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Maximizing the Benefit of Smaller Engineered Log Jams – Scoping Report

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Sean Kimbrel

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The motivation of this scoping proposal is to explore whether the installation of multiple, smaller wood features (e.g. many single key pieces), rather than a few, large, racked ELJs in a different orientation or anchoring, can provide the same or more habitat benefits. However, in general, smaller wood is more mobile and can impose unintended consequences to downstream infrastructure or not achieve desired habitat or geomorphic feature development if lost in the first flood following construction.

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Executive Summary

Maximizing the Benefit of Smaller Engineered Log Jams
Scoping Proposal X5796
Report of Findings

Prepared by: Sean Kimbrel

Introduction

Large wood, also known as large woody material or large woody debris (LW) within rivers has an influence on geomorphology and habitat (e.g. Montgomery et al., 1995; Abbe and Montgomery, 1996). Simply put by Montgomery et al (2003), when a tree falls into a river, it may remain intact or break into smaller more mobile pieces. Depending on the relative size of the tree and the size of the channel it fell into, the tree may remain stable at or near where it entered the channel or it may be transported downstream to lodge against the bank or in a logjam, or completely exit the system. Stable “key” pieces of large wood influence local channel hydraulics and sediment transport and can influence rates of bank erosion, create pools, or initiate sediment deposition and bar formation (e.g. Montgomery et al, 2003). Naturally present large wood in streams in the western United States has been historically removed for various reasons, such as navigation, for the conveyance of timber via splash damming (Montgomery et al, 2003), and the reduction of flooding. In recent years, in order to meet environmental goals of improving the habitat for endangered species that have an affinity to the presence of large wood jams, engineered log jams (ELJs) are often used in river restoration/rehabilitation design for such goals, in addition to other benefits such as establishing bank protection to protect infrastructure.

In degraded river systems, the general absence of large key pieces requires the design and construction of ELJs with a combination of smaller large wood pieces and likely some form of anchoring or ballasting (D’Aoust and Millar, 2000). Many ELJs are designed to remain stable for objectives of producing local effects on channel processes, in addition to minimizing risk to public safety and property (e.g. D’Aoust and Millar, 2000; Knutson and Fealko, 2014). In general, the stability of wood in rivers can be gaged by the size, shape, orientation, and species relative to the size of the channel (Montgomery et al, 2003). Once a key piece is established, smaller racking and loose members can lodge on key pieces to form a larger jam. Because of the large effort to “bridge the gap” in producing a large enough geomorphic process with LW that is symbiotic to dependent aquatic species. Designing and placing several large wood pieces racked on top of each other with ballasting can be costly and limited in scale of improving habitat locally in terms of improving cover and biota for aquatic species of interest. The net habitat benefit with few, large ELJs could possibly be less than if multiple smaller well-placed and well-designed ELJs were installed, such a few singular key pieces which allow the racking of other wood material. Just as well, the costs associated with installing large, racked ELJs could be substantially higher than with multiple, smaller ELJs. This habitat enhancement concept of large versus small is highly dependent on the scale and dynamics of the fluvial environment. For example, smaller treatments are more applicable to smaller (first to third order) streams, as opposed to sixth order or larger streams.

The motivation of this scoping proposal is to explore whether the installation of multiple, smaller wood features (e.g. many single key pieces), rather than a few, large, racked ELJs in a different orientation or anchoring, can provide the same or more habitat benefits. However, in general, smaller wood is more mobile and can impose unintended consequences to downstream infrastructure or not achieve desired habitat or geomorphic feature development if lost in the first flood following construction.

It may be important to first note or at least discriminate the difference between "small" and "large" wood. Some guidance documents and state laws provide a distinction. For example, Knutson and Fealko (2014) define large woody material as including any log of a diameter equal to or greater than 12 inches at breast height (DBH) and 10 or more feet in length. The newly enacted Washington State law regarding the limited liability in placing large wood in rivers also gives the same sizing designation and that the wood must be tagged for identification purposes (See the Revised Code of Washington (RCW_77.85.050 http://app.leg.wa.gov/RCW/default.aspx?cite=77.85.050). However, in some cases, what would be considered a "large" piece of wood would be relatively small on larger river systems, or a "large" piece of wood is indeed a large piece of wood on a smaller system. In further discussions in this scoping report, the terms smaller versus larger wood are meant in a relative sense. Smaller wood in this document is referenced as a relatively smaller size that would provide cover and biota in comparison to large ELJs, but could be larger than a discriminate split set by laws or guidance documents. The idea of smaller wood in the conceptual sense is the application of ELJs to be oriented in a smaller footprint to elicit a similar geomorphic change such as pool formation as a large ELJ would, or wood that is placed to be mobile and have the ability to rack against larger, stable features.

The following research questions were developed at the onset of this scoping study to address this issue of installing a few, large and stable ELJs as opposed to many smaller ELJs:

1. *What body of knowledge (literature) is available documenting the efficacy of designing and implementing smaller (less number of members) ELJs as opposed to large, racked ELJs on smaller fluvial systems in terms of habitat benefit and reducing risk?*
2. *Of the documented cases of implementing smaller ELJs, what were the associated factors of stability/mobility, failure modes, and what was the fate and damages associated with smaller mobile wood? How do these damages compare to damages sustained with larger ELJs?*
3. *Can smaller ELJs be designed to maintain the same stability (e.g. through orientation or ballasting) as larger ELJs or to passively break up during mobilization to minimize downstream damages?*

The goal of this scoping study is to explore potential research avenues on the design of smaller, more mobile wood features that also maximize habitat benefits in the long-term. This information may be beneficial for future planning, design, installation, and monitoring of ELJs for habitat restoration, which is applicable to several Reclamation habitat enhancement programs across the western United States.

Question 1: Literature Review of Small Wood Design Guidance

There is already an available body of knowledge to assist in the design and implementation of stable ELJs with multiple members. These design guidelines would certainly be applicable to the design of smaller, single pieces of wood for habitat projects. Reduction of risk has been addressed by incorporating design features to force the wood to be stable or allow it to be mobile during future floods. Habitat benefit of mobile wood is relatively limited in literature due to the complex life cycles aquatic species may have, particularly salmonids, across large spatial areas, and with the more recent application of this concept in river environments. Additional information from the literature review are discussed below.

The framework of re-introducing wood in rivers can be thought of as an "active" (placement) and/or "passive" (recruitment and transport) format. Wood in rivers is both a static and transient (mobile) process, with the composition of large "key" pieces, medium "racking" pieces, and small "loose" wood pieces (e.g. Montgomery et al, 2003; Manners et al, 2007). For example, in order for wood to form log jams, it must be introduced to the stream from various inputs from the forest and streambanks (e.g. landslide, deadfall, or erosion) and move through the fluvial system (e.g. Abbe and Montgomery, 2003). Wood loads in rivers vary based on the watershed's hydrology, geology, and ecology (e.g. forest characteristics and species that are inputs into the river). As a way of conceptualizing the storage and movement of wood and sediment in rivers, Eaton et al. (2012) developed a reach-scale long-term stochastic model estimating the temporal change in storage of sediment and wood in a reach based on a varied set of large wood processes of input, decay, and mobility. The model had three different base cases; first where wood was not allowed to move and form jams, the second where wood is mobilized but does not form jams, and the last where wood was allowed to mobilize and form jams. The long term results in the latter case showed more temporal variation in sediment storage and sediment output compared to the former case for the same reach, which presumably results in greater spatial and temporal variability of the channel morphology and physical habitat. The gain in temporal variability and greater habitat benefits with the mobility of wood, however, can pose risks to public safety and infrastructure.
In the past, the body of literature cites ELJs as not being effective given their original purpose or goal, too small or too simple (e.g. Frissell and Nawa, 1992; D'Aoust and Millar, 2000; Southerland, 2010). However, the process to design and place LW ELJs in river systems has improved in recent years. There are several sources available to consult in the design of a stable ELJ with consideration to site conditions. Examples include Herrera Environmental Consultants' *Conceptual Design Guidelines: Application of Engineered Logjam*s (Herrera, 2006), the Natural Resources Conservation Service's Technical Supplement 14J (NRCS, 2007), Rafferty (2013), most recently the Pacific Northwest Region's Large Woody Material – Risk Based Guidelines (Knutson and Fealko, 2014), and soon, the current development of a nationwide, Large Wood National Manual by Reclamation and the Army Corps of Engineers. Building off the works presented by Embertson and Monahan (2012), Knutson and Fealko (2014) provide risk-based design guidelines for the design and placement of ELJs in the Pacific Northwest Region with consideration to public safety and property damage. Because any modification to a complex system is not a simple feat, the given design team charged with implementing large wood into streams has moved toward an interdisciplinary effort, with members having expertise in hydrology, hydraulics, geology, fluvial geomorphology, fish biology, civil engineering, and other fields.

In general, design guidelines are typically used to size and place large wood according to the location and scale of the river system. The goals and objectives are set, the site conditions and constraints are identified, and the level of risk and effort is identified. Based on the time and spatial requirements set in the objectives, a force-based analysis is typically utilized with various potential failure modes such as buoyancy, sliding, scour, or rotation, with the application of safety factors, is applied to an ELJ design.

In cases where public safety and property damage is of relatively high risk, an additional amount of cabling and/or ballast material would likely be required in the design to keep smaller pieces stable.
Knutson and Fealko (2014) provide a brief introductory list of possible fasteners for application in the design and construction of large wood structures. They note that the best method to prevent catastrophic failure or the bulk transport of a large wood structure is to not use any fasteners on secondary pieces, so that they may mobilize one piece at a time.

The habitat benefit as a result of the placing of instream structures are generally described in Roni et al (2008). Since their review, the continuance of aquatic habitat enhancement for restoring endangered species provides the opportunity to build upon whether the benefits are purely from the physical changes stable large wood presents and/or whether mobile wood provides additional benefits. Discerning between the two in the natural environment is a difficult process.

Question 2: Associated Factors of Small Wood Mobility and Failures

Of the documented cases of implementing smaller ELJs, what were the associated factors of stability/mobility, failure modes, and what was the fate and damages associated with smaller mobile wood? How do these damages compare to damages sustained with larger ELJs?

There are studies available documenting the factors of stability and mobility of designed LW in streams. Factors that affect stability include forces of buoyancy, sliding, scour, or rotation which mobilize the structure and change the way the structure was originally intended to function. For example, D'Aoust and Millar (2000) field assessed 90 different ELJs in three different arrangements within British Columbia over the period of 1997-98 using a site-specific and force-based approach with factors of safety to determine the function of these structures. The three types of arrangements were a single log structure, a multiple log structure, and a single log structure with a rootwad. In addition, Southerland (2010) notes the success and failure of various ELJs in Washington State based on the location of the structure and the ratio of the channel radius of curvature to channel width.

The perceived risk of the mobility of large wood during floods is of chief concern to public/private property owners, public users, and other relevant stakeholders. In terms of the fate and damages of large wood as a result of catastrophic failure and mobilization, only anecdotal information was found regarding property damage and racking of wood on bridge piers. Without tagging or other tracking methods, it is difficult to track individual pieces of large wood among other materials conveyed during floods. The tagging of wood in ELJs is now a requirement for projects in Washington State (see RCW 77.85.050). The tracking of large wood is currently in performance by a Trout

Unlimited chapter in New Hampshire (MacCartney et al. 2013), on the Elwha River by University of Washington researchers, and most recently, an implemented loose wood project by the National Forest Service on the Yankee Fork of the Salmon River. Schenk et al (2013) tracks the mobility of tagged large wood through the Roanoke River in North Carolina to form a wood budget for the system. These studies can provide useful evidence of the fate of LW that is mobile in river systems.

Question 3: Smaller ELJ Applicability

Can *smaller ELJs be designed to maintain the same stability (e.g. through orientation or ballasting) as larger ELJs or to passively break up during mobilization to minimize downstream damages?* Because there is limited existing literature on designing and implementing many small ELJs, it opens up potential research avenues and application of this concept.

There can be risks to adding smaller, more mobile, large wood to a river when downstream infrastructure is present (e.g. undersized bridges, private property, diversions, etc.). In terms of the engineered placement of mobile wood, there is an unknown availability of guidance. Future research efforts could build upon providing guidance for practitioners.
Before this concept is applied to any river restoration project, the designers/decision-makers need to refer some other form of risk-based analysis (e.g. Knutson and Fealko, 2014) which covers the process of identifying the risk of implementing wood material in a particular river restoration project. Knutson and Fealko (2014) provide relative risk matrices for public safety and property damage for a given reach/study area. Using guidance similar to the process they have developed would be critical in moving forward with the decision to implement the following potential conceptual application of using smaller key pieces actively placed in a river system to allow the capture of mobile wood. For example, if the results of the Public Safety and Property Damage Risk matrices from Knutson and Fealko (2014) show both low-to-moderate risk in a particular reach *and* reaches downstream, the following concept of passively creating ELJs could apply.

Based on field studies presented in Abbe and Montgomery (2003) and discussions in Montgomery et al (2003), ten different types of ELJs can be classified, and different types of obstructions can be described. Of the four different types of obstruction, two noted are the vertical and pitched orientations of wood. These orientations show the most promise in terms of the most stability with the least amount of wood actively placed.

According to observations made by Davidson (2011) during flume studies, and the conceptual framework of large wood movement developed in Eaton et al (2012), the rules governing the movement of individual wood pieces are relatively simple. Eaton et al (2012) applies the probability of movement as the product of two conditional probabilities. The first being the relative size of the large wood piece to the channel width, and the second considers the effect orientation has on the key piece. Eaton et al (2012) notes that they neglect a third condition which is the effect of LW diameter on movement. Individual pieces of wood naturally deposited in streams generally maintain an orientation that is either slightly skewed or parallel to stream flow direction (e.g. Abbe and Montgomery, 2003; Eaton et al, 2012).

Multiple wood pieces placed in a vertical orientation, and in an array similar to the orientation of a larger natural key log with the direction of flow can simulate the one larger key member, collecting racking and loose members of woody material during higher flow events. This feature would emulate the natural process of wood falling, transporting, and forming jams in the river system.

For example, if the restoration goal/objective is to create split flow and more channels in a particular reach, rather than racking wood to form a gravity foundation, wood placed in a vertical orientation as piles would be the particular type of jam utilizing the least amount of materials and have a smaller extent. However, depending on site soil conditions, the placement of wood piles into coarse alluvium can be difficult and expensive. The placement of the piles can be spaced at approximately the sturdy log length, identified by means of taking an inventory of potential wood inputs from upstream forests.

Next, the recruitment of wood or supplementing with loose pieces of wood to rack against key members would then form a larger ELJ. In some cases of streams that are below dams which obstruct the recruitment of wood from upstream sources, racking wood members could be augmented into the stream to collect on downstream stable key members. This is similar to the idea of augmenting gravel into streams to increase the availability of spawning habitat for salmonids.

If the risk of public safety or property damage is too great (e.g. greater than Moderate according the risk scale in Knutson and Fealko, 2014), besides the construction of ballasted or anchored ELJs, out-of-channel modifications to the river system is recommended in order to provide the future ability of restoring the natural mobile supply of wood in the river system. The process of implementing smaller, more mobile wood would include education to the public using the particular reach of river. As far as preventing property damage; bridge modification, protection of in-channel structures, and protection or acquisition of property are means to allow the conveyance of wood through the river system.

Summary

Summarizing the above research questions and supplemental information, the first question can be answered in that there is already an available body of knowledge to assist in the design and implementation of stable ELJs with multiple members. These design guidelines would certainly be applicable to the design of smaller, single pieces of wood for habitat projects.

The second research question can be partially answered in that there are studies available documenting the factors of stability and mobility of designed LW in streams. Based on the hydrology of the system, factors of buoyancy, scour, sliding, and rotation of the structure can be accounted for to stabilize the structure, perhaps with fasteners and/or ballast material, meet the design objectives of the feature. In terms of the fate and damages of large wood as a result catastrophic failure and mobilization, only anecdotal information was found regarding property damage and racking of wood on bridge piers. Studies are currently in progress by other public entities studying the movement of tagged LW in streams. In terms of differentiating designing and impacts of a few, small wood structures versus many, large wood structures, no literature was found pertaining to this subject. Further research could identify any new efforts, or the development of this effort could be performed with a partner charged with implementing habitat enhancement features.

The third research question can be answered partially in that smaller wood structures can be designed with factors to increase stability to match larger wood features that have more ballasting and key members of wood. For example, the orientation of wood structures are oriented vertically as piles and arrayed in an orientation like a large log pointed downstream so that the pile structure is allowed to rack woody material in transport from upstream sources. The construction of piles as part of an ELJ is widely applied, with the general addition of racking members that are fastened to the pile structure.

Allowing the racking of material from upstream sources without fasteners could be a risky venture which affects public safety and downstream property/infrastructure. However the benefit of this approach can be a less costly system managed by the river itself. If there are natural wood supplies in many systems that can be incorporated into the design/implementation and it may cost less to design and construct a smaller wood feature. If systems are degraded to the state that there are no upstream wood sources due to deforestation or dams blocking conveyance, augmentation of wood in the river system could be implemented.

If the risk of implementing mobile wood is identified as too great, it is important to note that rather than modifying the river channel itself, means to allow the movement of wood in the river system could be implemented, such as the resizing or protection of bridges, and protection or removal of downstream in-channel and floodplain structures.

Future research and implementation avenues include the following:

1. Scoping/Communication:
    a. Review of habitat benefits of large wood implementation projects. Although the benefits of habitat are not easily translatable or scalable to other projects with a given set of different goals, environments, or species, information can be gained in conducting a survey of practitioners that have implemented large wood projects that are intended to be stable and/or mobile who are monitoring the habitat benefit to a particular species. This would be similar to the *Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques* performed by Roni et al. (2008).
    b. Evaluation/coordination of tagged large wood implementation projects that are passively placed. Wood projects that are passively placed are relevant to design smaller ELJs that are allowed to be mobile and possibly provide habitat benefits. This information is not widely available compared to the relatively longer practice in implementing larger stable ELJs.

2. Proposal:
    a. Demonstration wood augmentation project of a river system below a dam. This type of demonstration project, with habitat monitoring, would provide a dataset to answer the question of whether there is an increase in habitat benefit with smaller mobile wood as opposed to installing only larger stable ELJs.

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