A Primer on Large Woody Debris Management



Prepared for:

City of Rochester Hills
1000 Rochester Hills Dr.
Rochester Hills, MI 48309
248-656-4685 ph

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Prepared by:

JFNew

605 South Main Street
Ann Arbor, Michigan 48104
734-222-9690 ph
www.jfnew.com

JFNew Project # 060678

TABLE OF CONTENTS

Section	Page Number
Executive Summary	1
An Introduction to Large Woody Debris in Streams and Rivers	2
Recruitment of Large Woody Debris to Streams and Rivers	4
The Ecological Role of Large Woody Debris	5
The Impact of Large Woody Debris on Geomorphology	6
Stability of Large Woody Debris in Streams	10
Developing a Large Woody Debris Management Plan	12
Conclusion	26
Literature Cited	28
List of Densities of Various Trees Species Found Within Riparian Corridors and Weights of Various Sized Pieces	Appendix A
List of Densities of Various Tree Species and Their Dry-Weight Buoyancy Forces in Water	Appendix B
Woody Debris Assessment Datasheet and Evaluation Form	Appendix C
Large Woody Debris Management Action, Resources and Relative Cost	Appendix D
Duckbill Anchor and Cable Capacities in Relation to Buoyancy Force	Appendix E

TABLE OF TABLES

Table	Page Number
1. Habitats created by large woody debris.	7
2. Woody debris assessment data needs.	13
3. Descriptions of the American Fisheries Society Woody Debris Classification Scheme.	14
4. Minimum diameter of woody debris to be used in a stream as a function of bank-full width.	22
5. Techniques used to anchor large woody debris in a stream.	23

TABLE OF FIGURES

Figure	Page Number
1. A large woody debris dam in the Clinton River near Rochester Hills, Michigan.	2
2. A small debris dam in White Lick Creek near Plainfield, Indiana.	3
3. An example of a log with an attached root-wad in White Lick Creek near Plainfield, Indiana.	3
4. Example of geomorphology changes to a stream following the introduction of a log with a root-wad into a stream.	8
5. Example of a log stability plot.	11
6 - 10. Large woody debris structure conditions.	15 - 17
11. Large root-wads used for bank protection/flow redirection.	20
12. Logs used in a crib-wall bank stabilization technique.	21
13. Reuse of woody debris in large woody debris structures.	21
14. Example of a log recently cabled to the stream bank using the Palmiter Method.	25
15. Illustration of the Palmiter Method.	26

Executive Summary

The purpose of this document is to identify what constitutes large woody debris (LWD), how and where it is likely to get trapped and accumulate; its role in river ecology and fluvial geomorphology, and how to assess and manage LWD. A specific management plan, including recommended management actions for identified debris jams on the Clinton River within the City of Rochester Hills, is a companion document to this primer.

Large woody debris in streams includes snags, logjams, and other debris dams. They can vary in size from a couple of logs and associated branches to large accumulations of dozens of logs --“wood rafts”-- and other debris tangled together. Historically, large woody debris has been managed for complete removal to facilitate navigation, promote agricultural use and decrease flooding. Recently, scientific studies have demonstrated that LWD in streams plays a significant ecological role.

Woody debris accumulates in streams and rivers through biological and physical processes. Accumulations of debris generally occur at specific points in a stream. Woody material can play an important role in the ecological processes of a stream by providing habitat structure and food sources for a variety of organisms. Woody debris accumulations also affect the geomorphic processes of a stream. It may impact sediment storage and routing, stream bed and bank structure, velocity distributions, and sinuosity of a stream.

In developing a management plan for large woody debris in a particular stream or river, multiple factors should be considered. The goal and actions of the management plan should be based on the intent of the plan and the uses of a stream whether they are managing for wildlife habitat, commercial use, or recreational purposes. To determine management options and activities, an assessment of current conditions of large woody debris in a stream should be done. Management options may include taking no action, minimal removal or alteration of existing woody debris, complete removal, or even addition and/or reuse of woody debris.

Large woody debris plays an important role in the ecological processes of a stream. A management plan for large woody debris should include actions that balance the designated uses of a stream or river while maintaining the ecological integrity of the system.

An Introduction to Large Woody Debris in Streams and Rivers

Wood has been entering and affecting streams and river systems for more than 100 million years, however fluvial geomorphologists have only recently begun to link wood to channel properties and processes (Montgomery *et al*., 2003). Large woody debris (LWD) in streams is defined as woody material with a midpoint diameter of 10 cm or greater, a length of 2 m or greater, and protruding into the bankfull channel (Fox, 2004). Other names for LWD include snags, logjams, or debris dams and can vary in size from a few pieces of wood with associated organic material along the bend in a stream to several dozen large logs tangled together in a channel-spanning fashion across a large river (Figures 1 and 2). The biggest log jams often result from one large, "key" log that spans the stream channel and is positioned such that it collects other debris from upstream. One of the most significant types of LWD in a stream is the log with an attached root-wad (Figure 3).

Figure 1. A large woody debris dam in the Clinton River near Rochester Hills, Michigan.

Figure 2. A small debris dam in White Lick Creek near Plainfield, Indiana.

Figure 3. An example of a log with an attached root-wad in White Lick Creek near Plainfield, Indiana.

The management of LWD in streams and rivers has a long and extensive past. Historically, LWD was removed from large rivers to promote river navigation and decrease flooding. Large rivers in the United States were perceived as "national highways" and clearing debris was important for military and commercial navigation. In 1824, Congress made its first appropriation for snag removal in the Mississippi and Ohio Rivers. The LWD removal effort pulled out more than 800,000 snags in a 50-year period along the lower Mississippi alone (Montgomery *et al*., 2003). In smaller streams, LWD was removed to promote drainage for agriculture production, transport logs downstream for milling, and provide fish passage (Kauffman *et al*., 1997). In the 1970's, natural resource managers and biologists acknowledged the importance of LWD in streams after decades of removal practices contributed to the degradation of stream habitat and quality. Today in regions such as the Pacific Northwest, the presence of LWD in streams is viewed as a value and is protected or accounted for during activity that may negatively affect the stream to the point that "key pieces" of LWD such as a log with a root-wad are accounted for prior to an impact and mitigated for after an impact (Fox, 2004). The log with a root-wad is considered a "key piece" because it is likely to be stable during bank-full flows and influences many of the physical and ecological characteristics of a stream reach. The introduction of LWD is also one of the first and most frequently used techniques in stream restorations across the U.S. (White, 1996).

Although the importance of wood in streams has been acknowledged, integrated management of LWD within streams and along the riparian corridors is rarely practiced. When management of LWD does occur, it is primarily local and municipal entities and private landowners who enact the management activities. LWD has been managed to facilitate agriculture production, limit flooding, reduce bank erosion, and protect infrastructure such as bridges and culverts. With a basic understanding of the importance of LWD to streams and the processes that determine wood recruitment and stability in a stream, management of LWD in streams and the riparian corridor can protect and enhance stream quality while maintaining the designated uses of those streams.

Recruitment of Large Woody Debris to Streams and Rivers

Streams are dynamic systems that are constantly changing due to the physical, chemical, and biological process that are inherently occurring within them. Large woody debris is no exception to this rule. LWD is subject to breakdown from both decomposition and the physical forces of flowing water. It can be transported downstream during a storm event and it can be buried over time due to sedimentation. The amount of wood in a stream is determined by the rate of recruitment from terrestrial sources and the stability of LWD once it enters the stream. A stream's wood regime, analogous to the stream's sediment or discharge regime, is defined by the supply and size of wood delivered to a channel system. The recruitment and stability of LWD are also issues of concern for managers of stream resources.

The recruitment of large woody debris in streams is determined by biological and physical processes (Keller and Swanson, 1979), and by land practices. Biological factors include tree natural mortality, disease and pest outbreaks, and induced mortality (timber stand management). Physical factors include the results of storm events such as wind-throw and erosive bank failure. Different processes are responsible for recruitment in different portions of a river system. Typically, landslides and tree fall dominate wood inputs in steep headwater channels while bank erosion and failure result in the majority of wood inputs to larger floodplain rivers. Land practices such as removal of the adjacent streamside vegetation have been used to reduce recruitment into a stream by eliminating any potential trees from the vicinity of the stream.

Within a forested riparian area, the recruitment of wood to a stream is determined by tree height and distance to the stream (Robison and Beschta, 1990). Trees close to the stream and taller trees away from the stream have a greater chance of being recruited to LWD once they fall. The rate of recruitment varies by stand development and management history, and physical factors such as soil compaction, soil stability, valley form, and aspect (Cross, 2001). Wood loading varies with forest composition, due to inherent differences among tree species in growth height and proximity to water. Harmon *et al*. (1986) found substantial differences in wood loadings from redwood forests (>1,000 m^3/ha), other coniferous forests (200-1,000 m^3/ha), and deciduous forests (<200 m^3/ha).

Accumulation of large woody debris often occurs at specific points in a stream. The downstream end of a meander bend, the head of a side channel, the apex of a bar, pools, or other relatively low energy points often collect LWD that has been transported from upstream (Saldi-Caromile *et al*, 2004). Large accumulations are frequently the result of a key log that is transported or falls into the stream at a low energy point, becomes anchored in that location, and collects additional debris that is transported from upstream (Saldi-Caromile *et al*, 2004).

The Ecological Role of Large Woody Debris

From an ecological standpoint, woody debris can influence the local populations of aquatic organisms at the stream reach scale to ecosystem-level processes that operate on a landscape wide scale. Woody debris is integral in the food web for a stream ecosystem. LWD provides a habitat for aquatic organisms and modifies other habitats within the stream (Bilby and Likens, 1980; Angermeirer and Karr, 1984).

For a stream to have abundant macro-invertebrate and fish populations, food resources need to be present and transferred through the food web. The amount of nutrient cycling and energy transfer in a stream ecosystem is often related to the amount of wood present in the stream (Wallace *et al.*, 1993). LWD provides a substrate for biofilm or periphyton development, which is the slippery film coating on wood most people notice after picking up a piece of wood that has been submerged in a stream. In most streams, several species of macro-invertebrates use the biofilm as a food resource by grazing on it (Nilsen and Larimore, 1973; Hax and Golliday, 1993). Woody debris retains organic debris such as leaves, vegetation, and sticks that are being transported from the watershed through the stream. By retaining the debris, macroinvertebrates are able to process it into a form through shredding and filtering that can be used as a food resource and incorporated into the food web. If retention did not occur, the nutrients and energy in the organic debris would be transported downstream.

Woody debris also provides hard substrate for macroinvertebrates to colonize and perform important life functions such a feeding and reproduction. In cases where the surrounding stream lacks hard substrate such as sand-bottom streams, wood becomes an important habitat (Benke *et al.*, 1984, Wallace *et al.* 1993). In fact, wood habitats have been shown to significantly contribute to the overall abundance and diversity of macro-invertebrates (Johnson *et al.*, 2003; Smock *et al.*, 1989; Benke *et al.*, 1984).

Incorporating nutrients from organic debris and biofilm leads to abundant macro-invertebrate populations, which directly affect the fish community. LWD also affects the fish and macro-invertebrate communities by providing refuge for fish and invertebrates during periods of high and low flow conditions. During high flow, woody debris breaks up the current, creating eddies and areas of decreased flow. In low flow periods, pools created by LWD often are the last to dry up and provide habitat for aquatic organisms to retreat until the stream returns to a higher flow cycle. Some fishes rely on the habitat created by LWD for over-wintering, refuge from predators, and reproduction (Harvey *et al.*, 1999; Hax and Golliday, 1998; Solazzi *et al.*, 2000; Borchart, 1993; Angermeier and Karr, 1984). Recent work has also shown that some of the highest rates of denitrification (the conversion of nitrate to nitrogen gas) in suburban streams are in organic-rich debris dams and gravel bars (Groffman, *et.al*., 2005).

The Impact of Large Woody Debris on Geomorphology

Large woody debris influences geomorphology through alteration of sediment transport and storage, channel dynamics and processes, and channel morphology. These influences occur at multiple spatial scales within the riverine system, including the channel unit, the channel reach, the valley bottom, and the landscape.

At the channel unit scale, wood affects bed and bank erosion and influences the size and type of individual pools, bars, and steps. Large woody debris diversifies the velocity of water within a stream channel (Rutherford *et al*., 2002). Localized increases and decreases in velocity near LWD cause scour and deposition, respectively. Directly downstream from a channel spanning log, water velocity increases due to the flow being constricted. Upstream of a channel spanning log, velocity can decrease, creating sediment bars. Typically, erosion will occur directly downstream of LWD due to increased water velocity and scour, whereas deposition is more likely on the upstream end of LWD due to the decreased water velocity.

The specific influence of woody debris on velocity and habitat formation is determined by LWD type and orientation within the channel (Table 1). For example, a log with a root-wad in a stream will create a scour pool on the upstream end of the root-wad and a sediment bar on the downstream end (Figure 4; Saldi-Caromile *et al.*, 2004). In small streams, large woody debris often creates step pools. In larger streams, LWD creates scour pools, controls floodplain construction and side channel development (Saldi-Caromile *et al.*, 2004).

Table 1. Habitats created by large woody debris.

Orientation to Flow	**Habitat Created**	
	Upstream	**Downstream**
Parallel	Scour pool	Bar or island
Angled	Pool and bar	Pool and bar
Perpendicular: on bed	Depositional zone	Scour pool
Perpendicular: above bed	Scour pool	Scour pool

Modified from Treadwell *et al.*, 1999.

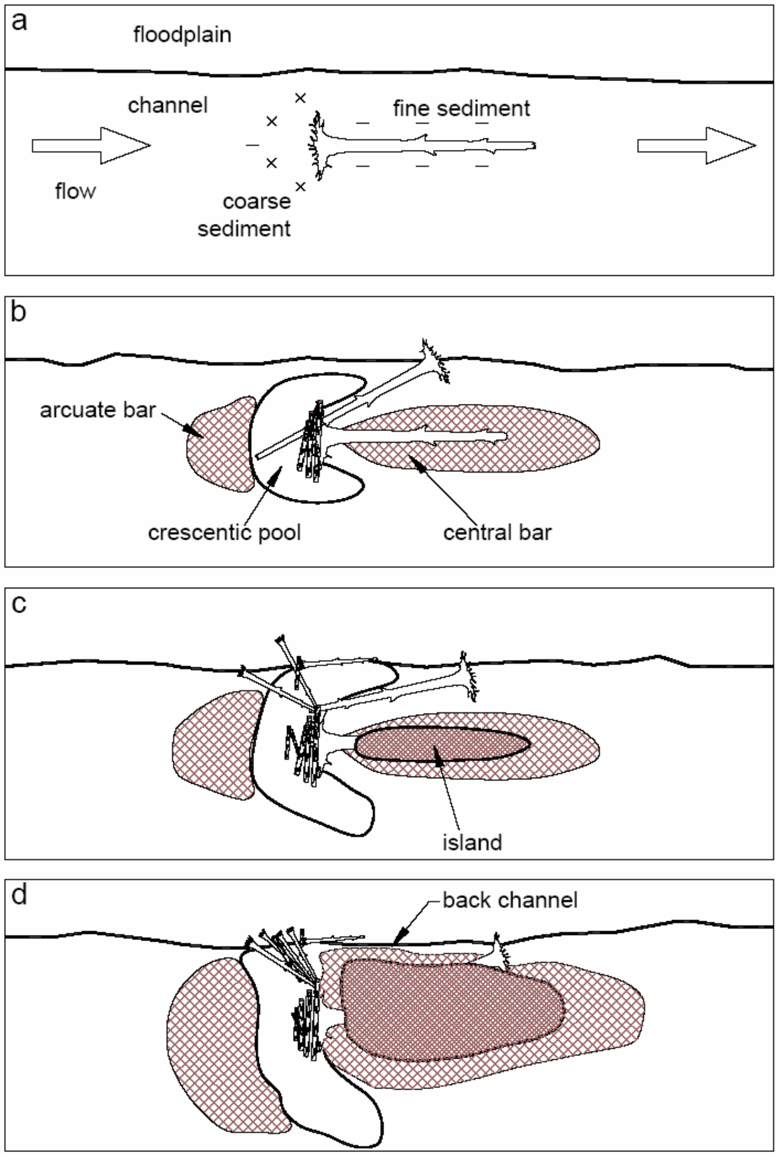

Figure 4. Example of geomorphology changes to a stream following the introduction of a log with a root-wad into a stream (Saldi-Caromile *et al.*, 2004).

Localized variations in channel width may occur near pieces of wood. Channel width may be maintained by LWD acting as armor to prevent streambank erosion. In contrast, channel widening may occur when LWD orientation causes flow to be directed into the bank, resulting in bank erosion.

At the channel reach scale, LWD affects hydraulic roughness, sediment storage, and channel type. Wood can create significant hydraulic roughness, not only from the wood itself, but also from non-uniform bed and bank topography, as discussed above. The combined effects of increased roughness caused by the wood, the bed, and the banks, can increase upstream water surface elevations, reduce flow velocity, shear stress, and reach-average surface grain sizes

(Montgomery *et al*., 2003). Changes in hydraulic roughness have been and can be estimated and translated into estimates of increases in water surface elevations for a range of flow events (Shields and Gippel, 1995).

Large woody debris facilitates sediment storage by reducing flow velocity and increasing channel roughness. A large LWD jam can effectively block the downstream transport of sediment. Blockage can cause deposition of bedload sediment on the upstream side. The wedge of deposited sediment can extend upstream several hundred feet (Bunte and Abt, 2001). In small, high gradient streams, up to 73% of the sediment in the stream can be stored behind LWD structures (May *et al.*, 2004).

Large woody debris creates and modifies habitat types within a stream. The number and spacing of pools or riffles can be influenced by the size and amount of LWD in the reach. Habitat features such as scour pools are created and maintained by the localized increase in velocity. LWD can increase channel width, the frequency of bend cutoffs and channel branching (Remich, 2002). LWD has the most significant impact on streams that have one to three percent gradient with alluvial channels and are classified as pool-riffle streams. For comparison sake, the Clinton River through the City of Rochester Hills has a slope of about 0.1 – 0.3% but is still composed of a pool-riffle stream type as well as a dune ripple stream type (Bunte and Abt, 2001).

Large woody debris can influence channel patterns and floodplain processes on the valley bottom scale. During high flows, woody debris in the floodplain increases the floodplain roughness, and results in an increase in sedimentation on the floodplain and a decrease in the amount of material transported downstream.

Because LWD decreases the velocity of water and may increase upstream water elevations in a stream, both past and present removal and management of LWD can be justified for decreasing potential flooding impacts. For LWD to have a significant effect on water levels, a minimum of ten percent of the cross sectional area of the whole channel needs to be occupied by LWD (Rutherford *et al.*, 2002). LWD abundance at this level would typically increase the duration of small flooding events (one to two year reoccurrence) by a day or two. Most streams that have a history of woody debris removal and management would not have LWD abundance that approaches that level. The impact that multiple pieces of LWD have on flooding is determined by the distance separating each piece. If several pieces are located within two times the diameter of the next piece, there is no greater impact on water levels than the one piece alone (Rutherford *et al.*, 2002).

On the landscape scale, LWD influences the sediment regime of the river system. Both erosion and deposition are influenced by LWD, and thus the overall sediment balance of the stream system may be affected. The majority of the erosion associated with LWD that enters a stream occurs during the first major flow event and decreases significantly with each high flow. Generally, the amount of erosion that results from a piece of LWD is equivalent to one to two times the area of the LWD (Rutherford *et al.*, 2002; Treadwell *et al.*, 1999).

Significant sediment deposition can occur behind log dams and debris jams. Log steps dissipate potential energy that would otherwise be available for sediment transport. In small streams, LWD can accumulate more sediment than the average annual rate of bedload transport (Marston 1982, in Montgomery *et al*., 2003). The combination of this sediment accumulation and changes in erosional processes may result in additional changes when LWD is removed. Sediment that was previously stored behind LWD may be more easily transported. Significant channel incision can also occur due to increased velocities resulting from the loss of hydraulic roughness attributed to the removed LWD.

Stability of Large Woody Debris in Streams

The stability of LWD once it enters a stream is determined by the interaction of the forces resisting its transport downstream and the forces driving its transport downstream. Examples of resisting forces would be the LWD's weight and friction on the streambed and channel banks. Driving forces would be the drag from the flowing water on the LWD and the buoyancy of the wood (Saldi-Caromile *et al.*, 2004). Large wood debris is stable when the resistive forces are greater than the driving forces. Stream flow, water depth, water velocity, the material strength of the wood, the wood decay resistance and deformability of the bed influence both the resistive and driving forces. Certain tree species such as red cedar will be more resistant to decomposition than other tree species. A water-soaked log will be heavier and potentially more stable than either an aged, dead tree or live tree. Woody material soaked for ten days has a density approximately 50 – 80% greater than dry woody material (Shields *et al.*, 2004). **Appendices A** and **B** list the density (lbs/cubic feet) of some common tree species found along riparian zones and the weight (**Appendix A**) and buoyancy (**Appendix B**) of some representative pieces of wood.

The size of the LWD, the type of the LWD (a log with root-wad vs. a log without), and the width of the stream channel influences the stability of the LWD (Saldi-Caromile *et al.*, 2004). The type of LWD is of particular importance. In eastern Washington streams, Fox (2001) found that 91% of the "key pieces" of LWD in streams with a bank-full channel of greater than 30 m were logs with root-wads attached. Due to their geometry, widely spreading or multiple-stemmed hardwoods are more prone to forming snags and acting as key members than the more cylindrical conifers which are more readily transported and accumulate as racked members, enhancing the development of log-jams. Previous research has demonstrated how log size and stream channel size and depth interact to influence LWD stability (Figure 5; Abbe *et al*. 1997). Abbe and Montgomery (in press) found that for wood longer than about half of bank-full width, those pieces with a diameter larger than about half of the bank-full depth tend to form key pieces.

In many stream systems, there is a generalized downstream change from randomly oriented wood and log steps in headwater channels to progressively larger, more complex jams in main-stem channels (Montgomery *et al.,* 2003). In headwater channels wood is likely to remain where it falls, resulting in randomly oriented pieces. In larger channels, wood is more mobile (i.e. less stable) due to increased flow and increased bank-full width, which leads to the development of larger, more organized jams.

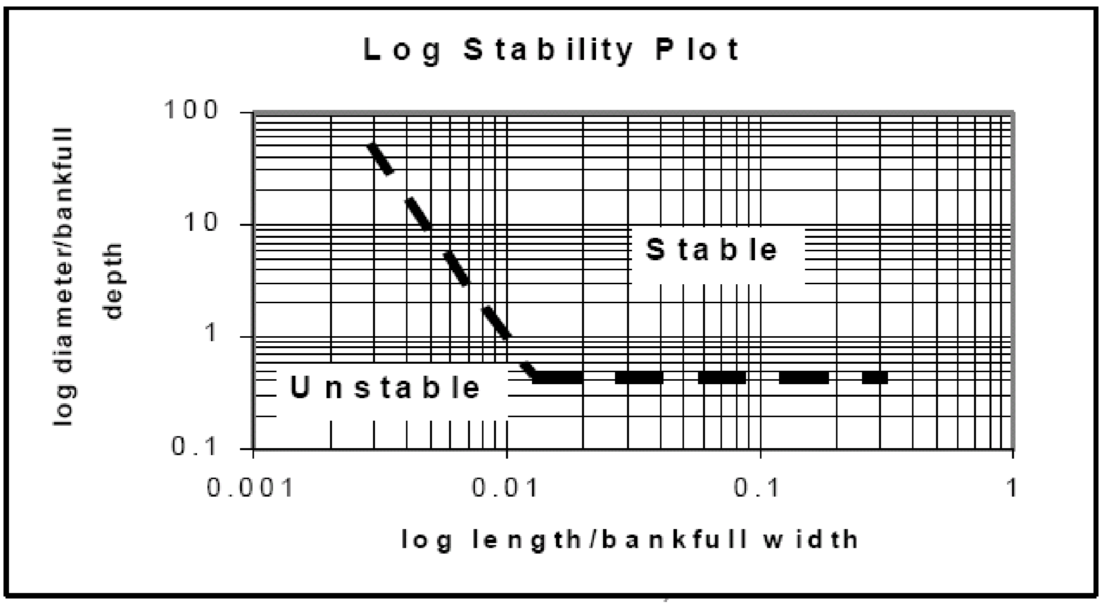

Figure 5. Example of a log stability plot from Abbe *et al*., 1997.

The presence of woody debris in a stream influences the recruitment and stability of additional LWD. Simply put, LWD recruits LWD (May *et al.*, 2004; Saldi-Caromile *et al.*, 2004; Washington State Aquatic Guidelines Program, 2002). This occurs because a stable LWD structure traps small organic debris that would typically be transported downstream. Often, the most stable LWD structure in a stream is a log with an attached root-wad (Fox, 2001) and/or a channel-spanning log. These “key pieces” are responsible for recruiting additional woody debris (Saldi-Caromile *et al.*, 2004). Through time, a large woody debris pile increases in complexity because it is trapping more organic debris. Some of the organic debris such as leaves and vegetation breaks down and is transported downstream or gets incorporated into the food web; however, large pieces of wood remain and continue to trap additional organic debris.

Developing a Large Woody Debris Management Plan

As demonstrated in the previous sections, LWD is a vital component to the natural functioning of a stream. In streams and riparian corridors with reduced human-influence, the natural processes in streams that result from woody debris such as channel meandering, habitat creation, and floodplain connectivity can operate with relatively little notice and contribute to the “wildness” of the resource for the users. The need to manage large woody debris in streams comes directly from the conflict between the effects of large woody debris and the designated uses of that stream. When developing a management plan for LWD, the requirements of the designated use and the benefits of LWD need to be balanced.

Large Woody Debris Assessment

The first step in developing a management plan for large woody debris in streams is to have a clear understanding of the designated uses for the stream. In Michigan, all Waters of the State are designated for the following uses: agricultural, industrial supply, public water supply, navigation, warmwater fisheries, aquatic life and wildlife habitat, and recreation. The Clinton River is also designated as a coldwater fishery. Defining the designated uses connects what is expected of the stream with the impacts of LWD on the stream. For example, if a stream is viewed as a significant recreational resource for canoeists and anglers, the stream might be expected to have a natural feel to it while providing unobstructed access for the canoes. Large woody debris that blocks the entire channel complicates boat access; however, the habitats created by LWD provide an important marcoinvertebrate and fishing resource. Management of LWD may require cutting channel spanning logs to allow canoe access and leaving other LWD for fish habitat. In other situations, the presence of LWD may present a significant risk to infrastructure such as sewer lines, roads or bridges. In those cases, channel meandering and the potential for downstream transport of LWD may require that large woody debris be removed, re-positioned and/or anchored.

Classifying and inventorying large woody debris within a stream is the second step in a woody debris management plan. This assessment provides a baseline on the amount and type of large woody debris and the locations along the stream. The assessment helps to quantify the impact of LWD on the designated uses of the stream. For instance, local residents may believe that large woody debris is creating flooding problems on their property. However, an assessment may reveal that although there were a number of LWD structures within a stream, very few structures covered more than ten percent of the channel cross sectional area (the amount required to significantly affect flow) and therefore the LWD present would not likely contribute to significant flooding.

The assessment prioritizes sites that require management action relative to the designated uses of the stream. Sites that create negative impacts to recreational uses or pose potential hazards to utilities or structures may be given higher priority. Areas with active or potential erosion problems may also be given priority. The assessment should also specify the techniques, equipment and materials used for particular management activities. The assessment also creates a baseline to track changes in locations and amounts of LWD through time. Tracking changes in LWD may illustrate changes in the factors that influence the recruitment and stability of LWD in streams such as watershed development and riparian land use and may provide insight on the future LWD management needs.

The information collected in the assessment should quantify the type of large woody debris structures, indicate which bank the LWD structure is anchored against, how it is anchored, and include observations on its impact to the local stream environment (Table 2). Examples of two different LWD assessment datasheets can be found in **Appendix C**. If management actions are anticipated, information about the channel width, depth, and a general sketch of the stream is valuable information during the management evaluation option phase. Additional tools include a camera to photograph the LWD structures and a Global Positioning System (GPS) unit to document relative location.

Table 2. Woody debris assessment data needs.

Data	Data Description	Example Data
Type of LWD structure	General description including size and composition of material; Use/create a classification scheme (Table 3).	Log with root-wad; channel spanning log; small debris dam
Anchor point and location	Indicate where the structure is located within the stream channel and how it is anchored	Located on left downstream bank with root-wad in channel and log out of water on bank.
General observations about influence on local site	Document any erosion that may be occurring upstream or downstream of structure and any habitat influences that structure is creating.	Log creating a scour pool directly downstream. Deep pool; quality fish habitat.
Channel width and depth	Measure the bank-full channel width and the depth of the channel to the top of the bank.	Bank-full width = 35 feet; Depth of the channel = 5 feet
General sketch of the stream	Drawing of the stream upstream and downstream of the structure indicating any bends, habitats, or areas of concern.	N/A

Classifying large woody debris can be difficult because structures can vary significantly over time and between streams. A classification scheme developed by the American Fisheries Society provides an example of a classification scheme that can be used by non-technical personnel. The classification scheme uses illustrations and definitions to place LWD into one of four condition classes (Table 3; Figures 6 – 10; AFS, 1983). Classifying LWD structures into one of the classes allows for easy communication between people that are familiar with the system; however, additional information is required for a more complete assessment.

Table 3. Descriptions of the American Fisheries Society Woody Debris Classification Scheme (AFS, 1983).

Condition	Description	Potential Management Action
Condition 1 (Figure 6)	LWD primarily composed of material that is transported downstream during high flows and is not impeding flow.	Material can be re-positioned and anchored through labor and hand tools.
Condition 2 (Figure 7)	LWD composed of multiple pieces that may span the channel, but do not cause upstream ponding.	Material can be re-positioned and anchored through labor and hand tools.
Condition 3 (Figure 8)	LWD spans the entire channel and is causing some flow reduction; however areas of flow through the structure exist.	Material may require the use of machinery or machine-assisted placement (winches).
Condition 4 (Figure 9)	LWD is a major stream obstruction with compacted debris and significant accumulated sediment.	Materials may require the use of machinery to remove or modify.
Condition 5 (Figure 10)	LWD is located in an area of special interest such as fish spawning and rearing areas, endangered species may be present.	Due to the sensitive nature of this area, little or no management is suggested without the guidance of a natural resource professional.

Figure 6. Condition 1 large woody debris structure (AFS, 1983).

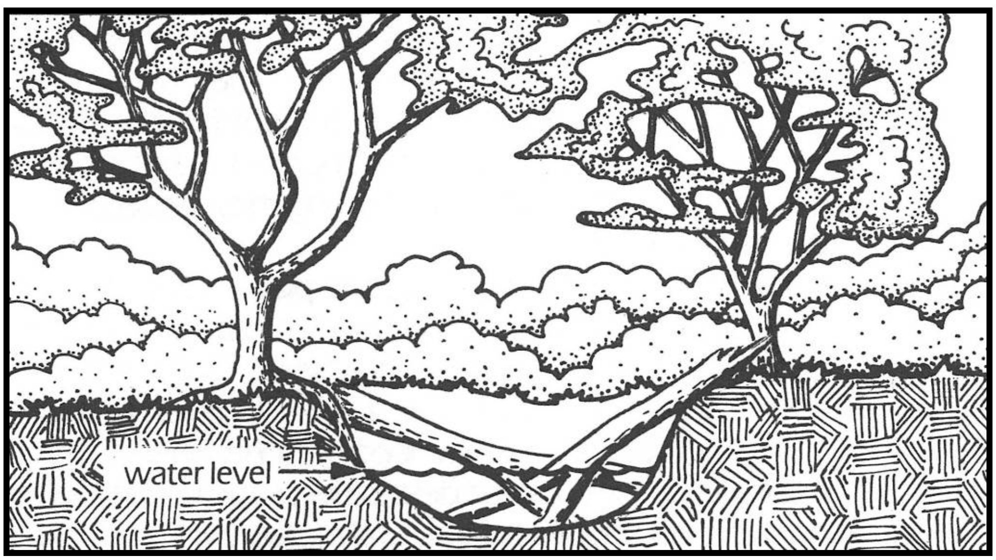

Figure 7. Condition 2 large woody debris structure (AFS, 1983).

Figure 8. Condition 3 large woody debris structure (AFS, 1983).

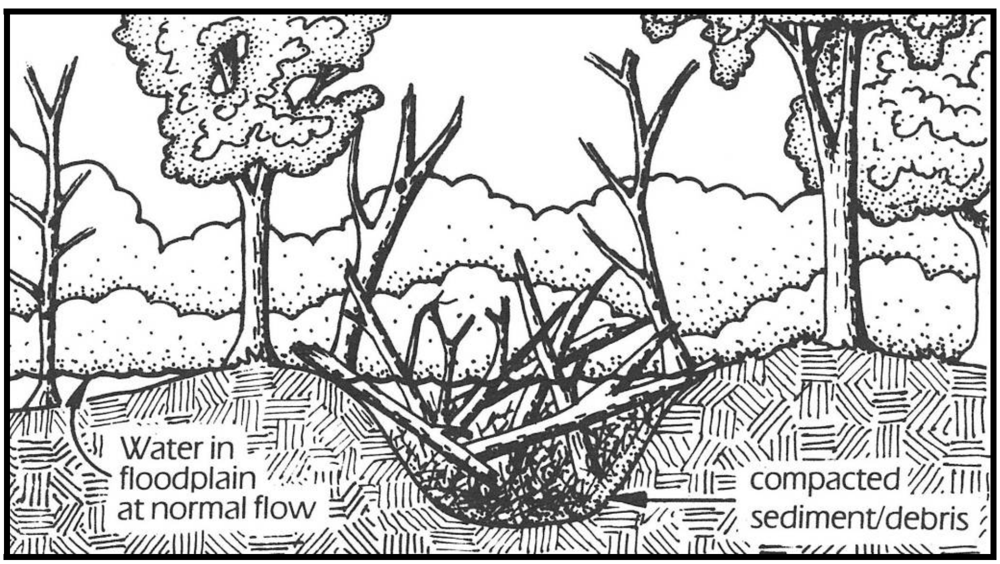

Figure 9. Condition 4 large woody debris structure (AFS, 1983).

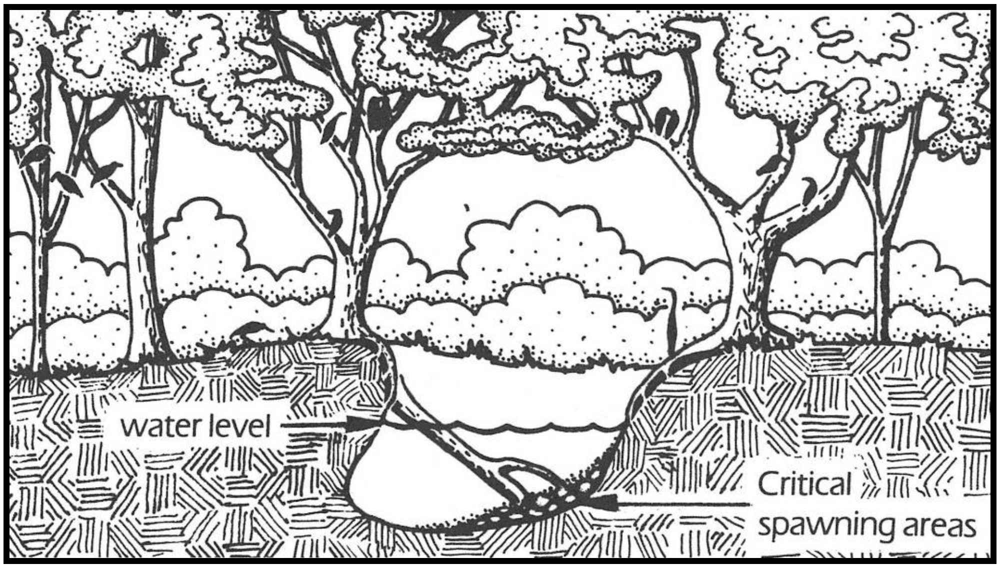

Figure 10. Condition 5 large woody debris structure (AFS, 1983).

Evaluating Large Woody Debris Management Options

Following a woody debris assessment, management options should be evaluated. Any management action needs to fit within what is expected of the stream through its designated uses and what is feasible based on the stream's characteristics. Other key factors that determine management options include cost and the experience of the responsible parties designing and/or implementing management activities. **Appendix D** lists management options, the resources needed, and a relative estimation of cost. Management actions are described in greater detail in the following sections. More than one management action may apply to any given woody debris structure; however, the selected management action should balance the benefits of woody debris and the impacted use that is requiring woody debris management. Certain management options may be regulated by local, state and/or federal agencies and would require permits to perform such actions. Management options involving heavy equipment or which may disturb the bank and/or bed of a stream or impact adjacent wetland areas are typically regulated activities.

As a rule of thumb for permitting, any activity that does not disturb the streambed and banks, and does not add a structure to the floodway does not require a Michigan Department of Environmental Quality (MDEQ) permit. Any activity that does disturb the bed or bank or places a new structure in the floodway (including an LWD structure) does require an MDEQ permit. In addition, for projects requiring heavy equipment, equipment access and set-up may impact riparian wetlands and/or habitat or plants of special concern. Impacts to wetlands or species of special concern may also require a MDEQ or Michigan Department of Natural Resources (MDNR) permit. To be on the safe side, it is best to contact the MDEQ before commencing any LWD management project to determine your permit needs.

Management options include:

- No-action
- Modification of woody debris to increase channel capacity without repositioning – Clean and Open Method.
- Removal of woody debris from the channel and disposal at an offsite location.
- Re-positioning, placement, and anchoring of either a portion or an entire LWD structure within the stream channel.
- Pre-emptive cutting and anchoring of dead or leaning trees along the stream-bank and/or within the riparian corridor.

No Action Required

No action may be required on debris structures that are stable such as a large log with a root-wad, structures that occupy less than 10% of the channel cross sectional area, or structures that are not positioned to trap and retain additional woody material within the stream channel. Results from the woody debris assessment will provide information about which sites require no action. These sites will need to be monitored for changes through time to prevent larger issues from developing.

Modification of Woody Debris Structure – Clean and Open Method

The simplest form of LWD management is to change the structure and orientation of existing woody debris to increase channel size and capacity, while preserving the function and anchor point of the woody debris. An excellent example of this is Michigan's Woody Debris Management 101 Clean and Open Method (Rouge River Riparian Corridor Management Technical Advisory Committee, 2004). The benefits of this management action are that typically no regulatory permits are required, untrained labor can be used, and the aesthetic value of the stream can be preserved. Branches that hang out into the channel that trap debris can be removed to increase capacity and passage for recreation without altering a stable LWD structure. Moving a log that is perpendicular to the stream channel to a forty-degree angle to the bank, away from the flow will increase the capacity of the channel and maintain the local habitat (Rutherford *et al.*, 2002). It is important to determine after changing the orientation of a LWD structure whether or not the structure will require additional anchoring. This should be done by estimating the net buoyancy force and drag force on the LWD (refer to Shields, et.al., 2004).

Woody Debris Removal

One of the objectives of a woody debris management plan may be to remove woody debris from a stream reach to facilitate a designated use such as conveyance or canoe passage and at the same time, preserve the function of the remaining LWD. Removal of large woody debris should be assessed at the stream reach scale to prevent negative impacts to the removal of LWD. The amount of woody debris, the type of LWD structures, and the stream characteristics should be considered prior to any removal.

There are two different approaches to estimate how much wood a stream reach should contain. A simple guideline is that the amount of wood within a stream should be approximately 20% of the amount found within the adjacent riparian area (Rutherford *et al.*, 2002). A more quantitative value suggests that a stream should have between 0.01 – 0.1 m^3 of LWD per m^2 of stream channel area (Treadwell, 1999). Removing woody debris to levels below these values may reduce the function of woody debris to a stream reach.

The type of woody debris in a stream reach can influence whether or not removal is an option. Structures such as embedded logs that are retaining sediments and acting as grade controls should not be removed. If it is determined that they have to be removed, this kind of activity requires a permit in Michigan. An increase in both local and upstream erosion may result. Woody debris that is naturally providing bank protection should be left in place. During the assessment, LWD structures that are directly creating or modifying a stream habitat such as maintaining a scour pool should be identified. The best option is to leave these structures alone; however, only partial modification should occur rather than complete removal.

Some reaches of a stream may possess physical characteristics that limit management to removal only including sections of a stream where the bed or bank material is unstable to the point that anchoring cannot occur. In stream reaches with high velocities, removal may be the preferred method to protect important infrastructure elements. Failure to understand a site's limitations for woody debris management can ruin public or institutional support for the project.

Wood that is removed from a stream has several different options that may vary depending on the adjacent site characteristics and regulatory limitations. Debris removed under permitted activities may be required to be disposed in an upland location. In situations where access is limited and the adjacent land use does not allow for stockpiling in an upland location, material should be removed to a proper location. Many municipalities operate a yard waste facility where large organic debris can be dumped and later turned into a reusable product such as wood chips or compost. Wood that has been submerged for a while will be extremely heavy and difficult to handle; and may require a drying out period before processing. Arrangements with the facility operators should be made prior to removal. Material could be chipped streamside if the condition of the material and site conditions allow it. Every attempt should be made to separate organic material from any trash that is incorporated with a woody debris structure. If an upland location is adjacent to the area, another option is to stockpile the removed material and offer it to the public for firewood. Burning would be another option, but is limited due to local ordinances on air quality and by site conditions. For large or multiple debris structures, several different disposal options may need to be employed due to differences in local site conditions and the type and condition of the woody material being removed.

Placing and pinning debris within the floodplain may also be an option; however, it is limited to situations where the adjacent riparian area is large and relatively unmanaged and is a permitted activity. Several states in the Midwest would require a permit for any material placed within the floodplain (Christopher B. Burke Engineering, 1999; Riparian Corridor Management Technical Advisory Committee, 2005). Placing woody debris within the floodplain increases the roughness of the floodplain, allowing for sediments to settle out during a high flow event.

Other options for reuse of woody debris removed from a stream reach include using the material for bank stabilization/protection or creating habitat in other reaches of the stream (Saldi-Caromile *et al.*, 2004; Washington State Aquatic Guidelines Program, 2002). Debris could be used to in bioengineering or flow redirection techniques to stabilize or protect eroding banks (Figures 11, 12: Federal Interagency Stream Corridor Restoration Working Group (FISCRWG), 1998 and Figure 13, Shields, et.al., 2004).

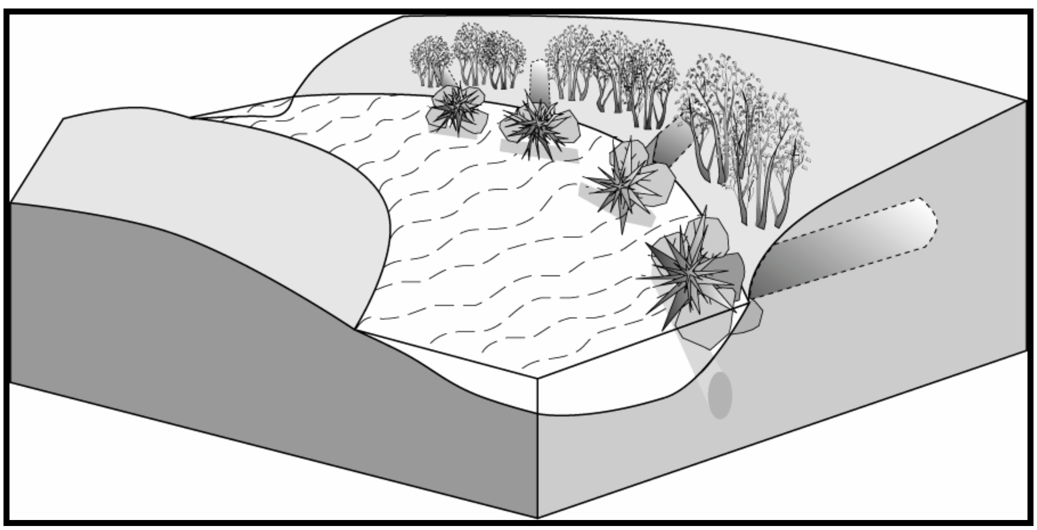

Figure 11. Large root-wads used for bank protection/flow redirection (FISCRWG, 1998).

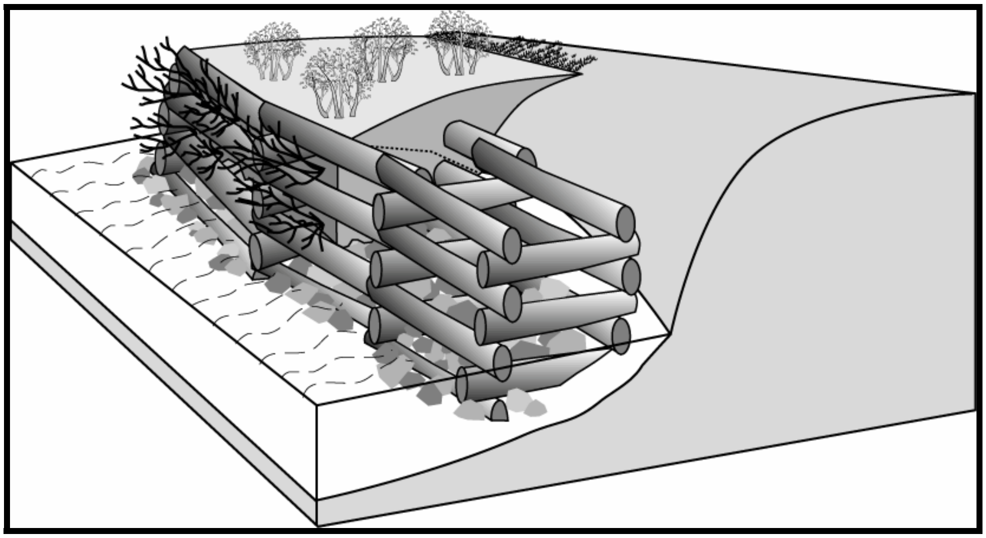

Figure 12. Logs used in a crib-wall bank stabilization technique (FISCRWG, 1998).

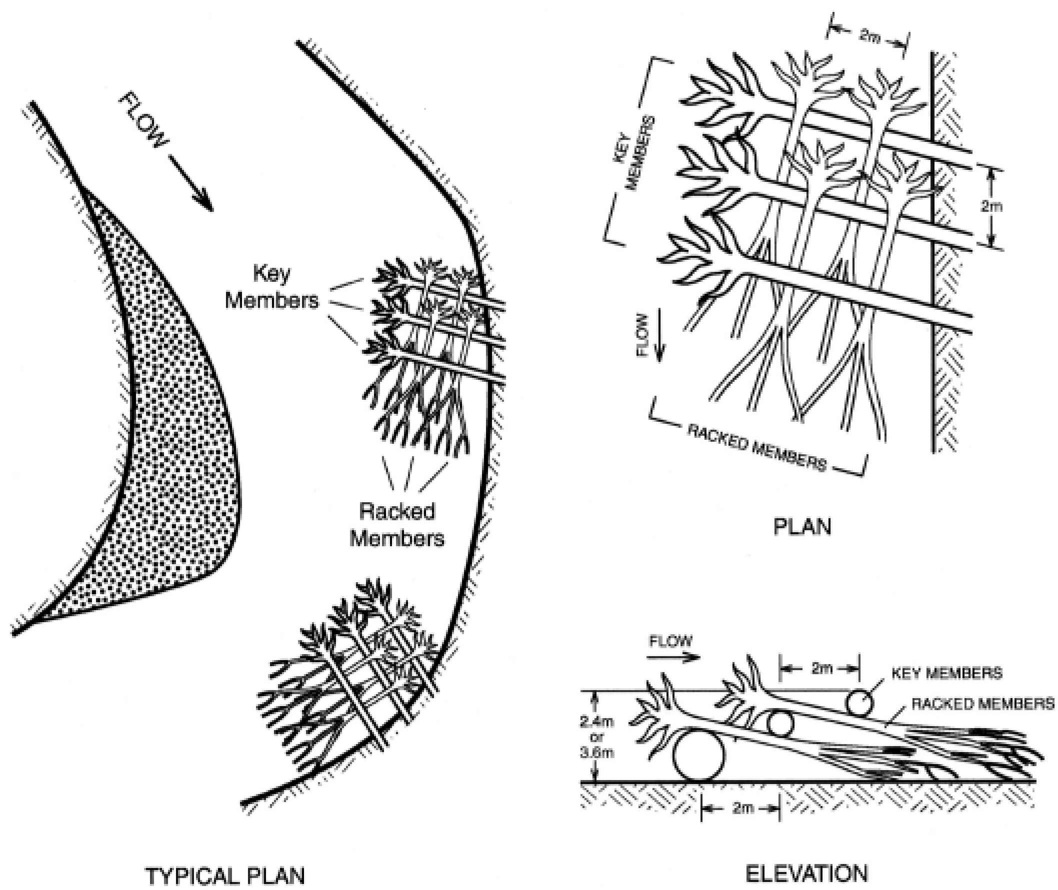

Figure 13. Reuse of Woody Debris in Large Woody Debris Structures. Note: key members are also referred to in this report as horizontal bank pilings (from Shields, et.al., 2004)

Orientation, Placement, and Anchoring of Large Woody Debris

A stream's habitats, flow regime, and bank stability can be impacted by modifying the orientation and placement of existing large woody debris. To prevent unintended negative impacts, basic information is required prior to any woody debris management project (Saldi-Caromile *et al.*, 2004). This information will be used to address the stated goals and objectives of a woody debris management design project. As stated in a previous section, the first step is to document and inventory the amount and location of existing large woody debris. The information provided in the inventory can be used to determine the placement of LWD and the techniques used. The second step is to collect project site hydrology data. Whether qualitative or quantitative hydrology data are needed depends on the energy of the stream, the risk involved in the project, and the experience of the designer. At a minimum, bankfull or flood elevations should be known or estimated. In more complicated projects the range of flows, depths, velocities and shear stresses should also be estimated. The locations of infrastructure items such as water and sewer lines and areas where equipment can access the project site should be mapped during or immediately following a woody debris inventory.

If woody debris will be placed in a stream as part of either re-positioning existing woody debris structures or pre-emptive felling of leaning or dead trees, both the size of the material and the size of the stream channel should be considered prior to placement. Table 4 lists the recommended minimum diameter of woody debris to be placed in a stream as a function of bank-full width (Oregon Department of Forestry, 1995). Generally, woody debris should not be placed in a stream channel that can fully contain a 20-year flood event (Saldi-Caromile *et al.*, 2004). Depending on the experience of the LWD designer, there can be uncertainty about the stability and placement of LWD structures within a stream. Observing large woody debris in other streams of equal or greater size can increase the understanding of how wood placement can affect the stream. Again, if the project scope calls for it, a detailed force balance can be performed to determine relative stability and possible anchoring needs (Shields, et.al., 2004).

Table 4. Minimum diameter of woody debris to be used in a stream as a function of bank-full width.

Bank-full Width (ft)	Minimum Log Diameter (inches)
0 to 10	10
10 to 20	16
20 to 30	18
Over 30	22

Large woody debris can be anchored to the stream channel or bed by one of four basic techniques (Table 5; Saldi-Caromile *et al.*, 2004; Washington State Aquatic Habitat Guidelines Program, 2002). The technique used depends on stream size, the type of woody material being used, management plan objectives, site-specific management goals, the materials available, and the experience of the designer. Each technique varies in the amount of stability provided and how well it mimics the function of naturally occurring wood. For woody debris that will be placed in areas where there is a potential for damage to infrastructure or other valuable resources, an engineer should be consulted. Due to the dynamic nature of LWD, a minimum safety factor of 2.0 should be designed into any woody debris anchoring and placement system (Saldi-Caromile *et al.*, 2004).

Table 5. Techniques used to anchor large woody debris in a stream.

Type	Description	Stability	Stream Function	Limitations
No anchors	Existing and newly recruited wood is mobile and finds stable locations based on stream characteristics.	Low	High; Allows for habitat creation and modification	Use in areas where wood can be allowed to move to find stable location.
Passive	The weight and shape of the LWD structure provides resistance to downstream transport	Moderate	High; May become mobile during high flows	Equipment may need access to the stream to move ballast material.
Flexible	LWD is tethered in by at least one point into the bank or bed, but allowed to float and rotate during high flows	Moderate	Moderate; provides roughness and cover	Should not be used in areas where public has access to the stream during high flows because structure will float.
Rigid	LWD is tethered by two or more connection points to anchors such as standing trees, duckbill or dead-man anchors or keyed into bank and not allowed to move	High	Moderate; provides long-term bank protection and grade control.	Exposed cabling provides the highest risk to humans during high flows.

Not anchoring any existing or newly recruited LWD, but rather allowing LWD to find stable locations based on the stream characteristics provides the greatest benefits to stream function; however, this technique is the highest risk to infrastructure and should not be used without a clear understanding of the potential consequences. Passive anchors use the weight and shape of the LWD structure to provide resistance against downstream transport. Materials typically used in passive anchors include root-wads, larger logs that cannot be transported by the potential stream power, and boulders. Logs may be cabled together to form a matrix that acts as a single unit; however, the structure remains unattached to any exterior anchor. Flexible anchors are typically attached to the bank with cables, allowed to float during high flows, and pivot to some degree, creating scour. Flexible anchors pose the greatest risk to public safety due to floating wood and exposed cables. This technique should be applied in the appropriate areas such as backwater and low velocity areas and in situations where public use (canoeing, fishing) is minimal. If designed and installed properly, rigid anchors provide the greatest stability to LWD, although the natural function is reduced when compared to other anchoring techniques.

Excluding the use of no anchors, the three types of anchors use a combination of several different techniques and materials.

- Ballast is the addition of weight to a structure to increase the resistance force. Ballast can be in the form a large logs, boulders, or gravel. Adding weight increases the resistive force of a LWD structure. Weight is most effective when it is applied to the portion of the log or debris pile that is out of the bank-full channel and on the floodplain.

- Pilings – large wood timbers, steel beams or pipes driven vertically into the bed or horizontally into the bank. Logs are attached to the pilings with pins or cables or are wedged between to the pilings to prevent movement. The use of pilings can stabilize existing LWD and recruit additional LWD. Approximately one-half to two-thirds of the length of the pilings is buried below the streambed surface. Approximately one-fifth to one-third of horizontal bank pilings are buried into the bank. The depth of the piling depends on the scour zone at the surface.

- Cabling or Chaining – Pieces of LWD are attached to an anchor through the use of cable, chain, or rope. If applied correctly, cabling provides a relatively high degree of permanence and control to the anchoring system. In high stress and abrasive conditions, cabling may be the preferred method. A common cabling technique used in the Midwest is called the Palmiter Method, where a log is cabled in a parallel fashion to an eroding bank (Figure 11; Herbkersman, 1982). The cabled is looped around the log in a minimum of two locations and anchored to a live tree (Figure 12). The cable around the tree has a rubber sleeve to prevent girdling of a tree.

In the absence of anchor trees, metal t-posts can be driven into floodplain to serve as anchor points. Dead-man anchors may also be used in certain situations; however, their use is limited to locations where equipment can have access to the bank or riparian corridor for installation. Duckbill anchors are also useful because they do not require an above-ground anchor point. See **Appendix E** for duckbill anchor capacity and recommended use in relation to buoyancy forces. Appendix E also includes the relationship of cable diameter to buoyancy force.

- Pinning – Logs and debris are pinned to the streambed or bank. Rebar is the most common type of pin used. A hole is drilled through the wood and a pin is pounded through the hole and into the bed or bank. The top of the rebar can be bent over or a large washed can be welded to the rebar to prevent the log from pulling out during high flows. The length and diameter of rebar used depends on the size of the stream, the size of the wood being anchored, and the type of bed or bank material.

Figure 14. Example of a log recently cabled to the stream bank using the Palmiter Method.

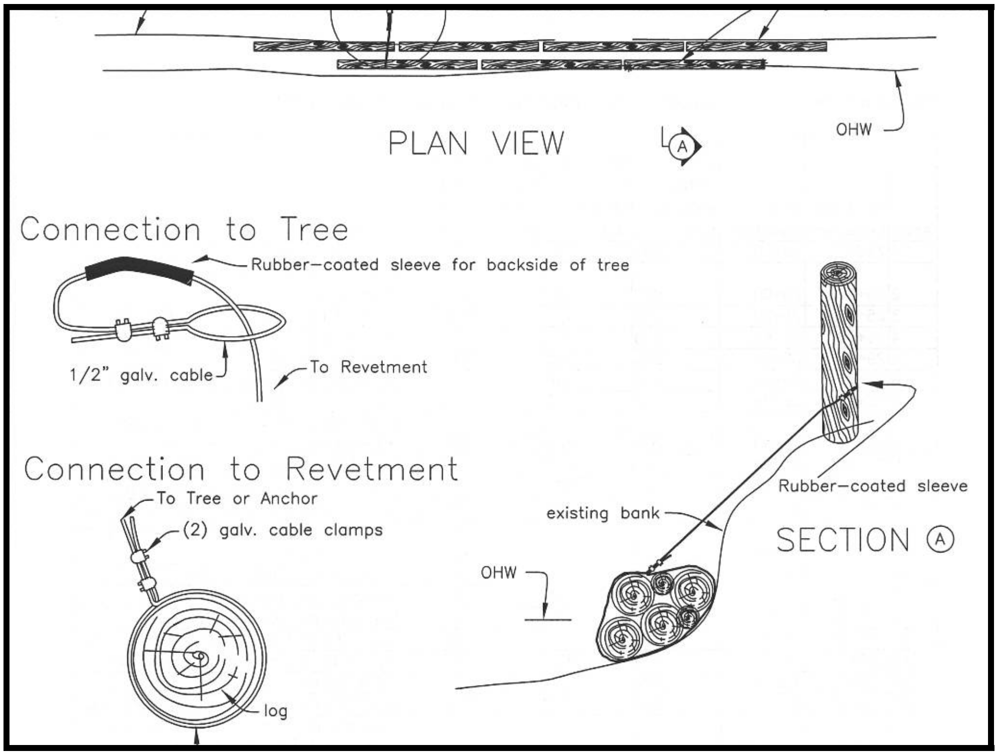

Figure 15. Illustration of the Palmiter Method.

Pre-emptive Removal of Dead or Leaning Trees
Another management action may be to identify and remove those trees along the stream corridor that are dead and/or leaning which may fall in the future. This action could control or prevent the addition of woody debris to a stream. Trees removed could be disposed of or re-used by previously mentioned methods.

Conclusion

Large woody debris is an important component to stream ecosystems. LWD influences both the biological and physical functions and processes of a stream ecosystem. The influence of woody debris on a stream can conflict with the designated uses of a stream, such as recreation and watershed drainage. A management plan provides the framework to preserve the integrity of the woody debris in stream function and to meet the needs of a stream's designated uses. An assessment of the size, location and type of woody debris within a stream along with measurements of the stream channel's width and depth allow for evaluating what management options are available. Management of large woody debris may include removal from the stream channel or repositioning and anchoring within the channel. Various techniques for anchoring exist including the use of ballast, cabling logs to anchors, pinning logs to the streambed or bank, or attaching logs to pilings driven in the streambed or bank. The anchoring technique used depends on the quality and size of the wood used in the stream, the stream channel's characteristics, the goal of the management plan, and the experience of the responsible parties in designing and implementing a woody debris management plan. Proper management of large woody debris can balance the benefits it provides to a stream with the needs of users of the stream.

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Appendices

Appendix A: List of Densities of Various Trees Species Found Within Riparian Corridors and Weights of Various Sized Pieces

Appendix B: List of Densities of Various Tree Species and Their Dry-Weight Buoyancy Forces in Water

Appendix C: Woody Debris Assessment Datasheet and Evaluation Form

Appendix D: Large Woody Debris Management Action, Resources and Relative Cost

Appendix E: Duckbill Anchor and Cable Capacities in Relation to Buoyancy Force

List of the density of various tree species found within riparian corridors and the weights (lbs) of various sized pieces.

Tree species	Density (lb/ft^3)[a]	6-inch diameter			12-inch diameter			18-inch diameter			24-inch		
		6-ft	12-ft	18-ft	6-ft	12-ft	18-ft	6-ft	12-ft	18-ft	6-ft	12-ft	18-ft
Black Walnut	57	67	134	201	268	537	805	604	1208	1812	1074	2148	3222
Burr Oak	62	73	146	219	292	584	876	657	1314	1971	1168	2336	3504
Cottonwood	58	68	137	205	273	546	820	615	1229	1844	1093	2185	3278
Eastern Red Cedar	37	44	87	131	174	349	523	392	784	1176	697	1394	2091
Green Ash	53	62	125	187	250	499	749	562	1123	1685	999	1997	2996
Hackberry	51	60	120	180	240	480	721	540	1081	1621	961	1922	2883
Hickory	64	75	151	226	301	603	904	678	1356	2035	1206	2412	3617
Sugar Maple	59	69	139	208	278	556	834	625	1251	1876	1112	2223	3335
Sycamore	63	74	148	223	297	593	890	668	1335	2003	1187	2374	3561
Willow	54	64	127	191	254	509	763	572	1145	1717	1017	2035	3052
Average	55.8	66	131	197	263	526	788	591	1183	1774	1051	2103	3154
Average-wet (50% increase)[b]	84	99	197	296	394	788	1183	887	1774	2661	1577	3154	4731

Note: Density of wood material will vary with moisture content and condition (live, seasoned, wet). This table should only be used as a guide for the weight of different sized pieces of large woody debris.

[a]Source: http://www.engineeringtoolbox.com/weigt-wood-d_821.html

[b]Estimated from data in Shields et al. 2004. Large Woody Debris Structures for Sand-Bed Channels. Journal of Hydraulic Engineering. 130: 208-217.

List of Densities of Various Tree Species and Their Dry-Weight Buoyancy Forces in Water

Tree species	Dry Wood Density	Water - Wood Density Difference	6 inch diameter			12-inch diameter			18-inch diameter			24-inch diameter		
			6 ft	12 ft	18 ft	6 ft	12-ft	18-ft	6 ft	12-ft	18-ft	6 ft	12-ft	18-ft
	(lb/ft3)	(lb/ft3)	1.178	2.356	3.534	4.712	9.425	14.137	10.603	21.205	31.808	18.849	37.698	56.547
Black Walnut	57	5.4	6.4	12.7	19.1	25.4	50.9	76.3	57.3	114.5	171.8	101.8	203.6	305.4
Burr Oak	62	0.4	0.5	0.9	1.4	1.9	3.8	5.7	4.2	8.5	12.7	7.5	15.1	22.6
Cottonwood	58	4.4	5.2	10.4	15.6	20.7	41.5	62.2	46.7	93.3	140.0	82.9	165.9	248.8
Eastern Red Cedar	37	25.4	29.9	59.8	89.8	119.7	239.4	359.1	269.3	538.6	807.9	478.8	957.5	1436.3
Green Ash	53	9.4	11.1	22.1	33.2	44.3	88.6	132.9	99.7	199.3	299.0	177.2	354.4	531.5
Hackberry	51	11.4	13.4	26.9	40.3	53.7	107.4	161.2	120.9	241.7	362.6	214.9	429.8	644.6
Hickory	64	-1.6	-1.9	-3.8	-5.7	-7.5	-15.1	-22.6	-17.0	-33.9	-50.9	-30.2	-60.3	-90.5
Sugar Maple	59	3.4	4.0	8.0	12.0	16.0	32.0	48.1	36.0	72.1	108.1	64.1	128.2	192.3
Sycamore	63	-0.6	-0.7	-1.4	-2.1	-2.8	-5.7	-8.5	-6.4	-12.7	-19.1	-11.3	-22.6	-33.9
Willow	54	8.4	9.9	19.8	29.7	39.6	79.2	118.7	89.1	178.1	267.2	158.3	316.7	475.0
Average	55.8	6.6	7.8	15.6	23.3	31.1	62.2	93.3	70.0	140.0	209.9	124.4	248.8	373.2

Woody Debris Assessment Datasheet

Date:______________ **Investigators:____________________**

Site No:___________ **Station Number (Start):___________**

Photo Numbers:	**GPS Points:**	**LWD Type:**	**AFS Condition No:**	**Quantitative Rating:**
General Description of LWD Structure (including orientation to flow, location along bank)				
Anchor or Attachment Point:	**Bankfull Channel Width (ft):**	**Average Channel Depth (ft):**	**Dimensions -Plan view area(LXW) of LWD:**	**Dimensions –cross sectional area(WX D) of LWD:**
Observations regarding LWD influence on stream reach (erosion, habitat creation and modification, recruiting additional LWD, grade control):				

Tree Species (if known)	**No. of pieces**	**Diameter**	**Length**	**Tree Species (if known)**	**No. of pieces**	**Diameter**	**Length**

Rough Sketch of LWD Structure including size, orientation to flow, flow direction, and bank features:

Clinton River Woody Debris Evaluation Form

Date: ______________ **Time:** ______________

Observers: ______________ **Current Weather (temp. & conditions):** ______________

Video Reference: ______________

Site Number[1]: ______________ **Auburn Hills USGS gage/flow (if known)** ______________

Digital Photo Numbers: ______________

GPS Start[2] ________ Lat ________ Long **Station Start[3]** ________ (Refer to stationing map)

GPS End ________ Lat ________ Long **Station End** ________

Nearest street: ______________ **Is the street upstrm. or downstrm.?** ________ Appox.Dist.________

Orientation of main jam axis[4]: ______________ (in relation to bank and flow)

Are trees in jam still rooted to the bank[5]? ________ **Are logs/trees embedded in streambed?** ________

Log Tally[6]

Diameter / Length	Tally approx. # and size	**Tree Species** if known ID species, or ID simply as conifer or deciduous	**Submergence** above water, completely under or partially submerged?
Six inch <6'			
6'>,<12'			
12'>,<18'			
18'>,<24'			
24'>,<36'			
Twelve inch <6'			
6'>,<12'			
12'>,<18'			
18'>,<24'			
24'>,<36'			
Eighteen inch <6'			
6'>,<12'			
12'>,<18'			
18'>,<24'			
24'>,<36'			
Twenty-Four inch <6'			
6'>,<12'			
12'>,<18'			
18'>,<24'			
24'>,<36'			
>Twenty-four inch			
6'>,<12'			
12'>,<18'			
18'>,<24'			
24'>,<36'			

Superscript numbers are keyed to guidance on reverse side of sheet.

NOTES: ______________

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GUIDANCE FOR DATA COLLECTION:

1. Please assign a number to each jam.
2. GPS approximate upstream and downstream ends of log jam.
3. River stationing along the reach of the Clinton River in Rochester Hills is provided on a separate map and is used as rough verification of jam location.
4. Is the jam perpendicular or parallel to the bank or at some angle between and 0-90 degrees.
5. Bank or bed embankment is a key threshold where removal would necessitate a MDEQ permit.
6. Roughly estimate no. and size of logs/trees in jam. This estimate and the photos may be used for bidding purposes.

SKETCH: Roughly sktech relative size, orientation, flow direction, orientation of jam and bank features.
For big jams, if possible, show potential access/staging areas for equipment

Large Woody Debris Management Actions, Resources and Relative Costs.

Management Action		Resources - Equipment Needed	Resources – Labor Needed	End Result	Relative Cost
Clean and Open		Hand tools such as saws; ropes and chains; winch or “come-along”.	Individuals needed to cut and carry material. If chainsaws are used, have a trained operator available.	Material that will be removed will be relatively small in either volume or size and can be placed along the streambank without anchoring. No major change to the character of the remaining LWD structure.	Low; Labor will be needed to cut and place debris.
Remove and Dispose		Equipment to lift wet, heavy debris into a dump truck. Size of equipment will vary with size of material.	Equipment operator, truck operator, and individuals to pick up associated, floating trash in LWD structure.	Material will be removed from the location and disposed of in an appropriate location such as a yard waste facility. No excavation of embedded LWD structures should occur.	Medium; Less labor involved than other techniques and less time-consuming.
Placement and Anchoring	No Anchors	Hand tools such as saws; ropes, chains, and cables; power winch or “come-along”; small equipment for larger logs.	Individuals to cut logs, position within the stream at appropriate locations.	Material will be placed in the stream at locations that promotes the greatest stability (at the end of outside bends). Material may move during high flows.	Low; Labor will be required to position logs in the correct position
	Passive Anchors	Heavy equipment to handle and position large logs and rock material for ballast. Saws for freeing tangled material. Cable for attaching to ballast.	Equipment operator, truck operator, and individuals to cable LWD pieces together or to rocks.	Material will be placed at appropriate locations within the stream channel and banks. The weight of the structure will provide stability.	High; Equipment will be required to move ballast material. Engineering consultant should provide ballast design.
	Flexible Anchors	Hand tools such as saws; ropes, chains, and cables; power winch or “come-along”. Equipment for larger pieces.	Individuals to cut logs, position against stream banks, and cable in place.	Material will be anchored to the stream bed or banks to provide stability; however, structure will be allowed to float and move laterally within the channel.	High; Engineering consultant should design the placement and anchoring techniques to prevent negative impacts to stream.
	Rigid Anchors	Hand tools such as saws; ropes, chains, and cables; power winch or “come-along”. Equipment for larger pieces.	Individuals to cut logs, position against stream banks, and cable in place.	Material will be anchored to the streambanks using cables and connectors. Anchors will be live trees or engineered anchors such as a dead-man anchor.	Medium; Labor will be required to move and anchor structures. Equipment may also be needed.

Appendix E: Duckbill Anchor and Cable Capacities in Relation to Buoyancy Force

Buoyancy Force (lb)	Capacity needed (lb)*	Duckbill Anchor	Duckbill Anchor Weight	Steel Cable	Installation Depth
0 - 200	0 - 300	Model 40	1 oz	1/16 " 7x7 GAC	20 inches
200 - 700	300 - 1050	Model 68	4.5 oz	1/8 " 7x7 GAC	30 inches
700 - 2000	1050 - 3000	Model 88	14 oz	1/4 " 7x19 GAC	42 inches.
2000 - 3300	3000 - 4950	Model 138	2.5 lb	5/16 " 7x19 GAC	60 inches

***SF = 1.5**

Foresight Products - Duckbill Anchor
http://www.earthanchor.com/duckmain.html

DuckBill Anchors

During installation, the anchor is driven into the soil using a steel driver and sledge hammer, post-hole driver, or hydraulic jack hammer. After the anchor is driven to depth, it is locked by pulling on the cable to toggle the anchor into the perpendicular locked position.

The capacities of anchors are based on a medium-firm clay, loose standard gravel, or compact coarse sand. Depending on the type of soil, the anchor capacities may be different than the ones specified in the table above. Modifications to the type of anchor used, or to the installation method may be required. When dealing with saturated soils or non-cohesive soils such as fill, loose sand, or silty clay, the required capacity will increase. Therefore, a larger anchor or multiple anchors may be needed. It is recommended that the driving hole be backfilled and tamped prior to anchor locking in these instances.
When dealing with rocky soils, excessive resistance to driving force may necessitate pre-drilling a pilot hole for the anchor.