EFFECTS OF VEGETATION IN CHANNELS

A summary of findings regarding vegetation interactions with channel processes and potential application to the lower Boise River

Picture courtesy of Frauke Koenig

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Boise River Flood Control District #10

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- DISCLAIMER -

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EXECUTIVE SUMMARY

One hundred and fifty years ago the Boise River was an un-managed, natural river. With the introduction of mining activities in the Boise River Basin in the late 1800s, the construction of Arrowrock Dam in 1915, Anderson Ranch Dam in 1950, Lucky Peak Dam in 1957 and the growth of population centers in the Lower Boise River Basin, the Boise River has evolved into a semi-channelized, managed urban river. Prior to these modifications the average bankfull width of the Boise River, just upstream of Eagle Island, was approximately 274 m. Now it is approximately 43 m. Before construction of the dams, the two year recurrence peak flow was approximately 10,700 cfs. Now it is 3,700 cfs. In its current configuration, the Boise River serves a broad range of constituencies including agriculture (through a system of irrigation canals), urban water supply, recreation (fishing, boating, municipal parks), habitat for a broad range animal species (including trout, deer and bald eagle) and provides an esthetically pleasing corridor for the cities of Boise, Eagle, Star and Caldwell. As these communities have grown and closed in upon the river, flood control has become a primary concern for those that live and work along the river as well as those who are responsible for managing the river and its environment.

Several flood control districts were created, along the Boise River, in response to the need for professional flood control management. Boise Flood Control District 10 (FCD10) was created in 1970 with a charter to *"...protect life and property along the Boise River and its tributaries."* Operational boundaries for FCD10 extend from near the Plantation Golf Course in Boise to just upstream of the steel bridge in Caldwell [(1)]. Common work for FCD10 includes the removal of woody debris deemed to pose a hazard to life and property in the event of a flood.

Historically, FCD10 has been granted river maintenance permits via the issuance of a joint permit from the Idaho Department of Water Resources (IDWR) and US Army Corps of Engineers (USACE). These permits enable FCD10 to work within the channel of the lower Boise River to reduce flood hazards. In the context of these permits and with respect to large woody debris (LWD) in the river, the operational philosophy of FCD10 has been to remove all LWD from the conveyance channel. In the recent past, when the river corridor was relatively undeveloped, access to work sites was generally unencumbered [(2)]. In that environment, FCD10 was able to remove wood from the river and place it well outside of the conveyance channel.

Recent development of the river corridor has led to a reduction in access locations for FCD10 (2). Starting in 1993 wood removed from the conveyance channel was placed in large debris piles along the bank of the river. Whereas previous work was conducted at the channel margins, current channel maintenance work is performed within the main channel by "walking" machinery up and down the channel from the nearest access location (2).

Recent concerns over the size, number and stability of these debris piles has caused FCD10 to review its permitting and management practices. As part of the review process, FCD10 is seeking input from all of the affected stakeholders. Having been identified as a stakeholder and institutional member of the community, the University of Idaho at Boise organized a course titled "Effects of Vegetation in Channels" to conduct a literature review and study of how vegetation along stream corridors interacts with and influences stream channels. As members of the river community and as partners with FCD10, the University of Idaho and the students of the CE504: Effects of Vegetation in Channels class have surveyed the relevant literature and produced this report in effort to inform the current understanding of the effects of LWD in urban rivers. The findings of this report are described, briefly, in the following sections.

The effects of vegetation and wood debris on river channels are very complex. Findings in the literature vary widely and sometimes are in conflict depending on climate, type of vegetation, and river characteristics (type of bed, hydrology, etc). Traditionally, wood has been removed from rivers to increase conveyance and reduce the flood peak water levels. Recently it has become understood that removing wood from a river can destabilize the channel, increase erosion and sediment loading and cause bank failures. Conversely, properly located wood can stabilize the river channel and provide hydraulic diversity, improve aquatic habitat for species living in the river corridor and improve flood conveyance. For example a study of engineered log jams installed in the Williams River (a river with flow hydrology very similar to the Boise River) in New South Wales, Australia found that Engineered Log Jams (ELJs) improved bank stability, sediment storage and habitat diversity without a loss of structural stability of the wood structures through several flood events and without an increase on the water surface elevations during these flood events. To ensure a successful installation of large wood in an urban stream, detailed hydraulic and engineering assessment of the proposed installation must be performed prior to installation. Sample hydraulic calculations are demonstrated in Chapter 5 of this report.

It would be worthwhile to recognize that if FCD10 takes the decision to adopt a regime of retaining LWD in the Boise River it will represent a significant departure from the management regime that has, in the past, served FCD10 reasonably well. It should be further understood that the practice of managing LWD in urban streams is not well defined. Though there have been many LWD projects, few have been monitored or well documented. As such, a decision to retain LWD in the Boise River creates both opportunity and uncertainty. One method that has been used successfully to manage natural resources in the presence of risk and uncertainty is adaptive management (AM). Fundamentally, AM is a process of assessment, design, implementation, monitoring and adjustment. We believe that FCD10 managers would be well served to adopt AM as part of any program that introduces or retains LWD in the Boise River.

CHAPTER 1: INTRODUCTION

1.0 Introduction

Rivers play an important role in moving nutrients, sediment, woody debris, and biota through the landscape. They are used by humans for fisheries, transportation, hydropower, and industrial, domestic and agricultural water supplies. The transformation of river corridors into urban and suburban landscapes is one of the most substantial alterations of American waterways today. Through time such modifications can give rise to extremely different hydrologic and ecologic characteristics of the river systems. River modifications include the acute impacts of dams and diversions, channelization, and long term hydrologic and sediment modifications that are the results of these activities. There are also natural resource concerns inherent to any landscape that becomes more urbanized. In the lower Boise River these resource concerns and trends include increased flooding.

The upper Boise River Basin, upstream from Lucky Peak Dam, is mountainous and sparsely populated with an average gradient of 2% [(3)]. Beginning in 1862, the discovery of gold in the upper basin preceded agricultural development in the lower basin. In the past, parts of the upper basin were heavily mined for gold using shaft-mining and placer-mining methods [(3)]. Although several canals and ditches were constructed for agricultural purposes, most farmers were initially able to take advantage of the slough system that already existed along the meandering river's floodplain. As agriculture continued to increase within the lower Boise River Basin, farmers soon began to recognize the need for flood control and the storage of irrigation water [(3)].

The Boise Project, one of the earliest Bureau of Reclamation (BOR) projects, was developed in 1905 to address the need for flood control and irrigation storage [(3)]. As part of the Boise Project the New York Canal and several small irrigation diversions were completed by 1906 [(4)]. Arrowrock Dam, located 10.5 km upstream from the City of Boise, was built in 1915 to provide flood control as well as storage for irrigation water [(4)]. This was followed by the construction of Anderson Ranch Dam on the South Fork Boise River in 1950. Lastly, Lucky Peak Dam was constructed approximately 6 km upstream of the City of Boise in 1957. Both Anderson Ranch and Lucky Peak Dam were constructed by the US Army Corps of Engineers (USACE) primarily for flood control [(3)]. Annual flooding has been reduced substantially since the construction of these three major dams due in large part to a combined storage capacity of one million acre feet between the three reservoirs. Reservoirs created by these dams reduce flooding in the lower Boise River and store water for use during summer irrigation.

Climate in the lower Boise River Basin is characterized as semiarid; winters are cool and wet, and summers are warm and dry. Ada County has a four season climate with generally mild temperatures. Average daily temperatures during the summer months are around 21°C with average highs reaching approximately 32°C during July and August (NOAA website, accessed May 2011 at URL http://www.wrh.noaa.gov/boi/climo.php). Average daily temperatures during the winter are just below freezing with average winter highs just above freezing temperatures. On average, the weather station in Boise receives just over 305mm of precipitation annually, including 508mm of snowfall a year. The maximum amount of snowfall on the ground in the valley at any one time rarely exceeds 152mm. Precipitation is heaviest during the winter and spring, while summers are typically characterized by dry, hot weather. Growing season for most agricultural crops is late April through early October.

The 3,341-km^2 lower Boise Basin, from the outlet of Lucky Peak Dam to its confluence with the Snake River at Parma, Idaho, stretches approximately 103km [(5)]. The lower Boise River Basin is in the northern part of the western Snake River Plain and lies in a broad, alluvium-filled basin with several steplike terraces which are more pronounced and continuous on the south side of the river. The basin floor slopes northwestward at a gradient of approximately 0.2% [6]. The altitude of the basin near Lucky Peak Dam is approximately 850m above sea level; the altitude near the river mouth is about 670m [6]. In addition to the lower Boise, several tributaries are interconnected by a complex system of irrigation canals, laterals, and drains that have been constructed over a period of time replacing many of the sloughs within the lower Boise River.

The flow regime in the Lower Boise River changed significantly between pre- and post-dam construction. Due to irrigation water releases, the late summer flows within the lower Boise River are found to be significantly higher than late summer flows compared to the pre-construction condition. The opposite is true in the case of winter flows. Winter flows in the lower Boise River were found to be significantly lower in the post-dam construction time period, sometimes approaching near zero. It was not until a second outlet was installed in Lucky Peak Dam to implement a minimum release of 150 cfs for the purpose of diluting effluents entering the river from waste water treatment facilities, that winter flows would be maintained in the river. In addition, the reservoirs, combined with flood control operations, have suppressed annual peak flows. For example, the two year recurrence peak flow calculated at Boise River at Glenwood (USGS 13206000) is 3,700 cfs. Using a re-constructed record of flow for the lower Boise River that represents unregulated flow, the two year recurrence peak flow was 10,700 cfs almost three times that of the regulated two year peak [7].

The habitat of the lower Boise River has changed dramatically over the past century, as indicated by comparison of recent (1994–2002) and historic (1867 and 1868) habitat features [4]. The dramatic change in river habitat stems from the reduced peak flows as well as anthropogenic alterations to the river banks. Both historic and recent data were available for average bankfull width, channel forms, and number of sloughs in the basin. The average bankfull widths measured in most reaches in recent years have decreased to less than one-half of the historic width [4]. For example, the historic average bankfull width of 274 m upstream of Eagle Island has decreased to 43 m. Historic channel forms and parafluvial surfaces (coarse sediments within the active channel and outside the wetted stream) have almost disappeared from all reaches of the lower Boise River. Gravel and sand bars were dominant downstream of Eagle Island, but these habitat features either have been stabilized or have been exposed. Historically, sloughs were abundant in the lower Boise River downstream of Eagle Island. Recently, the sloughs either have been filled or converted to irrigation drains.

The lower Boise River flows through the area of Idaho that contains the most industrialized and urbanized sections of the state. Land use and land cover in 1994 within the lower Boise Basin consisted of urban activities, irrigated agriculture (pasture, other agriculture-related activities), rangeland, water, and unclassified land [5] [8]. Due to several factors, including but not limited to, low cost of power, economic strength, and affordable property, both population and demand for water resources in the lower Boise Basin increased rapidly. In addition, land use in the lower Boise Basin has undergone major changes resulting in conversions of large tracts of farmland to residential subdivisions and commercial facilities.

Development along the area known as Eagle Island began as early as the 1860's when acreage was acquired for farming. Initially farmers took advantage of the system of sloughs that regularly routed water from the river to agricultural lands. Subsequently, irrigation canals to divert water from the Boise River to farm fields were constructed. Through time the canal system replaced the slough system, and sloughs were subsequently filled in or converted to regulated irrigation canals.

The Boise River channel geometry and flow characteristics at the head of Eagle Island have dramatically changed through time. Typically, flows are thought to have split around the island at approximately 70 percent in the north channel and 30 percent in the south channel [2]. Gravel deposits at the head of the island have altered flows so that they are now about half in the north and half in the south channel [2].

CHAPTER 2: HYDRAULICS, DYNAMICS, AND MORPHOLOGY OF VEGETATION IN CHANNELS

2.0 Introduction

The interactions of vegetation in the riverine environment are complex and can vary based on the characteristics of the river basin (environment), river channel (transport corridor), hydrologic regime (system forcing), vegetation type and distribution pattern (availability) and alteration history (natural events and anthropogenic impacts). The affect of vegetation upon channel hydraulics can be considered with respect to the following general: 1) rooted vegetation and the affect on channel hydraulics, 2) uprooted, mobile vegetation and the affect on channel hydraulics, and 3) uprooted, stable vegetation and the affect on channel hydraulics. Rooted vegetation will be considered to be any growth of vegetation that is either living or dead, but still maintains a connection to the substrate via a root system. Uprooted, mobile vegetation will be considered to be pieces of debris that are actively conveyed by channel discharge. Lastly, uprooted stable vegetation will be considered to be pieces of LWD and smaller debris that accumulate within the river network but are rarely transported with channel discharge. This review focuses primarily on large woody debris (LWD), typically defined as any piece with a diameter greater than 10 cm and length greater than 1 m, and its movement with channel discharge. Understanding how naturally stable debris structures form is expected to help inform management in an urban environment.

The interaction between flowing water and the vegetation in the river system is one component influencing the morphology of rivers containing vegetation and LWD. Many of the studies investigating morphological effects of wood in rivers have focused on forested, undeveloped catchments despite the worldwide importance of agriculture and urbanization that has modified many river systems [(9)]. This review summarizes morphological effects of wood in rivers, understanding that results in undeveloped catchments may not be strictly representative of the modified state of the Boise River. Lastly, implications of managing vegetation in rivers from a hydraulic and geomorphic perspective are briefly summarized.

2.1 Hydraulics of Rooted Vegetation in Rivers

Any scenario leading to a fluid moving through vegetation will result in the generation of drag forces. The resulting velocity gradients and eddies cause local momentum losses [(10)]. The energy losses and resulting change in velocity gradients can cause a marked variation from the typically assumed logarithmic velocity distribution when flow is interacting with vegetation. Figure 1 below shows velocity distributions resulting from interactions with vegetation.

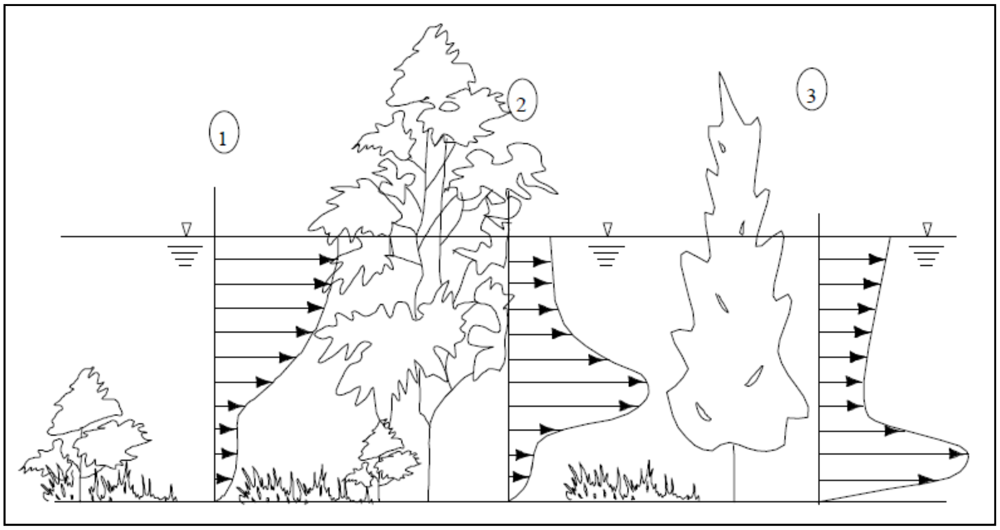

Figure 1. Velocity distributions for submerged and unsubmerged vegetation. From Fischenich (2000).

Since the drag resulting from vegetation can have a large effect on velocity and ultimately the water surface elevation, calculations of roughness in vegetated channels should account for vegetative drag [(10)]. Along with vegetative influences, surface roughness also influences total flow resistance. However, the impact of surface roughness is typically only significant for very shallow flows and vegetative drag becomes the dominant roughness factor for most flow conditions of interest [(10)].

When vegetation influences flow, an estimate of the vegetation density is typically needed to perform calculations estimating the roughness contributed by the vegetation. To estimate the vegetation density present in the channel, several methods have been proposed [(11)]. The point frame method consists of aerially measuring the number of vertical points that contact either vegetation or the ground surface to estimate vegetation density. The board method consists of moving a board away from a horizontal observer until 50 percent of the board is obstructed by vegetation. The resulting distance is related to vegetation density using some relevant distribution. The camera method uses a variable focus optical instrument to sight though vegetation to a background grid. Recently, work by Schneider et al. (2011) [(12)] has demonstrated that vegetation density can be estimated using image analysis techniques. Figure 2 below shows an example of how image analysis can be used to estimate vegetation density.

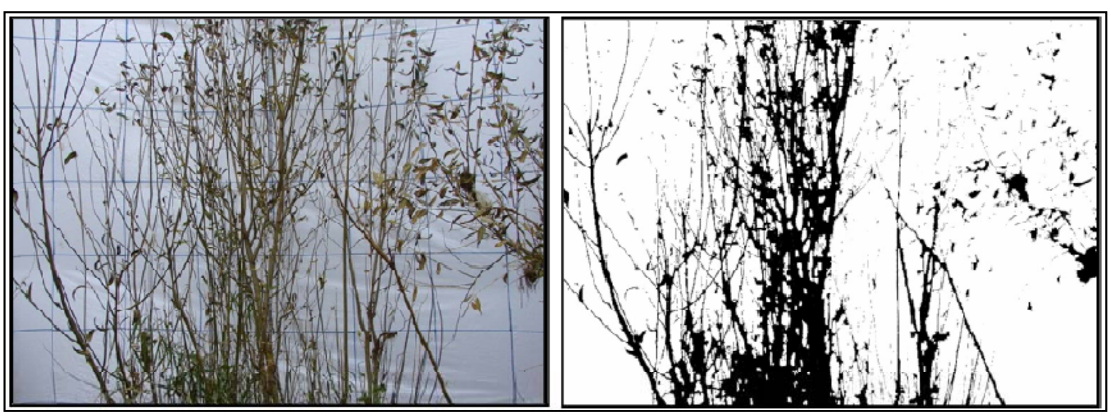

Figure 2. Image analysis techniques used to estimate vegetation density Natural vegetation in front of image grid is shown at left with final vegetation density analysis depicted at right. From Schneider et al. (2011).

The structure of most vegetative species becomes altered in the presence of dynamic fluid forces. Figure 3 shows the bending action of vegetation under flow conditions. The bending of vegetation in the presence of fluid flow is dependent on age, type, density, and size of vegetation. Refer to Chapter 5 for a more detailed analysis of vegetation and hydraulics that is specifically related to the Boise River.

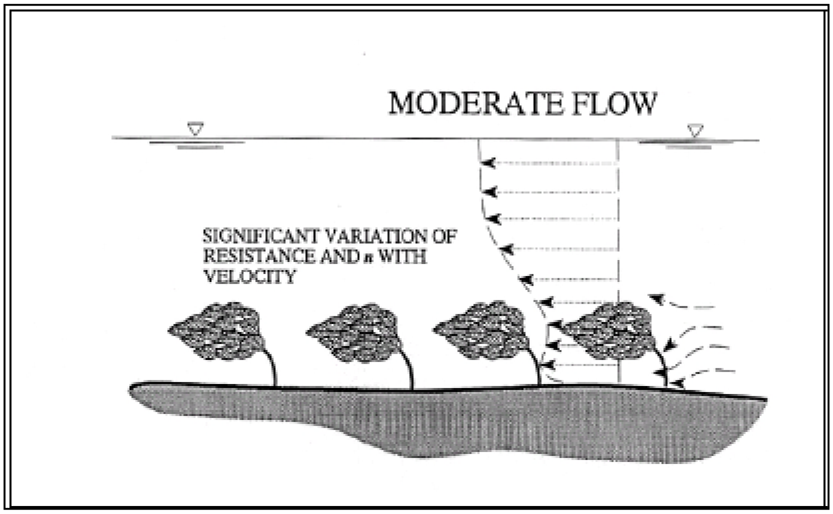

Figure 3. Plant bending at moderate flow. From Freeman et al. (2000).

2.2 Hydraulics of Uprooted, Mobile Vegetation in Rivers

2.2.1 Single LWD Hydraulics

Understanding when and how woody debris moves in channels is important for informing management practices. Braudrick and Grant (2000) [14] studied wood pieces to determine the thresholds of movement for pieces without rootwads (wooden dowels) and pieces with rootwads (wooden dowels with end discs). They found that, for all diameters tested, logs oriented parallel to flow were more stable than those oriented at 45°or 90° to the flow. Their findings also suggest that woody debris with rootwads are more stable than pieces without rootwads. Piece stability increased by 39% when pieces were oriented at 0° and by 71% when rootwads were added to the wooden dowels. Piece length was not found to significantly affect piece stability suggesting that buoyant forces dominate over drag forces. This study used wooden dowels that were shorter than the flume width, removing the interaction of the bed and channel banks for pieces that are shorter than bankfull width. Although not specifically studied, the researchers observed that pivoting seemed to be an important factor initiating motion for pieces oriented 45° or 90° to the flow [14]. Figure 4 below shows observed and predicted motion initiation parameters for the flume study conducted. In the figure, L_{log} is log length, D_{log} is log diameter, d_w is water depth, d_b is the buoyant depth of the log (depth at which flotation occurs for a horizontal channel), v is flow velocity and g is the acceleration due to gravity.

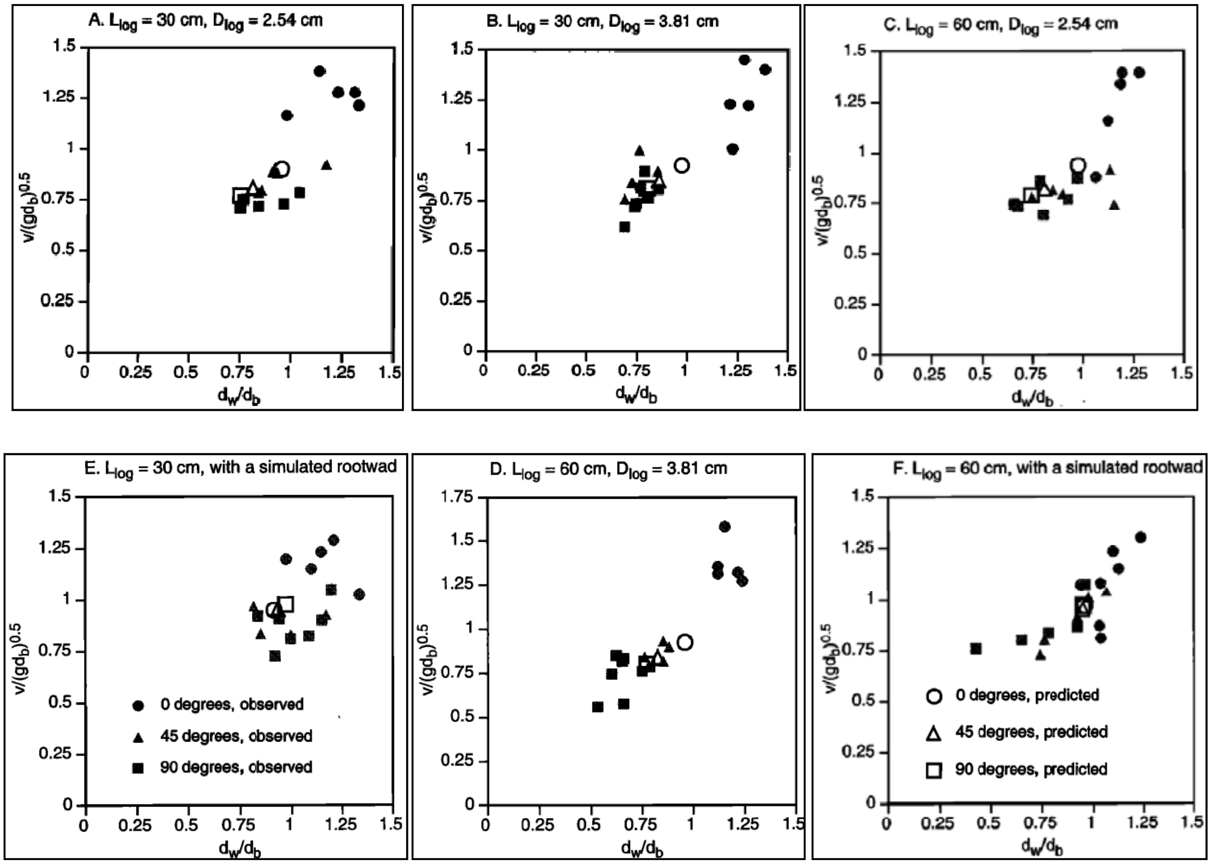

Figure 4. Predicted and observed values of d_w/d_b and $v/(gd_b)^{0.5}$ for flume experiments. From Braudrick & Grant (2000).

Since the density of woody debris is much less than that of sediments, buoyant forces are much greater for wood pieces than for sediments. Table 1 below shows several tree species and average density values for each. The subsequent equations, taken from Braudrick et al. (1997) [(15)], can be used define flotation thresholds for various tree species. Figure 5 below shows the numerical solution to the equations.

Table 1. Densities of some tree species at 12% moisture content. From Braudrick et al. (1997).

Common Name	Species	Density (kg m-3)
Douglas Fir	Pseudotsuga menziesii	537
Sitka spruce	Picea sitchensis	449
Western hemlock	Tsuga heterophylla	506
Western red cedar	Thuja plicata	359
Bigleaf maple	Acer macrophyllum	537
Black cottonwood	Populus trichocarpa	392
Old-growth redwood	Sequoia sempervirens	449

For wood densities less than 500 kg m^{-3}:

$$cos^{-1}\left(\frac{r-d_c}{r}\right)-\frac{r-d_c}{r^2}\sqrt{2d_c r-d_c^2}=\frac{\pi\rho_{wood}}{\rho_{water}} \quad (1)$$

For wood density equal to 500 kg m^{-3}:

$$r = d_c \tag{2}$$

For wood densities greater than 500 kg m^{-3}:

$$sin^{-1}\left(\frac{d_c - r}{r}\right) + \frac{d_c - r}{r^2}\sqrt{2d_c r - d_c^2} = \pi\left(\frac{\rho_{wood}}{\rho_{water}} - \frac{1}{2}\right) \tag{3}$$

where d_c is the critical depth at flotation (depth at which flotation occurs for a horizontal channel), r is the log radius and ρ_{water} and ρ_{wood} are the densities of water and wood, respectively.

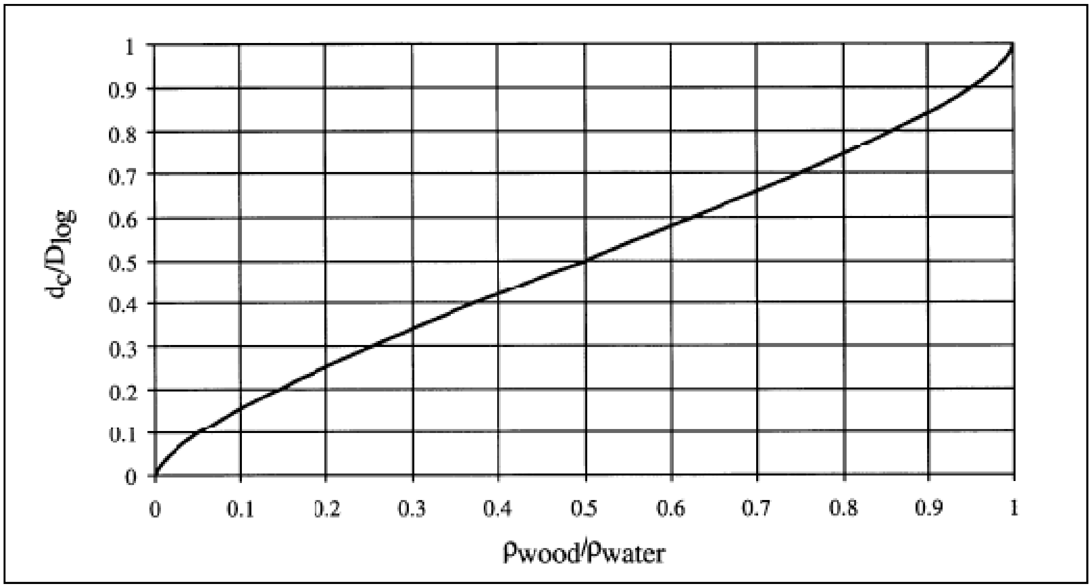

Figure 5. Critical floating depth versus wood density/water density. From Braudrick et al. (1997).

In related work, Braudrick et al. (1997) [15] studied fluvial transport of wood using flume experiments. Their experiments examined wood movements as a function of flow conditions, channel morphology, and wood size and input rate. Using wooden dowels without rootwads or branches they identified three transport modes of wood in channels: 1) uncongested transport, 2) congested transport, and 3) semi-congested transport. Boundaries between transport modes were not clearly defined by the experiments, although transport modes seemed to be best explained by the ratio of volumetric log input rate (Q_{log}) and flow discharge (Q_w). The boundary between uncongested and semi-congested transport occurred between Q_{log}/Q_w values of 0.015 and 0.06. Congested transport occurred at Q_{log}/Q_w values between 0.07 and 0.20. Congested transport was estimated to be most likely in the presence of obstructions such as bridge piers or boulders. Since most large rivers are characterized by larger discharges and relatively low woody input rates, the dominant form of transport in these systems is expected to be uncongested [15].

2.2.2 Aggregate LWD (Log Jam) Hydraulics

Since semi congested or congest transport is uncommon for many large rivers, the formation of aggregate structures of LWD and their interaction with flow is poorly understood for discharges greater than bankfull or at flood stages [16]. A flume experiment on jams, conducted by Bocchiola et al. (2008) [17], attempted to explore the interactions of multiple LWD pieces with complex channel geometry. By releasing wooden dowels in a flume containing random obstructions (cylinders obstructing flow) characteristics of wood aggregation were measured and related to flow conditions and channel form. Wooden pieces in the study were observed to travel as both single pieces and also in the form of jams. Generally, capture probability increased with piece length and decreased with flow velocity. The probability of stopping was found to be higher for single logs than for jams. Visual fitting methods determined that the movement of single logs in the system were best represented using a gamma distribution, while a uniform distribution best represented travel distance for jam features [17]. While it appears that a statistical linkage exists between jam size and travel distance, more investigations are necessary to determine this relationship and the applicability to real world river systems [17]. Figure 6 below shows the distribution of single logs and log jam features, respectively, plotted as the Weibull position (F, calculated as $n/(n_{tot}+1)$ with values in decreasing order) versus the traveled length (L_T, calculated as the ratio of observed travel distance to average travel distance) inside the flume.

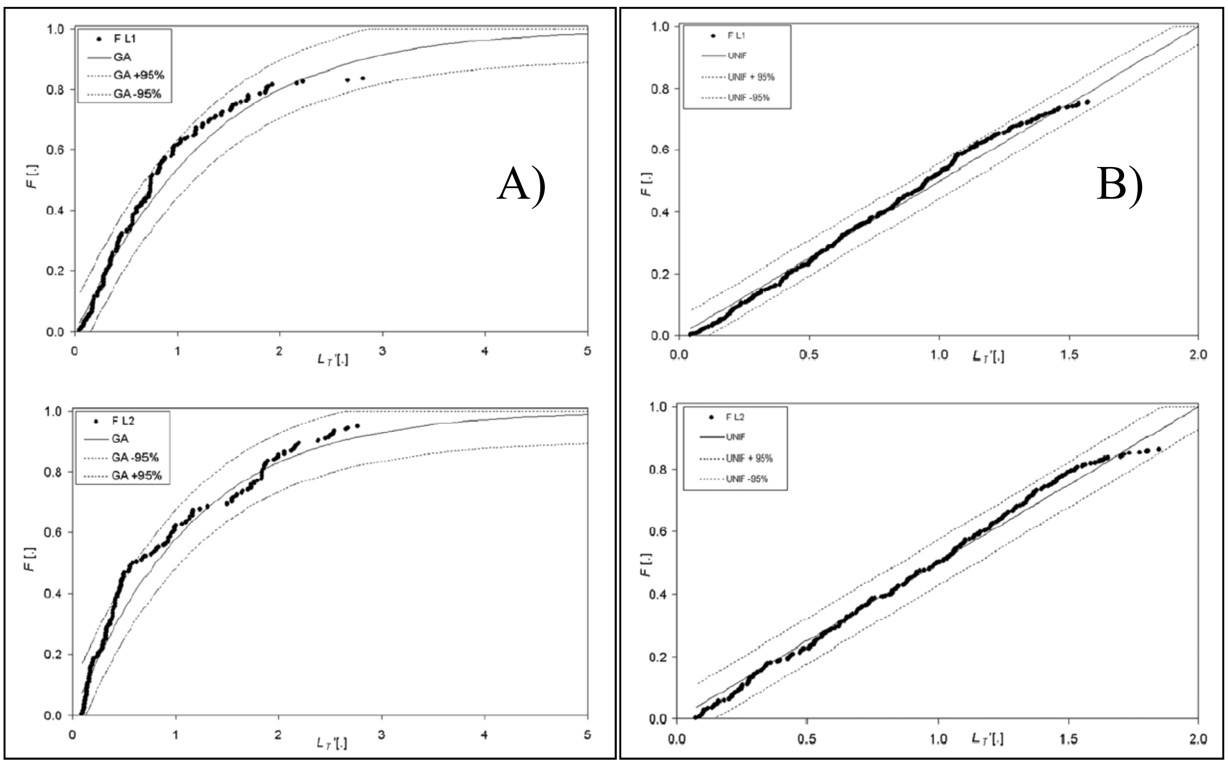

Figure 6. A) Gamma distribution of travel distance for single logs. B) Uniform distribution of travel distance for log jams. Two different piece lengths are represented by the two plots. From Bocchiola et al. (2008).

2.3 Hydraulics of Uprooted, Stable Vegetation in Rivers

2.3.1 Single LWD Hydraulics

Several flume experiments have been conducted to determine the effect that woody debris has on local hydraulics. For every study conducted in a flume setting, channel characteristics and system dynamism are simplified and controlled. Scaling of flume experiments to physical systems is done with much care in the laboratory, but it is impossible to capture the variability and uniqueness of natural stream systems. As a result, the findings of studies (and individual studies in particular) should be consulted, but never solely relied upon when estimating site-specific responses to a certain forcing. The flume experiments reviewed specifically studied the effect of woody debris on water surface elevation. This is important since the addition or removal of LWD from the stream creates a tradeoff between the ecological benefits of LWD, the geomorphic stability of the channel and maintaining the hydraulic capacity of the channel for flood conveyance [(18)].

In a flume experiment by Young (1991) [(19)], two series of experiments were conducted to determine the affect of LWD on water surface elevation. The first experiment utilized a downstream control in the flume, so that the LWD structure was not the controlling hydraulic feature. In the second experiment, the downstream control was removed and the LWD structure controlled hydraulic conditions upstream. For each experiment the relative frontal area (RFA), defined as the ratio of blocked area to total area was plotted against the percentage rise in water surface elevation, defined as the water surface elevation rise relative to the case where no woody debris was present. Figure 7 below shows the results of increased blockage area on water surface elevation.

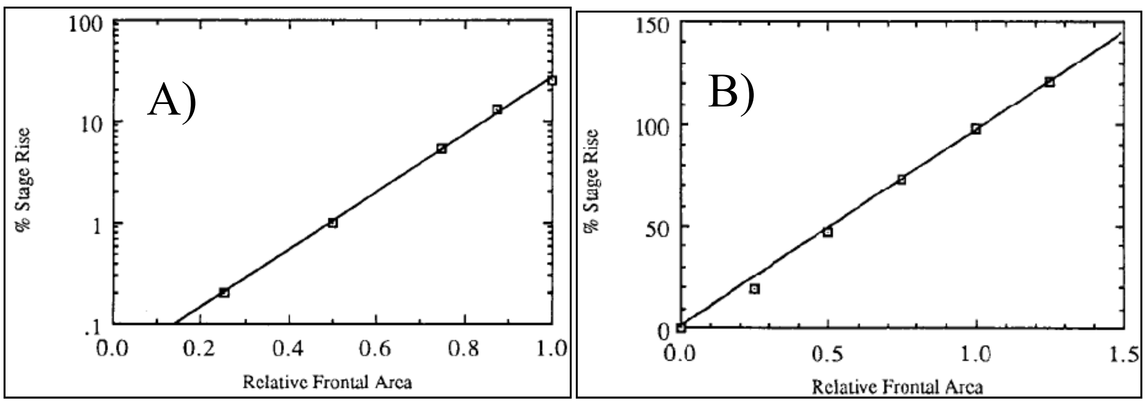

Figure 7. A) Percent stage rise versus relative frontal area of debris for experimental Case #1 (imposed downstream control). B) Percent stage rise versus relative frontal area of debris for experimental Case #2 (no imposed downstream hydraulic control). From Young (1991).

The results indicate that an insignificant increase in stage is expected for typical blockage areas encountered in most river systems (RFA values of 0.4 are considered quite large but cause less than a 10% increase in stage). This finding should not be applied as a rule, however, and the author warns that LWD near channel constrictions, obstructions (bridge piers), or where unusually high densities of LWD occur could still cause a significant increase in water surface elevations [(19)]. For the lower Boise River, where bridges and diversions are common in the highly urbanized setting, blockages at structures or constrictions points could result in a substantial increase in the flood water surface elevation.

Young (1991) [(19)] conducted further flume experiments to estimate the impact of varying height above the bed for debris, streamwise angle of debris, and spacing of debris on water surface elevation rise. Figure 8 below shows the results.

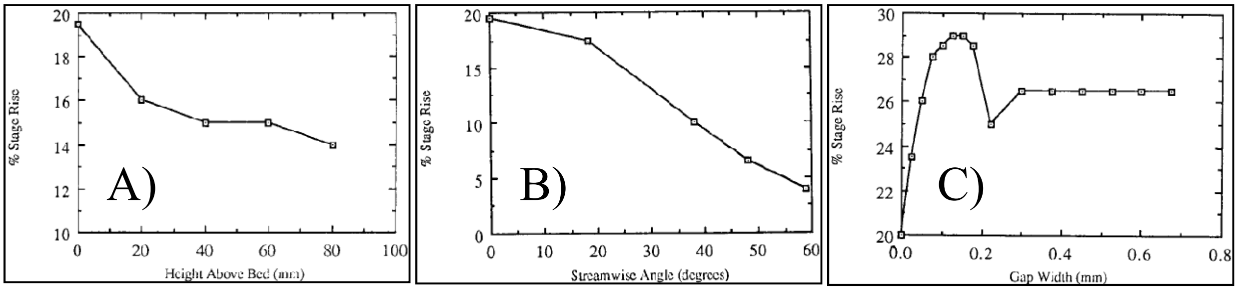

Figure 8. A) Percent stage rise versus debris height above bed. B) Percent stage rise versus streamwise angle of debris (0° defined as perpendicular to flow). C) Percent stage rise versus gap spacing of debris. From Young (1991).

The results of the experiments indicate that the increase in stage is reduced as debris height above the bed increases and as pieces are oriented more parallel to the flow. The findings for gap spacing indicate that systems may have some optimal spacing, where wave action harmonics are amplified for certain spacings and damped for others. Young (1991) (19) points out that the experiments did not consider many real world hydraulic variables such as varying bed roughness, interaction of LWD and banks, and channel cross section variations. However, the results provide a good order of magnitude indication of hydraulic effects of woody debris for lowland rivers.

Flume studies conducted by Gippel et al. (1996) (18) aimed to quantify the drag relationship for debris and use the results to estimate water surface rise that would result in river channels. Their findings suggested that for a Froude number below 0.5, a blockage ratio (percentage of cross section obstructed) below 30%, and debris diameter less than one-third of the flow depth, the drag coefficient is essentially independent. Therefore, the drag coefficient was considered to be constant with depth. Under constant drag coefficient conditions, the relative rise in water surface elevation was computed for debris of various sizes under different flow conditions. The hypothetical channel considered was 30 m wide and 2 m deep. Mean flow velocities were 0.5, 1.0, and 1.5 m s^{-1}. Wood sizes considered were 20 m x 1 m (length x diameter), 10 m x 0.5 m, and 5 m x 0.25 m. Figure 9 below shows the relative rise in water surface elevation for each woody debris size.

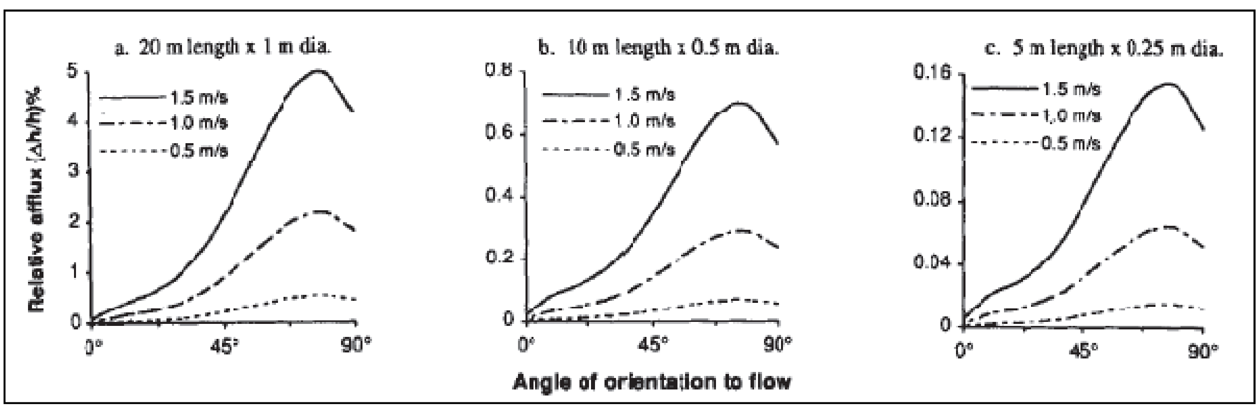

Figure 9. Percent stage rise for varying woody debris size, velocity, and angle of orientation to flow (0° is parallel to flow). From Gippel et al. (1996).

For all piece sizes, the maximum water surface rise is observed with the piece oriented nearly 90° to the flow. As piece size decreases, the observed rise in water surface also decreases. Larger velocities lead to increased water surface elevations for all piece sizes. Linear decreases in piece size result in logarithmic decreases in water surface elevation (18).

Flume experiments in a rectangular glass-walled flume 8 m long, 0.456 m wide, and with a slope of 0.025% evaluated the effects of multiple woody debris elements on water surface rise (18). Groups of two, three, four, five, six, and seven wooden cylinders were placed at varying distance apart, ranging from zero separation (touching) to 10 diameters apart. Figure 10 below shows the results of the water surface rise from varying groupings of cylinders.

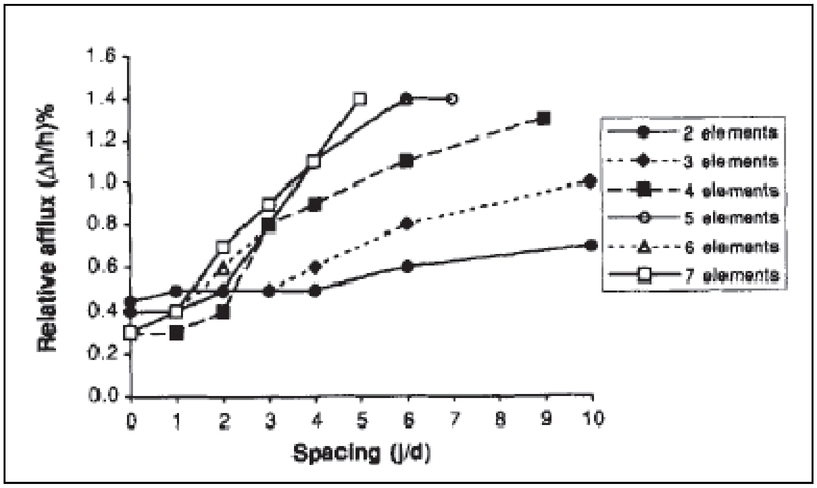

Figure 10. Percent stage rise for multiple groupings of woody debris. From Gippel et al. (1996).

At small spacings, the flume results show that debris clumped two to four diameters apart can be very hydraulically efficient (18). Even when spaced up to 10 diameters apart, the percent stage rise contributed by each of the woody debris elements was observed to be less than that produced by an individual cylinder, indicating that percent stage rise is not strictly additive for multiple elements (18).

2.3.2 Aggregate LWD (Log Jam) Hydraulics

Manners et al. (2007) (16) studied log jam composition and hydraulics and reported on shear stress and velocity changes with varying jam composition. They quantified drag force and drag coefficient for varying jam compositions and attempted to predict a link between natural jam characteristics and drag force. To conduct the study, several jam compositions were considered. These jam compositions were separated into categories A, B, C, and D. Category A consisted of a full jam that was wrapped in a tarp to represent a zero porosity jam. Category B represented the jam in its natural state. Category C consisted of a partial jam with small woody debris and any soil and leaf litter removed, while category D consisted of only the key members that were anchoring the jam formation. Figure 11 below shows velocity vectors and shear stress contours for each jam category. Values on the x-axis represent distance from the bank (in meters) and values on the y-axis represent distance downstream from the upstream flow boundary (in meters). Velocity vectors represent direction and relative magnitude of stream velocity and the contours represent shear stress values at 20 N m^{-2} intervals.

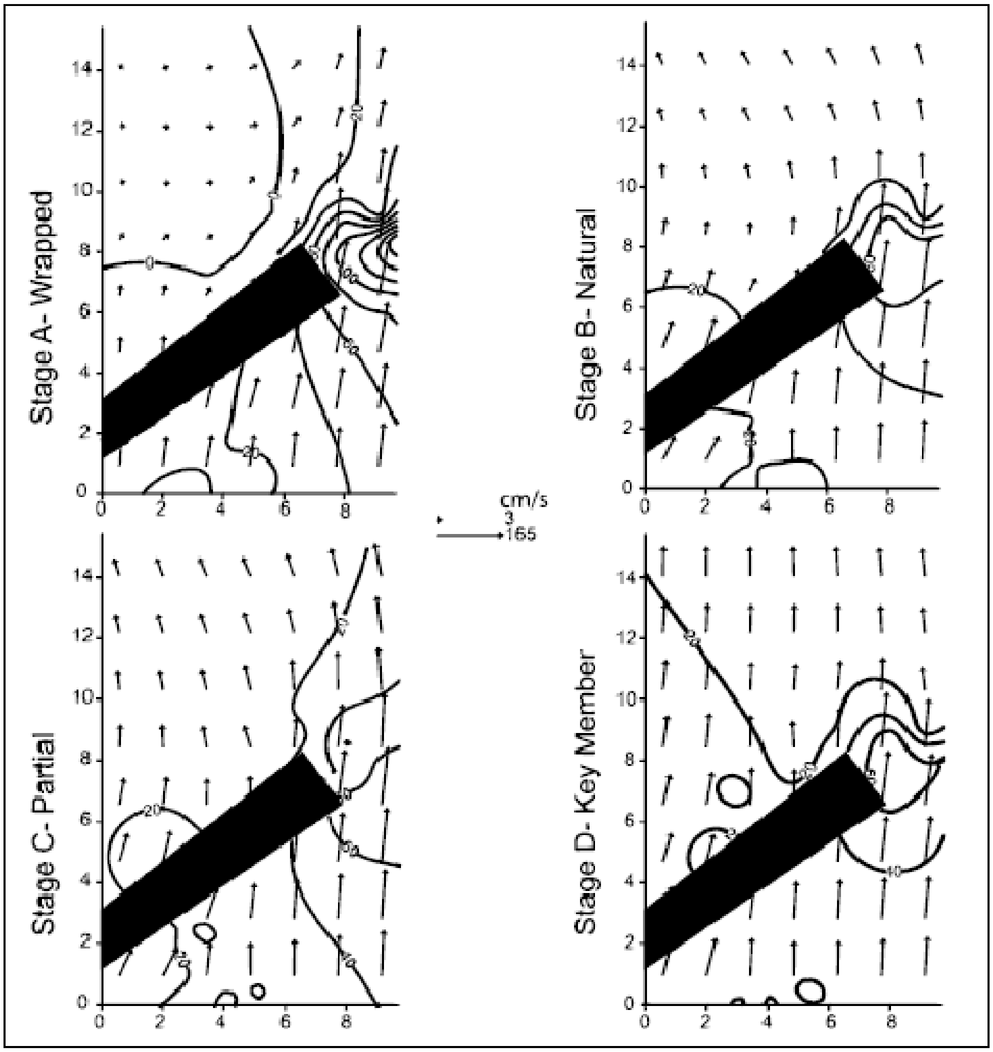

Figure 11. Velocity vectors and shear stress contours for jam categories A-D. From Manners et al. (2007).

The figure shows that velocity and shear stress distributions vary depending on jam composition. For non-porous jams (A) high shear stresses are observed adjacent to the jam and almost no velocity is observed at the downstream end of the jam. For natural jams (B) shear stresses adjacent to the jam are reduced compared to the non-porous case, and velocities at the downstream end of the jam are still very low. Partial (C) and key member (D) jams still show higher shear stresses adjacent to the jam, but also indicate high shear stress areas developing under and at the downstream end of the jam. Velocities downstream of the jams (C and D) are observed to be much larger than for the natural (B) and non-porous (A) states (16). The findings suggest that typical assumptions of zero porosity when calculating drag forces on jams may lead to an overestimate of the drag coefficient and drag force for natural jams. However, the relationship between debris jams and flow are observed to be quite complex and nonlinear making it difficult to determine the deviation from assumed non-porosity and natural case in other systems [(16)].

2.4 Morphology and Vegetation in Rivers

Vegetation (large wood will be primarily discussed in this section) and channel processes interact in a complex manner. The characteristics of the river system (channel dimensions, geomorphology and flow regime) and the river basin (hillslope characteristics, local geology and climate) affect the availability and transport of wood in the fluvial system [20]. The presence and input of wood into the fluvial system will interact with that system and can influence the stability and morphology of the river. In natural systems, these supply and demand interactions typically reach some form of dynamic equilibrium. Naturally catastrophic events such as fire, floods and landslides can alter wood input rates and river transport characteristics. Anthropogenic influences can also alter flow regime, floodplain characteristics, and other parameters that affect the interaction of wood with the fluvial system. Due to broad nature of this subject, the observations introduced in the following sections serve as an incomplete summary of wood and its influence in primarily natural systems.

Woody debris enters and distributes through the river system by several modes. Broadly, the modes are in situ or autochthonous input (wood does not move from input location), transport or allochthonous input (wood has traveled fluvially), or a combination of the two [21]. Local effects of stable log jam formations include flow redirection, pool scour and formation, sediment capture, and bar formation [21]. At the reach scale, jams can be found to increase channel width, decrease slope and depth, and contribute to anastomosing channels (rather than single threaded channels) [21]. Valley scale impacts of woody debris jams are to serve as sediment “reservoirs”, encourage channel initiation and migration, and to increase flow diversity [21].

Many unique woody debris jams have been identified by Abbe and Montgomery (2003) [21]. Without fully describing each jam type, it is sufficient to point out that different jam formations are to be expected depending on the method of recruitment and size of the river channel. For large channels, meander and raft type jams are the most likely to alter the channel while bar top debris or bar apex jams are less likely to alter the channel [21]. Figure 12 below shows wood debris accumulation types corresponding to drainage network location.

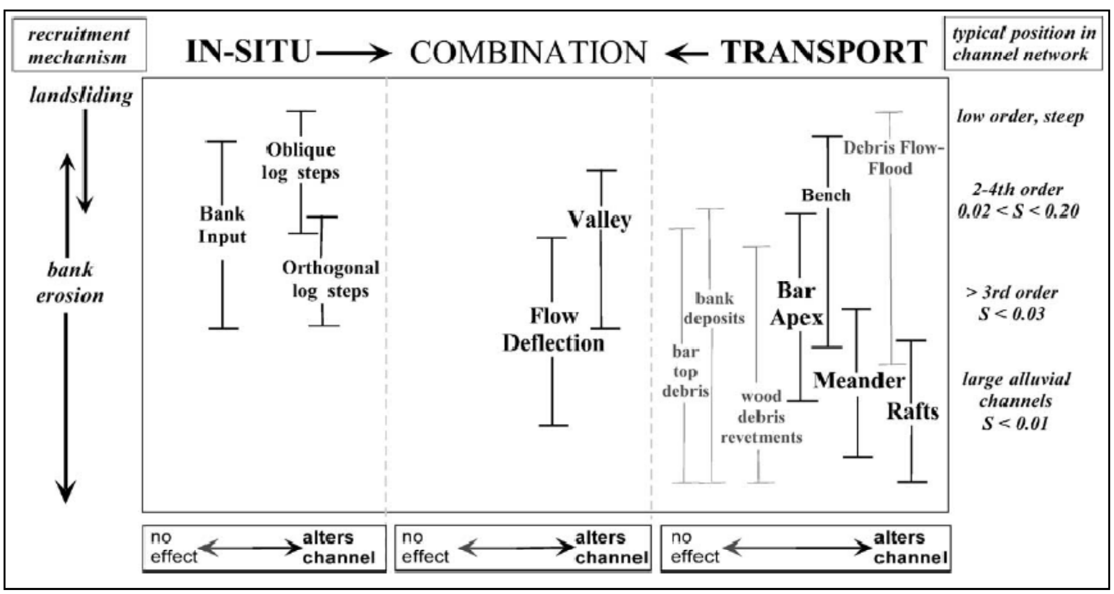

Figure 12. Wood debris accumulation types and channel alteration capability. From Abbe & Montgomery (2003).

Observations of wood storage within the active zone of the Fiume Tagliamento, Italy, suggest that wood is preferentially stored in three locations within the channel: 1) bar crests, 2) channel margins and 3) surfaces of islands (22). Areas of wood accumulation were typically associated with sediment capture, resulting in the recruitment of tree species and revegetation of these areas (22). This observation indicates the highly dynamic nature of wood in streams. Wood accumulation often leads to channel stabilization by vegetation recruitment for areas such as islands and bars. Channel stabilization and aggradation in these areas can lead to flow redirection and areas of high velocity near the channel banks. If the redirected flow velocities and shear stresses are large enough, then banks adjacent to aggrading islands and bars can potentially erode and fail. Bank failures of this nature have been observed to serve as input locations for LWD that was either rooted on the banks or had been deposited at the bank location. So, the dynamic nature of the system can result in a scenario where wood capture and deposition at one location leads to channel alterations and wood recruitment at an adjoining location (22).

Although large wood and vegetation can introduce local areas of scour and velocity complexities, vegetation and wood typically serve as an important stabilizer when considering the entire river system. Rivers lacking vegetation typically exhibit widths that are 20 – 50% wider than comparable rivers that have vegetation (23). Experimental removal of woody debris from an Alaska gravel-bed stream resulted in a fourfold increase in bedload transport rate at bankfull discharge. Other locations saw increases in sediment storage at low flow conditions (24). Despite local areas of sediment deposition, overall channel widening was observed as a response to woody debris removal (24).

2.5 Management of Vegetation in Rivers – Management Implications

River systems are usually a vital component influencing the development and sustainability of urban areas. However, urbanization is generally associated with increased nutrient, sediment, and contaminant loading as well as channel morphology changes, bank alteration, and hydrology changes (9). Development of the landscape typically includes clearing near channel vegetation, which ultimately reduces woody debris input into the river system (9). Due to flooding concerns and the presence of obstructions such as bridge piers in the river corridor, removal of wood from rivers is a common practice in urban environments (9). The origination of these practices is very understandable, since the societal costs of inaction could lead to economic and human life losses (9). Therefore, the balance of river channel conveyance with complex wood and vegetation interactions is a management challenge that will require careful thought and planning from all involved stakeholders and community members.

CHAPTER 3: ECOLOGY OF VEGETATION IN CHANNELS

3.0 Riparian Vegetation

Within the last century, the lower Boise River has been transformed from a meandering, braided, gravel-bed river to a channelized, regulated, urban river. This transformation has affected the composition of the river's riparian vegetation. Historically, riparian vegetation along the lower Boise River consisted of willow (*Salix spp.),* wildrose (*Rosa spp.*), and cottonwood (*Populus trichocarpa*), three plant species that thrive in large gravel-bed alluvial systems that experience dynamic flows and periodic flooding [(25)]. By 2002, cottonwood stands were confined to a narrow corridor at the river margins.

Work conducted by Rob Tiedemann at 18 randomly selected sites along the Boise River (from Diversion Dam to the head of Eagle Island) identified 188 species of grasses, grass-like species (e.g. Juncus spp., Carex spp., etc.), forbs, vines, shrubs and trees [(7)]. The study found that the plant community upstream from the City of Boise urban center differed from that downstream [(7)]. Only four tree species were observed at the study sites. In order of decreasing abundance, the tree species are black cottonwood, silver maple (Acer saccharinum), boxelder (Acer negundo) and ponderosa pine (Pinus ponderosa) [(7)]. Rocky Mountain Juniper (Juniperus scopulorum) was also observed but was considered to be more representative of a shrub species than a tree [(7)]. Of the five species mentioned above only black cottonwood, ponderosa pine and Rocky Mountain juniper are considered native [(7)].

Rood and Mahoney (1993) [(26)] list several impacts on riparian cottonwood forests on dammed rivers in North America, including the lack of extreme flows that reduce forest abundance and seedling production. Today's absence of parafluvial surfaces and the limited recruitment of new cottonwood or willow trees are largely due to the lack of extreme flows to recruit and move instream and riparian substrate. The lack of recruitment, since reducing peak flows through regulation, leaves the cottonwood stand that exists along the lower Boise River vulnerable and with limited variation in the age structure.

3.1 Vegetation and stream ecology/biology (habitat diversity, species diversity)

Several studies have reported that in the short term, such habitat elements as pools, substrate for fish spawning or invertebrate colonizers and cover for fish can be improved using instream structures [(27) (28) (29) (30)]. Some have shown that macroinvertebrate diversity increases when structures are added [(31) (32) (29) (28)].

The addition of organic matter from the terrestrial environment is an important energy source to a river system. Most of this material enters the river as relatively large particulate matter such as leaves or sticks (coarse particulate organic matter (CPOM)). Once in the stream theses materials are broken down through biological and physical processes into finer materials. These finer materials are classified as fine particulate organic matter (FPOM), dissolved organic matter (DOM), and finally carbon dioxide (CO_2). These changes in form, of the organic materials, may lead to a change in the biological community structure and functional diversity of that community. For example, in streams with abundant CPOM such as in headwater streams, many invertebrates that specialize in shredding and feeding on CPOM are present. While in larger river systems invertebrates that gather FPOM are more prevalent.

The ability of streams to break CPOM down into finer materials is well documented [(33) (34)]. In natural or quasi-natural streams there is a strong correlation between the amount of LWD and the retention of organic matter [(32)]. The introduction of LWD can increase the retention of fine sediment, CPOM, FPOM and increase the abundance of macroinvertebrates as demonstrated by Wallace et al. (1995) [(35)] in second order streams and Gerhard and Reich (2000) [(36)] in restored regulated, straightened channels. For CPOM to go through the process of breaking down into finer materials, it must be retained within the stream and not transported downstream as coarse material. Large woody debris (LWD) allows for the retention of CPOM, and in turn allows for the time needed to break the CPOM into fine particulate organic carbon FPOM. The result is greater amounts of organic matter available to the macro-invertebrate community [31].

LWD often in the form of fallen trees and limbs acts to slow the flow of water within the affected part of the channel. As the water slows upstream of the LWD dams, organic material builds upstream of the LWD and a pool often forms. This action allows for the retention and in turn the breakdown of the CPOM into finer and finer organic materials. Bilby and Likens (1980) [31] found that the levels of DOM doubled upstream of LWD, and that during periods of higher flows the DOM was then transported downstream. As DOM is transported downstream, it becomes available for downstream macro-invertebrates communities.

In addition to LWD increasing the retention time and allowing greater local breakdown of CPOM, LWD also increases channel habitat diversity. As downed trees and branches fall into rivers, the hydraulics of the river changes such that pools are created upstream of the LWD, and riffles on the downstream side. This transition from ‘plane-bed’ to these flatter ‘pool-riffle’ channels, under a particular sediment-supply and flow regime, can be controlled by the presence and placement of LWD that form scour pools, bars, sediment storage sites, and steps in channels that would otherwise maintain a relatively flat and uniform bed. This increase in habitat diversity has been shown to increase both macro-invertebrate and fish communities [27] [28].

CHAPTER 4: CASE STUDIES

4.1 The Effect of Artificial Placement of LWD in the River Y Fenni, in the Great Triley Wood, Near Abergavenny in South Wales

4.1.1 Introduction

As part of a larger project sponsored by the European Union to study forest and river management practices, a project called Robinwood was carried out in Wales to study the effects of LWD dams in a small riparian stream as a method to attenuate downstream flood flows. The study area was located on the Y Fenni River, located in the Great Triley Wood two kilometers upstream of Abergavenny, Wales. The Y Fenni River drains approximately 9.2 km^2. Altitudes in the study area range from 44m to 486m. Average annual rainfall is 1080mm. The average annual flood discharge is 2 m^3/s. Like many streams in the industrialized world, the Y Fenni was deficient, as compared to natural streams in its in-stream wood content. To test the effectiveness of debris dams as flood attenuation devices, constructed LWD dams were placed every 7 to 10 bankfull widths of the 500m treatment reach length. Water surface elevations were monitored in the treatment area (Great Triley Wood) and downstream in Abergavenny [37]. The structure of the debris dams are shown schematically and in actual installation in Figure 13 and Figure 14, respectively.

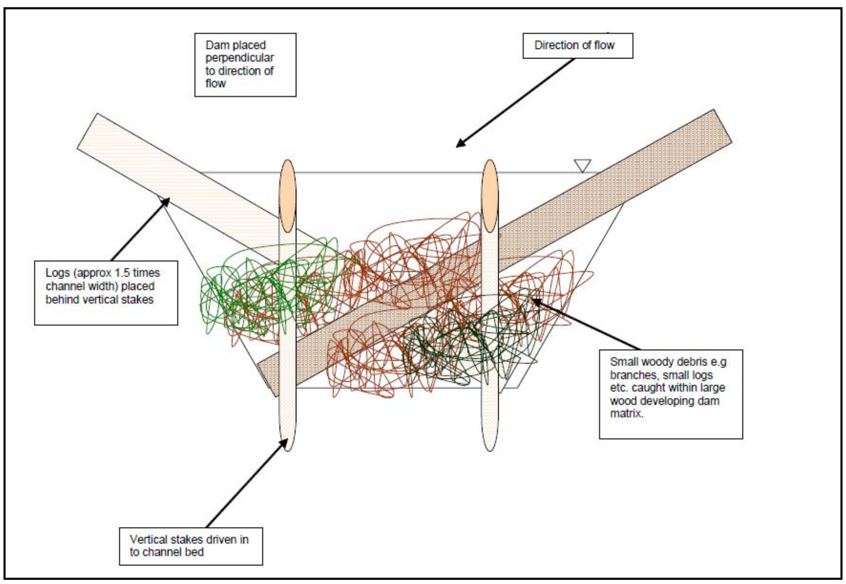

Figure 13. Schematic diagram of the LWD debris dam structure used in the Robinwood project. From Robinwood report.

Figure 14. Photo of one of the LWD dams installed on the Y Fenni River. From Robinwood report.

4.1.2 Results

As a result of the LWD dam placements the researchers found that, for a 1 year return flood event, the flood stage increased by approximately 1.3 meters in the section of the study reach containing the LWD dams. Figure 15 and Figure 16 below show the water elevation, at peak flood stage, in the treatment reach, in the longitudinal and transverse directions, respectively. Flow velocities within the main channel were reduced by approximately 54% as a result of the LWD installation.

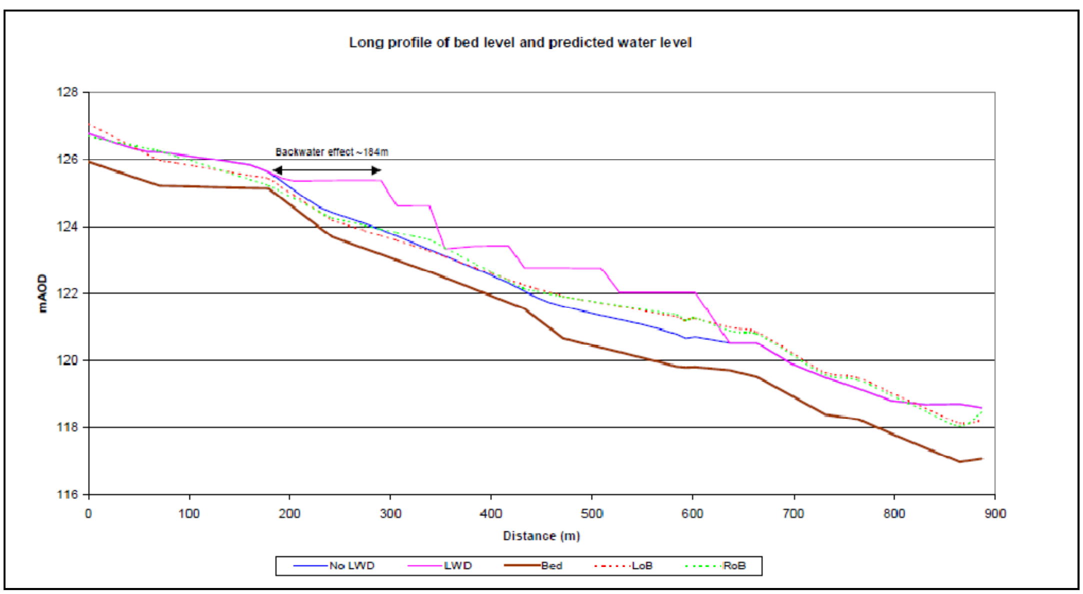

Figure 15. Longitudinal water surface elevation profile with and without LWD dams. From Robinwood report.

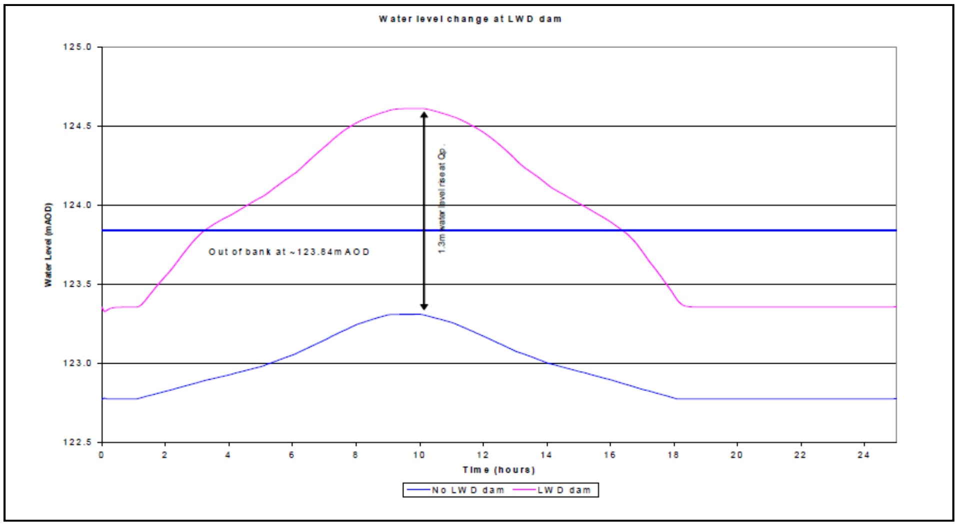

Figure 16. Water surface elevation, at peak flood stage, at a LWD dam. From Robinwood report.

Downstream of the LWD dams, within the town of Abergavenny, the timing of the flood peak was delayed by a small amount as a result of the installation of the LWD dams (Figure 17). Slightly more significantly, the water surface elevation at the peak of the flood was substantially reduced as a result of the installation of the LWD dams. Figure 18 below shows storm hydrographs for two different storms, one before the placement of the LWD dams and one after. The peak flows were 0.45 m^3/s and 0.41 m^3/s, respectively. Before placement of the LWD dams the flood peak depth was about 0.62m. After LWD dam installation the flow peak corresponding to the hydrograph peak depth was only approximately 0.47m. Both of these effects are a direct result of storage of flood waters in the riparian zone in response to the placement of the LWD dams.

An addition benefit that was observed as a result of the installation of the LWD dams was an increase in sediment storage within the treatment portion of the reach. With the increased sediment storage, previously erroded banks were healing and vegetation was being recruited on the sediment bars. Above one of the LWD dams, a braided stream structure had begun to evolve.

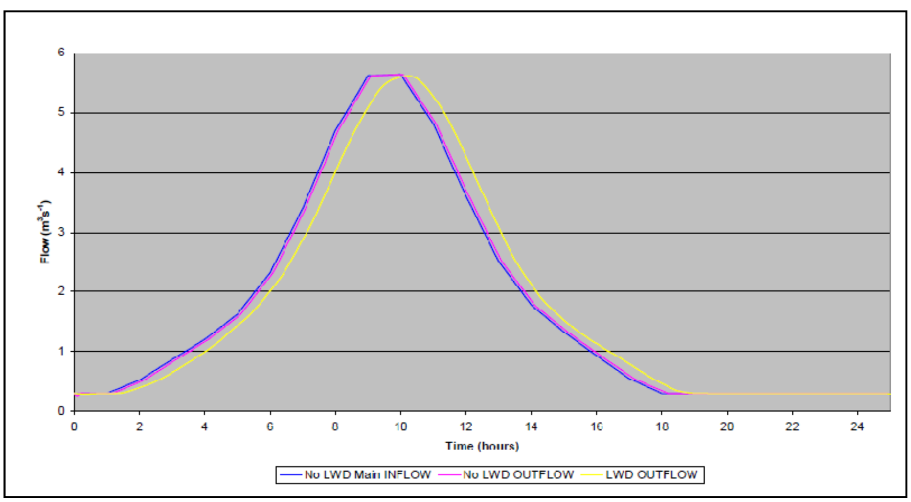

Figure 17. Flood hydrograph showing a modest delay in flood peak timing as a result of the installation of LWD dams. From Robinwood report.

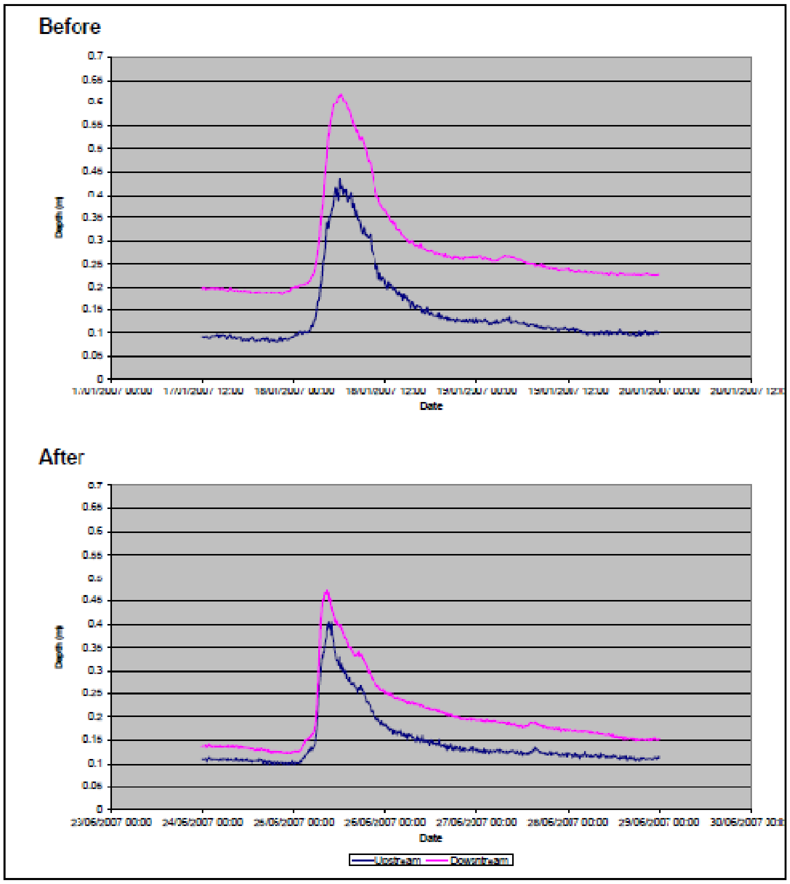

Figure 18. Flood hydrograph, before and after placemant of LWD dams. The "after" hydrograph shows a significant reduction of the peak water surface elevation. From Robinwood report.

4.2 Large Woody Debris in Streams of the Pacific Northwest

4.2.1 Introduction

For roughly the past 200 years the worldwide approach to river management, at least in the industrially developed countries, was to remove all large wood from within the bankfull boundaries of urban and navigable streams and to modify the stream morphology to maximize conveyance [(38) (39)]. The consequences of this management approach include: 1) channel widening, 2) channel bed scour, 3) increased sediment load and 4) a loss of morphological and biological diversity leading to a loss of high quality aquatic habitat. In the Pacific Northwest, this latter effect has lead to a precipitous drop in anadromous salmonid populations [(40) (41)].

Since about the 1980's, particularly in the Pacific Northwest, the belief that a more natural approach to river management can be employed that will improve habitat for aquatic species while still meeting the commercial and societal goals of the people living along rivers under human management has gained widespread acceptance [(42) (43)]. A principle component of this more natural river management approach is the retention or reintroduction of LWD into urban rivers. Evidence of the widespread interest in this new paradigm of river management can be seen in the wide variety of guidelines, directives and legislation that have been put in place worldwide. A few of these are listed below.

- Washington State Aquatic Habitat Guidelines Program [44]
- A Guide to Placing Large Wood in Streams [45]
- Australian Legislative Initiatives and Guidelines [46] including:
  - Threat Abatement Plan: Removal of large woody debris from NSW rivers and streams.
  - Managing Wood in Rivers: Fact Sheet 7.
  - Fisheries Management Act 1994.
  - Native Vegetation Act 2003.
  - Water Management Act 2000.
- Stream Corridor Protection and Adaptive Management Manual – City of Independence, Missouri [47]
- Yahara River large Woody Debris Management Primer – DeForest, WI [48]

In general, the common philosophy that runs through these various guidelines and directives is that:

- Unless it is a threat to life and property, wood that is in streams should be allowed to remain.
- If wood in the stream does create a threat to life or property, if possible, it should be moved or realigned rather than removed from the stream.
- Wood loadings should be matched to approximate wood loadings in reference, natural streams located in the same region.
- Riparian zones along urban rivers should be restored where possible.

The common goals of these river management initiatives generally include [39]:

- Bank stabilization
- Bed stabilization
- Habitat restoration
- Water quality.

With all of this interest in “natural stream management” one might surmise that there would be a vast body of literature available from which one could draw experience and knowledge. Unfortunately, quite the opposite is true. Alexander and Allan [49] surveyed 1,345 stream restoration (the term “restoration” being used very broadly) projects and found that only 11% of the projects included any sort of monitoring, post project completion, as part of the project plan. The majority of the monitoring was related to water quality. The authors surmised that this was due to the fact that water quality monitoring protocols are well established and that water quality is relatively easy to assess as compared to stream morphology or habitat quality.

Larson et al. (2001) [50] found a similar situation when they surveyed over 300 stream rehabilitation projects in the Puget Sound area. Of these projects, only 5% had any monitoring function for biological or habitat suitability. Johnson et al. (2006) [51] when surveying large woody material (LWM) projects in the Redmond, Washington area found that the budgets for these projects were time critical and that little emphasis or funding was given to post-project monitoring. Even though only a small number of projects provide post-installation monitoring, there are a number of good studies available that are very instructive on the implementation and effectiveness of LWD in urban streams.

4.2.2 Durability of Pacific Northwest Instream Structures Following Floods [40]

Roper et al. (1998) [40] surveyed 3,946 instream, river rehabilitation structures that had been installed in 94 rivers in the Pacific Northwest to assess their physical stability in the presence of flood events that exceeded 5 year return intensity. The structures that they considered included:

- log structures,
- boulder structures,
- log and boulder structure and
- gabions.

The physical integrity of the instream structures was classified as:

- in-place, indicating that the majority of structure had not moved from its original position,
- shifted, indicating that the structure was basically at the same location but had changed orientation and
- removed - the majority of the structure was no longer at the original location.

In general, they found that most of the structures remained in place. For flood events with a return intensity of greater than 5 years and less than 15 years, 80% of the structures remained in their original location. Only 8% of the structures in this flood category had been removed from their original locations. Not surprisingly, as flood intensity increased, structure durability decreased. But only after the flood intensity exceeded a 64-year return interval did the in-place durability fall below 50%. At that flood intensity only 25% of the structures were removed from their original locations (Figure 19).

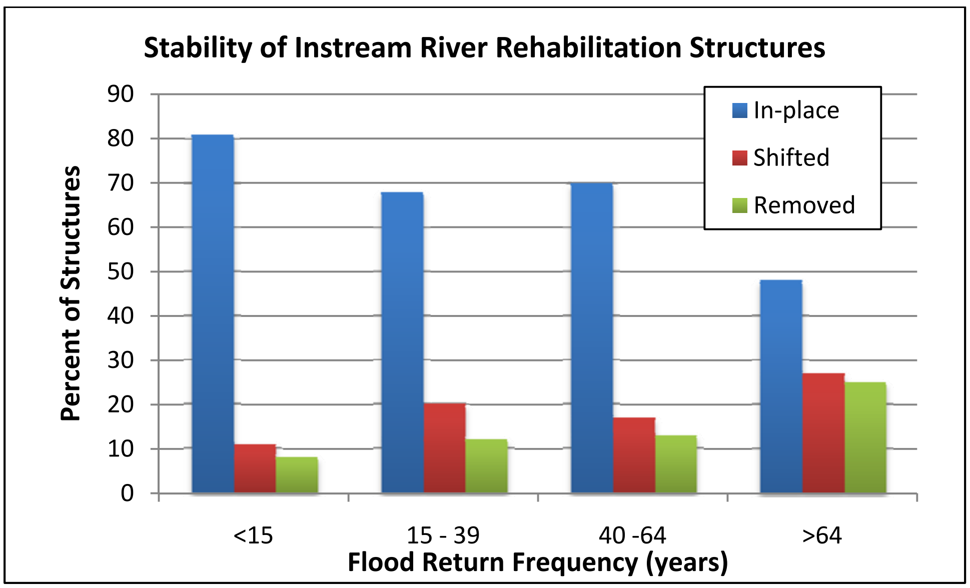

Figure 19. Relationship between flood magnitude and structure durability. From Roper et al. (1998).

Instream structure durability decreased with increasing stream order. For 1st order streams almost 90% of all structures remained in place at all flood intensities, with only 3% of the structures being removed over all flood intensities. For 6th order streams, 63% of the structures were removed over all flood intensities with only 15% remaining in their original locations (Figure 20). Durability of structures was also found to correlate with building material. Structures made of logs or boulders were more likely to stay in place (67%) than structures made of logs and boulders (57%).

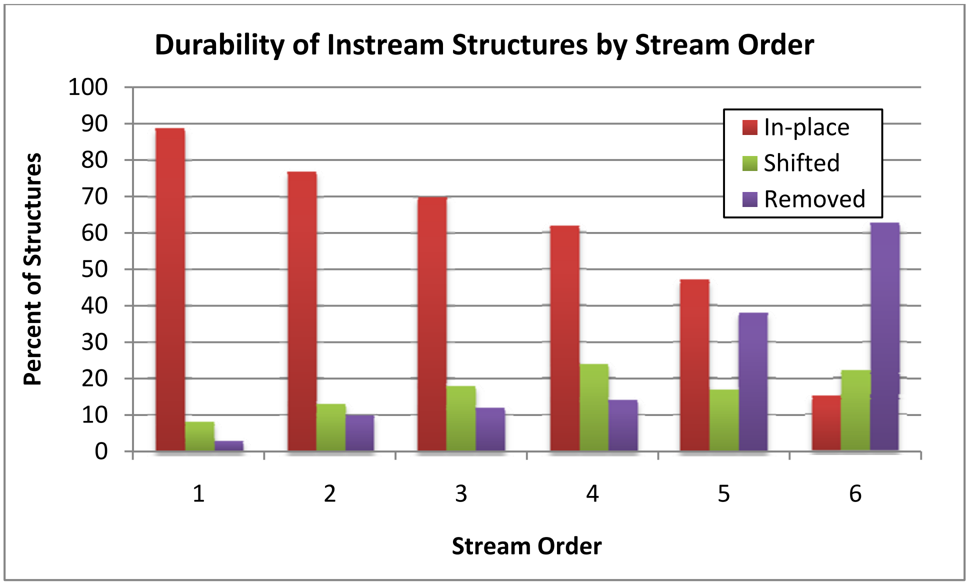

Figure 20. Relationship between stream order and structure durability. From Roper et al. (1998).

4.2.3 Effectiveness of large woody debris in stream rehabilitation projects in urban basins (50)

Larson et al. (2001) (50) evaluated six stream rehabilitation projects in the Puget Sound Lowland area of western Washington. The projects were assessed for their effectiveness in bank stability control, sediment control and habitat enhancement. Also, structure stability was evaluated. Study reaches ranged from 210 to 1,430m in length and 3.5 to 10.4m bankfull width. The stream characteristics are listed in Figure 21.

LWD installations consisted of both anchored and unanchored wood. The amount of wood and the size of the wood used in the installations bore no correlation to the size of the reach or the size of the stream. Five of the projects had been completed within four years of the study. One of the projects was ten years old. All of the installations had experienced at least a two-year flood since its installation and two of the sites experienced a ten-year flood.

For all of the study sites, none of the anchored logs moved. But in the Swamp Creek site, two unanchored logs moved out to the study area. In the Laughing Jacob's Creek study area numerous logs moved several tens of meters. In the Soosette Creek site several smooth logs moved several tens of meters and several debris piles were mobilized.

Watershed and stream characteristics	Forbes	Thornton	Swamp	Hollywood Hills	Laughing Jacob's	Soosette
Stream characteristics						
Average bankfull width (m)	3.5	5.4	10.4	4.1	6.4	8.7
Bed slope	0.037	0.006	0.005	0.046	0.028	0.019
Median grain size (mm)	14	18	14	11	39	51
Upstream drainage (km^2)	3.5	25.4	53.6	2.2	11.1	13
Percent upstream development						
Watershed (%)	82	93	72	62	52	58
Riparian buffer (100 m) (%)	70	75	47	44	43	34 (45)[a]
Basin relief (m)	45	45	150	50	40	40
Basin gradient (relief/basin length)	0.009	0.005	0.003	0.002	0.008	0.008

[a] Percent development in riparian buffer of the upstream end of the project.

Figure 21. Stream characteristics of the Larson study. From Larson et al. (2001).

The authors found that the frequency of pools increased with wood loading particularly in areas where the wood was anchored. In all but one of the streams, sediment storage increased by 50-100%. In general, the effect downstream of the study reaches was marginal. The added wood in the treatment areas had little impact on the biological condition of treatment areas as compared to untreated areas. The authors suggested that the time scale of the study may have been too short for the rivers to adapt to the new conditions.

The authors attributed the generally poor performance of the projects to:

- Ineffective log spacing
- Failure of the LWD to remain within the bankfull channel
- Placement of LWD that was too small to affect the flow
- Placement of wood that did not interact with base flow conditions. Only 30% of the installed wood interacted with the base flow.

4.2.4 Density and size of juvenile salmonids in response to placement of large woody debris in Oregon and Washington streams [52]

In contrast to the Larson study, Roni et al. (2001) [52] found a strong positive correlation between added LWD and juvenile salmonid population densities. The researchers surveyed more than 100 restoration projects and, from these, selected 30 of the projects for their study. They selected only projects in which the installed wood had been in place for several years and had survived several flood events. Additionally, they only selected study sites that had suitable reference reaches within a few hundred meters upstream of the study reach. The researchers recorded LWD density, pool area, pool counts, fish counts (Coho and Cutthroat juveniles) and fish length.

In the treated streams the total number of pieces of LWD per 100m averaged 1.83 and 1.89 times greater than that of the reference streams in summer and winter, respectively. Pool area in treated reaches was approximately 1.5 times greater than that of the reference reaches. Total wetted area of the treatment reaches was approximately 1.1 times that of the reference reaches. Total riffle area, however, showed no significant difference between the treatment and reference areas.

Populations of juvenile Coho salmon in the treatment reach were approximately 1.8 and 3.2 times greater than that of the reference reaches in summer and winter, respectively. Cutthroat trout juvenile populations exhibited no difference between the treatment and reference reaches in the summer but were

1.7 times higher in the treatment reaches during the winter. Fish lengths showed no significant differences between the treatment and reference reaches.

4.3 The Response of Engineered Log Jams Introduced Into the Williams River, New South Wales, Australia

4.3.1 Introduction

In similar fashion to prevalent river management practices in the United States and Europe, river de-snagging has been common practice in Australian rivers for the past 200 years. As a result of this practice nearly all of the natural, LWD has been removed from many Australian rivers [53] [46] [54]. Recent research has shown that the perceived benefits of de-snagging and LWD removal have been over shadowed by the adverse impact upon stream morphology and the aquatic ecosystems [53]. Further, the same research has shown the hydraulic objectives of traditional river management practice can be achieved through the proper implementation of engineered log jams (ELJ) while preserving or even enhancing aquatic habitat and stream morphology [53] [41] [43].

4.3.2 What are engineered log jams?

Engineered log jams have been described extensively in the literature [55] [56] [41] [57] [58] [43] [48] [59] and will only be described briefly.

The term "engineered log jam" was first used by Dr. Tim Abbe in 1996 to describe river management structures (primarily erosion control) that are built using natural materials (primarily LWD, rocks and gravel) and which are installed with the benefit of full engineering structural and hydraulic analysis. Engineered log jams (ELJs) are, to a large degree, a response to early haphazard attempts to reintroduce wood into streams. These early installations suffered from insufficient of understanding of the fluvial and ecological processes and responses to wood in rivers. These early LWD placement projects raised concerns about wood in rivers due to the instability of some of these installations, dangers associated with anchoring techniques and the general lack of demonstrated positive results. The design of ELJs is modeled upon natural log jams that can provide morphological stability for hundreds of years at individual locations [43]. A typical ELJ is shown in Figure 22.

4.3.3 Types of Engineered Log Jams

The main types of ELJs in use are: 1) deflector jams (DFJs), 2) bar apex jams (BAJs), 3) bank revetment structures (BRVT) and 4) log sill bed controls (LS). They are described briefly in the following sections [53] [54].

Figure 22. An ELJ designed to provide bank stability. From Brooks et al. (2006).

Deflector Jams (DFJs)

Deflector jams are bank-attached jams and are multi-layered, impermeable structures that are backfilled with rock and gravel for anchoring and ballast. The basal logs are buried to a depth greater than the predicted scour depth. The intended purposes of DFJs are:

- An alternative to traditional rock revetment structures. They are typically located on concave eroding banks to actively divert the thalweg away from the bank.
- Induce channel contraction to modify flow conditions through a section of the channel.
- Redirect flow to maximize pool scour and energy dissipation.

The structure of DFJs is shown in Figure 23 and Figure 24.

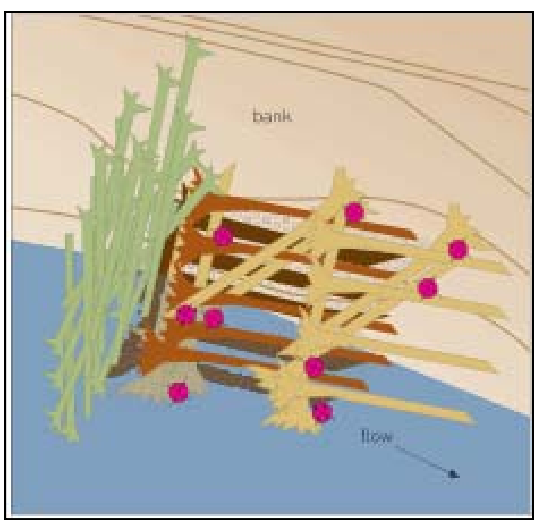

Figure 23. Diagram of a deflector jam. From Brooks et al. (2006).

Figure 24. Deflector jam installed on the Williams River, NSW, Australia. From Brooks et al. (2006).

Bar apex jams (BAJs)

BAJs are multi-layered, impermeable log jams built mid-channel to protect bar features. They are anchored with gravel ballast and existing bar vegetation. The purposes for BAJs include:

- Mid-channel roughness control
- Bar stabilization and accretion
- Habitat enhancement.

A bar apex jam is shown in Figure 25.

Figure 25. Bar apex jam installed on the Williams River, NSW, Australia. From Brooks et al. (2006).

Bank revetment structures (BRVTs)

BRVTs are built from staggered or layered logs that are placed in parallel to the flow at the edge of low banks or inset benches. Basal logs are buried into the stream bed. The purposes for BRVT structures include:

- Bank erosion protection via buttressing of the bank toe and protection of the bank face.
- Habitat enhancement of the bank structure.

A bank revetment structure is shown in Figure 26.

Figure 26. Bank revetment structure installed on the Williams River, NSW, Australia. From Brooks et al. (2006).

Log sill bed-controls (LS)

LS structures are placed perpendicular to the flow direction and are buried almost flush with the bed structure. Generally, these structures are comprised of three logs placed one on two in pyramid fashion with about one quarter of the top log's diameter exposed to the flow. Purposes for log sill bed-control structures include:

- Grade control
- Prevent bed mobilization.

An LS structure is shown in Figure 27.

Figure 27. Log sill bed-control structure installed on the Orara River, NSW, Australia. From Brooks et al. (2006).

4.3.4 ELJs on the Williams River

Study area

The Williams River, located south of Sydney in New South Wales (NSW), Australia is a coastal gravel-bed river with a mean annual flood discharge of 170 m^3/sec (~6,000 cfs) and 100 year flood discharge of 800 m^3/sec (~28,250 cfs). The study area consisted of a test reach and a control reach. The test reach was 1,100 meters in length, with a reach bed slope of 0.0025 and a median grain size of 76 mm. The drainage area of the test reach was 185 km^2. The control reach was located 3.1 km upstream of the test reach. The drainage area of the control reach was 180 km^2 and it was 550 meters in length. The bed slope for the control reach was 0.0017 and the median grain size was 77 mm.

The history of the Williams River includes extensive de-snagging and channel modification. The channel has been realigned by bulldozing channel bars. Other river modifications include the removal of gravel amour and boulders from riffles, installation of wire fences and the installation of about 40,000 riparian willows. Vegetation has been removed from in-channel bars. It is estimated that from the mid-1950s to present, at least 8,000 trees have been removed from 86 km of the channel, including the area of the test and control reaches. The logs removed from the river were hauled to the adjacent floodplain and burned (54).

Study treatments

To evaluate the effectiveness and safety of ELJs, 20 ELJ structures were installed in the Munni region of the Williams River, NSW Australia. The 20 ELJs incorporated 436 logs with a total weight of 350 tons. These included 9 DFJ structures, 2 BAJ structures, 3 BRVT structures and 5 LS structures. The broad study objectives were (43):

- To demonstrate the safety of using ELJs to reintroduce LWD into medium to high energy rivers,
- To test whether a reach based rehabilitation strategy based on the reintroduction of LWD would help to stabilize the reach by reducing bank erosion and increasing sediment storage,

- To test whether or not ELJs would increase morphological diversity and by extension habitat diversity and suitability.

A diagram of the study area and treatments is shown in Figure 28.

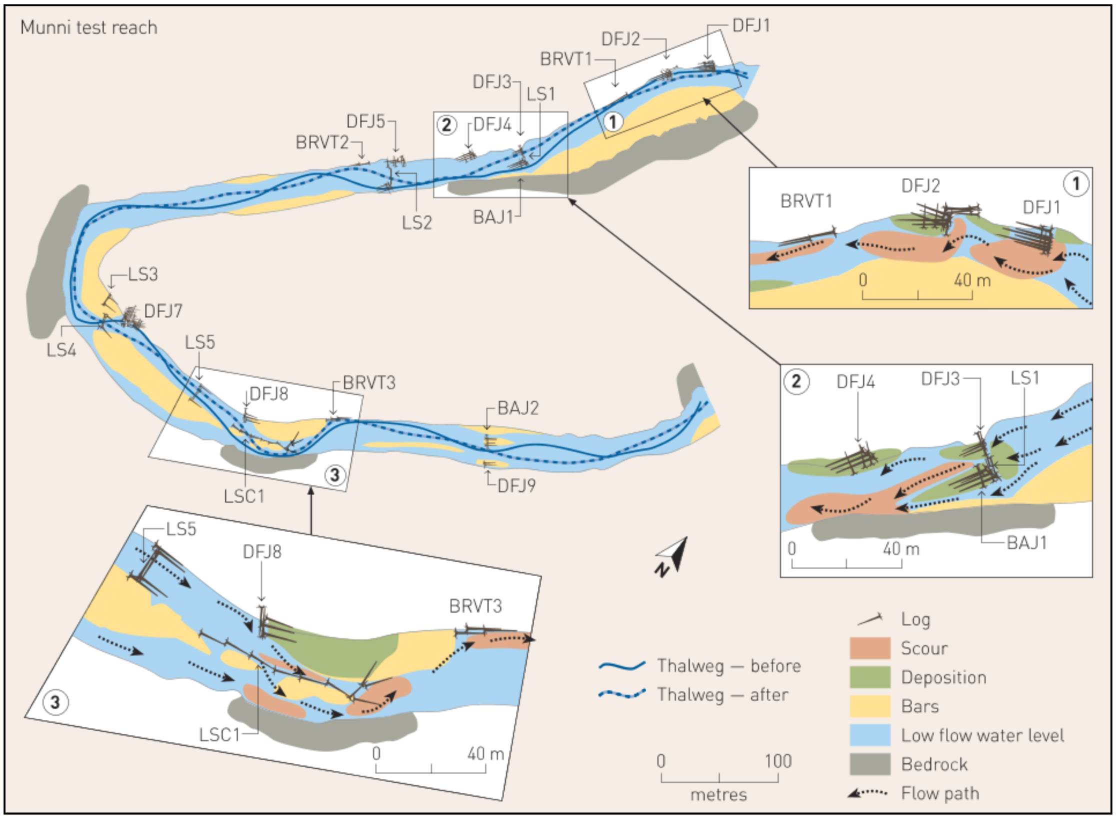

Figure 28. Layout of the Williams River study area with locations of ELJs. From Brooks et el. (2006).

Results

Engineering response of ELJs

From installation through May of 2004, the ELJs experienced 10 overtopping flood events. Three of these flood events were larger than the mean annual flood event. The flood hydrograph for the study period is given in Figure 29.

- All of the structures survived all of the flood events with little damage.
- Twelve non-structural logs moved and one structural log moved. Travel distances were not given, but none of the logs moved out of the study reach.
- Two of the LS structures failed to function properly due to outflanking. The researchers concluded that for sill structures to survive and function properly long-term they should be accompanied by abutting bank attachment jams on both sides.
- The measured flood stage increase was less than 10% at three-quarter bankfull flow. The researchers note that this difference was within the gauge measurement error.
- All bank erosion control structures were very effective in controlling bank erosion [43].

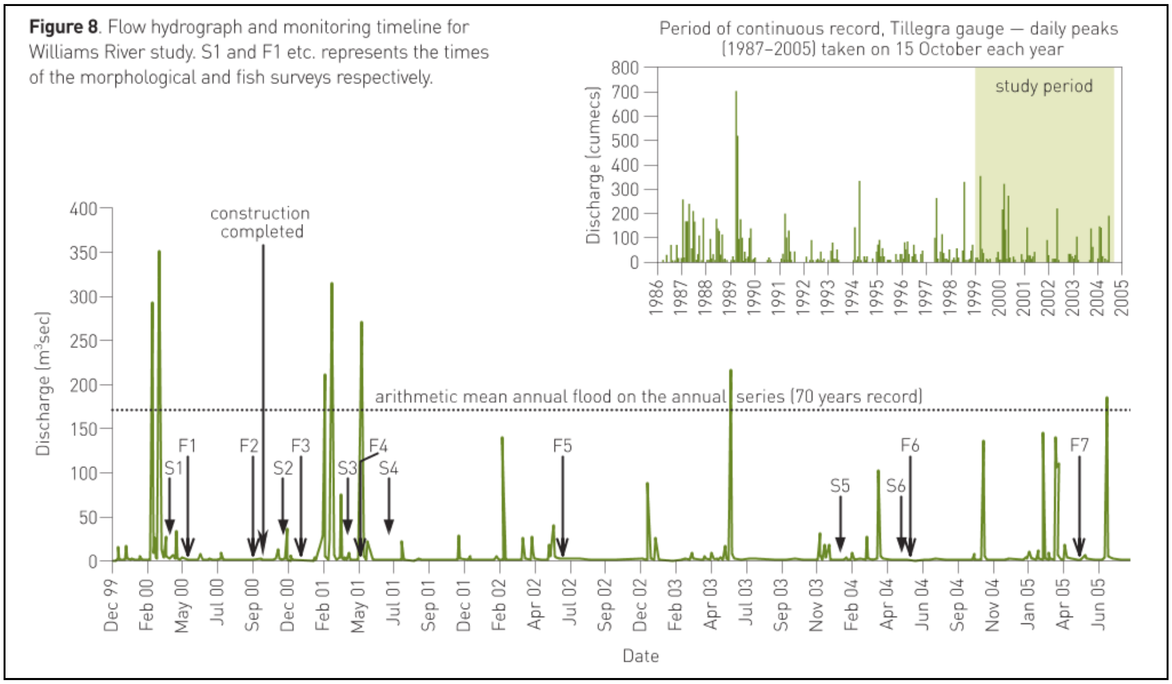

Figure 29. Flood hydrograph of the Williams River. From Brooks et al. (2006).

Morphological response to ELJ placement

In general the study reach experienced a substantial increase in morphological diversity as compared to the control reach for the same period. Changes to the study reach included [53] [54] [43]:

- There was a net increase of sediment storage in the study area of 40 m^3 per 1,000 m^2. The control reach experienced a loss of 15 m^3 per 1,000 m^2 in the same time period.
- Pool/riffle amplitude increased in the treatment area.
- Riffle area increased in the treatment area.
- The bed material was finer in the test reach after placement of the ELJs.

Ecological response to ELJs

In the first year the mean abundance of fish species inventoried increased by 53.4%. But after 5 years, the species abundance between the treatment reach and the control reach showed no significant difference. The authors suggest that it may take one or two decades for a measurable response to habitat change to take permanent affect [54].

4.4 Riparian Restoration on the River Enz, Germany

Schneider and Koenig (2011) [60] investigated the effects of riparian restoration within the floodplain of the River Enz in Germany (Figure 30). Their research focused on the hydraulic effects of vegetation within the floodplain. Their work also proposes a decision making process that could be used to identify the best locations to plant trees and shrubs. The objective of identifying suitable planting areas is to maximize the vegetation density without increasing the risk of flooding along the urban corridor.

Figure 30. The photo on the left shows the River Enz prior to riparian restoration. The photo on the right was taken after riparian restoration. From Schneider and Koenig (2011).

The researchers hypothesized that vegetation planted within the floodplain area would have little effect on the water surface elevation when corresponding flow velocities were less than 0.4 m s^{-1}. Two-dimensional hydraulic models support their hypothesis at this point, although a range of velocity thresholds could possibly be used with similar results. Within that context they propose a step-by-step process for identifying suitable locations for riparian tree and shrub plantings. Factors considered include: 1) ecological suitability, 2) flow dynamics and 3) land use rights. The process is shown, diagrammatically in Figure 31.

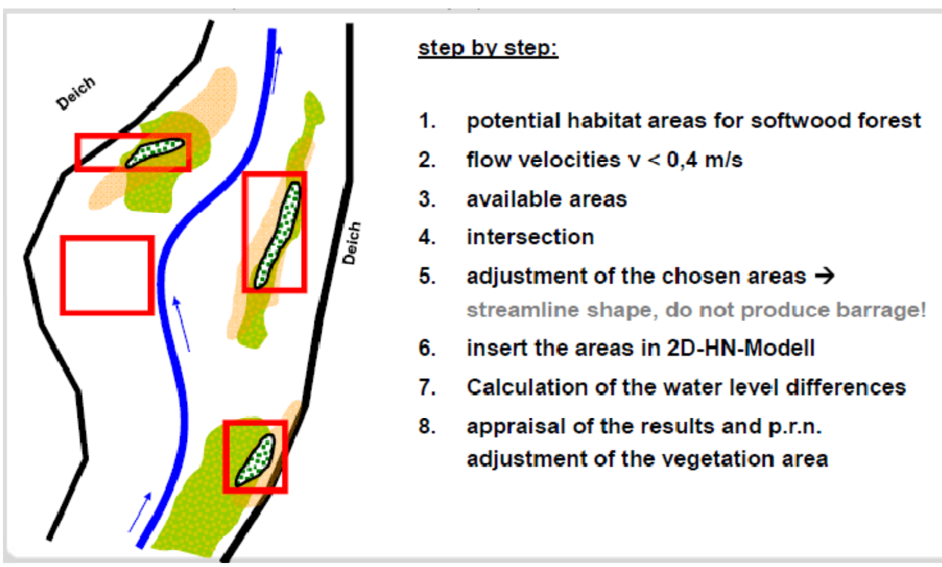

Figure 31. A step-by-step decision making process for locating riparian vegetation in an urban stream environment. From Schneider and Koenig (2011).

This decision making process that has been used to locate vegetation plantings for riparian restoration projects may be useful to inform the decision making process for locating LWD installations. In the LWD scenario, potential planting area becomes potential LWD location areas. By using low velocity areas within the floodplain the potentially negative impacts of water surface elevation rise and LWD mobility during a flow event are reduced.

CHAPTER 5: EXAMPLE CALCULATIONS

5.1 Hydraulic Methods

In natural channels, flow is resisted by the roughness of the bed and banks due to bed material type, bed forms, curvature, vegetation, and obstructions (e.g., large woody debris). Frequently, the effect of these resisting forces to flow is represented by a composite roughness coefficient based on literature values (61) or hydraulic model calibration. However, to better understand the relative importance of these resisting forces, it is necessary to compute the composite roughness coefficient based on a subarea approach to the Manning formula.

Based on uniform flow assumptions, the Manning formula is often used to predict the depth and velocity of based on channel geometry, slope, and the composite hydraulic roughness:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{4}$$

where V is average velocity, R is the hydraulic radius, S is the bed slope, and n is the hydraulic roughness coefficient (all in English units). An alternative to the Manning formula is the Darcy-Weisbach formula:

$$V = \left(\frac{8gRS}{f}\right)^{1/2} \tag{5}$$

where f is the friction factor and g is the acceleration due to gravity. The friction factor f is usually depth dependent and related to Manning's n by the following:

$$n = 1.486 R^{1/6} \sqrt{\frac{f}{8g}} \tag{6}$$

5.1.1 Composite Roughness

There are different methods for compositing roughness, as summarized by Chow (1959) (61), all of which involve dividing the channel into subareas (see Figure 32). Based on the assumption that the Manning formula can be applied to the subareas as well as the cross section as a whole:

$$A_i = \left(\frac{V}{S^{1/2}}\right)^{3/2} (n_i)^{3/2} P_i \tag{7}$$

where A is the flow area, P is the wetted perimeter, and subscript i is the subarea index. In the method proposed by Horton (1933) (62), each subarea is assumed to have the same mean velocity and energy gradient, which is consistent with 1D hydraulic model assumptions:

$$n = \left[\frac{\sum_{i=1}^{N} P_i (n_i)^{3/2}}{P}\right]^{2/3} \tag{8}$$

Similarly, if the Darcy-Weisbach formula is used under the same assumptions, then:

$$Pf = \sum_{i=1}^{N} P_i f_i \tag{9}$$

5.1.2 Subarea Partitioning

There are several methods to calculate the roughness for each subarea. Of the two methods to be discussed, the first method was developed by Cowan (1956) [63] and is presented in great detail in USGS Water-Supply Paper 2339 [64]. In summary, the Cowan (1956) [63] procedure estimates the effects of the type and size of material composing the bed and banks as well as the shape of the channel by:

$$n_i = (n_b + n_1 + n_2 + n_3 + n_4)_i m \tag{10}$$

where n_b is the base value for a straight, uniform, smooth channel in natural materials (see Section 5.1.3 for gravel beds); n_1 is a correction factor for the effect of surface irregularities (e.g., sloughed or scalloped banks); n_2 is a value for variations in the shape and size of the cross section (i.e., due to the frequency of alternating small and large cross sections); n_3 is value for obstructions based on percent blockage; n_4 is a value for vegetation and flow conditions; and m is a correction factor for meandering of the channel. By default, all of these values can be estimated from tabled ranges. However, n_3 does not explicitly account for the effect of LWD size and density (see Section 5.1.6 for more details) and n_4 does not account for the effect of submergence on riparian species (see Section 5.1.5 for more details).

The second method uses the Darcy Weisbach friction factor f to represent the total flow resistance, which can be partitioned as:

$$f_i = \left(f_g + f_{form} + f_{bend} + f_{veg} + f_{lwd}\right)_i \tag{11}$$

where f_g is the grain resitance, f_{form} is the form resistance due to bars, f_{bed} is the bed resistance as the sum of f_g and f_{form} (see Section 5.1.3 for details), f_{bend} is the resistance due to bends in the channel (see Section 5.1.4 for details), f_{veg} is the resistance attributed to riparian vegetation (see Section 5.1.5 for details), and f_{lwd} is the resistance contributed by LWD in the channel (see Section 5.1.6 for details).

5.1.3 Gravel Bed

If the gravel bed channel is rigid wherein there is no active bedload transport, then the following equation of (Griffiths, 1981) [65] can be used to describe the resistance contributed by the bed due to grain resistance and form resistance, which is similar in form to the equation previously proposed by Bray (1979) [66]:

$$\frac{1}{\sqrt{f_{bed}}} = 0.760 + 1.98 \log_{10}\left(\frac{R}{d_{50}}\right) \tag{12}$$

where d_{50} is the median particle size of the bed material. If the channel has active bedload transport wherein the bed is mobile and bedforms develop, then the following equation of (Griffiths, 1981) [65] can be used to describe the resistance contributed by the bed:

$$\frac{1}{\sqrt{f_{bed}}} = 2.21\left(\frac{V}{\sqrt{gd_{50}}}\right)^{0.340} \tag{13}$$

5.1.4 Bends

If the channel reach is not straight and includes bends, then resistance due to bends, as presented by Shields & Gippel (1995) (67), can be computed as:

$$f_{bend} = \frac{8R}{L}\sum_{j=1}^{N}\frac{B_j}{r_{cj}} \tag{14}$$

where B_j is the wetted width in the bend, r_{cj} is the radius of curvature in the bend, L is the reach length, and subscript j is the bend index.

5.1.5 Vegetation

There are several recent publications that provide methods for estimating resistance due to vegetation from quantifiable measures of vegetation characteristics. Two of these methods were developed by the USACE. The first method by Freeman et al. (2000) (13) relied upon laboratory experiments to develop empirical relationships to estimate Manning's n (i.e., as n_4 in the Cowan (1956) (63) procedure) for partially and fully submerged vegetation using quantifiable measures of vegetation characteristics. While it is understood that this method may not be ideal for estimating roughness due to mature riparian vegetation due to the limitations of the empirical relationships (Ronald Copeland, pers. comm.), this method does represent one of the better, practicable alternatives for estimating roughness coefficients. The relationships for partially (top) and fully submerged (bottom) vegetation are provided below:

$$n_i = K_n 0.00003487\left(\frac{E_s A_s}{\rho A_i^* V_*^2}\right)^{0.150}(MA_i^*)^{0.166}\left(\frac{V_* R}{v}\right)^{0.622}\left(\frac{R^{0.667}S^{0.5}}{V_*}\right) \tag{15}$$

$$n_i = K_n 0.138\left(\frac{E_s A_s}{\rho A_i^* V_*^2}\right)^{0.183}\left(\frac{H}{Y}\right)^{0.243}(MA_i)^{0.273}\left(\frac{v}{V_* R}\right)^{0.115}\left(\frac{R^{0.667}S^{0.5}}{V_*}\right) \tag{16}$$

where K_n is the units conversion factor for Manning's equation, E_s is the modulus of plant stiffness, A_s is the total cross sectional area of all the stem(s) of an individual plant, ρ is the density of water, A_i is the frontal area of an individual plant blocking the flow, A_i^* is the submerged frontal area, V_* is the shear velocity, M is the plant density, H is the undeflected plant height, H is the flow depth, and v is the kinematic viscosity. The submerged frontal area is described by Figure 33:

$$A_i^* = \big(Y - (H - H')\big)W_e \tag{17}$$

where H' is the undeflected height of the leaf mass and W_e is the average plant width taken as A_i/H'.

Submerged flow for the above equations is defined as $Y > 0.8H$. The modulus of plant stiffness (lbf/ft^2) can be approximated with following relationship:

$$E_s = 0.00001597\left(\frac{H}{D_s}\right) + 454\left(\frac{H}{D_s}\right)^2 + 37.8\left(\frac{H}{D_s}\right)^3 \tag{18}$$

where D_s is the stem diameter measured at $H/4$.

The second method by Fischenich (2000) [11] relied on the derivation of hydraulic principles to develop relationships to estimate Manning's n for partially and fully submerged vegetation. Based on the author's experience, the Freeman et al. (2000) [13] method was easy to apply while the Fischenich et al. (2000) [11] method was difficult to apply (e.g., estimating drag coefficients from Fischenich & Dudley (2000) [11]) and would appear to produce roughness estimates that were either very low for submerged conditions or unreasonably high for unsubmerged conditions in full foliage. As such, the reader is referred to the source documents.

5.1.6 Large Woody Debris

If LWD is present in the main channel, and assuming that the roughness is uniformly distributed along the reach, then the following equations [67] can be used to describe the friction contributed by the blockage area, A_k, of multiple pieces of LWD within a reach of length, L, and wetted width, B (e.g., the length corresponding to an individual cross section in a 1D model):

$$f_{lwd} = \frac{4\sum_{k=1}^{N} C_{dk} A_k}{\propto BL} \tag{19}$$

where C_{dk} is the drag coefficient for each piece of LWD, $\propto$ is kinetic energy correction factor assumed to be 1.15, B is the reach average water surface width, and subscript k is the LWD piece index. The drag coefficient is further described by:

$$C_{dk} = \frac{C_d'}{a\left(1 - \frac{A_k}{BR}\right)^b} \tag{20}$$

where C_d' is a drag coefficient for a cylinder in flow of infinite volume, the value of which varies with orientation and whether or not the LWD includes branches and a rootwad [68] [67] [18]. The coefficients a and b are experimentally determined by Shields & Gippel (1995) [67] to be $a = 0.997$ and $b = 2.06$.

5.2 Example Calculations of LWD Effects

A basic hydraulic calculation is presented to demonstrate the effects on water surface elevation as a result of retaining some degree of LWD in the Boise River as part of future management strategies. The reach of interest is upstream of the Eagle Island flow split in the urbanized reach upstream of the diversion weir and downstream of the Glenwood Bridge. Figure 34 and Table 2 depict typical reach conditions and hydraulic parameters assumed in the example calculation. Since there is already a calibrated MIKE FLOOD hydraulic model (7 m grid size) that extends from Glenwood Bridge to Star Road the example calculation was simplified assuming:

$$n = n_{calib} + n_{lwd} \tag{21}$$

where n_{calib} is the calibrated hydraulic roughness based on 2006 conditions when there was no visible LWD in this reach of the Boise River, and n_{lwd} is based on the equations of Shields & Gippel (1995).

To expedite the analysis, HEC-RAS (RAS) was used to perform uniform flow computations based on the information presented in Table 2. Parameter #8 (k) and Parameter #12 (L) were then adjusted in Table 3 to determine the effect of LWD density and reach length for a range of conditions in the urbanized Boise River reach. Based on Table 3, Manning's n increases from the calibrated value of 0.030 up to 0.031, assuming 1 piece of LWD placed within the 8000 foot reach between Glenwood Bridge and the upstream end of Eagle Island, to a maximum of 0.035 assuming 1 piece of LWD spaced every 500 feet (see Figure 35). The Manning's n values in Table 3 where then implemented in RAS to determine the effect of LWD density on the increase in water surface elevation (WSE). As shown by Table 4 and Figure 36, the WSE is expected to increase 0.15 feet (or by 2%) with 1 piece of LWD placed within the 8000 foot reach, to a maximum of 0.59 feet (or by 9%) assuming 1 piece of LWD spaced every 500 feet. In comparison to Figure 9 by Gippel et al. (1996), the relative increase in stage is comparable even though the hydraulic characteristics of the Boise River differ from the lowland rivers evaluated by Shields & Gippel (1995).

For additional consideration, Table 4 also presents an example where LWD might be incorporated into a flood and vegetation management plan whereby LWD reintroduction could be balanced with modifications to flood flow releases. In this example, reductions in bankfull flood flows were used to maintain a constant bankfull WSE to counteract increases in LWD density. In the minimum case tested with 1 piece of LWD placed within the 8000 foot reach, the bankfull flood flows would need to be reduced by 4% from 7000 cfs down to approximately 6700 cfs. If 1 piece of LWD is placed every 500 feet, the bankfull flood flows would need to be reduced by 14% from 7000 cfs to 6000 cfs (see Figure 37).

Table 2. Boise River example reach geometry and LWD assumptions.

Parameter #	Parameter	Parameter Value	Units
1	n	0.032	s/ft$^{1/3}$
2	n_{calib}	0.030	s/ft$^{1/3}$
3	n_{lwd}	0.002	s/ft$^{1/3}$
4	$factor$	1.486	std units
5	g	32.2	ft/s^2
6	f_{lwd}	0.0004	-
7	C_{dk}	0.99	-
8	k	1	# pieces
9	A_k	40	ft^2
10	$\propto$	1.15	-
11	B	170	ft
12	L	2000	ft
13	C_d'	0.9	-
14	R	5.15	ft
15	a	0.997	-
16	b	2.06	-

Table 3. Effect of LWD density on Manning's n in the Boise River.

LWD Pieces, *k*	Reach Length, *L* (feet)			
	2000	4000	6000	8000
1	0.032	0.032	0.031	0.031
2	0.033	0.032	0.032	0.032
3	0.034	0.033	0.032	0.032
4	0.035	0.033	0.033	0.032

Table 4. Effect of LWD on water surface elevations in the Boise River.

Manning's n value	Holding Q = 7000 cfs[1]		Holding WSE = 2601.11 ft[1]	
	WSE (feet)	% Change	Flow (cfs)	% Change
0.030	2601.11	--	7000	--
0.031	2601.23	2%	6771	-3%
0.032	2601.35	4%	6560	-6%
0.033	2601.46	6%	6361	-9%
0.034	2601.59	8%	6174	-12%
0.035	2601.71	10%	5997	-14%
0.036	2601.82	11%	5831	-17%
0.037	2601.92	13%	5673	-19%
0.038	2602.02	15%	5524	-21%
0.039	2602.12	16%	5382	-23%
0.040	2602.21	18%	5248	-25%
0.041	2602.30	19%	5120	-27%
0.042	2602.39	21%	4998	-29%
0.043	2602.48	22%	4882	-30%
0.044	2602.56	23%	4771	-32%

[1] Assumes a hydraulic depth of 6.21 feet and a slope of 0.0026

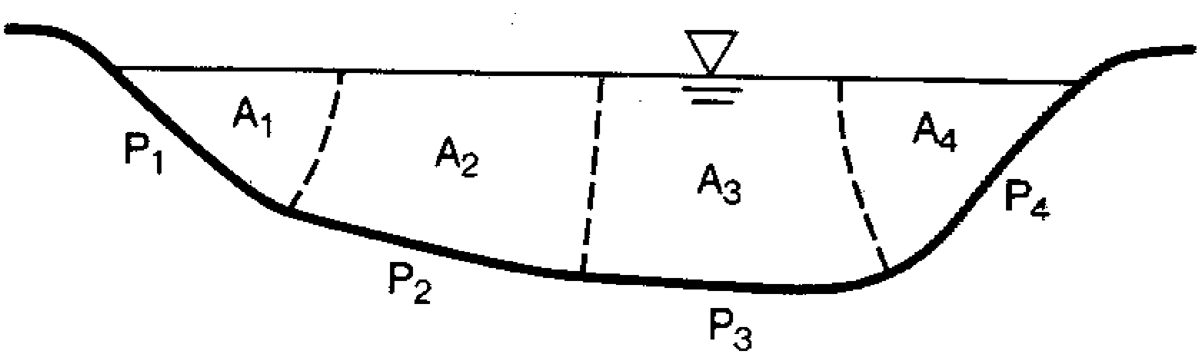

Figure 32. Example of cross section subareas. From Chang (1998).

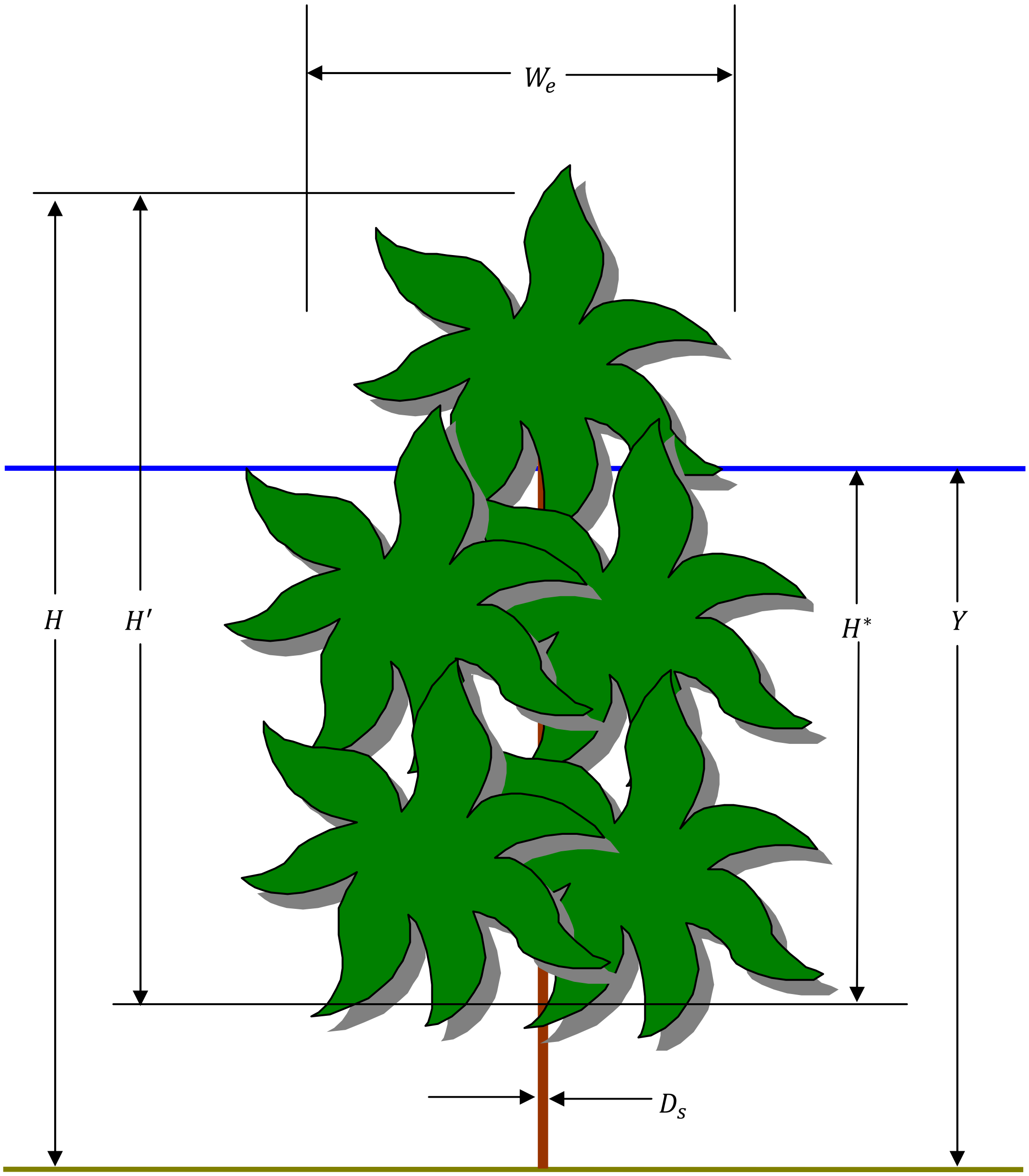

Figure 33. Plant dimension definitions. From Freeman et al. (2000).

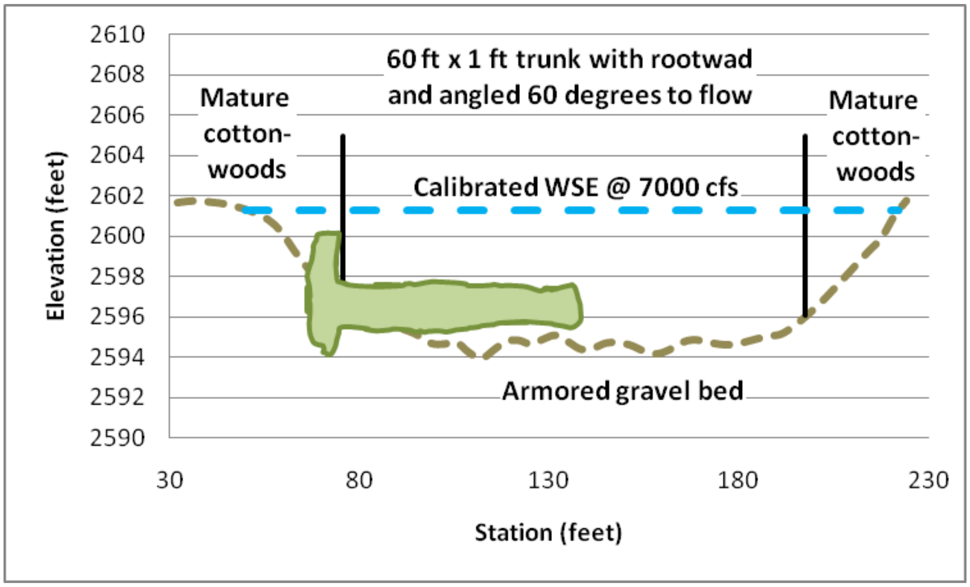

Figure 34. Example LWD blockage for the lower Boise River example calculations.

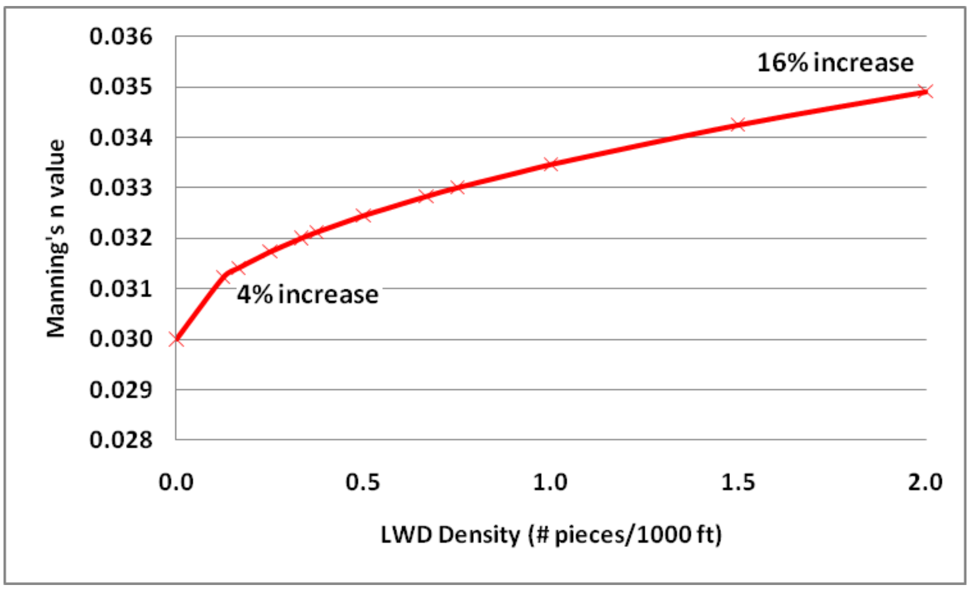

Figure 35. Increase in Manning's n value due to LWD for the lower Boise River example calculations.

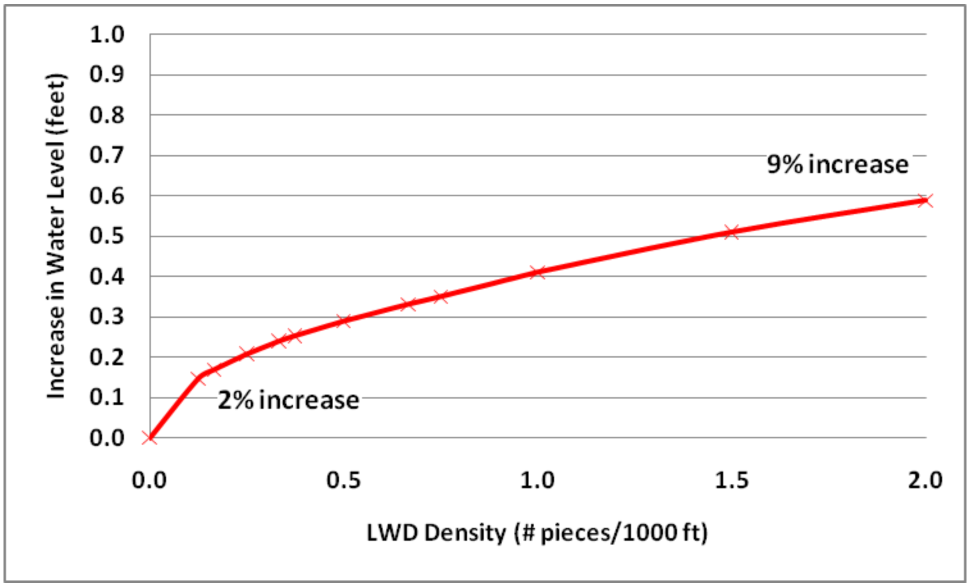

Figure 36. Increase in WSE due to LWD for lower Boise River example calculations.

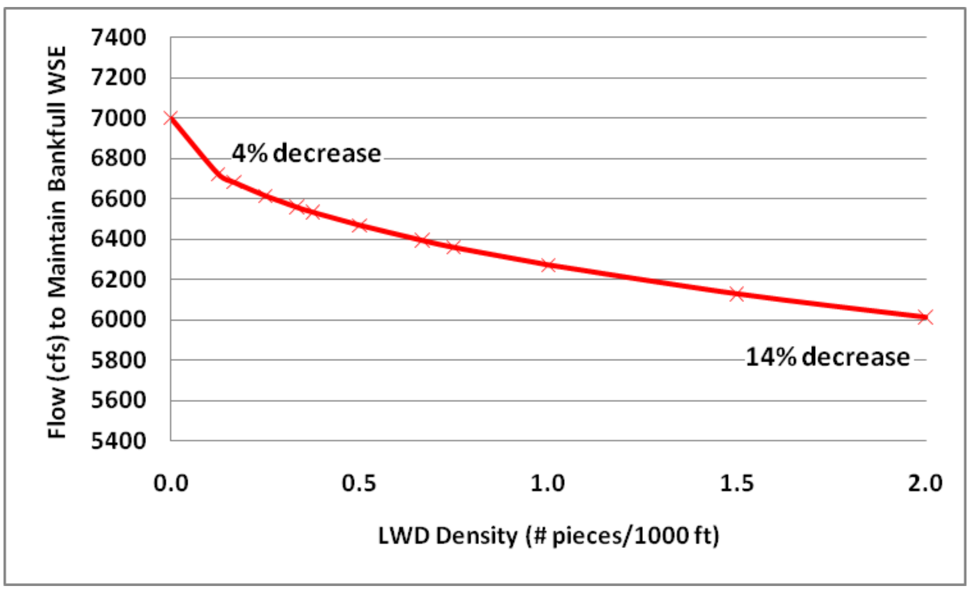

Figure 37. Decrease in discharge to maintain bankfull WSE due to LWD impacts for lower Boise River calculation.

CHAPTER 6: ADAPTIVE MANAGEMENT

6.1 Introduction

As the review demonstrates, the nature of woody debris in urban streams and rivers is not completely understood. Due to of the unique character and context of any individual urban stream it is probably not possible to ever completely understand the response of that stream to the retention or reintroduction of LWD into its conveyance channel. As such, in an environment that thrives on certainty, a decision to reintroduce LWD into a previously "cleaned" urban channel will create, among many stakeholders, a certain level of uncertainty about the future behavior of that stream. " *The presence of uncertainty about the management consequences complicates decision making for these resources and create the potential for disagreement and controversy among stakeholders*." [69]. Specifically, in the Eagle Island region of the Boise River Basin, one should have some concerns about potential LWD to affect flood stage water surface elevations. Therefore, in the face of risk and uncertainty the question becomes: What is the best way to move forward while managing the risk that is inherent in the decision making process? One approach that has been used successfully in watershed management is adaptive management (AM).

6.2 What is Adaptive Management?

Most succinctly stated, adaptive management is "learning by doing" [70] [69] [71]. More completely stated, "*AM is a rigorous process for learning through deliberately designing and applying management actions as experiments*" [70]. Adaptive management is not a panacea for all management situations. Not all decisions can or should be adaptive. Doremus et al. (2011) [71] identified the following prerequisite conditions for applying AM to a management problem:

- There are gaps in the information and understanding of the item to be managed. Adaptive management is only useful when learning is needed to achieve management goals.
- There are good prospects for learning. AM will not improve management outcomes unless important information gaps can be closed over time.
- There are opportunities for adjustment. Adaptive management cannot help where there is no way to correct an initial mistake, for example when the consequences of the original decision are irreversible.

Fundamentally, AM is a process of assessment, design, implementation, monitoring and adjustment. Figure 38 shows the process diagrammatically. The diagram shows an iterative process in which decisions are made, implemented, monitored, assessed and adjusted on a cyclic and iterative basis.

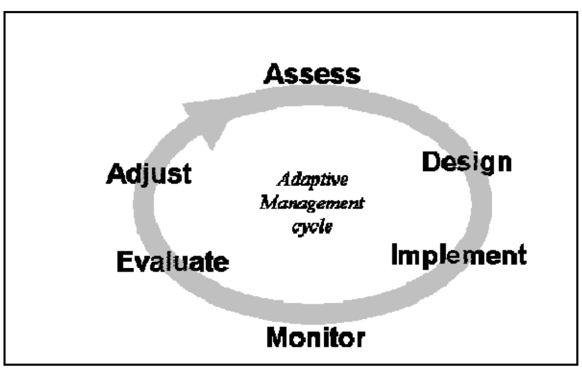

Figure 38. Adaptive management cycle. From Grieg et al. (2008).

It should be noted that for AM to work:

- The management strategy needs to be tailored to the specific problem and to achieve specific, agreed upon objectives,
- The management project must enjoy the benefit of sustained commitment by project managers and stakeholders,
- The AM must enjoy sustained and sufficient funding. Presently, most river management projects do not include, within the project budget, funds for post-implementation monitoring and assessment. These activities are essential to an adaptive management program.

Properly executed, an AM program will result in the best use of management funding. In the context of the Boise River, the benefits might include:

- Avoidance of channel destabilization (bank scour, capture of gravel pits, massive deposition and erosion patterns)
- Minimization of induced flooding
- Minimize costly capital projects to protect infrastructure with high levels of annual maintenance.

CHAPTER 7: CONCLUSIONS

7.0 Introduction

The findings presented in the previous chapters serve as a starting point for informing management decisions regarding vegetation in the lower Boise River system. The tools and findings presented show that complex, dynamic systems such as the lower Boise River require careful planning and regular assessment of activities to provide the best overall management practice. Conclusions of this study are presented in grouped sections and in list format below.

7.1 Hydraulics

- The effects of vegetation and trees on river channels are very complex. Findings in the literature vary widely and sometimes conflict depending on climate, type of vegetation, and river characteristics (type of bed, hydrology, etc).
- Removing vegetation from a river channel can destabilize the channel. Destabilization can result in local bank failures, altered channel morphology – and if the sediment scours, it will end up elsewhere. This de-stabilization could worsen flood risk for neighbors or downstream communities as well as altering the ecology (fish and birds).
- Floating wood and toppled trees can create obstructions – particularly at bridges and other constrictions such as diversion dams.
- To some extent it is possible to encourage woody debris to deposit in concentrated areas by, for example, the installation of ELJs.
- ELJs can be used with no increase in flood risk – but must be analyzed and engineered properly.
- On a small scale, woody debris (particularly when combined with overbank flows in parks and nature reserves) can attenuate peak flows in streams and reduce downstream flood risks. This is one possible measure in the small tributaries along the Boise River (Cottonwood Creek in Military Reserve is a good example).
- Planned vegetation management can improve or decrease flood conveyance.

7.2 Ecology

- It is important to understand the ecologic function and value of channel and riparian vegetation – what are we as a community giving up if the cottonwoods or willows disappear?
- Encouraging a healthy and stable vegetation community to replace dead or stressed vegetation could enhance system sustainability and function.

7.3 Management

- One approach would be to develop an Adaptive Management Plan, where vegetation management practices would be monitored and altered based on performance. This science-based approach is also defensible and demonstrates responsible stewardship of the public financial investment. Part of this plan could be to obtain a census of what trees (age and size) are currently in the channel and floodplain, what are the risks of these trees falling into the channel, how much of the vegetation is likely to accumulate in a single flood and over time and what measures would reduce the risk of many trees accumulating in a single event. Long term morphological monitoring could also be used to quantify and understand channel responses to vegetation management over time.

7.4 General

- Most of the information appears in the ‘grey’ literature (non peer-reviewed conference proceedings or engineering reports prepared for agencies and local government).
- There is an opportunity to do something special on the Boise River that protects lives and property, enhances the river environment, is defensible and improves recreational opportunities and aesthetics along the river. The fact that this process of information gathering and stakeholder involvement is occurring proves the community can achieve this goal!

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