Improving Public Safety of Large Wood Installations: Scoping Proposal Report of Findings

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Connie Svoboda, Hydraulic Engineer, Bureau of Reclamation, Hydraulic Investigations and Laboratory Services, Technical Service Center, (303) 445-2152, csvoboda@usbr.gov

Christopher Cuhaciyan, Hydraulic Engineer, Bureau of Reclamation, Pacific Northwest Regional Office, (208) 378-5143, ccuhaciyan@usbr.gov

Sean Kimbrel, Hydraulic Engineer, Bureau of Reclamation, Sedimentation and River Hydraulics, Technical Service Center, (303) 445-2539, skimbrel@usbr.gov

Introduction

Large wood structures (i.e., large woody debris, engineered log jams, large woody material, etc.) are an important component of Reclamation's overall river restoration strategy due to the many realized benefits for fish and other aquatic organisms, for channel stability, and for protection of infrastructure. However, large wood structures can pose a public safety hazard to river recreational users such as boaters, swimmers, fisherman, and children. In many remote locations this is not a concern but, closer to populated areas these issues become increasingly important to consider. Installing large wood structures in rivers can produce what are known in the boating community as "strainers." Flow through or flow beneath the structure can pin boaters or swimmers against the structure or pull them under the water surface. Large wood structures also produce an attractive location for fishing, playing, and climbing. Design features such as structure porosity, structure orientation, log submergence, percent river obstruction, and use of cables and metal bars affect the safety of the structure. Public safety is typically considered during the design process; however, there appears to be lack of cohesive information on this topic. In addition, the liability associated with large wood structures has become a widely discussed topic within the river restoration community.

A technical workshop on Large Wood Applications and Research Needs in River Restoration was hosted jointly by Reclamation & U.S. Army Corps of Engineers in February 2012. The primary goal of the workshop was to provide an opportunity for individuals and agencies that are actively working in the field of the engineered large wood structures to collectively develop a road map for future large wood research needs and priorities. The workshop summary report identifies the need for design criteria to improve the safety of structures as high priority (Bureau of Reclamation, 2012). Reclamation is currently developing a manual on engineered logjams and wood placement in river restoration. Research conducted in the area of the safety of large wood structures can be used to augment this manual and serve as a single point of reference for design and installation of safer large wood structures.

The goal of this scoping-level study is to identify specific research gaps on safety issues and determine the best way to address these gaps in order to design and install safer large wood structures. Researchers identified four major topics relating to safety issues of large wood structures:

1. Public Safety – human interaction with large wood structures
2. Structural Stability – failure and downstream movement of part or all of large wood structures
3. Liability – identifying responsibility for accidents and damage related to large wood structures
4. Risk Analysis – determine the likelihood of adverse outcomes related to large wood structures and the consequences of those outcomes

This scoping level paper will focus on these four topics areas. A brief literature review was conducted on these topics and research needs in each area were identified.

Public Safety

Public safety, in this instance, involves the dangers of human interaction with large wood structures. Wood can pose a significant hazard to swimmers, rafters, kayakers, tubers and other recreationists in rivers. People can be literally pinned against the structure by the force of approaching water, entrapped under or against the structure, or snagged on branches. American Whitewater's paddling accident database (www.americanwhitewater.org/content/Accident/view) shows that wood is among the leading factors contributing to paddling deaths.

There are many factors that should be considered when designing a large wood structure which can enhance public safety. These factors are outlined in the following sections.

Porosity of Large Wood Structure

The porosity of a large wood structure is the measure of voids or empty spaces in the structure. Porosity often reflects the amount of water that flows through a structure. The force of water flowing into and through the voids can increase the force that might pin boaters and swimmers to structure, causing entrapment. Log structures are often referred to by boaters and swimmers as "strainers".

Structures with little to no porosity force water to move around the structure which provides forces in directions that are likely to help a swimmer or boater to also move around the structure. In addition, the reduced direct flow-through reduces the forces that would otherwise press and hold a person, boat, or other equipment to the structure. Therefore, low porosity structures may be an important design consideration in high river use areas.

Several techniques are available to reduce flow-through in a structure. The logs may be placed tightly together but this can often only work to reduce the porosity as the natural materials generally will not provide for a tight seal. Other options include filling the structure with slash or rock which can provide ballast making the structure even more stable.

The interstitial spaces within the structure provide substantial habitat which is often the goal of projects. This requires carefully balancing the requirements of the habitat structure with the safety needs of the public.

Flow under the Structure

Logs located just above or somewhat submerged below the water surface can produce an entrapment hazard and may be difficult to see. Large wood structures are designed for a specific design discharge which determines the level of wood submergence. The recreational flow range should be compared to the exceedance curve for the river to determine when boaters will be exposed to the structure (Embertson and Monahan, 2012).

Orientation of Wood

The orientation of logs determines the flow patterns and scour near and around the structure. Vertically oriented logs are an impact or entrapment hazard for boaters and swimmers. Placing logs at an angle towards the downstream may be more effective at deflecting boaters during impact with a structure. More research is needed to determine if different log orientations can be equally effective while minimizing public safety risk.

Structure Placement/Percent River Obstruction

Safe log structures only partially span a river channel and provide a safe navigable area to allow boaters and swimmers the ability to reasonably and safely avoid the structure. River spanning logs can also form large symmetrical hydraulic drops (“holes”) which can be extremely dangerous. Large wood structures should not be located downstream of “drops” or swift current. Rather they should be placed where recreationalist have ample visibility, stability, and time to safely react.

Anchoring

Large wood structures can be anchored with cable, rope, chain, rebar, and similar hardware in order to minimize the movement of logs. Large wood structures are typically designed for a specific river flow. Above the design discharge, there is no expectation that the structure will remain stable and intact. Anchoring can provide further assurance that the structure will not move at discharges lower than the design discharge. However, anchoring mechanisms are a possible entrapment hazard for boaters and swimmers. Plus the materials tend to have a very long lifespan, typically much longer than that of the wood in the structure. This leads to unnatural and dangerous materials being left on the rivers long into the future, which possess unknown and long-term risk. In addition, many landowners, funding agencies, and permitting agency do not allow structures to be anchored with hardware. Researching safer ways to anchor structures could improve the safety of large wood installations.

Visibility

Large wood structures should be highly visible to boaters and swimmers well in advance of the approach such that they have time to safely avoid the structure. An equation should be produced to determine the reaction time of a recreationalist to the large wood structure. This approach is similar to a traffic engineering framework for driver reaction time to avoid accidents. The total reaction time to avoid an accident is the sum of the time to recognize a hazard, time to physically move to the brake, and the device response time. Placing logs on a river bend may be good for protecting bank lines or producing habitat, but the sight distance to the structure should be checked to ensure that boats and swimmers have enough time to evade the logs.

For a given large wood project the sight distance to the structure should be identified. If the structure is located on a bend or downstream of significant drops or turbulence, the sight distance must be more than in a calm, straight section. With a specified design river velocity, the amount of time that a recreationalist has to avoid a structure can be calculated. This should be compared to the total reaction time of a typical recreationalist, comprised of time to recognize the hazard, time to start paddling or swimming, and the time to paddle or swim away from the structure. If the recreationalist does not have sufficient time to avoid the structure, the structure location should be moved or signage should be posted. This type of approach could be included in Reclamation's upcoming manual on engineered logjams and wood placement for fish habitat and river restoration.

Availability to Avoid Structure

If a logjam cannot be safely navigated, there should be a clear avenue for portaging around the structure. American Whitewater notes that an upstream eddy or set of eddies upstream of the structure is valuable for safety and portage (Colburn, date unknown). The stream bank should not be too steep to traverse and the near-bank velocities should be low.

Limiting Access

Large wood structures can be attractive locations for fishing & playing. There should be education and outreach with the local community about the purpose of large wood installations and the potential dangers to the public. Signage or limiting access with fences or other obstacles may be valuable in minimizing human interaction with the structure.

Structure Stability

The loss of stability of large wood structures can cause damage at and downstream of the structure, which can lead to the loss of habitat enhancement goals at the site. The amount of damage to property and infrastructure downstream due to large wood structure mobility is dependent on the size of the wood members or wood cluster, the forces experienced during mobilization at flood flows, and the amount and resilience of property and infrastructure affected. Because large wood structures may become a hazard to life and property during large flood flows, the stability of the treatment becomes paramount in minimizing the possible liability the landowner, sponsor, designer, and/or constructor could experience if life and property damages were to occur as a result of the mobilization of a large wood structure. Where there is significant valued property and infrastructure present near a large wood structure, there should be increased importance on designing for longer-term stability of the installation. This will also benefit the objective of increasing aquatic habitat with the treatment, along with other possible objectives (e.g. recreational safety).

Large wood structures can be simple, comprised of only 2 or 3 logs, or they may be built with fifty or more logs to maximize the benefits of the structure and minimize the chance of structural failure. These large structures can be hazardous for recreationalists. If logs are installed in an optimal configuration, it may be possible to accomplish the same project goals with fewer logs. More research is needed to determine the best configuration of logs in a logjam structure for specific project goals, such as habitat production.

One of the challenges of installing large wood structures is that they tend to not be static over time. Wood recruitment from natural or free floating logs in a river may alter an initially safe structure. The base load of logs in a river should be considered when designing a large wood structure. Collecting information from installed projects to see how installations change over time would give designers information on possible changes due to wood recruitment.

Stability

A compilation of guidelines for assessing the stability of large wood features during a range of flow events will be part of the content in the Large Wood Design Guidelines, which is currently being led by Reclamation (DJ Bandrowski) and the US Army Corps of Engineers (Jock Conyngham), with the support of several experts in the field of designing and installing large wood structures for aquatic habitat enhancement. One of the intentions of these guidelines is to provide the current state of science for designing large wood structures with consideration of longer term stability. Related investigations by others including D'Aoust and Millar (2000) assessed the stability of ballasted wood debris habitat structures through a design approach.

Currently there is a limited amount of literature available for assessing the stability (or mobility) of large wood features and the resulting fate and/or damages as a result of failure. One of the few available sources is a study by the Natural Resources Conservation Service, where a field evaluation of constructed large wood features in Washington was performed by an interdisciplinary team (Southerland, 2010). This study documented the field performance of large wood structures constructed in the mid-1990's, and less so on the fate of wood pieces that became mobile. Several factors relating to channel response and structural stability of the larege wood structures were derived in the study. One of the big factors driving the stability or mobility of large wood structures placed on the outside of channel bends was the 'tightness' of the channel bend (channel bend radius divided by bankfull width). The tighter bend, the less likely the feature is to remain stable. The study found that 40 percent of bend Jam Type structures became mobile after 5 years of monitoring and 60 percent of bend jam style large wood structures exposed to main channel flows became mobile.

Mobility

A hypothesis can be formed that depending on the size of the fluvial system, the size of wood, and natural wood recruitment in the watershed, naturally occurring wood jams may have been more mobile and transient than current habitat enhancement programs and projects possibly design for. There is literature documenting the stable key members influencing the recruitment and creation of large wood structures controlling local channel hydraulics on rivers in the Pacific Northwest (Abbe and Montgomery, 1996), but little is known at the moment regarding the dynamics of mobility and transience of smaller wood members and features during large flow events, particularly in more arid systems that may not have naturally had such 'large' wood. Specifically, what may the difference be in terms of geomorphology and aquatic life cycles between large wood structures that are meant to remain stable (e.g. installing 'key' features to influence planform and morphology), as opposed to providing allowance for some mobility of both large, medium, and small wood features to form log jams by the driving morphology of the fluvial system?

There is currently little literature known or available describing a quantifiable increase in spatial and temporal habitat around in-place large wood structures that are meant to remain stable as opposed to mobile additions/loadings of wood. Southerland (2010) touched on the goal of assessing the short term vs. long term fish habitat benefits through further investigation. Recent studies by MacCartney (2013) applied tagged mobile wood to a degraded stream with little infrastructure downstream to improve habitat for aquatic species, and tracked the movement of wood loadings through repetitive surveys. The study demonstrated a mix of stable and transient wood features with the mobile additions forming wood debris clusters with the influence of hydraulic processes. Ultimately, the issue with performing mobile additions is limited by the knowledge of potential damages that can be caused by mobility and the associated liability.

Relevance

The topic of habitat performance of stable versus mobile wood structures could benefit from a literature review through a scoping proposal. This niche or field within large wood could be relevant to conducting detailed performance assessments of constructed wood projects or as part of developing techniques to model linkages between biologic benefit and use and hydraulics, both identified as high priority research items in the large wood research workshop (Reclamation, 2012).

Liability

Liability associated with large wood structures has grown as a topic of discussion in recent years. Often, there are multiple agencies, funding sources, designers, installation contractors, landowners, and others involved in a project. A common question then, is who is responsible for any negative consequences of the structure. Washington State (WA State HB 1194) and Oregon State (Oregon Law ORS 496.270) have both recently implemented laws regarding the liability. In certain situations, those involved in the installation and landowners have no liability assuming specific conditions for the design and implementation are met. Unfortunately, these conditions can’t always be met or are not always in the best benefit of projects goals. Reclamation currently has no formal stance on liability of large wood structures other than to reduce risk whenever possible following professional standards of the trade.

Risk Analysis

In order to understand the degree and type of liability that may be present, there must be some way of determining risk. Without risk, liability is less of an issue. Practitioners can design the structure based on the risk at a particular river location and the tolerance for risk at that location.

Reclamation’s Dam Safety Office uses risk analysis to estimate dam safety risks for a range of potential failure modes. Reclamation has published a best practices manual describing different levels of risk analysis and the components of a risk analysis study (Bureau of Reclamation, 2011). Risk is defined as the likelihood of an adverse outcome and the consequences of that outcome. A risk analysis is a quantitative calculation or qualitative evaluation of risk. A risk assessment is the process of deciding whether risk reduction actions are needed.

The major components of risk analysis include:

- What are the failure modes?
- What is the probability of failure?
- What are the consequences if failure occurs?
- What is the associated risk?

After failure modes are identified, an "event tree" is formed to designate the probability of each outcome. Some possible failure modes for large wood structures are:

- Scour and subsequent destabilization of the structure
- Flood event greater than design flood
- Human interaction
- Impact of incoming debris
- Recruited debris causing instability or added scour from recruited debris
- High sedimentation (burial)
- Material (structural) failures
- Improper placement of materials or anchoring

Consequences for dam safety consider loss of life; however, for a large wood installation, consequences may include:

- Private property damage
- Public infrastructure damage (bridges, roads, utilities, etc.)
- Personal injuries
- Loss of life
- Loss of habitat feature or other project benefit
- Negative public perception
- Lawsuits

Another approach to a risk analysis framework is the use of logistic regression. Logistic regression uses the probability of failure (0) or success (1) based on the probability of various outcomes. An assessment model is another tool that graphs risk based on structure characteristics and reach characteristics (Embertson and Monahan, 2012).

Many researchers agree that a risk assessment approach would be valuable for large wood installations. This type of approach would help designers and project managers determine how to design and secure large wood structures and where to place installations to minimize risk based on potential consequences at the site.

Summary of Research Needs

This document defines four major topics that would benefit and improve public safety of implementing large wood structures:

1. Large wood design and placement
2. Structure Stability and Mobility
3. Risk Analysis
4. Liability

The following research subjects could provide benefit for one or more of the above major topics:

1.) Many researchers agree that a risk assessment approach would be valuable for large wood structure installations. This type of approach would help designers and project managers determine how to design and secure large wood structures and where to place installations to minimize risk based on potential consequences at the site.
2.) Traffic engineering framework for identifying reaction time to avoid large wood structures.
3.) More research is needed to determine the best configuration of logs in a logjam structure for specific project goals, such as habitat development.
4.) Developing application methods of implementing smaller large wood structures while minimizing risk and maximizing habitat benefits.
5.) Database of information on installed projects showing how installations change over time. This would give designers information on how a structure may change when exposed to a certain base load of logs in a river.
6.) Research safe ways to anchor large wood structures that do not require cable, chains, anchors, or other non-natural or non-degradable materials.
7.) Provide design guidance to help understand how structures may fail so that they may be designed to fail as safely as possible.
8.) Improving design elements for safer large wood structures such as porosity, flow through, and log orientation.
9.) Assessment of habitat performance of stable versus mobile wood.

The authors selected two research paths into fiscal year 2014 and beyond that would benefit the four major topics from a technical perspective, which are 1) improving the safety of large wood structures from a design standpoint, through the focus of enhancing the safety of features in the design process, and 2) developing application methods of implementing smaller large wood structures while minimizing risk and maximizing habitat benefits. Proposals for funding these research paths will be pursued.

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