape plans; however, it is not expected that it could mobilize.

10-9.1 *Benefits of Using SWM/Slash*

Adding organic matter to streambeds provides multiple benefits including the following:

- Providing a source of nutrients
- Adding hydraulic roughness
- Providing cohesion of the inorganic components of the bed
- Increasing overall bed strength
- Enhancing channel complexity features
- Slowing the bed degradation process
- Increasing bank strength
- Enhancing hyporheic flow

SWM can offer stable sites where vegetation can quickly colonize, further stabilizing the stream system.

SWM on the surface of the bed and above provides refuge from high-velocity flows, and wracks on large wood and other similar hard points, which can promote log-jam formation. SWM with large wood also promotes more mature pool formation (rather than a large wood piece alone), bar formation, and channel widening (channel morphology).

SWM can also enhance hyporheic flow. Water has been shown to flow vertically up laminar surfaces, such as wood, providing for temperature regulation. It also can force intergranular flow into multiple paths, laterally as well as vertically, increasing the latency of hyporheic water.

10-9.2 *Design of SWM/Slash*

Use of SWM generated on site is required. The way the SWM is used depends on the LWM and other habitat complexity features. SWM can be used to fill voids in LWM structures, accelerating the natural racking of debris on these structures, and reinforcing their function.

10-10 Inspection and Maintenance

As wood members decay, they lose strength and may ultimately fail and then be transported by the stream. LWM may also capture MWM transported from upstream in which the accumulation of wood becomes a hazard by either redirecting flow or constricting the channel. Although LWM used for fish passage projects is intended to mimic natural channel wood, it may also be used to provide bank protection or bank stability and needs to be inspected to ensure that it provides the function intended and does not become mobilized or present a risk to infrastructure. Therefore, it may be necessary to develop a site-specific inspection and maintenance plan as part of each project. The following inspection and maintenance criteria should be used in evaluating the function of placed wood intended for stability:

- LWM should be inspected by the stream design engineer prior to completion of the project and demobilization of the contractor to verify that the LWM was installed in accordance with the design. Because pieces of wood are irregular, field adjustments may be necessary.
- LWM should be inspected after the first significant flood (2-year or greater) or within 1 year, whichever is sooner, to verify that the LWM is functioning as it was intended to function.
- LWM should be inspected every 5 years of service or more frequently if identified by maintenance staff for a performance issue. The LWM should be examined for rot, and the anchoring system (if used) should be inspected for pullout, corrosion, abrasion, or breakage.

If a maintenance or repair need is identified, the RHE shall coordinate with the State Hydraulics Office to determine an appropriate course of action to repair, modify, replace, or abandon the LWM. Additional guidance will be provided in future revisions to the *Hydraulics Manual*.

10-11 Appendices

Appendix 10A	LWM Structure Examples

Appendix 10A Woody Material Structure Examples

10A-1 Self-ballasting Large Wood Structures

These structures are for habitat primarily but can be used to encourage natural processes to enhance a stream system, such as encouraging aggradation in a degraded system. A log of sufficient size, relative to the stream, and placed correctly, can be stable without anchors. Additionally, the design flow may be lower than the 100-year flow if site conditions permit.

Figure 10A-1 Self-ballasting Large Wood Structure, Swauk Creek, Kittitas County

10A-2 Rootwad Habitat Structures

As the name implies, these structures consist of logs with rootwads or a series of logs with rootwads located to interact with the channel at low and high flows to provide habitat variability and structure in the stream corridor. These may or may not have anchors.

Figure 10A-2 Rootwad Habitat Structures, Evans Creek, King County

10A-3 Log and Rock Revetments

These revetments consist of a rock revetment with one or two layers of logs with rootwads at the toe of the streambank. These structures provide roughness, energy diffusion, some habitat value, and minor flow deflection. They are relatively simple to install and often can be done with WSDOT Maintenance resources.

Figure 10A-3 Log and Rock Revetments, Newaukum River, Lewis County

10A-4 Crib Walls

Crib walls are constructed with logs in a rectilinear array, with voids backfilled with mineral and/or organic soils. Wood or steel piles may be integrated for additional stability. They provide contiguous protection to the bank with a great deal of roughness and complexity. Crib walls are narrow in profile and minimize encroachment into the channel. They are especially useful in narrow channels/banks that cannot accommodate wider structures. Depending on the scour risk, the designer may include wood or steel piles for added stability. Several examples of crib walls are shown below.

Figure 10A-4 Crib Wall with Wood Piles, Beaver Creek, Okanogan County

Figure 10A-5 Crib Wall with Steel Piles, Sauk River Side Channel, Skagit County

Figure 10A-6 Crib Wall with Soil Lifts (No Piles), Sauk River, Skagit County

10A-5 Flow Deflection Jams

Flow deflection jams consist of a series of logs with attached rootwads (key members) and often include large volumes of material. These are sometimes linked with revetments or crib wall structures where contiguous protection is desired.

Figure 10A-7 Flow Deflection Jams, Hoh River, 2004, Clallam County

10A-6 Apex Bar Jams

Apex bar jams are crescent- or fan-shaped structures constructed at the head of islands or gravel bars. Apex bar jams act to split and turn flows. Bars forming downstream of them tend to grow and become persistent. Apex bar jams recruit large volumes of additional wood. The potential for major changes in hydraulic and geomorphic functions resulting from wood recruitment is an important risk factor than must be considered in design.

Figure 10A-8 Apex Bar Jams, Hoh River, 2004, Clallam County

10A-7 Dolotimber

The use of dolotimber structures, or other ballasted prefabricated LWM structure matrices, may be considered in situations with extreme high flows and imminent danger to infrastructure. They offer excellent interstitial habitat and are extremely effective at reducing near-bank shear stress (Abbe and Brooks 2011).

Figure 10A-9 Dolotimber Structures, Skagit River, Skagit County

10A-8 Log Jacks

Log jacks are discrete structural units that are composed of four to six logs that hold a central ballast rock. The logs are connected to each other with cable, threaded rods, or chains. The rock in turn is connected to the logs with a wire rope cradle, and secured with wire rope clips or brackets. They can be assembled in a nearby spot with ample work space and then moved into position on the water body. Each log jack is a component of a larger array of log jacks. The array is deformable, and can respond to scour.

A major advantage of log jacks is that they can be deployed without flow diversion. Being modular, log jack design can be easily adapted to various scenarios/terrains. A potential disadvantage is that portions of the log jacks that are subaerially exposed can degrade quickly over time, and may come apart. However, when used in a river with significant recruitable wood, log jacks can rack and trap wood, which can reinforce the array's stability.

Figure 10A-10 Log Jacks, Wynoochee River, Grays Harbor County