Guide to Placement of Wood, Boulders and Gravel for Habitat Restoration

Draft 9/2009

Please note: this is a preliminary draft and subject to change.
If you have any comments or suggestions please respond by e-mail to kevin.herkamp@dsl.state.or.us no later than November 20, 2009. Please type “LW&B guide comments” in the subject line.
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INTRODUCTION
Over the past century or more, the role of large wood and large boulders in forming and maintaining stream habitat was not understood or was largely ignored. As settlement and development increased so did the removal of large wood and boulders from the states waterways. In some streams, splash dams were built to drive logs down to mills. Opening of the splash dams resulted in a large torrent of logs and water that scoured the streambed and removed wood, boulders, gravel, and other material from the stream channel and riparian areas. Past logging practices often removed trees to the edge of the stream limiting future wood input to the stream. In some cases streams were also cleared of wood and boulders to improve navigation or fish migration. Over time, these, as well as other, activities resulted in depletion of habitat and channel forming structure in many streams. The removal of these structures often narrowed and simplified the stream channel, and sped up the flow of water. These in turn increased the rate at which gravel was moved through the river system. This and other activities such as the construction of dams, culverts, and stream bank protection have limited the availability of spawning gravels for native fish species.

Since natural process have been eliminated, altered, or reduced in many area, aquatic habitat restoration activities are the primary method for reintroducing the necessary structure to stream channels that have been simplified due to past management practices and/or disturbance events. Aquatic habitat restoration activities are also a key to the success of the Oregon Conservation Strategy and the Oregon Plan for Salmon and Watersheds (OPSW). In the broad context of the OPSW, habitat restoration includes a multitude of activities. Aquatic habitat restoration activities are intended to address the watershed functions necessary to support healthy watersheds. This includes improving water quality, water quantity, channel complexity, flood plain interaction and the quality of riparian vegetation. The best approach habitat restoration is recreating a natural event like a windstorm or landslide to guide the structure design. This approach is most effective when the site has all the components for good habitat except for key pieces of wood or boulders to develop complex habitat or limited spawning gravel retention.

This guide has been developed to facilitate the placement of large wood, boulders and gravel in manner that is consistent with these principles. These techniques when done independently or in conjunction with other restoration activities increase the channel complexity and diversity of habitat necessary to help restore and support a healthy aquatic ecosystem.

DESIGNING A PROJECT
In Oregon, the geology and rainfall patterns can be dramatically different from one location to another. One type of structure may achieve the desired effect in one stream but be inappropriate in another. Locating a reference reach or wood jam structures in a stream with the same size and slope as the project stream will increase likelihood of success. The closer the reference area is to project site the higher the probability of creating desired habitat. The reference reach will allow comparison of the frequency of pools, riffles, meander bends, frequency and configuration of wood and boulders, and prevalence of gravel. The size of a log or boulder can be measured to determine why that
log or boulder is in a stable position, and what impacts it had on the stream channel. If a reference reach is not readily available contact the local ODFW biologist for assistance and guidance with the project design.

This guide is intended to focus on restoring natural stream structure, function and processes. Therefore, the use of weirs (e.g., step pools, drop structures), barbs, dams, anchoring, cabling, streambank stabilization, or structural armoring of any kind is also not covered. These actions are technically complex, site dependent, and may affect fish passage, as such are beyond the scope of this guide.

Planning
In planning a wood placement project, the first step is to decide whether the stream is suitable for the placement of large wood, boulders, or spawning gravel. This guide is intended to be used for streams that have an established riparian plant community. The riparian plants contribute branches (coarse wood) and leaves that will eventually be incorporated into any new structure, the roots provide soil stability and the standing trees will eventually replace or augment the large wood that is being added.

Three important questions when planning a restoration projects are:

1: Is the stream fish bearing?
   The information can be found in a Stream Classification Map available from any Oregon Department of Forestry (ODF) district office or from ODFW. It is helpful to determine what fish species is in that stream section since different species have different preferred habitat. A list of ODFW offices and telephone numbers can be found in Appendix A.

2: What is the limiting factor that the project would address?
   Large wood can accomplish multiple purposes by trapping gravel above the structure, create pools and increase the connection with the floodplain vegetation. The limiting factors will influence the number of structures, the spacing between structures and number of logs per structure.

   Boulders can accomplish the retention of gravel by physically intercepting the bed load or slowing the water, increase the interaction with the floodplain habitat by increasing the bed elevation and providing pool habitat. Boulders are most effective in high velocity or bedrock dominated streams.

   Gravel can provide substrate for food organisms, fill voids in wood and boulder habitat structures to slow water and create pool habitat and provide spawning substrate for fish.
3: When can the work be done?
When implementing a wood, boulder, or spawning gravel placement project the project should be constructed during the work period specified in the ODFW has \textit{In-water Timing Guidelines}. This window occurs when the impact to the fish is at its lowest. The \textit{In-water Timing Guidelines} can be found at the ODFW website or by contacting the local ODFW biologist. Placement of wood may be done outside this time period but it would be dependant on the location, type of equipment used, and potential impacts. Contact the local ODFW biologist to determine if this is an option.

\textbf{WOOD HABITAT RESTORATION PROJECTS}

\textit{Introduction}
In the last 30 years, we have learned that large wood is important part of the forest stream ecosystem and is critical for the survival of trout and salmon that inhabit the streams. Large Wood (LW) diverts water flow, changes water velocity to trap sediment or create pools and providing cover for juvenile fish. Pristine and managed streams vary a lot in their debris content, depending on their geographic location, fire history, and time since debris flow, floods or windstorms. The best approach habitat restoration is recreating a natural event like a windstorm or landslide to guide the structure design. So prior to undertaking a large wood project the site, reach, and if possible reference reaches should be assessed in order to ensure the greatest project success.

\textit{Designing a wood project}

The potential effectiveness in changing the stream shape by large woody debris placement varies with the stream’s slope and width. In very steep streams with very large boulders and rocks, log placement will have little impact because the substrate is usually immovable. In low gradient or very small streams, the force of the water may not be enough to move sediment to change the shape of the stream. Figure 1 outlines a “sweet spot” where the combination of the streams width and slope mean that large wood will have the greatest impact on the physical habitat for fish. Streams whose measurements are within this “sweet spot” have enough slope and width to scour and deposit substrate material, yet probably still contain smaller material, which can be moved around when large wood placement changes flow paths. In larger streams, log placement can have a lot of benefit, but logs will need to be stabilized to prevent excessive movement or working along the edge of the stream.

It is quite possible that a given stream already has enough wood in it creating multiple functional logjams. A functional logjam is an assemblage of different logs, branches and leaves of different plant species in different stages of decomposition. This diverse bio-structure provides the base for different aquatic life to find food, shelter, and space to thrive. A logjam also changes water velocity and direction to sort gravels and create pool and riffle habitat.
Determine the stream width and slope

Larger and steeper streams have more stream flow or power that can lift and move large wood that makes large wood placement more complex and may require more expertise. Figure 1 shows the stream slope and bankfull width which, taken together make for ideal, acceptable, or requires review of the design. Figure 1 is based on literature review and experience on effective habitat restoration.

Figure 1. Stream slope and width dimension that constitute ideal, acceptable conditions without extensive review and conditions that would require ODFW review of the plans.

Determining Bank Full Width

Bankfull width is the width of the stream at bank full flow that occurs every 1 or 2 years (Leopold et al 1995). This is also known as ordinary high water or the point where water starts to flow into the floodplain. In lower gradient streams and in wider valleys where the stream has not cut down below the surrounding land (incised), the bankfull mark usually is where the bank slope changes from steeper to more gentle or even flat (see figure 2) Unfortunately most small stream that are candidates for placement work are either incised or confined by side slopes. This is often seen as the stream channel forming a cross section shaped like a V or a U. In those cases look for clues such as an abrupt change in vegetation or the level water drifted material left on the bank or on over hanging branches. Changes in rock color or an abrupt change in texture of the bed or bank material may also be clues.
Bankfull width (also called an active channel width) is measured from one side bank mark to the other. (Figure 2) The width of large islands that would be dry event under bankfull conditions should be subtracted from the bank to bank measurement. To get an accurate bankfull width measure at least 10 points along the part of the stream where the work will be done. The measurements should be at least 1 or 2 channel widths apart covering the length of the project area. Previous stream surveys by ODFW or by other agencies may be used to determine bankfull width.

Figure 2. Cross section of a stream with normal and bankfull flow levels indicated. Area above bank full would be considered floodplain.

Diameter
The key to establishing a logjam is larger diameter wood that resists decay. Conifers (spruce, fir, cedar) have the potential to last 7 times longer than hardwoods (alder, cottonwood, and ash) given the same diameter and conditions and therefore conifers should be used as the key pieces of wood. The combination of conifers and hardwoods increases the complexity of the structure and the hardwoods serve other functions. Since hardwoods break down more rapidly it serves as a feeding platform for a variety of insects increasing biological diversity. Hardwoods also are structurally weaker so during flood events the hardwood pieces will break allowing water pressure to be reduced through the new open area. The smaller pieces move down stream and can be accumulated on the next structure.

Wood can improve fish habitat only if the wood is large enough to stay and to influence water flow. Larger diameter wood retains its size longer as abrasion and decay occurs over the years. Larger diameter wood is more effective in creating pools and complex channels that improve fish populations. The minimum diameter required for a key piece of wood depends on the bankfull width of the stream:
### Bankfull Width Minimum Diameter

<table>
<thead>
<tr>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 10</td>
<td>10</td>
</tr>
<tr>
<td>10 to 20</td>
<td>16</td>
</tr>
<tr>
<td>20 to 32</td>
<td>18</td>
</tr>
<tr>
<td>Over 32</td>
<td>22</td>
</tr>
</tbody>
</table>

## Length

The length of the wood is also important to stability. A piece that is longer than the stream is wide is less likely to be carried away when the water is high. To be considered a key piece a log with a rootwad still attached should be at least one and one-half times (1.5X) the bankfull or a log without a rootwad should be twice (2X) the length of the stream’s bankfull width. As the best fish habitat is formed around jams composed of 3 to 7 logs, at least 2 key pieces should be used at each structure. These logs lengths require a larger storm event to move them to a new location and have a higher probability of becoming stable at the next meander bend or obstruction. Leaving limbs and branches on the logs also increases stability and provides additional cover for fish. Hardwood logs or smaller trees with branches can be added to the structure to accelerated the development of a functional logjam.

## Making wood placement more effective

When ever possible a tree with a rootwad attached should have the rootwad in the active channel. 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. In both windthrow and landslides small material is often pinned under the larger trees so coarse wood should be included in the project.

The first few upstream structures capture most of the coarse wood floating down stream and matures quickly, so the addition of coarse wood is very important for the downstream structures to become fully functional.

## Windthrow emulation

As mentioned earlier one of the keys to a successful wood placement project is to mimic natural processes. One such option is to mimic the deposit of wood that occurs during windstorms. Windthrow emulation is essentially a tree becoming up rooted during a storm and landing in the stream. In a natural process, trees may have only part of the tree in the active channel often with some of the trunk still on the stream bank. The weight of the log on the bank increases the salability and reduces down stream movement. The orientation of the wood is not important because the length and diameter of the wood along with the stream forces will position the wood to form a stable structure. Equipment can manipulate the logs to increase their stability by placing the wood between 2 standing trees that will lock the log in place by creating pivot and stop point (Figure 3 panel A). In addition, one log can be placed on top of another so the weight of the top tree can pin the second tree (Figure 3 panel B). This is a simple windstorm emulation that allows the
wood to adjust to the stream flow. Complex structures with multiple logs with interlocking pieces of wood provide better habitat and would mimic wood accumulation over time. Figure 4 can provide some ideas on the configuration of the key pieces of wood in a restoration structure.

Figure 3. Panel A is single log placed between two standing trees to create a pivot and lock point. Panel B is an X pattern where the weight of the top log pins the bottom log to reduce the movement. Not show is coarse wood (CW) or limbs that will create better habitat.
Large wood may be positioned in the stream in a various configurations. The examples to the left are some patterns that can be used.

To increase hiding areas for juvenile fish, it is recommended that the roots or limbs be in contact with the summer flow channel.

Coarse wood should be added to the structure if the tree does not have roots wads or limbs. The preferred species for the key log species are conifer because they remain intact for a longer period of time. Hardwoods like ash and alder can be a component of the structure to provide other habitat values for insects.

Simple patterns can be combined to form complex structures.

A stream creates the best fish habitat when there are 3 to 7 large logs per structure.
Slide emulation

Another method to recreate natural processes and project success is to mimic the deposition of material that occurs during landslides. Slide emulation is the direct deposit of wood into the channel and achieves a stable position at constricted or shallow sections of the stream. With the length of the logs being twice the active channel, the first higher water will float the logs to the natural choke points. As the flow rises, more force is exerted on the logs locking them in place. This should not be attempted in streams that are prone to flash flooding. Because this approach allows for the natural, repositioning of the logs it should only be used if there are identified choke points and are well above roads. A minimum of 2 meander curves should be between the last placement and any road crossing. This technique can be very useful where ground based equipment cannot safely reach the stream. This strategy can be used by a helicopter where flight hazards prevent placement at the desired location or can be done in conjunction with timber harvest that have a cable highline suspended above the stream and can lower the logs only in the corridors.

Acquisition

Logs and trees to be placed in streams are best obtained from locations where their removal will not conflict with other valuable functions they might serve. Wood within the bankfull flow marks of the streambed should not be used for placement. Those trees should be reserved for shade and long-term wood recruitment into the stream. However, if other trees can fill those functions, streamside trees may be pushed or pulled over into the stream with the rootwads intact. Down wood in the riparian area should be kept for wildlife habitat rather than being relocated into the stream channel. This wood serves as refuge habitat for fish and reduces the chances of avulsion, a sudden changes in channel location, during extremely high flows. Wood delivered by high water events serves an important function. Wood should be repositioned in the stream only as necessary to alleviate threats to public safety or substantial property damage, provided the habitat and resource value of the wood is maintained in that stream segment.

Adding wood in floodplains/wetlands

In most cases it is beneficial to the stream and riparian environment if wood is not just placed in stream but rather in the stream and on the floodplain along the stream. This addition of wood can improve the habitat of multiple-fish and wildlife species, provide refuge habitat during extreme high flow, provide future wood recruitment, and reduce the chances of avulsion or sudden channel shifts following wood placement in the stream. Many watershed professionals look at the entire area where a channel may migrate, this often extends from valley wall to valley wall. Placing wood throughout this entire area is a comprehensive restoration approach and provides habitat and structure to side channels, wetlands, and floodplains that have been lost to development and land use. This approach is most effective in areas where infrastructure or property would not be at risk. However, as with any wood project, in areas where there is development or infrastructure near or downstream of the project area caution must be used to ensure that the wood does not flood or impact those properties.
BOULDER HABITAT RESTORATION PROJECTS

Introduction
In bedrock dominated systems and other areas where it may not be practical or effective to place large wood, boulders can be used to create complexity in the stream. Projects of this type should occur only in channels with intact, well-vegetated riparian areas or be conducted in conjunction with riparian restoration and/or management. This approach needs to be carefully designed to provide stable functional structures and in many cases additional permitting and agency review may be required. In order to ensure fish passage and reduce risks it is recommended an ODFW fisheries biologist be contacted and involved in the planning and design of any such project.

Designing a boulder project
Boulder placement is most effective in high energy or bedrock dominated stretches of stream where spawning gravel and summer pool habitat is lacking or where large wood is not readily available. Placing boulders in streams not dominated by bedrock can narrow the channel, increase scour, widen the channel, alter the direction of the thalweg, cause erosion, and increase channel meandering. The key to success with a boulder project is to ensure that the boulders are sized appropriately for the stream system and placed in clusters or patterns that replicate natural stream conditions and that do not substantially modify stream hydraulics. In general, boulders should only be placed within stream channels where rock and boulders would naturally occur but are currently lacking.

For the purpose of this guide, boulders structures are not suitable for placement in:
- Low gradient meadow streams. Boulders in meadows warm the water by collecting solar radiation and cause significant changes in channel hydraulics, which can possibly destabilize the channel and banks.
- Gravel rich streams with a high bed load movement. In gravel rich streams scour around the boulders may cause the boulder to move down stream and slide into the new scour hole and eventually become buried by the gravel as it sinks rendering them ineffective (Fischenich and Seal 1999).
- Stream where the streambed and banks are composed primarily of small gravels, silts, or sands. In these systems the effects of boulders can be unpredictable and require specialized planning and design.
- Unstable, braided or aggrading channels.
- Streams with a gradient of more than 10%.

When developing a project to address spawning gravel recruitment there needs to be enough water backed up to maintain a wetted channel during lower flows. The use of unanchored wood to occupy part of the channel is important during high water events since they occupy the upper portion of the water column creating slower moving water in the area upstream from the wood. The combination of water being impeded at the streambed and the upper water column creates a deposition zone that extends further up stream.
The boulder constellations can trap gravels at the edges of the stream and narrow the summer flow into defined channels. The water will move through the collected gravel along with a narrower channel have less area exposed to daytime temperatures keeping the water cool. On bedrock streams this can turn shallow sheet flow into summer rearing habitat. The water flowing over the top of the boulders during high flow events maintains the pools in the spaces between the sets of boulder constellations. The first sets of boulder constellations may trap most of the bed load, so gravel may be needed added for the down stream boulder sets to become functional. Boulders are effective in capturing gravel where large wood can intercept wood drifting down the stream. The combination of boulders and large wood can turn a bedrock-dominated stream to complex in stream habitat with pools, riffles, and cover that can support a wide range of fish species.

Boulder Sizing

Boulders can provide stable habitat structures if the boulders are properly sized and orientated in relationship to the stream flow. For stability, it is recommended that key boulders be a minimum of twice (2X) the diameter of the average of the 10 largest naturally occurring boulders in the project stream reach. The intent of this is to identify a size for key boulders that is sufficient to be stable under expected high flows (typically a 25-year recurrence interval). Smaller sizes of key boulders should be used only if a shear stress analysis of the stream reach shows that a smaller boulder would be stable at high flows or if the overall project will be stable. In gravel rich streams it maybe difficult to determine the size of the boulder because of the boulder is partially embedded into the streambed or in bedrock areas there may not be many reference boulders. In those cases or where the 2X boulders are not available, a shear stress analysis of the stream reach may be needed. Shear stress analysis involves specialized expertise and is used to calculate the size of the boulder that would be stable at high flows. This analysis is especially important if there is a structure downs stream such as a culvert or water intake. For the purposes of this guide, boulders must not be permanently anchored (including rebar or cabling to meet size or stability criteria).

Boulders change the water velocity and can be used to create a variety of habitats. The table below provides a rough guideline on the stream velocities needed to move different sizes of sediment. By speeding up or slowing down the water velocity, bed load sediments can either be transported or deposited.
Table 1. Approximate threshold conditions for granular material to start moving (adapted from Erosion and Sedimentation, Pierre Julien, 1995).

<table>
<thead>
<tr>
<th>Material</th>
<th>Size</th>
<th>Diameter</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>in</td>
<td>m/s</td>
</tr>
<tr>
<td>silt</td>
<td>medium</td>
<td>0.0160</td>
<td>0.0006</td>
</tr>
<tr>
<td>sand</td>
<td>fine</td>
<td>0.1250</td>
<td>0.0049</td>
</tr>
<tr>
<td>sand</td>
<td>very coarse</td>
<td>1.0000</td>
<td>0.0394</td>
</tr>
<tr>
<td>gravel</td>
<td>very fine</td>
<td>2.0000</td>
<td>0.0788</td>
</tr>
<tr>
<td>gravel</td>
<td>very coarse</td>
<td>32.0000</td>
<td>1.2600</td>
</tr>
<tr>
<td>cobble</td>
<td>small</td>
<td>64.0000</td>
<td>2.5200</td>
</tr>
<tr>
<td>cobble</td>
<td>large</td>
<td>128.0000</td>
<td>5.0400</td>
</tr>
<tr>
<td>boulder</td>
<td>small</td>
<td>256.0000</td>
<td>10.0800</td>
</tr>
<tr>
<td>boulder</td>
<td>medium</td>
<td>512.0000</td>
<td>20.0000</td>
</tr>
<tr>
<td>boulder</td>
<td>large</td>
<td>1024.0000</td>
<td>40.3500</td>
</tr>
</tbody>
</table>

Arranging the Boulders

For the purposes of this guide the most appropriate method of boulder placement is to mimic natural boulder accumulations by installing non-full spanning boulder structures such as randomly placed boulders, boulder fields, clusters or constellations that do not restrict fish passage(See figure 5). Full spanning structures like weirs, cross vanes, J-hooks, Newberry riffles or other drop structures while useful in certain applications require specialized expertise and significant design considerations for fish passage and stability therefore are not covered in the scope of this guide. More information on full spanning structure can be found at the Washington Department of Fish & Wildlife Habitat Technical Assistance website: [http://www.wdfw.wa.gov/hab/ahg/shrg/18-shrg_drop_structures.pdf](http://www.wdfw.wa.gov/hab/ahg/shrg/18-shrg_drop_structures.pdf). Even non-full spanning structures when placed at the wrong angle or location can create additional problems that may not be easy to correct. Therefore it is recommended that the local ODFW biologist be contacted as they can review and make suggestions on the proposed structures and identify possible advantages and disadvantages. Finding a reference reach near the project site, where boulders are providing the desired habitat, will also increase the success of the project.

In order to ensure the most effective and least problematic design the following criteria should be followed when designing and implementing a project. Individual bolder constellations should not exceed 1/3 of the active channel width and not shift the stream flow to a single flow pattern in the middle or to the side of the stream. If the channel is narrowed to one pathway, it will increase the velocity, can cause excessive erosion and can simplify the stream habitat. The boulder constellations should have gaps between constellations to allow adult and juvenile fish passage. It is recommended that there is a minimum of a 2-foot gap between constellation structures to allow adult and juvenile passage. By staggering the positions of the boulders and not placing them along just one side of the channel an alternating pattern of water flow around the boulders is created this allows the water to be concentrated in a travel pathway with resting areas for juvenile...
fish. This concentrated flow allows passage during low flow periods therefore no more than 25% of the cross-sectional area of the flowing channel at the time of installation (e.g. low flow channel width) should be blocked. The use of coarse wood placed under the boulders may extend into these fish passage gaps to increase the recruitment of gravel. Smaller (12-18 inches) rock may be place upstream from the gaps to allow resting places for juvenile fish. The distance smaller rock should be placed away from the boulder should be equal the diameter of the small rock. The combination of boulders, smaller rock and coarse wood replicates a small landslide.
Small trees, 6-12 feet in length can be added to any boulder constellation to enhance bedload capture.

Boulders may be positioned in the stream in various configurations. The examples to the left are some patterns that can be used.

The first series of boulders should act as a velocity break and are spaced farther apart (C1 or C2).

Boulders are placed in a tighter configuration to form sets of boulders that are 1-2 channel widths in length. This backs water up to create pools and areas for gravel to settle.

The next boulder set located downstream so top of the first boulder in the downstream set is at the bottom elevation of the upstream set.

Figure 5 is examples of boulders constellations that can be used to slow the water down to collect gravel. Each constellation may have their orientation changed to meet the site-specific requirements. For clarity of the illustration, the boulder constellations are spaced further apart than what will be used in the habitat restoration project.
Making Boulders more effective

Boulder clusters capture bed load in two major ways. The first, is physically intercepting the bed load that is sliding or salting down stream. Salting is where a bed load material slide along the stream bottom and occasionally being suspended over a short distance and may bounce off of larger material before resting in a stable position. The second way is to reduce the velocity of the water to a point where bed load material cannot be carried.

The greatest accumulation of bed load material occurs when 30 to 60 % of the pre-project bankfull area is occupied by boulders or a combination of boulders and wood. For example, if 50% of the pre-project bankfull area is occupied, the 5-year floodplain may become the new bankfull elevation, and the existing 25-year flood elevation may become the new functional 5-year floodplain area. This elevation is important to determine if the new flood elevation may impact infrastructure such as roads of buildings and to determine the amount of winter refuge habitat created. The acceptable percentage of occupied bank full area must be determined on a site-specific evaluation of surrounding land uses, infrastructure, and landowner concerns.

The interception of bed load that is sliding or salting can be illustrated in figure 6 where each structure blocks the down stream the direct down stream movement of coble or gravel.
Figure 6. Shows the accumulation of bed load material above boulder constellations with gaps to allow fish passage for all life stages at all flows.

Bolder cluster also create low velocity backwater conditions upstream side of the structure. Raising the effective bed elevation, thereby reducing channel slope and also decreases. Backwatering commonly induces sediment deposition and increases the water surface elevation upstream of the structure at low to moderate flows. At high flows, backwatering effect of the structure is evident provided the structure lies high enough in the channel profile and reduces the channel cross-section. Deposition upstream of a structure is particularly common in moderate to high bed load channels. Sediment deposition upstream of the structure is not as likely for low bed load or incising channels due to limited sediment availability. The upstream extent of backwater depends upon the scale of the structure and the slope of the channel. Backwater effects extend much further on low-gradient streams than on high gradient streams. However, if the structure causes a significant reduction in channel cross-sectional area or a series of structures collectively increase the hydraulic roughness of the channel, backwater effects may be more far reaching. Effects of large-scale backwatering can include increased flood levels and frequency of floodplain inundation, potential change in riparian species composition and distribution in response to changing inundation patterns and water table elevations, and reduced reach transport of sediment. Other effects associated with reduced sediment transport include channel aggradation, channel widening during high flow event and confinement during summer flows, and increased channel meandering.

Slide Emulation
Landslides produce a combination of material that is delivered to the stream to provide the components for complex habitat structures. In bedrock dominated areas the singular use of either wood or boulders may not achieve the desired effect. Unanchored wood can trap gravel but during channel forming events can float allowing the accumulated gravel to be transported down stream. Boulders used as the only material can intercept the gravel but as the water level raises any wood will be carried down stream. Adding boulders to a large wood project can fill in the gaps to slow down the water by increasing the pool depth. Projects in the Umpqua River Basin found that adding a ½ cubic yard boulder for every 10-foot of tree length provide good results in long term retention of gravel. Smaller boulders can be used when adding to a wood dominated structure because the wood can reduce the pressure on the directly boulder by slowing the water or indirectly by slowing down the water to partially burying boulder and thereby reducing the area exposed to the water force.

Wood can be added to a boulder structure to assist with gravel deposition or to scour pools. The wood can be place in configurations in figure 4 to provide complex lateral pool habitat in the gaps between the boulder constellations or as a full spanning suspension log to increase the deposition of bed load or to scour pools at high flows.
GRAVEL HABITAT RESTORATION PROJECTS

Introduction
Areas that are appropriate candidates for the placement of large wood and or boulders frequently also lack adequate abundances of spawning gravel. Adding gravels to the stream to supplement the existing gravels can be an effective method to jumpstart the creation of areas capable of supporting spawning fish. However, prior to a gravel placement project it is important to identify why gravel is limited in the project reach. Without addressing the causes of limited gravel (e.g. lack of structure to retain gravel, upstream dams that are blocking gravel recruitment) any augmentation will only be temporary and not provide long-term benefit.

In streams where there is active bed load movement of gravel the addition of wood and boulder structures as mentioned previously in this guide will help slow the transport of gravels and retain them in the system. However, supplementation may be needed to address short-term deficiencies or speed up the recovery process. When the restoration project involves a long reach of a stream, the first few structures may intercept all the gravel and coarse wood until such time as sufficient gravels accumulate and flows move the gravels to the next structure down stream. Addressing the short-term deficiency by the placement of gravel above the wood or boulder structures in the middle and lower segments will achieve the full function in a shorter timeframe.

Designing a gravel project
The primary purpose of placing spawning gravels is to improve spawning substrate by compensating for an identified loss of a natural gravel supply. Therefore gravel placement should occur only in locations where gravel would naturally occur but is currently lacking and be done in association with a current or past in-stream habitat restoration project. The following criteria allows for the stream to naturally sort and distribute the gravel to provide optimum spawning habitat and suitable substrate for aquatic insects:

a) Gravel should be made up of multiple sizes of material, with no more than 5% of the gravel being smaller than 0.25 inch and 10% of the gravel being larger than 4 inches
b) Gravel should be rounded (less than 25% fractured face), composed of hard durable particles resistant to weathering, and be composed of similar type of rock to that which is found in the stream basin. Organic soils, silt, clay or soft friable particles should not be included as part of the gravel placement
c) Gravel must come from a commercial source or an upland source outside of the riparian area. Removing gravels from a stream system typically requires a permit and agency review as it is not always considered restoration and can have other impacts to the stream system.
d) Fabric or wire mesh must not be used to hold the gravel in the stream. Experience has shown that these only provide limited short-term retention and pose future risks to fish and wildlife species in the waterway. The placement of coarse wood to retain gravel is encouraged.
e) Gravel placement should not be done in low gradient depositional areas where historically they would not be present.

As accessibility to project sites is highly variable gravel may not be able to be placed in the most desirable manner or method. The best option is to add gravel at the time of the construction of in-stream wood and boulder structures as gravel can be placed with the available equipment. In areas with limited access or where impacts to riparian areas need to be minimized or avoided the use of a conveyor belt or helicopter can be effective methods to deliver gravels. With any of these methods gravel can be placed above a structure to properly seed the area or below the structure to allow it to be mobilized to downstream structures. If the gravel is placed to be mobilized with the first significant rain event the deposition should not exceed 1/3 of the active channel width and at no time block fish passage.

Gravel placement is not an appropriate restoration technique as a stand-alone project in most circumstances. In high-energy channel reaches, gravels may be washed out of the reach in a relatively short period of time. High-energy sites are typically dominated by cobbles and boulders where such material is available or by bedrock or hardpan where it is not. In bedrock-dominated streams the lack of in stream structure may be the only limiting factor. A survey of the stream should include notations on pockets of gravel accumulated at the streams edge, next to wood or boulders hydraulic shadow. Some high-energy sites might have supported salmonid spawning habitat in the past, but the historic gravel deposits have been scoured out due to channel modifications that have increased the shear stress on the channel bed preventing the retention of gravel.

**LITERATURE CITED**

