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1 DEBRIS JAM- [MODERATE]

1.1 Introduction

Wood habitat restoration discussed in the Stream Habitat Restoration Guidelines (SHRG) is organized under four general techniques: 1) Debris Jams, 2) Large Wood Replenishment 3) Log Cover, and 4) Structures to Create and Maintain a Diverse Channel Bedform. In nature, habitat functions change depending on a wide variety of geomorphic, biologic, hydrologic, hydraulic and watershed processes that occur over time. Wood habitat can be variable between and within watersheds. Local watershed knowledge and watershed analysis may be helpful when used during the design of wood related habitat to maximize success.

Large wood techniques described in the SHRG overlap. For example, a cover log complex can become a debris jam when downstream wood replenishment is implemented. The techniques provided facilitate understanding natural large wood processes. The goal is to emulate and "jump-start" natural processes that benefit aquatic environments through design and construction. The debris jam technique described in this section naturally occurs in alluvial and non-alluvial channels.

1.1.1 Natural Debris Jams in Alluvial Channels

Debris jams in alluvial channels are most often collections of large woody debris that redirect flow to provide stability to a downstream bar or island, collections that help stabilize a streambank along a meander bend and in more rare cases form broad channel-spanning jams.

Debris jams that provide stability or form a downstream bar or island are formed when a large key wood piece enters the active channel that is relatively immobile during floods. The key piece normally becomes oriented so the root fan faces upstream. As mobile wood material becomes racked against the key piece a downstream bar forms and an upstream pool is scoured as flow accelerates around the face of the key piece root wad and racked large wood. Abbe and Montgomery (need citation date) called these types of jams Bar Apex Jams, as they are located at the apex of a bar that develops in the slow velocity water behind the jam. In larger alluvial river systems this natural wood process played a critical role in redeveloping forested communities on the bar behind the debris jam as stream banks migrated across valley floors.

Meander bend debris jams can form on the outside of alluvial meander bends as large trees are undercut and fall into the active channel. These have been referred to as meander jams. In a process similar to bar apex jams a large tree is undercut, falls into the channel, becomes re-oriented so the root fan faces upstream and is large enough to be immobile at flood flows. Wood that is floating downstream is racked up against the root fan. The racked wood and remaining tree act to stabilize the stream bank and prevent further lateral migration. The degree of roughness associated with these wood deposits can compress the radius of curvature far greater than what one would expect in most natural streams and rivers (Abbe and Montgomery 1996). This naturally creates much more complex habitat, deeper pools and channel length than would be expected without adjacent large wood forest communities.

Channel-spanning debris jams can also occur in alluvial channels. These can occur below confined channel segments that transport upstream wood sources to lower gradient alluvial reaches where the wood can deposit. Channel-spanning debris jams have also occurred in areas below debris torrent tracks and landslides that can deliver large volumes of wood to downstream lower gradient alluvial reaches that become overwhelmed with large wood material. A channel-spanning debris jam is more likely in a smaller alluvial channels than larger rivers simply because smaller rivers have less stream energy to transport larger wood and require less wood volume to span the channel. Today, most channel-spanning jams in alluvial channels occur in upper watersheds of National Forests and Parks where alluvial channel segments exist. Historically many large channel-spanning jams occurred on valley bottom river channels that created large areas of backwater and complex fish habitat. However, they created navigational and flooding problems because this is where human settlement was occurring. As a result channel-spanning debris jams in these alluvial valley bottom channels were removed and no longer exist. This type of habitat is could be replicated in very few places today, since most alluvial channels are located where human settlement and infrastructure is well established and any channel-spanning jam would cause extensive flooding and channel migration into existing human infrastructure.

1.1.2 Natural Debris Jams in Non-Alluvial Channels

In non-alluvial channels debris jams can be both channel-spanning and occupy a smaller percentage of the active channel forming what could be called a lateral debris jam. One could compare the lateral jam in non-alluvial channels to a meander jam in an alluvial channel. However, in non-alluvial channels the lateral debris jam may or may not be acting to stabilize the banks and are often a function of flood flow stage and hydraulics depositing mobile wood debris against living riparian vegetation or trees that have fallen across or parallel to the stream channel. Debris jams in non-alluvial steeper channels can greatly improve habitat conditions, floodplain connectivity and especially gravel sorting that would not occur without the presence of large wood.

Debris jams in non-alluvial channels also have a collector mechanism similar to the key piece of large wood that start bar apex jams or meander jams in alluvial channels. In larger non-alluvial channels, large boulders and bedrock constrictions in combination with large trees as well as large immobile trees by themselves act as key piece members that from the foundation of a debris jam. Once established, large wood that transports downstream can be racked up against key piece members forming habitat and influencing local channel morphology and hydraulics beneficial to aquatic resources. Depending on the size, orientation and local hydraulics key piece members can form channel-spanning debris jams or lateral debris jams that occupy a smaller percentage of the channel width.

In smaller non-alluvial channels the physical processes are the same but smaller-sized wood material also becomes immobile and has a greater ability to influence channel morphology. As one enters smaller non-alluvial channels large trees that fall across stream channels have substantially more mass than can be moved by the watershed hydrology and local hydraulics. This can backwater and locally aggrade channels upstream of the wood deposit and produce high quality complex fish habitat with available spawning gravel and complex fish habitat at a variety of flows.

1.1.3 Description of Technique

The debris jam restoration technique uses existing local large wood near a project site or imported large wood to establish debris jams that simulate natural processes previously discussed in alluvial and non-alluvial stream channels. The goal of this technique is to improve the establishment of debris jams in areas that have been previously degraded by either land management activities and/or stream cleanout efforts. Debris jams are also commonly referred to as log jams and should be considered interchangeable in this document. In Washington most of the wood projects and debris jams have been constructed are in streams greater than 20 meters bankfull width. Preliminary unpublished data by G. Pess has suggested that this technique has benefited Chinook salmon by creating or increasing spawning and holding areas that didn't exist before (Roni et al. 2002).

Depending on the stream or river size, large wood used to construct debris jams can vary in size from slash to whole old growth trees. The volume needed is highly dependent on the objectives and size of the river channel, and local site conditions. The design and need to ballast debris jams is dependent on objectives, location, wood size, hydrology and local hydraulics. There are several techniques or methods to approach simulating natural debris jams. In all cases debris jams are initiated by on or two key large piece of wood that are relatively immobile during high flows. Some techniques simulate the establishment of a key member that will over time capture or rack mobile wood on the upstream of the initial key member that will develop and expand a debris jam. Other techniques completely construct the debris jam including the placement of mobile wood pieces within the jam.

Debris jams can occupy a variety of locations within the channel. Some debris jams exist higher in the channel and function only at flood flows. Others can take up substantial percentages of both low and high flow cross sectional area. Channel-spanning debris jams that occupy the entire channel cross-section can substantially change the upstream channel morphology, habitat and store large volumes of sediment and spawning gravel. The following are descriptions of ways to simulate the development of debris jams.

1.1.3.1 <u>Large Wood Key Piece</u>

In remote environments this technique can encompass the felling of large trees to start the establishment of key piece wood material essential for the development of complex debris jams. In this technique the wood placed as key piece members are properly fit for the stream channel and do not have to be anchored. In some cases key piece wood can be felled into smaller non-alluvial channels and left to develop into debris jams naturally. In some cases specialized heavy equipment can be utilized to place and orient trees felled near the project site to maximize longevity and interaction with flood flows. The utilization of helicopters to deliver large wood to begin debris jam development can also be used for this technique.

In larger stream channels whole old growth trees have been pulled over with root wads intact. This requires proper soil moisture conditions reasonable equipment access and talented loggers using cable to rig the top portion of the tree with cable connected to a large dozer winch line. The tree is then pulled over using the bulldozer. Whether imported or utilized on site, the ability to utilize old growth sized wood material within larger stream channels greatly increases the success of long-lived debris jams that provide high quality habitat.

It should be stressed that utilizing adjacent wood sources may reduce the quality of other habitat values. For example wood laying on the floodplain is very important to both fish at high flows and wildlife. Standing trees utilized for instream habitat may also reduces wildlife values. When utilizing adjacent wood or importing wood from outside sources it is important to determine the cumulative impacts a project may have within the project area and the location where the large wood used in the project comes from.

1.1.3.2 Anchored Key Piece Wood

In areas with good equipment access and limited large wood size, smaller large wood can be delivered to the site, oriented with heavy equipment and anchored to simulate the mass and size of a key wood piece needed to start a debris jam. This technique works best and is easiest to implement in non-alluvial environments. In alluvial environments it is much more important to utilize trees with root wads as key piece members as the root fan plays an important role in collecting smaller wood material. It is also more difficult to emulate the hydraulic function of a large root fan with smaller sized material in alluvial environments and be successful. In non-alluvial environments wood is commonly perpendicular to the channel flow and therefore it is easier to emulate using smaller wood or logs and anchoring. In steeper channels large boulders, local constrictions, heads of alluvial fans or debris torrent run outs, and stream bends can be areas where natural wood accumulations would develop and area areas where smaller anchored wood could be utilized to establish and emulate debris jams.

1.1.3.3 Engineered Debris Jams or Log Jams

This technique includes the construction of channel-spanning debris jams in non-alluvial environments, and the development of bar apex jams and meander jams in alluvial channel segments. Success of this technique depends on the ability to properly anchor debris jams and place them in locations where they would otherwise form naturally.

Large trees are necessary to initiate stable debris or log jams in larger rivers. It is important to match the scale of the stream or river with the size of wood. In engineered log jams, a minimum of one to two key wood pieces strategically placed can trigger log jam formation based on the fundamental aspects of mechanics, hydraulics, and fluvial geomorphology. In designing logjams, the wood should be sized and arranged to assure stability for the peak flow, except in highly confined, steep streams where this may not apply (Abbe et al. 1997).

Engineered-log-jam projects are patterned after these stable, natural log jams and can be either unanchored or anchored in place using man-made materials. Methods of anchoring depend on the size of the wood compared to a streams ability to move it. As wood transport at any given site increases, the need for thorough design calculations increases. The same is true as the percentage of channel blockage increases.

1.1.3.4 Mobile wood supplementation

In some debris jam projects only the foundation key piece large wood or larger wood component of a debris jam is constructed. Natural log jams have a small wood and organic mass texture that is very important and provides a food base for macroinvertebrates. Small wood incorporated within debris jams also creates a great deal of cover complexity and hydraulic refuge during flood flows for salmonids. Therefore, one aspect that should be considered in debris jam projects is the supplementation of mobile small wood upstream of constructed debris jam projects. This technique allows mobile wood placements to occur above completed debris jams. During high flows the small wood floats downstream and becomes racked up against the constructed debris jams. In areas with poor natural wood debris loading this may be a viable addition. In areas with natural small wood recruitment it may not be needed. Wood supplementation is a stand-alone technique and is discussed in greater detail within the Stream Guidelines document. It is included here because it could be an appropriate part of any debris jam project.

1.1.4 Physical and Biological Effects

1.1.4.1 Geographic Considerations

The role and habitat value of large wood varies by stream type and ecoregion. Some streams, particularly in non-forested areas of eastern Washington, evolved with little to no wood. Wood has its greatest influence in intermediate streams where it controls the morphology, and least influence in small and large streams and rivers. In forested streams, wood traps sediment, creates scour, and develops a step-pool channel profile. Boulders and cobbles stabilize many small channel beds. In steep gradient channels, wood is less important because these reaches are transport areas where the stream moves the material to lower gradient areas. In large streams and rivers, large wood controls floodplain construction and side channel development (Slaney 1997; Cedarholm et al. 1997; Montgomery et al. 1993; Booth 1996). Slaney (1997) states that placement of large wood is effective as a restoration tool in simple shallow pools and glides.

Differences in the watershed stability, geology, disturbance regimes and vegetation communities have a great influence on the type and quantity of debris jams that can develop within watersheds. It is important to realize that these differences exist in order to emulate and properly apply this technique to the quantity and size of debris jams that could develop within individual watersheds. The goal should be to reflect conditions that would naturally occur within a watershed and emulate a range of conditions aquatic and wildlife species within a watershed have evolved in (Roni et al. 2002).

An important part of stream restoration is the understanding of the watershed. Watershed assessments are a valuable first step in understanding watershed processes that influence aquatic habitat in general and this restoration technique specifically. The appropriateness of this technique within individual watersheds can be assured with a good understanding of watershed processes learned from watershed assessment efforts. For further discussion of watershed assessment, refer to Chapter 3.

1.1.4.2 Large Wood Key Piece

Placement of large wood into streams can result in the creation of pools that may influence the distribution and abundance of juvenile salmonids (Beechie and Sibley 1997; Spalding et al. 1995). Bilby and Ward (1989) state that large wood influences the physical form of the channel, retention of organic matter and biological community composition. The presence and abundance of large wood are correlated with growth, abundance and survival of juvenile salmonids (Spalding et al. 1995; Fausch and Northcote 1992). Carlson et al. (1990) found that pool volume was inversely related to stream gradient with a direct relation to the amount of large wood. Fausch and Northcote (1992) indicate that size of wood is important for habitat creation. Hicks et al. (1991) indicate that lack of large wood available for recruitment from the riparian zone also leads to reduction in the quality of fish habitat. Large wood can also restore the connectivity of the stream to the riparian ecosystem and floodplain (Cedarholm et al. 1997).

Placement of key piece elements that will establish debris jams over time are a way to help the physical and biological processes become re-established where riparian large wood has been removed through forest management practices, splash damning or stream cleanout activities.
The advantage of using large key piece placement is that it is matched with the size of the stream channel, which eliminates the need for anchoring (Hilderbrand et al. 1998)

1.1.4.3 Anchored Key Piece Wood

Undersized, anchored wood to simulate key piece wood needed to establish debris jams of various sizes and dimensions is very similar to the biologic and physical benefits of using wood naturally fit for the size of the stream channel or river one is working in. There are both advantages and disadvantages in anchoring large wood material. The biggest advantage is the ability to use smaller material to create a debris jam that would require larger and longer wood material if formed naturally. Recently, studies in Washington and Oregon have shown that logs that are placed and anchored are more likely to scour pools and have a more positive benefit than those that are not anchored (Roni et al. 2002). Successful anchoring is more probable when force/balance calculations are utilized to wood anchoring stability at various flows.

Disadvantages of using smaller anchored wood is the difficulty in orienting and placing the wood in a way that would function like larger immobile pieces at high flow. For example anchored wood doesn't float during large floods whereas even immobile wood in some channels float as stage increases. The difference between anchored wood and natural wood is that anchored wood is submerged at flood flow and natural wood that floats but stays in place at flood stage and has a greater ability to collect more driftwood. Anchoring wood lowering in the channel is good for scour hole development but it also reduces the collection mechanism for small wood moving downstream at flood flow. At flood flow water flows over the top of the anchored debris jams. One way to improve the racking ability to anchored wood is to have enough vertical height so that a portion of the anchored debris jam is above the water surface at higher flood stages.

1.1.4.4 Engineered Debris Jams or Log Jams

The structural and hydraulic diversity that logjams provide creates habitat for a multitude of fish species at nearly every stage of life. Engineered logjams create excellent cover, holding and rearing habitats. Spawning habitat may be created at the tail out from the scour hole created by an engineered logjam. The detritus they accumulate, particularly smaller twigs and leaves that decay rapidly, also serves as a food to some aquatic insects that fish consume.

In alluvial channels, depending upon their size relative to the channel, the constriction caused by an engineered log jam may result in scour at the opposite bank or point bar. Engineered log jams generally produce scour adjacent to themselves. The scour at the margin of the jam, and the associated downstream deposition, moves the location of the thalweg away from an eroding bank. One observed effect is the tendency for a side channel to form on the back side of the jam, against the bank.[1] This is a result of the jam causing an obstruction to flows above the bankfull elevation. Jams tend to split the flow, and the flow directed along the bank may create a side channel. If side-channel development is anticipated and undesirable, extend the jam into the bank and floodplain, and anchor it to a stable location. Sites where riparian vegetation has been removed from the bank have a high risk that over-bank flows will erode the bank around the logjam and leave it isolated in mid channel.

Down logs serve a variety of functions for wildlife species. Smaller logs provide escape cover and shelter for small mammals, amphibians and reptiles (Bull et al 1997). Increased log volume may increase densities of certain amphibians and small mammals (Butts and McComb 2000). Small mammals use logs for runways, which in turn attracts predators of these small mammals (Bull and Henjum 1990).

Because they are so valuable to fish and wildlife, normally only construction impacts need to be mitigated. Immediately following placement of engineered log jams, there may be temporary, short-term impacts on spawning. Existing spawning areas may shift or scour while others may accrete with fines while new spawning areas are forming. It may take the channel a period of time to adjust to the jams. However, the long-term habitat benefits of engineered log jams far out-weigh these short-term impacts.

The structural and hydraulic diversity that engineered log jams provide creates habitat for a multitude of fish species at nearly every stage of life. Engineered log jams create excellent cover, holding and rearing habitats. The detritus they accumulate, particularly smaller twigs and leaves that decay rapidly, also serves as food to some aquatic insects that fish consume.

Construction-related impacts do, however, require mitigation. Care should be used in gaining equipment access to the site to minimize construction impacts. Consideration must also be given to insure that in obtaining large wood, adverse impacts to terrestrial wildlife and riparian functions are avoided. In Washington, riparian areas support more species than any other habitat type. Mature riparian trees provide important habitat for a variety of species, including northern spotted owls, bald eagles and marbled murrelets, all listed under the ESA. Birds use mature trees extensively for breeding, and removal of trees during breeding and nesting season should be avoided. In forests west of the Cascade crest in Washington, 150 terrestrial wildlife species are known to use dead and down woody materials (Brown 1985). Dead and down woody materials furnish cover and serve as sites for feeding, reproducing, and resting for many wildlife species. Snags are also an important structural component and used by 100 species in Oregon and Washington for breeding, shelter, roosting, and food needs (Brown 1985). See the Riparian Appendix for more information on wildlife use of woody vegetation.

1.1.4.5 Mobile Wood Supplementation

Mobile wood supplementation provides an important fine wood component to any debris jam project. By loading upstream project reaches with small wood, debris jams developed downstream have a source to accumulate the fine wood component during high water events. The complexity generated around the log jam is a benefit to fish habitat and a greater fining of larger wood material around a debris jam increases the amount of fine particulate matter beneficial to macroinvertebrates (Smock et al. 1989).

1.1.5 Application of Technique

1.1.5.1 Large Wood Key Piece

Large wood key placement is best used when the size and volume of wood is enough to function naturally to develop a debris jam. This technique is best suited when whole trees with root wads are available to use. Orienting the wood material to maximize habitat and function is most often achieved by using heavy equipment. In some cases helicopters have been used to develop the establishment of debris jams. In all cases the wood must be properly sized to function naturally in the stream channel. Force/balance/momentum, geometric calculations and forces, sum of moments, factors of safety, tree densities, proportion of rootwad area to flow depth should be used to determine at what flow wood available for a project will become mobile (Sampson and Castro 2001).

1.1.5.2 Anchored Key Piece

Anchored wood is technique commonly used when the size of the material is too small to function naturally without anchoring it in some manner. This is especially true when working in larger stream systems where stream power begins to outpace the ability to find large enough wood material to function naturally. Anchored large wood debris can produce quality stream habitat when applied properly. Working in stream powerful stream systems with undersized wood requires an understanding of stable anchoring systems and mobility of the wood used in the project. Analysis on the mobility and stability of wood in rivers has been completed by Gippel (1995), Braudrick and Grant (2000), and D'oust and Millar (2000) that are applicable to channel design and anchoring needs. The use of Force balance/momentum, geometric calculations and forces, sum of moments, factors of safety, tree densities, proportion of rootwad area to flow depth compared to the weight of any anchor ballast are important aspects when applying any anchoring to large wood material.

1.1.5.3 Engineered Debris Jam or Log Jam

1.1.5.3.1 Alluvial Channels

Large-woody-debris jams create a hydraulic shadow, a low-velocity zone for some distance downstream that allows sediment to settle out and stabilize. This creates spawning gravel for adult salmon and complex rearing habitat for juvenile salmon. They are also used to increase channel roughness to reduce flow velocities and shear stress along eroding banks. Engineered log jams are also often used to realign a channel or redirect flow away from a streambank to protect it from erosional forces. For further detail on the use of debris jams for protection of streambanks, refer to the Integrated Streambank Protection Guidelines.

Engineered log jams are useful for capturing and storing sediment and large woody material.[3] They can slow the rate of erosion in an equilibrium channel that is migrating laterally or where there is potential for a chute-cutoff, though they still allow for gradual meander migration. Large-woody-debris jams occur naturally at the inlet of many side channels. Jams can be assembled at the inlet of pre-existing or constructed side channels to regulate the amount of flood flow entering the side channel. This protects the banks in the side channel, prevents the side channel from capturing the main channel and protects existing spawning and rearing habitat in the side channel.

Engineered log jams also recruit floating, large woody debris, which reduces the likelihood of the jam becoming buried and ineffective over time. When a channel has been disturbed and is carrying a high bedload, jams can be constructed in upstream reaches to stabilize sediment movement. Over the long term, engineered log jams reduce aggradation and erosion in the downstream reach. These jams can be placed either at the bank or in mid-channel.

1.1.5.3.2 Non-alluvial channels

Depending on location, large wood in non-alluvial channels can over power hydraulic and geomorphic processes in a stream channel. In these cases the wood is larger than the streams ability to move it during flood flow. Channel-spanning log jams can substantial improve upstream fish habitat and complexity by store substantial volumes of sediment, spawning sized substrate and upstream backwater habitat that would not be available without the wood due to the natural valley width and stream gradient. In these locations imported or locally available wood can be utilized to create natural channel-spanning log jams to re-establish habitat lost from historic stream clean out and logging activity. In both alluvial and non-alluvial engineered log jam construction it is important to calculate the ability of each stream channel to mobilize the material used in the debris or log jam construction. With this understanding either correct wood debris sizes can be collected or proper anchoring systems applied to insure project objectives are met.

1.1.5.4 Mobile Wood Supplementation

Mobile wood supplementation is best applied in areas that may be deficient of fine wood debris loading that would benefit constructed debris dam structures. This is often the case below dams, and urban environments. This technique could be used to enhance and improve fine wood loading within debris jams in all watersheds. Since it is desired to have wood supplementation move downstream the size mobility calculations are not critical. Mobile wood material can be inferred by looking at material on adjacent banks. It may be helpful to determine the upper limits of mobility in some channels to focus material gathering efforts to meet project objectives.

1.2 Scale

Wood habitat, function, transport and deposition changes depending on the size of the stream, river and wood. Regardless of the size of wood chosen, as one moves from the headwaters of any watershed down to the ocean the function and behavior of that wood changes as the hydrology and geomorphology acting on the wood changes.

In small streams trees can be large enough to act like bedrock when they fall into the channel. The hydraulic forces acting around the large wood create pools and redistribute or accumulate gravel around the immobile wood debris. In larger streams and rivers very large immobile trees can accumulate smaller wood that would have normally been transported downstream. Over time the complexity and size of a single original tree can grow to a lateral or channel-spanning logjam that backwaters entire stream reaches.

As one moves downstream the ability of flood flows to transport larger material becomes greater. The size of the tree and location within the watershed are factors controlling where and to what extent wood deposits and habitat is formed or whether wood is transported. Eventually rivers become large enough to transport substantial wood volumes to the ocean, and ocean beaches that establish valuable aquatic and wildlife habitat.

The volume and scale of debris jams for each stream channel is best determined through a watershed assessment. Watershed assessments would determine where historical debris jams may have occurred and point towards opportunities that exist today. Priorities for individual watersheds are highly variable and assessments seem to be the most effective way to determine what technique is best for a watershed and to what extent it should be applied (Roni et al. 2002).

1.3 Risk and Uncertainty

Engineered log jams pose inherent risks to infrastructure and human stream users. These risks include:

- Safety hazards caused by the log jams or the cables that anchor them (this risk can be somewhat reduced by placing warning signs upstream from the log jams to alert boaters),
- Blockage of culverts or bridge openings by large woody debris that has been dislodged from a log jam upstream,
- Unanticipated erosion across the channel or to the adjacent streambank,
- Increased channel roughness and constriction,
- Increased flood stage and/or
- Channel avulsion.

Constructing logjams immediately upstream of culverts or bridges or next to infrastructure or denuded riparian zones should not be attempted without careful consideration of risks.

Booth (1996) notes that extreme increases in flow discharge complicate the use and placement of large wood for channel rehabilitation in urban environments. Limitations to placing wood in urban streams include; management concerns (flooding and damage), hydrologic changes, sediment fluxes, wood recruitment, human intrusion, and aesthetics. He also notes that flow deflection by the wood can cause localized bank erosion or channel incision, reducing or negating the net increase in sediment storage resulting from wood placement.

Slaney (1997) cites an example in Oregon where large wood was restored in an extensive reach of Fish Creek without a watershed assessment. The large wood held for 10 years and then most of it was lost along with 53% of the previously existing pools after the 1996 flood event (a 100-year event) from debris-sediment flows. A watershed analysis with identification of at-risk drainages and slopes could have been used to alter management activities or improved road construction to reduce road related hill slope failures and prevent much of the impact to the restored habitat. A more comprehensive study of nearly 4,000 anchored wood structures on over 100 streams on 8 National Forests in Oregon and Washington showed a high level of durability following the major floods in 1996 and 1997. Less than 20% of the structures moved from the original site placement in this study (Heller et al. 2000).

Reeves et al. (1991) indicate that stream hydraulics, hydrology and geomorphology are important and parameters that should be carefully evaluated before any instream work is started, and that care must be taken to identify aspects of habitat that limit production. Carlson et al. (1990) also stressed the importance of considering all aspects of a watershed for its potential capacity for fish production.

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1.4 Data Collection and Assessment

An understanding of peak flow hydrology and geomorphic field indicators are important when planning and designing debris jams. Professional geomorphologists can measure bankfull dimensions, identify flood terraces, bar deposits, wood deposits, sediment gradations and vegetation disturbance patters at potential restoration or enhancement sites. This knowledge is important because construction usually occurs during low flow. Design and wood orientation has to consider the consequences of bankfull discharge and high flow events on the large wood utilized in a project in order to have long-term success.

Measured watershed and geomorphic field indicators needed to properly design a debris jam includes a minimum of:

- Watershed hydrology.
- Representative cross section and profile data.
- Bankfull and higher flood stages at the project site.
- Debris jam design dimensions.
- Stream bank stability, material and bank shear at design flows.
- Mobility of various large wood sizes in the project reach.
- Stable channel dimensions.
- Bed substrate.
- Riparian area condition.
- Air photo analysis of current and historical conditions if possible.
- Identification of upstream and downstream abandoned or active channels and side channels.
- Current and historical wood loading within the project reach.
- Species and age class of adjacent riparian vegetation.
- Identification of any historic backwater terraces or flood terraces indicative of bedload transport, stage elevation during floods and historical debris jams.

In smaller streams where the wood is larger than flood water can move analysis is not as critical as locating quality pools where cover habitat would benefit salmonids. Matching wood size with the size of the stream channel is important for project success. The goal is to emulate naturally occurring and functioning debris jams one would see naturally in the project area being considered. The development of key piece large wood that naturally forms debris jams whether in alluvial channels or non-alluvial channels should be the primary focus when developing debris jams. If this is done properly either using naturally large on site wood that would naturally function as a key piece member or utilizing smaller material using anchoring mechanisms a successful outcome over all flood flows is likely.

1.5 Methods and Design

1.5.1 Large Wood key Piece Placement

Placing large wood to begin the development of debris jams requires a good understanding of what wood material is mobile and what is immobile within the stream reach one is working in. Once this is determined the collection of proper wood sizes can be undertaken. Wood placement should occurs in areas that may have pool habitat and are in a location where a debris jam could benefit the pool function and provide complex cover and rearing habitat at higher flows. These locations are best determined in the field after preliminary analysis on wood mobility is completed. In areas were no pool habitat exists effort should be made to determine locations where debris jams would naturally form and develop over time – once established these areas are likely to develop pool habitat.

1.5.2 Anchored Key Piece Placement

Anchored wood design methods are similar to using non-anchored wood placement except the wood is undersized for the stream hydrology and needs to be anchored to function as a debris jam. A good understanding of wood mobility and anchoring systems needed to keep it on site is needed before design begins. Location of anchored key piece wood placements should occur where wood occurs naturally and in areas that would benefit existing pool habitat. An increase in cover habitat provided by debris jams improves the quality of pool habitat for fish at all design flows.

1.5.3 Engineered Debris Jam or Log Jam

1.5.3.1 Debris Jams in Large Alluvial Channels

The design of any engineered log jam requires a thorough analysis of channel hydraulics, which should be conducted by a licensed professional engineer. Engineered log jams can be designed with or without the use of anchoring hardware.

In alluvial and non-alluvial debris jam environments stabilizing key members (large logs with rootwads attached) can be accomplished at most flows by the ballasting effect of large logs and/or boulders.[2] Determining the necessary ballast mass requires a detailed stability analysis of fluid drag, buoyancy, lift and friction-resisting forces, and weight of the ballast logs and/or boulders.[2] A structure is stable when the sum of the resisting forces exceeds the sum of the driving forces (e.g., drag, lift, and buoyancy). Alluvial hydraulic conditions often result in sediment deposition on the downstream side of a log jam. This deposition buries much of the wood and will increase the effective weight and, hence, the stability of the log jam. The process of deposition can occur naturally or be accelerated by placing excavated sediments during initial construction to bury the key members.[2] In non-alluvial environments backwater conditions caused by debris jams causes deposition upstream of the log jam. The deposit stores substantial volumes of sediment and decreases the average grain size diameters upstream of the debris jam.

Designing an unanchored debris jam may require excavation of the streambed or bank to provide a trench for the key member(s). The depth of excavation depends on channel hydraulics, substrate characteristics, bank material, channel dimensions, existing vegetation, and the size of wood. Once a key member is placed in a trench, the trench is covered with excavated sediment to provide additional ballast and frictional resistance to drag forces and planted. Large woody material (whole trees with rootwads attached) is stacked (stacked members) on the key members for ballast. Next, whole trees, logs and/or rootwads are racked (racked members) on the upstream side of the key-piece rootwad(s) The number of pieces racked against the rootwad(s) depends upon the need for immediate protection, channel dimensions and hydraulics, and the likelihood of recruiting additional debris.

Unanchored, engineered log jams must be dense, with racked and stacked pieces carefully interlocked. The more dense the rack, the less flow will pass through it, thereby increasing the stability of the log jam. Scour under part of a loosely assembled structure may destabilize it and allow portions to be washed away. Dense structures, on the other hand, act as a unit. They settle uniformly and hold ballast well.

Engineered log jams can be anchored with pilings (there is a good figure available for this in ISPG), most commonly applied to bank protection applications. In small-grained substrates, a row of log pilings can be driven vertically into the streambed using the excavator bucket. In larger substrate, pile-driving equipment may be required, as well as steel tips on the logs. The logs need to be long enough to extend below estimated scour depths. A second row of pilings should be driven into the streambed at least 20 feet downstream, and brace logs should be anchored between them. Large woody debris is then racked against the upstream side of the brace logs and the first row of pilings, just as they are for unanchored engineered log jams. The braces are needed because there is a limit to the size and, consequently, the strength of logs that can be driven with an excavator. The braces distribute the shearing force of the racked logs between the two rows of pilings. The upstream row of piles is in the area where scour will form around the log jam. The downstream row is positioned in the deposition zone, safe from the undermining effects of scour.

Other methods of anchoring include attaching cable or natural fiber rope to the key logs and possibly with the using of an adhesive (e.g., epoxy) to glue the eye hooks or anchors to boulders for ballast. If possible, the boulders should be buried in the bed to act as deadman anchors. Another approach is to partially bury logs into the bank so that they still extend into the channel, perpendicular to the direction of flow. Logs are then racked against the upstream side of the partially buried log. Some sites may require brace logs and/or a rock toe as additional reinforcement. To learn more about how to anchor large woody debris, refer to Integrated Streambank Protection Guidelines Appendix I, Anchoring and Large-Woody-Debris Placement.

The shape of engineered log jams depends upon channel hydraulics, desired results and cost. In naturally formed jams, the most stable configuration is one where key members are oriented parallel to the high flow, with their rootwads upstream. Racked wood is generally positioned perpendicular to the flow direction. In many cases, debris collects upstream against the bank and forms a concave shape (from plan view) that is more streamlined. Using different methods of anchoring the jam may allow different shapes and alignments to form, and collection of additional wood on the engineered log jam during floods will potentially change the shape and dimensions of the jam.

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The correct spacing and dimensions of jams are closely related. When positioning a series of engineered log jams along an eroding channel bend, they should begin below the crossover riffle at the head of the bend. Spacing should be similar to that recommended for groins, but bear in mind that engineered log jams may become longer than groins as woody material is captured and collected over time. Groins are discussed in detail in the Integrated Streambank Protection Guidelines. The effective length (L_e) of an engineered log jam is the distance the structure extends into the channel, measured perpendicular to the bank. It does not include that portion that is keyed into the bank. Effective length must be considered when establishing spacing requirements. The furthest upstream jam in a series should be expected to grow the most as it will intercept additional floating woody material before it reaches subsequent jams. This phenomenon allows increased spacing between the first and second structures. Downstream structures may accumulate debris, but it will probably collect at a slower rate than the first jam in the series. Expect the accumulation to occur in both the upstream direction and laterally. This growth must be anticipated and may present a problem if channel constriction is an issue.

The size of materials used in the engineered log jam will depend upon the method of anchoring. The required size of pieces will be based on the calculations of drag, friction, lift and buoyancy. It's also important to take into consideration the anticipated rate of wood decomposition, wood density and the length of project life. Racked pieces do not usually function as structural members of engineered log jams, so they can be any size, particularly if accumulation of additional debris on the rack is anticipated. Determining the correct size for structural members should be accomplished by a qualified engineer.

In order to successfully create habitat structure, wood must be placed specifically to interact with the flow. They alter channel hydraulics, sediment transport, and morphology. Each structural type placed at any particular location will interact somewhat differently with the flow. There are direct effects when placing a habitat improvement structure in a stream; a change of physical boundary or channel shape and form (morphology) occurs that changes the shape of the channel, which in turn causes changes in flow patterns near the structure as well as changes in local flow velocities and boundary shear stress. During larger discharges there are additional effects that involve sediment transport, channel morphology adjustments, boundary adjustments, and flow pattern. Structure orientation is also important, for instance an upstream oriented structure may not cause bank erosion, whereas a perpendicular or downstream orientation will increase boundary shear stress and possibly cause considerable bank erosion (Klingeman 1996). It is, therefore, essential to the success of these restoration efforts that baseline information is gathered and understood before constructing instream structures. The most relevant and essential properties of stream morphology to understand are bankfull width, bankfull depth, dominant bed sediment size, and channel gradient.

Rosgen (1996) states that, "excessive introduction of large wood without regard to stream type and related sediment transport characteristics will upset the established balance of processes with potential adverse consequences and it is critical that habitat improvement guidelines be established as functions of slope and stream width, which must be linked to watershed condition, physical characteristics, and processes." Rosgen (1996) has also noted that instream structure failures are often due to; a poor understanding of river response, a lack of experience and or documented procedural guidelines, constraints which limit pre-project research, lack of state-of-the-art knowledge in the applicability of structures to field conditions, or the tendency to install the same structure on all stream types with a one-size-fits-all approach (Rosgen 1996).

It is important to understand the functional relationships between dimension, pattern, and profile of the natural stable channel form for a variety of river types. Both Rosgen (1996) and Montgomery (1993) have developed guidelines for wood projects based on stream type. In addition, post project monitoring of the effectiveness of a stream rehabilitation project is important and "any habitat manipulation proposal should specify procedures for pre- and post-construction studies so resulting physical and biological changes can be evaluated" (Reeves et al. 1991).

1.5.3.2 Debris Jams in small alluvial channels and non-alluvial channels

Debris jams in small streams can influence the channel by backwatering and storing sediment in steeper channels and creating complex multi-channel habitat in smaller alluvial channels.
Natural or engineered logjams that span small streams can lead to avulsions and side channel development during floods. This is particularly true where open fields are adjacent to a channel with a narrow or non-existent riparian zone. The lack of roughness and resistance in the floodplain can lead to head-cutting and channel avulsions.

Some projects have been successful in moving a channel from a degraded alluvial environment to re-establishing flow in abandoned healthy riparian channels. These designs use grade control where necessary or remove log jams that resulted from upstream degradation, that returning flow to the low point of the valley within undisturbed riparian environments. These types of projects are generally unique opportunities but when possible, provide a rapid restoration to historical habitat that is very hard to emulate. Success depends on understanding the valley bottom elevation of historic stream channels compared to the elevation of current degraded stream channels, flood hydrology, watershed stability, flood stage up to the 100-year return interval and channel capacity within historic channels.

Often, the current channel has incised to an elevation where it is impractical to re-establish historic channels. In these environments alluvial channels re-establish habitat at a lower elevation by re-working valley bottom sediments the channel has incised into. Large wood habitat has been used to accelerate this lateral migration and habitat development. This is possible in channels that are small compared to the size of large wood structures.

Large debris jams in small degraded alluvial environments must either have enough wood imported to re-establish bank and floodplain roughness to a level equivalent to a healthy forested riparian environments or the level of adjacent riparian forest must be recovered enough to meter the level of bank erosion that results from large wood debris jams in incised alluvial channels.

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These types of project can be very complex and require a high degree of hydrologic, geomorphic and hydraulic analysis in order to maintain a balance between habitat formation over time vs. rapid erosion and instability. The size width and location of debris jams are subject to this analysis as the wood used in these types of projects are larger than what can be moved by the channel at flood stage. Therefore, the wood will have a great influence on the bed and bank erosion and the habitat developed. Wood can be used to push the channel into developing habitat by lateral migration, scour pool development and gravel sorting as long as it is metered by importing bank and floodplain roughness or working in channels where riparian recovery has occurred. Pushing a channel too far too soon can create channel instability at the project site and downstream. This type of project has been completed on two streams within the Hood River Watershed in Oregon.
Debris jams in non-alluvial channels are less complex in design because the channels are laterally stable. Debris jams can be channel-spanning or be formed on a bend in the channel near a pool or locally wide section where transported wood may naturally deposit. Channel-spanning jams require one or two key piece trees that cannot be moved by flood flow. Some natural jams start with a large tree perpendicular to flow, others can start with a root wad facing upstream that then collects material perpendicular to flow. Regardless of the origin, the wood complex that develops begins to backwater upstream channel segments and has a mass that the flood hydrology cannot move. This enhances the depositional nature of the area and helps collect and grow the debris jam above the key wood pieces.

Channel-spanning jams in non-alluvial channels should have stable and healthy stream banks upstream of the debris jam site. Shear stress may increase near and around the debris jam. Large wood that extends up the bank at the highest expected design flows is an important aspect of any channel-spanning debris jam design.

Debris jams that don't span the entire channel can be placed on channel bends, inlets to side channels or near pools. In these locations a key piece can extend into the channel and function to trap more large wood against the key piece and the bank at flood flows. The location and orientation is site specific and requires an understanding of flood stage elevations and hydraulics.

Imported wood that is smaller than would normally stay on site can be used and anchored together to form a debris jam. In this case, ballast and cable or rope must be used to emulate the friction resistance and mass of a key piece with a root wad. When using undersized wood in larger streams or rivers it is very important to calculate hydraulic forces acting on the proposed debris jam. A thorough understanding of the upstream backwater consequences and geomorphic processes occurring on the site are important. As with debris jams constructed in alluvial environments it is recommended that experienced and qualified practitioners design and implement projects in areas where wood transport potential is higher.

1.5.4 Wood Supplementation

Design needs for this technique are minimal. An understanding of mobile wood particles is needed. Logistical requirements needed to get the wood to the stream channel have to be figured out as well as sources for mobile wood material appropriate for use within individual stream channels.

1.6 Project Implementation

1.6.1 Permitting

Information regarding specific permits necessary to proceed with construction are addressed in Chapter 4.6. Information that will generally be required to obtain permits for in-stream wood placement include the volume of the wood and rock ballast incorporated in the project, wetland locations, design drawings, site maps, access areas, sediment control plan, and re-vegetation plan for disturbed sites.

1.6.2 Construction

Large woody debris should be of a size (length and diameter) and species that can remain intact and stable for many years. Use material that would be native to the site. Avoid using species such as alder or cottonwood, which decay rapidly. Coniferous species such as cedar and fir are better choices. If sufficiently large key members are not available or can not be transported in one piece to the site, several trees could be cabled or pinned together to form a composite key member. Large, long logs imported from off-site locations may need to be cut into pieces for transport and then reassembled on site by splicing, gluing and tacking pieces back together.

Appropriating single logs from dry gravel bars is an option with minimal short-term impacts. Consider the density or loading of large wood in the reach before deciding to use on-site wood. If the channel is deficient of large wood, it may be necessary to import wood for the structure(s). One of the factors that will help determine whether off-site wood can and should be imported to the site is whether or not equipment can move wood of the required size and length from a distant site to the work site. Permitting agencies may limit the use of on-site wood, so their approval should sought before proceeding.

Use of on-site wood resources can greatly simplify construction and reduce costs but, has some environmental consequences. Removal of downed wood adjacent to the channel reduces wildlife habitat. Removing standing trees also reduces wildlife habitat by reducing nesting and future potential snag habitat for birds. An analysis of cumulative impacts should be undertaken to insure the removal of wood doesn't create unintended habitat degradation for other endangered species such as spotted owls. Construction activities should not degrade the watershed and create instability or stream sedimentation.

In alluvial channels, wood buoyancy can be a problem during construction since much of the log needs to be installed below the water surface. To address this problem, the site may need to be dewatered to allow for placement and anchoring of large pieces. The use of previously saturated wood can simplify construction by reducing buoyancy problems during installation. Turbidity may also be a significant problem during. This can be avoided by dewatering the installation site, using erosion control fabric, minimizing disturbance area, or by creating a coffer system that isolates the immediate site from flowing water.

Protection of the existing riparian zone is a high priority, particularly in drier climates where replacement of the canopy can take decades. The use of walking excavators, winches and hand labor may be required at some sites. However, it should be noted that using smaller equipment to reduce impacts can in fact increase ground impacts if the equipment is undersized for the job. Undersized equipment can create more ground disturbance by having to drag, pull and push large wood that could have been lifted with a larger machine.

1.6.3 Cost Estimation

Costs for installing engineered log jams are site-specific and are affected primarily by availability of wood materials, dewatering needs and equipment access. Engineered log jams constructed in Washington State have ranged in cost between $1,800 to $80,000 to install.

Large wood placements that are properly sized for the stream channels and require no cabling and placement with an excavator would make this method the least expensive. Excavator costs are generally $120/hour depending on size. Log placement can be very rapid once it is mobilized to the site making this technique potentially one of the least expensive ways to develop debris jams. In remote locations helicopters have been used to transport large wood. Depending on the size of the wood flown helicopters range from $900 per hour up to $8200/hour for a 234 Chinook capable of lifting old growth sized material up to 26,000 pounds.

Engineered log jams are labor intensive and often require an excavator depending on the size, access and amount of wood mobilized to the site. An important aspect of all large wood project costs is the cost of mobilizing the wood and equipment to the construction site. In some cases wood shuttling can be a half-mile or more from a road. This greatly increases project costs. Rubber tired skidders are generally around $70/hour.

Anchored wood debris jams have similar equipment access and logistic variables as other projects however the wood has to be anchored which can increase the cost of the project substantially. Anchoring often requires hand labor and be very time consuming and expensive. For example anchor cabling projects using rock drills can take up to 25% of a total project cost in remote areas. In small streams or areas with little anchoring needed it can be less than 5%.

Wood supplementation is the least expensive aspect of debris jam type projects and requires the use of a dump truck and hand labor to get through wood material off a road or a bridge. Dump trucks are commonly around $65/hour.

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Large woody debris can vary considerably in cost from virtually free (as locally salvaged wood), to quite costly (large-diameter, full-length cedar trees that may have to be sawn for transport and later re-assembled). Large woody debris can cost between a few hundred dollars to a thousand dollars per piece. Equipment costs can also be substantial, especially when specialized equipment is required, such as helicopters for wood delivery, spider hoes for access and considerable manual labor for installation. Appendix L, *Cost of Techniques,* provides additional information and a case study on estimating project costs.

1.6.4 Monitoring and Tracking

Monitoring debris jams should determine if the restoration project is meeting objectives. Because large-woody-debris projects generally involve impacts to the channel and banks, they will require comprehensive monitoring of both channel and bank features, with particular attention to habitat monitoring. For a comprehensive review of habitat-monitoring protocols, refer to *Inventory and Monitoring of Salmon Habitat in the Pacific Northwest –Directory and Synthesis of Protocols and Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia*.[4] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

Monitoring to evaluate structural integrity should be conducted annually and following any flow events that meet or exceed design flow events. This can be accomplished by surveying precise locations of key members relative to a stationary point on shore by determining whether the jam has lost key members and by conducting a visual inspection of anchoring systems.

1.6.5 Contracting Considerations

Construction bid contracts and time and material contracts are two methods that could be used to build debris jams. Time and materials construction provides designers the ability to adjust wood to field conditions found on site. Often unforeseen events create conditions where a field change would make the project better. This is a great advantage to time and materials construction. It assumes a motivated and fair contractor.

To insure exact project costs a construction contract is another way to build a project. This type of contract places more of the cost liability on the contractor. Construction contracts require much more design work because all of the wood placements have to be specified on paper. The disadvantage to construction contracts is there is limited ability to make a change without an adjustment in compensation. In both types of contracting, construction oversight by experienced practitioners is recommended to insure designs are being constructed properly.

1.7 Operations and Maintenance

Maintenance of debris jams should not be required except in a few situations where the jam was no longer meeting project objectives. This should be done only after careful evaluation to determine what went wrong to avoid repeating the mistake. This may include replacement, realignment or removal of pieces following a storm event equal to or greater than what they were designed to withstand. If anchored, the anchoring hardware may also need to be readjusted, replaced, or removed. It is important to properly design and size the large wood material used in any debris jam with the objectives and hydraulic forces expected at the project site. This will help limit the need for any project maintenance.

1.8 Examples

West Fork of the Hood River

A large channel-spanning debris jam was constructed at the upstream end of an alluvial fan that was historically subject to debris torrents. The site was a natural area of deposition within the Pacific Silver Fir vegetation zone. The size of historical large wood material was up 5 feet in diameter. Over time the initial debris jam accumulated more wood from upstream sources and aggraded the channel 700 feet upstream up to 4 feet near the debris jam substantially reducing the average grain sized diameter upstream. Complex over bank habitat was increases and historic side channels are now re-watered during low flow. Off channel beaver activity has increased. The log jam was constructed in 1991 and has sustained numerous over bank flows and one 25-year return interval flood.

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1.10 Photo and Drawing File Names

EDJ Drawing1.dwg
EDJ Drawing 2.dwg
EDJ Photo1
EDJ Photo2
EDJ Photo3

Need a good photo of a large river debris jam